Layout of power plants

Installation directive
Planning energy supply plants with gas engines
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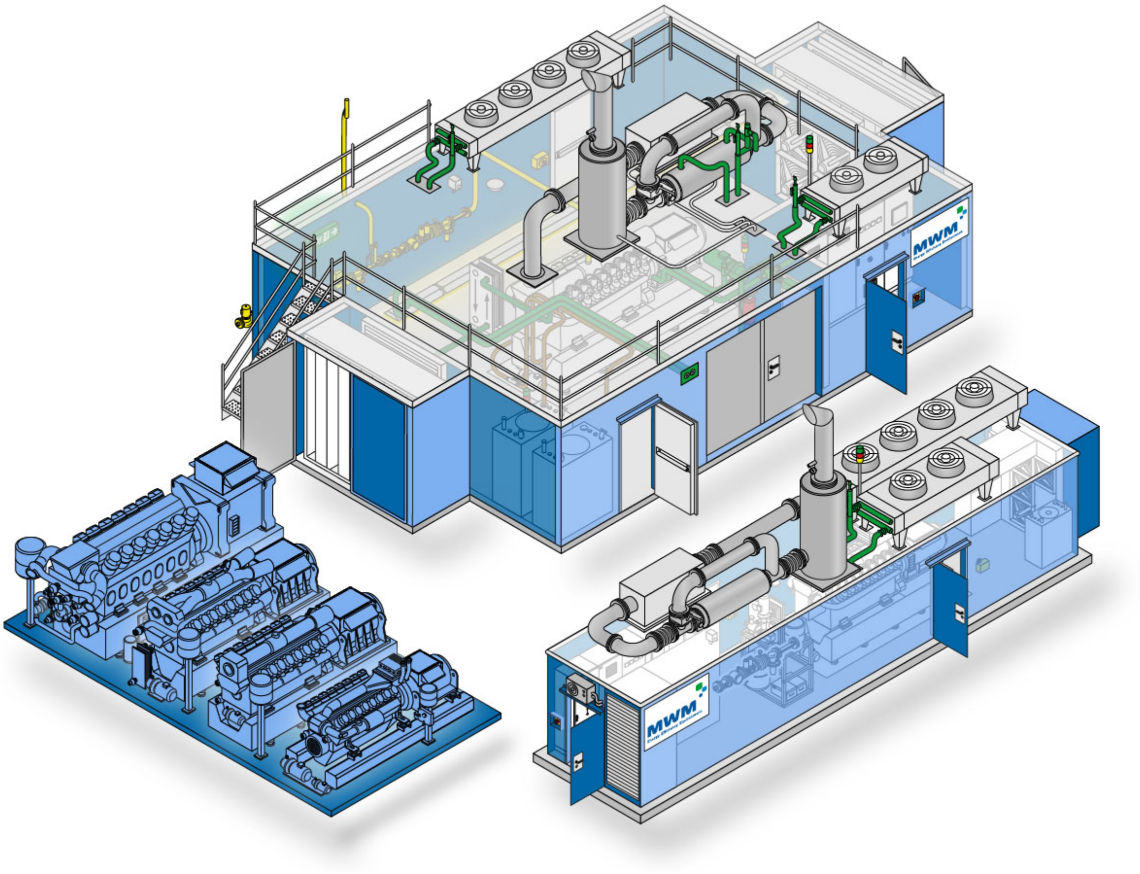

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1 Information

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1.1 Foreword

This guideline applies to gas engines and power gensets (with or without heat utilization) as well as the associated auxiliary systems and switchgear of the manufacturer Caterpillar Energy Solutions GmbH (CES for short). Target audiences of the guideline are planners, manufacturers, operators and contractors of CES.

The specifications of the directive serve as a technical basis for the planning, operation and maintenance of safe, functional and efficient energy supply plants with integrated CES products. The aforementioned target audiences must therefore observe and implement the aforementioned specifications. Project-related deviations are possible after approval by CES.

This guideline is not an operating manual! However, the implementation of the content is fundamental for the intended use of the product and can protect against hazards that may be caused by the use of the product or the energy supply plant.

Due to the variety of installation options, it is only possible to specify generally valid information and notes for planning purposes. Further product and application-related regulations in the technical documentation supplement this guideline and must be observed. We therefore recommend that the planning phase be carried out with CES or an authorized dealer.

Only qualified personnel with the required qualifications and knowledge in the field of energy supply plants may plan the use of CES products. Appropriately qualified personnel are also required to safely and properly install, commission and maintain the product. The product is operated by personnel with the minimum requirements specified by CES. The availability and qualification of personnel must therefore be taken into account in planning.

Standards, directives, and regulations listed have no claim to completeness. Therefore, the local requirements must be investigated and duly taken into account in each individual case.

CES shall not be liable for any personal injury, environmental damage, property damage, or claims resulting from failure to comply with the information, notices, and specifications in this policy. This also applies to warranty and guarantee claims.

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2 Safety

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2.1 General

The safety aspects indicated and described below play a very important role for energy supply plants with gas engines. However, no claim is made regarding completeness of this consideration as each plant is different in regards to its structure, location, operating method and technical condition, and different regional regulations also apply. Furthermore, all safety notes in the operating manual and other manufacturer information apply and must be observed.

2.2 Responsibilities

2.2.1 Manufacturer

The plant manufacturer is responsible for product safety within the scope of its intended use.

The plant manufacturer shall use suitable product design measures as a result of the risk assessment to minimize all foreseeable hazards. This shall ensure that there is a suitable level of safety for persons working at the plant, persons in the area of influence of the plant and also for the environment.

2.2.2 Operator and employer representative

The plant operator shall make all necessary decisions regarding the safe operation of the plant. When doing so, they shall take all manufacturer specifications into account.

Employers of persons working on the site shall conduct the job safety analysis. Measures tailored to plant operation are defined and implemented. The aim is to ensure adequate safety for persons working on the plant, for persons in the area of influence of the plant and for the environment.

2.3 Possible hazards at energy supply plants

2.3.1 Mechanical hazards

Hazard	Hazard descriptions	Risk reduction or emergency response measures (examples)
Risk of impact	There is a risk of impact in the case of protruding or low-hanging plant components. These can be, for example, a low-hanging gas pressure controller or gauge fitting on piping. This can lead to serious injuries and/or prevent escape in an emergency situation	• The required headroom and passage width shall always be observed. In particular, components, gauge fitting etc., shall not be located in passageways • Marking and impact protection in hazardous locations can prevent injuries

Hazard	Hazard descriptions	Risk reduction or emergency response measures (examples)
		– As part of personal protective equipment, bump caps can prevent injuries
Moving/rotating parts	Rotating and other moving parts on machines can cause serious injuries or even death due to shearing and drawing in.	• In general, all relevant machine parts shall be protected to protect against direct contact
Risk of falling	There is a risk of falling when working on work platforms, plant roofs and other work at a height. Falls can result in severe injuries or death.	• Structural fall protections include, for example, railings, self-closing passage barriers, etc. • If fall protections are not permanently installed, protection against falling shall be ensured in another manner. In addition to scaffolding, the use of personal protective equipment can be necessary to prevent falling. Suitable anchor points shall be provided and defined for this purpose
Falling objects	Particularly during maintenance work, components and tools can fall from a height and injure or kill persons.	• Lifting equipment and cranes shall be erected, operated and checked in accordance with applicable regulations • Work platforms shall be equipped with base edging so that tools, etc. cannot fall over the edge of the work platforms • Personal protective equipment such as safety shoes and hard hats can protect against falling objects

Hazard	Hazard descriptions	Risk reduction or emergency response measures (examples)
Slippery surfaces	Surfaces can become slippery due to their texture or impurities. Falls may result in serious injury.	• All walking paths shall be designed to be sufficiently slip-resistant. This applies in particular to areas where contamination, e.g. water, coolant or lube oil, is to be expected • The plant shall be cleaned regularly and based on requirements during maintenance. Escaping operating media and other impurities shall be collected without delay • Safety shoes shall have sufficient anti-slip properties
Tripping points	The following examples can be tripping hazards: thresholds, foundation edges, protruding earthing lugs, piping running on the ground. Falling can result in serious injuries.	• Thresholds and edges as well as piping running on the ground shall be avoided as far as possible by design • Grounding lugs shall not be located in passageways • If tripping hazards in passageways cannot be avoided, they shall be marked so they can be easily noticed
Automatic startup	If the genset is not sufficiently secured against being turned back on, it can start up unexpectedly, especially when performing maintenance measures. The unexpected startup of the genset can cause severe injuries or death. The same applies for other parts of the plant that can start up automatically.	• Sufficiently securing against automatic startup normally includes the safe disconnection of all power sources. Any residual stored energy shall be dissipated or released • During implementation, the information in the operating manual shall be fully taken into account.

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Hazard	Hazard descriptions	Risk reduction or emergency response measures (examples)
System breakage	If the permissible operating pressures and operating temperatures are exceeded, especially in the cooling system and heat extraction system, this can lead to leaks or the breakage of system components. Hot pressurized media can escape and injure or kill persons. The plant can be seriously damaged.	• The necessary personal protective equipment for the monitoring and limitation of pressure and temperature shall be installed • A function test of the personal protective equipment shall be performed regularly during maintenance measures

2.3.2 Electrical hazards

Hazard	Hazard descriptions	Risk reduction or emergency response measures (examples)
Short-circuit electric arc	Short-circuit electric arcs can generate severe explosions and abruptly vaporize metallic contact material. Arc flashes can occur at extremely high temperatures. This can severely injure or kill persons. The plant can be severely damaged or destroyed.	• The uncontrolled occurrence and propagation of short-circuit electric arcs in the switchgear must be taken into account as early as the planning stage in order to ensure the highest protection objective, personal protection • If there is nevertheless a risk of a short-circuit electric arc, suitable measures must be taken against the harmful effects of the short-circuit electric arc • The five safety rules shall be observed and implemented
Hazardous body currents	Voltage potentials due to a fault of the electrical plant equipment as well as due to tribo-electrical charging can lead to hazardous current flows that can injure or kill persons.	• Protective earthing must be established for the whole plant. This shall include all electrical components, all piping, air ducts and other components and assemblies. The protective grounding must be dimen-

Hazard	Hazard descriptions	Risk reduction or emergency response measures (examples)
		sioned in such a way that possible fault currents to be expected can be safely discharged • Proper coordination of protective measures in the different network systems is necessary during planning. The differences between the TT and TN systems and the IT system must be taken into account with regard to the shutdown times of the protective devices. The following protective measures are permissible, taking into account external influences: – Protection by automatically shutting down the power supply. – Ensure that the impedance between the outer conductors and the protective conductor of a circuit or the equipment is sufficiently low. – The protective equipotential bonding is intended to bring all conductive parts of electrical equipment to approximately the same potential in the event of a fault. The protective equipotential bonding as an additional protective measure thus provides increased protection against dangerous touch

Hazard	Hazard descriptions	Risk reduction or emergency response measures (examples)
		voltages until disconnection by the upstream overcurrent protective device. – Protection through double or reinforced insulation. – Protection by protective separation for the supply of a consumable. – Protection by extra-low voltage by means of SELV or PELV.

Required information

- Concept for protective grounding, protective conductor and protective equipotential bonding [▷ 29]

2.3.3 Thermal hazards

Hazard	Hazard descriptions	Risk reduction or emergency response measures (examples)
Hot surfaces	Exhaust lines and coolant lines and the engine as well as other plant components are hot when operating. This can cause burns to the skin in case of brief contact.	• Isolation and shielding of the components concerned – especially in passageways
Hot exhaust gas	Hot exhaust gas can escape during maintenance work on the exhaust system and cause burns.	• Organizational measures and personal protective equipment permit safe work
Hot coolant	Hot coolant can escape during maintenance work on the cooling system and cause burns.	• Emptying nozzles shall be easy to reach and positioned as low as possible to prevent body scalding • Organizational measures and personal protective equipment permit safe work

2.3.4 Hazard due to noise

Hazard	Hazard descriptions	Risk reduction or emergency response measures (examples)
Noise in the genset room	The high noise load in the genset room can cause irreversible hearing loss, even if staying in the room only for a short time.	• When working in the genset room, suitable ear protection shall be worn while the genset is operating • The access doors to the genset room shall be marked with suitable prohibition signs that mandate the use of ear protection
Noise in the genset room	Low frequency noise emissions can cause discomfort if staying in the genset room for a longer period of time, thereby endangering safe working.	• It is necessary to adhere to break times outside of the genset room and take breaks as necessary
Noise emissions	The genset and auxiliary drives emit a considerable amount of acoustic power that, depending on the distance, can damage hearing or have a disturbing effect.	• The genset and the related auxiliary drives shall be suitably enclosed in a housing with a muffling wall structure

2.3.5 Hazards generated by radiation

Hazard	Hazard descriptions	Risk reduction or emergency response measures (examples)
Electromagnetic fields	Electrical plant components generate electromagnetic fields. They can have a damaging effect on medical implants and disturb signals inside and outside the plant. This can lead to injuries or death as well as malfunctions of the plant.	• Electrical components are shielded by their housings • All components in the plant shall be suitably shielded by a housing in accordance with the local specifications • Control cables in the plant shall in general be shielded and, if possible and necessary, laid with spacing in metal cable trays separately of power cables • Prohibitory signs with "No access for persons with pacemakers or implanted defibrillators" shall be attached to all plant access points

Hazard	Hazard descriptions	Risk reduction or emergency response measures (examples)
		• In principle, no persons with medical implants whose function can be disturbed by electromagnetic fields may enter the plant • If restricted work areas are still to be accessed by persons with EMF sensitive medical implants, then all necessary measurements must be carried out to determine the EMF load in these areas. Only medical clearance for the defined work in the defined work areas shall allow affected persons to perform any work in the plant. It shall be ensured that the work and work areas always comply with the defined scope

2.3.6 Hazard generated by materials and substances

Hazard	Hazard descriptions	Risk reduction or emergency response measures (examples)
Operating media	Operating materials can cause various specific hazards. Lube oil, coolant or fuel gas, for example, can have a toxic effect if ingested. The corresponding hazard potential is described in the safety data sheets for the substances. In the case of fuel gases, their composition must be known exactly to be able to precisely identify the hazards.	• In general, measures to prevent hazards and for first aid are described in the safety data sheets. These precise measures shall be applied in any case. In addition, other measures can be helpful or required • In the case of fuel gas, ambient monitoring and maintenance is also required in permanently technically sealed systems, whereby any leaks can be detected and protective measures can be initiated as a result

2.3.7 Ergonomic hazards

Hazard	Hazard descriptions	Risk reduction or emergency response measures (examples)
Visibility	Insufficient lighting or a lighting failure can lead to an accident, as obstacles and hazards can no longer be seen. This makes it difficult or impossible to evacuate the plant in the case of a failure.	• Plant lighting shall be implemented according to normative specifications in order to ensure a safe working environment at and in the plant • If workstations cannot be sufficiently illuminated by the plant lighting, suitable temporary lighting shall be used while working • If the regular plant lighting fails (e.g., due to a power failure), emergency lighting shall be implemented such that the plant can be left safely. Danger areas, evaluation routes, exit doors and emergency stop equipment shall be easily recognizable even with the emergency lighting

2.3.8 Hazards in conjunction with the application environment of the machine

Hazard	Hazard descriptions	Risk reduction or emergency response measures (examples)
Dust	Dust can enter the genset room via the supply air, damaging the equipment and endangering people. Dust can also be a source of damage and danger over time due to poor cleaning. Dangerous leakage currents are possible via a dust layer. Furthermore, dust can hinder the dissipation of heat and thus lead to overheating of plant components. It is possible that components of the plant are not sufficiently protected against dust and may be damaged or destroyed. Hazards may not be detected due to	• Supply air filters of at least the filter class indicated in the document shall be used • The plant shall be cleaned regularly and based on requirements during maintenance • Plant doors shall always be kept closed

Hazard	Hazard descriptions	Risk reduction or emergency response measures (examples)
	dust layer. The resulting unsafe plant operation leads to an increase risk of injury for persons.	

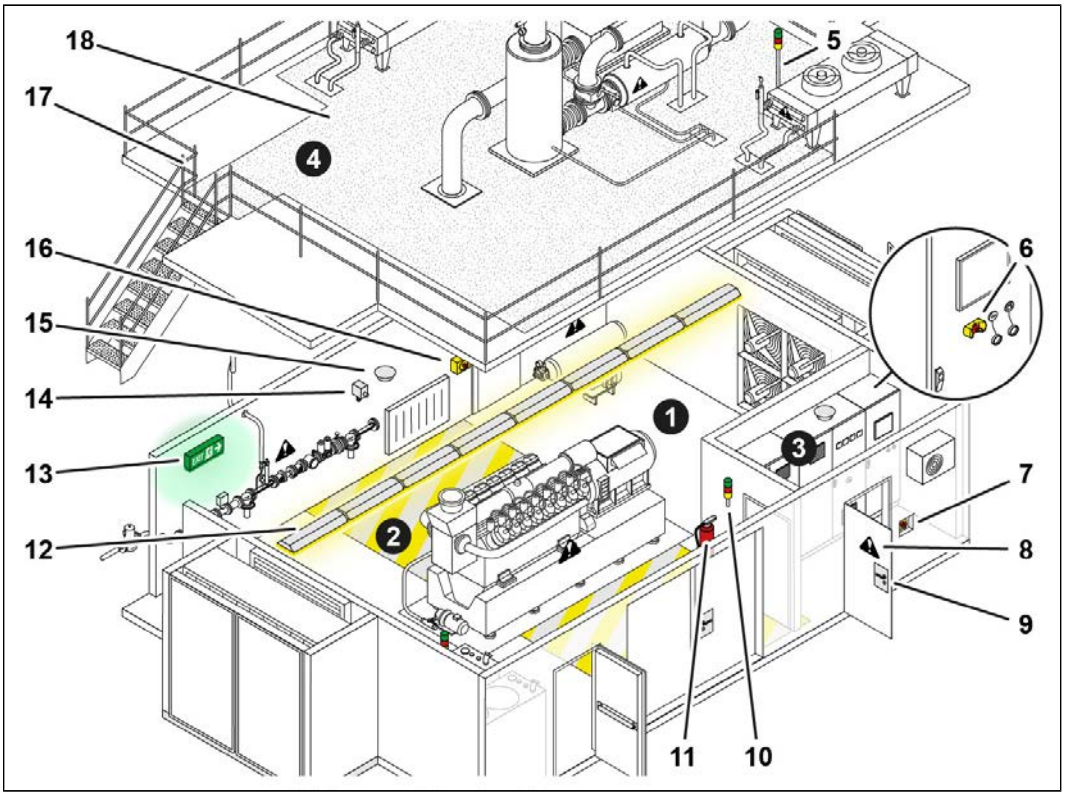
2.3.9 Combination of hazards

Hazard	Hazard descriptions	Risk reduction or emergency response measures (examples)
Effort and high temperatures	Considerable fluid loss due to sweating is possible in particular when performing maintenance work on the exhaust system or in the warm genset room. If the work is also strenuous, the body can overheat quickly. As a result, misjudging hazards and reduced responsiveness can lead to serious injuries or even death.	• Work on the exhaust system is normally performed with the exhaust system turned off and with the exhaust gas routing sufficiently cooled down. The surface temperature shall be sufficiently reduced depending on the work • If this is not possible, e.g., in the case of exhaust gas emission measurements, the work time shall be limited, with sufficient breaks, and the work shall be performed with particular caution • Ensure sufficient fluid replacement

2.4 General safety concept

2.4.1 System overview of the safety concept

The following illustration shows an example division of a plant into rooms and zones as well as a selection of typical equipment and a selection of typical switching elements that should be operated or used by persons working on the plant for protection in the event of a detected hazard. The illustration also shows signal devices that display a hazardous state on the plant and examples of areas for safety markings.



3615131787: Simplified example illustration

1	Genset room	2	Danger zone
3	Switchgear room	4	Roof with auxiliary systems
5	Signal tower (external)	6	Emergency stop button (switchgear cabinets)
7	Emergency stop button (external)	8	Various safety signs
9	Example of access door (lockable, with panic bar)	10	Signal tower (internal)
11	Fire extinguisher with suitable extinguishing agent	12	Lighting
13	Indication of escape route with emergency lighting	14	Gas sensor
15	Smoke and temperature sensor	16	Emergency stop button (internal)
17	Suitable ladder with railing	18	Non-slip floor covering (in access area)

2.4.2 Scope

The CES products have been designed in compliance with the applicable safety requirements and CES knowledge so that hazards are ruled out and risks are sufficiently reduced. The relevant risk reduction and hazard prevention measures are specified for each product in the safety concept.

During project planning for the scope of delivery for an energy supply plant, CES, in consultation with the client, also defines measures for the integration of the client's own scope of supply in the overall plant. This is done based on an order from CES, the client or both.

Depending on the scope of delivery, the regional regulations and the situation on site, the safety concept comprises:

- Structural division of the plant into rooms and danger zone
- Definition of workstations for operation
- Number and positions of emergency stop buttons and emergency switching off buttons
- Fire and explosion protection
- Emergency exit signs and safety signs on all doors
- Panic locks on all entrance doors. These doors can also be opened from inside even when locked
- Marking of walk-accessible areas on the roof with non-slip coating and fall protection concept
- Interior lighting and emergency lighting
- Potential equalization and grounding
- Safeguarding all cooling circuits by means of safety fittings against hazards due to an impermissibly high operating pressure
- Low-water protection that responds in case of leakages
- Pan-shaped design of the base of the machine enclosure for holding escaped liquids in case of leakages
- Safeguarding access to the operating computer against unauthorized operation
- Safeguarding access to the machine enclosure
- Safeguarding all access to the overall plant
- Lightning protection

2.4.3 Safety matrix

The safety matrix for complete plants provides an overview of safety functions and other important plant functions. The overview assigns the follow-up actions for hazard prevention or for protecting the genset and the plant to the signals from activated sensors or buttons.

2.5 Selected safety concepts for hazard prevention in CES plants

2.5.1 Fire protection concept

Hazard description

- For required information on specific hazards and consequences of a fire, see Chapter Hazard generated by materials and substances [▷ 19]

Probability for the occurrence of fires

Minimizing potential fire loads, using flame retardant materials, and performing electrical installations and maintenance as directed makes fires unlikely to occur. Organizational measures such as prohibiting open fires and keeping flammable materials out of the plant continue to reduce the risk of fires starting.

Fire loads outside of the plant must also be taken into account. Observing adequate safety distances and minimizing fire loads can therefore effectively prevent a fire from spreading from outside to the plant.

Risk reduction measures

Legal requirements and established technical possibilities to reduce the risk of fires or their early detection to a sufficient level require the implementation of additional technical measures for fire protection.

Early detection of smoke and heat development can make a significant contribution to warning people in good time of possible dangers and preventing injuries as well as keeping property damage within limits. Countermeasures can be initiated early that can prevent or contain a fire.

In CES plants, the concept described below counteracts the development of fires and thus sufficiently reduces the risk of dangerous consequences of fires.

At least one smoke and one heat sensor each with sufficient sensitivity with regard to smoke development and heat development is installed in the genset room and switchgear room.

An external quick closing valve must close immediately in the event of a fire, so that the supply of fuel gas to the genset room is safely interrupted.

Upon detection of smoke and / or a sufficiently high temperature rise, the following follow-up actions are triggered by the plant control in the auxiliary cabinet (HAS):

- The control issues an alarm
- Optical and acoustic signals are activated
- The genset stops without delay with emergency stop
- The shut-off valves of the zero pressure control line close immediately
- The supply, exhaust and circulating air louver dampers are closed
- Supply and exhaust fans are switched off

- Fresh and used oil pump (if present) are stopped
- External quick closing valve (QCV) closes

The follow-up actions of fire alarm have priority over the follow-up actions of gas alarm. The reason for this principle is that subsequent actions to protect against explosion can strongly promote a fire event and the fuel gas supply is interrupted anyway in the event of a fire alarm.

2.5.2 Explosion protection concept

Hazard description

The use of fuel gases to drive gas engines may result in the release of flammable gases or gas mixtures in the event of leakage. If these fuel gases occur in a mixing ratio with air in which ignition is possible, there is a risk of explosion. This is referred to as explosive gas mixtures, which are defined by a lower and an upper explosion limit with regard to the volume proportions of fuel gas and air. For example, in a methane-air mixture, the lower explosion limit of methane is 4.4 vol.% and the upper explosion limit of methane is 16.5 vol.%. Outside these limits, the explosion of a methane-air mixture is not possible. Within these limits, there is a risk of explosion if sufficient ignition energy is present, e.g. from sparks or hot surfaces. Depending on the mixture quantity and reaction kinetics, an explosion has the potential to injure or kill persons and to damage or destroy plant equipment.

Probability for the occurrence of dangerous fuel gas leaks

The fuel gas line, including the installed parts such as gas trains, are permanently technically tight. The gas engine is technically tight.

This means that, in principle, no hazardous quantities of fuel gas escape when used as intended.

Despite proper execution of installation and maintenance measures, there is a residual risk of leakage of fuel gas or gas mixture. If these leaks occur, they are usually relatively small (e.g. leaking flange connection) or initially small and gradually increasing in size (e.g. cracks on expansion joint increasing in size over time).

When the plant is operated, fresh air flows through the genset room. In terms of volume flow, this corresponds at least to the combustion air and at most to the cooling air required at high ambient temperatures. If the plant is not operated, no fuel gas flows to the engine via the gas train. Double shut-off valves interrupt the flow of fuel gas. This means that in the condition of relatively increased probability of fuel gas leakage, the genset room is well-ventilated and in the condition of much lower probability of fuel gas leakage, there is no operational ventilation of the genset room. This means that the plant is usually so well ventilated that the probability of the formation of hazardous explosive fuel gas mixtures is considered very low.

Risk reduction measures

Legal requirements and established technical possibilities to reduce the risk of explosions to a sufficient level require the implementation of additional technical measures for explosion protection.

The hierarchical approach to implementing explosion protection measures is the basis for selecting suitable measures. This means that primary explosion protection measures must be implemented first, before any secondary or tertiary explosion protection measures might be required.

Primary explosion protection has priority and aims to prevent a hazardous explosive atmosphere. This can be achieved by diluting fuel gas leaks with sufficient fresh air.

In CES plants, the concept described below counteracts the formation of hazardous explosive atmospheres and thus sufficiently reduces the risk of an explosion.

At least one gas sensor with sufficient sensitivity to the fuel gas is installed in the genset room. An evaluation tool evaluates the measurement signal and sends signals in each case at fuel gas concentrations of 20 % and 40 % of the lower explosion limit.

An external quick closing valve must close immediately in the event of a gas leak with 40 % LEL, so that the supply of fuel gas to the genset room is safely interrupted.

When fuel gas with a concentration of 20 % of the lower explosion limit is detected, the following follow-up actions are triggered by the plant control in the auxiliary cabinet (HAS):

- The control issues an alarm
- Optical and acoustic signals are activated
- The genset is shut down in a controlled manner, pumps run for heat dissipation after
- The supply and exhaust air louver dampers are fully opened
- The circulating air louver damper is closed
- The supply air ventilators rotate at maximum speed
- The shut-off valves of the zero pressure control line close when the genset is running down

When fuel gas with a concentration of 40 % of the lower explosion limit is detected, the following follow-up actions are triggered by the plant control in the auxiliary cabinet (HAS):

- The control issues an alarm
- Optical and acoustic signals are activated
- The genset stops without delay with emergency stop

- The shut-off valves of the zero pressure control line close immediately
- The supply and exhaust air louver dampers are fully opened
- The circulating air louver damper is closed
- The supply air ventilators rotate at maximum speed
- Gas solenoid valves close
- External quick closing valve (QCV) closes

In order to ensure the function of the effective ventilation and to detect a possible failure of the ventilation at an early stage, flow monitors are arranged in the supply air. If the monitors do not detect sufficient flow, the genset is shut down in a controlled manner after a defined delay time.

2.5.3 Lightning protection concept

Hazard description

- For required information on specific hazards and consequences of lightning, see Chapter Hazards in conjunction with the application environment of the machine [▸ 20]

Probability of lightning strikes and transient overvoltages

The probability of lightning strikes and transient overvoltages from the upstream network are possible in principle, depending on the installation site and the type of network there.

Energy supply plants must therefore be adequately protected against lightning strikes and against dangerous and disturbing potential differences in accordance with local conditions and regulations.

Risk reduction measures

A lightning protection zone concept according to IEC 62305-4:2010 can provide help. A building or plant is divided into zones with different levels of hazard potential. Based on these zones, it is determined where which internal and external measures, air-termination systems and arrester types are necessary.

When planning and installing lightning protection systems, national specifications, special features, applications or safety data from the respective country-specific supplementary sheets must be taken into account.

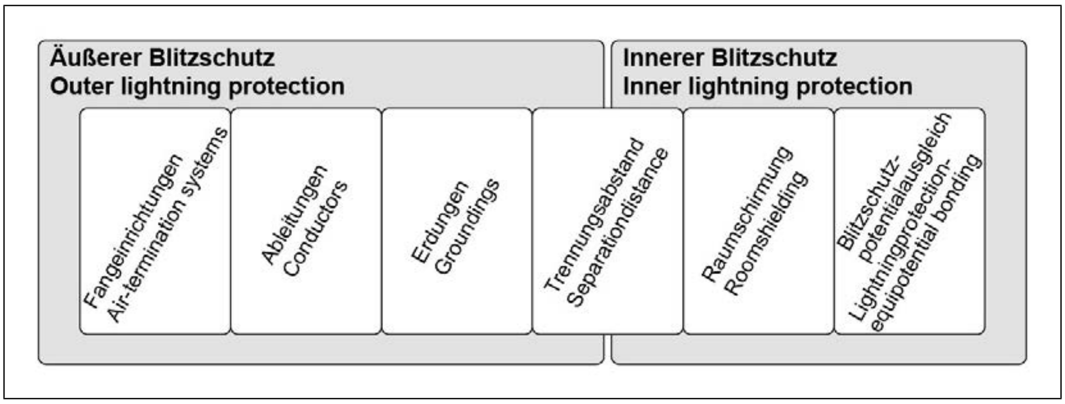
A lightning and surge protection system consists of several coordinated systems.

Basically, a lightning and surge protection system consists of an internal and an external lightning protection system.

These are again divided into the following systems and measures:

- Air-termination systems
- Discharges/conductors

- Groundings
- Room shielding
- Separation distance
- Lightning protection equipotential bonding



4037227531: Diagram of a lightning and surge protection system

These systems must be selected for the specific application and used in a coordinated manner. Various user and product standards form the normative basis that must be complied with during construction.

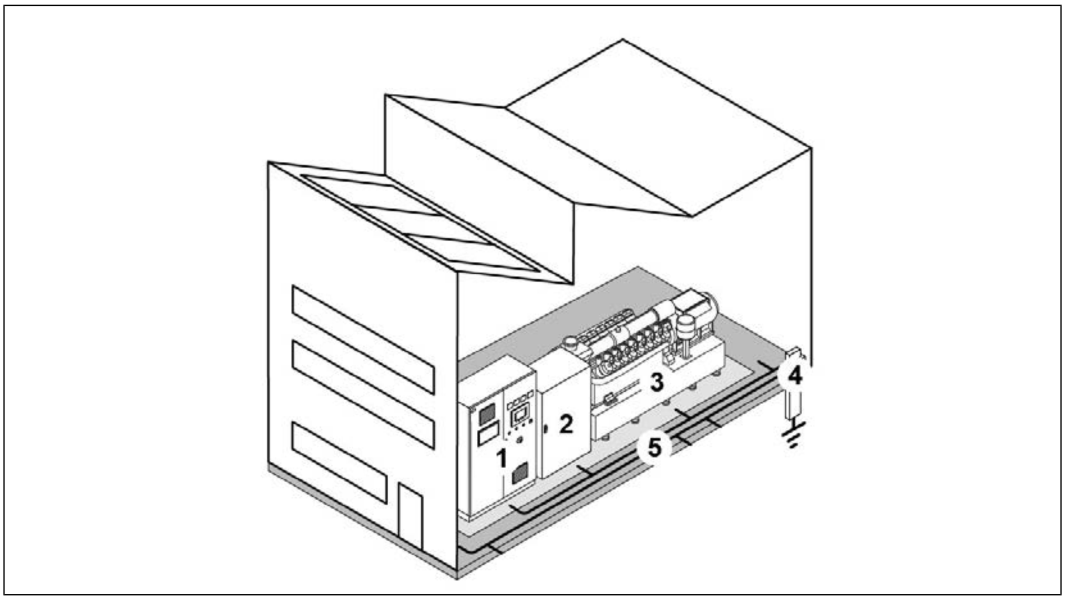
The supplementary sheets of the IEC international guidelines and the harmonized European versions of the respective country-specific translations often contain additional informative (country-specific) data.

If lightning protection equipotential bonding is required, it primarily influences the execution of the preceding forms of equipotential bonding and necessarily requires their revision.

2.5.4 Concept for protective grounding, protective conductor and protective equipotential bonding

General

Protective earthing (PE) and equipotential bonding of the energy supply unit must be connected to the relevant wiring system and the operator's foundation earth electrode.



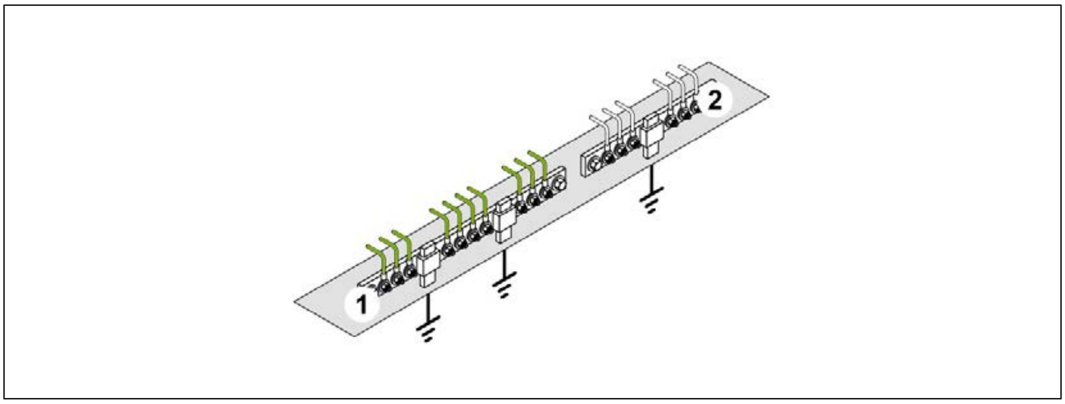
3611695499: Example illustration of the integration of an energy supply unit into the higher-level plant

1	Auxiliary cabinet (HAS)	2	Genset control (AGS)
3	Genset	4	Foundation with foundation earth electrode
5	Plant-side wiring system ≤0.1 Ω		

Lightning protection

Separate grounding rails and foundation earth electrodes with terminal lugs are required for lightning protection.

The lightning protection must not be connected to the main grounding rail (protective and functional equipotential bonding)!



3615132299: Example illustration of installations with lightning protection

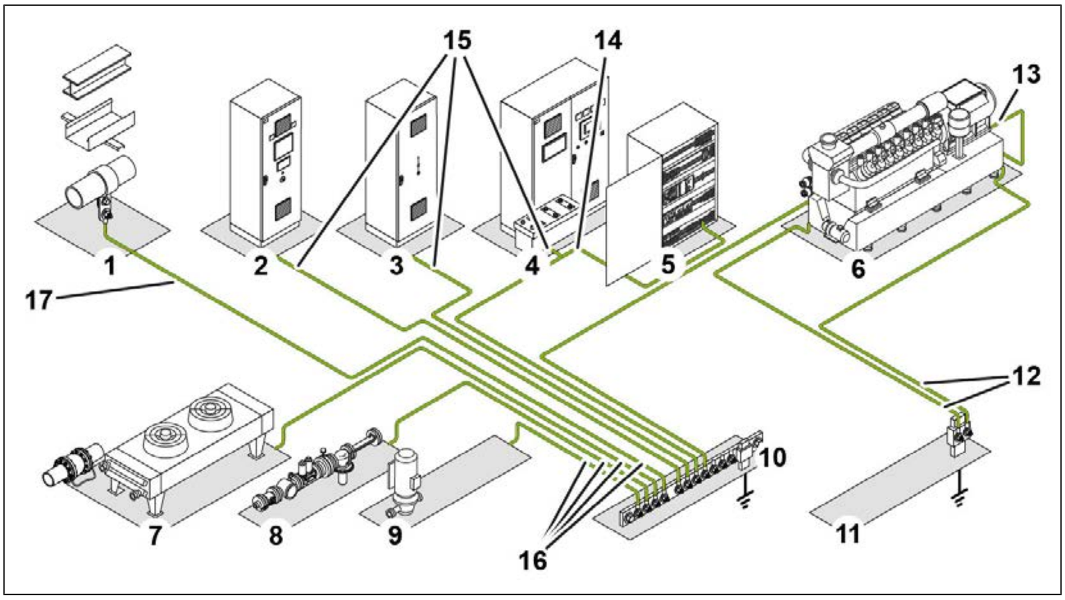
1	Main grounding rail for genset and auxiliary drives	2	Grounding rail for lightning protection

TEM and TPEM system

Observe the following during design and assembly:

- Control battery capacity >40 Ah, with 35 A protection (TCG 3016) or 45 A protection (TCG 3020)
- Check line cross-sections vs. line lengths (**see Circuit diagram**)
- The cable cross-section of the connection line must be dimensioned in accordance with the preliminary fuse and distance from TPEM CC
- Never connect the 24 V supply for the TEM/TPEM system directly to the starter battery
- PE of the power supply and GND must be connected (HAS <-> AGS), avoid using double connections
- The main equipotential bonding between the genset and switchgear must be connected before commissioning
- If several power supplies are used, the signals must be switched to TEM/TPEM via potential-free relays.

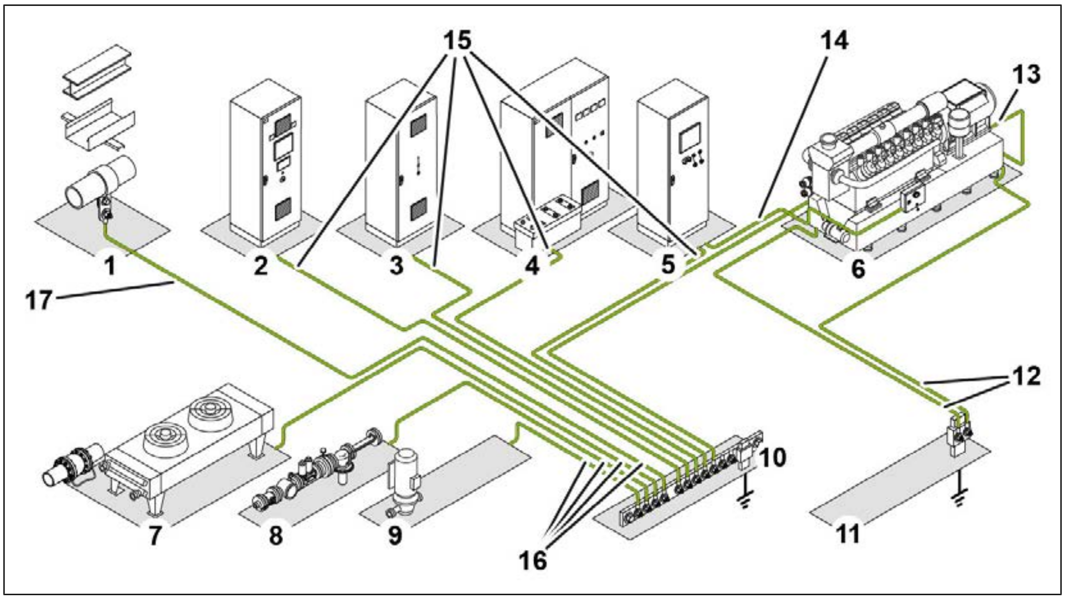
Overview of the TEM system



3615132811: Example illustration of the TEM system

1	Installations: supports, cable trays, piping, etc.	2	Master control cabinet (ZAS)
3	Generator power field (GLF)	4	Auxiliary cabinet (HAS)
5	Genset control (AGS)	6	Genset
7	Radiator	8	Gas train
9	Coolant pumps and other components	10	Main grounding rail
11	Earthing leads in the foundation	12	Base frame: ≥70 mm^2
13	Generator: 95 mm^2	14	AGS connection line: ≥10 mm^2
15	Connection lines: min. 35 mm^2 (depending on power supply)	16	Connection lines for auxiliary systems: 6 mm^2
17	Connection lines for installations: 6 mm^2		

Overview of the TPEM system



3615133323: Example illustration of the TPEM system

1	Installations: supports, cable trays, piping, etc.	2	Master control cabinet (ZAS)
3	Generator power field (GLF)	4	Auxiliary cabinet (HAS)
5	TPEM Control Cabinet (TPEM CC)	6	Genset
7	Radiator	8	Gas train
9	Coolant pumps and other components	10	Main grounding rail
11	Earthing leads in the foundation	12	Generator: 95 mm^2
13	Base frame: ≥70 mm^2	14	TPEM CB connection line: 6 mm^2
15	Connection lines: min. 35 mm^2 (depending on power supply)	16	Connection lines for auxiliary systems: 6 mm^2
17	Connection lines for installations: 6 mm^2		

2.5.5 Concept for power supply if the mains supply fails

The power supply of the TEM system or the TPEM system is provided by one or multiple switching power supplies in combination with batteries. The batteries provide sufficient voltage in the case of a mains failure so that the plant can be shut down in a controlled manner.

The requirements specified in the circuit diagrams and in the switchgear cabinet specification apply for the power supply of the TEM system and the TPEM system as well as optional measurement devices or some actuators in the auxiliary drive cabinet.

2.5.6 Concept for protection against water and soil hazards

Hazard description

Operating materials are used in energy supply plants that can potentially endanger water and soil.

Especially during filling and leakage of operating fluids such as coolant and lube oil, water and soil can be contaminated, causing environmental damage.

Probability of leakage of operating materials

The systems for coolant and lubricating fluid must be closed and tested for leaks.

Overfill protections must reliably prevent overflow when filling the systems.

If the above-mentioned measures are implemented, the risk of unintentional leakage of operating fluids is significantly reduced, but leakage can still occur.

Risk reduction measures

Legal requirements and established technical possibilities to reduce the risk of water and soil contamination to a sufficient level require the implementation of supplementary technical measures for water and soil protection.

Retention facilities must be implemented for substances hazardous to water. This usually includes all system components that contain substances hazardous to water.

In practical implementation, the following structural measures usually have to be implemented depending on individual requirements:

- Impermeable installation area for the genset and associated systems with operating media hazardous to water
- Impermeable refueling surfaces (e.g. for lube oil)
- Suitable geometries of the installation surfaces that prevent the operating media from flowing beyond the surfaces and can fully absorb any leaks
- Placing operating materials in containers on set-up areas intended for containment or in adequately dimensioned drip pans

When implementing technical measures to retain leakage, precipitation water and firefighting water must be taken into account.

CES containerized power station

CES containerized power stations usually have coolant-carrying systems installed on the roof. Leakage can occur there.

Unintentional leakage of lube oil may occur during refueling and draining.

For these cases of leakage, necessary structural measures must be taken to retain leakage in order to direct it to the prescribed disposal routes. Regional regulations apply.

For leakages in the genset room of the container, the container floor is designed as a sump, which is sufficiently large to retain leakages.

Fluid-carrying systems can be continued outside the plant. This often affects the heating circuit for heat extraction. If this system is not hydraulically separated from the container and the possible leakage volume exceeds the containment volume of the container sump, the manufacturer of the continued system must provide containment of any leakage from this system. Regional regulations apply.

2.5.7 Cyber Security concept

Definition and relevance of Cyber Security for the control systems and switchgear systems of energy supply plants

Cyber Security for energy supply plants encompasses all measures implemented to protect the digital infrastructure and control systems in these plants against unauthorized access, tampering or sabotage. In the age of increasing digitalization, energy supply plants are no longer isolated, but are part of networks that are exposed to a wide range of threats.

The primary focus is on safe and reliable protection of automation and communication interfaces, e.g., through the Remote Plant Gateway, to ensure reliable and controlled data exchange between plant control and external systems. The objective of Cyber Security is to ensure the integrity, availability, and confidentiality of all critical data and processes.

Key components of Cyber Security include:

- Network segmentation: The separation of operating, office and remote maintenance networks to minimize points of attack.
- Encryption and authentication: The use of modern technologies to secure data transmission and access.
- Regular updates: Ensuring that all systems and gateways have the latest security updates and patches.
- Risk management: Performing risk analyses and penetration tests to identify and eliminate vulnerabilities at an early stage.
- Monitoring and alerting: Continuous monitoring of the networks to immediately detect and prevent attacks.

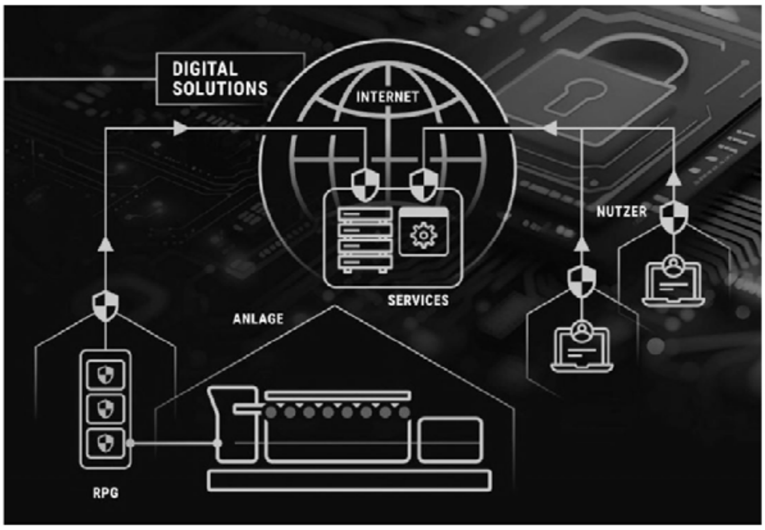
Cyber Security is therefore a central prerequisite for reliable and fault-free operation of power plants and plays a key role in preventing operational downtimes, data theft, and financial loss.

Cyber Security and Connectivity at Caterpillar Energy Solutions

Caterpillar Energy Solutions places particular importance on the Cyber Security of networked plants as they are increasingly becoming the focus of potential attacks. A compromised control system can have significant consequences for operational safety and availability. The Remote Plant Gateway is a key element of our security strategy, as it represents the central interface between the local plant control systems and external access options.

Secure Digital Solutions at a glance

With the Digital Solutions, you can monitor your energy supply plant and access it remotely in real time. Caterpillar Energy Solutions uses a VPN gateway (Remote Plant Gateway) on the plant that establishes a secure connection to the remote maintenance server. Thus, no incoming connections to the plant are needed. Access is granted only to authorized users. Two-factor authentication, firewall segmentation, and regular updates protect against unauthorized access. System security is continually improved by carrying out periodical inspections.



9685354763: Caterpillar Energy Solutions Cyber Security for Digital Solutions

Digital Solutions	Tools for remote monitoring and operation of energy supply plants in real time.
Services	Services for plant operators include the remote access service with regular maintenance intervals and software updates.
Plant	The connection is established only in the direction of the protected servers.
RPG	The encryption of the VPN connection to the remote maintenance server is performed by the Remote Plant Gateway (RPG).
Internet	The plant data is transmitted digitally to the verified users via encrypted connections.
User	Two-factor authentication for role-based user access protects the system against unauthorized access.

Please note that for TEM systems, the Remote Plant Gateway is available as an optional component to establish connectivity. In TPEM systems, on the other hand, the Remote Plant Gateway is already integrated in the TPEM CC cabinet at the factory. All control systems can generally be operated without an Internet connection, but it is important to know that the Caterpillar Energy Solutions digital solutions are not available in this case.

Multi-level security with the Remote Plant Gateway

To ensure the highest level of system protection, we consistently rely on multi-level security, which involves the use and cascading of multiple protection mechanisms.

Network segmentation

This essentially includes network segmentation based on the Purdue Model. The various networks of the control systems are strictly separated from one another. The Remote Plant Gateway acts as a clearly defined transfer point that controls and monitors the data flow between the protected automation network (Operational Technology, OT) and external networks such as the local network and cloud services. Network segmentation must also be carried out for these external networks.

Secure communication with firewall and encryption

Targeted protection mechanisms such as firewalls and clear, defined communication paths significantly reduce potential points of attack. This ensures that the connection between the individual areas of the plant and external networks remains secure and transparent. The restrictive configuration of local firewalls to support this security measure must be implemented in accordance with our firewall rules.

Another important module is the use of current encryption mechanisms and authentication procedures for all connections to the remote maintenance server (rendezvous server) used by the Remote Plant Gateway. Only authorized access from registered routers and users is permitted, and all communication channels are kept up to date through regular updates and patches.

Secure software development and targeted continuous measures

Secure software development processes and targeted measures minimize vulnerabilities and protect critical interfaces from attacks. Regular checks and the use of proven methods strengthen the robustness of industrial systems, ensuring a high security standard for power plants.

Maintenance and updates

An important aspect is the updating and maintenance of the Remote Plant Gateway: To ensure that security-relevant updates and new functions – particularly for remote access and digital services – can be reliably provided, the associated update servers must be accessible from the local network. In addition, proper registration of the Remote Plant Gateway is required to obtain updates; only then can the full functionalities for remote access and system updates be used. This also includes a check and, if necessary, replacement of the hardware.

Responsibility of the plant operator

We also recommend that plant operators plan the network architecture according to proven network security principles: This includes the use of VLANs for additional segmentation, consistent separation of office and production networks, and monitoring of all data flows using modern monitoring solutions. Regular risk assessments of the interfaces as well as penetration tests further support the early identification and elimination of vulnerabilities.

This is particularly important when using customer interfaces and SCADA connections. We offer these customer interfaces as an option for flexible integration into the local network infrastructure. In this context in particular, we recommend adhering strictly to the fundamental principles described in this chapter and performing a comprehensive risk assessment of the entire system architecture. This enables early identification of potential risks and threats and the implementation of appropriate countermeasures. This protects the integrity and sustainably increases plant availability, while consistently extending the security approach of the Remote Plant Gateway in the local plant network.

Conclusion

In summary, Caterpillar Energy Solutions pursues a holistic approach in which Cyber Security and Connectivity are inseparably linked. By complying with international standards and proven concepts such as the Purdue Model, role-based access concepts, and encrypted VPN connections, we ensure that the Remote Plant Gateway acts as a secure bridge between OT and IT, thereby protecting the operators’ power plants.

We strongly advise plant planners and plant operators to follow our recommendations on network segmentation, firewall configurations, and update cycles, and to actively engage with Cyber Security.

In doing so, unauthorized access and associated risks can be effectively reduced in line with individual risk assessments.

3 Technical support and services

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3.1 General

For plants with CES gensets, various services are available that are helpful or required for planning, design, commissioning, operation and maintenance.

3.2 Plant planning

3.2.1 Basic principles

During the plant planning stage, the functions of the plant are defined, and suitable components are then selected.

These components are integrated into building structures. The installation of piping, electrical cable routes and signal lines connects the components to a functional energy supply plant.

All the requirements from applicable regulations must be met during planning. All the measures that are required as a result of a risk assessment must be implemented in order to ensure a safe plant. A job safety analysis must be performed by the operator. This analysis is the basis for safe work procedures for all activities on the plant.

Layout of power plants is intended as a generally applicable reference document providing help and assistance for plant planning. Many planning documents are also created and made available for specific projects. Some central services are mentioned and described below.

3.2.2 Plant diagram and single line diagram

CES provides piping and instrumentation diagrams that define the integration of the genset and components of the auxiliary systems as well as important operation parameters.

CES also provides customized piping and instrumentation diagrams for customers on request. These take into account the order-specific design of the plant within the permissible operating limits of the plant.

CES creates single line diagrams that are tailored to customer requirements.

3.2.3 Plant control

CES provides switchgear solutions that are tailored to customer requirements.

This can include an auxiliary cabinet, a generator circuit breaker cabinet for low voltage, and a master control cabinet for multi-engine plants. In addition, low voltage and medium voltage distribution systems as well as transformers with plant cabling are also available.

3.2.4 System components

Components of the auxiliary systems of the energy supply plant that are designed specifically for the relevant order can be obtained directly from CES. These components are ordered and delivered along with the genset.

Many components that have been tried and tested during the operation of plants with CES gensets as well as components that are specified and designed according to customer requirements can be obtained from CES.

3.2.5 Plant units and complete plants

In addition to individual components that must be integrated into piping and electrotechnical systems, CES also provides pre-installed functional units made up of multiple components.

This may be a cooling module, for example. This is a component arrangement made up of pumps, heat exchangers, sensors, etc., mounted on a frame construction. This component arrangement is already connected to the piping and can be pre-wired. The cooling module is optimized in terms of its function and the space required for installation.

A cooling module has been prepared for mounting on the genset's piping connections and can be positioned directly on the genset as a unit. This makes it possible to minimize the assembly work at the plant's installation site.

The cooling module is a tried-and-tested functional unit that performs important functions for every genset's operation.

CES also provides complete energy supply plants. The planning and design can relate to plants in permanent buildings, but can also be done for containers.

For containerized power stations, the genset is installed in a sound-insulated container together with all the necessary auxiliary systems. Components of the exhaust system and radiators for the cooling systems are mounted on the roof of the container.

Further information

- Types of power stations [▶ 73]

3.2.6 Replacing existing plants

Following many years of operation, plants must be replaced if the plan is to continue using them. This often includes an overhaul of the genset or replacing the genset as well as replacing components of the auxiliary systems. Plant conversions may even be required in order to meet new functional requirements and/or to increase the efficiency of the plant.

3.3 Services

Various services are often provided for products. Your dealer will tell you exactly which services you can get for your product.

3.4 Training

The Mannheim Learning Center regularly offers training courses for various target groups, such as customers and service personnel. The training program covers the genset as well as plant engineering auxiliary systems.

The main topics are:

- Fundamentals of gas engine systems
- Engine control/Plant control
- Generator technology
- Fundamentals of electrotechnology
- Annual re-training courses for electricians

Contact address: *ces_learning@cat.com*

The Mannheim Learning Center is the point of contact for all Learning Centers worldwide.

Further information

- Training portal: https://ces.docebosaas.com/home/learn

3.5 Documentation

The documentation is part of the product. It includes various documents aimed at the relevant target groups. For example, there is operator documentation and service documentation.

The documentation covers all the relevant information about the following life cycle phases. The life cycle phases are storage, transport, assembly, commissioning, operation, maintenance (incl. maintenance and inspection schedule) and dismantling if necessary.

Safety notes are provided in a separate safety chapter and are described at the relevant points in the component documentation.

As a rule, the documentation is delivered in printed form with the product. The documentation is also available in digital form in the Service Library.

3.6 Service Library

The Service Library is an online portal where product information from Caterpillar Energy Solutions Mannheim is made available.

The portal is an online web application that can be used on every PC or on mobile devices.

The full-text search and various filters can be used to search for, view, download and comment on content.

A vast quantity of information is provided, such as operating manuals, maintenance information, work instructions and software.

You can find further information on accessing the Service Library at https://caterpillar.service-library.net. To register, please contact your business partner or your superior.

4 Basic planning principles for energy supply plants

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4.1 Structure and function

4.1.1 Purpose

The purpose of energy supply plants is the provision of energy in usable form. This energy is mainly used in private households, in industry and for the operation of infrastructure, such as telecommunications and traffic.

4.1.2 Structural design

Energy supply plant

The heart of the energy supply plant is the combustion engine unit, where one energy supply plant can have several combustion engine units.

Combustion engine unit

A combustion engine unit consists of:

- Genset
- All auxiliary systems that are directly assigned to this genset
- Any other systems that are also required for the genset's operation

Genset

The genset is a mechanical engineering and functional unit with the following main components: combustion engine, generator, power transmission (coupling), support structure system (base frame) and engine control.

Auxiliary systems

Various auxiliary systems are required for the operation of the genset and are often connected directly to the genset.

The following auxiliary systems are often part of energy supply plants with combustion engines.

- Ventilation system
- Cooling systems
- Heat extraction system
- Fuel system
- Lube oil system
- Combustion air system
- Exhaust system
- Support structure system
- Machine enclosure
- Compressed air system

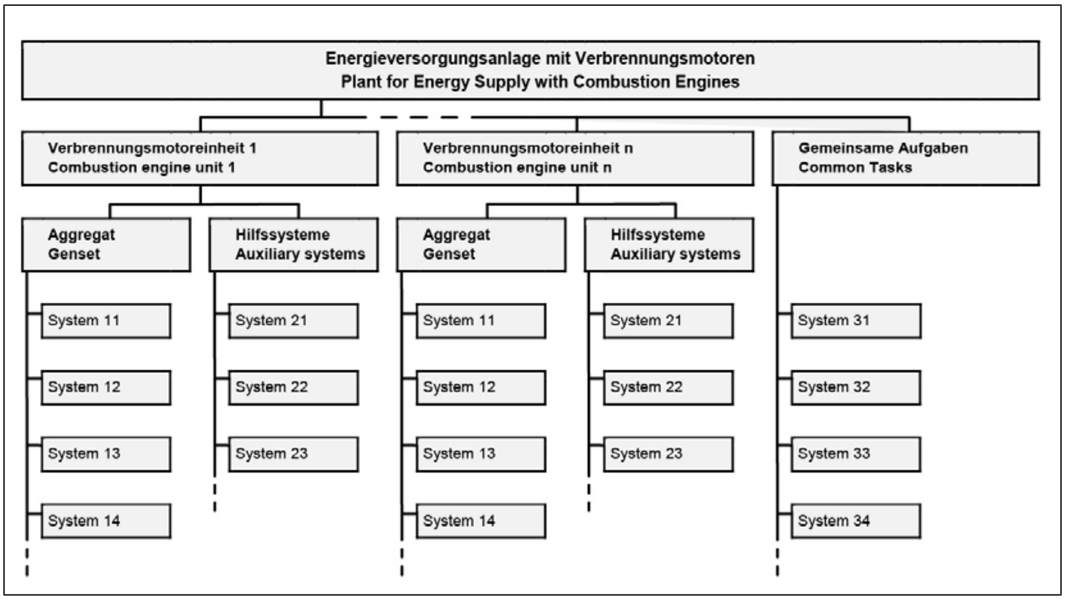
- Electrical power system
- Electrical auxiliary power system
- Plant control system

Other systems

In addition to the combustion engine units, other systems for shared tasks can also be part of the energy supply plant. These include, for example, a shared fuel storage tank, a shared transformer station as well as office and social buildings.

Schematic plant structure

The following illustration shows a schematic view of the described plant structure.



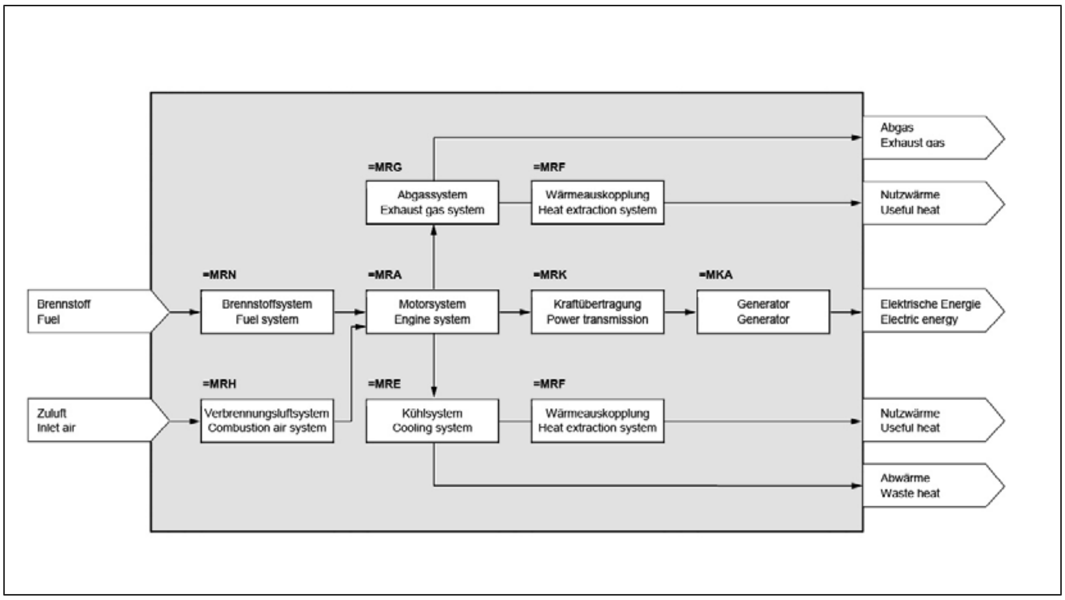
3539201419: Structure of a typical energy supply plant

4.1.3 Energy conversion process and media flows

"Plants for energy supply with combustion engines convert a chemical energy source into various forms of usable energy in several steps.

Depending on the operation mode (power- or heat-driven), electrical energy and thermal energy for heating purposes is primarily provided. Plants for energy supply with combustion engines can essentially be used for the provision of control energy because the chemical energy used for conversion can be stored and can be converted as needed." [VGB Guideline S-823-34]

Combustion engines can be used to make a fuel energetically usable with combustion air. The following illustration shows the most important media and energy flows in plants with combustion engines. It may be the case that the heat utilization shown in the illustration does not occur. In this case, only the electrical energy is made available and the thermal energy that is produced is unused and is discharged into the environment.



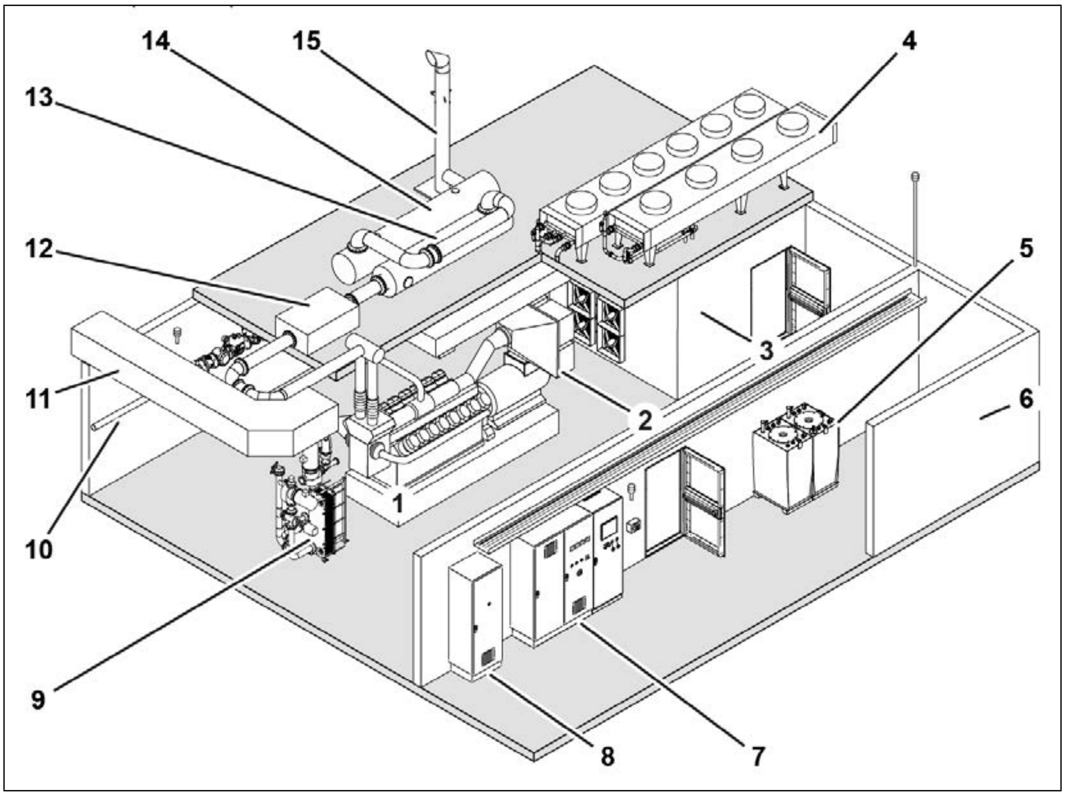
3539201931: Media and energy flows of a typical combustion engine unit

Further information

- Gas engine [▶ 88]

4.1.4 Example

The illustration shows a plant with a gas engine genset and various auxiliary systems and components. It is used only to understand the interconnections and is not to scale, detailed or complete. The concrete design of a plant and the arrangement of the components must correspond to the local conditions and is carried out during project planning.



2963981323: Simplified representation of a combined heat and power station (CHPS)

1	Genset	2	Combustion air filter (combustion air system)
3	Supply air filters and supply air fans (ventilation system)	4	Radiators (cooling systems)
5	Fresh oil tank and waste oil tank (lube oil system)	6	Building walls and ceilings (machine enclosure)
7	Switchgear cabinets (genset and plant control system and electrical auxiliary power system)	8	Switchgear cabinet with generator circuit breaker (electrical power system)
9	Cooling module with pumps, valves and plate heat exchanger (cooling and heat extraction system)	10	Fuel gas line and gas train (fuel system)
11	Exhaust air system (ventilation system)	12	Exhaust gas cleaning system (exhaust system)
13	Exhaust heat exchanger (heat utilization system)	14	Exhaust muffler (exhaust system)
15	Exhaust stack (exhaust system)		

4.2 Assessment of demand

4.2.1 Annual consumption curves

The size of the genset design is based on the electricity and heat demand using annual consumption curves.

4.2.2 Power demand

The power demand curve is decisive in determining the demand for power in grid-parallel operation. Investigate whether it is appropriate to split the total output between several gensets. For back-up power operation, in addition to the power demand in grid-parallel operation, the back-up power output must also be considered. A distinction must be made between "important" and "non-important" consumers and their permissible downtimes.

Not all consumers are connected or achieve their maximum current consumption simultaneously (simultaneity factor).

Some consumers purely consume active power, while others merely consume an apparent power output. Particular consumers, such as those with impact load characteristics or that make extreme demands in terms of constant voltage and frequency, must be taken into account.

Under special climatic mounting conditions, e.g., high altitude, high air temperatures and air humidity, the engine and generator are unable to produce their normal output. This results in reduced power as per ISO 8528-1 or DIN VDE 0530 and DIN EN 60034.

4.2.3 Heat demand

The heat demand curve can be used to determine the size and number of gensets required for heat-driven operation. However, with heat-driven operation, it is essential to consider the generation of and demand for power. The choice of operating mode may lead to negative feed and/or to power being drawn from the mains.

4.3 Overview of control modes, operation modes and reference variables

4.3.1 Introduction

This chapter serves as the basis for the planning of the operating concept, the control concept and the proper and efficient use of the CES combustion engine units and their auxiliary systems on site.

An overview in table form first lists the most important control modes, operation modes and reference variables with a brief description of their purpose. This is followed by more detailed information about typical operation modes that must be taken into account during planning.

As this document cannot describe every use and the use of the product will be influenced by the situation on site, CES will be happy to answer any questions you may have and generally recommends a coordinated approach to project planning.

4.3.2 Overview tables

The operation modes listed here are based on various differentiation criteria. Several operation modes are therefore relevant for each specific application.

Operation modes, listed according to control mode

Designation	Description
Automatic operation	Automatic operation in order to start the operationally ready module automatically via an external signal or power demand and connect to the power grid
Manual mode	Manual operation in order to start the module manually as required. The start-up and power demand is performed by the operating personnel in steps

Table 1: Overview according to control mode

Operation modes, listed according to reference variable for operation of the plant

Designation	Description
Power-driven operation	Operation mode of a heat power station in which the power station performance is based on the demand for power. • For more information: Power demand [▷ 50]
Heat-driven operation	Operation mode of a heat power station in which the power station performance is based on the demand for heat. • For more information: Heat demand [▷ 50]
Fuel gas-driven operation	Operation mode of a power station in which the power station performance is based on the supply of fuel gas.

Table 2: Overview according to reference variable

Operation modes, listed according to fuel gas supply

Designation	Description
Single-gas operation	Operation mode of a genset in which a certain type of fuel gas is continuously used as fuel.
Dual gas operation	Operation mode of a genset in which one of two possible types of fuel gas or a mixture of both types of fuel gas is used as fuel. For more information: Notes on assembly of gas trains [▷ 176]
Admix operation	Dual gas operation using a mixture in which the volume fraction of one type of fuel gas is at least 10 % and the volume fraction of the other type of fuel gas is max. 90 %.
Switch-over operation	Dual gas operation in which the volume fraction of one type of fuel gas is 100 % and the volume fraction of the other type of fuel gas is 0 %. It is only possible to switch over from one type of fuel gas to the other when the genset is at a standstill.

Table 3: Overview according to fuel gas

Operation modes, listed according to integration into the power grid

Designation	Description
Grid-parallel operation	Operation mode in which one energy supply plant feeds electric current into a power distribution grid into which one or more other energy supply plants are already feeding electric current. Further information • Grid-parallel operation [▷ 268]
Island operation	Operation mode in which one energy supply plant with just one genset is the only power source in the power distribution grid. For more information: Island operation and island-parallel operation [▷ 274]
Island-parallel operation	Operation mode in which one energy supply plant contains several gensets as an island and these gensets are operated together in this island.

Designation	Description
	For more information: Island operation and island-parallel operation [▷ 274]

Table 4: Overview according to power grid

Operation modes, listed according to coverage of demand for electrical energy

Designation	Description
Base load operation (continuous operation)	Operation of an energy supply plant with the objective of covering the base load that is present in an energy supply grid. The base load is the constantly required electrical power in a supply area.
Peak load operation (flexible operation)	Operation of an energy supply plant with the objective of covering the peak load that is present in an energy supply grid. The peak load is the share of electrical power in a supply area that is required only at relatively short notice and for a limited time.

Table 5: Overview according to coverage of demand

Operation modes, listed according to the provision of electrical and/or thermal energy

Designation	Description
Full load operation	Operation mode of a genset in which the genset is running at 100 percent of the rated power.
Partial load operation	Operation mode of a genset in which the genset is running at less than 100 percent of the rated power.
Overload operation (not permissible)	Operation mode of a genset in which the genset is running at more than 100 percent of the rated power.
Power-reduced operation	It is possible that the genset cannot run at full load for various technical reasons. These are generally operating conditions detected via the engine control that bring about a situation in which the genset can only be operated at reduced power.

Table 6: Overview according to provision of energy

Operation modes, listed according to loading during plant operation

Designation	Description
Steady-state operation	Operation mode of a genset during which the genset is almost constantly loaded over a long period of time.
Transient operation	Operation mode of a genset during which the genset's loading often changes.

Table 7: Overview according to loading

Starting

Designation	Description
Fast Ramp-Up	Additional option during flexible operation that makes it possible to ramp up the genset to the demanded power faster over a steeper power ramp after starting. For more information: Fast Ramp-Up [▷ 57]
Black start	Start an energy supply plant from a totally switched off state using its own auxiliary energy source without supplying electrical energy from an external source. For more information: Black start capability (island operation) [▷ 69]

Table 8: Overview of starting

Switching off

Designation	Description
Emergency stop	Instantaneous shutdown of the genset with interruption of the fuel gas supply and opening of the generator circuit breaker. All the pumps continue running. The emergency stop is useful for interrupting or preventing possible hazardous operating situations. An emergency stop can be used to reduce the risk of dangerous machine movements.

Designation	Description
	Depending on the type of emergency stop, either all the pumps can continue running for cooling purposes or they can also be stopped at the same time.
Emergency switching off	Instantaneous interruption of the power supply of the genset and the directly related equipment. During emergency switching off, an emergency stop of the genset is always performed as well. Emergency switching off reduces the risk of danger from an electric shock or another electrical hazard.

Table 9: Overview of switching off

4.4 Minimum loads

Especially for island operation, island-parallel operation but also for grid-parallel operation, restrictions for the operation of a gas engine genset must be observed. These restrictions have a particular effect on the maximum availability with minimum maintenance cost.

No stable behavior of the following is guaranteed for power outputs below the recommended minimum load in continuous operation:

- Emissions
- Lube oil consumption
- Fuel use

Fixed values for the genset output are still saved in the TEM control or TPEM control. The genset is switched off after a prior warning if these values are undercut.

The following table contains information about minimum loads and shutdowns for the engine types used in the current genset series. The information also applies to the different versions of each type of engine.

Short-term operation		Continuous operation
Engine type	Shutdown limit in kW (*)	Recommended minimum load in kW (**)
TCG 3016 V08	100	200
TCG 3016 V12	150	300
TCG 3016 V16	200	400
TCG 2020 V12	305	600
TCG 2020 V16	410	780

Short-term operation		Continuous operation
TCG 2020 V20	585	1000
TCG 3020 V12	420	690
TCG 3020 V16	560	920
TCG 3020 V20	700	1150
TCG 2032 V12	800	1666
TCG 2032 V16	1060	2150
(*) TEM gensets: A warning is issued after 45 min / a shutdown is performed after 60 min (*) TPEM gensets: A warning is issued after 15 min / a shutdown is performed after 60 min (**) Operation below the limit value for continuous operation is not recommended and should be limited. If this is required, however, make sure that the genset is then operated at a power that is above the limit value for a long period of time (>120 min).		

Table 10: Minimum loads and shutdowns

4.5 Provision of control energy

In an electric power supply system, generation and consumption of power must always balance each other out. Power can only be stored in an electrical supply system to a limited extent. The purpose of control energy is to balance out deviations between generation and extraction. There are two different types of control energy here:

- Positive control energy: In the event of an unpredicted increased power demand, positive control energy is necessary. Generation must be increased or the decrease in performance must be reduced (energy deficit).
- Negative control energy: The power production is above the current demand; current collectors must be temporarily switched on or power generators temporarily limited (energy surplus).

There are three different types of control energy:

- Primary control energy: Power is required for quick stabilization of the mains within 30 seconds so that frequency deviation is stopped.
- Secondary control energy: Power must be fully available within five minutes so that frequency deviation is reduced.
- Tertiary control energy (minute reserve): Is used for the replacement of the secondary control energy within a lead time and is retrieved for a period of at least 15 minutes at a constant level.

The amount of renewable energies is continuously increasing. Power generation from controllable energy supply units is gaining ever greater significance, since wind and solar energy are not permanently available.

Gas engine gensets can be operated with flexible operation.

In flexible operation of the Caterpillar Energy Solutions gensets, two operation modes are possible for participation in the control energy market:

- Provision of the power in the part-load operational range (secondary and tertiary)
- Starting from a standstill and using the full power of the genset (secondary and tertiary)

Operation in the part-load operational range protects the genset. A flexible mode that involves starting from a standstill up to full load places much more stress on the genset. This can cause wear, for example.

Adjustments to the prelubrication and to the preheating contribute to the reduction in wear with these gensets.

Whether a genset in question is suitable for the output of primary, secondary or tertiary control power and which technical requirements and additions are necessary in order to fulfill the pre-qualification requirements must be clarified on a project-specific basis.

4.6 Fast Ramp-Up

To balance excess supplies and reduced supplies of electric current in the interconnected grid, there is a need for increasingly high flexibility during power generation. This flexibility results in the required extra power (positive or negative) and serves to balance situations in which the electricity demand in the grid is higher or lower than the forecast demand. This extra power is purchased by the grid operators from private or public electricity providers with individually defined contract terms. Examples of this include the STOR (Short Term Operating Reserve) program in Great Britain or the balancing energy market (primary, secondary and tertiary) in Germany.

The “Fast Ramp-Up (FRU)” option was developed within the TEM control system to show fast reaction times. This option makes it possible to move a preheated engine to the rated power in a short period of time. This requires that the genset, or rather the complete engine cooling system including the lube oil circuit, must be constantly kept warm at temperatures above 40 °C. This option is approved for the genset TCG 2032B V16.

4.7 Back-up power operation

For some special applications, it is necessary in an emergency situation to supply power to important consumers for 15 seconds. In order to realize this kind of emergency power supply, the function and consumers must be clearly defined in the project planning phase. The power available after 15 seconds corresponds to the first load step as per the load table.

For this application, the gas engine must be able to black start. This condition can only be fulfilled by single-engine plants with gensets TCG 3016, TCG 2020 V12 and TCG 2020 V16. The gensets TCG 2020 V20 and TCG 3020 V20 are not suitable for back-up power operation because their startup time is too long.

In island operation with more than one gas genset, the first genset supplies the back-up power. The other gas gensets start once the power supplied by the first genset is stable. The auxiliary drive power for the subsequent gas gensets is supplied by the first genset. The other gensets will be synchronized to the first one. In some special cases, it is possible to start more than one gas genset to cover a higher amount of back-up supply as well. In this case a run-up synchronization is necessary.

The available back-up power will be calculated according to the first load step multiplied by the number of running gensets. This is a very special application of the gas gensets and must be planned in detail.

Required information

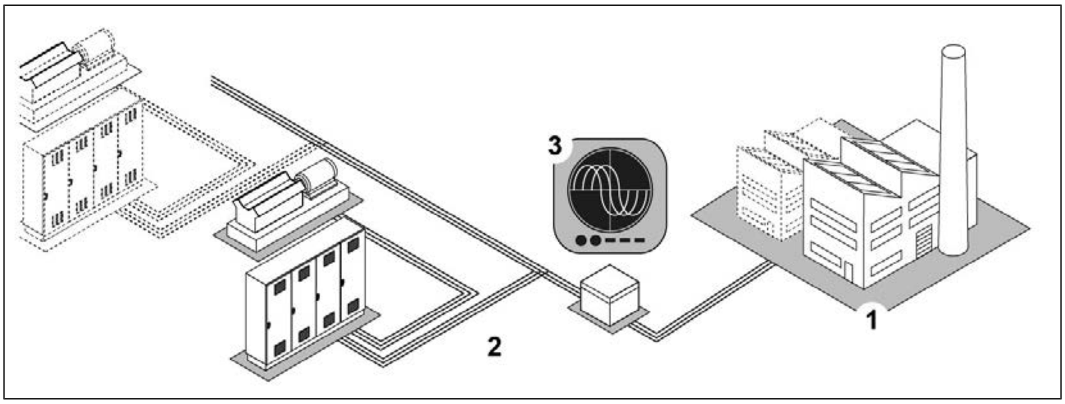
- Transient performance capability (island operation) [▸ 59]
- Black start capability (island operation) [▸ 69]

4.8 Transient performance capability (island operation)

4.8.1 Processes and terms

Island operation and island-parallel operation

Unlike transmission grids with a large number of infeed gensets and power consumers, an island grid is made up of a small number of nodes (1). Power is supplied (2) by just one genset (island operation) or by multiple gensets (island-parallel operation).



3522499723: Example illustration of an island grid

Voltage and frequency holding in island operation

In island operation, the speed of the gas engine determines the frequency of the generated voltage (3), and the generator excitation determines its value. The lower number of nodes causes the frequency to fluctuate much faster than in large grids as power consumption changes, and the frequency must be kept stable within the desired limits by the genset's control system.

Control accuracy and performance classes

The permissible voltage fluctuations are preset by the requirements of the equipment used by the grid participants. The definition of performance classes in G-classes, for example, generally serves as the basis for combustion engines. The following list provides an initial overview:

- G1 with requirements for the frequency and voltage curve during a load change: simple household equipment, simple drives.
- G2 with standard requirements for the frequency and voltage curve during a load change: comparable with the public mains.
- G3 with higher requirements for the frequency and voltage curve (even sinusoidal) during a load change: comparable with electronic data processing systems, telecommunications equipment, etc.
- G4 is intended for complex applications that cannot be classified in the classes G1 – G3 and are planned during special project planning.

Standards

Exact information about the requirements and tolerances of the performance classes can be found in ISO 8528-5:2022-06 Reciprocating internal combustion engine driven alternating current generator sets - Part 5: Generating sets, for example.

Switching loads on and off

During operation, the power consumption fluctuates as a result of switching on and switching off consumers (loads). For the genset, this means:

- When loads are switched on, the drive of a power-generating genset (gas engine) is more or less braked and the speed (frequency) drops for a short time.
- When loads are switched off, the drive of a power-generating genset (gas engine) is more or less relieved and the speed (frequency) increases for a short time.

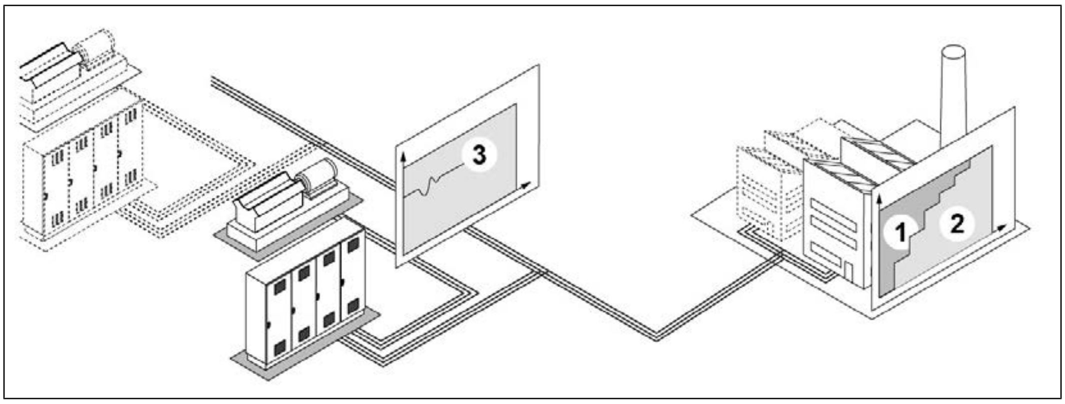
Every change in the speed of the genset has a direct effect on the amplitude of the generated voltage and its frequency in island operation. The generator's voltage controller then very quickly regulates the voltage. It takes longer to regulate the frequency. To keep the frequency stable, the energy supply plant's control system must do the following, depending on the situation:

- Adjust the power of the gensets
- Switch more gensets on and off

Load steps and wait time

Generally, loads are not switched on and off slowly in the form of ramps, but are switched very quickly. Since the control system needs a certain amount of time to regulate, short-term frequency and voltage fluctuations occur. These are proportional to the value of the load that was switched on or off.

To comply with the requirements of the desired control accuracy, the power demand is not therefore changed in one step (1) in the event of large load jumps, but step by step (2) in accordance with the technical performance of the genset and its control capabilities.



3935320075: Simplified interaction between load steps and wait time

The permissible size of the steps depends on the design of the genset and the position of the current operating point.

To ensure that the genset is regulated to its required setpoint by the control system (3) after a step is switched, there is a certain wait time before the next step is switched.

Because of the processes involved, gas engines have a reaction time before the emission control interventions have an effect on the exhaust emissions produced in the combustion chambers and subsequently at the provided measuring point. When the genset is set correctly and in steady-state operation, the specified wait time is sufficient for standard applications. For transient operation with its flexible operating modes, special measures may be required, depending on the required emission targets. This is one of the tasks performed during planning of the connected exhaust system (exhaust gas cleaning).

4.8.2 Notes for planning

General procedure

Knowledge of the island grid to be supplied is important during project planning for an energy supply plant. Depending on the required control accuracy and the required control capabilities for switching loads on and off on site, the island grid is classified into a performance class.

A suitable standard genset can then be selected or adapted to the island grid using measures implemented by the manufacturer. Depending on the operating conditions for the genset on site, appropriate adaptations must be taken into account.

For transient operation with flexible and frequent load changes in island operation and island-parallel operation, customers may need to implement special measures, depending on the required customer loads. For example, customers may need to limit loads that are active at the same time, or reduce activation currents by implementing suitable measures (soft starter). This is one of the tasks involved in planning the plant and specifications for island operation and island-parallel operation

- For required information on performance and control: Island operation and island-parallel operation [▷ 274] and Active power load share (island-parallel operation) [▷ 70]

General conditions for load switching

The following applies for switching loads using load steps in accordance with the genset-specific technical specifications:

- Exhaust emission 500 mg/m^3 NO_x, or 5 % O_2 (stationary)
- Natural gas operation
- Warm engine
- ISO conditions
- Line from the zero pressure controller of the gas train to the gas mixer valve max. 1.5 m long

- A minimum gas pressure upstream of the zero pressure control line according to applicable SPI (note plant design)
- Installation height < 500 m above sea level

The permissible load steps change in the case of deviating conditions. When connecting electric drives (pumps, compressors) to the isolation busbar, it is necessary to consider their switching power in addition to their rated power.

Genset-related operational influences

The following operation parameters influence the height of the load steps:

- Air cleaner, clean or contaminated
- Increased exhaust back pressure
- Net calorific value and methane number of the fuel gas
- Engine wear
- Installation height
- Air inlet temperature
- Emission limits for NO_x emissions
- Generator controller
- Wait time between individual load acceptances or load rejections

Operation deviating from the design generally leads to a reduction in the permissible load step height.

NOTE

Deviating NO_x emission values

The transient load step capability is affected by the set NO_x emission level and actual on-site conditions.

Calibration of set NO_x value via in-cylinder temperatures map is performed only in steady state engine operation. Emissions may deviate from calibrated set NO_x values during transient engine operation.

- Required information: Exhaust gas emissions (island operation) [▸ 69]

Influence of the performance class

With an increasing performance class:

- The requirements for the genset increase. The tolerance bands become narrower and the required stabilization times become shorter.
- The permissible step height decreases with load switches for the same genset.

When planning a plant, choose only the required performance class for the respective application.

The maximum step height can be illustrated only outside of the most roughly standardized performance class G1. Here it is ensured only that the engine is not damaged or goes into fault shutdown. The frequency drops or stabilization times, however, are no longer defined.

Genset-specific information and required bulletins

The capability of load acceptance and load rejection depends on the engine specification, the gas engine's and generator's total moment of inertia and the plant conditions. Genset-specific technical data on the load steps is therefore available as bulletins for planning. These are available for every standard series and contain the possible load steps with wait time for the performance classes G1 – G3. The genset-specific transient performance capability is shown in diagrams and tables.

- Required information: Technical Bulletins TR 2170 and TR 2172

For each of the series TCG 2020 and TCG 2032, there are diagrams for the maximum load steps without an allocation to one of the standardized performance classes. For the new engine series TCG 3016 and TCG 3020, the diagrams and tables for the performance classes G1, G2, and G3 have been determined for the individual numbers of cylinders and speeds (50 Hz and 60 Hz).

The bulletins are split into:

- Transient performance capability without performance classes
- Transient performance capability with performance classes

4.8.3 Introduction to the genset-specific description

4.8.3.1 General

In the following explanations, tables and diagrams, the fundamental capability of load acceptance and load rejection is shown for a gas engine genset. The information is intended to help you understand the bulletins and is therefore a general description.

NOTE

If the wait time is too short, there is a risk of unstable engine operation and the requirements of the ISO classes may not be complied with. Depending on the instability, the genset control even shuts down the genset to protect against damage

4.8.3.2 Information shown in tables

Introduction

In the tables listed below, the first column shows the engine load acceptance in steps from zero load up to 100 % load. The second column shows the required stabilization time in order to get the frequency back into the tolerance band around the rated frequency after a load step. The third column shows the maximum speed drop expected when the specified steps are fully exhausted. The tables for the load rejection show the load rejection in steps from 100 % load to idle. Load rejection from any load to 0 % or on auxiliary power is generally allowed in island operation, but should be avoided during normal operation. This protects the genset.

Example: The gas engine genset illustrated in the tables can be loaded with a maximum of 25 % in the first load step in accordance with the “load acceptance” table column. Based on a preload of 25 %, this is a maximum of 17 %. With a preload of 42 %, it is a maximum of 13 %. In the last load step this is 7 %. The same applies for the “load rejection” table column. Only a limited load rejection can occur starting from the current load.

Load steps without a performance class allocated

General, exemplary representation without reference to a genset.

Conditions				Moment of inertia of generator		
Intake air temperature		30 °C		Number of cylinders 1		≥ XX kgm^2
MCC inlet temperature	Natural gas	40 °C		Number of cylinders 2		≥ YY kgm^2
				Number of cylinders 3		≥ ZZ kgm^2
Load acceptance (Z)				Load rejection (A)		
P_N [%]	t_f [s]	n [%]		P_N [%]	t_f [s]	n [%]
0 - 25	15	-13		100 - 93	8	+6
25 - 42	15	-11		93 - 85	10	+6
42 - 55	15	-10		85 - 75	12	+9
55 - 65	15	-10		75 - 65	12	+9

65 - 75	12	-9		65 - 55	15	+10
75 - 85	12	-9		55 - 42	15	+10
85 - 93	10	-6		42 - 25	15	+11
93 - 100	8	-6		25 - 0	15	+13

P_N	Current load	t_f	Stabilization time
n	Speed change		
Z	Load acceptance	A	Load rejection

Load steps with performance classes according to ISO 8528

General, exemplary representation without reference to a genset

Intake air temperature	30 °C		Perfor-mance class	Wait time (s)
MCC inlet temperature	45 °C		G1	25
Moment of inertia of generator	≥ XX kgm^2		G2	20
			G3	15

1 Lastzuschaltung (Z) Load acceptance (Z)

2 Lastabschaltung (A) Load rejection (A)

G1		G2		G3	
P_N [%]	LS [%]	P_N [%]	LS [%]	P_N [%]	LS [%]
0	30	0	20	0	15
30	20	20	20	15	15
50	20	40	15	30	10
70	10	55	10	40	10
80	10	65	10	50	5
90	10	75	10	55	10
100	0	85	10	65	10
100	-10	95	5	75	5
90	-10	100	0	80	10
80	-10	100	-5	90	10
70	-20	95	-10	100	0
50	-20	85	-10	100	-10
30	-30	75	-10	90	-10
0	0	65	-10	80	-5
		55	-15	75	-10
		40	-20	65	-10
		20	-20	55	-5
		0	0	50	-10
				40	-10
				30	-15
				15	-15
				0	0

3624235531: Example table

1	Load acceptance (Z)	2	Load rejection (A)
P_N	Current load	G	Performance classes
LS	Load step		

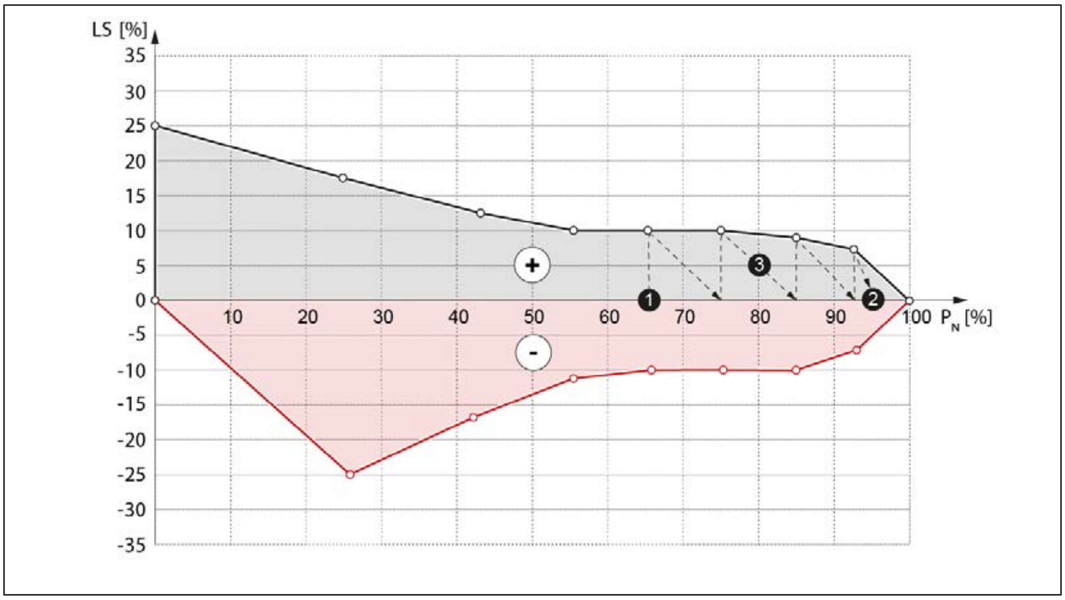
4.8.3.3 Information shown in diagrams

The following diagrams show the permissible load acceptance or load rejection of the engines. On the x axis, you have the current load of the engines. The y axis shows the possible load acceptance or the possible load rejection related to the current engine load.

Load steps without a performance class allocated

Let's look at the example used in chapter Load steps without a performance class allocated [▹ 64] again. The following diagram shows a falling curve between 0 % and 55 % in the engine loading range, in the area of the load acceptance. In this load range, the permitted load acceptance decreases from 25 % to 10 % if the engine output is increased. In the load range from 55 % to 75 %, the permitted load acceptance is 10 %. Above 75 % to 100 % the permitted load acceptance continues to decrease. Upon reaching 100 % load, no additional load acceptance is possible. The load rejection behaves in the same way.

Example: The current operating point (1) of the genset is at 65 % of the rated power. The desired load acceptance brings it to 95 % of the rated power. This is done in 4 steps with the load steps (LS) 10 %, 10 %, 9 % and 8 %.

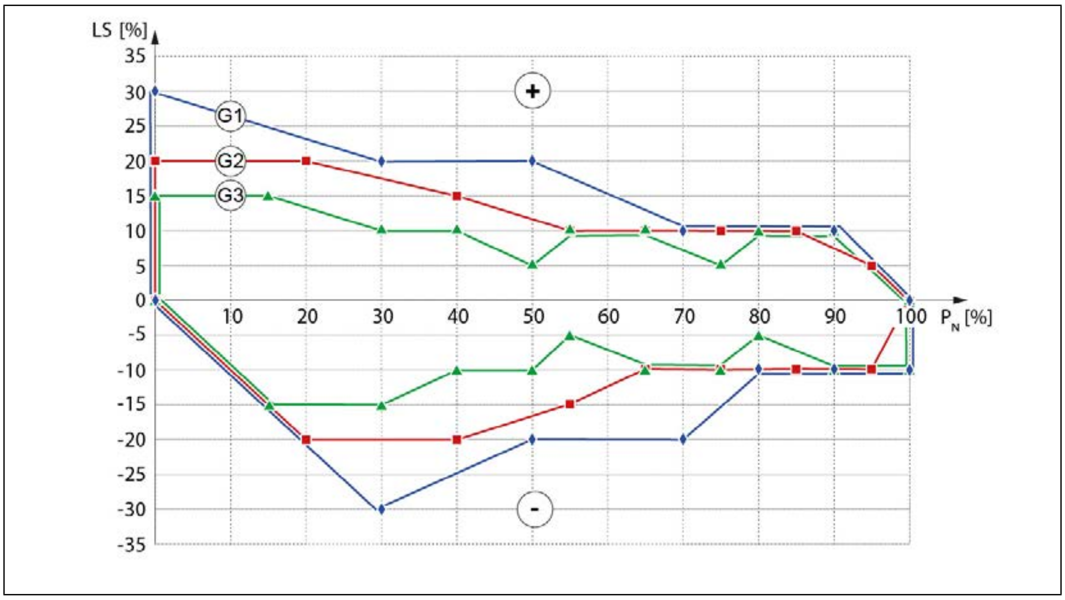


3624240395: Load steps without performance classes

(+)	Load acceptance	(-)	Load rejection
P_N	Current load in percent (based on the rated power)	LS	Load step

Load steps with performance classes according to ISO 8528

The following diagram shows the example used in chapter Load steps with performance classes according to ISO 8528 [▹ 65].



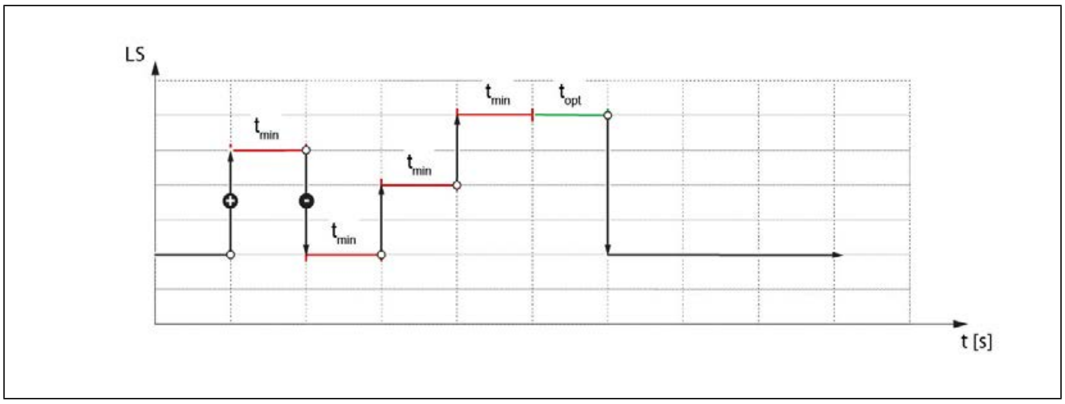
3624239883: Load steps with performance classes

(+)	Load acceptance	(-)	Load rejection
G	Performance classes (G1, G2, G3) (as per ISO 8528)	P_N	Actual power in percent (based on the rated power)
LS	Maximum permitted load acceptance and load rejection in percent (based on the rated power)		

4.8.3.4 Information on wait time

After the load step from 0 % to 30 %, there must be a wait time of a minimum of 25 seconds (t_{min}) before the next load step from 30 % to 50 % may be initiated. The wait time must be complied with for each load step (see next illustration).

Example of load progression with wait time:



3625220235: Wait time

(+)	Load acceptance	(-)	Load rejection

LS	Load step	t	Time in seconds
t_{min}	Minimum wait time	t_{opt}	Optional wait time extension

4.9 Starting of large consumers (island operation)

Some consumers such as pumps or fans have an effective starting power, which is a multiple of the rated power. In the case of a high effective starting power, it is necessary to use special starting procedures. For example, star/delta starting or soft starting. If there are consumers with a heavy starting torque, it is sometimes necessary to use load banks or battery storage to start these large consumers. For this reason, it is necessary to check the customer plant consumers and to coordinate the load acceptance and load rejection during project planning.

4.10 Black start capability (island operation)

If a gas genset is “black-started”, the gas genset starts without auxiliary drive power for prelubrication and cooling water pumps. The gas genset is started directly after the demand contact in the TEM system or the TPEM system has been closed. The cooling water pumps start as soon as the auxiliary drive power supply is available. Furthermore, the gas genset will be started without a prior leakage check of the gas train. The black start is an emergency function of the gas gensets and should be used only for emergency situations. Due to the high wear of the gas engine, this function should not be used more than three times a year.

The following gas engines are able to black start:

- TCG 3016
- TCG 2020
- TCG 2020 K
- TCG 3020

The black start is purely a function for island operation and is not possible in grid-parallel operation. The TCG 2032 is not capable of black-starting. This series requires prelubrication before the start. Therefore, a power supply for the auxiliary drives is required, for example using an emergency diesel or UPS.

4.11 Exhaust gas emissions (island operation)

During island operation, the TEM system or TPEM system regulates the exhaust gas emissions automatically. The typical value is 500 mg NO_x/Nm^3 (in relation to 5 % O_2, dry) or higher and can be parameterized by the commissioning staff. The higher enrichment of the fuel gas and air mixture provides a better load changing behavior of the gas engine, but leads to a higher NO_x value. If the emissions value must be lower than 500 mg/Nm3 in island operation, the fuel gas and air mixture has to be leaner. In this case, the load step table must be readjusted. In this way the height of the steps must be decreased so that the number of steps from idle to full load will be increased.

Required information

- Transient performance capability (island operation) [▸ 59]

4.12 Active power load share (island-parallel operation)

An active power load share function is required for island-parallel operation of a plant with multiple gensets. This should be provided as an integral component of the genset control (TPEM/TEM system) during project planning if at all possible. Alternatively, however, external, superior control is also possible.

This superior control for the load share must be suitable for the TPEM/TEM system and must have at least the following properties:

- Common frequency control of all gensets connected in parallel
- Analog setpoint speed specification for power control of the individual gensets
- Parameterizable PI and PID speed governors

Only a suitable load share ensures stable island-parallel operation. Based on experience with gensets in island-parallel operation, Caterpillar Energy Solutions GmbH offers a load share solution for island-parallel operation:

- Load share via the master control cabinet (ZAS)
  - Additional mounting plate for installation in the ZAS
  - Load-dependent speed governor parameterization (8-stage) for dynamic high-power control
  - Variants for Island-parallel operation of up to 4 gensets or up to 8 gensets (as well as optional control of a coupler circuit breaker)
  - Other special load shares for more than 8 gensets are possible on request
- Load share via the TPEM Multi Function Relay (TPEM MFR)
  - Additional function for the TPEM MFR in the TPEM Control Cabinet (TPEM CC)
  - Data exchange between the gensets via CAN bus

It is strongly recommended to implement Island-parallel operation for large gensets on the basis of the CES load share solution. The selection of an insufficient load share solution can lead to the following problems:

- Load fluctuations between the gensets
- Delays in the commissioning of the plant and additional costs for components and labor
- Necessity of retrofitting in the superior control solution

Costs or delays resulting from the use of an insufficient control of the load share system are not the responsibility of Caterpillar Energy Solutions GmbH.

Required information

- Island-parallel operation [▷ 278]

4.13 Other operation modes

This document only describes selected typical operation modes and reference variables for the planning of energy supply plants with combustion engine units. Depending on the situation on site, other concepts, modifications or combinations may be useful and can be taken into account during project planning.

Further information

- Technical support and services [▷ 39]

5 Types of power stations

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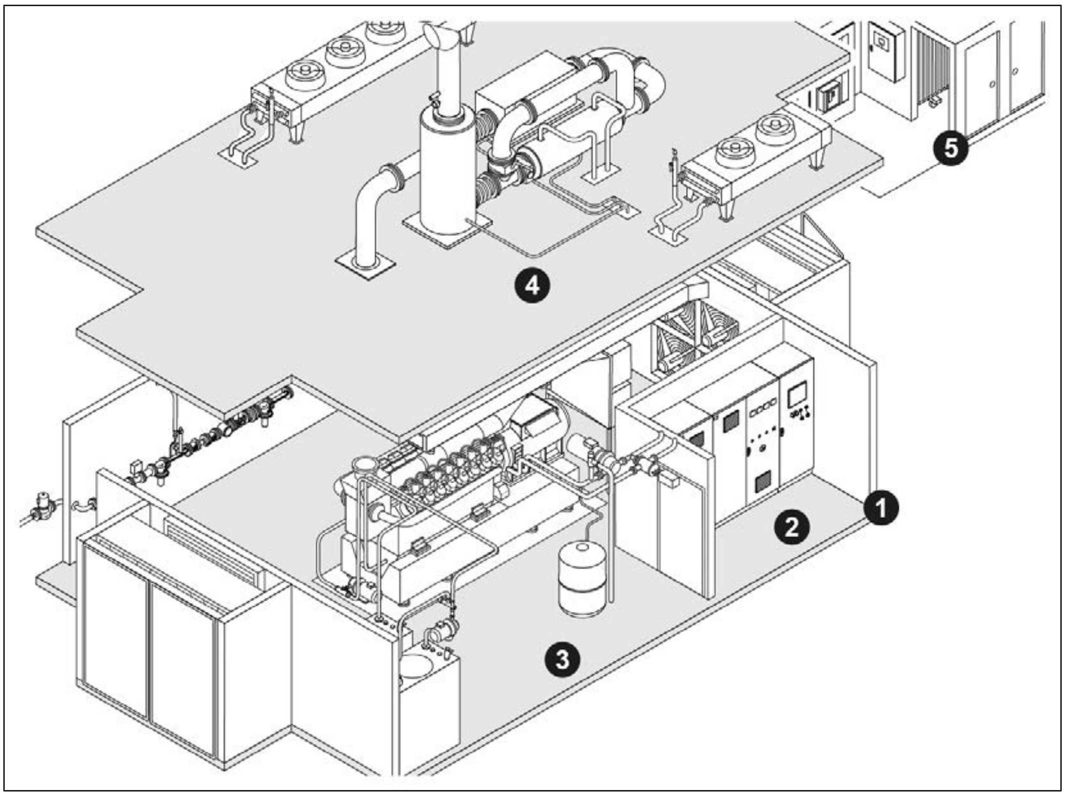
5.1 Power station with one genset

5.1.1 Power station overview

The following illustration shows an example of a typical power station with one genset. It is intended as a starting point to help you understand the components of an energy supply plant. To simplify the overview, the proportions and spaces are not to scale.



3522759051: Simplified example illustration

1	Building (machine enclosure)	2	Switchgear
3	Genset with auxiliary systems	4	Roof attachments
5	Superior control		

5.1.2 Structure and function

Power stations with a single genset generally consist of the building with the required rooms for the genset and the auxiliary systems. All the auxiliary systems are designed only for this single genset and are located in the same room (gas train) or adjacent room, or outside the building, depending on the auxiliary system and its components.

An energy supply plant like this generates low voltage or medium voltage. A heat extraction system via heat exchanger increases efficiency considerably. The choice of power input is important during planning:

- Only grid-parallel
- Only island operation
- Grid-parallel and island operation, depending on the situation

In terms of control technology, an energy supply plant like this consists of:

- the control for the combustion engine unit with the control tasks and regulating tasks for the combustion engine, the generator, the auxiliary systems and the power part of the combustion engine unit (the generator circuit breaker for low voltage generation, for example)
- the superior control for the energy supply plant with the control tasks and regulating tasks for the grid connection or the power supply into an island grid, and control of the combustion engine unit with relevant signals for the power demand

The switchgear for the combustion engine unit is generally located in a switchgear room outside of the genset room. The superior control or regulating system of the energy supply plant can be in the immediate vicinity or far away. Since the functional scope of the control system for the energy supply plant depends to a large degree on the regional requirements of the grid operator, it is particularly important that those involved in project planning define the competence level and requirements for this interface.

The flexible control concept of the TEM/TPEM system means that various concepts for the operation modes and reference variables can be selected during project planning. Customer-optimized concepts are also possible.

Various options are available for online access to the combustion engine unit.

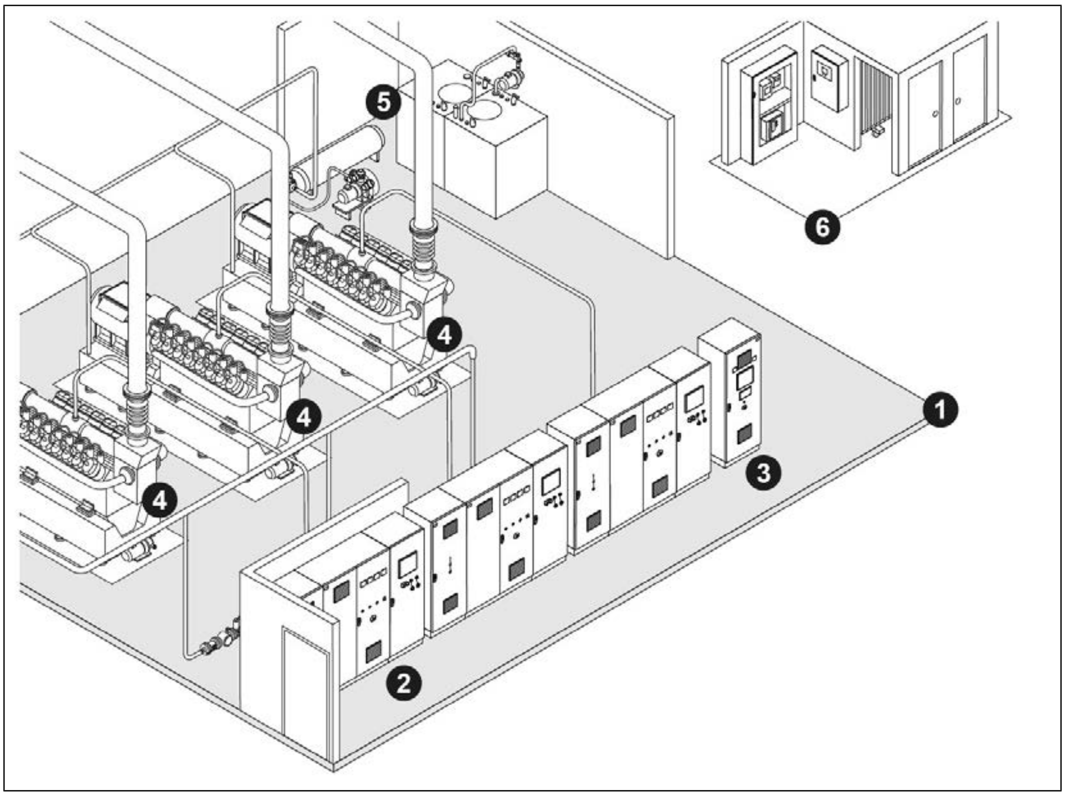
Further information

- Overview of control modes, operation modes and reference variables [▷ 50]
- Control systems and switchgear [▷ 245]
- Power grids and genset connection [▷ 267]

5.2 Power station with several gensets

5.2.1 Power station overview

The following illustration shows an example of a typical power station with one genset. It is intended as a starting point to help you understand the components of an energy supply plant. To simplify the overview, the proportions and spaces are not to scale.



3522762379: Simplified example illustration

1	Building (machine enclosure)	2	Switchgear
3	Master control cabinet (ZAS)	4	Gensets with auxiliary systems
5	Central auxiliary systems	6	Superior control

5.2.2 Structure and function

Power stations with several combustion engine units increase the amount of power generated and the energy distribution capabilities.

Unlike power stations with a single combustion engine unit, individual auxiliary systems, such as the lube oil supply, are often designed for the entire energy distribution system and supply all combustion engine units. In addition, there is often a shared genset room, a shared crane system or a shared supply and stock of operating media.

Depending on project planning and the number of combustion engine units, the generators are connected to a busbar. In many combustion engine units, the busbar is often divided into segments and can be controlled via coupler circuit breakers.

The optional master control cabinet (ZAS), which serves as the interface to the superior control of the energy distribution system, is recommended. The master control cabinet (ZAS) makes the following possible, for example:

- Control of individual gensets, depending on the situation
- Load management system
- Central monitoring and control of shared systems

For complex systems, it is also possible to implement the optional SCADA application, which uses a visualization of the plant parts to allow a quick overview and intervention.

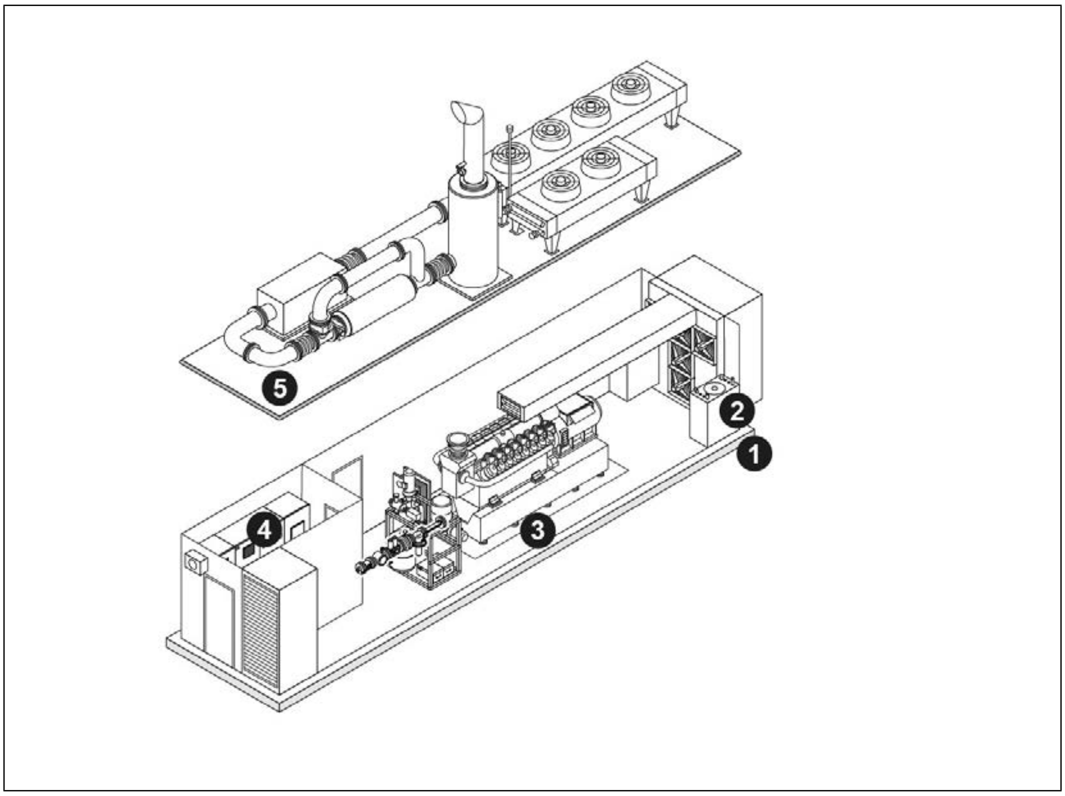
Further information

- Central plant control - Master control cabinet (ZAS) [▸ 264]

5.3 Containerized power station

5.3.1 Power station overview

The following illustration shows an example of a typical power station with one genset. It is intended as a starting point to help you understand the components of an energy supply plant. To simplify the overview, the proportions and spaces are not to scale.



3522760715: Example illustration

1	Foundation	2	Container as the machine enclosure
3	Genset room	4	Switchgear room
5	Roof attachments		

5.3.2 Structure and function

Containerized power stations are manufactured in a factory and are disassembled into a small number of assemblies for transport to the installation site. At the installation site, the assemblies are combined to form the complete plant and are connected to the on-site interfaces, e.g., foundation, fuel gas line, power cabling, heat grids and other interfaces if required.

Containerized power stations can be operated both as power stations with only one genset and power stations with several gensets. If there are several gensets, the containerized power stations are usually relatively close together.

5.3.3 Transport and installation of containers

5.3.3.1 Overview of transport and installation of containers and assembly of components

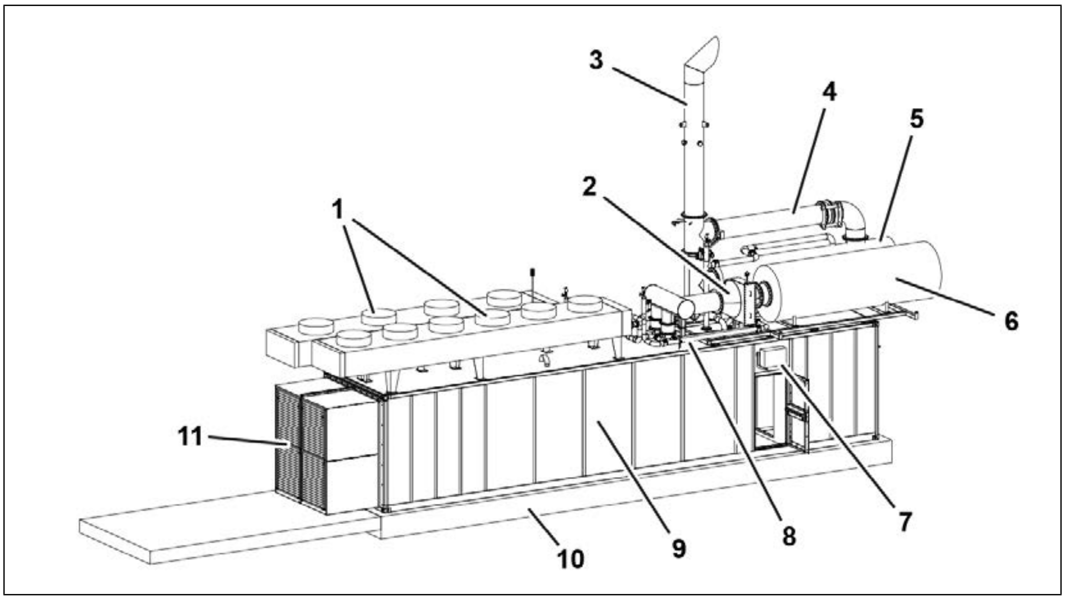
The transport of a container from the factory to its final destination can be divided into the following steps:

1. Loading onto truck by stationary crane or mobile crane.

2. Transport by truck to destination or to harbor for shipping.
3. Reloading in harbor or when changing truck.
4. Unloading at destination by mobile crane or permanently installed crane.
5. Installation on the foundation.

Assembly of components

In the case of containerized plants, the genset is ready mounted and installed in the container. Plant components such as exhaust mufflers and exhaust heat exchangers are arranged on a shared frame or on several frames made of square pipes on the roof of the container. These frames are only mounted on the roof of the container, connected to the piping and wired at the plant's installation site. When transporting a containerized plant, the components located on the roof are removed and transported next to the container as separate freight. The following illustration shows the containerized plant ready mounted; the other illustrations show the division of the components into individual batches for transport. The plant shown involves a CHPS container.



9692965515

1	Radiator
2	Exhaust catalytic converter
3	Exhaust stack
4	Exhaust bypass
5	Exhaust heat exchanger
6	Exhaust muffler
7	Air conditioner
8	Coolant pipes
9	Container
10	Foundation (provided by the customer)
11	Supply air components

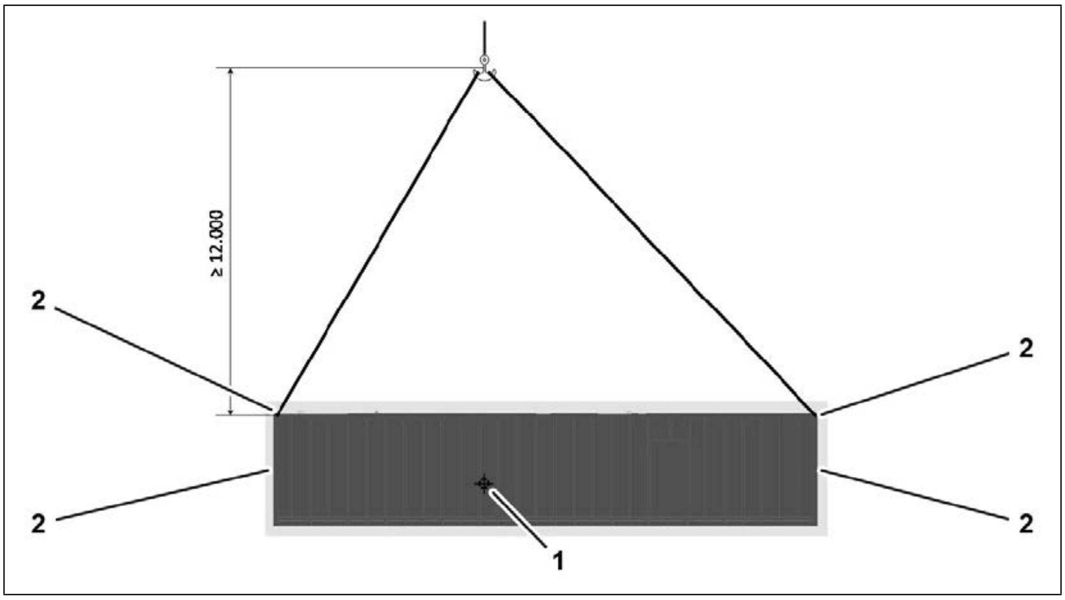
5.3.3.2 Lifting

For loading the container for transport, in the case of potential reloading and unloading at the construction site, the container must be lifted and moved while suspended on a crane.

The components inside the container, in particular the elastically mounted genset, are secured for transport. The genset is firmly interlocked using several threaded rods and underlays comprising hardwood blocks between the genset base frame and foundation rail. In addition to this, the genset is firmly strapped at the four corners of the base frame using tensioning straps with holding lugs attached to the container structure. Components for commissioning or other parts that are transported loosely along with the container are also secured for the transport. Nevertheless, it must be ensured that the container is lifted as evenly and horizontally as possible during hoisting.

The container corner plates welded in the roof of the container are used as load support points. The rope lengths must be chosen so that the crane hook is level with the center of gravity of the container. The position of the container's center of gravity is marked outside on the side wall of the container (see illustrations below).

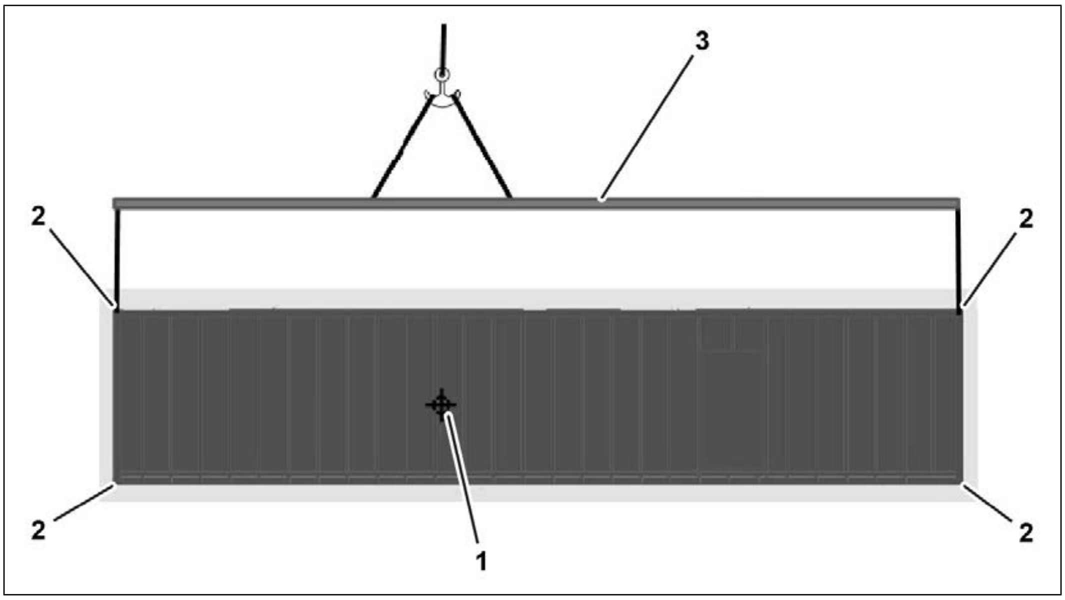
Lifting the container at upper container corner plates using ropes



3720906123: Lifting the container at upper container corner plates using ropes

1	Center of gravity marking	2	Container corner plate

Lifting the container at upper container corner plates using a traverse

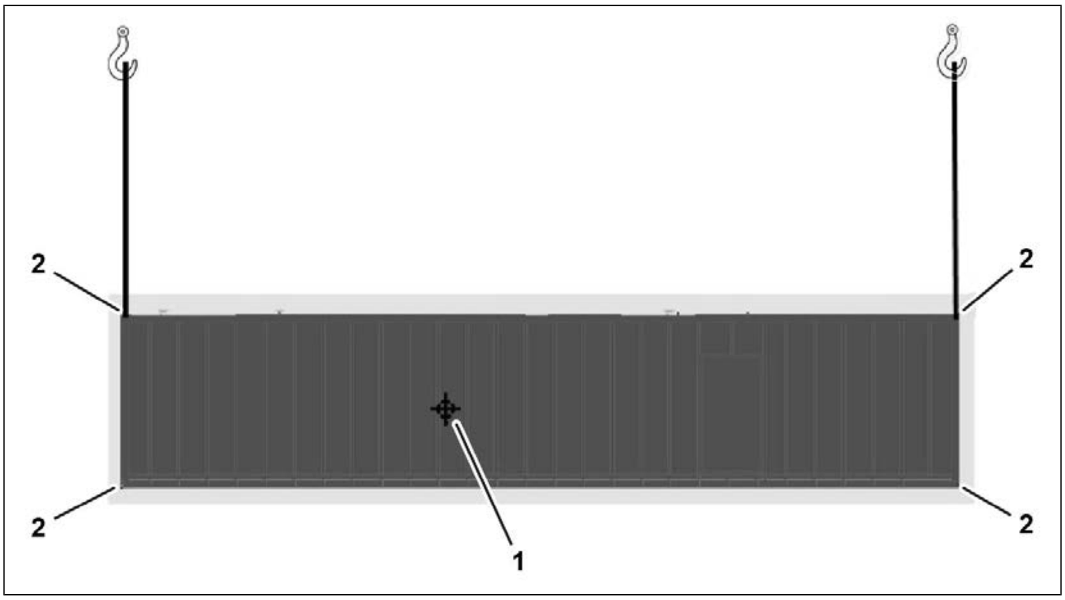


3720908811: Lifting the container at upper container corner plates using a traverse

1	Center of gravity marking	2	Container corner plate

3 Traverse

Lifting the container at upper corner plates using two cranes



3720924299: Lifting the container at upper corner plates using two cranes

1 Center of gravity marking

2 Container corner plate

5.3.3.3 Container transport

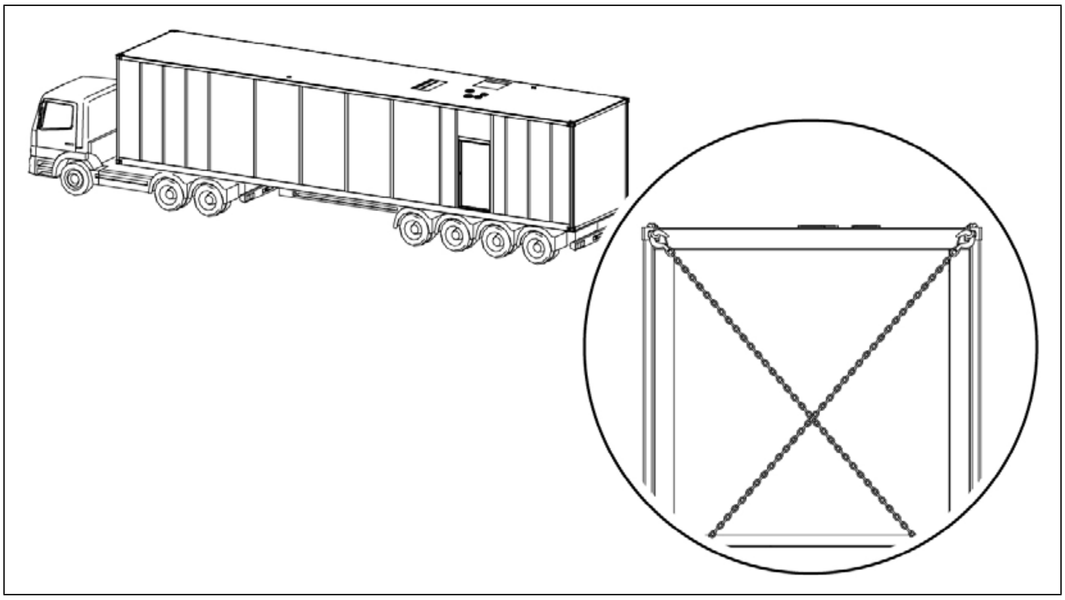
In most cases, the container and accessories are transported directly to the destination by truck.

If plants are to be shipped overseas, the containers are transported to a seaport and loaded onto a ship. The containers are usually transported further from the destination port to the installation site by truck.

When transporting the container and the components, the loads must be appropriately secured according to the relevant regulations (e.g., VDI 2700), similar to how this is described for the genset.

Depending on the specifications, it can also be the case that the containers are packed in a crate for sea transport.

Both the container and the components mounted on the frame must be secured for transport. The container corner plates can be used on the upper side for fastening the container on the low loader.



9692966923: Fixing a container for transport on a low loader

Required information

- Transport on vehicles and ships [110]

5.3.3.4 Assembly instructions

General assembly instructions are supplied for each containerized plant with the documentation. Specific documents for mounting the assemblies, the foundation dimensions, etc. are provided for the individual order.

6 Gas engine genset

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6.1 Overview of gensets

6.1.1 Model series

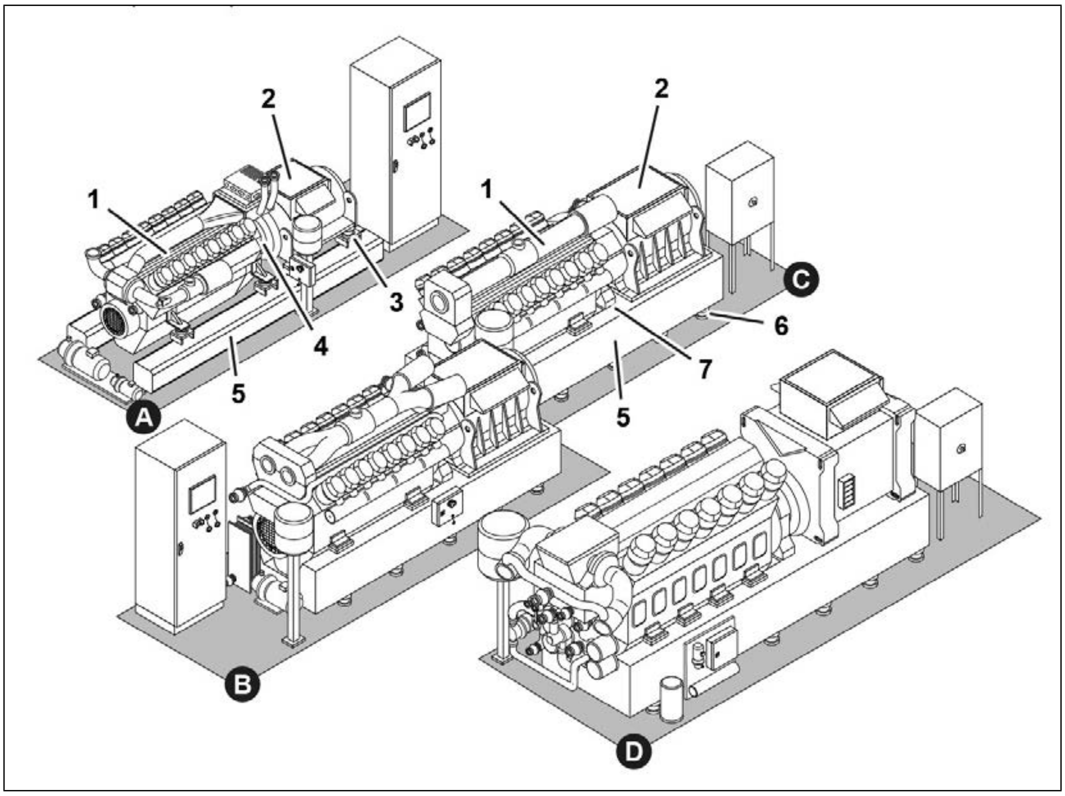
CES offers various series of gensets for use in power stations with combustion engines. The gensets are controlled by the TEM system or the TPEM system, depending on the series.

To meet the requirements on site, various variants (for example, number of cylinders) and various attachments are available for selection within the different series. Special customized solutions are also available on request.

Main components of the gensets

The main components of gensets are the base frame, gas engine, torsionally flexible coupling, generator and anti-vibration mounting.

The following illustration shows an overview of the typical genset series and their main components as an example. To simplify the overview, the proportions are not to scale, and the components are merely sketched.



3534928523: Simplified example illustration

A	Series TCG 3016 with TPEM system	B	Series TCG 3020 with TPEM system
C	Series TCG 2020 with TEM system	D	Series TCG 2032 with TEM system
1	Gas engine	2	Generator
3	Anti-vibration mounting	4	Flange housing

5 Base frame
6 Anti-vibration mounting
7 Coupling

In the TCG 2020, TCG 3020 and TCG 2032 series, the gas engine (1) and generator (2) are linked by a torsionally flexible coupling (7) and rigidly mounted on the base frame (5). The base frame (5) is mounted on the foundation with an anti-vibration mounting (6).

In the TCG 3016 series, the gas engine (1) is permanently connected to the generator (2) via a flange housing (4). A torsionally flexible coupling in the flange housing absorbs the torque transmission from the engine to the generator. The engine (1) and generator (2) unit connected via the flange housing (4) is elastically mounted on the base frame with the anti-vibration mounting (3). The base frame is installed rigidly on the genset foundation. All flexible connections for the operating media are installed on the genset. Auxiliaries such as prelubrication and lube oil level monitoring systems are mounted on the base frame (5).

Preheating must be provided for every engine. Dependent on the design of the plant, the preheating may be installed either at the genset (TCG 2032 only) or in the plant.

Technical data of the series

The genset data sheets and genset drawings contain comprehensive specifications for the technical data of the individual series (dimensions, weight, power, etc.).

6.1.2 Power specifications on the rating plates

6.1.2.1 Rating plate of the engine

The output SCN (continuous output, cannot be overloaded) for gas engines is outlined according to DIN 3046-7. The gas engine is run with natural gas on the test cell. In the case of engines which are run with other gas types in later operation, the output for the gas type is additionally stated on the rating plate. The gas type is specified after the output description by an extension.

For example, the following outputs can be indicated on the rating plate:

SCN n	Continuous output during operation with natural gas; n stands for natural gas. This power output is run on the test cell.
SCN b	Continuous output during operation with biogas; b stands for biogas.

Table 11: Power specifications on the rating plate

Further extensions may be:

m	Mine gas
s	Sewage gas
l	Landfill gas

Table 12: Fuel gas specifications on the rating plate

6.1.2.2 Rating plate of the generator

According to IEC 60034-1 (DIN EN 60034-1) the rating plate of the generator lists the apparent power of the specific type and the power factor (cos φ) of the generator. The specification is given in kVA (Kilo Volt-Ampere), the power factor is dimensionless.

6.1.2.3 Genset rating plate

The electric rated power of the genset is given on the rating plate of the genset. The name of the power category is outlined according to ISO 8528-1. The power is specified in KW_{el} (Kilowatt electric).

Gensets with gas engines are designed for continuous operation. Therefore, the power category COP is always stated on the genset rating plate.

6.2 Structure and function

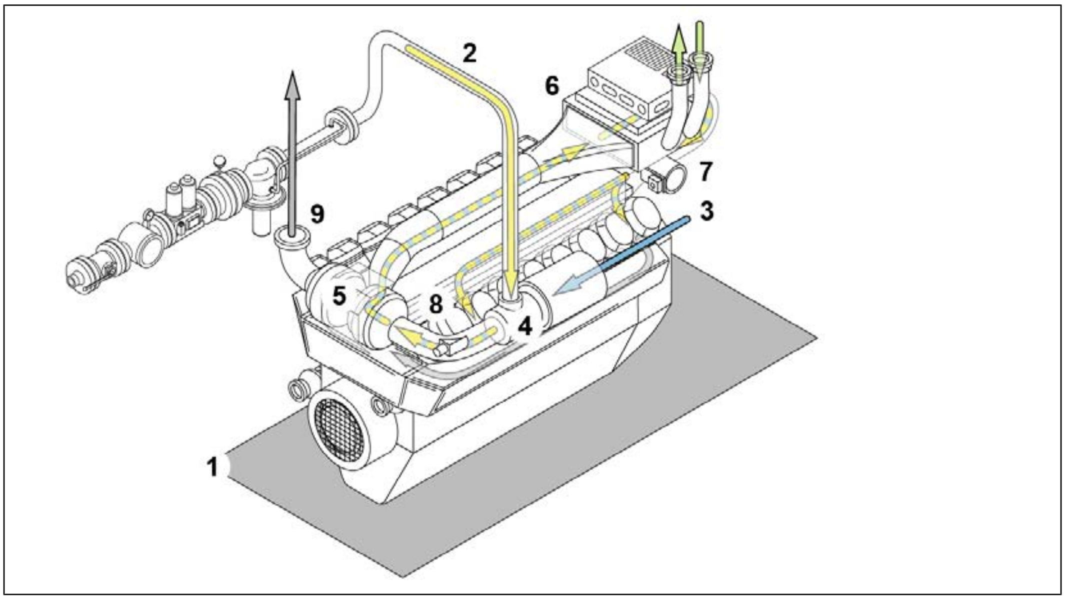
6.2.1 Gas engine

Physical design of the energy conversion process

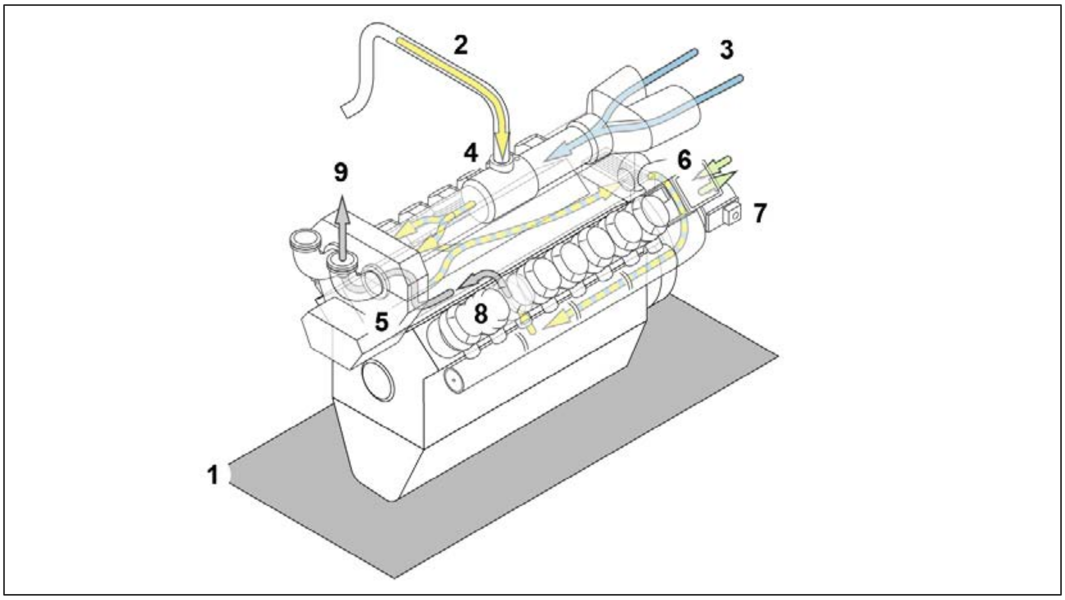
The gas engine (combustion engine) **(1)** draws fuel gas and combustion air in via the fuel gas system **(2)** and combustion air system **(3)**. The gas-air mixer **(4)** mixes both to form an ignitable fuel gas-combustion air mixture. The charging module **(5)** compresses, mixture coolers **(6)** cool and throttle valves **(7)** or in the case of the TCG 2032, rotary valves regulate the fuel gas-combustion air mixture that flows into the combustion chambers **(8)** of both cylinder rows.

In the combustion chamber, the spark plug ignites the mixture. The connected generator converts the kinetic energy into electrical energy. Much of the thermal energy generated during combustion can be discharged as available heat. This ensures a particularly high overall efficiency of the energy conversion. The exhaust gases produced during combustion enter the environment via the exhaust system **(9)**.

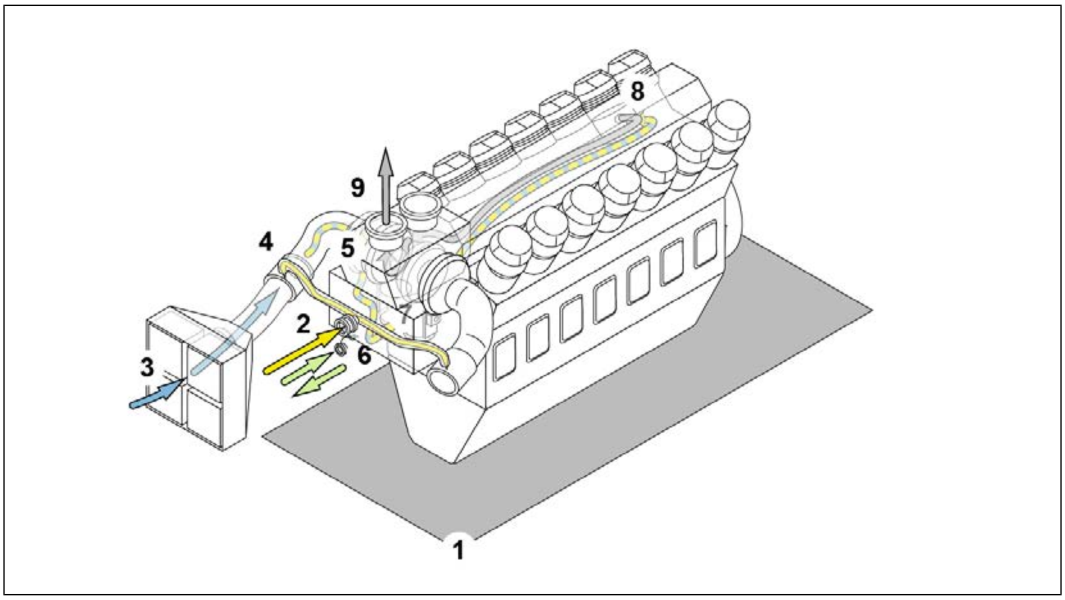
The arrangement and design of the components will differ depending on the assembly. The following illustrations show the differences between the individual series in simplified form.



4780300683: Example illustration of energy conversion in the gas engine TCG 3016



3789164427: Example illustration of energy conversion in the gas engine TCG 2020 or TCG 3020



4780301195: Example illustration of energy conversion in the gas engine TCG 2032

Regulation concept

Regulation of the mechanical power generated by the gas engine depends on the desired electrical power, the operating situation and the grid connection with its specific demands for electrical power supply. Essentially, a distinction is made between:

- Speed control (primarily for island operation or synchronization for grid-parallel operation)
- Power control (primarily for grid-parallel operation)

Throttle valves and rotary valves (TCG 2032 only) for controlling the mixing quantity in the combustion chambers and the gas-air mixer for controlling the mixing ratio of fuel gas to combustion air mainly serve as actuators for the speed control and power control.

Operation and service

The quality of the fuel gas, the combustion air, the performance of the auxiliary systems and the current technical state of the gas engine and its settings are decisive factors for efficient operation and low emission of pollutants.

NOTE

In addition to appropriate and correct project planning, assembly and commissioning, we therefore recommend that you avail of the comprehensive range of services provided by your service partner throughout the entire service life of the product.

6.2.2 Generator

6.2.2.1 General

The types used as standard are brushless synchronous generators, which, depending on the application, may be suitable for grid-parallel operation and/or back-up power mode.

Depending on output and the available mains supply, low-voltage generators or medium-voltage generators are used as standard. 400 V to 690 V low-voltage generators or 4.16 kV to 13.8 kV medium-voltage generators. Depending on the specific project, the implementation of further voltage levels can be checked.

The efficiencies of the generators are between 95.0 % and 98 % at full load, depending on the size and displacement factor cos (φ).

For example, a 400 kW generator with a cos (φ) = 1.0 has an efficiency of 96.6 %. A 4,500 kW medium-voltage generator with a cos (φ) = 1.0 has an efficiency of 97.9 %. If the generator is operated at a power factor of cos (φ) = 0.8, efficiency is reduced by approx. 1 % to 1.5 %. Operation at partial load and deviation between the mains voltage and generator rated voltage also have an effect on the efficiency.

As per DIN VDE 0530/IEC 60034, the generators are designed for an ambient temperature of 40 °C and an installation altitude up to 1000 m. At higher ambient temperatures or higher altitude, it is possible to check whether a reduction in rated power is necessary depending on the specific project.

All generators can be operated continuously at full active power output under the following conditions:

- Frequency range f_n: +3 % / −5 % of rated frequency
- Displacement factor cos(φ): 0.8 overexcited to 0.95 underexcited

As generators can improve the cos(φ) at the grid connection point, they are ideal for reactive power compensation in grid-parallel operation.

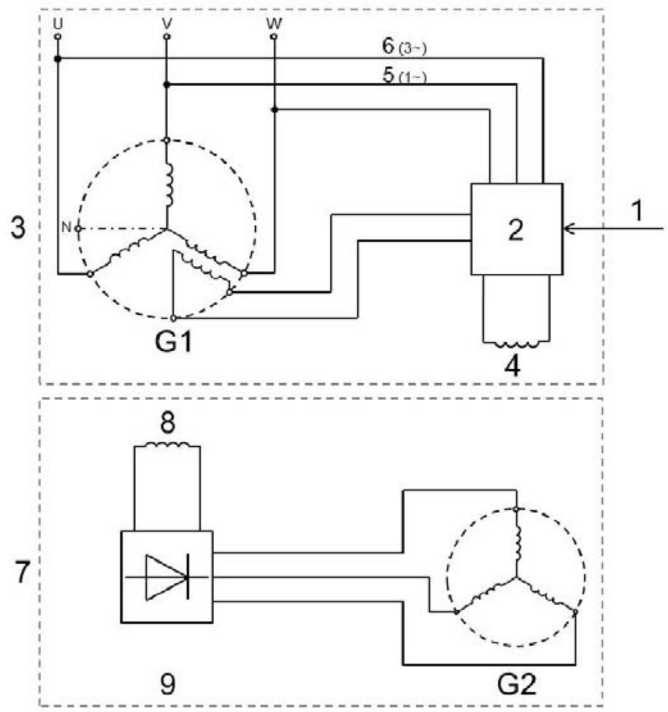
With the corresponding local or country-specific requirements in grid connection regulations, various specifications for the connection point must always be considered for the design. Generators must be specially designed for use outside the specified range.

The max. permissible unbalanced load of the generator must be observed (according to DIN EN 60034, the upper limit for negative-sequence system / rated current = 8 %).

6.2.2.2 Generator control

The generator controller is used to adjust the voltage in island operation. In grid-parallel operation the generator controller controls the power factor or the reactive power by adjusting the exciting current accordingly. The exciter system is designed without brushes for all generators. When using a digital generator controller (e.g., ABB Unitrol), it is possible to specify external setpoint values for the controller. The generator controller is usually integrated in the generator terminal box. The following illustration shows the systematic layout.

Generator control system (for example with supply from an auxiliary winding)



3620722059: Generator control system (for example with supply from an auxiliary winding)

1	External setpoint value	2	Generator controller
3	Stator	4	Exciter field
5	Current measurement	6	Voltage measurement
7	Rotor	8	Primary field
9	Diode wheel	G1	Main machine
G2	Exciter		

General function of the generator control system

The supply to the generator controller can be implemented in various ways: either from an auxiliary winding directly via a voltage transformer from the stator terminals or via a permanent magnet generator (PMG). The principal functionality of the controller is the same in all cases. The controller affects the exciter current of the brushless exciter machine, which is designed as an external pole machine. The rotor of the exciter machine is mounted on the shaft of the main machine and supplies a three-phase voltage system proportional to the exciter field current. The three-phase voltage system is rectified via the diode bridge that rotates with it. The output direct current of the diode bridge is supplied to the rotor winding of the main machine. The reaction to an external voltage set value or power factor set value results in a corresponding change in the exciter field current and hence indirectly affects the primary field current.

Setpoint value specification

If a digital generator controller (e.g., ABB Unitrol) is used, the setpoints for the corresponding control mode must be either parameterized in the controller or an external specification (e.g., via a 4...20 mA analog signal) must be implemented via a remote technical connection. The generator controller measures the generator terminal voltage three-phase either directly or via a voltage transformer as well as the generator current single-phase via a current transformer and calculates the actual value of the controlled variable from this. The precision of the measurement must be taken from the corresponding generator circuit diagrams. In island operation, this is the voltage; in grid-parallel operation, it is the reactive power or the power factor. The corresponding exciter field current to be output is calculated via a comparison between the setpoint and actual value.

6.2.2.3 Generator protection

To protect the generators, the monitoring devices marked as required ("REQ") in ISO 8528-4: 2005 must at least be used.

These monitoring devices are not included in the TEM system and must be implemented externally. The TEM MFR Multi Function Relay available from Caterpillar Energy Solutions includes synchronization functions as well as generator monitoring and decoupling protection functions on the energy supply unit. If required, additional on-site and project-related functions can be implemented through the use of another protective unit. In conjunction with the Grid Demand Interface (GDI), the TEM MFR is used to implement various requirements from grid connection rules at the genset level.

In the TPEM system, the multi-function relay (MFR) performs synchronization functions as well as generator monitoring functions and decoupling protection functions on the energy supply unit. The MFR is installed in the TPEM Control Cabinet (TPEM CC) as standard.

The international standard ANSI/IEEE C37.2 allocates fixed numbers for functions, including the generator protection functions. The following table shows the generator protection functions.

Number as per ANSI/ IEEE C37-2	**Designation**	**MFR TEM**	**MFR TPEM (TPEM CC)**	**LV[1]**	**MV[2]**
59/27	Overvoltage/undervoltage	x	x	x	x
81 O/U	Overfrequency/underfrequency	x	x	x	x
32	Overload	x	x	x	x
32 R/F	Reverse load/reduced load	x	x	x	x
47	Voltage asymmetry	x	x	x	x
46	Current asymmetry	x	x	x	x
50	Defined overcurrent	x	x	x	x
51/51V	Inverse time overcurrent monitoring	x	x	x	x

Number as per ANSI/ IEEE C37-2	Designation	MFR TEM	MFR TPEM (TPEM CC)	LV[1]	MV[2]
87G	Generator differential protection				x
50N/51N	Stator ground fault protection				x
[1] Requirement of ($U_N \leq 1000$ V) in low-voltage generators [2] Requirement of ($U_N > 1000$ V) in medium-voltage generators					

Table 13: Generator protection functions

All generators supplied by Caterpillar Energy Solutions are equipped with the following sensors:

- Temperature sensors for winding temperature
- Temperature sensors for generator bearing temperature

The TEM/TPEM control is always equipped with the function to monitor the generator winding temperatures as well as the generator bearing temperatures.

Monitoring of the generator bearing temperatures is not implemented in TCG 2020 K series gensets with TEM control. In these cases, monitoring of the generator bearing temperature should be implemented as follows:

- Ordering of two parameterizable measured values in the TEM system
- Monitoring in the customer's plant

Further information

- Structure and function of the TPEM system [▷ 255]
- TPEM Control Cabinet (TPEM CC) [▷ 258]

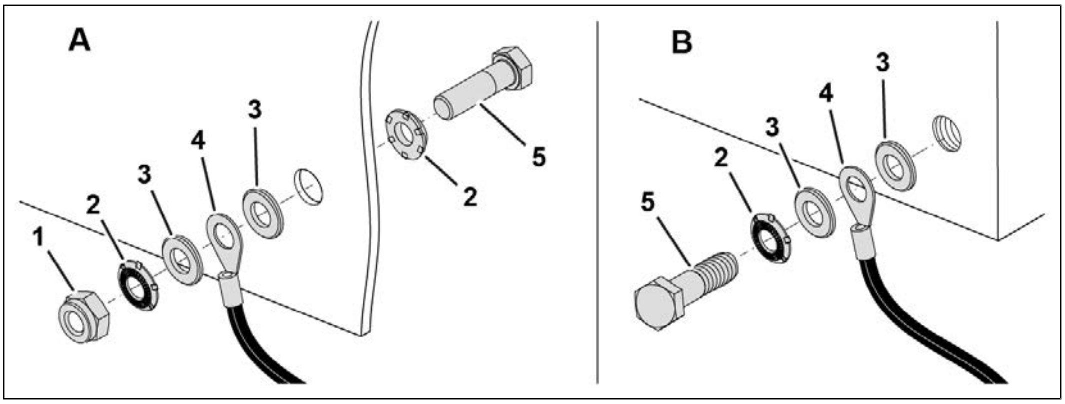
6.2.2.4 Grounding

The protective conductor (PE) and the protective equipotential bonding must be considered for the earthing.

Protective conductor

In the event of a housing short-circuit, the protective conductor has the task of diverting the fault current to the ground. The connection is made at the generator housing. A bore hole is provided for this on each of the generator feet on the non-drive end side (see next section “Connections on the generator”).

The protective conductor is routed from the generator housing to the main grounding electrode of the plant. This arrangement must be made short-circuit-proof. The connection of the protective conductor must be realized according to specification (see next illustration).



9692968075: Recommended screw connection of a protective conductor

A	For through holes
B	For threaded bores
1	Nut
2	Tooth lock washer
3	Washer
4	Protective conductor
5	Screw

The following must be observed: The area must be free of paint and dirt at the connection. The tooth lock washers serve to protect the screw connection from becoming loose. According to the latest insights, it must be ensured that the tooth lock washers are realized with so-called stop teeth.

The cross section of the protective conductor is calculated via the following formula:

$$S = \frac{I_k''}{k} \times \sqrt{t}$$

3620721547: Formula for cross section of the protective conductor

S	Cross section in mm^2
I_k"	Initial short-circuit alternating current in [A]
k	Coefficient that depends on the conductor material (e.g. 143 for copper)
t	Time in which the fault current flows over the conductor

So as not to have to consider every case, the recommendation for the cross section of the protective conductor at low voltage is 240 mm^2 for the TCG 3016 series gensets and 300 mm^2 for the TCG 2020 and TCG 3020 series gensets. In the case of medium-voltage gensets, a cross section of 95 mm^2 can be used for all series. This data only refers to copper conductors; a corresponding calculation is required for other materials.

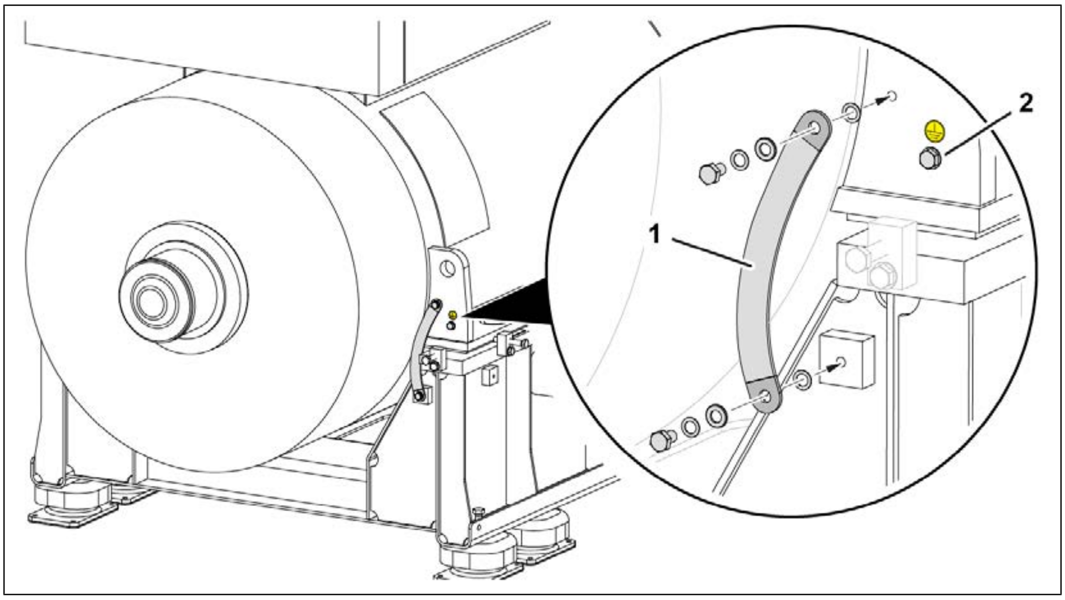
Protective equipotential bonding

The protective equipotential bonding serves as protection upon indirect contact. Protective equipotential bonding ensures that the potential difference between metallic parts always remains below 50 V. Thus, no dangerous shock currents flow in the event of a fault if a person comes into contact with the genset. The protective equipotential bonding is routed between all metallic parts and the main equipotential bonding. The generator is connected to the genset base frame via two grounding strips.

The engine, coupling protection and other metallic parts are also connected to the frame via copper conductors. The frame must be routed to the main equipotential bonding at two diagonally opposite corners each with a copper conductor (min. 70 mm^2). Likewise, all metallic lines (gas, water, etc.) as well as all other metallic parts in the genset room must be integrated in the equipotential bonding. The cross sections depend on whether a fault current can issue from the relevant part or not and must be adapted to the conditions on site.

The local power supply company rules or safety regulations must be observed in order to ensure that the genset is grounded correctly.

Connections on the generator



9692969611

1 Protective equipotential bonding

2 Connection for the PE

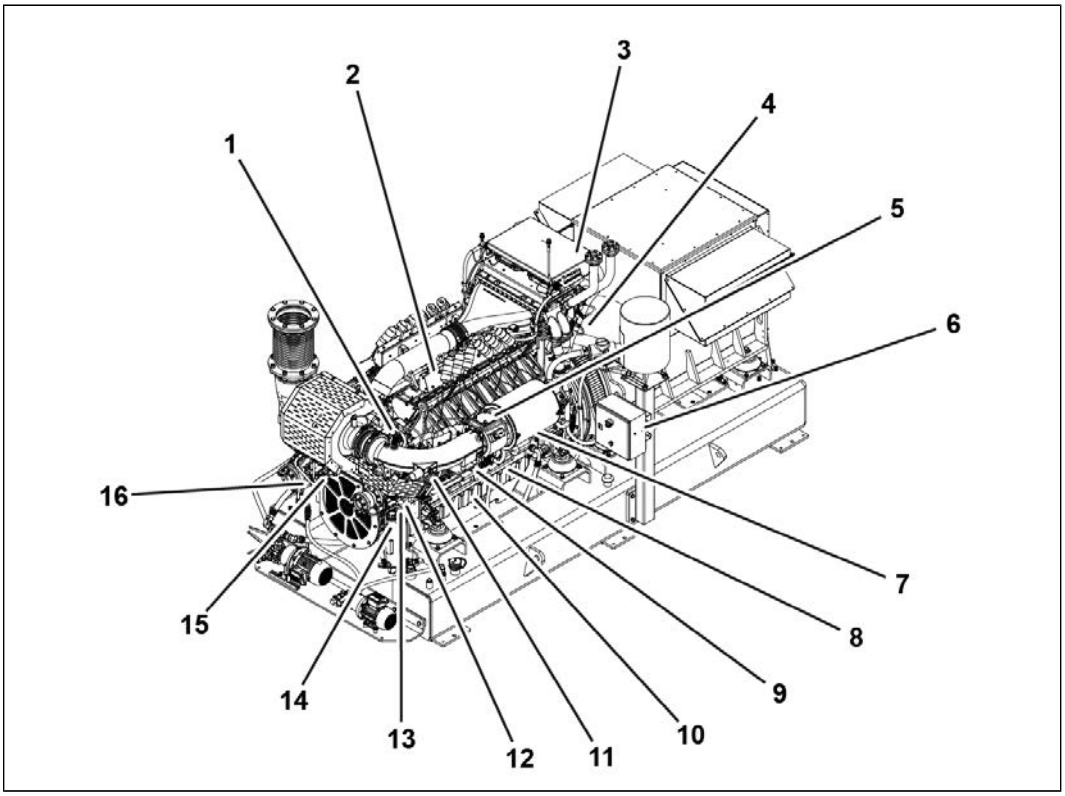
6.2.3 Actuators and sensors on the gas engine

The gas engine is equipped with actuators and sensors for monitoring and control purposes. The actuators and sensors are wired to a multifunction rail at cylinder rows A and B. Bus cables run from each multifunction rail to the TEM system or TPEM system.

All parts that need to be earthed are connected to the copper rail on the gas engine. The copper rail must therefore be connected to the switchgear earthing system.

Overview

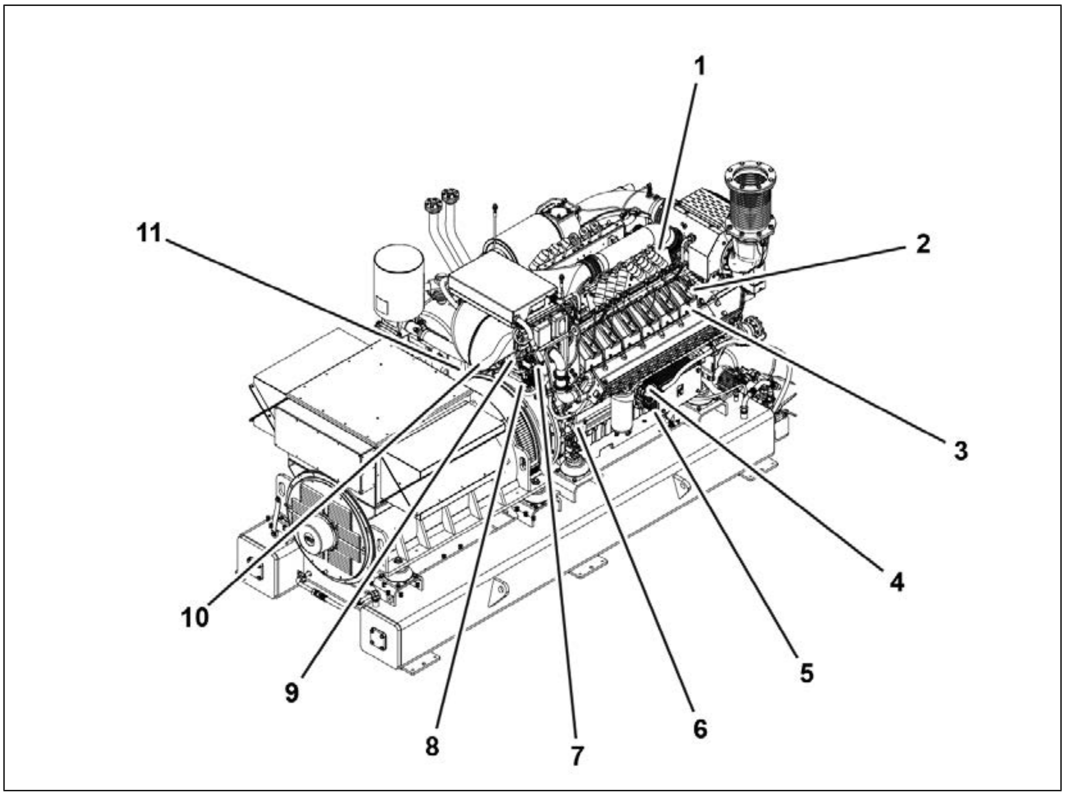
An overview of the monitoring systems is shown in the following gas engine diagrams.



9709937163: TCG 3016 V12

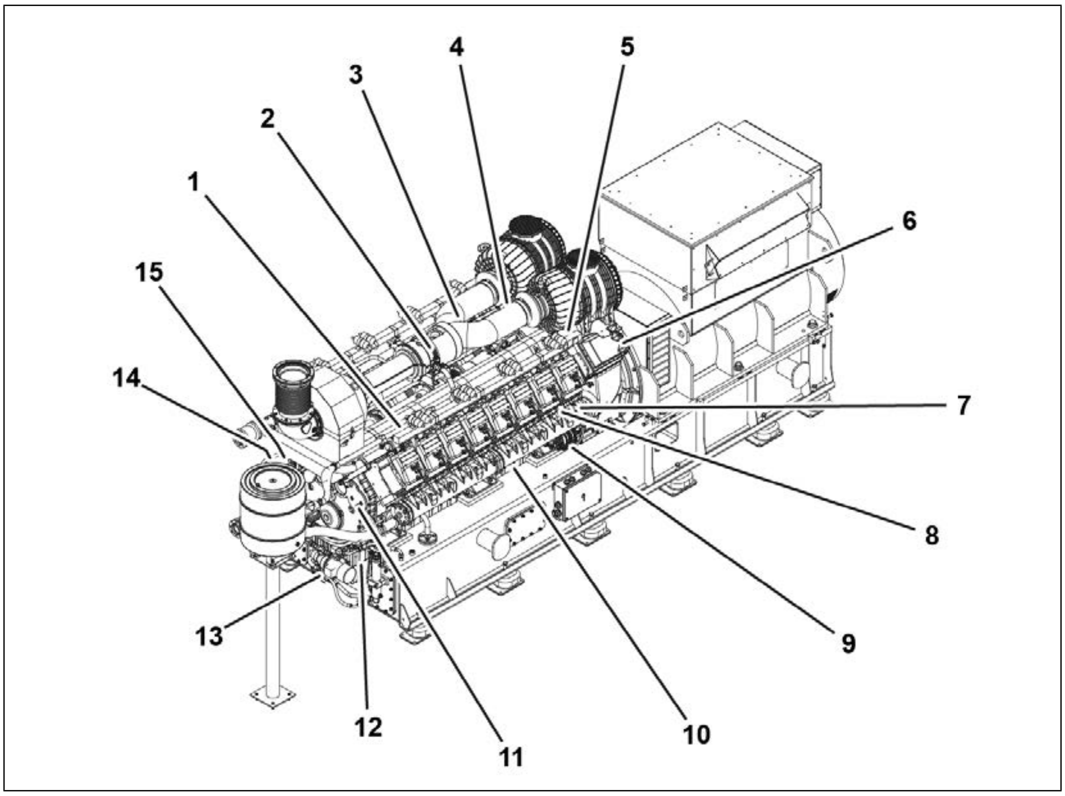
1	Mixture temperature sensor upstream of exhaust turbocharger	2	Receiver pressure sensor
3	TPEM Control Unit (TPEM CU)	4	Coolant temperature sensor (mixture cooling circuit input)
5	Gas-air mixer position proximity switch	6	TPEM Connection Box
7	Starter relay	8	Starter
9	Knock sensor, one sensor for every two cylinders	10	Control device - gas-air mixer
11	Stepper motor for gas-air mixer	12	Coolant temperature sensor (high-temperature output)

13	Coolant pressure sensor (high-temperature output)	14	Lube oil level sensor
15	Camshaft sensor	16	Coolant temperature sensor (high-temperature input)



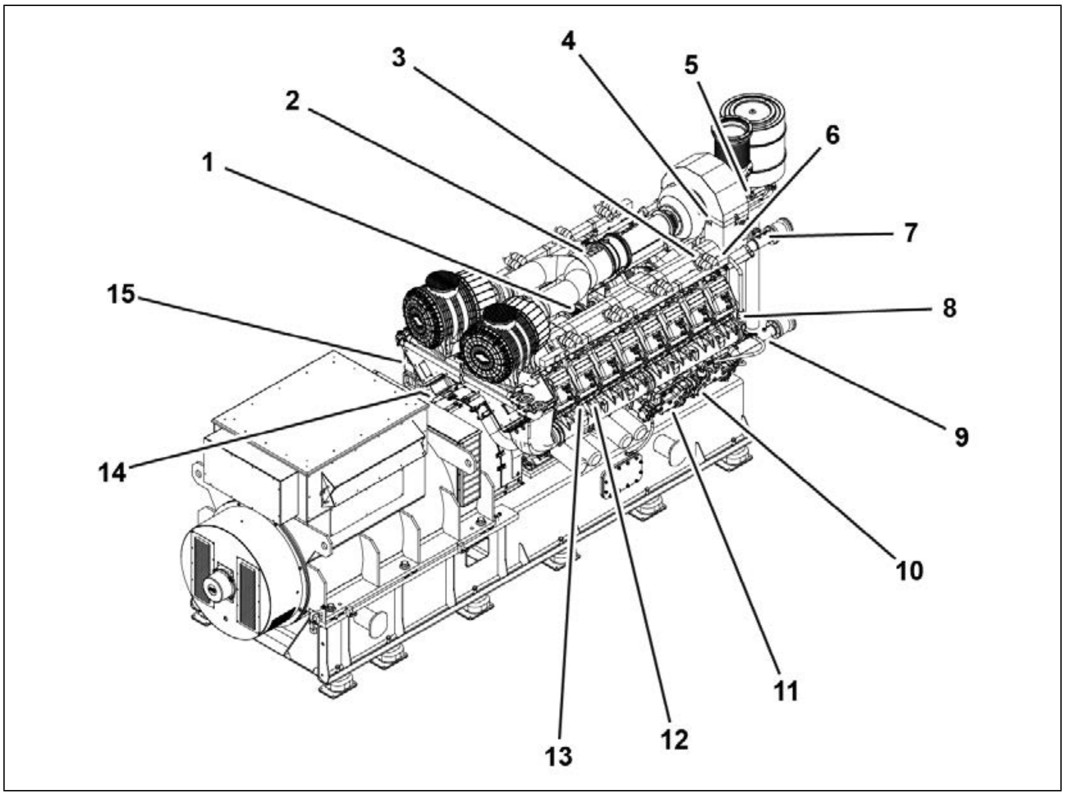
9709937675: TCG 3016 V12

1	Ignition coil, one ignition coil for every cylinder	2	Spark plug, one spark plug for every cylinder
3	Combustion chamber temperature sensor, one sensor for every cylinder	4	Lube oil pressure sensor
5	Lube oil temperature sensor	6	Flywheel sensor
7	Differential pressure sensor - throttle valve	8	Control device - Throttle valve/wastegate
9	Throttle valve	10	Receiver temperature sensor
11	Starter relay		



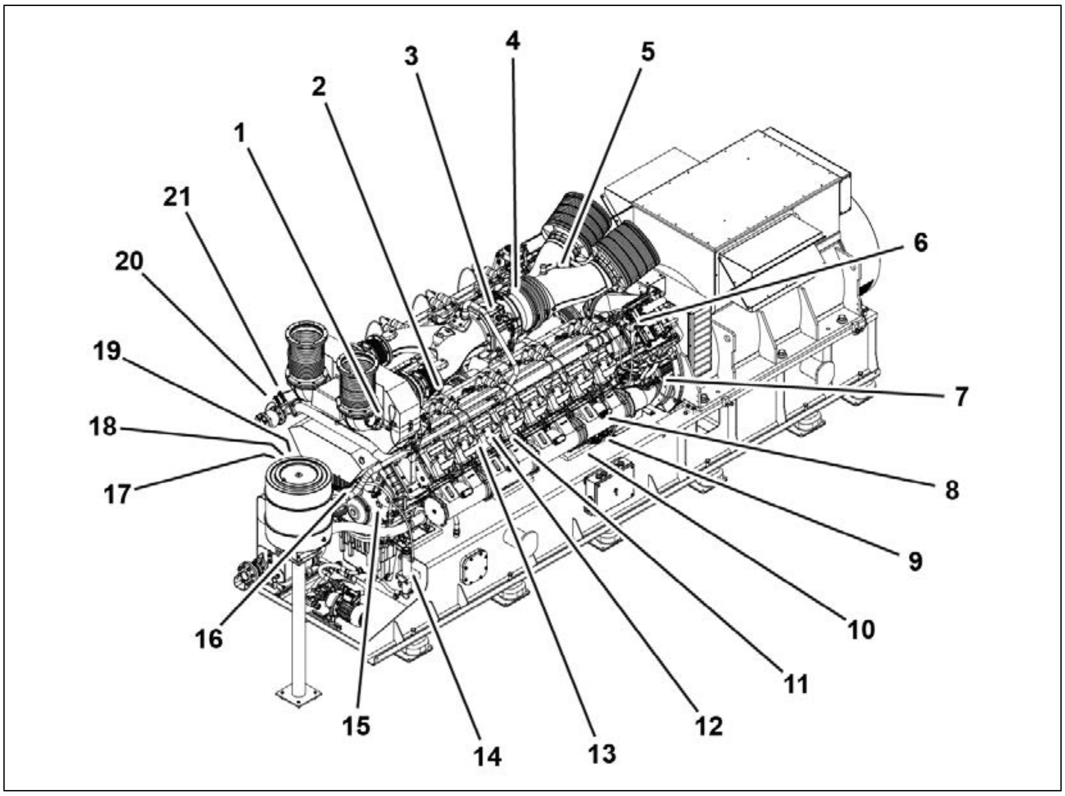
9709935115: TCG 2020 V16

1	Multifunction rail cylinder row A	2	Gas-air mixer proximity switch
3	Intake air temperature sensor V16 engine	4	Intake air temperature sensor V12 engine
5	Ignition coil, one ignition coil for every cylinder	6	Coolant temperature sensor upstream of mixture cooler
7	Knock sensor, one sensor for every cylinder	8	Combustion chamber temperature sensor, one sensor for every cylinder
9	Starter	10	Starter relay
11	Crankcase pressure sensor	12	Lube oil level sensor
13	Prelubrication pump	14	Lube oil pressure sensor
15	Camshaft sensor		



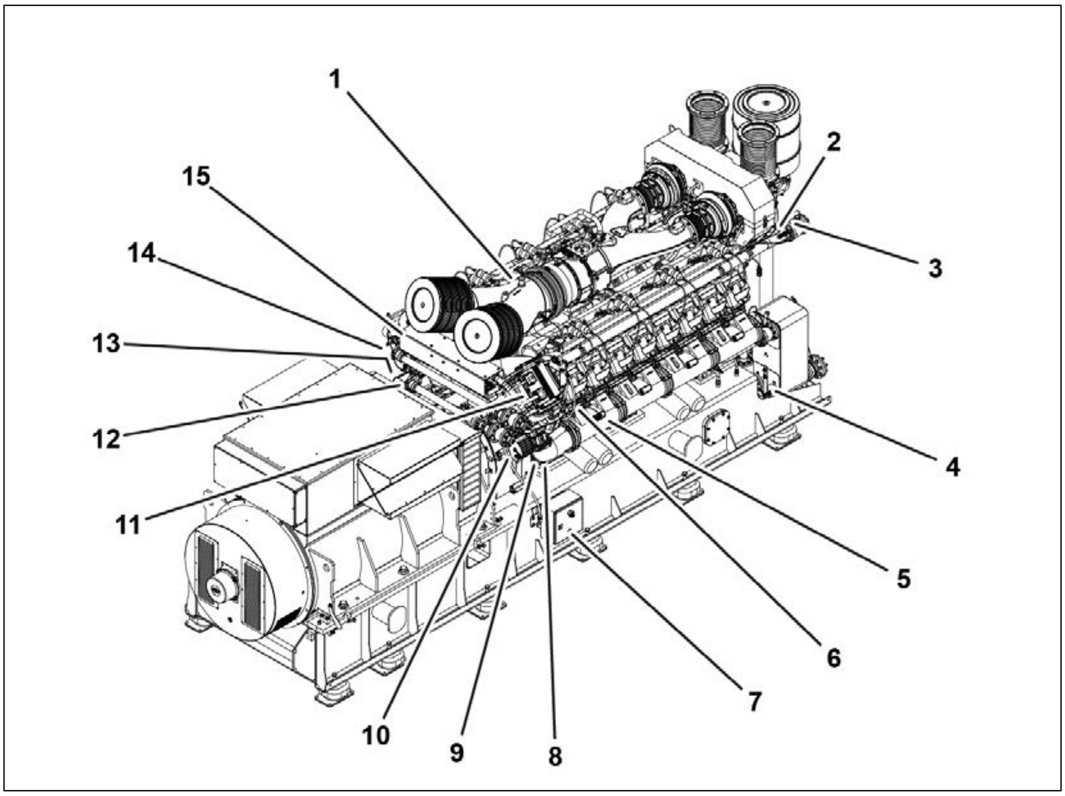
9709935627: TCG 2020 V16

1	Actuator	2	Stepper motor for gas-air mixer
3	Ignition coil, one ignition coil for every cylinder	4	Exhaust turbocharger speed sensor
5	Exhaust turbocharger temperature sensor	6	Multifunction rail cylinder row B
7	Coolant temperature sensor (engine outlet)	8	Mixture temperature sensor
9	Coolant temperature sensor (engine inlet)	10	Lube oil temperature sensor
11	Lube oil pressure sensor	12	Knock sensor, one sensor for every cylinder
13	Combustion chamber temperature sensor, one sensor for every cylinder	14	Flywheel pulse sensor
15	Ignition control device		



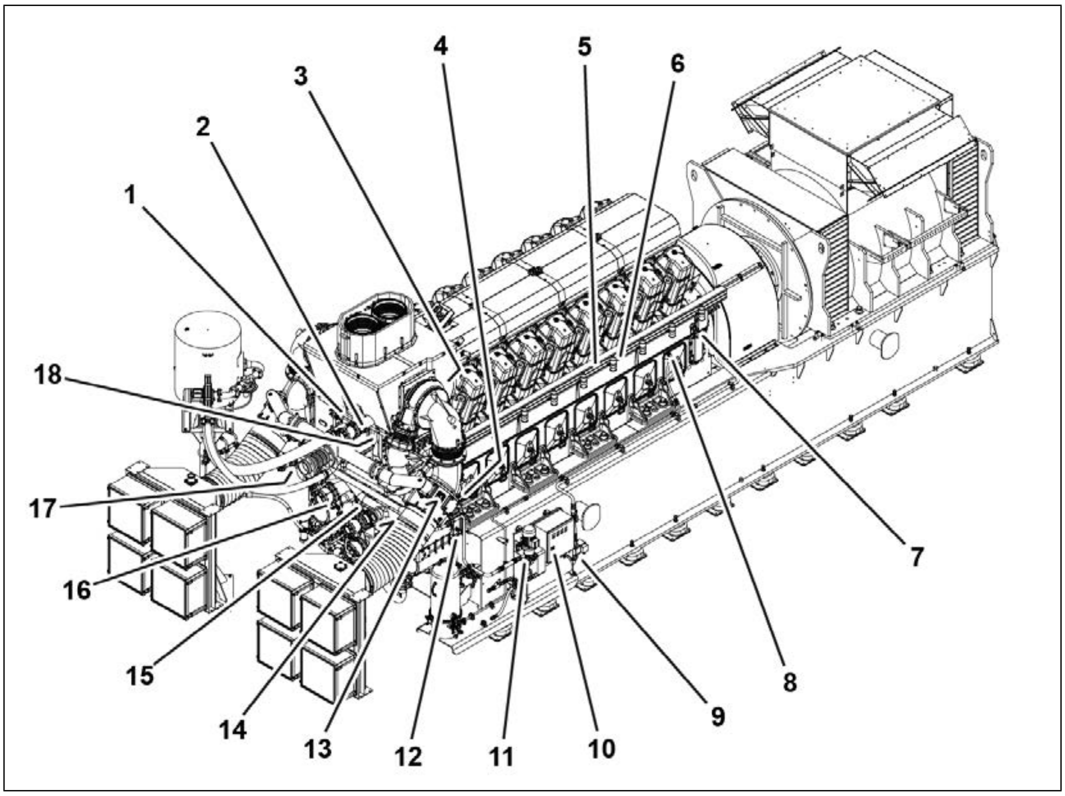
9709938187: TCG 3020 V16

1	Exhaust turbocharger temperature sensor	2	Ignition coil, one ignition coil for every cylinder
3	Gas-air mixer proximity switch	4	Stepper motor for gas-air mixer
5	Service indicator - Combustion air filter	6	Control device
7	Actuator - Throttle valve (cylinder row A)	8	Mixture pressure sensor (cylinder row A)
9	Starter	10	Starter relay
11	Knock sensor, one sensor for every cylinder	12	Spark plug, one spark plug for every cylinder
13	Combustion chamber temperature sensor, one sensor for every cylinder	14	Connector - Lube oil level sensor
15	Crankcase pressure sensor	16	Coolant temperature (engine inlet)
17	Camshaft sensor	18	Exhaust wastegate actuator
19	Coolant temperature sensor upstream of mixture cooler	20	Coolant pressure sensor (engine outlet)
21	Coolant temperature sensor (engine outlet)		



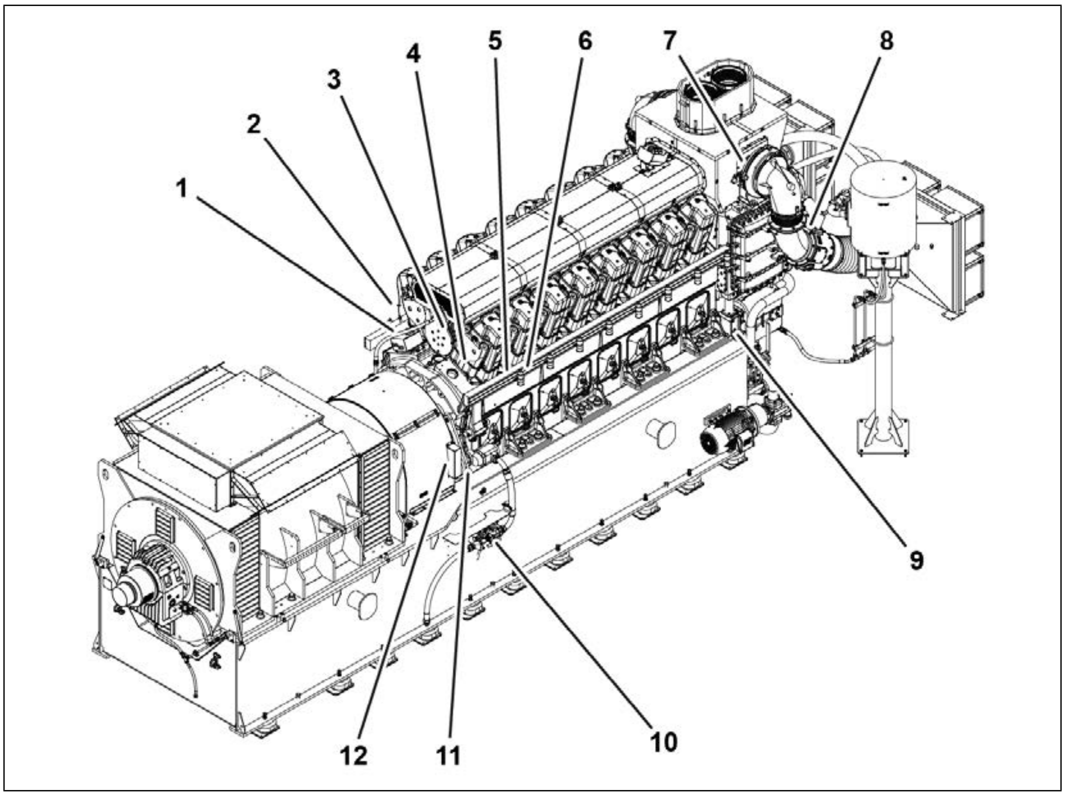
9709938699: TCG 3020 V16

1	Combustion air temperature sensor	2	Coolant pressure sensor (engine outlet)
3	Coolant temperature (engine outlet)	4	Coolant temperature (engine inlet)
5	Mixture pressure sensor (cylinder row B)	6	Differential pressure sensor, differential pressure via throttle valve (cylinder row B)
7	Terminal box	8	Lube oil temperature sensor
9	Lube oil pressure sensor	10	Actuator - Throttle valve (cylinder row B)
11	Control device	12	Flywheel pulse sensor
13	Actuator - Throttle valve (cylinder row A)	14	Coolant temperature sensor upstream of mixture cooler
15	Control device		



9709936139: TCG 2032 V16

1	Actuator	2	Coolant temperature sensor (engine cooling circuit outlet)
3	Exhaust turbocharger speed sensor, one sensor for every exhaust turbocharger	4	Mixture temperature sensor, one sensor for each gas-air mixer
5	Multifunction rail cylinder row A	6	Ignition coil, one ignition coil for every cylinder
7	Camshaft sensor	8	Crankcase pressure sensor
9	Electric pump for preheating genset (coolant)	10	Electric preheating device for coolant and lube oil
11	Electric pump for preheating genset (lube oil)	12	Lube oil temperature sensor
13	Stepper motor gas-air mixer, one stepper motor for each gas-air mixer	14	Coolant temperature sensor (engine cooling circuit inlet)
15	Lube oil level sensor	16	Lube oil pressure sensor (lube oil pressure upstream of lube oil filter)
17	Coolant temperature sensor (mixture cooling circuit inlet)	18	Charging mixture pressure sensor A side, mixture cooler - depending on version



9709936651: TCG 2032 V16

1	Ignition control device	2	Lube oil pressure sensor (lube oil pressure after filter)
3	Charging mixture pressure sensor, one sensor each for A side and B side; combustion chamber temperature sensor, one sensor for every cylinder	4	Knock sensor, one sensor for every cylinder
5	Multifunction rail cylinder row B	6	Ignition coil, one ignition coil for every cylinder
7	Exhaust turbocharger speed sensor, one sensor for every exhaust turbocharger	8	Charging mixture temperature sensor, one sensor each for A side and B side (V12 engine: between cylinders A4 and A5 as well as before B6; V16 engine: between cylinders A6 and A7 as well as before B8)
9	Lube oil temperature sensor	10	Solenoid valve for compressed air starter
11	Start backup for engine turning device	12	Flywheel sensor - installation location depending on version

6.3 Transporting the genset

6.3.1 Overview

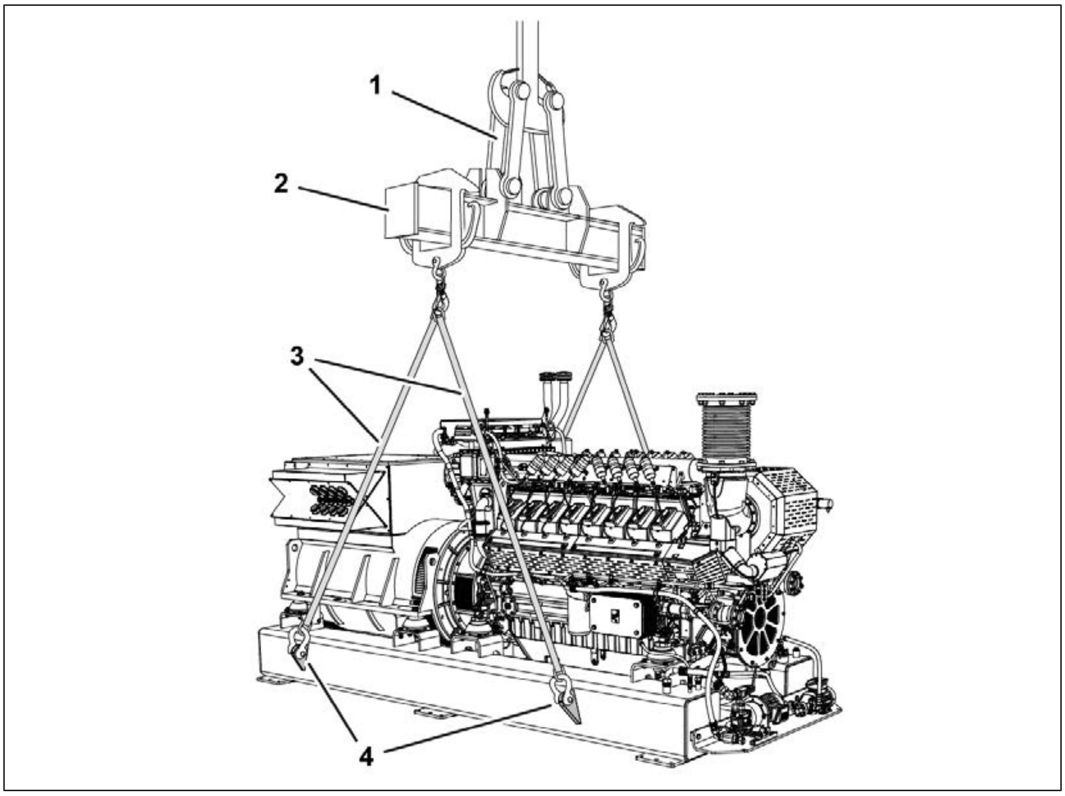
The transport of a genset or container from the factory to its final destination can be divided into the following steps:

1. Loading onto truck by mobile crane or permanently installed crane.
2. Transport by truck to destination or to harbor for shipping.
3. Reloading in harbor or when changing truck by mobile crane or permanently installed crane.
4. Unloading at destination by mobile crane or permanently installed crane.
5. Positioning and installation on the foundation by mobile crane or permanently installed crane.

6.3.2 Loading by crane

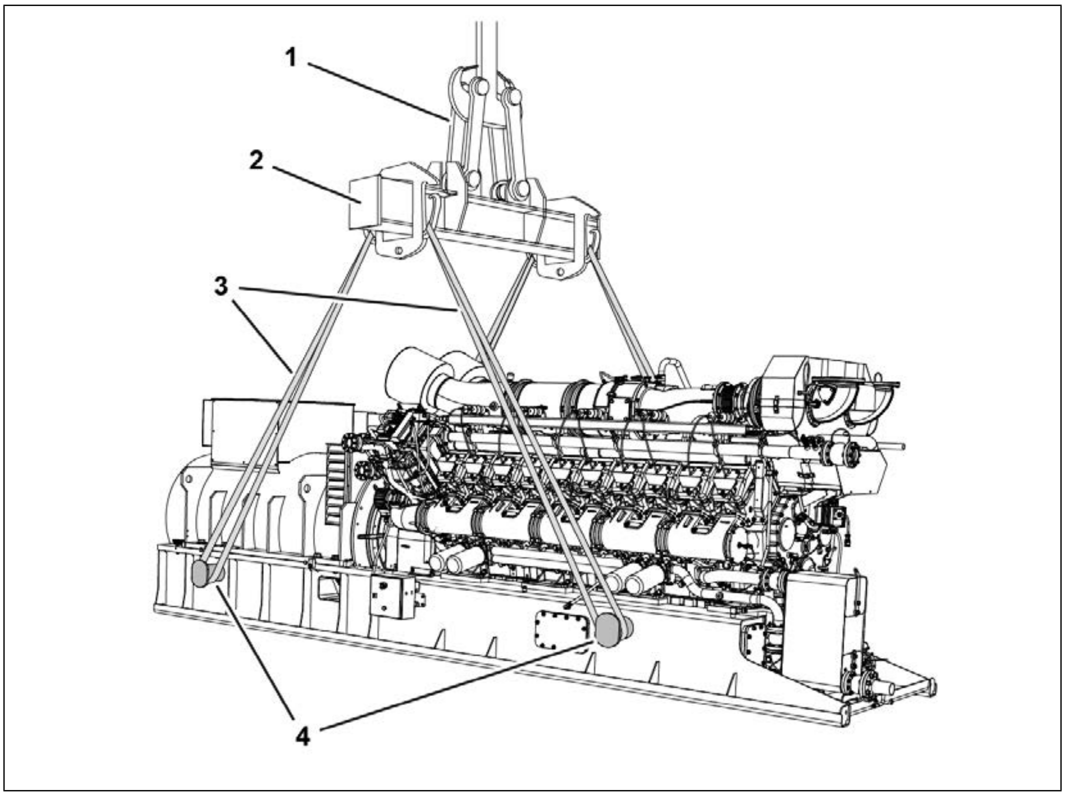
The loading of gensets in the factory is done using either an indoor crane or a mobile crane. The gensets are equipped with load support points that are arranged on each side of the genset base frame. In special cases, they also have two double-T members that are arranged below the base frame and equipped with legs for fixing the fastening equipment (ropes or chains). The load support points are arranged symmetrically with respect to the genset's center of gravity. The genset is suspended in a stable horizontal position during lifting when using four ropes or chains of equal length. One end of the chains or ropes must be hooked to the crane hook or to the suspension element (e.g., a traverse). The opposite ends are fastened to the load support points. The fastening must be secured against unexpected sudden loading. For this reason, chains and ropes must only be secured using either clamps (lifting clamps) or textile slings when fastening them to the transport brackets.

When arranging chains or ropes for lifting a genset, it is important to ensure that the chains or ropes are only touching the genset at the load support points. This prevents damage, for example, to genset components due to slanting ropes or chains. Corresponding traverses are used for this (see next illustration). If appropriate traverses are not used, straddling devices must be attached to the ropes or chains.



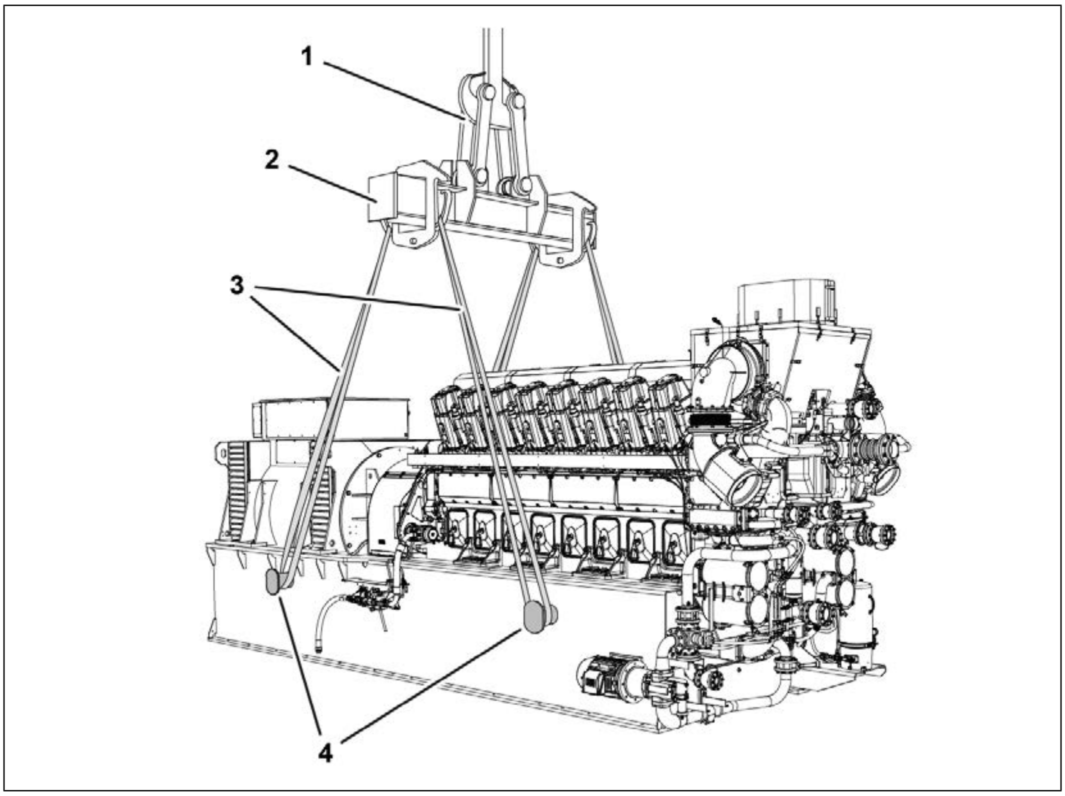
9692964235: Example illustration of genset TCG 3016 V16

1	Crane hook
2	Suspension element (traverse)
3	Fastening equipment (ropes or chains)
4	Load support points (legs)



9692964747: Example illustration of genset TCG 3020 V20

1	Crane hook
2	Suspension element (traverse)
3	Fastening equipment (ropes or chains)
4	Load support points (bollards)



9692963723: Example illustration of genset TCG 2032 V16

1	Crane hook
2	Suspension element (traverse)
3	Fastening equipment (ropes or chains)
4	Load support points (bollards)

Load support equipment, lifting equipment, and fastening equipment

Load support equipment, lifting equipment and fastening equipment used for lifting and transporting heavy loads are subjected to special monitoring and checks during manufacturing and operation. In the European Union, the rules according to Classification as per German Health and Safety at Work Regulations (BetrSichV) and the rules of the Employers' liability insurance association (DGUV = German Statutory Accident Assurance) must be observed. Some key points are listed below.

- Only trained persons may use the lifting and transport equipment.
- The permissible load must not be exceeded on any equipment.

The devices should be checked to see that they are in proper working order before they are used. This means there must not be any signs of damage that affect safety or function (e.g., breaks, chamfers, cracks, cuts, wear, deformations, damage caused by exposure to heat or cold, etc.).

The equipment must not be overloaded by impacts.

There must not be any knots or twists in the ropes and chains. Ropes and chains must not be routed over sharp edges without the appropriate safeguards; edge protection must always be used.

Asymmetric loading of the equipment must be avoided.

Ropes and chains must be shortened correctly.

Loading should be performed by two people.

Servicing load support equipment and lifting equipment

Load support equipment and lifting equipment must be checked for visible damage by an authorized expert. This check must be done at fixed time intervals (at least once a year). External faults include deformations, wear, corrosion, cracks and fractures.

In the event of impermissible defects, the devices must no longer be used. When carrying out maintenance on devices, it is forbidden to make any change affecting the function and the load capacity of the load support equipment.

Service limits for load support equipment and lifting equipment

When exposed to high or low temperatures, the capacity of load support equipment must be reduced accordingly.

6.3.3 Transport on vehicles and ships

During transport on trucks or on board ships, an appropriate intermediate layer between the load floor and the bottom of the base frame must be provided. Providing anti-slip mats or blocks made of hard rubber or wood is recommended. In addition, it is necessary to attach tensioning straps, lashing chains, mounting links, and hardwood blocks to secure the genset against slipping or tilting. The hardwood blocks must be used in the area of the spring elements to relieve these. During transport, the genset must be protected from the effects of weather using an appropriate transport cover. In the case of sea transport, seaworthy packaging will be provided.

6.3.4 Reloading and unloading

Gensets are normally reloaded and unloaded using mobile cranes. As far as the choice of hoists and the instructions and rules to follow are concerned, the same regulations apply as described for loading the gensets.

Required information

- Loading by crane [▸ 106]

6.3.5 Storage of gensets and plant components

Depending on the duration of a project, gensets, switchgear, and plant components are stored temporarily until such a time as they are installed.

The following points should be observed during storage:

- The storage area must be dry and properly ventilated.
- The storage area must be heated if the temperature is likely to fall below the dew point due to daily or seasonal change.
- The storage area must be frost-proof.

The technical data sheets for the individual components specify storage temperatures which depend on the materials used in the components.

Especially during transport and also during storage at harbors or at haulers, it is not always possible to comply with the conditions described above. We accept no liability for damages caused by frost or humidity.

Corrosion protection is applied to the inside and outside of the gas engines and lasts for a period of 24 months. If the engine is stored for longer than the protection allows, an additional corrosion protection treatment is necessary. The length of corrosion protection provided is valid only if the storage conditions described above are complied with.

Generators must be rotated every 6 months, regardless of whether they are individually stored or installed in a genset.

Plant components such as pumps or ventilators must also be rotated at specific intervals. Refer to the manufacturer's documentation for specifications.

Plant components which are installed in the open air during operation can also be stored in the open air. These are, for example, ventilator coolers or exhaust gas mufflers.

6.4 Assembling the genset

6.4.1 General

The object of these instructions is to ensure that the genset is correctly positioned and installed in the genset room and to avoid resultant damage arising from incorrect assembly.

Observe the relevant specifications for the installation location and for connecting to auxiliary systems, power cables, piping, etc.

Required information

- Buildings and installations [▷ 287]

6.4.2 Assembly steps

The genset must be moved on site through a suitable opening to the installation site in the genset room and aligned there. To lift and position the genset, load support points are attached at the sides of the base frame.

Genset assembly involves a number of steps:

1. Checking the foundation
2. Preparing the utility space in front of the access opening
3. Setting down the genset onto the utility space
4. Moving the genset to the installation site
5. Positioning the genset at the installation site
6. Setting down the genset and removing the transport equipment
7. Lifting the genset and mounting the bearing elements
8. Setting down the genset
9. Checking and connecting the genset

Required information

- Operating manual > Assembly note > Genset installation
  - Installing the genset

6.4.3 Lifting and positioning the genset

The genset may only be lifted at the designated load support points. Suitable load support equipment, lifting equipment and load securing devices that have been approved for the task must be used.

Required information

- Loading by crane [▹ 106]

6.4.4 Protecting the genset

After the genset has been mounted and aligned on its foundation and before piping and cabling works can begin, the genset must be protected against dust and dirt with a tarpaulin, for example.

To protect the electronics and the bearings in the engine and generator, welding must not be carried out on the genset!

Parts attached to the genset, such as transmitters, temperature sensors or attachments such as pumps, filters, etc. must not be used as "conductors".

In order to maintain the value of the equipment and its reliability, the following must be observed:

- Keep the genset room and the switchgear room free from dust. Dust reduces the service life of the engine, shortens the lifetime of the generator and impairs the functioning of the control system.
- Condensation and dampness in genset rooms can cause corrosion of both the genset and the switchgear. High-quality CHPS plant installations require dry, preferably heated rooms (above 5 °C).
- After the test run at the factory, interior corrosion protection is applied to the engine as per works standard. Standard preservation lasts for the period of 24 months. If the genset is to remain at a standstill for an extended period, the insulation resistance of the generator must be checked before commissioning. In the event of dampness, the generator must be dried (stationary heating or other suitable means).
- If the genset is set up in a container, the genset must be fully emptied (risk of freezing) and secured against movement for storage or transportation.

6.4.5 Anti-vibration mounting

For the medium and large platforms, steel bellows are used as standard for the anti-vibration mountings of the gensets. These are equipped with a leveling device as standard. Beneath the footplate of the mounting element is a rubber plate which can be set directly onto the foundation. Ensure that the foundation surface is free of grease, lube oil, fuel or other contaminants. The foundation surface must have a tolerance of +/- 2 mm in the area of the anti-vibration mountings. The remainder of the foundation surface can be designed according to the standard building regulations for foundations. The foundation must not be tiled.

In TCG 3016 series gensets, the gas engine and generator are connected rigidly via a flange housing. The gas engine and generator unit is mounted on the base frame with rubber elements. The base frame is installed rigidly on the foundation.

It is not necessary to screw or dowel the spring elements to the foundation. In order to fix the genset in place on the foundation, the 4 mounting elements on the corners of the genset can be screwed (doweled) or fixed with steel stoppers when installed in a container. The number and arrangement of the bellows are indicated in the genset drawing relevant to the order. The genset drawing contains a reference to the installation specification and alignment specification of the steel springs used. For those regions most at risk of earthquakes, there are special requirements for mounting the gensets. For those installations, the bearings must be doweled to the foundation. A recalculation of this connection must be carried out by a structural engineer.

If a genset is installed in a container, a transportation safety lock must be provided between the genset's base frame and the foundation plates in the container base for transport. The transportation safety lock prevents movements of the genset on the steel bellows. The transportation safety locks must be removed before commissioning the genset.

6.4.6 Torsionally flexible coupling

After aligning the genset on the foundation, the axial runout and radial runout of the coupling must be measured.

Required information

- Operating manual > Assembly note > Genset installation
  – Installing the genset

6.5 Notes on commissioning

Before commissioning and handover to the client, thoroughly clean the genset.

Please note the following:

- Check the adjustment of the anti-vibration mounting elements.
- Check the alignment of the coupling.
- Check that the expansion joints have been installed as specified.
- No tension on cooling water expansion joints.
- Hoses exhibit prescribed bending radius.
- Specified pre-tension on exhaust expansion joint.
- Cables fitted with strain relief and laid with specified bending radius.
- Air cleaners free from dirt and contamination.

7 Machine room ventilation

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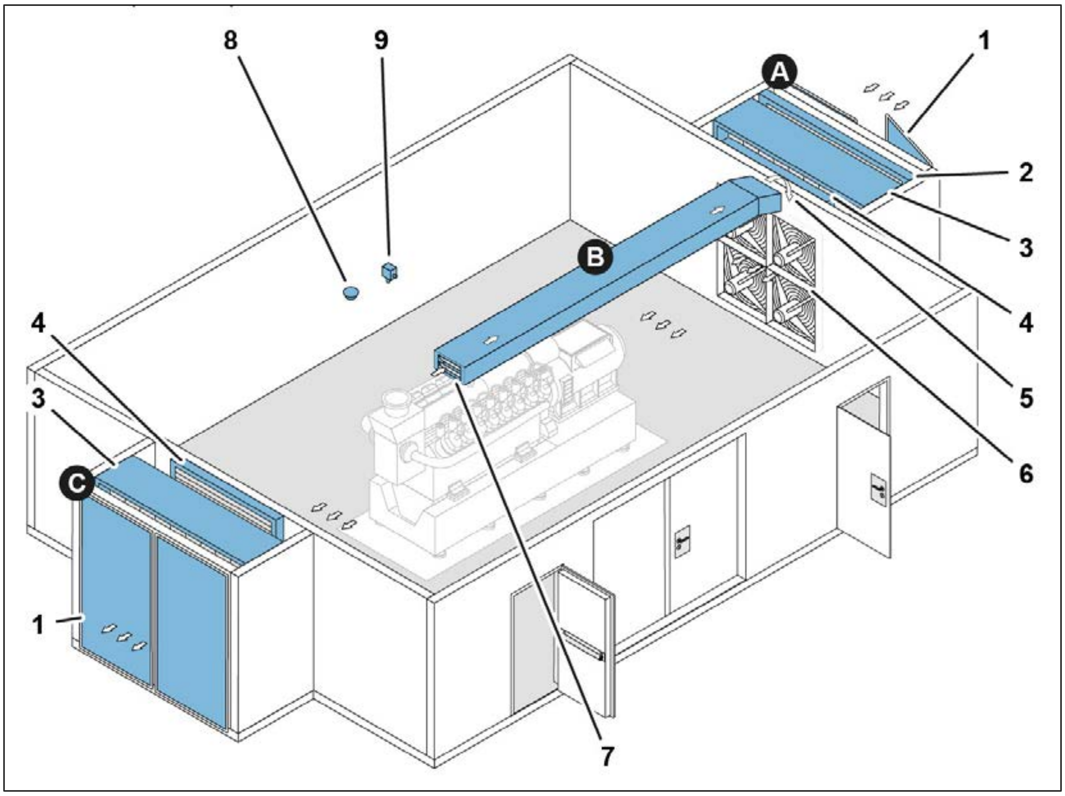
7.1 System overview

The schematic illustration shows and lists typical components and interfaces to help you get started. Proportions are therefore not to scale and the arrangement is just an example.

Example: Pressurized ventilation system with circulating air



3620521739: Simplified example illustration

A	Supply air	B	Circulating air
C	Outlet air		
1	Protective grating and bird screen	2	Supply air filter
3	Sound-proofing baffles	4	Air flaps
5	Circulating air intake	6	Supply air ventilators
7	Circulation flap	8	Smoke and heat sensors
9	Gas sensors		

7.2 Structure and function

7.2.1 Machine room ventilation

7.2.1.1 General

The genset room is heated by convection and radiation from the engines installed therein. Furthermore, heat is produced by generators, the heat utilization system and the piping systems.

To avoid impermissibly high temperatures for the machines, components and switchgear, this heat must be dissipated with the aid of a ventilation system.

Also, for plants operating in areas with extremely low ambient temperatures, it is important to ensure that the minimum intake air temperatures specified in the genset data sheet are complied with. The radiant heat of the components can be used to heat the genset room. In this case, the building must be leak-tight and must have good heat insulation.

The ventilation system is of particular importance, firstly for the dissipation of the radiant heat in summer, and secondly for the utilization of the radiant heat for genset room heating in winter.

NOTE

General note: Intake air temperatures (and minimum temperatures) must comply with the values specified in the genset data sheets!

Always ensure that the intake air temperature does not fall below the permissible starting temperature (see Chapter Combustion air requirements [▶ 197])

The machine room ventilation also serves the purpose of making the volume of air for combustion required by the genset available. In the case of multi-engine plants, each genset should have its own adjustable ventilation system.

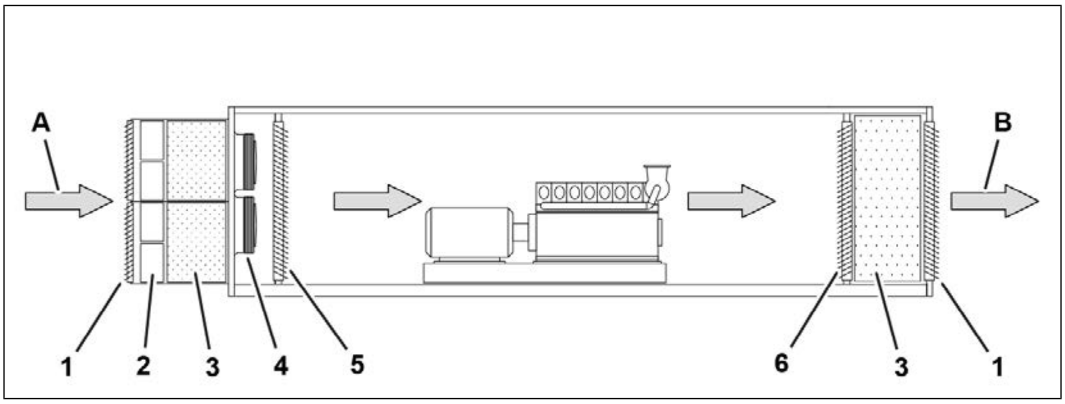
The kind of ventilation systems feasible for genset rooms can be divided into three types (see sections below):

- Pressurized system (recommended)
- Extraction system (not recommended)
- Combined system (recommended)

7.2.1.2 Pressurized system (recommended)

Air at ambient temperature is drawn in from the outside by a ventilator. The ambient air is then forced through the genset room and returned to the environment via outlet air openings. An overpressure prevails inside the genset room.

The use of this system is especially recommended in environments with a high dust content (desert regions). The overpressure inside the genset room prevents dust from penetrating into the room through leaks in the walls of the building or through open doors or windows. The ventilation systems used must be fitted with suitable filters, e.g., inertial filters or pocket filters, to filter out the dust. The filtration efficiency to be achieved with the supply air filters used must correspond to the filtration efficiency of a class G3 filter.



9709704459: Ventilation systems - Pressurized system

A	Supply air
B	Outlet air
1	Protective grating
2	Supply air filter
3	Sound-proofing baffle
4	Supply air ventilator
5	Supply air louver damper
6	Exhaust air louver damper

Further information

- Filter [▹ 128]

7.2.1.3 Extraction system (not recommended)

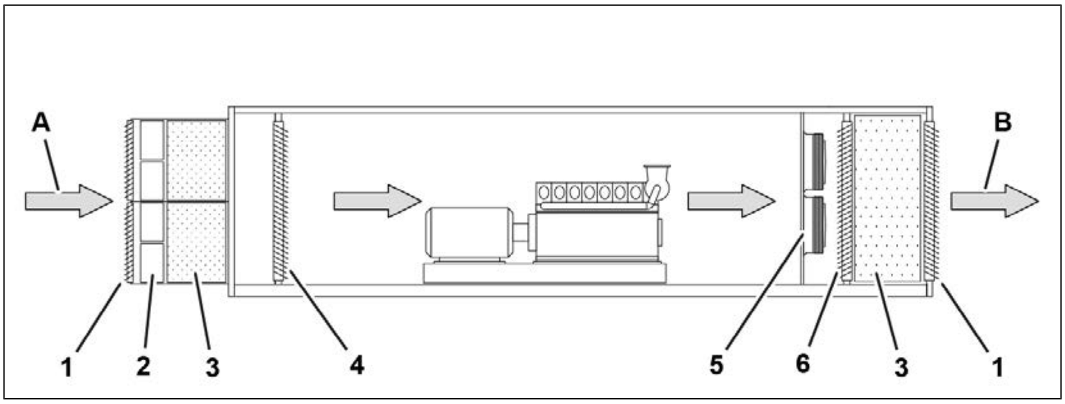
Outside air is sucked into the genset room via the supply air system (protective grating, filter, sound-proofing baffle and louver damper). The air flows through the genset room, is extracted by a ventilator and returned to the environment. Negative pressure prevails inside the genset room.

The ventilation system is arranged on the suction side in such a way that the negative pressure created in the genset room is considerably below 1 mbar. Particularly in the case of gas engine systems that extract combustion air from the genset room, there may be complications on startup if the negative pressure in the genset room is too high. Mixture formation is not optimal. If negative pressure on the exhaust turbocharger is too high, the genset's efficiency may drop below the guarantee value.

Furthermore, the doors of the genset room are not easy to open if the negative pressure is too high. The genset room doors are generally also escape doors and must open outwards.

The plant works like a large vacuum cleaner and unfiltered secondary air enters as a result of leaks in the genset room walls and genset room windows. This leads to the genset room becoming contaminated more and more over time. The filtration efficiency achieved with the supply air filters used must correspond to the filtration efficiency of a class G3 filter.

For the reasons listed, avoid using an extraction system when planning the ventilation system.



9709705227: Ventilation systems - Extraction system (not recommended)

A	Supply air
B	Outlet air
1	Protective grating
2	Supply air filter
3	Sound-proofing baffle
4	Supply air louver damper
5	Exhaust air ventilator
6	Exhaust air louver damper

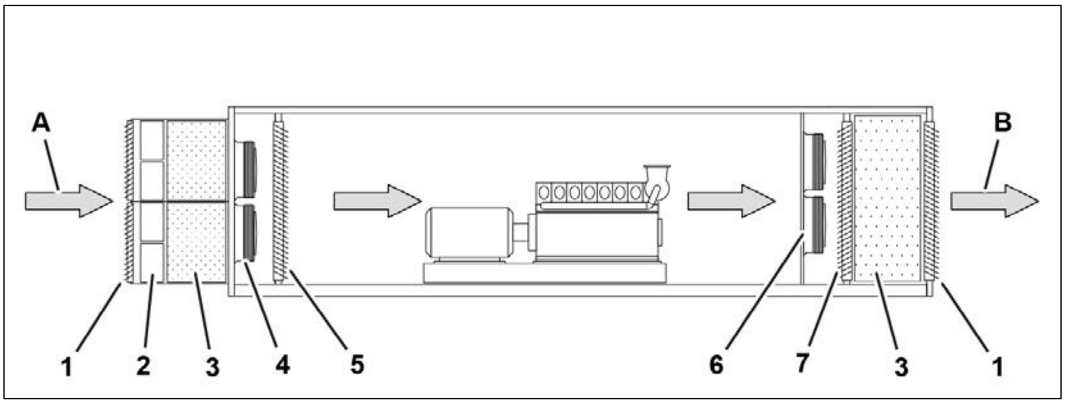
Further information

- Notes on ventilation system planning and operation [▷ 126]
- Filter [▷ 128]

7.2.1.4 Combined system (recommended)

The air for machine room ventilation is blown into the machine room by a supply air ventilator and extracted by another ventilator on the outlet air side. By suitable tuning of the supply air and exhaust air systems, the air pressure in the genset room is approximately equal to the external ambient pressure.

This system must always be used for plants exhibiting significant pressure losses at both the supply air side and the outlet air side. This is particularly the case where the air for the machine room ventilation must be drawn in and discharged again over great distances. The same applies to plants whose components such as protective grating, sound-proofing baffles, louver dampers and filters exhibit a high loss in pressure.



9709705995: Ventilation systems - Combined system (recommended)

A	Supply air
B	Outlet air
1	Protective grating
2	Supply air filter
3	Sound-proofing baffle
4	Supply air ventilator
5	Supply air louver damper
6	Exhaust air ventilator
7	Exhaust air louver damper

7.2.2 Circulating air temperature control

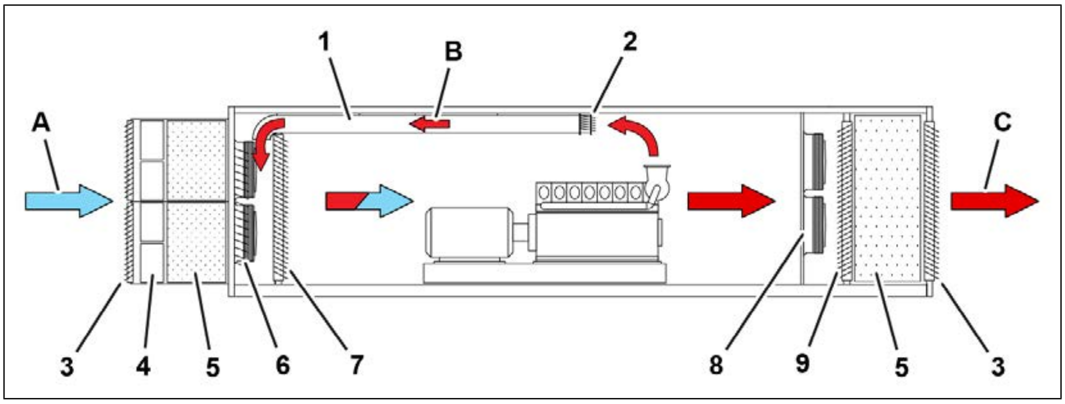
To avoid impermissibly low temperatures in the genset room, the room temperature can be controlled by mixing outlet air in with the supply air.

For all systems, the air flow must be designed in such a way as to ensure that the air flows through the entire genset room. No short-circuit air flows are permitted from the supply air opening to the outlet air opening. Sufficient air circulation must occur around the components that give off heat. If necessary, air ducts must be installed which provide an air flow specifically targeted towards the individual components in the genset room.

Recirculation control is generally recommended for plants whose ambient air temperatures are below the minimum permissible intake air temperature.

In order to minimize the radiant heat occurring in the genset room and thus the volume of air required, mufflers and exhaust lines inside the genset room must be insulated. It is generally necessary to insulate exhaust systems inside buildings.

In many cases, the combustion air for the engines is drawn from the genset room. This additional volume of air must be taken into consideration when designing the supply air ventilators. Depending on the design of the plant, the engine's air cleaners can be located in areas where the air has already been considerably heated. In such cases, “cold” air must be conducted to the air cleaners via separate ventilation ducts.



9709706763: Ventilation systems - System with circulating air temperature control (recommended)

A	Supply air
B	Circulating air
C	Outlet air
1	Circulating air duct
2	Circulating air louver damper
3	Protective grating
4	Supply air filter
5	Sound-proofing baffle
6	Supply air ventilator
7	Supply air louver damper
8	Exhaust air ventilator
9	Exhaust air louver damper

7.2.3 Ventilation by use of frequency-controlled or electronically commutated ventilators (EC)

When operating gas engines, the intake air temperature must be kept within a relatively narrow range. The air temperature must not be less than the minimum air temperature specified in the data sheet, as the exhaust turbocharger's compressor will otherwise pump. Engines with an exhaust wastegate permit an additional intake air temperature range.

The required minimum intake temperatures for the engine in a ventilator designed for summer conditions and with a fixed speed may not always be maintained in winter. By adapting the ventilation volumetric flow rate and the use of radiant heat from the engine and generator, the use of frequency controlled or electronically commutated ventilators allows the intake air temperature to be kept in the permissible range even at varying ambient temperatures using a closed-loop control. Controlling the intake air temperature by adjusting the ventilation volume flow is only possible up to minimum ambient air temperatures that are very close to the minimum permissible intake air temperature. A recirculation system is required for lower ambient air temperatures.

7.3 Requirements and guide values

7.3.1 Determining the air requirement

7.3.1.1 Calculation overview

The air requirement to be determined in order to design the ventilation system is composed of the following individual requirements:

- Combustion air requirement of the engine
- Cooling air requirement of the engine and components
- Radiant heat
  - Radiant heat of the engine
  - Radiant heat of the generator
  - Radiant heat of the auxiliaries
  - Radiant heat of the heat utilization unit

Once the individual requirements have been determined, the required air quantity can be determined.

7.3.1.2 Combustion air requirement of the engine

If the engine draws the combustion air from inside the genset room, the combustion air must be supplied via the ventilation system for the genset room and taken into account in the design. The combustion air temperature is one of the factors which influence the location-dependent output achievable by the engine. It is important therefore to ensure that the air temperature in the intake area neither exceeds nor falls short of the value established to determine the location-dependent output.

7.3.1.3 Cooling air requirement of the engine and components

The radiant heat from the engine and the generator must be discharged via the genset room ventilation system. Other heat-radiating components are the pumps, separators, heat exchangers, boilers, etc.

Heat-radiating components that operate only intermittently, such as compressors, are likely to be neglected in most cases when determining the cooling air requirement.

7.3.1.4 Determining the radiant heat

To determine the air requirement, the radiant heat of the engine and generator must be determined first.

Radiant heat of the engine

The radiant heat of the engine (Q_M) is specified in the current data sheets.

Radiant heat of the generator

The radiant heat of the generator (Q_G) is specified in the current data sheets.

Radiant heat of the auxiliaries

The radiant heat of the piping, especially from the exhaust lines, exhaust mufflers, mixing coolers and pump units, can be determined only with considerable effort. Experience shows that this radiant heat equates to approx. 10 % of the engine's radiated heat.

$$Q_{\mathrm{H}} = 0{,}1 \times Q_{\mathrm{M}}$$

3714904459: Formula for the radiant heat of the auxiliaries

Q_H in kW	Radiant heat of the auxiliaries
Q_M in kW	Radiant heat of the engine

Radiant heat of the heat utilization unit

If components are installed in the genset room to utilize the heat energy, experience indicates that the heat radiated from the cooling water heat exchanger and exhaust heat exchanger will be approx. 1.5 % of the respective available heat as per the data sheet.

$$Q_{\mathrm{W}} = 0{,}015 \times (Q_{\mathrm{KW}} + Q_{\mathrm{Abg}})$$

3714924555: Formula for the radiant heat of the heat utilization unit

Q_{WN} in kW	Radiant heat of the heat utilization unit
Q_{KW} in kW	Engine cooling water heat
Q_{Abg} in kW	Usable engine exhaust heat

Total radiant heat

The total radiant heat Q_S is the sum of the above-mentioned values:

$$Q_{\mathrm{S}} = Q_{\mathrm{M}} + Q_{\mathrm{G}} + Q_{\mathrm{H}} + Q_{\mathrm{W}}$$

3714930955: Formula for total radiant heat

Depending on ambient conditions, some of the radiant heat is dissipated via the genset room walls. This value can be determined only with great difficulty owing to variable circumstances, such as the ambient temperature or the design of the genset room walls, and is therefore not taken into account.

7.3.1.5 Required ventilation air (excluding the combustion air for the engine)

Accordingly, the air requirement is finally calculated as a function of the total radiant heat. In addition, the permissible air temperature increase in the genset room and the specific heat capacity of the air are incorporated into the calculation:

$$m_{\mathrm{Lerf}} = \frac{Q_{\mathrm{S}} \times 3600}{\Delta T \times c_p}$$

3714936715: Formula for the required air mass flow

m_{Lerf} in kg/h	Required air mass flow for cooling
Q_s in kW	Total radiant heat
ΔT in K	Permissible temperature increase
C_p in kJ/kgK	Specific heat capacity of the air

The above equation calculates the required air mass flow. To determine the required volume flow, the density of the air must be taken into account. The density depends on the air temperature, air pressure and relative humidity. The required air volume flow is:

$$V_{\text{Lerf}} = \frac{m_{\text{Lerf}}}{\rho_{\text{L}}}$$

3714939403: Formula for the required air volume flow

m_{Lerf} in kg/h	Required air mass flow
V_{Lerf} in m^3/h	Required air volume flow
ρ_L in kg/m^3	Air density, e.g., 1.172 kg/m^3 at 1002 mbar and 25 °C

Air pressure decreases as the geodetic height increases. The following table indicates pressures and densities depending on temperature and the geodetic height.

The specified values apply to dry air. In humid air, density decreases as relative humidity increases. At a relative humidity of 60 %, the drop in density can be up to 10 %.

Air pressure and air density at 25 °C as a function of the geodetic height								
Geodetic height	Temperature 25 °C		Geodetic height	Temperature 25 °C		Geodetic height	Temperature 25 °C	
in m	mbar	kg/m^3	in m	mbar	kg/m^3	in m	mbar	kg/m^3
0	1013	1.184	700	940	1.099	1800	835	0.976
100	1002	1.172	800	930	1.087	2000	817	0.955
200	991	1.159	900	920	1.075	2200	800	0.935
300	981	1.147	1000	910	1.064	2400	783	0.915
400	970	1.135	1200	890	1.041	2600	766	0.896
500	960	1.122	1400	871	1.019	2800	750	0.877
600	950	1.110	1600	853	0.997	3000	734	0.858

Table 14: Air pressure and air density depending on the geodetic height

Density can be converted for other temperatures by applying the following equation:

$$\rho_L(t) = \rho_L(25\ °C) \times \frac{(273 + 25)}{(273 + t)}$$

3714942091: Density conversion formula

ρ_L(25 °C) in kg/m^3	Air density at 25 °C
$\rho_L(t)$ in kg/m^3	Air density at temperature t
t in °C	Air temperature

In the case of plants which extract air from the genset room, the volume of air for combustion in the engine on the supply side must also be taken into account.

Further information

- Combustion air quantity [▸ 200]

7.4 Notes on ventilation system planning and operation

7.4.1 Planning

After determining the required amounts of ventilated air, the openings and ducts must be designed so as to maintain the following air speeds.

Component	Air speed in m/s
Supply air opening and exhaust opening	1.5 to 2.5 or 2.5 to 4
Ventilation duct	10 to 20
Free flows in the genset room	0.3
Muffler section	6 to 8

Table 15: Components and air speeds

Additional restrictions owing to flow noise must be taken into account.

Air change rate

The number of air changes may also be taken as a characteristic figure for a ventilation system. It represents the number of air changes per hour, i.e., how often the complete volume of air in the genset room is exchanged. From experience, the number of air changes should not exceed 100 for large-scale plants in buildings. In extremely small genset rooms (e.g., containers) or at high ambient temperatures, the number of air changes may reach up to 500 per hour.

7.4.2 Operation

The operation of the ventilation system may affect the pressure conditions at the combustion air intake of the engine. It may even cause problems when starting the engine or the engine may not even start. In such cases, before starting the engine, only the supply air and exhaust air louver dampers must be opened. Particularly during the start phase or synchronization of the genset, the ventilators must be operated without pressure peaks in the genset room. This means that the ventilators must run at constant speed during the start phase.

Position of supply air openings and exhaust openings

The supply air openings must be positioned in such a way that the air drawn in is as clean and cool as possible. The position for the outlet of exhaust air must be selected so that the function of other plant components such as cooling systems is not impaired by the warm exhaust air flow.

7.5 Ventilation system components

7.5.1 Main components

The main components of a genset room ventilation system are the protective grating, sound-proofing baffles, louver dampers, filters, air ducts and ventilators.

7.5.2 Protective grating

Protective grating is installed on the outside wall of the genset room building on both the supply side and the exhaust side. It prevents rain and snow from entering the ventilation system. A bird screen integrated in the protective grating stops small animals from entering the plant.

7.5.3 Sound-proofing baffles

Especially when plants are installed in residential areas or areas with restricted noise levels, significant effort may be required in terms of measures to sound-proof the ventilation system of the plant. In such cases, sound-proofing baffles must be fitted at both the air supply side and the exhaust air side. The main data for configuring these are the air flow to be conveyed through the baffles, the required sound reduction index and the available duct opening. The depth of the baffles, their thickness and distance from each other are then determined. The sound-proofing baffles must be designed by specialized companies with an appropriate degree of care. Subsequent improvements are very costly if the required values are not achieved.

7.5.4 Louver dampers

Louver dampers are used to block the ventilation system connection between the genset room and the external environment when the plant is at a standstill. Louver dampers prevent undercooling of the room in winter. The louver dampers are controlled by the switchgear and activated by electric drives. In large plants, cooling air can be admitted to certain areas of the plant by selectively controlling the louver dampers. In winter, the genset room temperature can be regulated by controlling the louver dampers.

7.5.5 Filter

Generally, filters should be installed in the ventilation system. This particularly applies to plants located on the premises of industrial facilities. The air is heavily contaminated in these environments, e.g. landfills, coal mines, cement factories, steel mills, etc. Plants located in regions where sandstorms occur are also affected. In this case, the appropriate filter type must be selected according to the degree of contamination. This allows heavy particles to be separated easily via inertia filters. When lightweight fibers occur, conventional fibrous filters must be fitted, which, in view of the relatively large quantities of air involved, can reach considerable dimensions. Filters as per DIN EN 779, filter class G3, are suitable. A correspondingly higher filter class must be selected for special requirements. Effective filter monitoring must be ensured.

7.5.6 Ventilators

The ventilators are designed mostly as axial fans, rarely as radial fans as well. Both must be suitably dimensioned based on the required air quantity and pressure difference. Control of the genset room temperature is achieved by changing the amount of air being blown through the room. The air volume flow can be modified by using variable-speed ventilators or by switching single ventilators (special function) on and off.

NOTE

When using single ventilators, consider that standing ventilators - particularly axial types - can be driven in reverse by the differential pressure. This can lead to problems when large ventilators are used.

When dimensioning the ventilators, the pressure reserve must be correctly selected. It is important to ensure that the design air volume is actually achieved while taking the installed components, such as protective grating, sound-proofing baffles, louver dampers, etc. into account.

7.5.7 Air ducts

Depending on the plant's design or the location of the genset room inside a larger building, e.g., in the basement in the case of emergency power systems, the air to ventilate the genset room may have to be brought in over longer distances. Air ducts are used to do this. Pressure losses in these ducts must be considered when designing the ventilators. To avoid condensation, external air ducts should be insulated.

7.5.8 Flow monitors

As part of the explosion protection concept, the use of one or more flow monitors may be necessary to detect a failure of the ventilation system at an early stage.

Required information

- Explosion protection concept [▷ 25]

7.5.9 Smoke and heat sensors

As part of the fire protection concept, smoke and heat sensors may be required to mitigate the risk of fire or limit its spread. The measures required in the event of the sensors responding are defined in the fire protection concept and must be implemented accordingly.

Required information

- Fire protection concept [▷ 24]

7.5.10 Gas sensor

Gas sensors may be required as part of the explosion protection concept to mitigate the risk of an ignitable gas mixture occurring. The measures required in the event of the sensors responding are defined in the explosion protection concept and must be implemented accordingly.

Required information

- Explosion protection concept [▷ 25]

8 Engine cooling systems

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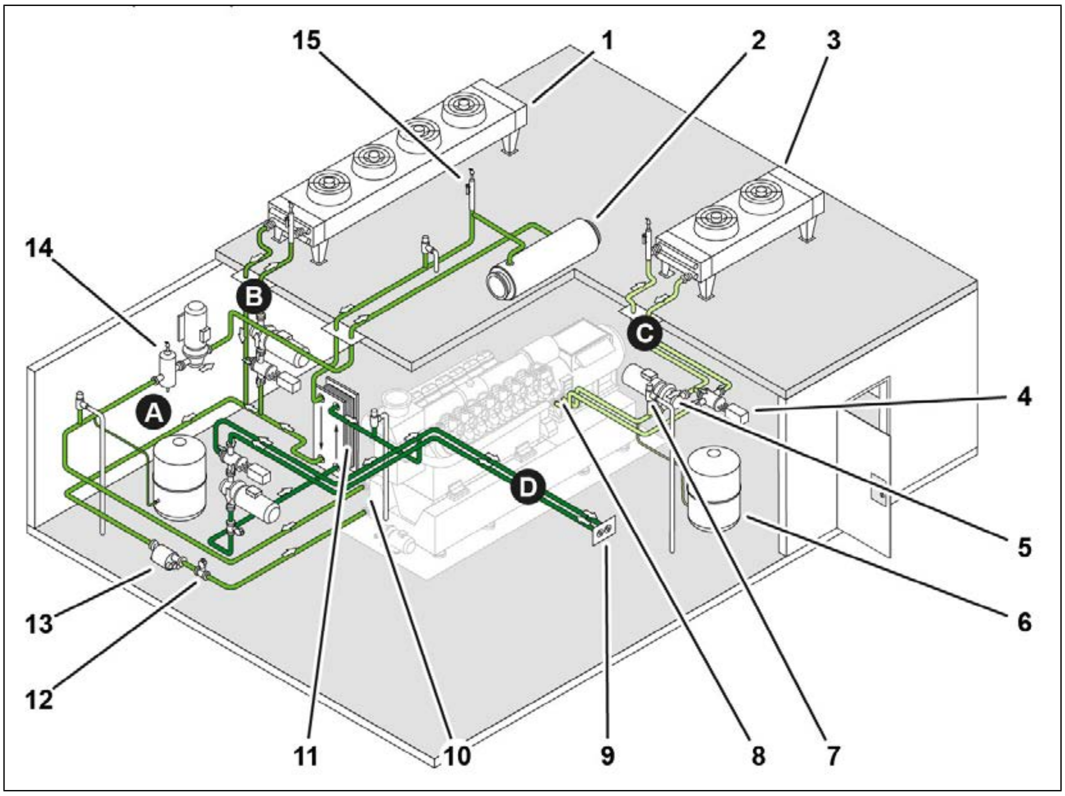
8.1 System overview

The schematic illustration shows and lists typical components and interfaces to help you get started. Proportions are therefore not to scale and the arrangement is just an example.



3620523403: Simplified example illustration

A	Engine cooling circuit	B	Dump cooling circuit
C	Mixture cooling circuit	D	Heating circuit
1	Dump cooling circuit radiator	2	Exhaust heat exchanger
3	Mixture cooling circuit radiator	4	3-way valve
5	Recirculating coolant pump	6	Diaphragm expansion vessel
7	Safety valve	8	Genset connection (depending on engine type)
9	External heating circuit connection	10	Genset connection (depending on engine type)
11	Plate heat exchanger	12	Throttle valve
13	Electric preheater	14	Gas and dirt separator
15	Monitoring group		

8.2 Structure and function

8.2.1 General

The cooling systems used have coolant as the operating fluid and are closed systems from the engine side. Genset engines use dual-circuit cooling. The layout must be as shown in the illustrations below. Deviations require approval in writing. The Technical Bulletin TR 2091 “Specification for coolant” must be observed.

8.2.2 Dual-circuit cooling

In addition to the engine cooling circuit, the engines also have a mixture cooling circuit at a lower temperature level. Because the temperature level in the mixture cooling circuit is comparably low, the heat from that circuit is normally discharged to the environment via a radiator or cooling tower with a separate circuit.

8.2.3 Cooling systems for gas engines

All gas engines of the series TCG 3016, TCG 2020, TCG 3020 and TCG 2032 are equipped with a two-stage mixture cooler. The HT stage is integrated in the engine cooling circuit, while the LT stage is integrated in the mixture cooling circuit.

In the TCG 3020 and TCG 2032 series, the lube oil cooler is not mounted on the engine.

In the TCG 3020 series, the lube oil cooler is mounted on the base frame on the front of the genset and connected to the engine on the oil and coolant side. The lube oil cooler is always integrated in the engine cooling circuit.

In the TCG 2032 series, the lube oil cooler is installed in the plant separately. In this case, the lube oil cooler (depending on the design of the overall system) can be installed on the coolant side in the engine cooling circuit, in the mixture cooling circuit or in the heating circuit.

The notes on the lube oil cooler must be observed.

Required information

- Lube oil system [▷ 187]

8.2.4 Examples of the layout of cooling systems for gas engines

A heat exchanger to be provided by the client transfers the heat absorbed by the coolant for use in a heating circuit or another technical process. If there is no means of heat recovery at hand, the heat must be discharged into the atmosphere via a radiator or cooling tower.

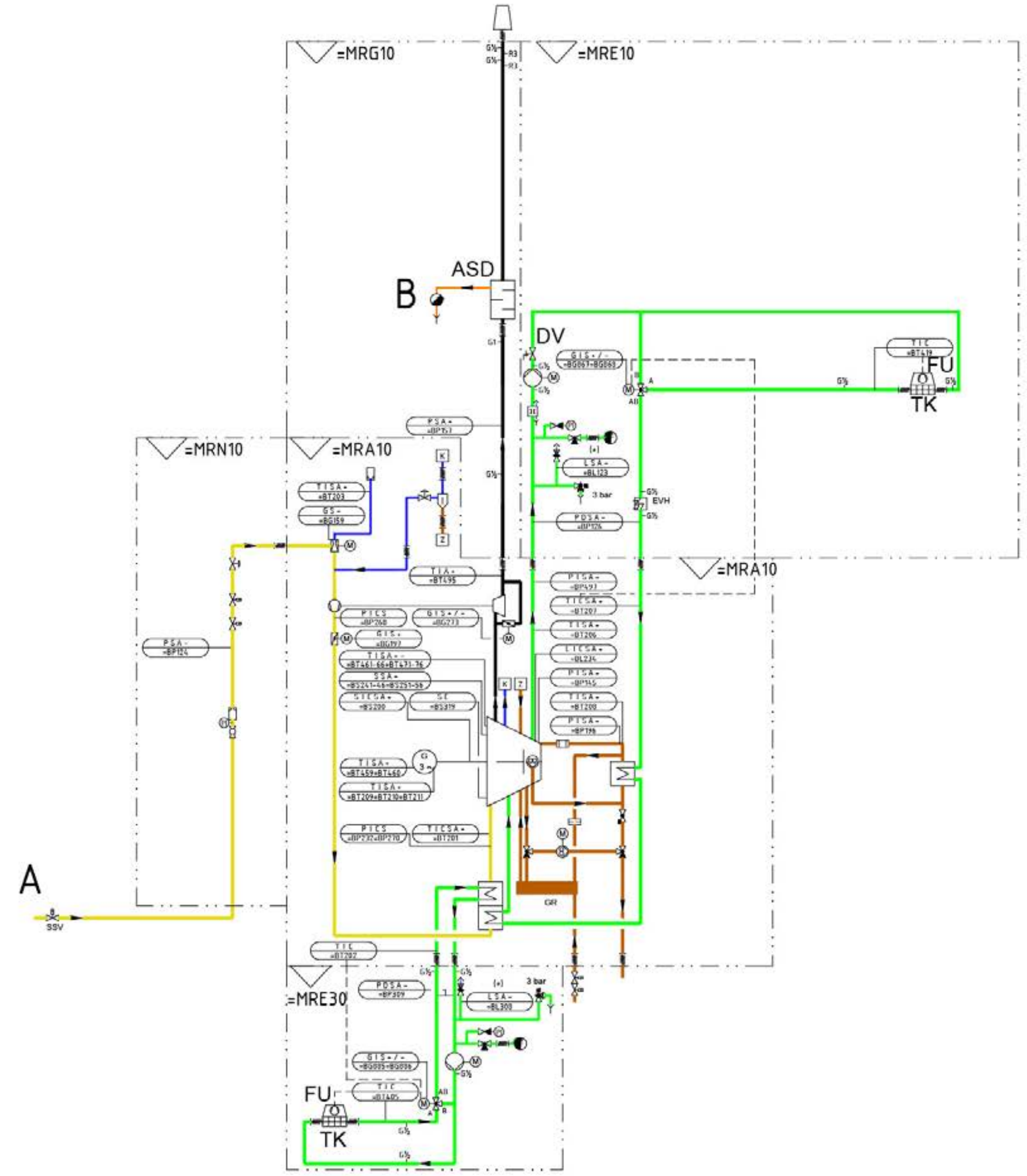
Running the cooling tower liquid straight through the engine is not permissible. A decoupling heat exchanger or closed cooling tower must be provided.

The inlet temperature of the coolant is generally controlled in the gas engine. Depending on the design of the plant, the temperature controller may be installed directly in the engine cooling circuit or in the heating circuit. Electrically driven pumps are always used as coolant pumps. Fine adjustment of the coolant flow is achieved with an adjustable throttle or using a suitably adapted fixed pump speed.

The expanding volume is accommodated in a diaphragm expansion vessel. The level of each of the cooling circuits is monitored by a safety valve, a ventilation valve and a low water safety device. The ventilation valve and the low water safety device must be positioned at the highest point of the cooling circuit

Like the engine cooling circuit, the mixture cooling circuit is equipped with an electrically powered circulation pump, diaphragm expansion vessel, monitoring group and temperature controller. With multi-engine plants, it is not permitted to connect the engine cooling circuits together, because the definitive closed-loop control of each engine inlet temperature cannot be guaranteed.

Example of a cooling system without heat utilization

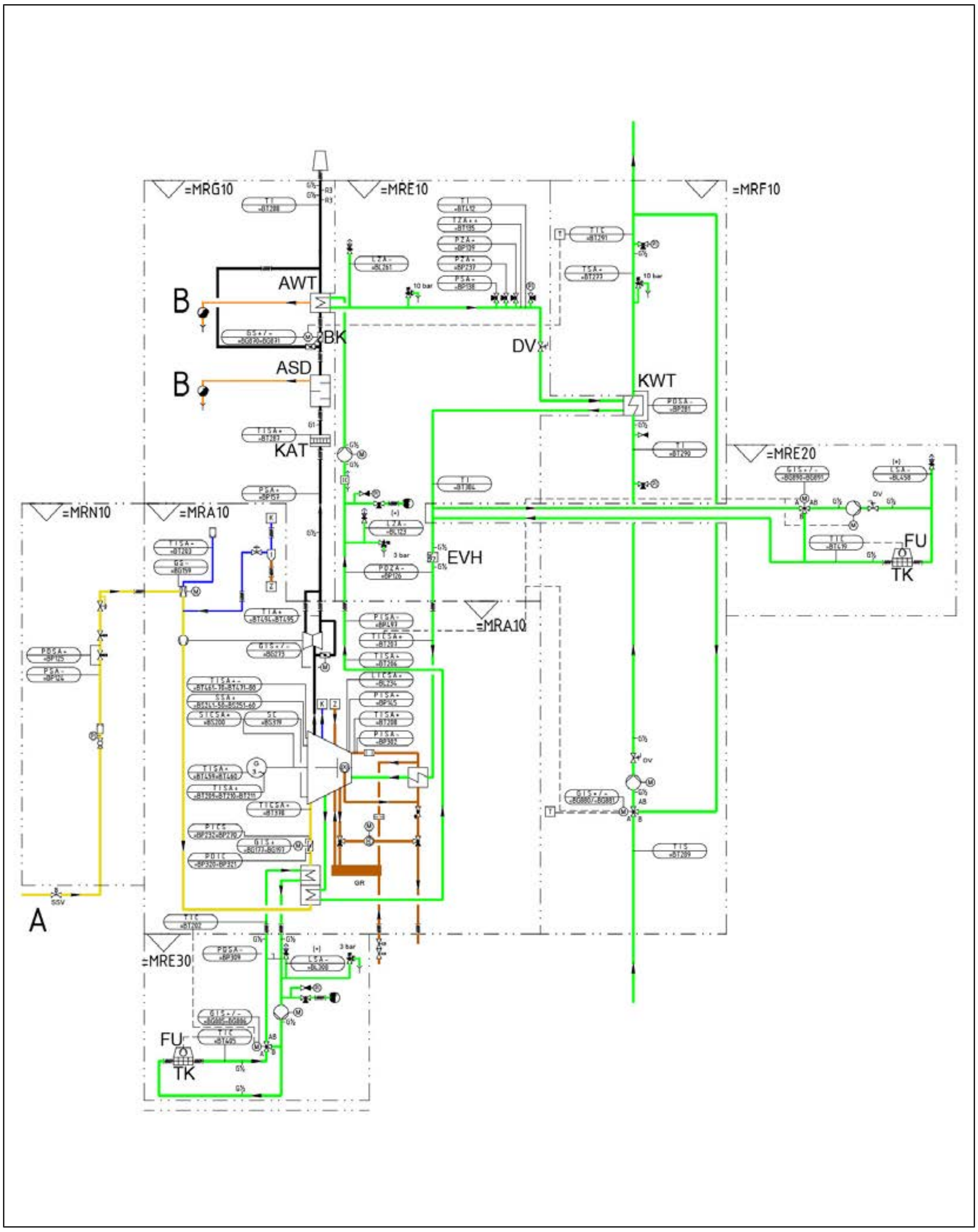


3621261067: Diagram of a plant without heat utilization

A	Fuel gas	ASD	Exhaust muffler
B	Condensate	DV	Throttle valve

MRA10	Genset	EVH	Electric preheater
MRE10	Engine cooling system	FU	Frequency converter (FC)
MRE30	Mixture cooling system	TK	Radiator
MRG10	Exhaust system		
MRN10	Gas train		

Example of a cooling system with heat utilization



3621260171: Diagram of a plant with heat utilization

A	Fuel gas	ASD	Exhaust muffler

B	Condensate	AWT	Exhaust heat exchanger (EHE)
MRA10	Genset	BK	Bypass flap
MRE10	Engine cooling system	DV	Throttle valve
MRE20	Dump cooling system	EVH	Electric preheater
MRE30	Mixture cooling system	FU	Frequency converter (FC)
MRF10	Heat utilization	KAT	Catalytic converter (CAT)
MRG10	Exhaust system	KWT	Coolant heat exchanger (CHE)
MRN10	Gas train	TK	Radiator

8.3 Notes on planning, design and operation

8.3.1 Engine cooling circuit

The engine cooling circuit mainly dissipates the heat from the HT level of the mixture cooler, cylinder cooler, and lube oil cooler. Due to the high temperature level, the heat can be transferred efficiently to a heating circuit. The volume flow must be set, independently of the engine load, as per the information on the genset data sheet.

8.3.2 Mixture cooling circuit

The mixture cooling circuit dissipates the heat from the LT level. Due to this low temperature level, the heat is dissipated to the environment or used in a low temperature heating circuit.

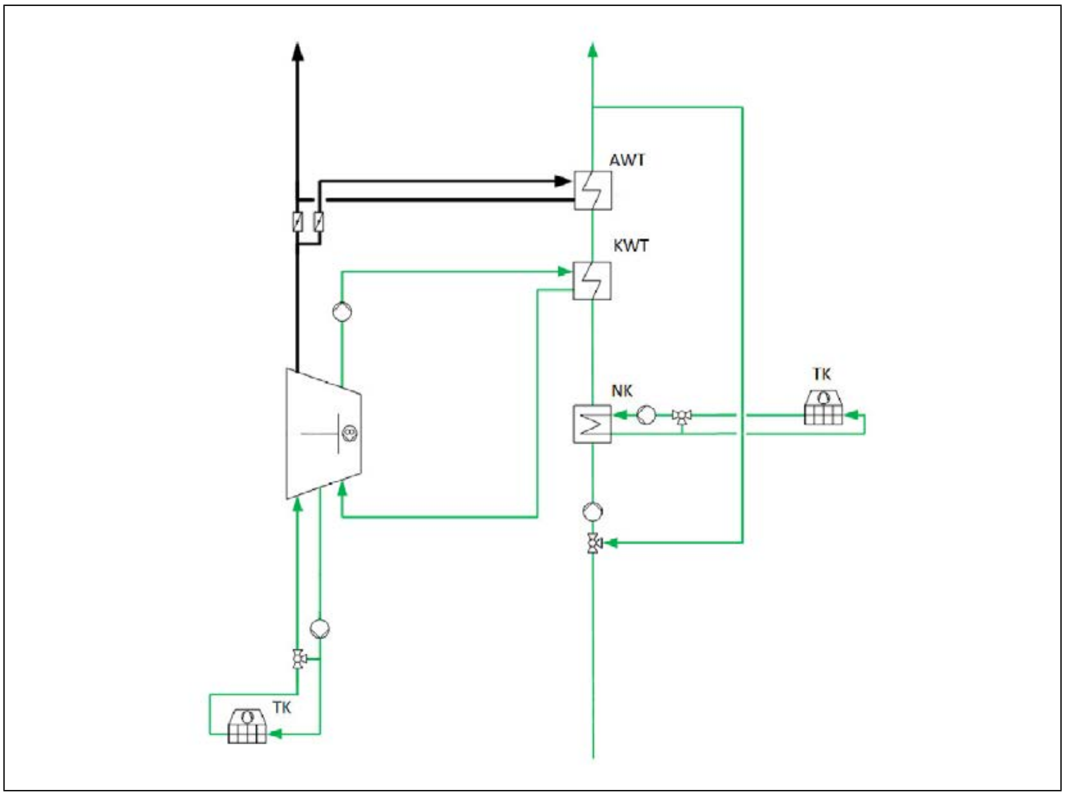
Plants with propane as fuel gas

Due to the high knocking tendency during operation with propane, a low inlet temperature in the mixture cooler on the engine is necessary in accordance with the genset data sheet. In addition to compliance with the general specifications for the structure of cooling circuits, the following points must be observed when planning the plant:

- Opening time and closing time of the 3-way valve < 65 s (completely open after completely closed)
- Compactly constructed mixture cooling circuit; short piping must be provided between the pump, 3-way valve and the genset
- Short piping lengths to the radiators
- In the mixture cooling circuit, the temperature sensor downstream of the radiator must be installed directly at the output of the radiator (max. distance of 1 m)
- The radiator ventilators in the mixture cooling circuit must be equipped with infinitely variable speed control. Stage switching is not permissible.

8.3.3 Dump cooling circuit

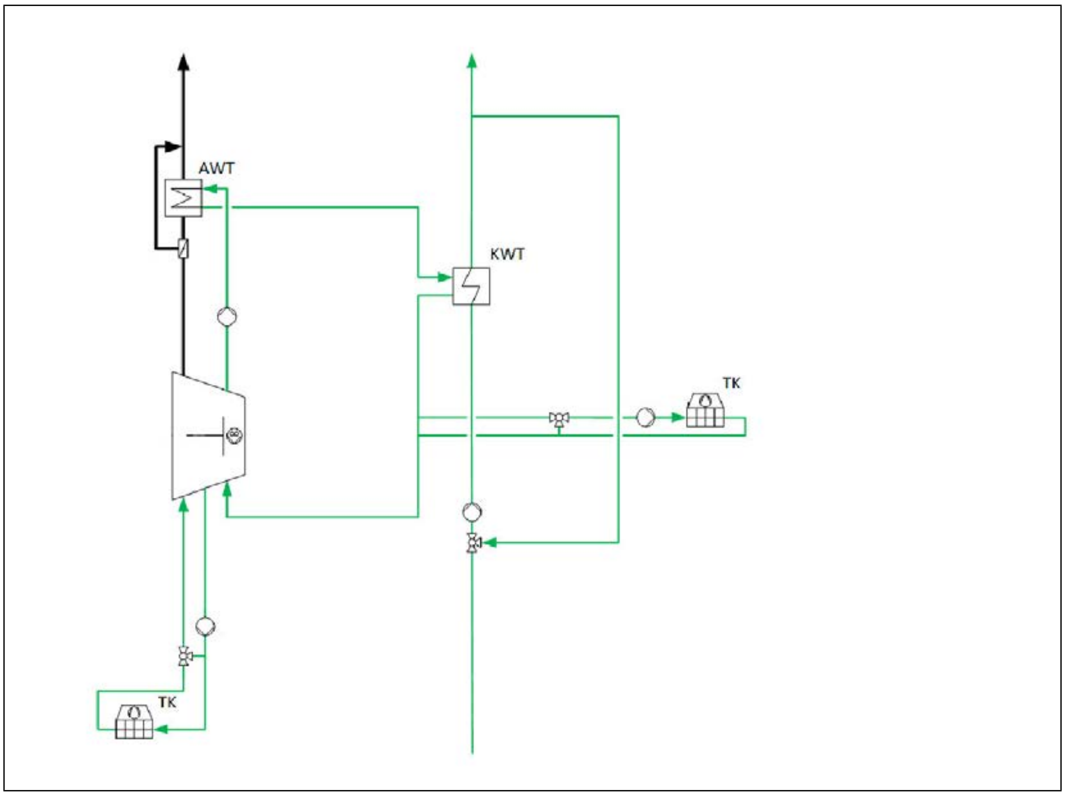
In plants where the dispersal of heat via the heating circuit is not always guaranteed, yet the electrical power of the genset must still be available, the heat generated by the engine is dissipated via the so-called dump cooling circuit. The arrangement of the dump cooling circuit depends on the plant design. Depending on the arrangement of the exhaust heat exchanger or the lube oil cooler for plants with TCG 2032 gensets, the integrated dump cooling system must ensure safe operation of these components even if there is no heat discharge via the heating circuit. Normally, the heat is dissipated via a dump cooling heat exchanger integrated into the heating circuit and connected to a radiator or a cooling tower (see next illustration). When determining the size of the pump, the volume flow increased according to the capacity reserve and the associated higher pressure losses must be taken into account.



3622801419: Dump cooling with coupling heat exchanger in the heating circuit

AWT	Exhaust heat exchanger (EHE)	KWT	Coolant heat exchanger (CHE)
NK	Dump cooler (DC)	TK	Radiator

If the heat produced by the engine cooling water, exhaust gas and lube oil (for TCG 2032) is transferred to the heating circuit by a heat exchanger, the dump cooler can be integrated directly into the engine cooling circuit without an additional coupling heat exchanger (see next illustration).



3622801931: Direct integration of the dump cooling system in the engine circuit

AWT	Exhaust heat exchanger (EHE)	KWT	Coolant heat exchanger (CHE)
TK	Radiator		

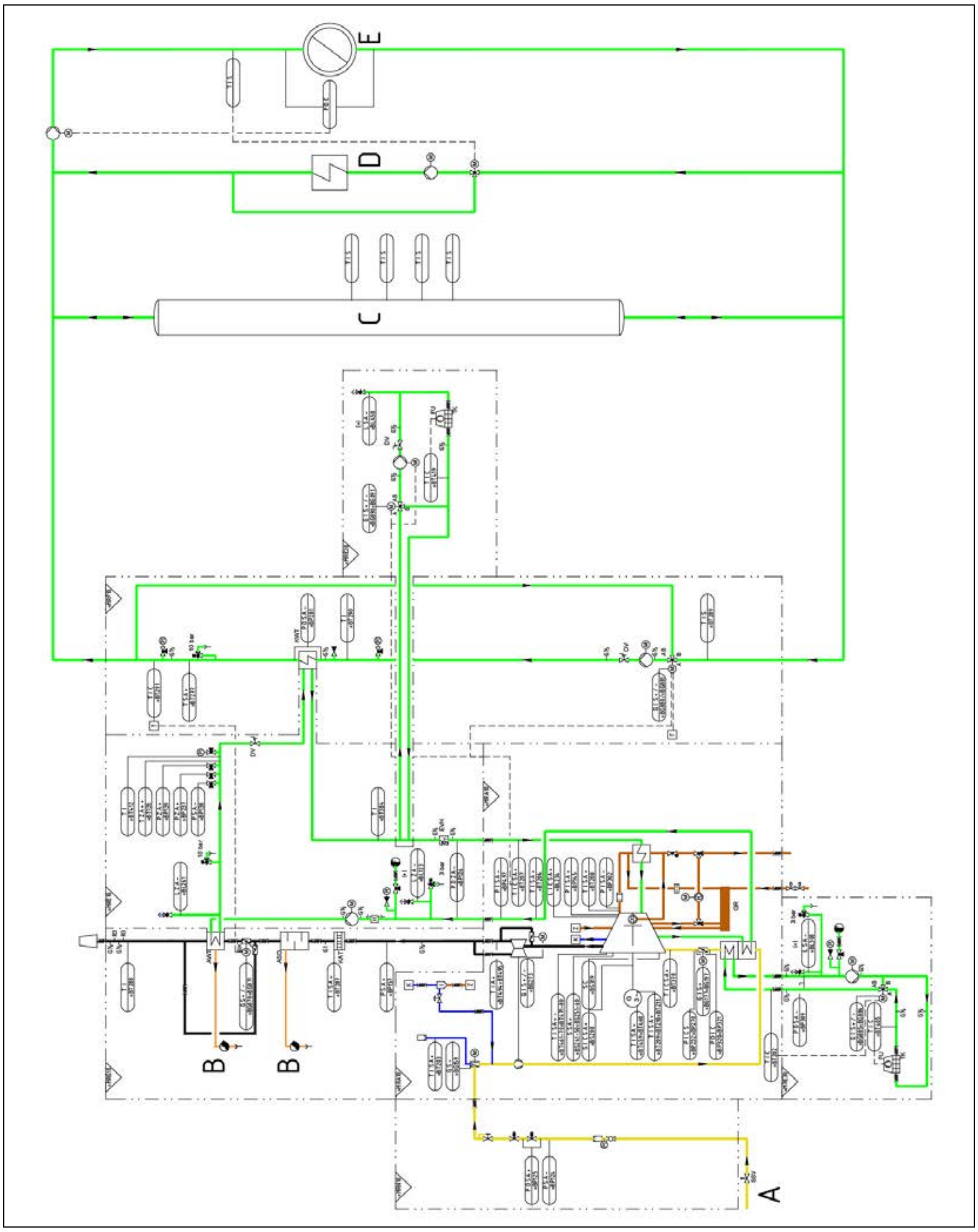
8.3.4 Heating circuit

Overview of heating circuit

For plants with heat recovery, the heat generated by the engine is transferred to the heating circuit. The main components integrated into the heating circuit on the CHPS side are the cooling water heat exchanger, the exhaust heat exchanger, the circulation pump, the throttle valve and the 3-way valve for temperature control.

The heat output from the engine contained in the cooling water and the exhaust gas, and the associated flow rates and temperature differences have been established for the engines in their respective operation modes. The capacity of the circulation pump in the heating circuit is determined by the temperature difference between the flow and return of the heating circuit. When determining the size of the pump, the volume flow increased according to the capacity reserve and the associated higher pressure loss must be taken into account (see illustration "P&I diagram for plant with heat utilization"; system limits MRF10 in Examples of the layout of cooling systems for gas engines [▸ 134]).

The heating circuit should be designed in such a way that, independent of the adjusting processes and regulating processes, the flow in the section of the heat generating branch of the heating network is ensured without fluctuation of differential pressure. Hydraulic disconnection of the heat-generating and heat-using side of the heating network is achieved with a hydraulic gate. The function of hydraulic decoupling can be performed by heat accumulators (see next illustration).



3622802443: Diagram with hydraulic decoupling

A	Fuel gas	ASD	Exhaust muffler
B	Condensate	AWT	Exhaust heat exchanger (EHE)
C	Heat storage tank	BK	Bypass flap
D	Boiler	DV	Throttle valve
E	Consumers	EVH	Electric preheater

MRA10	Genset	FU	Frequency converter (FC)
MRE10	Engine cooling system	KAT	Catalytic converter (CAT)
MRE20	Dump cooling system	KWT	Coolant heat exchanger (CHE)
MRE30	Mixture cooling system	NK	Dump cooler (DC)
MRF10	Heat utilization	TK	Radiator
MRG10	Exhaust system		
MRN10	Gas train		

Coolant in the heating circuit

The heating circuit is a closed circuit. In this circuit too, a certain water quality must be maintained. The required water quality is described in TR 2091. Oxygen, chlorides, and hydrogen sulfide in particular cause corrosion in the system. Salts in solution are precipitated as crystals at high heat transfer locations, leading to deposits, which have a negative impact on heat transfer (e.g., boiler scale). At exhaust heat exchangers in particular, there is a risk of crystalline deposits because of the high water temperatures at the heat transfer points.

These phenomena can be reduced by adding inhibitors to the heating water operating medium and by selecting suitable materials for the heat exchangers. This must be investigated for each individual application. If the exhaust heat exchanger is installed in the heating circuit and if the heating water quality does not comply with the figures as stated in the Technical Bulletin for coolant, minimum requirements of the water quality of heating circuits, it is necessary to provide a separate coupling circuit with an additional heat exchanger between the exhaust heat exchanger and heat consumer. Now the exhaust heat exchanger is protected against any potential damage through contamination in the heating water.

Direct integration of engine cooling circuits into the heating circuit

In some applications, e.g., maintaining a high temperature level, a heat exchanger is not used for decoupling the engine cooling circuit or mixture cooling circuit from the respective heating circuit. These cases require strict compliance with the following conditions:

- Compliance with the water quality as per Technical Bulletin TR 2091
- The maximum cooling water pressure at the engine and LT mixture cooler outlet must not exceed the set pressure of the safety valve (see Chapter Fluid pressures [▸ 143]).
- The cooling systems must be closed and must have reliable leakage detection.
- Systems with automatic cooling water backfeed are not permissible.
- In the engine cooling circuit, a coolant volume of 3.5 m^3 must not be exceeded.

NOTE

Cooling water leaks at the mixture cooler cause water to enter the combustion chamber and cause damage to the engine. Therefore if a low water level is detected, the cause must be determined. Continued operation of the engine is only permissible once a leak at the engine has been ruled out.

Heating circuit design regulations

The regional regulations for water heating systems and steam boiler systems also apply to the design of the heating circuit. These may include, for example:

DIN EN 12828	Heating systems in buildings (for max. operating temperatures up to 105 °C). When planning or designing CHPS plants requiring temperature monitoring/limiting temperatures above 110 °C, we recommend that you consult the local authority responsible for certification of the system. The favored scope of necessary equipment and the setting of the inspection periods (German Health and Safety at Work Regulations) can be agreed at that time.
DIN EN 12953	Shell boilers

Table 16: Heating circuit design regulations

Depending on the flow temperature in the heating water circuit (90 °C, 100 °C or 120 °C), the appropriate sensors must be installed to protect and maintain the safety chain for the exhaust heat exchanger and to secure the heating circuit. The signals from the sensors are processed by the TEM system and TPEM system.

An approval has been granted by TÜV for the monitoring systems (transmitters plus processing of signals via the TEM/TPEM system), with the result that the individual inspections to be carried out on each plant by TÜV can be completed quickly.

8.4 Requirements and guide values

8.4.1 Fluid pressures

All pressures for fluids are generally indicated in bar overpressure. All heat exchangers, pumps and radiators are designed as standard for 10 bar; the lube oil heat exchanger of the TCG 2032 is designed for 16 bar.

Minimum pressure in the engine cooling circuit with 3 bar safety valve

The following information does not apply to the engine cooling circuit of the TCG 2032B series.

All gas engines monitor the pressure at the coolant outlet in the engine cooling circuit. The target operating pressure at the engine outlet is approx. 2.5 bar. The minimum required operating pressure is 2 bar, or 2.2 bar for the TCG 3020 series.

The information on the permissible pressures at the engine outlet on the genset data sheet must be observed.

There are two engine-specific limit values in each case for a pressure undershoot at the engine outlet. The upper limit value of the pressure undercut leads to a warning. The lower limit value of the pressure undercut leads to a shutdown of the engine.

The diaphragm expansion vessels should be dimensioned in such a way that a static gas inlet pressure of at least 1.5 bar and a filling pressure of at least 2 bar at the engine outlet are maintained when the plant is stopped and cold (see Chapter Diaphragm expansion vessel [▹ 156]).

Maximum pressure in the engine cooling circuit with 3 bar safety valve

The following information does not apply to the engine cooling circuit of the TCG 2032B series.

When taking into account a coolant reserve of 10 to 15 % of the coolant content, a filling pressure of approx. 2 bar is achieved when the system is cold. Under these conditions, the pressure at the engine outlet reaches the desired value of approx. 2.5 bar during engine operation. To avoid cavitation in the cooling system, a pressure of approx. 2.5 bar must be maintained at the engine outlet, particularly in the engine cooling circuit.

The maximum permissible pressure at the engine outlet is 2.5 bar. The safety valve that must be installed directly downstream of the engine outlet opens at 3 bar.

High coolant pressure reduces the tendency to cavitation in areas of the cooling circuit where high flow velocities prevail at simultaneously high medium temperatures. It is therefore advisable to operate the engine at the maximum permissible pressure level.

Minimum pressure in the engine cooling circuit for the TCG 2032B series with 4 bar safety valve

Gensets of the TCG 2032B series each have pressure monitoring in the engine cooling circuit at the coolant inlet and at the coolant outlet.

The target operating pressure at the coolant inlet is 5.0 bar to 5.2 bar, while the minimum required operating pressure at the coolant inlet is 4.5 bar. The minimum required operating pressure at the engine outlet is 3.1 bar.

There are two limit values each for a pressure undershoot at the coolant inlet and coolant outlet. The upper limit value of the pressure undercut leads to a warning. The lower limit value of the pressure undercut leads to a shutdown of the engine.

The diaphragm expansion vessels should be dimensioned in such a way that a static gas inlet pressure of at least 2.3 bar and a filling pressure of at least 2.8 bar at the engine outlet are maintained when the plant is stopped and cold (see Chapter Diaphragm expansion vessel [▹ 156]).

Maximum pressure in the engine cooling circuit for the TCG 2032B series with 4 bar safety valve

When taking into account a coolant supply of 25 liters to 50 liters, a filling pressure of approx. 2.8 bar is achieved when the system is cold. Under these conditions, the pressure at the engine outlet reaches the desired value of approx. 3.3 bar during engine operation. To avoid cavitation in the cooling system, a pressure of approx. 3.3 bar with maximum deviations of +0.1 bar and -0.2 bar must be maintained at the engine outlet, particularly in the engine cooling circuit.

The maximum permissible pressure at the engine outlet is 3.4 bar. The safety valve that must be installed directly downstream of the engine outlet opens at 4 bar.

The maximum permissible operating pressure at the coolant inlet of the genset is 5.5 bar. There is a limit value above which the genset switches off automatically.

To prevent possible premature triggering of the safety valve downstream of the engine, the pressure at the engine outlet must be limited to approx. 3.4 bar relative while the coolant pump is running. If this does not produce the desired 5.0 bar of relative inlet pressure, then this is acceptable. High coolant pressure reduces the tendency to cavitation in areas of the cooling circuit where high flow velocities prevail at simultaneously high medium temperatures. It is therefore advisable to operate the engine at the maximum permissible pressure level.

8.4.2 Pump location

If there are high pressure losses as a result of external resistance in the engine circuit (heat exchangers, control valves, etc.), the pump must be installed on the outlet side of the engine. Otherwise the maximum and minimum pressure limits on the outlet side of the engine are not maintained.

8.4.3 Max. permissible volume

In the engine cooling circuit, a coolant volume of 3.5 m^3 must not be exceeded. When an exhaust heat exchanger is integrated into the engine cooling circuit, the manufacturer’s requirements must also be met.

8.4.4 Max. permissible temperature gradient

If the secondary inlet temperatures of the engine cooling circuit, mixture cooling circuit and dump cooling circuit as well as the inlet temperature of the heating circuit are controlled by the customer, the max. permissible temperature modification speed of 1 K/min needs to be maintained. In order to maintain stable behavior of the temperature control, it is necessary to minimize disturbing external influences.

NOTE

Always provide all coolers and pumps with an adequate reserve.

8.5 Cooling water system components

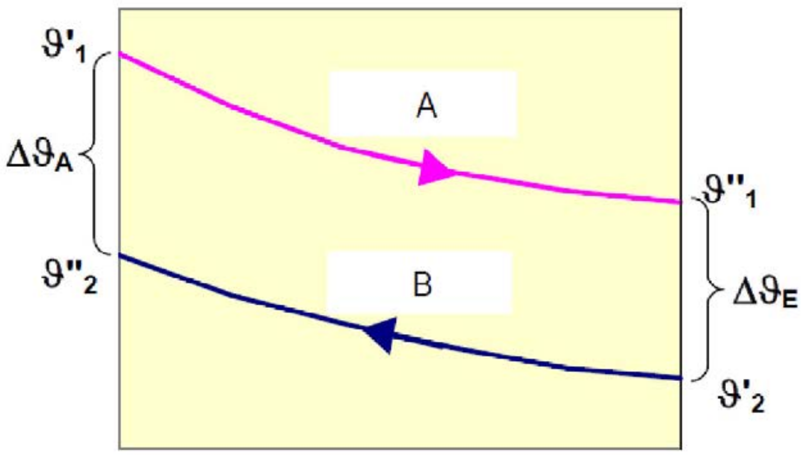
8.5.1 Cooling water heat exchanger

A sufficient capacity reserve and area reserve must be taken into account (see next illustration).

The specified engine inlet temperatures and engine outlet temperatures must be observed (see engine data sheet).

The secondary temperatures must be selected so that the coolant heat exchanger has a logarithmic temperature difference of at least 4 K and the inlet temperature difference/ outlet temperature difference is at least 2 K.

In the case of liquid coolants, plate heat exchangers or pipe radiators are used on the secondary side. Plate heat exchangers are highly compact in construction and easy to clean. Their performance can, within certain limits, be varied at a later date by altering the number of plates.



3621645323: Logarithmic temperature difference

$$\Delta\Theta = \frac{\Delta\vartheta_A - \Delta\vartheta_E}{\ln\left(\frac{\Delta\vartheta_A}{\Delta\vartheta_E}\right)}$$

3621645835: Formula for logarithmic temperature difference

A	Operating medium 1	B	Operating medium 2
ln	Natural logarithm	ΔΘ	Logarithmic temperature difference

Example

An engine coolant heat exchanger in the heating circuit has the following design data:

Engine side:	Inlet temperature $\vartheta'1$		90 °C
	Outlet temperature $\vartheta''1$		84 °C
Heating circuit side:	Inlet temperature $\vartheta'2$		70 °C
	Outlet temperature $\vartheta''2$		85 °C
This yields:	$\Delta\vartheta_A$	90 °C – 85 °C	= 5 K
	$\Delta\vartheta_E$	84 °C – 70 °C	= 14 K
	$\Delta\vartheta_A - \Delta\vartheta_E$	5 K – 14 K	= -9 K
	$\ln(\Delta\vartheta_A/\Delta\vartheta_E)$	ln(5 / 14)	= -1.0296
	$\Delta\Theta$	-9 K / -1.0296	= 8.74 K

This plate heat exchanger therefore complies with the minimum requirements:

$\Delta\varphi \geq 4K$, $\Delta\vartheta_A \geq 2K$ and $\Delta\vartheta_E \geq 2K$.

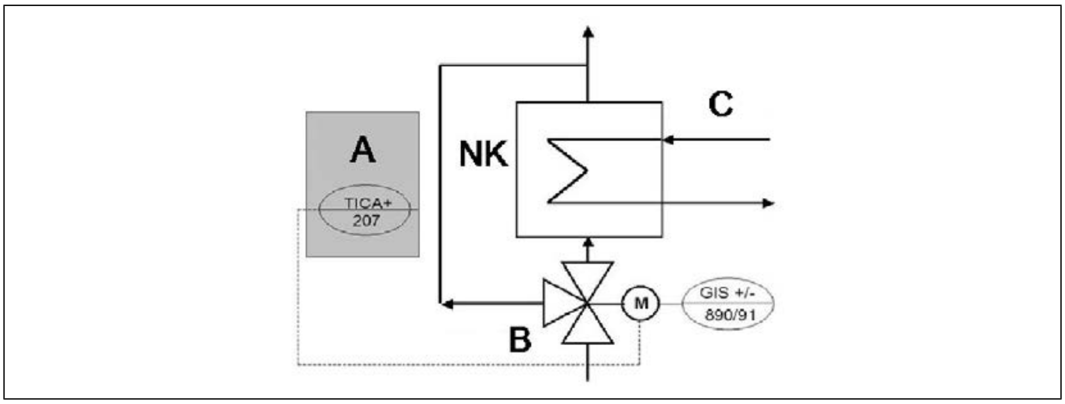
Integration of cooling water heat exchangers for dump cooling with raw water

The temperature gradient on the raw water side should not exceed ±1 K/min.

For the actuators, the I/O Controller of the TEM/TPEM system has digital outputs for ± (24 V signal) for opening and closing the valve. In order to achieve a reasonable closed-loop control, the valve opening time (from limit stop to limit stop) must be approx. 1 minute.

Correct layout

For dump cooling systems with raw water cooling, the control for the primary-side dump cooler outlet temperature should also be arranged in the primary circuit (see next illustration). With this design, hot water flow over the mixing cooler will only occur when excess heat is discharged. The volumetric flow rate on the secondary side must be selected so that an outlet temperature of approx. 45 °C is not exceeded.

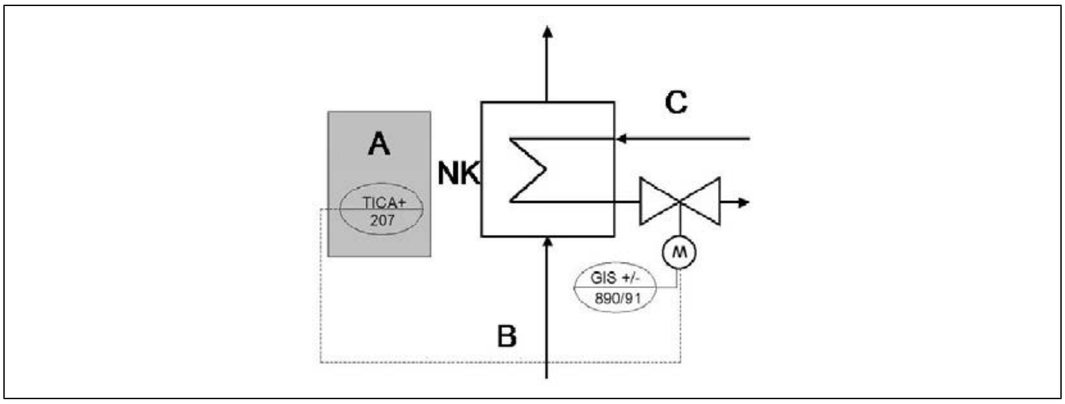


3621646347: Integration of cooling water heat exchangers for dump cooling with raw water (correct)

A	Engine cooling circuit	B	Primary side (engine circuit or heating circuit)
C	Secondary side	NK	Dump cooler (DC)

Incorrect layout

The temperature should never be controlled as shown in the illustration below. In this illustration, hot water is constantly flowing through the dump cooler plate heat exchanger. Depending on the rate of flow, this can cause the raw water on the secondary side to reach the hot water temperature. The plate heat exchanger becomes calcified over time.



3621646859: Integration of cooling water heat exchangers for dump cooling with raw water (incorrect)

A	Engine cooling circuit	B	Primary side (engine circuit or heating circuit)
C	Secondary side	NK	Dump cooler (DC)

8.5.2 Exhaust heat exchanger

Exhaust heat exchangers are used to absorb exhaust gas heat and direct it to heat utilization. In doing so, the exhaust gas cools depending on the discharged heat.

When setting the exhaust gas cooling temperature, the amount of H_2S and sulfur must be taken into account in the fuel gas. This prevents acidic condensate that can damage the exhaust heat exchanger.

- Required information: General planning notes [205]

Recommended exhaust gas cooling temperatures	
Natural gas	≥ 120 °C
Sewage gas	≥ 150 °C
Landfill gas and NAWARO gas	≥ 180 °C

Table 17: Recommended exhaust gas cooling temperatures

To ensure adequate cooling of the exhaust heat exchanger, the minimum volume flow and minimum pressure specifications specified by the manufacturer must be observed. After switching off the genset, it is necessary to keep the pump running for a while in order to discharge the accumulated heat from the exhaust heat exchanger to the water. This function is provided in the TEM/TPEM system.

The capacity reserve and area reserve must be taken into account as shown in table Layout of components - Reserves [154].

Operation

- The exhaust temperature downstream of the exhaust heat exchanger for natural gas-powered engines is normally 120 °C. When using a low temperature exhaust heat exchanger, exhaust recooling temperatures < 100 °C can be achieved.
- The exhaust temperature downstream of the exhaust heat exchanger for bio, sewage and landfill gases and other special gases should not be lower than 180 °C
- To prevent corrosion damage, it is important to ensure that the exhaust system does not undercut the dew point in order to safely prevent the condensation of acids and water during operation
- Generally, in all plants where the exhaust heat exchangers are mounted higher than the engine, a sufficiently large and continuous condensate drain valve must be installed. In addition to the condensate drain valve, this prevents water from reaching the engine via the exhaust line in the case of a water breakthrough in the exhaust heat exchanger
- Hydrogen sulfide in the fuel gas can damage and destroy the exhaust heat exchanger. These notes must be observed and the limit values must be complied with
  – Required information: Sulfur oxide in the exhaust gas [215]

- The water qualities with respect to the heating requirements must be complied with (see TR 2091 “Technical Bulletin for coolant”)
- In large heating circuits, complying with the minimum requirements for the water quality may pose a problem. In this case, the installation of a small closed decoupling circuit between the exhaust heat exchanger and the heating circuit is urgently recommended
- For increased chloride ion content and increased flow temperatures in the heating circuit, the stainless steel pipes usually used in the exhaust heat exchangers are subject to stress corrosion cracking, which can lead to the exhaust heat exchanger being damaged. Therefore, providing there are no contrary requirements on the exhaust side, an exhaust heat exchanger with water-bearing components (pipes, pipe plate and casing) made of normal steel should be provided for directly integrating the exhaust heat exchanger into the heating circuit and for water temperatures > 110 °C
  - Required information: Heating circuit [▸ 140] and, in particular, the information provided under “**Coolant in the heating circuit**”
- The exhaust heat exchangers expand at operating temperature. Floating bearings and expansion joints must be provided accordingly
- The manufacturer's specifications on the minimum and maximum volume flows and pressures must be observed. Particularly in the case of heating circuits with low pressures, e.g. due to the integration of a pressureless heat accumulator, impermissibly low pressures may occur depending on the position of the exhaust heat exchanger. Especially in the case of low temperature exhaust heat exchangers that are integrated in the heating circuit upstream of the return temperature increase, it must be ensured that the minimum volume flow is maintained.

Additional planning notes

The exhaust heat exchangers are usually made of stainless steel (1.4571 or equivalent).

In the case of plants which are operated with sewage gas, landfill gas or other special gases, the increased content of sulfuric acid, hydrochloric acid and hydrofluoric acid in the exhaust gas shall be kept in mind when selecting materials. These acids have a highly corrosive effect and can even damage stainless steel exhaust heat exchangers. If there is a risk of increased concentration of chlorine and other halogenated substances in the fuel gas, there is a risk of local pitting and stress corrosion. Therefore thick-walled material made of low alloyed boiler steel should be used here instead of thin-walled stainless steel. This steel is less sensitive to this type of corrosion.

8.5.3 Cooling systems

8.5.3.1 General

Each cooling system must be capable of discharging the generated heat even at maximum ambient temperatures.

Where air is the secondary side coolant, ventilator coolers and cooling towers are used. Up to a certain size, ventilator coolers can be implemented as front coolers (vertically arranged cooling network); larger plants take the form of radiators.

The occasionally high noise level of the fans must be taken into account when installing plants in residential areas. Either slow-moving fans can be used here, or special soundproofing measures will be needed.

8.5.3.2 Radiator

The capacity reserve and area reserve must be taken into account (see Table Layout of components - Reserves [▹ 154]). Where there is a risk of contamination resulting from the environment (e.g., leaves, pollen, sand, carbon dust), an appropriate fin spacing must be selected. An enlarged space between the fins prevents the cooler from becoming clogged too fast. Contamination causes the heat transfer to deteriorate and the heat cannot be dissipated anymore. In the case of air coolers, because of the risk of freezing, antifreeze must be added to the cooling water.

If the radiator is set up higher than 15 meters above the engine, it is necessary to install a coupling heat exchanger between the engine and radiator. This ensures that the maximum permissible operating pressures in the engine are not exceeded (see Chapter Fluid pressures [▹ 143]). Negative pressure in the coolant at the radiator is also avoided.

Radiator control

The power of radiators is influenced both by the ambient temperature and the number of running fans or the fans' speed. For the closed-loop control of the radiator power via the number of operating fans, we talk about step control. For the closed-loop control of the radiator power via the speed of the fans via FC closed-loop control or EC closed-loop control. The FC closed-loop control and EC closed-loop control offer the advantage of continuous adaptation of the cooler power to thermal power which should be discharged.

For the different engine types, the radiator control in the single cooling circuits must be implemented as per Table Layout of components - Reserves [▹ 154].

For the discharge of the heat in the mixture cooling circuit and/or engine cooling circuit or dump cooling circuit via a radiator, the following assignment must be ensured for the gas engines.

Radiator control			
	Cooler MCC	**Cooler ECC**	**Cooler DCC**
TCG 2032	FC/EC controlled	FC/EC controlled	FC/EC controlled
TCG 2020	FC/EC controlled	FC/EC controlled	FC/EC controlled

Radiator control			
TCG 3020	FC/EC controlled	FC/EC controlled	FC/EC controlled
TCG 3016	FC/EC controlled	≥ 6 levels	≥ 6 levels
EC = electronically commutated; FC = frequency converter; MCC = mixture cooling circuit; ECC = engine cooling circuit; DCC = dump cooling circuit			

Table 18: Radiator control

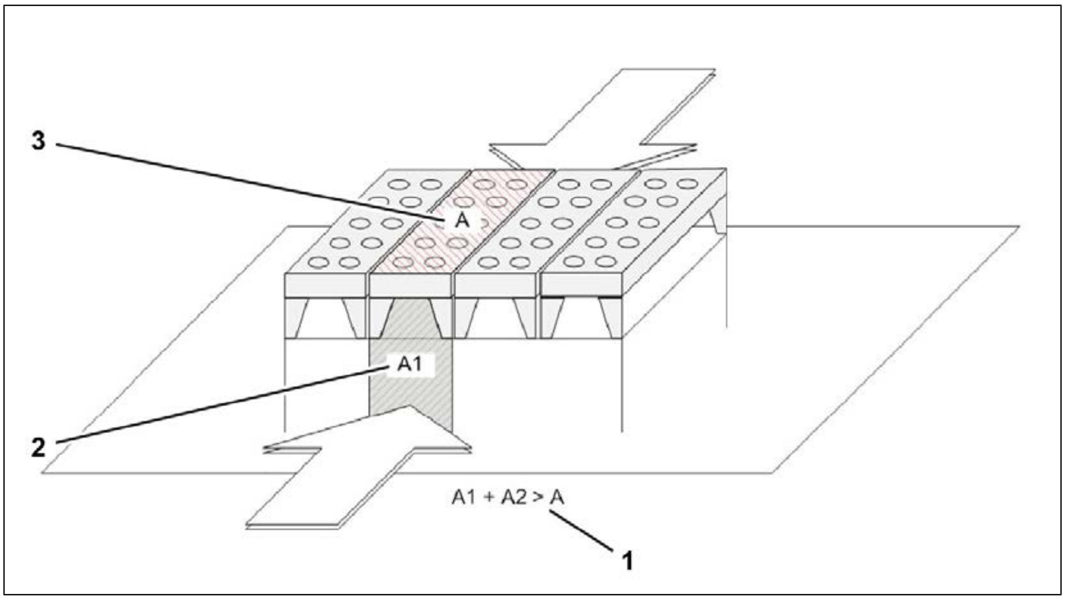
In summary, the heat in the mixture cooling circuit must be discharged via frequency controlled radiators for all gas engine types. For the TCG 3016 engines, the engine cooling circuit (ECC) and the dump cooling circuit (DCC) can be equipped with an at least 6-step mixing cooler (6 fans). Fewer levels is not permissible. Alternatively, the FC or EC controlled variant is recommended. With extremely low ambient temperatures, i.e., regularly low temperatures below -15 °C, all cooling circuits must be FC- or EC-controlled. By this requirement, the boundary conditions for proper operation of the gas engines are kept for a wide range of altering ambient conditions.

Sandwich radiator (only for pure power generation plants)

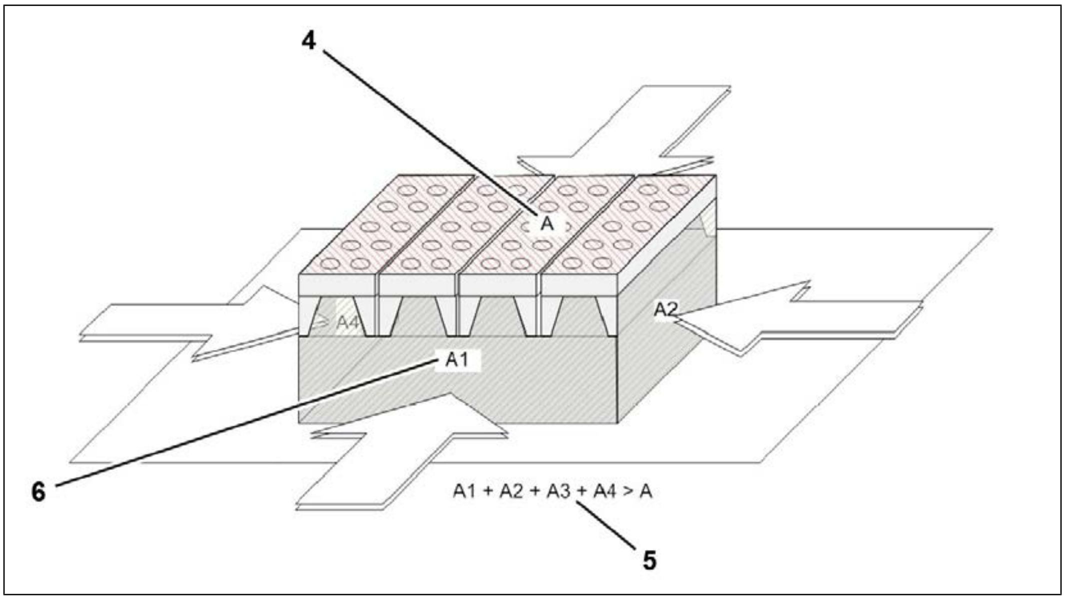
A special design of radiator is a dual core radiator. With this radiator type, there are two cooling stages arranged one upon the other and the air supply is provided by common fans. The first stage is the LT stage (LT = low temperature), the second stage the HT stage (HT = high temperature). Normally, the heat from the mixture cooling circuit is discharged in the LT stage and the heat from the engine coolant in the HT stage. Use of this type of cooler is only permissible for pure power generation plants. The load on the HT and LT stages in the radiator is appropriately uniform only in pure power modules. For plants with heat utilization, normally the HT-cooling stage of a dual core radiator is used for dump cooling purposes. With heat utilization (no or minimal heat discharge via dump cooler), the speed of the fans is defined by the heat to be discharged from the mixture cooling circuit in the LT circuit. For this mode of operation, the dump cooler (HT stage of the dual core radiator) might be ineffectively oversized in case of a partial load on the dump cooling power and, as a consequence, the coolant temperature control might become unstable. Therefore the use of dual core radiators is not agreed for plants with heat utilization.

Installation and layout of radiators

When installing the radiators, make sure that the installation height above the ground is sufficient to allow a proper air flow. The free inflow area for the air supply must correspond at least to the floor space of the radiator. Where several coolers are installed, short-circuiting of air flows must be prevented. Radiators should therefore be installed either flush next to each other or with sufficient space between them. When doing so, erect the radiators so that the required inflow area for the air supply is ensured at the free sides.



3622799371: Installation of radiators



3622799883: Installation of radiators

1	A1 + A2 > A	2	Supply flow areas of cooling air A1 and A2 (not visible) for this radiator
3	Floor space of a single radiator	4	Floor space of all radiators
5	A1 + A2 + A3 + A4 > A	6	Supply flow areas of cooling air A1, A2 and A3 (not visible) and A4 (not visible)

8.5.3.3 Cooling towers

Cooling towers exploit the evaporation cooling effect and are used in both closed and open forms. With an open cooling tower, part of the circulating cooling water (approx. 3 %) evaporates. The evaporated water volume must always be replenished. In addition, a blow-down device must be provided. This prevents an undue increase in concentration of dissolved salts in the supplementation water in the cooling tower.

All the engine cooling circuits use treated water with corrosion-protection and/or frost protection. These cooling circuits may only be connected to an open cooling tower via a decoupling heat exchanger.

In open cooling towers, it is necessary to clean the plate heat exchanger more often because algae form in the cooling tower water. Algae are deposited on the plates of the heat exchanger. The thicker the layer of algae in the plate heat exchanger, the worse the heat transfer. No more heat is dissipated in the circuits to be cooled.

In the case of closed cooling towers, the cooling water tubes are sprayed with water. The water evaporates and the medium in the tube is thereby cooled. Since there is no loss of water in the cooling circuit itself, closed cooling towers can be linked directly to the engine cooling circuit. The most important design parameters for economical cooling tower operation are the air temperature and, above all, the humidity.

8.5.4 Layout of components - Reserves

In the case of the layout of components for the cooling system, the reserves must be observed. The amounts of heat given in the data sheets are rated values, which do not consider tolerance for possible increased fuel consumption. The reserves for capacity and area to be considered in the design are set out in the following table.

Reserves for capacity and area		
Component	Capacity reserve [%]	Area reserve [%]
Heat exchanger water/water	15	5
Heat exchanger water/oil	15	5
Mixing cooler ventilator	15	5
Exhaust heat exchanger	7	10 for natural gas 0 for biogas, sewage gas and landfill gas etc.

Table 19: Components and reserves for capacity and area

Example: In the data sheet for the TCG 2020 V20, a coolant heat of 1000 kW is specified. Result: The coolant heat exchanger must be designed for 1150 kW in power with an area reserve of 5 %.

8.5.5 Chillers

Chillers should not be directly integrated into the engine cooling circuit. In case of leakages, LiBr, for example, could flow into the engine cooling circuit. This is prevented by a coupling heat exchanger in the engine cooling circuit. There are cases in which the required water-temperature level of the chiller can only be achieved via a direct integration in the coolant circuit of the engine. In this case, the following conditions must be met:

The requirements with respect to the quality of the coolant in the engine, corrosion protection or frost protection have to be met.

The coolant additives that are approved by the manufacturer of the engines need to be approved for the chiller as well.

In case of leakages in the heat exchanger of the chiller, both the cooling system and the engine are damaged. The manufacturer of the engine accepts no liability for this damage.

8.5.6 Coolant pumps

A fixed volume flow must be observed over the entire load range in the engine coolant circuit and in the mixture circuit (ECC and MCC) for all series. Therefore coolant pumps driven by electric motors with fixed speeds corresponding to the mains frequency are generally used. If pumps with frequency-controllable electric motors are used, these must be set to a fixed speed corresponding to the plant operating point.

In the case of plants with heat recovery from the coolant, to achieve the maximum efficiency and component service life, the engine inlet temperature and engine outlet temperature must be exactly maintained. In order to more accurately and individually match the required pump capacity and the discharge heads needed for each plant, electric pumps selected with regard to the operating point are used for these plants. When designing heat exchangers and radiators, the specified capacity reserves must be taken into account.

- Required information: Layout of components - Reserves [▸ 154]

This increased heat output must be taken into consideration with increased volume flow, while maintaining the design temperature. When determining the size of the pump, the increased volume flow according to the capacity reserve and the associated higher pressure losses must be taken into account. In order to attain the desired design temperature spread, the speed must be fixed for the design point in the case of pumps with frequency-controllable drive motors. In the case of pumps with non-controllable drive motors, the coolant volume is set precisely via a throttle valve.

Electric pumps with fixed speeds are also generally used in heating circuits with a return temperature increase via a 3-way valve. Special requirements in the heating circuit, e.g., maintaining a constant flow temperature in the part-load range of the genset, are occasionally shown with only a variable volume flow in the heating circuit. In these cases, pumps with frequency-controlled electric motors are used. If exhaust heat exchangers are installed in these heating circuits, it must be ensured that the volume flow at no point during operation falls below the minimum stated for the exhaust heat exchanger. Otherwise the exhaust heat exchanger might overheat and become damaged.

Block pumps are generally used in inline design with standard engines. The conveying chamber is sealed by an uncooled mechanical seal. The pumps must not be operated when dry, since the floating seal is damaged in the case of dry running. Attention must also be paid when filling the cooling systems that they are filled with preconditioned coolant. Pure antifreeze can also damage the floating seal. The permissible minimum inlet pressure on the pump suction side must be maintained to avoid cavitation.

8.5.7 Diaphragm expansion vessel

To compensate the expansion in volume as the coolant heats up, diaphragm expansion vessels are provided in the cooling system. The expansion in volume as the coolant heats up is compensated for by compressing a gas bubble. The resulting static increase in pressure in the system is dependent on the size of the expansion vessel selected. Expansion vessels must be connected on the inlet side of the pump. Where a diaphragm expansion vessel is used, the coolant circuit must be protected against overpressure by a safety valve. Safety valves with 3.0 bar set pressure are used in the engine cooling circuit and mixture cooling circuit, while safety valves with 4.0 bar set pressure are used in TCG 2032B series engines.

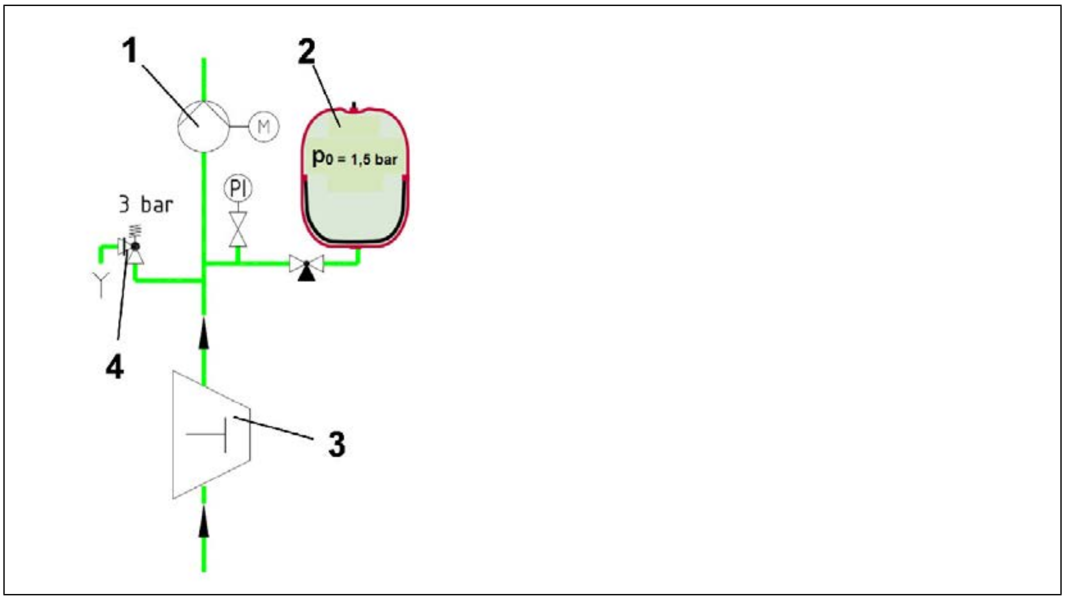
The installation location must be as close as possible to the engine coolant outlet. There must be no shut-off devices between the genset and safety valve. It is recommended that the length of the supply line to the MAG should not exceed 2 m. When designing the expansion vessel, the static pressure, the flow pressure loss between the safety valve and the expansion vessel and the coolant supply must be considered. The coolant supply in the engine cooling circuit and mixture cooling circuit should equate to 10 to 15 % of the coolant content, subject to a minimum of 20 liters. The resulting mixing temperature in the diaphragm expansion vessel during plant operation must not exceed 65 °C. This eliminates the need for a ballast vessel.

The following illustrations clearly show the pressure conditions in the diaphragm expansion vessel. The conditions in the cooling circuit before filling, after filling and during operation are shown here.

Before filling the cooling circuit

The diaphragm expansion vessel is filled with nitrogen at a gas inlet pressure p_0 of 1.5 bar.

The rubber membrane lies against the wall.



3622802955: Before filling the cooling circuit

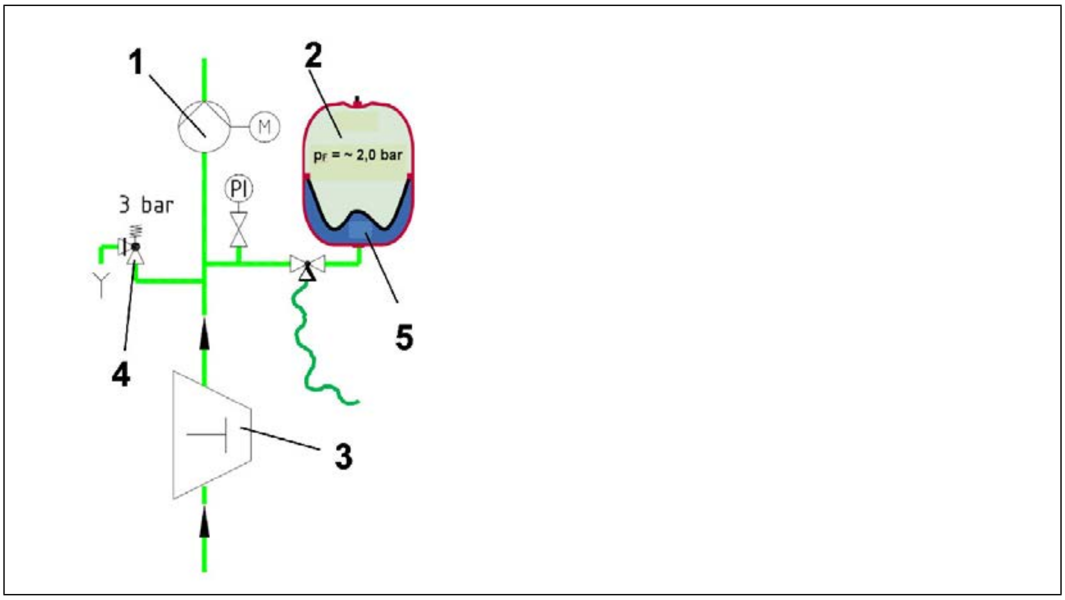
1	Coolant pump	2	Diaphragm expansion vessel
3	Gas engine	4	Safety valve

Filling the cooling circuit

When filling the cooling circuit, the pressure on the coolant side exceeds the gas pressure in the gas bubble.

Coolant flows into the diaphragm expansion vessel and the pressure increases to the filling pressure p_F.

The diaphragm expansion vessel is sized so that a coolant reserve in the range of 10 % to 15 % of the coolant content is present in the diaphragm expansion vessel when the plant is cold. The filling pressure p_F is approx. 2 bar.



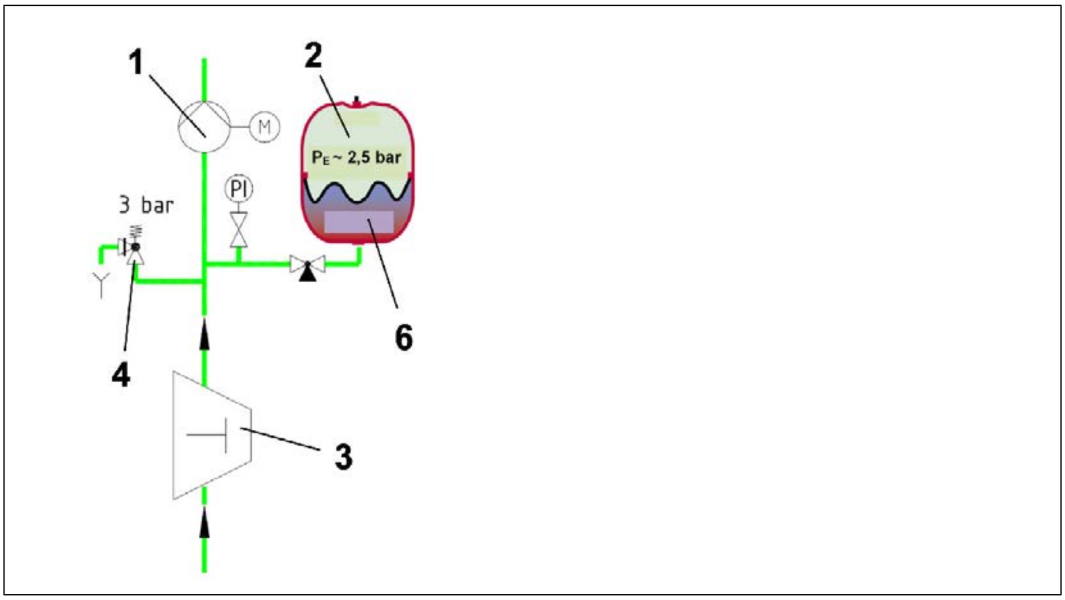
3622803467: Filling the cooling circuit

5 Coolant supply when system is cold

Engine operation conditions

Under operation conditions, the coolant heats up and expands.

The expansion volume leads to a further pressure increase in the diaphragm expansion vessel. A final pressure p_E of approx. 2.5 bar is achieved.



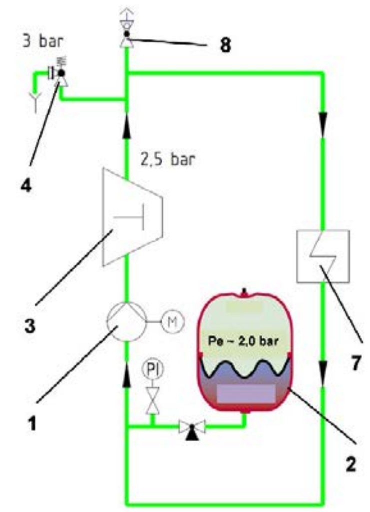
3622803979: Engine operation conditions

6 Coolant supply when system is at operating temperature

Pump at the engine inlet

When installing the coolant pump at the gas engine inlet, the diaphragm expansion vessel must also be installed at the engine inlet upstream of the coolant pump. However, the pressure at the engine outlet reached during operation must still be approx. 2.5 bar. In this case, when designing the diaphragm expansion vessel, the pressure loss across the components located between the engine outlet and the diaphragm expansion vessel must be taken into account. In the illustration, for example, this is a coolant heat exchanger. In this case, the final pressure in the diaphragm expansion vessel must be lower.

When the diaphragm expansion vessel is arranged at the engine inlet, this leads to a larger diaphragm expansion vessel, since a smaller pressure difference can be used to compensate for the expansion volume.



3622804491: Pump at the engine inlet

7	Coolant heat exchanger	8	Ventilation valve

8.5.8 Temperature control valves

Temperature control valves are designed with an electronic controller and an electric actuating drive. Temperature control valves can control the set temperature to a constant setpoint. The controlled variable may be located in an external circuit. Precise temperature control is needed, especially in the case of plants with heat recovery and where, at the same time, high overall efficiency is called for. The nominal sizes of the temperature control valves must be determined so that the pressure loss via the valve is within the 0.2 to 0.5 bar range in straight flow (bypass closed) at the respective nominal flow rate.

The temperature control valve and temperature sensor must be installed as close as possible to each other (controlled variable measuring point). Long pipeline sections between the temperature control valve and temperature sensor must be avoided.

8.5.9 Coolant monitoring group

There are three functions integrated into the coolant monitoring group: security against overpressure, venting the cooling circuit and coolant level monitoring. The coolant monitoring group must be installed immediately downstream of the engine, as this contains the protection against overpressure. If there is a point in the system that is higher than the engine outlet, the vent and coolant level monitor must be installed at that point. For TCG 3016 series engines, venting lines must be fed to the monitoring group. In addition, it is also necessary to monitor the flow of coolant through the engine via differential pressure.

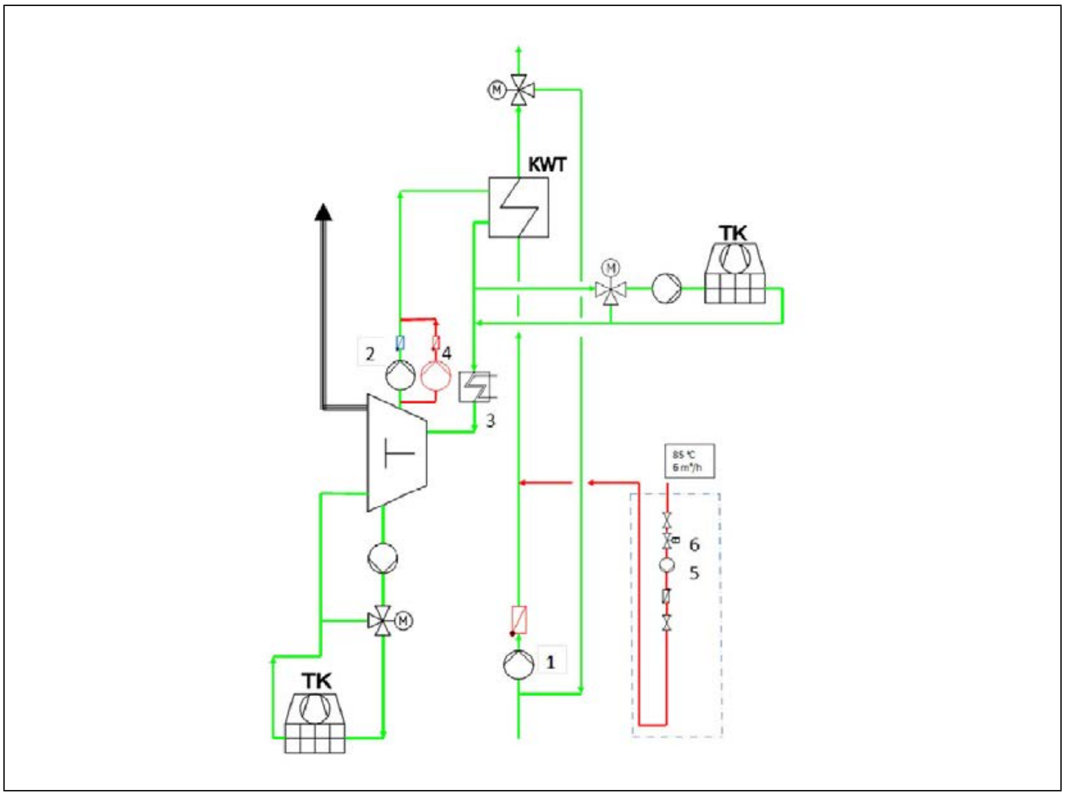
8.5.10 Coolant preheating

Gas engine gensets must, as a matter of principle, be equipped with a coolant preheating system to ensure reliable engine starting. For the TCG 2032 series, complete preheating gensets with a pump, heat exchanger with heating elements and electrical control are used as a preheating system for the engine coolant and oil. For the TCG 3016, TCG 2020 and TCG 3020 series. an electric preheating system has been developed which is installed in the coolant line upstream of the engine. The electrically powered coolant pump is used as the circulation pump. It is controlled via the TEM/TPEM system.

Coolant preheating for gensets in flexible operation

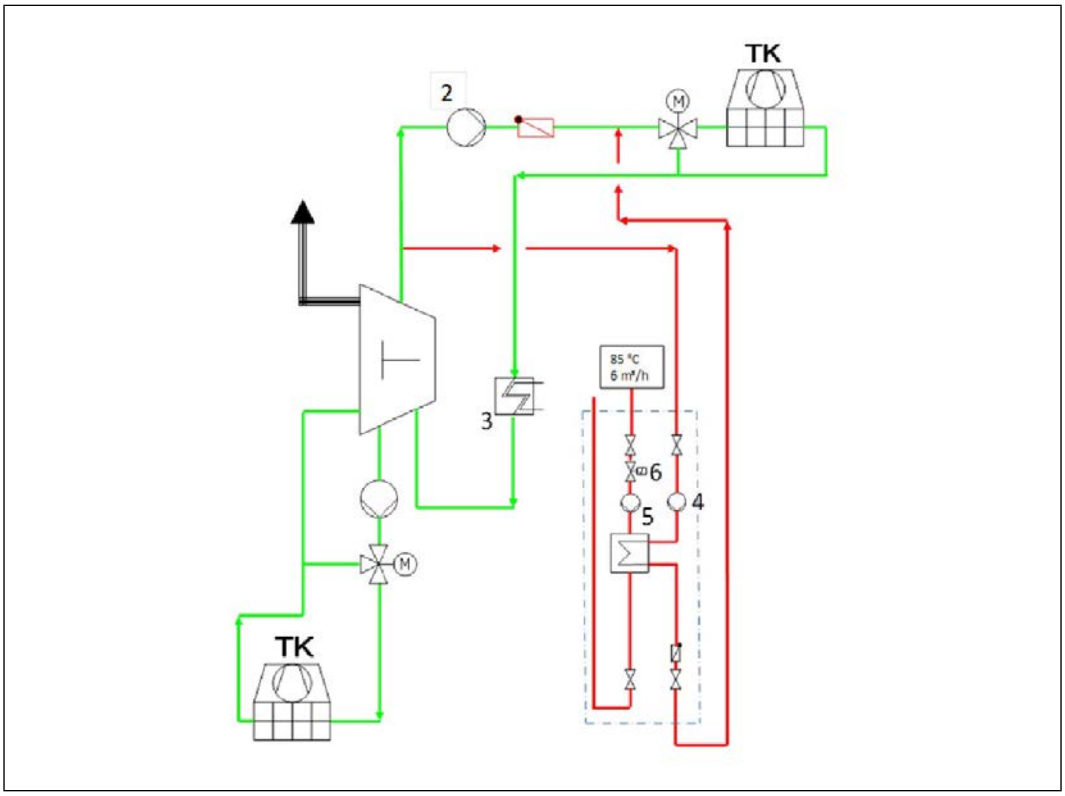
As previously mentioned, adjustments to the coolant preheating and prelubrication systems are required in order to guarantee the readiness of the gas engine gensets for the provision of control energy (see Chapter Provision of control energy [▸ 56]).

Quickly starting up and subsequently transferring loads require that the gensets and/or the complete engine cooling system are constantly preheated to temperatures above 60 °C. If warm coolant is available from one external heating system, it can be used to keep the gensets warm. In the case of CHPS gensets, the coolant heat exchanger is used as the heat exchanger, with the coolant circulation being handled by highly efficient glandless pumps. In this case, the conventional electrical preheating system with a connection for the engine coolant pump has only a back-up function. In flow modules, an additional small heat exchanger is integrated into the system for transferring heat. This minimizes the consumption of electrical energy for preheating during the phases when the gas engine gensets are at a standstill. The following illustrations show the basic layout of a "Flex preheating" system. Control of the preheating is implemented in the auxiliary cabinet (HAS).



3622800907: Flex preheating of CHP genset

1	Heating circuit pump	2	Engine circuit pump
3	Electric preheating	4	Engine circuit circulation pump
5	Heating circuit circulation pump	6	Solenoid valve
TK	Table cooler	CHE	Coolant (water) heat exchanger



3622800395: Flex preheating of flow module

-	-	2	Engine circuit pump
3	Electric preheating	4	Engine circuit circulation pump
5	Preheating circuit circulation pump	6	Solenoid valve
TK	Table cooler		

8.5.11 Gas and dirt separator

A device for the combined gas and dirt separation must be provided in the engine cooling circuit. This device also removes the smallest gas bubbles and dirt from the system. This leads to improved coolant quality. Corrosion, cavitation and erosion are considerably reduced. Devices with a radially arranged mains are not recommended. In this case, the mains is loaded with dirt during operation, which impedes device function.

The preferable installation position of the device is on the engine outlet on the inlet side of the coolant pump.

The following planning notes apply for the gas and dirt separators used by CES.

Assembly

Installation must take place at the point with the lowest system pressure, e.g., in the flow direction as the first component before the coolant pump, as the maximum possible gas separation can take place there.

The separator must not be installed between the engine and the safety valve, as the safeguarding of the engine would no longer be sufficient.

The length of the straight horizontal piping upstream of the inlet flange of the separator must be 3 × DN, but at least 30 cm. Only in this way can a flow with low turbulence be set, which can provide good separation results.

Operation

The separator vents the cooling circuit automatically during operation.

Dirt can be released without interrupting plant operation.

In order to be able to separate gas and dirt effectively, a velocity of 3 m/s at the inlet to the separator must not be exceeded.

Maintenance

Ensure the provision of sufficient space for maintenance work. The operating elements must be easily accessible.

There must be at least 10 cm of free space above and below the separator for the possible replacement of attachments.

8.5.12 Piping

The piping for the coolant systems must always be made of seamless steel pipe. Galvanized steel or copper pipes are not permissible.

- Required information: Piping [▹ 339]

When determining the size of the pipes, the following guide values must be observed:

Flow speed, plant-side pipework: < 3.5 m/s.

The efficient speed for fluids in pipes from DN 50 to DN 300 is within the range of 2 m/s.

For the design volume flow, the flow pressure loss in the cooling circuit must be lower than the discharge head of the pump being used.

Piping should be kept short and laid without tension. All components must be firmly fixed in place and, if necessary, vibration-decoupled. Sharp pipe elbows and reducers must be avoided. The materials used for seals, rubber sleeves, and hose lines must be resistant to corrosion protection agents, antifreeze, and the external effects of lube oil.

8.6 Quality of the coolant

For liquid cooled engines, the coolant must be treated and monitored, as otherwise damage may arise due to corrosion, cavitation, or freezing.

The Technical Bulletin for coolant TR 2091 contains comprehensive details on water quality, corrosion protection agents, and antifreeze. There is also a list of approved coolant additives from reputable manufacturers. No substances may be used other than those which are approved.

Over long running times of gas engines, water loss occurs especially in the engine circuit due to outgassing. In order to maintain the pressure conditions favorable for operation, the coolant must be refilled. Only a coolant with the correct specification may be used for this purpose.

8.7 Venting of the cooling systems

The cooling system must be constantly vented.

In plants with diaphragm expansion vessels, the system is vented via the ventilation valve integrated into the monitoring group or installed in the piping. The line routing must be designed in such a way as to avoid air becoming trapped in the system. Vents must be provided at the top points. Automatic venting at the engine outlet is recommended, particularly for a constantly vented engine cooling circuit. For safe operation of the cooling system without any pressure surges, it is necessary that the system is ventilated properly and that any gas in the cooling circuit is automatically released from the cooling circuit.

9 Fuel gas system

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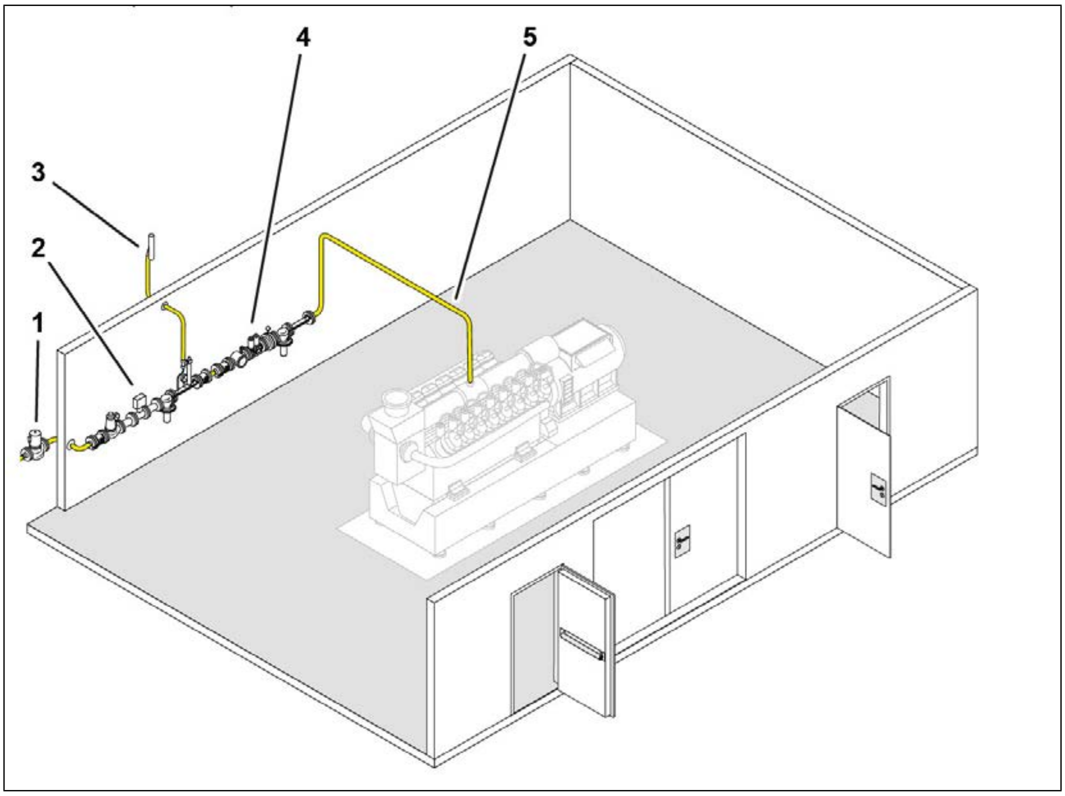
9.1 System overview

The schematic illustration shows and lists typical components and interfaces to help you get started. Proportions are therefore not to scale and the arrangement is just an example.



3620523915: Simplified example illustration

1	Quick closing valve (QCV)	2	Pre-pressure gas train
3	Blow-out opening with gas blowout	4	Zero pressure gas train
5	Line to the combustion engine		

9.2 Structure and function

The engines operated by combustible gases work as 4-stroke engines following the Otto cycle. The fuel gas-air mixture is fed to the combustion chamber. Combustion is initiated by external ignition via a spark plug.

The pressure of the supplied fuel gas must correspond to the air pressure. The pressure is regulated by a gas train. If required, a pre-pressure gas train is installed upstream of the gas train. The interface to the gas network is a shut-off valve.

9.3 Fuel gases

9.3.1 General

When using a common fuel gas in gas engines, fewer pollutants and ash are generated as compared to fluid fuels. A requirement for this is that the fuel gas corresponds to the requirements of the genset manufacturer. Special safety regulations apply due to the danger of explosion.

The principal constituents of these common fuel gases are hydrocarbons (methane, ethane, butane and propane) as well as nitrogen and carbon dioxide. When burning, the gas-air mixture reacts and produces exhaust gas, which contains harmful components.

The minimum fuel gas characteristics must be maintained according to the data given in the Technical Bulletin for fuel gas (TR 3017).

9.3.2 Fuel gas type overview

Natural gas

Natural gas is a combustible gas with a high net calorific value found in underground deposits. Natural gases consist mainly of methane but differ in their further chemical composition depending on the place of discovery.

LNG

LNG is liquefied natural gas. Liquefaction occurs through compression and cooling.

Propane

Propane has a clearly higher net calorific value than natural gas and is present in liquid form already at low pressures. Fluid propane must be vaporized for use in a gas engine. This must not lead to a higher concentration of the single components.

- Required information: Mixture cooling circuit [▹ 138]

Lean gases

Sewage gas, landfill gas and biogas are also used as fuel gases. Sewage gas, landfill gas and biogas are also known as lean gases because of their low heat value compared to natural gas.

Natural gas-hydrogen mixture with up to 25 vol. % hydrogen

A mixture of natural gas and hydrogen with up to 25 vol. % hydrogen can also be used as the fuel gas. Among other things, special requirements for the equipment of the gas train must be observed here. With regard to explosion pressure and explosion group, the natural gas-hydrogen mixture with up to 25 vol. % hydrogen is classified as pure natural gas.

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Special gases

Operating engines with special gases such as associated petroleum gas, mine gas, syngas, etc. is subject to approval by the genset manufacturer.

9.3.3 Methane number

An important characteristic determining the use of a gas in a gas engine is its knock resistance. This means that the gas mixture must not self-ignite before ignition, nor must any self-ignition effect cause it to explode suddenly after ignition.

Its methane number gives the knock resistance of a gas. The methane number indicates when a fuel gas in a test engine shows the same knock characteristics as a comparable mixture of methane and hydrogen. To ensure knock-resistant operation with different gases to be used, the methane number must comply with the data sheets. The methane number for a fuel gas can be determined by means of a gas analysis. A job card describes the procedure on how to take gas samples. This job card is included in each operating manual.

9.3.4 Accompanying gases and materials

Sewage gases and biogases are primarily accompanied by a proportion of hydrogen sulfide. Landfill gases are mainly contaminated with chlorinated hydrocarbons and fluorinated hydrocarbons. As a result, during combustion, sulfuric, hydrochloric and fluoric acids are produced in the fuel gases. These acids damage the motor, the service life of the oil and the entire exhaust system. In order to avoid damages to the external exhaust system because of acid temperatures falling below dew point, the exhaust gas temperatures should not fall below 180 °C. When cooling below 180 °C, the fuel gas must be treated accordingly (e.g., desulfurization).

Additionally, landfill gases are often contaminated with gaseous siloxanes. During the combustion in the gas engine, siloxanes become silicon dioxide and form deposits. These deposits cause premature wear in the motor, pistons and cylinder liners. Gas treatment is necessary in this case. The minimum fuel gas characteristics are outlined in the Technical Bulletin for fuel gas. This data applies only to the use of gases in gas engines. If plants are to be equipped with catalytic converters in the exhaust system, in addition to the minimum characteristics specified for the engine, further restrictions must be taken into account depending on the catalytic procedure selected. In general, a gas treatment has to be planned.

The gases to be used must be carefully tested for pollutants and assessed on the basis of the respective limits.

9.3.5 Water vapor, hydrocarbons and dust in the gas

In all operating conditions that occur, even when the engine is started cold, spontaneous condensation in the engine must be ruled out, so the water vapor content in the engine must be limited. Vaporized higher hydrocarbons lead to a reduction in the methane number. When these vapors condense in the intake tract, the result is heterogeneous droplet combustion. There is a risk of knocking combustion. Also, it is no longer possible to comply with the exhaust emissions purification regulations. To avoid spontaneous condensation, it is important to ensure that in the entire fuel gas system the relative humidity of all substances in the fuel gas, at the highest pressure and lowest temperature, is below 80 % and that undercutting the dew point can be ruled out. Higher humidity limit values for water must be approved. The required gas temperature in accordance with TR 3017 must be maintained. Some gases, for example liquefied gases, associated petroleum gas, etc., according to TR 3017, require a higher gas temperature to be maintained throughout the pipe run after evaporation, for example by means of trace heating.

In gas supply systems in which condensate may occur despite compliance with the limit values according to TR 3017, this condensate must be removed by suitable measures, such as condensate shafts at the low point of the gas line.

The maximum dust content (concentration specifications and grain sizes) in the fuel gas must be maintained in accordance with TR 3017. Higher dust contents of this grain size lead both to the possibility of deposits in the combustion chamber and to increased contamination of the lube oil, which causes increased wear.

9.3.6 CH_4 measurement

For fuel gases whose methane content can fluctuate during engine operation, e.g.: mine gas, biogas and other “lean gases”, but usually not natural gas, continuous measurement of the methane concentration in the fuel gas is required. The methane concentration must be provided by the customer as an analog input value for the TEM/TPEM control system. This also applies to applications where mixed operation with two different fuel gases takes place. Further details regarding the change in calorific value can be found in TR 3017.

9.4 Requirements and guide values

9.4.1 Regulations

When installing gas lines and gas system components, increased safety requirements must be complied with.

Both when carrying out works on the system and when selecting components, the DIN, TRD, DVGW, etc. regulations must be complied with. The most important ones are listed in the following table:

DIN 6280-14	Combined heat and power system (CHPS) with reciprocating internal combustion engines; basics, requirements, components and application
DIN 6280-15	Combined heat and power stations (CHPS) with reciprocating internal combustion engines - Tests
DIN EN 161	Automatic shut-off valves for gas burners and gas appliances
DIN EN 14382	Safety devices for gas pressure regulating stations and installations - Gas safety shut-off devices for inlet pressures up to 100 bar
DIN EN 16678	Automatic actuators
DVGW G 262	Use of gases from regenerative sources for the public gas supply
DVGW G 491	Gas pressure regulating systems for inlet pressures above 4 bar to 100 bar
DVGW G 493/I	Qualification criteria for manufacturers of gas pressure control and measuring systems
DVGW G 495	Operation and maintenance of gas plants
DVGW G 600	Technical regulations for gas installation
GUV-R 127	Safety regulations for landfills
GUV 17.5	Safety regulations for waste water treatment plants - Construction and equipment
DGUV I 203-092	Occupational safety during the operation of gas plants

Table 20: Important regulations for fuel gas systems

Following the installation of the gas line and valves, an expert must be commissioned to confirm that the assembly has been performed in a technically correct manner and in accordance with the legal regulations.

Before commissioning the gas train, a corresponding application must be submitted in good time to the relevant authorities.

9.5 Components of the fuel gas system

9.5.1 Gas cool drying

The fuel gas must be dried for all biogenic special gases and all gases that exceed the limit of 80 % relative humidity. A technically effective variant of this is gas cool drying. Biogas (from renewable raw materials), sewage gas and landfill gas are generally saturated with moisture and hence too damp for direct use. As a side effect of gas cool drying, pollutants are also washed out of the gas. Especially water-soluble substances (e.g. ammonia) can be found in the condensate.

The minimum setup for gas cool drying comprises a gas cooling system, a drop separation and a heating of the gas. The gas cooling system, mostly equipped with a cold water chiller, lowers the dew point and hence the absolute moisture content in the fuel gas. The drop separation must ensure that small drops that are carried away by the gas flow are also separated and do not vaporize again in the reheating phase. Although the reheating does not change the absolute humidity, it does change the relative humidity. The gas can only be dried in this step. The reheating comprises either a water-heated gas heater, a gas-gas heat exchanger, which utilizes the heat of the gas entering the cooling system, or the heat input of a compressor.

Other structures are possible if the function is ensured. Gas lines laid in the ground are not really advisable in the power classes in which the genset manufacturer offers products. They are not generally suitable for cooling the gas over the whole year.

9.5.2 Activated carbon filter

Doped and impregnated activated carbon has proven to be effective for fine desulfurization of biogas. Biological processes can also break down the higher hydrogen sulfide contents in the biogas reliably and at low cost. However, biological methods are not usually enough to desulfurize the biogas to the extent that an oxidation catalytic converter with subsequent exhaust heat exchanger can be safely installed in the exhaust tract.

The doped/impregnated activated carbon (frequently potassium iodine) adsorbs the hydrogen sulfide (H_2S) on the carbon surface and oxidizes it there catalytically to elementary sulfur (S). H_2S can also be desorbed again as a gas. One reason for this may be warm or damp fuel gas, e.g. due to failure of the gas cool drying. Elementary sulfur cannot be desorbed as a solid. As a result of this chemical reaction, the sulfur is therefore bound more strongly on the carbon. The load-bearing capacity of the activated carbon is also therefore higher. Thus the load-bearing capacity with good activated carbon in good operating conditions is 500 g of sulfur per 1 kg of activated carbon and more (see the manufacturer's specifications). As a result, relatively long operating times of 2000 to 8000 oh can be reached in many biogas plants.

If the activated carbon of the gas flow (flowing speed and pressure loss) is correctly designed and the necessary retention times of the fuel gas in the activated carbon layer are complied with, iodized activated carbon will be able to lower the H_2S flow to the extent that this can no longer be validated with the field measuring instrumentation. This degree of purification is retained over the entire service life. The reactivity of the activated carbon is very high with the result that the activated carbon can theoretically be divided into three layers:

- Unpolluted activated carbon before the adsorption zone
- Adsorption zone in which adsorption occurs (small in relation to the tank)
- Polluted layer after the active layer.

The adsorption zone migrates in the direction of gas flow through the adsorber. At the gas outlet, this migration of the adsorption zone cannot be measured by measuring the H_2S content.

It is therefore not possible to determine the pollution of the adsorber at the outlet. When the adsorption zone reaches the outlet from the adsorber, the H_2S flow rises within a few days to the full input concentration. This process is referred to as break point and must be prevented technically because it progresses rapidly.

One option is to provide permanent H_2S monitoring in the activated carbon layer at some distance from the gas outlet, so that an advanced warning can be generated by sampling the gas from the activated carbon layer. In this way, the activated carbon can be replaced before the break point of the adsorption front by the activated carbon, whereby a certain amount of non-polluted activated carbon always has to be disposed of.

Another approach is to reserve two separate activated carbon fillings. A working filter, in which adsorption occurs, and a control filter, which ensures at the break point of the working filter that the gas continues to be finely desulfurized. A continuous H_2S concentration measurement between the two layers makes a statement concerning the break point of the working filter possible. Upon replacement, the working filter, which is now fully polluted, is disposed of. The control filter becomes the new working filter and the control filter is filled with fresh activated carbon. This can be realized by refilling or by means of a corresponding flap system. If the control filter is designed large enough (e.g., as large as the working filter), the change of the working filter can be delayed. In this way, the activated carbon replacement can be synchronized with maintenance work on the engine.

The activated carbon must not be able to be bridged with a bypass. Firstly, it is then difficult to demonstrate that this bypass has not been activated and that the fuel gas therefore had the required quality. Secondly, short operating times with fuel gas containing H_2S are also sufficient to form sulfuric acid via the exhaust catalytic converter, which condenses in the exhaust heat exchanger.

The load-bearing capacity of the activated carbon also depends on the gas humidity and gas temperature. In general that gas should be dried. However, the gas should not be too dry and should not be too cold either, as the chemical reaction on the surface of the activated carbon is impeded by this. The exact target values can be found in the data sheets of the activated carbons. It should be mentioned here in particular that the fuel gas must have a certain oxygen content depending on the activated carbon. The required oxygen content is on the order of 1 percent by volume. Fuel gases that do not have a corresponding minimum oxygen content must be oxygenated to guarantee the reliable function of the activated carbon filter.

Due to the more controllable gas states, gas cooling dryer with reheating for conditioning should be installed upstream when activated carbon is used.

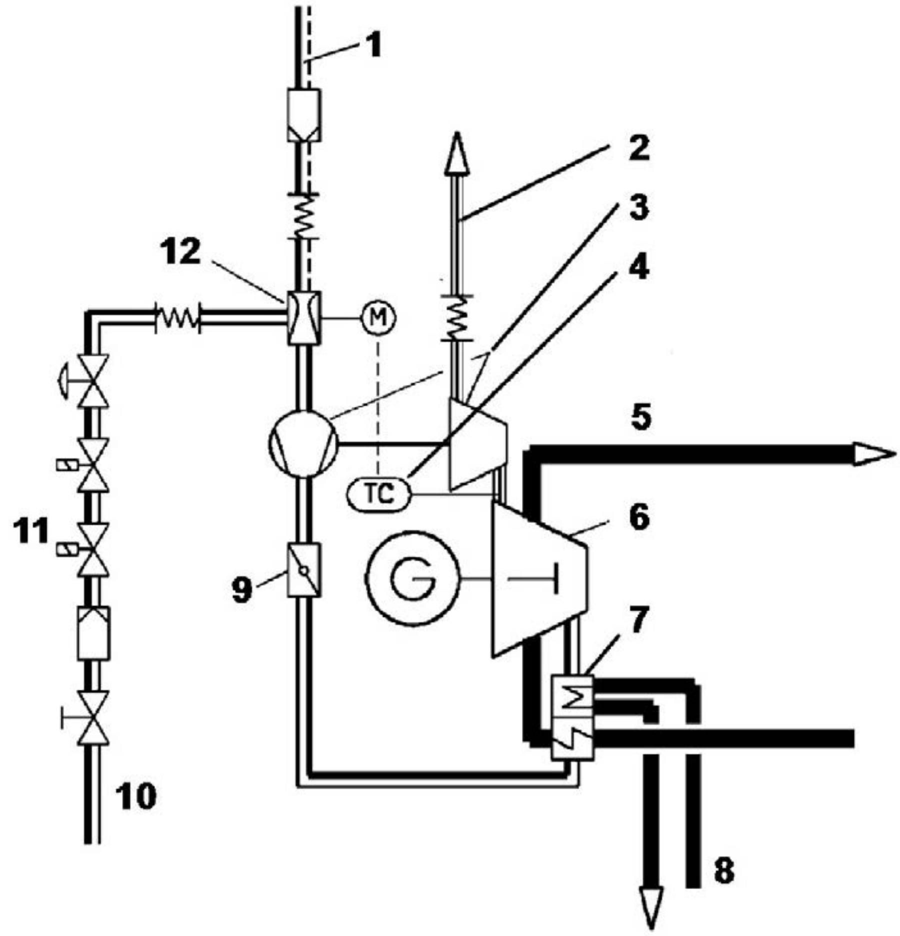
The adsorption of organosilicon hydrocarbons cannot be compared with the H_2S adsorption. These can be found in sewage gas and landfill gas and sometimes also in the fuel gas of biogas plants serving for waste recycling.

Non-doped activated carbon filters are used for organosilicon compounds. These adsorb the pollutants on the surface. However, no chemical reaction occurs there, meaning that the adsorbed substances can be desorbed again.

Two further hurdles are: firstly, that the loading capacity for hydrocarbons is not very high and tends to be in the magnitude of percent, and secondly, that not only organosilicon compounds are adsorbed but all hydrocarbons are adsorbed (although pure hydrocarbons in the engine combustion do not present any problems and would not therefore have to be cleaned). Although a reliable economical system is available for the fine desulfurization, the removal of other pollutants using activated carbon is significantly more complex and expensive with the result that a corresponding estimation has to be made here.

9.5.3 Mixture treatment

The exhaust emissions of the gas engine are regulated by controlling the air-gas ratio. The main components for the processing of the air-gas mixture before it enters the combustion chamber are the gas train, the venturi mixer and the throttle valve. The following illustration shows the components for air-gas mixture treatment for lean-burn combustion.



3644642955: Principle of lean-burn combustion with turbocharging, dual-circuit cooling and combustion chamber temperature control

1	Combustion air	2	Exhaust gas
3	Exhaust turbocharger	4	Combustion chamber temperature measurement
5	Cooling water	6	Engine
7	Mixture cooler	8	LT mixture cooling water
9	Throttle valve	10	Gas
11	Gas train	12	Mixer with actuator for mixture formation

9.5.4 Notes on assembly of gas trains

Gas engines are permitted to be operated only with gas trains approved by the genset manufacturer.

Only gas hoses approved by Caterpillar Energy Solutions GmbH may be used.

The nominal size of a gas hose and of piping and bends in the pipe must not be less than the initial nominal size of the zero pressure gas train.

The gas train must be arranged in the same room as the gas engine in order to allow the gas pressure controller to respond to changes in intake air pressure. The opening of the breather pipe of the gas pressure controller (volume control valve) must also be in the same room as the gas engine. For corrosive gases like sewage gas, biogas or landfill gas, non-ferrous metal (brass) must not be used for parts carrying gas.

Gas pressure regulating devices and piping must not be installed under tension. The arrow on the actuator housing must point in the direction of flow. The gas train must be installed horizontally. Controllers and control devices must be arranged in a normal position.

Blow-off lines from the safety blow-off valve (SBV) must be routed from the genset room into the open air with a sufficient cross section.

The gas trains must be arranged as close to the gas engine as possible.

The following maximum distances from the outlet of the zero pressure gas train to the inlet of the gas-air mixer must be observed:

Series	Island operation		Grid-parallel operation	
	Connection with expansion joint	Connection with gas hose	Connection with expansion joint	Connection with gas hose
TCG 3016, TCG 2020, TCG 3020	max. 1.5 meters	Only gas hose without any other pipes	max. 3 meters and max. 3 bends in the pipe (90°)	Only gas hose without any other pipes
TCG 2032	max. 1.5 meters	Not permissible	max. 3 meters and max. 3 bends in the pipe (90°)	Not permissible

If a flame arrester is installed and the size of the gas train is less than DN 65, the maximum distance between the outlet of the gas train and the inlet of the gas-air mixer at the engine is reduced to 50 x “line size (DN)” (example for DN 50: 50 x 50 mm = 2.5 m).

The connection to the engine is made via a flexible hose that is laid as a 90° bend or a specially designed expansion joint that must be installed without tension. If necessary, the expansion joint can be combined with a 90° elbow between the gas-air mixer and expansion joint. A pipe support designed as a fixed point must be provided directly upstream of the flexible hose or expansion joint. The distance from this fixed point, to the hose or expansion joint should not exceed 3 x DN. The rest of the gas line and the gas train must also be properly supported so that no vibrations or oscillations can affect the gas train.

Depending on the equipment of the plant, a gas flow meter may be installed in the feed line to the engines upstream of the control line.

The evaluation tools for temperature monitoring at the flame arrester, for the SSOV in the pre-pressure gas train and for the gas flow meter must be integrated in the switchgear.

To safeguard the gas engine system, there must be a shut-off device in the gas connection line suitable for manual operation outside of the genset room in a non-hazardous location. This shut-off device must be closed quickly in the event of danger. Remote-operated valves with permanent auxiliary power (e.g., closing spring) are recommended.

Notes

As no further filtration of the gas occurs upstream of the inlet into the gas engine, the line between the gas train and gas-air mixer must be cleaned on the inside (see General [▸ 111]).

In fuel gas mixtures that also contain oxygen as a component (e.g. sewage gas, biogas and landfill gas), backfiring could occur in the gas line. There is also a risk of re-ignition with fuel gases where the introduction of oxygen cannot be ruled out. To prevent flames from penetrating the gas supply line, flame arresters with temperature monitoring must be selected in the standard gas trains.

In the case of liquefied gases (e.g. propane), oxygen may enter the fuel gas, e.g. during refueling or maintenance work. In these cases, suitable measures must be taken to exclude backfiring into the gas train.

If the absence of oxygen in the fuel gas cannot be guaranteed, a flame arrester with temperature monitoring approved for the type of gas is required.

9.5.5 Fuel gas system with multi-engine plants and high gas pressures

For multi-engine plants connected to a gas network with higher pre-pressures (0.5 ... 10 bar), it is recommended to equip each genset with a pre-pressure gas train and zero pressure gas train. This design has the advantage that the gas collection line to the gensets can be designed with a smaller cross section. Furthermore, the system has a higher stability against pressure fluctuations, which are caused by starting and shutting down the individual gensets.

It is not recommended to operate several gensets with one pre-pressure gas train. If, nevertheless, several gensets are fed by a pre-pressure gas train, it must be dimensioned in such a way that the maximum flow rate is ensured at full load of all gensets. Furthermore, it is important to ensure that at minimum fuel gas flow the pre-pressure controller is operated outside the low-load pump, e.g., when only one genset is operating at idle, and the other gensets being fed are at a standstill.

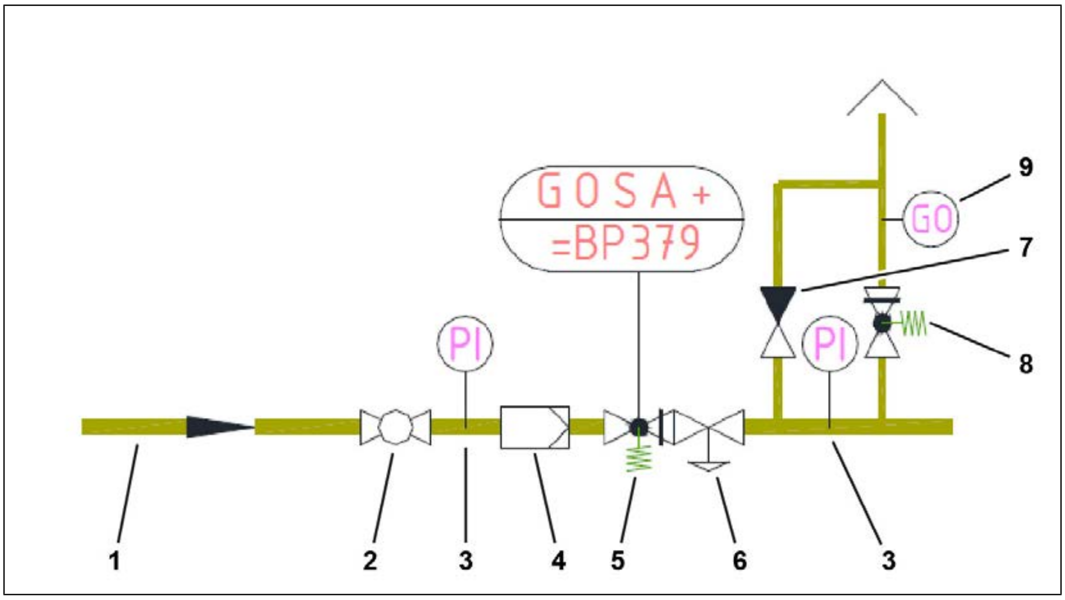
9.5.6 Quick closing valve (QCV)

A quick closing valve (QCV) is mandatory upstream of the gas train system, regardless of the fuel gas used. This QCV has the effect that in case of leakage, or pre-leakage rupture, the amount of emergency gas in the genset room is limited and the gas supply becomes a self-sealing source. The QCV must be installed outside the genset room, but should be installed as close as possible upstream of the gas trains to keep the amount of gas in the piping between the QCV and the genset low.

9.5.7 Pre-pressure gas trains

The pre-pressure gas train reduces the gas pressure to below 200 mbar. The principal components of the pre-pressure gas train are the ball valve at the inlet, the fuel gas filter, the gas pressure controller with safety shut-off valve (SSOV) and the safety blow-off valve (SBOV). The safety shut-off valve shuts off the gas supply when the outlet pressure downstream of the pre-pressure gas train exceeds the preset limit. Smaller pressure surges, which occur when the solenoid valves close in the downstream zero pressure gas train, for example, are compensated by the safety blow-off valve, which opens against spring force.

The following illustration shows the basic layout of a pre-pressure gas train.



3642287243: Pre-pressure gas train

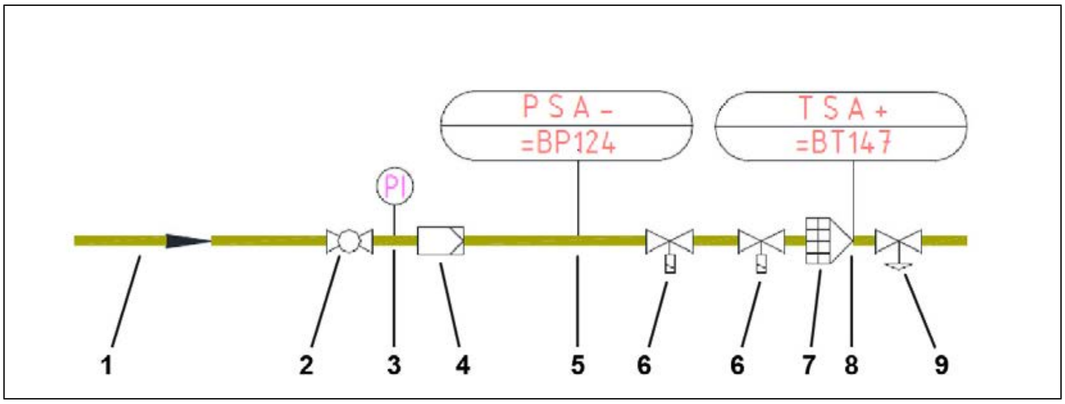
1	Fuel gas	2	Ball valve
3	Pressure gauge	4	Fuel gas filter
5	Safety shut-off valve (SSOV)	6	Gas pressure controller

7	Ball valve for venting	8	Safety blow-off valve (SBOV)
9	Leak gas indicator		

9.5.8 Zero pressure gas trains

Before the fuel gas and air are mixed in the venturi mixer, the pressure of the fuel gas must be reduced to atmospheric pressure. This is performed by the membrane zero pressure controller in the zero pressure gas train.

The following illustration shows the basic layout of a zero pressure gas train.



3642576651: Zero pressure gas train

1	Fuel gas	2	Ball valve
3	Pressure gauge	4	Fuel gas filter
5	Pressure monitor	6	Solenoid valve
7	Flame arrester (project-specific)	8	Temperature sensor (project-specific)
9	Gas pressure controller		

At the inlet of a zero pressure gas train is a manually operated ball valve. This is followed by a fuel gas filter as protection against impurities. The filter element consists of a filter mat. A (minimum) pressure monitor is always mounted upstream of the solenoid valves. Then come two shut-off valves, which are implemented as solenoid valves or pneumatically operated valves depending on the nominal size. If it is not possible to reliably prevent oxygen from entering the fuel gas, a short-fireproof bidirectional flame arrester in accordance with DIN EN ISO 16852 must be provided. This flame arrester must be installed downstream of the shut-off valves and upstream of the gas pressure controller. Finally, there is the gas pressure controller. The gas pressure controller has no auxiliary power. Depending on the safety requirements for the plant, the gas train may be equipped with a valve proving system, an intermediate vent valve or a (maximum) pressure monitor.

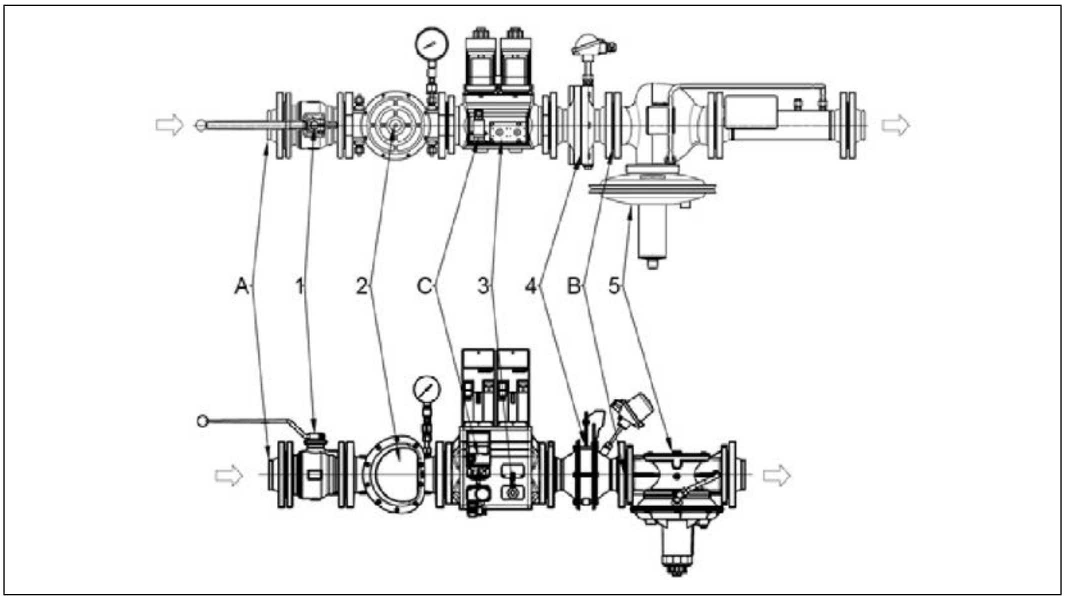
The zero pressure gas trains can be operated with a pre-pressure of up to 200 mbar. For higher pre-pressures, either a pre-pressure controller (inlet pressure < 500 mbar) or a pre-pressure gas train (inlet pressure > 500 mbar) is required.

Requirements for the gas supply to the zero pressure gas train

For fault-free operation of the gas engine, a minimum gas pressure of approx. 10 mbar to 20 mbar must be ensured directly at the inlet of the gas pressure controller of the zero pressure gas train (see next illustration, position B). The minimum pressure is calculated from the KG value of the controller, the dry flow at full load, and the gas equivalent factor if the gas type, and thus the gas density, is different from natural gas. Based on the minimum gas pressure at the inlet of the gas pressure controller, the minimum gas pressure upstream of the zero pressure gas train is defined by the design of the zero pressure gas train (see next illustration).

The required relative minimum pressure at the inlet of the zero pressure gas train (see next illustration, pos. A) depends on the following factors:

- Fuel gas volumetric flow rate
- Temperature of fuel gas
- Relative humidity of fuel gas
- Fuel gas density
- Gas equivalent factor, if different from natural gas
- Nominal size of the zero pressure gas train
- Total pressure losses of the individual components of the zero pressure gas train



3642579851: Zero pressure gas train

1	Ball valve	2	Fuel gas filter
3	Solenoid valve	4	Flame arrester
5	Gas pressure controller	A	Fuel gas inlet of zero pressure gas train
B	Fuel gas inlet of zero pressure controller	C	Pressure monitor

Each zero pressure gas train contains an adjustable (minimum) pressure monitor. The (minimum) pressure monitor must be set so that fault-free operation of the gas engine at full load is guaranteed with this pre-pressure. If the pressure falls below the set minimum pressure, the genset will not start or will be shut down. The installation location of the pressure monitor is usually between the fuel gas filter and the solenoid valves (see illustration above, pos. C). The pre-pressure to be ensured at the inlet of the zero pressure gas train must therefore be greater than the setting value of the pressure monitor plus the pressure loss of the upstream components at full load.

The minimum gas pre-pressure as per the currently valid SPI is required.

Load changes with steep grid parallel ramps and with load jumps in island operation lead to changes in the fuel gas consumption at the gas engine, and thus also to changes in the pressure loss via the zero pressure gas train. If possible, these changes should have no effect, or only a limited effect, on the pre-pressure of the zero pressure gas train. This equally applies when starting the gas engine. This is where the change in gas volume flow over time is at its highest. Therefore, a buffer volume must be maintained between the zero pressure gas train and the gas supply. The buffer volume should be of the order of 1 m^3 i. N. (in the standard state) per 1000 $m^{3\ i.\ N.}$ / h gas consumption. The piping between the gas supply and the zero pressure gas train can be regarded as the buffer volume. In biogas plants, for example, this function is performed by the activated carbon filters that are normally installed between the fuel gas compressor and the zero pressure gas train.

Example:

A gas engine genset has a natural gas consumption of 480 $m^{3\ i.\ N.}$ / h, while the fuel gas pre-pressure is 100 mbar. If the piping upstream of the zero pressure gas train is regarded as a buffer volume and the nominal size of the piping is assumed to be DN 125, this results in a piping length of approx. 35.6 m.

To keep the upstream mains as short as possible, the inlet pressure can also be increased, but this may then lead to the use of a pre-pressure gas train.

Zero pressure gas trains are operated with a max. inlet pressure of 200 mbar, the optimum for genset operation is approx. 150 mbar. However, the components are designed for natural gas for a maximum pressure of 500 mbar. For biogas and special-gas trains, the maximum pressure is 200 to 400 mbar, depending on the flame arrester used. For systems with inlet pressures greater than 200 mbar and less than 500 mbar overpressure, single-step pre-pressure controllers are therefore sufficient to reduce the pressure to the inlet pressure of the zero pressure gas train. For pre-pressures greater than 500 mbar, the installation of a pre-pressure gas train with safety shut-off valve (SSOV) and safety blow-off valve (SBOV) is required. Pre-controllers are usually installed directly in the zero pressure gas train downstream of the fuel gas filter. Pre-pressure gas trains are installed in close proximity upstream of zero pressure gas trains. Pre-pressure controllers and pre-pressure gas trains are matched together with the zero pressure gas trains as an overall system. In these cases, the requirement for the buffer volume to be maintained upstream of the zero pressure gas train does not apply.

9.5.9 Dual gas operation

Dual gas operation with switchover at standstill

Each gas type requires its own gas train with filtration, shut-off valves and precise pressure keeping. After passing through the gas trains, the two gas types are fed to the engine via a separate or a common piping.

Because the two gases have different heat values or pre-pressures, this may produce large differences in the nominal sizes of the gas trains and also as a result in the nominal sizes of the connection lines to the gas-air mixer on the engine. Special attention must be paid here to ensure that the dead volume between the gas trains and gas-air mixer on the engine is kept as small as possible for the respective operation mode. For this reason, it is necessary, especially when there is a large difference in the nominal sizes, that the two gas lines to the gas-air mixer are laid with the nominal size of the respective gas train and only merge just before the gas-air mixer.

Separate lines must be provided if the difference in nominal sizes between the two lines is greater than or equal to two nominal sizes.

In case of unfavorable configurations, the interaction between the membranes of the two zero pressure controllers can cause permanent pressure fluctuations in the gas volume between the zero pressure gas trains and the gas-air mixer. This may even cause stable operation of the gas engine to no longer be possible. In these cases, another automatic shut-off device must be provided in the respective fuel gas line upstream of the gas-air mixer.

Dual gas operation is possible only with a multi-gas mixer (adjustable gap). The switch over from one gas type to another takes place automatically when the engine is at a standstill by switching over the solenoid valves at the gas trains.

Two-gas mixing operation

A two-gas mixing mode is used for simultaneous operation with a fuel gas mixture of two fuel gas types and continuous changeover between two fuel gas types during operation without shutting down the genset.

In two-gas mixing operation, the genset can be operated with mixing ratios between approx. 10 vol.% and 90 vol.% gas type A and approx. 10 vol.% and 90 vol.% gas type B. Operation with 100 vol.% gas type A or 100 vol.% gas type B is also possible.

A gas mixing unit is required for two-gas mixing operation. These must be controlled via the plant control (TEM/TPEM system) belonging to the genset. The control of the gas mixing unit by the TEM/TPEM system is designed as an open-loop control without feedback of a measured value. After the gas mixing unit, only a zero pressure gas train is used, which is designed for the leaner of the two fuel gases.

A two-gas mixing operation places increased demands on the minimum required gas inlet pressures into the gas mixing unit. If necessary, the genset can only be started with one of the two gases; starting with mixed gas is not possible.

Two-gas mixing operation is permissible only in grid-parallel operation. It is possible only after synchronization with the power grid and from approx. 40 % electrical power. This may result in restrictions on the maximum possible electrical power and fluctuations in nitrogen oxide emissions.

9.5.10 Breather pipes and blow-off lines

The opening of the breather pipes of the zero pressure controllers must be in the same room as the gas engine. For pre-pressure controllers with a safety diaphragm, there is no need for the breather pipe into the open air.

Otherwise, the following shall apply:

Pipes to the atmosphere have to be laid without restriction in the diameter (observe pressure loss) as indicated by the manufacturer of the gas pressure controller and safety device.

Block valves are not allowed in breather pipes. Blow-off lines must not be combined with breather pipes into a common pipe. This does not apply to lines to the atmosphere on equipment in which respiratory blow-off devices and safety blow-off devices are combined.

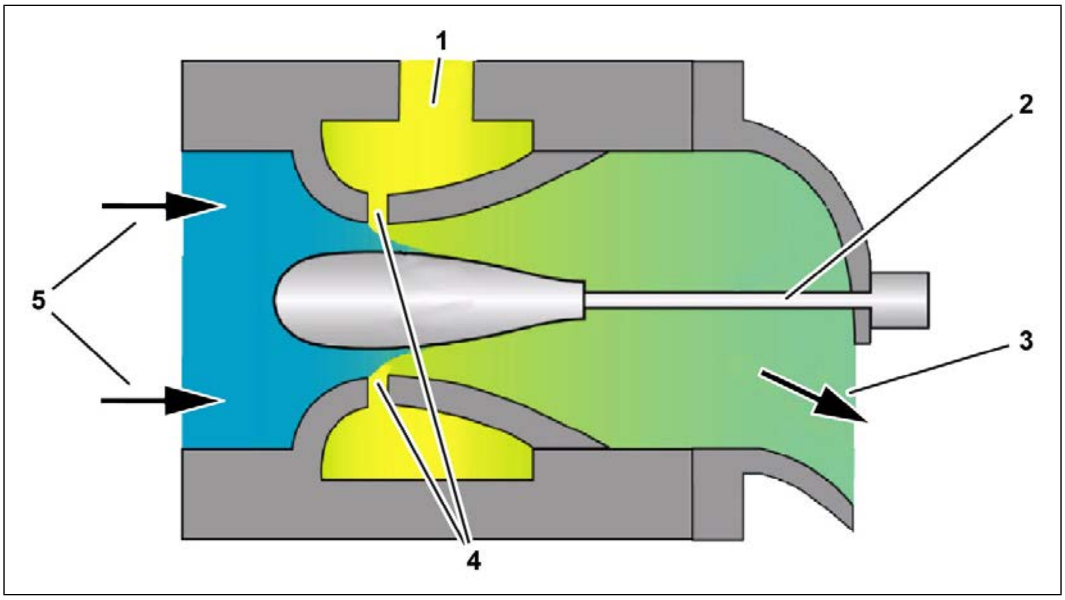
As per DVGW Technical Leaflet G 491, the following applies: Breather pipes and blow-off lines must be routed outdoors. The gases released at the outlet points are to be discharged without hazard. There must be no ignition sources within the potentially explosive atmospheres at blow-out openings. Furthermore, the blow-out openings must be protected against the ingress of foreign matter that could cause blockage or malfunction of the equipment. Instructions for the design of the gas blowouts and for determining the potentially explosive atmospheres at blow-out openings of lines to the atmosphere are given in DVGW Technical Leaflet G 442. Other nationally applicable regulations must be applied if necessary.

9.5.11 Gas-air mixer

Air and gas are combined in the mixer. The mixer is designed as a venturi pipe. The air flows through a nozzle-like constriction and then through a gradually expanding diffuser. The constriction accelerates the flow, which is then slowed down again with minimal loss in the diffuser. The acceleration at the constriction (nozzle) creates a negative pressure, so that the gas is automatically drawn in through a gap at the point of minimum cross-section. Thanks to the subsequent deceleration, the pressure then increases again until it is virtually equal to atmospheric pressure, with the result that the mixing process takes place without any great loss of pressure.

The advantage of this type of mixing is that the quantities of air and gas remain in the same proportion to one another even when output is varied by altering the throttle valve position and thereby varying the central air mass flow.

A multi-gas mixer is used with which the gap geometry in the mixer itself can be altered via an actuator. The exact maintenance of the gas-to-air ratio in the mixture depends on the gas pressure before the mixing gap being equal to the air pressure before the venturi pipe. The following illustration shows the principle of a gas-air mixer with adjustable gap.



3642584331: Multi-gas mixer

1	Gas inlet	2	Speed controller linkage to the stepper motor
3	Gas-air mixture outlet	4	Gas gap
5	Air inlet		

9.5.12 Throttle valve

The power output or the speed of the engine is regulated via the throttle valve by means of controlling the amount of the compressed mixture to the engine.

9.6 Notes on the fuel gas system

9.6.1 Start-up of biogas plants

If there is no biogas in the initial phase, alternative gases can be used to start-up the engine. Permissible alternative gases and engine settings are defined in a Technical Bulletin.

The installed biogas train is normally slightly too large due to the restricted maximum mechanical power and, if applicable, a higher net calorific value H_i of the alternative gas. Therefore, the inlet pressure of the alternative gas must be able to be adjusted as low as possible (approx. 5 to 30 mbar).

It is not possible to install fixed faceplates in order to lower the inlet pressure (because flow rate for engine startup and idling is too low).

The zero pressure controller must be correspondingly adjusted by an authorized commissioning engineer.

9.6.2 Servicing and maintenance

When working on gas lines, DGUV I 203-092 and DVGW worksheets G 491 and G 495 or other nationally applicable regulations must be observed. In particular, it is important to ensure that all work on the gas system (e.g., opening a gas train, dismantling and servicing a device) is carried out only when depressurized. This work must be carried out by trained and qualified specialist personnel only. With regard to service intervals, it is essential to comply with the manufacturer's recommendations for the particular type of operation in terms of visual checks, inspections, function testing and maintenance.

10 Lube oil system

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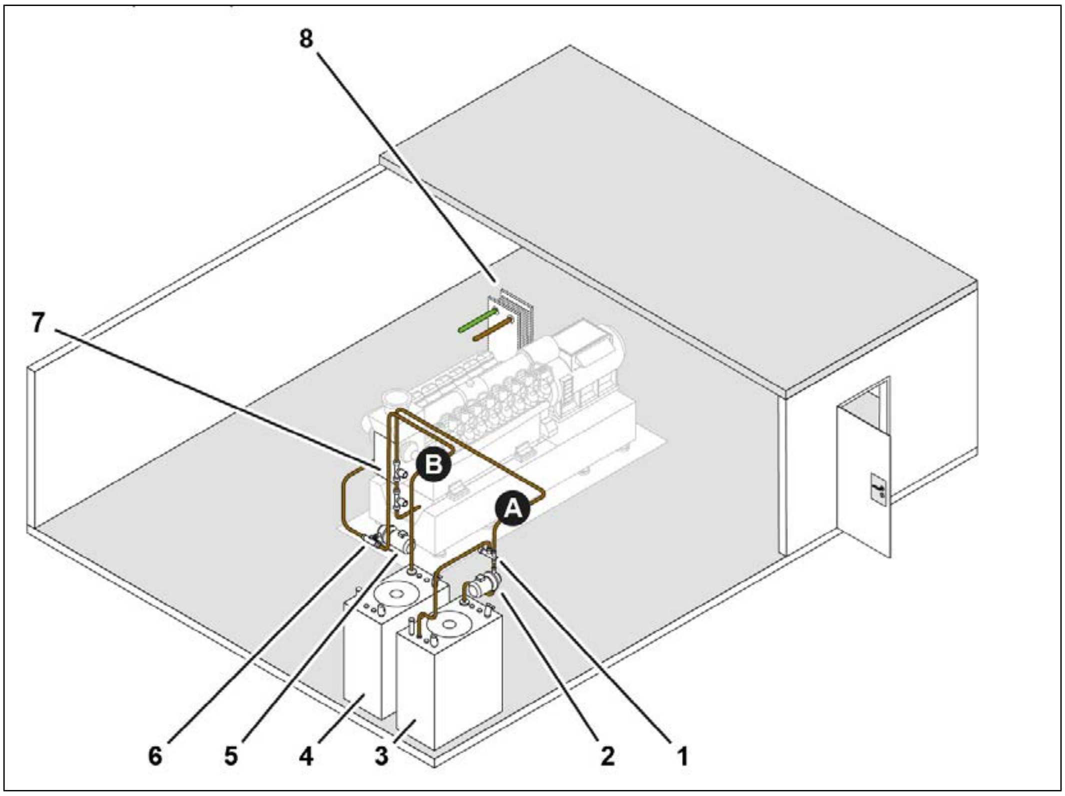
10.1 System overview

The schematic illustration shows and lists typical components and interfaces to help you get started. Proportions are therefore not to scale and the arrangement is just an example.



3620526731: Simplified example illustration

A	Fresh oil system	B	Waste oil system
1	Overflow valve	2	Fresh oil pump
3	Fresh oil tank	4	Waste oil tank
5	Prelubrication pump	6	3-way valve
7	Lube oil solenoid valves	8	External lube oil plate heat exchanger (only for TCG 2032)

10.2 Structure and function

10.2.1 Genset

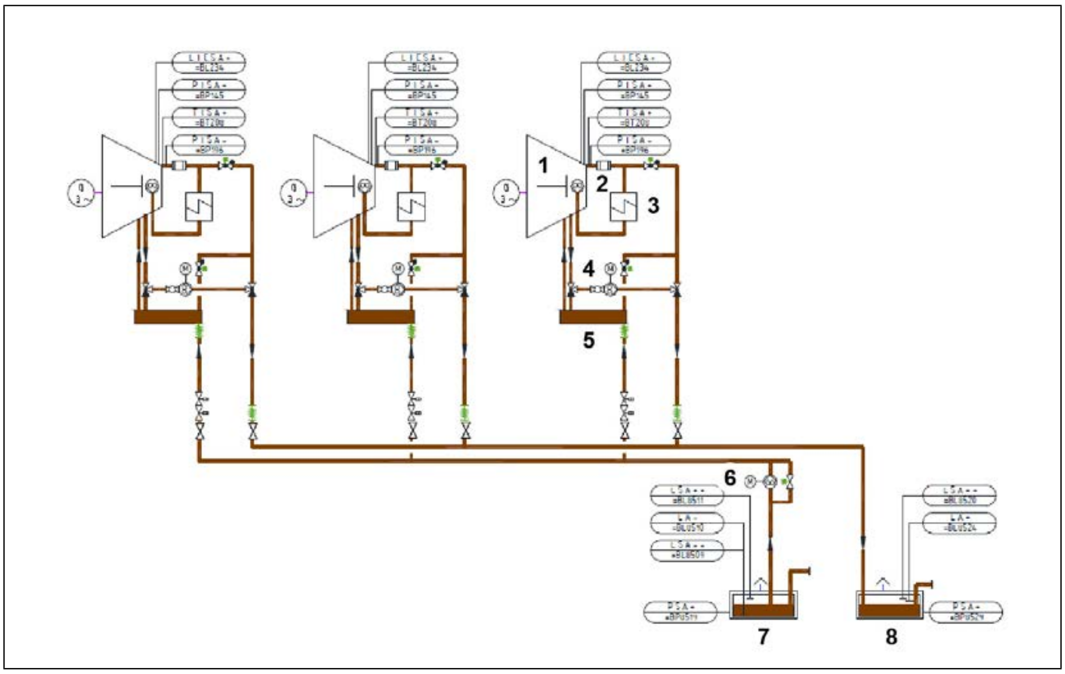
The lube oil systems of the engines are implemented as wet sump lubricating systems. The following table shows the various lube oil systems used for the different engine series.

Engine type	Wet sump Lube oil sump at engine	Expanded lube oil tank in base frame	Fresh oil tank in base frame	External lube oil tank in the plant
TCG 3016	X	X	X	
TCG 2020	X	X		
TCG 3020	X	X		
TCG 2032	X			

Table 21: Engine types and lube oil systems

10.2.2 Plant

The lube oil system of the plant depends on the design.



3689774987: Plant lube oil system

1	Gas engine	2	Lube oil filter
3	Lube oil cooler	4	Prelubrication pump
5	Lube oil tank base frame	6	Fresh oil pump
7	Fresh oil tank	8	Waste oil tank

10.3 Requirements and guide values

10.3.1 Gas engines

For the TCG 2032 series, the external lube oil circuit components (e.g., heat exchanger) must be arranged at the same level as the genset foundation or lower. This arrangement prevents the oil from flowing back into the lube oil sump when the machine is at a standstill. For plants with TCG 2032, the external lube oil cooler should be installed as close to the genset as possible. This means that the lube oil volume is kept as low as possible in the plant system.

Shut-off elements must not be installed in the pipes between the genset and the lube oil cooler. The nominal size of the piping must be at least DN 125, and the nominal pressure of the lines must be at least 16 bar. External lube oil coolers and assembly parts must also be designed for a minimum pressure of 16 bar. The lube oil lines between the genset and lube oil cooler must be laid below the level of the lube oil outlet on the genset. If the upper connection to the lube oil cooler is higher than the lube oil outlet on the genset, the pipes must be fitted below this level.

When using synthetic oil, it is important to use materials that are approved for ester-based oils.

The oil cooler should not be installed directly in front of the air cleaners of the engine, because the radiation heat from the oil cooler might affect the combustion air temperature. In this case a thermal insulation of the heat exchanger must be provided.

The lube oil filters fitted to gas engines are designed for operation as per the maintenance and inspection schedule. No further measures are required on the part of the client to treat the lube oil.

10.3.2 Fresh oil tank

The fresh oil tank must be arranged in a way which prevents it from emptying into the engine due to gravity. In general, lube oil is replenished using a gearwheel pump and with a defined filling amount. Compared to refilling with gravity flow, refilling by gearwheel pump is preferred. The size of the supply tank will be dependent on the operation mode of the plant and the associated oil supply required. The minimum recommended size is equal to the quantity required for one oil change plus the amount consumed during two intervals between changes.

10.3.3 Waste oil tank

The minimum recommended size is equal to the quantity yielded by two oil changes.

10.3.4 Service tank

If a service tank is provided for refilling, it must be designed for the required consumption quantity of approx. 200 oh (e.g., for TCG 2032, approx. 600 dm^3).

10.3.5 Container application

In containers, the available free space might be heavily restricted due to the size of the genset itself and also due the auxiliary equipment. With this available free space, the recommendations given above for the size of the fresh oil tank and waste oil tank cannot be fully adhered to.

10.4 Lube oil system components

10.4.1 Introduction

All engine series have integral lube oil pumps; the lube oil is filtered and cooled by either engine-mounted or separate filters and oil coolers.

10.4.2 Engine prelubrication

Prelubrication is generally provided for all engine types. The prelubrication significantly reduces the engine wear. For prelubrication, electrically driven prelubrication pump modules are used. The prelubrication pumps are mounted on the genset base frame or on the lube oil sump. When prelubrication is activated, lube oil flows through all the components installed in the lube oil system between the oil pump and the engine (filters, mixing coolers). The capacity and supply pressure of the pump modules must be matched to the respective engine type.

Engine prelubrication takes place immediately before the start when the engines are at a standstill. Optionally, a process called interval prelubrication can be provided. In other words, the engine is prelubricated at preset intervals while at a standstill for a defined period of time.

In plants with gas engines, prelubrication is controlled by the TEM system or the TPEM system. Prelubrication is inactive when the engine is running. The TCG 2032 series does not have interval prelubrication and must therefore be prelubricated before each start.

10.4.3 Crankcase ventilation

The engines of all series are equipped with closed crankcase ventilation. Crankcase vapors are returned to the combustion air or mixture pipe via an oil separator.

The separated lube oil flows back into the crankcase chamber.

In some gensets, an additional exhaust fan is used to support the crankcase ventilation.

10.5 Lube oil

10.5.1 Lube oil types

The Technical Bulletin TR 2105 for lube oil contains a list of lube oils available from reputable manufacturers. Only these lube oils are approved for operation with the gas engines. No other lube oils may be used without written approval. The Technical Bulletin TR 2105 also contains information on lube oil change intervals, used oil analyses and maintenance of the lube oil filters fitted to the engine.

Before commissioning, an analysis of the fresh oil supplied must be compared with the manufacturer's specification.

10.5.2 Lube oil with biogas applications

Further information regarding the lube oil with biogas applications can be found in the Technical Bulletin TR 2135 “Optimization of the oil management for biogas applications”.

10.5.3 Changing and replenishing the lube oil

Lube oil changes must be carried out in accordance with the operating manual for the respective engine, and in the case of gensets in continuous operation, lube oil consumption must be compensated by refilling the system with fresh lube oil. When changing the lube oil, make sure that the oil in the plant components, e.g., piping, heat exchangers etc., is changed. Drainage options for the lube oil are provided at the lowest points of the plant-side system. Depending on the plant layout, it is effective to provide a permanently installed or mobile emptying pump.

Fresh lube oil is replenished from the fresh oil tank via the top-up pump. This operation can be either manual or automatic. In the case of plants equipped with gas engines, the TEM system or TPEM system controls the lube oil replenishment.

Two solenoid valves are installed in series in the lube oil refill line before the engine. When the minimum level in the lube oil sump is reached, the TEM system or the TPEM system opens the solenoid valves (and/or the top-up pump starts) and the tray is refilled with lube oil. When the maximum level is restored, the solenoid valves close (and/or the top-up pump stops).

When topping up under gravity from the service tank, it must be ensured that the lines have a large enough cross section and that the oil does not become too viscous due to low temperatures.

The lube oil sump is emptied with the prelubrication pump.

The waste oil is pumped into the waste oil tank by shifting the three-way valve installed in the line after the prelubrication pump. The top-up pump is then used to fill up with clean oil. The three-way valve behind the prelubrication pump is switched back to the “prelubrication” position. Operating the prelubrication pump refills the complete lube oil system with lube oil.

NOTE

The respective safety regulations and other legal regulations must be observed when handling and storing fresh oils and waste oils.

11 Combustion air system

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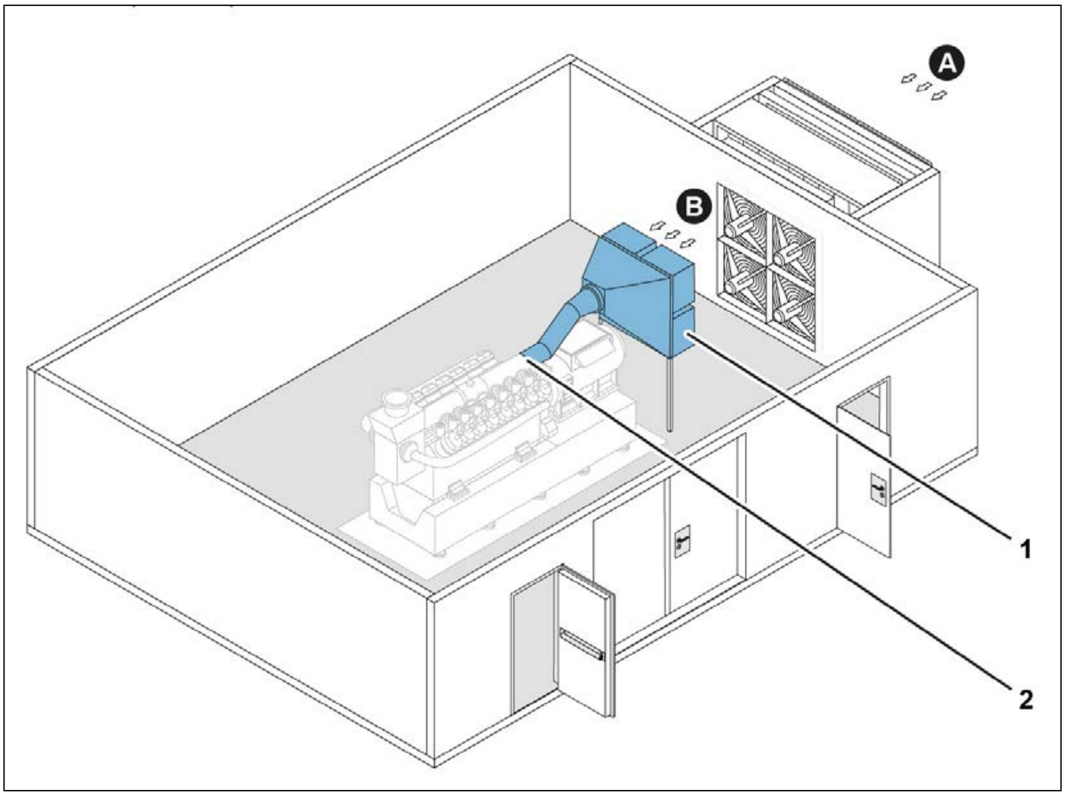
11.1 System overview

The schematic illustration shows and lists typical components and interfaces to help you get started. Proportions are therefore not to scale and the arrangement is just an example.



3620528395: Simplified example illustration

A	Ambient air	B	Combustion air
1	Combustion air filter	2	Combustion air line

11.2 Structure and function

11.2.1 Definition of ambient air

The air in the free environment is called ambient air.

Ambient air supplies the gas engine system with the amount of air required for cooling and combustion.

The ambient air temperature is measured exclusively outdoors and always at a height of two meters above ground. The measurement may only be carried out in the shade and thus not in the blazing sun. Influences from heat radiation (for example from a house wall) must also be avoided.

Depending on the design of the plant ventilation system, there may be an increase or decrease compared to the measured ambient air temperature.

11.2.2 Definition of combustion air

Combustion air (or intake air) is the air that is directly in front of the combustion air filter of the gas engine.

The temperature of the combustion air may differ from the temperature of the ambient air.

11.3 Requirements and guide values

11.3.1 Combustion air requirements

In the data sheets, the electrical terminal power is specified according to the ISO 8528-1 standard. In this standard, the following standard reference conditions are defined in respect to the combustion air parameters:

Air temperature	298 K (25 °C)
Air pressure	1000 mbar (100 kPa)
Relative humidity	30 %

Table 22: Standard reference conditions for combustion air

The performance specification in the data sheets may differ from the standard reference conditions listed in the table above.

Depending on the actual installation conditions, the customer-specific reference conditions are listed on the data sheets.

Engine start-up and operation: combustion air temperature requirements:

- When starting the engine, the temperature must not fall below the minimum permissible combustion air temperature specified on the data sheet
- When operating the engine, the combustion air temperatures (minimum/design) according to the data sheet or P&I diagram must be observed
- If air preheating is present, the combustion air supplied to the engine must have the same temperature for bank A and bank B

Influence of operating conditions that differ from the reference conditions specified on the genset data sheet:

- Combustion air temperatures that fall below the minimum permissible combustion air temperature specified on the genset data sheet can lead to massive damage to the exhaust turbocharger and the engine due to compressor pumps with knocking combustion caused by this
- Installation heights that are significantly lower than the height listed on the genset data sheet can lead to massive engine damage
- Combustion air temperatures and installation heights that deviate upwards from the reference conditions can lead to a power decrease

11.3.2 Composition of the combustion air

The normal composition of combustion air is considered to be dry air with a certain amount of steam.

Relative humidity

Relative humidity is a percentage ratio measure. It describes how strongly the combustion air is saturated and how close the state of the combustion air is to the saturation line.

Together with the indication of the air temperature and air pressure prevailing during the measurement of relative humidity, the mass of the water vapor content in the air can be determined.

Risk of destruction of components

High amounts of condensate can cause damage to the engine

For the determination of the engine setting values or also operating limits of the engine, it is necessary to specify the maximum relative humidity occurring on site as accurately as possible (together with the associated air temperature and the corresponding air pressure or the engine installation altitude)

A high water vapor content in the combustion air can, if necessary, lead to condensation of the water vapor in the combustion air or mixture system of the engine

Main components of dry air

The next table specifies the main components of dry air at sea level. (In total 99.999 vol.%. The remaining 0.001 vol.% are so-called trace gases; especially noble gases).

Main components of dry air	
Gas	Volume contents
Nitrogen N_2	78.084 %
Oxygen O_2	20.946 %
Carbon dioxide CO_2	0.035 %
Argon Ar	0.934 %
Total	99.999 %

Table 23: Main components of dry air

11.3.3 Harmful components in the combustion air

The combustion air must be free of acid or base-forming components.

As a rule, it is not permissible for acid formers such as SO_2, SO_3, HCl or HF (but also other corresponding substances) to be in the combustion air.

The occurrence of process gases or even solid components, e.g., from nearby industrial plants or chemical plants, can have a negative effect on the composition of the combustion air.

The current version of the Technical Bulletin TR 2132 “Specification for combustion air” lists the relevant harmful components and the maximum permissible proportions in the combustion air.

NOTE

If the fuel gas already contains harmful components, the permissible proportions in the combustion air are reduced by the proportions present in the fuel gas.

Required information: Current Technical Bulletin TR 3017 “Specification for fuel gas”

Influence of harmful components on maintenance intervals and plant components

The harmful components mentioned in TR 2132 negatively affect the maintenance intervals of the engine and the engine service life. Furthermore, these substances can also damage or even destroy downstream emission control systems.

The combustion air system must therefore always be designed in such a way that no combustion air can be drawn in from areas contaminated by harmful associated gases.

11.3.4 Filtering of the combustion air

Fine sand, dust or other particles contained in the combustion air significantly reduce the service life of the engine due to increased component wear. Therefore, an effective and high-quality filtration of the combustion air is required.

The current Technical Bulletin TR 2132 “TR Specification for combustion air” lists the combustion air filters that are generally recommended for this purpose.

11.3.5 Tropical conditions

General

When using highly supercharged combustion engines with charge air or mixture cooling, the water vapor drawn in with the combustion air can condense to liquid water depending on the ambient conditions (high air temperatures together with high relative humidity).

This condensate leads to corrosion and wear on the corresponding components (from inlet into the charge air / mixture cooler). If the combustion air also contains associated gases that form acids or bases, the corrosion of the corresponding components increases many times over.

- Required information: Harmful components in the combustion air [▷ 198]

For such a tropical operation, there is a tropical version for many engine variants. In addition to more corrosion-resistant materials, condensate is separated by a condensate separation system in these designs. These measures significantly reduce the risk of corrosion and contribute considerably to an increase in component service life.

The operation and maintenance of these separation systems is carried out in accordance with the instructions in the respective operating manuals.

For special attention

- The condensate lines between the genset and condensate collection tank or duct system must be fitted with a steady downward incline.
- A flammable mixture can escape together with the condensate or upon malfunction of a condensate drain. Therefore, it is mandatory that the condensate collection tank or the duct system has a sufficiently dimensioned venting into the open air.
- Required information: Operating manual for the gas engine, especially the corresponding assembly notes.

11.3.6 Combustion air quantity

The amount of combustion air required for combustion depends on several parameters, in particular the fuel gas composition and the combustion air ratio required to represent the desired NO_x emission.

The combustion air quantities can be found in the plant-specific genset data sheets.

11.4 Combustion air system components

11.4.1 Types of filtration for the combustion air

The standard built-in combustion air filters are designed as plate filters, pocket filters or round filters.

Depending on the engine series, the combustion air filters are either mounted directly on the genset in appropriate filter housings or installed in front of the genset.

The number of combustion air filters installed on the unit depends on the model series.

As the combustion air filter becomes increasingly dirty, the pressure drop across the filter increases.

Possible effects of increased pressure drop on engine operation may include:

- A slight increase in fuel consumption
- In extreme cases: compressor pumps, which means that safe operation of the genset is no longer possible and damage can occur to the exhaust turbocharger

Basically, a differential pressure monitoring or differential pressure display is provided for the filters. To avoid the negative effects on engine operation when differential pressures are too high, check these indicators regularly and replace the air cleaner if necessary.

11.4.2 Muffler

In the case of combustion air filters installed outside the genset room, the combustion air line in particular transmits the compressor noise to the outside. The compressor noise makes its presence felt as a high-frequency whistle.

In such cases, mufflers must be provided in the combustion air lines, the size of the mufflers being determined in accordance with the respective requirements.

11.4.3 Combustion air line

If the combustion air filters are not mounted on the engine, then a combustion air line must be installed between the combustion air filter and the engine.

Smooth and clean piping must be used for this line (e.g., painted or galvanized piping).

In the intake line, all joints between the combustion air filter and the engine connection must be airtight.

If the intake line is routed with a downward incline towards the engine, a water trap must be provided with a drain-off upstream of the engine.

The reference value for the dimensioning of the combustion air duct is the flow velocity of the combustion air. This velocity should be < 20 m/s.

11.5 Pressure losses

Pipes, bends, filters, mufflers, etc. cause a pressure loss in the combustion air system. The pressure loss that occurs at nominal volume flow must not exceed the specified values.

The maximum permissible pressure losses are listed in the current Technical Bulletin TR 2132 “Specification for combustion air”.

12 Exhaust system

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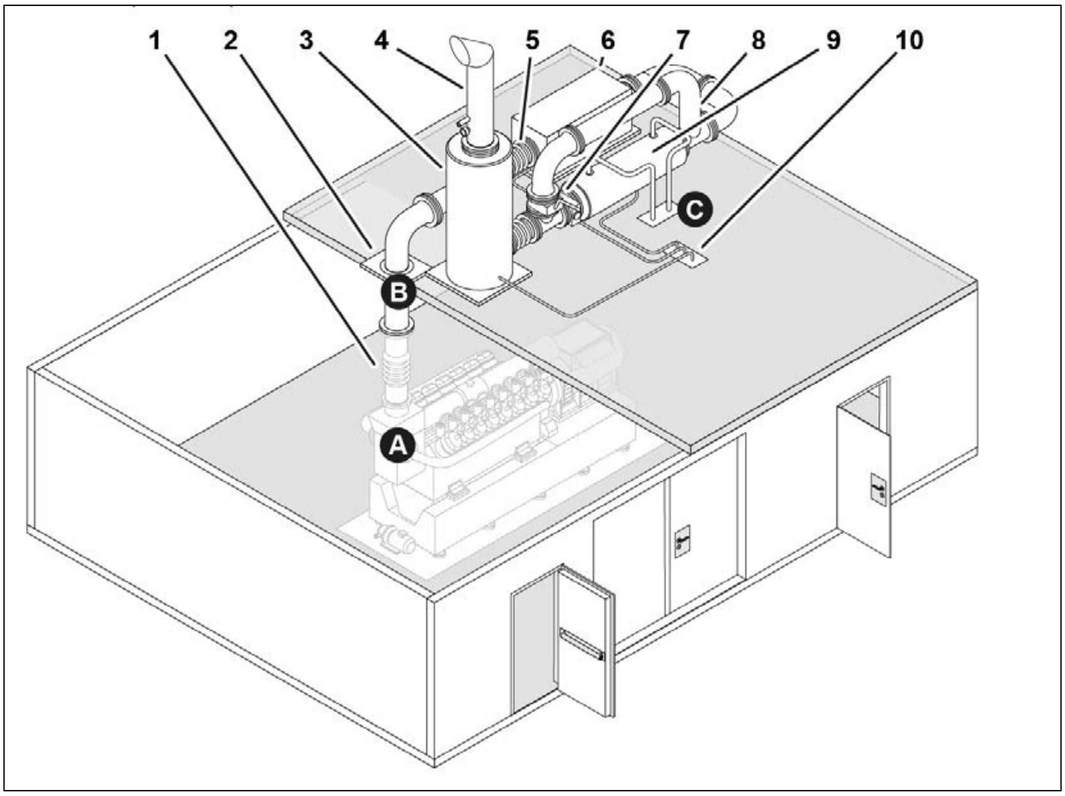
12.1 System overview

The schematic illustration shows and lists typical components and interfaces to help you get started. Proportions are therefore not to scale and the arrangement is just an example.



3620530059: Simplified example illustration

A	Combustion engine	B	Exhaust system energy distribution unit
C	Cooling system: heating circuit		
1	Interface to the exhaust system	2	Pipe opening (depending on project planning)
3	Exhaust muffler (horizontal or vertical, depending on project planning)	4	Exhaust stack
5	Exhaust expansion joint	6	Exhaust catalytic converter (depending on project planning)
7	Exhaust flap combination for bypass (depending on project planning for exhaust heat exchanger)	8	Exhaust bypass (depending on project planning for exhaust heat exchanger)
9	Exhaust heat exchanger with connection to the heating circuit (depending on project planning)	10	Condensate lines

12.2 Structure and function

The exhaust system removes the combustion exhaust gases from the engine and usually discharges them finally into the atmosphere. Components of the exhaust system often include components for reducing exhaust noise emissions as well as components for reducing the concentrations of pollutants in the exhaust gas. The exhaust system includes the complete exhaust line and installed components.

In order to comply with the regulations that apply at the plant installation site, the exhaust system must be designed to fulfill these requirements. The regulations relate mainly to the emission of exhaust gases and noise.

If internal engine measures do not fulfill the requirements on the exhaust gas emissions, the exhaust gas must be treated, for example with the aid of exhaust catalytic converters. The exhaust noise emissions are reduced through the installation of mufflers.

Every engine must be fitted with a fully independent exhaust system.

12.3 General planning notes

12.3.1 Service life

Assembly

- Lifting lugs must be provided on particularly large and heavy exhaust gas components to facilitate lifting. It may also be useful to replace them later.
- When installing exhaust gas components such as mufflers and catalytic converter housings, it is essential to ensure that the components are not overturned via the feet. This would most likely damage the components. Mounted feet are only intended for the installed load.
- The customer must state the installation situation of the components at the latest when placing the order.
- If the components are not directly screw-fixed to the foundation or a steel frame, they are equipped with a foot with a sleeve bearing. There must be sufficient lubricant between the sliding plate and foot plate for assembly. Periodic checks should be conducted to ensure that enough lubricant is always present during operation.
- Unauthorized tightening of floating bearings will generally cause exhaust system components to be damaged or destroyed as a result of thermal expansion during plant operation.

Operation

If exhaust gas components for contact protection and to reduce heat loss are already isolated, usually no additional protection against structure-borne noise is required. An exception to this is the fastening of the exhaust system:

- When fastening exhaust gas components, keep in mind that structure-borne noise can be transmitted by the exhaust system when operating the plant and can cause disruption. The use of vibration-decoupling elements on the feet of the mountings of exhaust gas components can be useful
- In particular, when starting the plant, water can condense in the exhaust system. Therefore, permanent condensation drains must be provided in points where condensation can accumulate in the system. Each individual condensate line can be directed to a siphon, for example. The water columns shall safely counteract the exhaust back pressure every time in order to prevent hot exhaust gas from flowing through the condensate lines
- When selecting the material for the exhaust pipe and the components in the exhaust system, the exhaust temperatures in the partial load range must be taken into account and sufficient chemical resistance must be considered, as otherwise line breaks with exhaust gas leakage may occur

Maintenance

- Regular checks should be conducted to ensure that the sleeve bearing is sufficiently lubricated.
- There must be sufficient space available near maintenance openings and safe access to these openings must be guaranteed. For example, if an exhaust heat exchanger is used, make sure that sufficient space is available to be able to clean the exhaust pipes if necessary.

12.3.2 Exhaust back pressure

Besides the exhaust mass flow and the exhaust temperature, the most important design parameter determining the size of the exhaust system is the permissible exhaust back pressure. Exceeding or undercutting the permissible exhaust back pressure has a significant impact on power, fuel consumption and the thermal load of the engine. The exhaust back pressure is measured at full load immediately behind the turbine of the exhaust turbocharger. The permissible exhaust back pressure must not be exceeded or undercut.

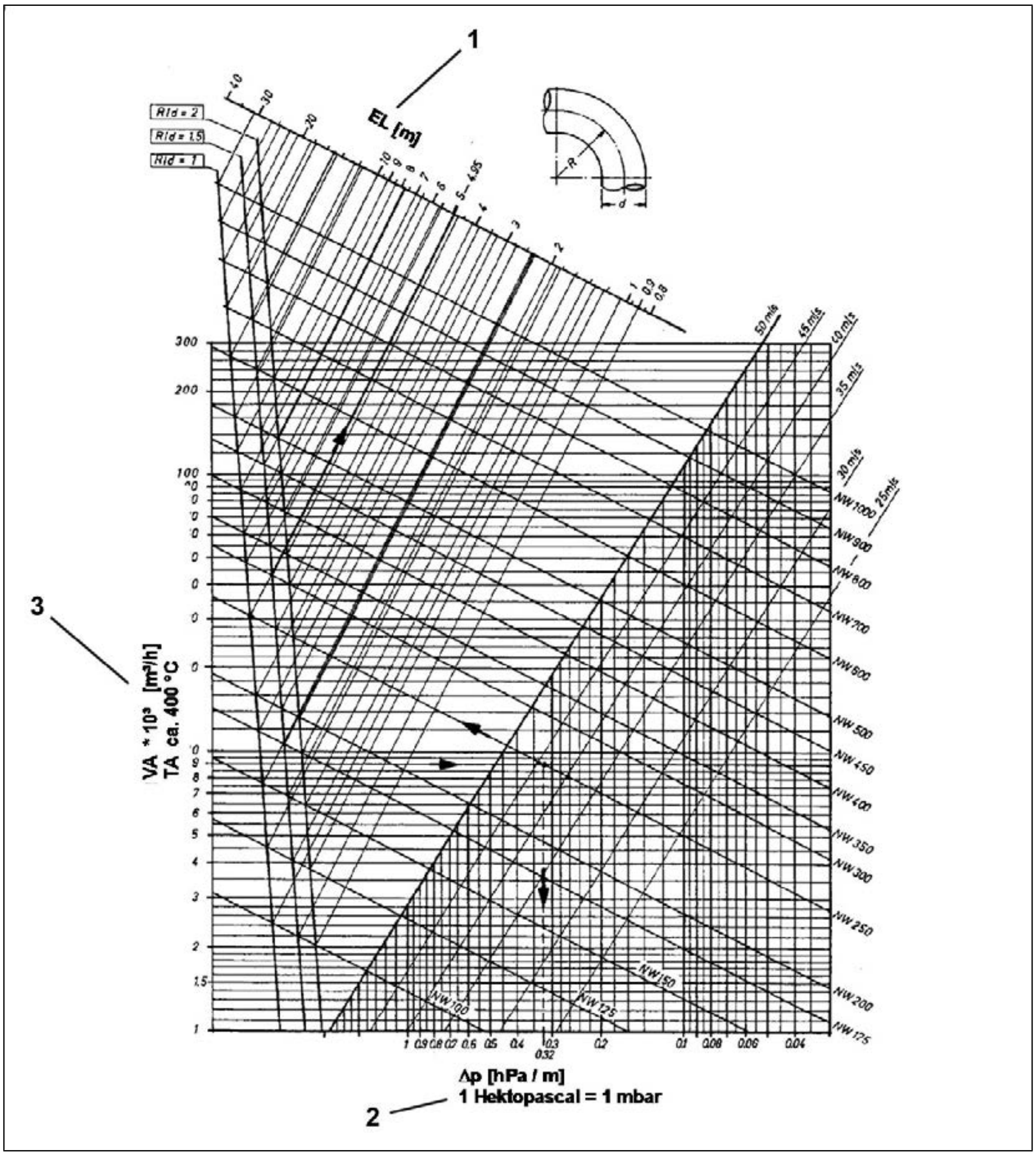
Exhaust back pressure is generated, for example, by flow resistance in piping, expansion joints, exhaust heat exchangers, catalytic converters, mufflers, deflection hoods and stacks. All flow resistance must be taken into account when determining the exhaust back pressure. The flow resistances in the exhaust piping and piping elbows can be determined based on the exhaust volume flow with the diagram below. For the flow resistance of the components installed in the exhaust system, refer to the data sheets of these components. The permissible exhaust back pressures for the single engine series are listed below in the table.

Engine series	Permissible exhaust back pressure in mbar at 100 % engine load
TCG 3016	30 to 50
TCG 2020 K	30 to 50
TCG 3020	30 to 50
TCG 2032	30 to 50

Table 24: Exhaust back pressure

Higher exhaust back pressures may also be possible, depending on the engine configuration.

In designing the exhaust system, the information contained in the data sheets for the individual engine series must be taken into account. A useful guide to the design of the exhaust system is the speed of the exhaust gas in the exhaust pipe. The speed should be in the 20 to 35 m/s range.



3759358987: Flow resistance for exhaust gas piping

1	EL: Substitute length for a 90° pipe bend	2	Δp: Pressure loss per meter of straight piping
3	VA: Exhaust volume flow	TA	Exhaust gas reference temperature
NW	Nominal size of the exhaust pipe in millimeters	R	Radius of the bend
d	Pipe diameter in millimeters		

Example for illustration purposes

Specified	Exhaust volume flow VA = 9000 m^3/h
	Straight piping: l = 10 m
	3 bends 90° with R/d = 1

Wanted	Dp of the piping
Solution	NW 250 at approx. 44 m/s
	Δp = 0.32 hPa/m straight pipe
	Substitute length for a bend 4.95 m
Total pipe length (L_{ges})	10 + (3 × 4.95) = 24.85 m
Pressure loss (Δp_{ges})	24.85 × 0.32 = 8 hPa (mbar)

12.3.3 Exhaust gas emissions

All CES gas engines operate according to the lean-burn principle. Due to the lean-burn principle, the emission of pollutants in the exhaust gas is very low. Depending on local specifications, the limit values for certain pollutants, such as nitrogen oxide and carbon monoxide must be observed.

If the limit values cannot be undercut through engine settings, procedures must be introduced to reduce pollutant emissions. The use of oxidation and SCR catalytic converters is possible.

Exhaust emissions according to the 44th BImSchV in Germany

The 44th BImSchV replaced the TA-Luft in June 2019. According to the latest ordinance, the following emission limit values, among others, are specified for lean-burn engines with gaseous fuels in §16:

Gas type	Exhaust gas components	Limit value according to TA-Luft 2002	Limit value according to the 44th BImSchV §16	Valid for new plants from
Sewage gas, mine gas	NO_x	500	500	
	CO	650	500	June 20, 2019
	HCOH	60	20	January 01, 2020
Biogas	NO_x	500	100	January 01, 2023
	CO	650	500	January 01, 2025
	HCOH	60	20	January 01, 2020
Landfill gas	NO_x	500	500	

Gas type	Exhaust gas components	Limit value according to TA-Luft 2002	Limit value according to the 44th BImSchV §16	Valid for new plants from
	CO	650	650	
	HCOH	60	40	June 20, 2019
Natural gas	NO_x	500	100	January 01, 2025
	CO	300	250	January 01, 2025
	HCOH	60	20	January 01, 2020
	NO_x	500	500	
	CO	650	500	June 20, 2019

Table 25: Limit values for exhaust emissions

The validity of this ordinance is regulated differently for new plants and existing plants. For example, the limit values of the ordinance apply to new plants with natural gas operation from 2025-01-01, and to plants with biogas operation from 2023-01-01. For existing plants, the limit values only apply from 2029 and later. Existing plants are understood as plants that went into operation before 2018-12-20 and for which a permit under the Federal Immission Control Act was already granted before 2017-12-19. New plants are understood as plants that went into operation after 2018-12-20.

The old TA-Luft limit values can be complied with by using an oxidation catalytic converter in the exhaust system. The reaction in the oxidation catalytic converter reduces carbon monoxide and formaldehyde accordingly. An appropriate engine setting ensures only permissible nitrogen oxide emissions are released.

The nitrogen oxide emissions required by the new 44th BImSchV of BImSchV 100 mg/ Nm^3 cannot be achieved with engine settings. SCR catalytic converters are therefore used in the exhaust system. Selective catalytic reduction (SCR) converts the nitrogen oxides into nitrogen and water through the addition of a urea solution. As before, the reduction of carbon monoxide and formaldehyde takes place in a downstream oxidation catalytic converter.

Furthermore, in accordance with the 44th BImSchV, the emission of organic substances in exhaust gas, indicated as total carbon, shall not exceed the limit value of 1300 mg/Nm^3 in any application.

Exhaust systems using selective catalytic reduction to reduce emissions must be adjusted to ensure that the emission of ammonia is less than 30 mg/Nm^3.

The 44th BImSchV is the implementation of the EU Directive (EU) 2015/2193 for Germany. For plants outside of the EU, other provisions apply with regard to compliance with exhaust gas emission limit values.

The 44th BImSchV Section 24 (7) requires that operators of gas engine plants working under the lean gas principle monitor and document the emissions of nitrogen oxides in the exhaust gas of each engine as a daily mean value with suitable qualitative measuring equipment. This can be calculated, for example, using NO_x sensors. In order to implement this requirement, all gas engine plants in operation within the scope of the 44th BImSchV must be equipped with nitrogen oxide emission monitoring. It is irrelevant when which limit values are valid. This applies equally to new plants and to existing plants. Compliance with the currently valid limit value must be documented in accordance with the requirements of the 44th BImSchV.

Measuring position on the gas engine

The measurement of the exhaust emissions for gas engines with an exhaust turbocharger takes place behind the exhaust turbocharger after an exhaust pipe length of at least 5 × exhaust pipe diameter.

The measurement of the exhaust gas emission for gas engines with multiple parallel exhaust turbochargers takes place behind the junction of the entire exhaust gas after an exhaust pipe length of at least 5 × exhaust pipe diameter.

In addition, the regional specifications for exhaust gas emission measurement must be observed.

- Required information: Exhaust gauge connections [▸ 226]

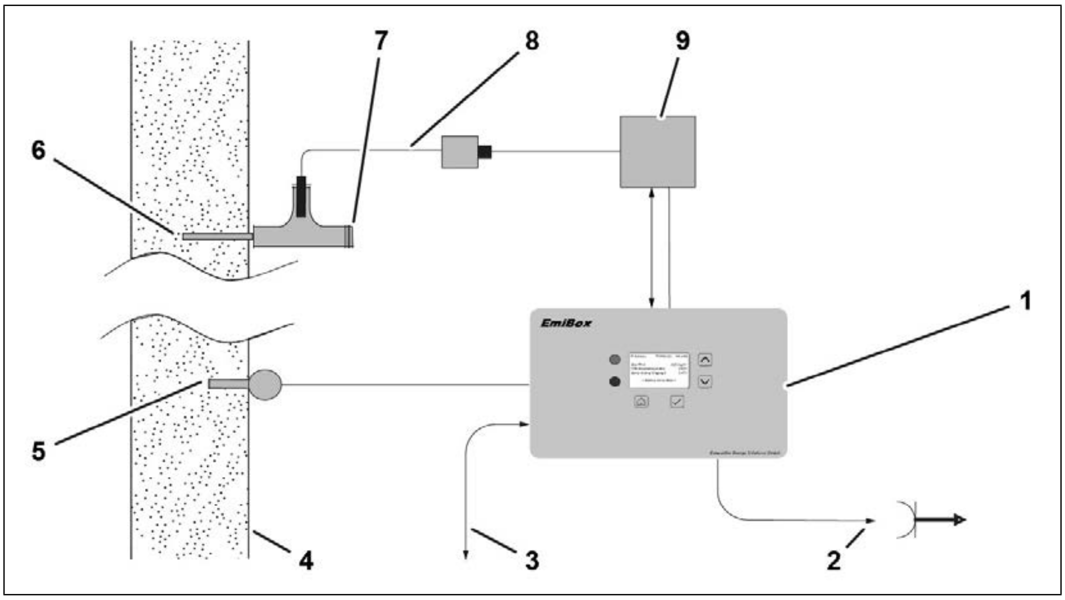
Measurement of nitrogen oxide emissions

Depending on the engine control system used, Caterpillar Energy Solutions offers appropriate equipment for measuring nitrogen oxide emissions. For plants with the TEM system, the recording, evaluation and storage of the measurement data takes place in the EmiBox. Plants with the TPEM system are able to record, evaluate and store the measurement data within the TPEM system itself. The components of which the measurement data logging is made up (NO_x sensor, measuring lance and connection accessories) are the same for both versions.

Measurement of nitrogen oxide emissions with EmiBox – Plants with TEM system

The following illustration shows the principle measuring configuration.

The EmiBox can be connected via PC or online. Its primary purpose is to record and store the data required by the 44th BImSchV. These are the daily average values for nitrogen oxide emissions based on an oxygen content of 5 % in the dry exhaust gas. Alongside the nitrogen oxide emissions, the NO_x sensor measures the oxygen content in the exhaust gas. The EmiBox converts the daily average values for nitrogen oxide emissions based on the reference oxygen content.

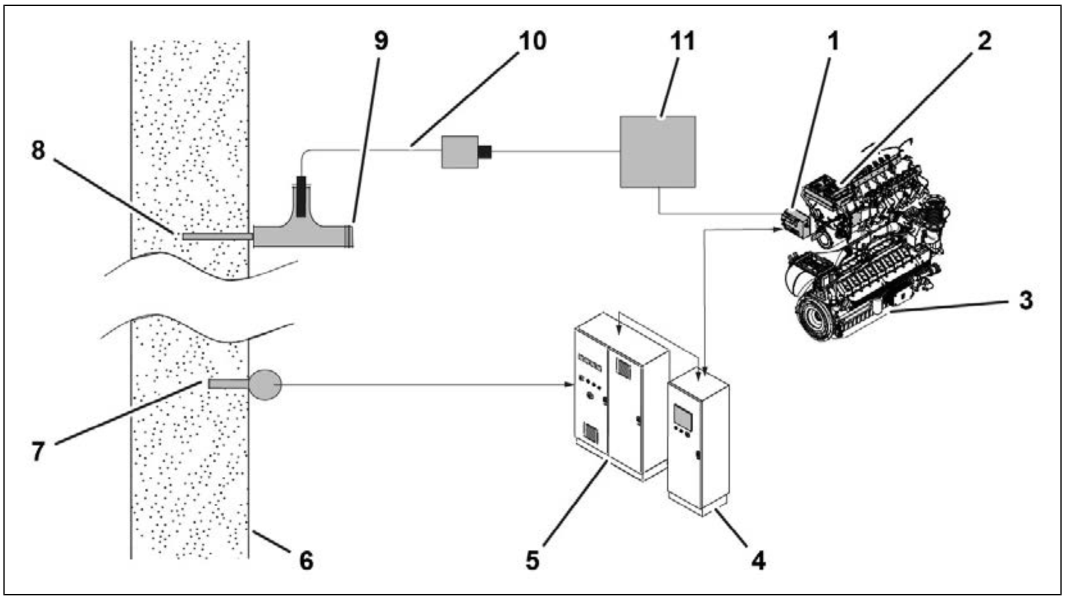


3759380875: Measurement of nitrogen oxide emissions with the EmiBox in the TEM system

1	EmiBox	2	Power supply
3	Signal line	4	Exhaust line
5	Temperature sensor	6	Measuring lance
7	Connection accessories	8	NO_x sensor with control device
9	Terminal box		

Measurement of nitrogen oxide emissions – Plants with TPEM system

For plants with the TPEM system, the role carried out by the EmiBox is taken over directly by the TPEM system. For example, the peripheral components, i.e., NO_x sensor, measuring lance and connection parts, remain the same. TPEM CU or TPEM CB must be retrofitted in order to connect the NO_x sensor. The terminals, plugs and switches required for this are part of the scope of delivery for NO_x measurement. The following illustration shows the principle measuring configuration.

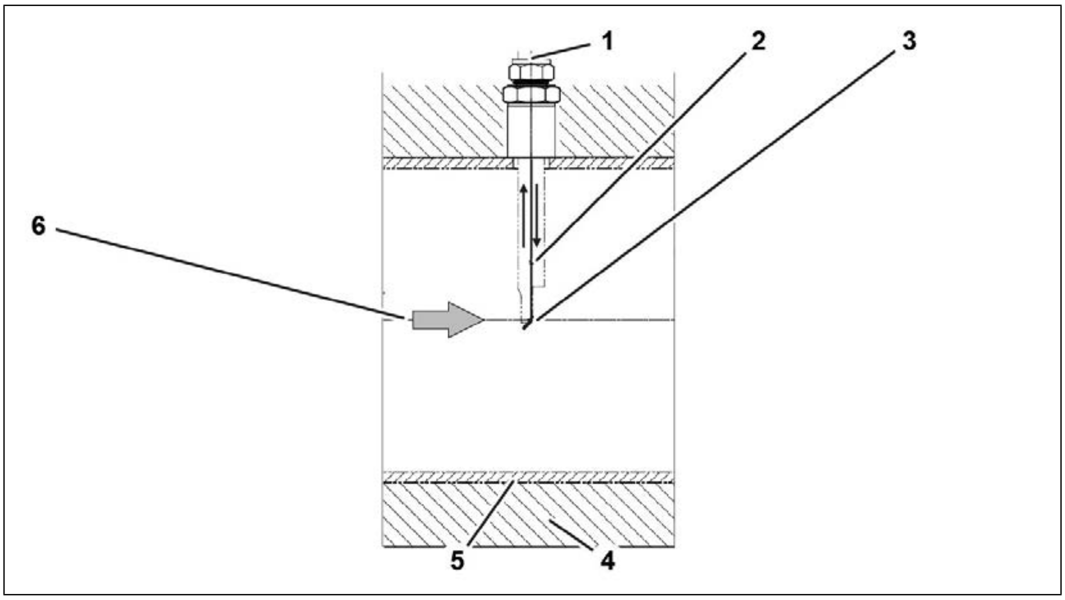


3759383563: Measurement of nitrogen oxide emissions with the TPEM system

1	TPEM Connection Box	2	TPEM CU
3	Example engine	4	TPEM Control Cabinet (TPEM CC)
5	Switchgear cabinet (e.g., HAS) with TPEM I/O Controller (TPEM I/O)	6	Exhaust line
7	Temperature sensor	8	Measuring lance
9	Connection accessories	10	NO_x sensor with control device
11	Terminal box		

Notes on connecting NO_x sensor to exhaust system

The NO_x sensor is located outside the exhaust line. A measuring lance protrudes into the exhaust line. The measuring lance consists of a tube into which a separating plate is inserted. This creates two flow channels for the constant supply and discharge of exhaust gas at the sensor. At the open end of the lance, the separating plate is angled against the direction of flow to form a spoon. For fault-free functioning of the probe, it is important that the axis of the probe is perpendicular to the direction of flow of the exhaust gas. The spoon must sit in the middle of the exhaust pipe and be aligned exactly against the direction of flow (see next illustration). The installation angle of the measuring lance may only be selected so that it is above the horizontal to prevent condensate from flowing in.



3759386251: Installation and alignment of the measuring lance in the exhaust pipe

1	To the NO_x sensor	2	Measuring lance
3	Middle of the exhaust line	4	Insulation
5	Exhaust pipe	6	Exhaust gas flow

12.3.4 Exhaust piping

Because of the relatively high exhaust temperatures, heat expansion is quite considerable (approx. 1 mm/m to 1.5 mm/m at 100 °C). To avoid unacceptably high stresses in the exhaust pipes, expansion joints must be fitted at suitable locations. The expansion joints compensate for the heat expansion in the exhaust pipes and components.

Depending on how the exhaust line is laid, the supports should be fixed and movable. They must not be supported on the exhaust turbocharger or the engine. The first fixed point must be located directly after the expansion joint at the turbocharger outlet.

In particular, components integrated in the exhaust system must be protected against stresses. Heat exchangers, catalytic converters, mufflers, etc., are protected against stresses arising from the expansion of the exhaust pipes by fitting expansion joints on the inlet and outlet sides of them. The exhaust expansion joints must be installed in accordance with the manufacturer's directions. The permissible axial and lateral offset must be complied with.

Required information

- Insulation [▷ 215]

12.3.5 Insulation

Because of the high operating temperatures, the exhaust system is permanently provided with insulation. When installing pipes outside, a contact protection is only sufficient for exhaust lines after exhaust heat exchangers. When designing the insulation of the exhaust lines, the following point must be taken into account.

The insulation in the area of the flange connections and revision openings must be easy to dismantle and reassemble. This is necessary because the screws on the flange connections and inspection openings must be inspected after the first 50 operating hours and retightened if necessary. This also applies to continued operation if a leak occurs at a flange connection or inspection opening.

12.3.6 Sulfur oxide in the exhaust gas

Some fuel gases, and in particular biogas, can contain small to large amounts of H_2S. H_2S has the potential to cause damage to the engine and plant.

H_2S in fuel gas is oxidized to SO_2 and in small amounts to SO_3 and water by burning in the engine. If an oxidation catalytic converter is operated in the exhaust system, SO_2 can oxidize to SO_3. SO_2 can form sulfuric acid and SO_3 with water. Sulfurous acid and sulfuric acid can lie far above the dew point of the exhaust gas depending on their concentration. This means that the presence of SO_2 and SO_3 in the exhaust gas can cause condensation of sulfurous acid and sulfuric acid at high temperatures. The condensation of acids can take place in particular in exhaust heat exchangers as well as when starting and shutting down the engine.

These acids attack the exhaust system depending on their concentration. This can lead to more or less severe corrosion or even the destruction of the component.

In particular with exhaust heat exchangers, in addition to the corrosive action of acids, there is often a buildup of acids, reaction products of the acid attack and lube oil ash. This often involves a clear increase in the pressure loss of the exhaust gas of the exhaust heat exchanger and the outlet temperature of the exhaust gas.

With these problems, the water inlet temperature and the exhaust gas outlet temperature of the exhaust heat exchanger play a decisive role. The water temperature has a strong influence on the temperature of the heat exchanger walls. If the water temperature is low, there will be a correspondingly low wall temperature that lies only slightly above the water temperature. The lower the water temperature is, the greater the risk is that the dew point will be undercut. Therefore the following limits apply in relation to the exhaust gas and water temperature of the exhaust heat exchanger for the indicated typical cases.

NOTE

All information about the limits of use for the exhaust heat exchanger and catalytic converters only apply if more severe project-related limits were not indicated!

Case 1

1. No oxidation catalytic converter is installed before the exhaust heat exchanger
2. H_2S in the fuel gas: < 200 ppm (often H_2S: < 10 ppm applies. This must be checked for the specific project!)

- Design of the exhaust heat exchanger for an exhaust gas outlet temperature of ≥ 180 °C without area reserve
- The water inlet temperature in the exhaust heat exchanger must be ≥ 80 °C

Case 2

1. An oxidation catalytic converter is installed before the exhaust heat exchanger
2. H_2S in the fuel gas: < 5 ppm[1]

Biogas

- Design of the exhaust heat exchanger for an exhaust gas outlet temperature of ≥ 180 °C without area reserve (≥ 100 °C rarely applies – this must be checked for the specific project!)
- In this case, the water inlet temperature in the exhaust heat exchanger is ≥ 80 °C

Natural gas

- Design of the exhaust heat exchanger for an exhaust gas outlet temperature of ≥ 100 °C without area reserve
- In this case, the water inlet temperature in the exhaust heat exchanger is ≥ 80 °C

Case 3

1. An oxidation catalytic converter is installed before the exhaust heat exchanger
2. H_2S in the fuel gas < 10 ppm

- Design of the exhaust heat exchanger for an exhaust gas outlet temperature of ≥ 180 °C without area reserve
- In this case, the water inlet temperature in the exhaust heat exchanger is ≥ 80 °C

The use of gross calorific value exhaust heat exchangers or exhaust heat exchangers under operating conditions with low water and exhaust temperatures is possible in principle, but must first be coordinated with the system manufacturer. Generally, it is safe to assume that fuel gas must be technically free of H_2S. The following then applies: At < 5 ppm H_2S in the fuel gas, the fuel gas is considered "technically free of H_2S". Peaks of H_2S above 5 ppm are not allowed. Fuel gas desulfurization must be designed to be break-proof.

SO_2 and SO_3 do not have a harmful effect on the catalytically active materials of SCR and oxidation catalytic converters.

To be able to estimate the SO_x concentrations in the exhaust gas result from known H_2S concentrations in the fuel gas, in the case of lean-burn engines with an air ratio of 1.7 and the ambient conditions of 20 °C and 60 % relative humidity, the following general statements can be made.

	H_2S in the fuel gas		Sum from SO_2 and SO_3 in the exhaust gas	
	ppm	mg/Nm³	ppm	mg/Nm³
Natural gas 80 – 100 % CH_4	10	13.9	1.1	3.6
Biogas 50 % CH_4	10	13.9	0.6	1.9

Table 26: Sulfur oxide in the exhaust gas

	Without exhaust heat utilization	With exhaust heat utilization (exhaust heat exchanger)
No catalytic converter	• Recommended with < 200 ppm H_2S in the fuel gas. • Above 200 ppm H_2S in the fuel gas, there can be considerable condensation of sulfurous acid, as a result of which corrosion and formation of deposits in the exhaust system can be expected. • With H_2S contents far above 200 ppm, massive plant faults and irreversible corrosion damage occur in a very short period of time.	• Recommended with < 200 ppm H_2S in the fuel gas. • < 10 ppm H_2S applies rarely – this must be checked for the specific project! • Above 200 ppm H_2S in the fuel gas, there can be considerable condensation of sulfurous acid, as a result of which corrosion and formation of deposits in the exhaust system can be expected. • When using an exhaust heat exchanger, increased corrosion and the formation of deposits in the exhaust heat exchanger and downstream

	Without exhaust heat utilization	With exhaust heat utilization (exhaust heat exchanger)
		exhaust gas components can be expected above 200 ppm H_2S. • H_2S contents above 200 ppm lead to massive plant faults and irreversible corrosion damage within a short period of time.
Oxidation catalytic converter	• Recommended with < 20 ppm H_2S in the fuel gas. • Above 20 ppm H_2S in the fuel gas, there can be condensation of sulfurous acid and the formation of sulfuric acid in the catalytic converter, as a result of which corrosion and formation of deposits in the exhaust system can be expected. • With H_2S contents far above 20 ppm, massive plant faults and irreversible corrosion damage occur in a very short period of time. • Brief H_2S peaks in the fuel gas between 20 and 1000 ppm do not lead to a considerable increase in the risk for damage to the plant as long as they do not exceed a total of 100 h/a based on 8000 operating hours per year. If the gas engine plants are operated with less than 8000 h/a, the 100 h/a must	• Mandatory at < 10 ppm H_2S in the fuel gas. • Above 10 ppm H_2S in the fuel gas, there can be considerable condensation of sulfurous acid and the formation of sulfuric acid in the catalytic converter, as a result of which corrosion and formation of deposits in the exhaust system can be expected. Irreversible corrosion damage and the formation of deposits can occur in particular in the exhaust heat exchanger and downstream exhaust gas components. • Brief H_2S peaks in the fuel gas above 10 ppm are also not permissible. • H_2S contents above 10 ppm lead to massive plant faults and irreversible corrosion damage within a short period of time. • The harmful substance reduction performance in the case of carbon monoxide and formaldehyde is not reduced in the case of H_2S

	Without exhaust heat utilization	With exhaust heat utilization (exhaust heat exchanger)
	also be reduced proportionally. A H_2S peak is limited to 60 min. • The harmful substance reduction performance in the case of carbon monoxide and formaldehyde is not reduced in the case of H_2S contents of up to 100 ppm. Above 100 ppm this can however be the case, so that corresponding limit values can no longer be complied with.	contents of up to 100 ppm. Above 100 ppm this can however be the case, so that corresponding limit values can no longer be complied with.
SCR catalytic converter (without oxidation catalytic converter)	• Recommended with < 200 ppm H_2S in the fuel gas. The NO_x reduction performance of the catalytic converter is not impaired. • < 20 ppm H_2S applies rarely – this must be checked for the specific project! • Above 200 ppm H_2S in the fuel gas, there can be considerable condensation of sulfurous acid, as a result of which corrosion and formation of deposits in the exhaust system can be expected.	• Recommended with < 200 ppm H_2S in the fuel gas. • < 10 ppm H_2S applies rarely – this must be checked for the specific project! • Above 200 ppm H_2S in the fuel gas, there can be considerable condensation of sulfurous acid, as a result of which corrosion and formation of deposits in the exhaust system can be expected. • When using an exhaust heat exchanger, increased corrosion and the formation of deposits in the exhaust heat exchanger and downstream exhaust gas components can be expected above 200 ppm H_2S.

	Without exhaust heat utilization	With exhaust heat utilization (exhaust heat exchanger)
	• With H_2S contents far above 200 ppm, massive plant faults and irreversible corrosion damage occur in a very short period of time. • Above 200 ppm H_2S in the fuel gas, the catalytic converter can be damaged by corrosion and the formation of deposits.	• H_2S contents above 200 ppm lead to massive plant faults and irreversible corrosion damage within a short period of time. • Above 200 ppm H_2S in the fuel gas, the catalytic converter can be damaged by corrosion and the formation of deposits.
SCR catalytic converter with oxidation catalytic converter	• Recommended with < 20 ppm H_2S in the fuel gas. • Above 20 ppm H_2S in the fuel gas, there can be condensation of sulfurous acid and the formation of sulfuric acid in the catalytic converter, as a result of which corrosion and formation of deposits in the exhaust system can be expected. • With H_2S contents far above 20 ppm, massive plant faults and irreversible corrosion damage occur in a very short period of time. • Brief H_2S peaks in the fuel gas between 20 and 1000 ppm do not lead to a considerable increase in the risk for damage to the plant as long as they do not exceed a total of 100 h/a based on 8000 operating hours per year. If the gas engine plants are operated with less than 8000 h/a, the 100 h/a must	• Mandatory at < 10 ppm H_2S in the fuel gas. • Above 10 ppm H_2S in the fuel gas, there can be considerable condensation of sulfurous acid and the formation of sulfuric acid in the catalytic converter, as a result of which corrosion and formation of deposits in the exhaust system can be expected. Irreversible corrosion damage and the formation of deposits can occur in particular in the exhaust heat exchanger and downstream exhaust gas components. • Brief H_2S peaks in the fuel gas above 10 ppm are also not permissible. • H_2S contents above 10 ppm lead to massive plant faults and irreversible corrosion damage within a short period of time. • The harmful substance reduction performance in the case of carbon monoxide

	Without exhaust heat utilization	With exhaust heat utilization (exhaust heat exchanger)
	also be reduced proportionally. A H_2S peak is limited to 60 min. • The harmful substance reduction performance in the case of carbon monoxide and formaldehyde is not reduced in the case of H_2S contents of up to 100 ppm. Above 100 ppm this can however be the case, so that corresponding limit values can no longer be complied with. • Above 200 ppm H_2S in the fuel gas, the catalytic converter can be damaged by corrosion and the formation of deposits.	and formaldehyde is not reduced in the case of H_2S contents of up to 100 ppm. Above 100 ppm this can however be the case, so that corresponding limit values can no longer be complied with. • In case of an overdosage of urea in combination with sulfur in the exhaust gas, ammonium bisulfite can be formed, which can deposit on cold surfaces (such as the exhaust heat exchanger) and be corrosive.

Table 27: Influence of exhaust heat use on the sulfur oxide in the exhaust gas

12.3.7 Silicon oxide in the exhaust gas

Organosilicon compounds are found mainly in landfill gases and sewage gases. Biogases that were not generated only from native organic substrates can also contain these compounds.

The organosilicon compounds are oxidized in the gas engine to SiO_2 and cause damage to the engine, mainly due to accelerated wear. Generally, the reduction performance of the catalytic converter is reduced quickly, as its surface is coated with SiO_2. There are no known cleaning procedures that can restore the function of the catalytic converter.

If a fuel gas that contains organosilicon compounds is used as a fuel for gas engines, the fuel must be cleaned using suitable procedures. If a catalytic converter is used, there shall not be any measurable silicon in the fuel gas at any time. The operator shall ensure this by providing measuring-technology proof on a regular and sufficiently frequent basis. Even with silicon quantities below the validation limit, over time the smallest amounts of SiO_2 can coat the surface of the catalytic converter and reduce its service life.

12.3.8 Deflagration

All technically feasible prerequisites are created for gas engine gensets from Caterpillar Energy Solutions in order to ensure the highest degree of safety against deflagrations in the exhaust system. The following conditions can be viewed as the most critical for the occurrence of deflagrations:

- The engine does not start and, as a result, gas-air mixture gets into the exhaust system.
- The ignition fails because of a technical defect or the ignition is switched off in a fault shutdown. In both cases the gas/air mixture flows into the exhaust system.

The components, functions and procedures that prevent the unrestricted transport of unburnt gas/air mixture into the system are described in the following.

Gas trains

All gas trains have two separate, electrically or electro-pneumatically operated, airtight shut-off valves that are closed when the genset is at a standstill. An optional leakage check before each genset start verifies whether the valves were secure whilst the genset was at a standstill. During this time no fuel gas can get into the exhaust system. The shut-off valves are controlled separately in a safety-oriented manner.

Start failure and start retry

In case of a start failure, e.g., fault in the plant's gas supply (bad gas or too low gas pressure), an unburned gas-air mixture can enter the exhaust system. However, this mixture is then outside of the ignition limit. However, the gas-air mixture can be considered non-combustible, as even the enabled high-energy ignition system could not make it burn. In this case, there is also no speed increase of the gas engine to the rated speed. No speed increase means that the shut-off valves in the gas train close after the time specified in the control system expires. The engine comes to a stop and conveys air into the mixture system and exhaust system during this time. The ignition remains switched on until the genset is at a standstill. If the start is repeated, more air is initially conveyed into the exhaust system through the flushing process described above. This continues to dilute the non-combustible mixture from the previous start attempt.

It must be ensured that the zero pressure controller of the gas train is set correctly and not incorrectly shifted. The regularly prescribed maintenance work on the gas-air mixer must be carried out so that it does not lock. The TEM/TPEM control system issues a warning to show that maintenance of the gas-air mixer is required.

Only two repeats of the start-up can be carried out. If the gas engine does not start after the second repeat of the start-up, a fault alert is triggered by the TEM/TPEM control system. The gas engine genset can no longer start automatically. In order to manually start again, the fault must be manually acknowledged. Before acknowledging, the cause of the failure has to be eliminated. The temperature of the engine and exhaust system will continue to be included in this consideration. If the gas engine and exhaust system are cold, the temperature of the gas-air mixture is at a level similar to the ambient temperature. At these temperatures the chance of a deflagration is excluded.

Therefore the probability of a deflagration of the unburnt gas/air mixture starts to become greater if the gas engine is warm and the exhaust lines are hot.

Normal stop of the gas engine genset

For these shutdown processes, the shut-off valves of the gas train are firstly closed. The ignition system remains in operation so that the unburnt mixture still in the system is burnt inside the engine. The rotational energy of the rotating masses causes the speed to decrease slowly and finally causes the gas engine genset to reach a standstill. The throttle valve is left completely open during this phase. This ensures the best possible flushing of the lines with air.

Ignition fault in operation

When the gas engine genset is operating, the function of each individual spark plug is monitored. If a spark plug fails, the power of the gas engine genset is reduced and once the generator switch is opened, the gas engine is stopped. During this time, unburnt gas/air mixture gets into the exhaust system via the cylinder with the faulty ignition. This is mixed with the exhaust gas from the other cylinders and diluted to the point that the combustion air ratio is far outside the ignition limit. The carbon dioxide and water contained in the exhaust gas pushes the ignition limit further up.

If the ignition system fails as a result of a technical fault, the genset is immediately shut down by closing the gas valves in the gas train. In this case, the mixture lines on the gas engine are still filled with the gas/air mixture. This mixture is then pushed into the exhaust line as a “cold” lean mixture at a combustion air ratio of approx. 1.8. When the genset continues to run until standstill, the mixture lines and exhaust lines are emptied.

Mixture quantities and air quantities

Cold engine start: Before starting the genset, i.e., before opening the gas valves, approx. 1.5 times the total swept volume of air is flushed through the genset. The engine does not start if the control system detects a start failure and cancels the start. Until then 22 times the total swept volume of the gas/air mixture is conveyed into the exhaust system. When the genset runs until standstill, an additional total swept volume of air is flushed into the exhaust system while the genset is cold.

Warm engine start: A warm engine has a higher starter speed and the air volume for flushing before start up heats up on the hot exhaust lines. A flushing volume of approx. 3.5 times the total swept volume is flushed through the system. If the engine fails to start, approx. 60 times the total swept volume of the gas-air mixture is fed into the exhaust system until the start procedure is aborted. When the warm genset comes to a stop, the exhaust system is flushed through with approx. 3 times the total swept volume of air.

Ignition fault at full load: Although the shut-off valves of the gas train are immediately closed in the event of an ignition fault, the "cold" mixture present in the mixture lines gets into the hot exhaust system with a combustion air ratio of approx. 1.8 and is heated up there by the hot surfaces. The quantity of the mixture is approx. 40 times the total swept volume. When the gas genset runs until standstill, the mixture and exhaust lines are flushed with "cold" air, which also warms up on the hot surfaces of the exhaust system. The quantity of air flushed through is approx. 100 times the total swept volume.

Exhaust temperatures

Gas engine gensets from Caterpillar Energy Solutions are operated with low exhaust temperatures because of the high electrical efficiency. The exhaust temperatures reach approx. 400 °C at full load and approx. 470 °C at 50 % partial load when operated with natural gas. So the exhaust temperature does not pose any risk of deflagration in natural gas operation.

Ignition sources in the exhaust system

In practice, there are two possible ignition sources in an exhaust system:

- Hot surfaces or a generally high exhaust line temperature.
- Ignition sparks in the exhaust system from electrostatic discharge

High temperature

If the exhaust temperature is at or above the ignition temperature of a mixture, the mixture will ignite.

1. If the fuel gas is biogas or natural gas with an ignition temperature of approx. 700°C (biogas) and approx. 600°C (natural gas), the ignition temperature will not be reached. During partial load operation, the exhaust gas coming from the engine will have a temperature of max. 580°C* when operated with biogas and 510°C* when operated with natural gas. A temperature that is 90 K to 120 K below the ignition temperature will be reliably maintained. *Temperatures during 50 % partial load operation + tolerance of 10 K.
2. If the fuel gas is CH_4 with proportions of long-chain hydrocarbons and/or H_2, the ignition temperatures will be lower than for CH_4. If there are correspondingly high proportions of these highly flammable components in the mixture, the ignition temperatures can therefore be significantly lower than 600°C. Associated petroleum gases, coke oven gases and synthetic gases, in particular, can contain larger amounts of long-chain hydrocarbons and can therefore cause deflagrations in the exhaust system under normal operating conditions.

Sum formula	Designation	Ignition temperature °C	Ignition limits in air vol. %
CH_4	Methane	595	4.4 – 16.5
C_2H_6	Ethane	515	2.7 – 15.5
C_3H_8	Propane	470	2.1 – 9.4
C_4H_{10}	n-butane	365	1.4 – 9.4
C_5H_{12}	n-pentane	260	1.8 – 8.7
...	...	...	...
C_8H_{18}	n-octane	205	0.8 – 6.5
...	...	...	...
H_2	Hydrogen	585	4.0 – 75.6

Table 28: Overview of fuel gases and ignitability

Electrostatic discharge

Differences in potential may arise between individual components of the exhaust system or even between the pipes installed in the exhaust system because of electrostatic charge and those differences may under some circumstances be discharged in a spark. If spark discharge and the

gas/air mixture occur simultaneously in the exhaust system, there is an increased risk of a deflagration.

On-site measures for reducing the risk of deflagrations

Despite all measures taken, events can generally rarely occur in which ignitable mixture enters the exhaust line and ignites there, thus triggering a deflagration.

This can damage the exhaust line and the exhaust gas components. Insufficiently pressure-resistant components, such as housings for mufflers, SCR catalytic converters as well as catalytic converter blocks can be damaged or destroyed.

The following measures must be implemented on site to reduce the probability of a deflagration in the exhaust system or to further limit its possible effects.

- The protective equipotential bonding of the exhaust line and the components in the exhaust system **must always** be designed according to TRGS 727 or other national provisions.
- In addition, gas types with a significant amount of long-chain hydrocarbons, carbon monoxide and / or hydrogen must be considered as having a reduced ignition temperature in comparison to methane. As a result, the ignition of an unburnt mixture must be expected even at normal exhaust temperatures. In this case, a technical reduction in pressure of the exhaust system must be implemented.

12.3.9 Exhaust gauge connections

The exhaust gauge connections offer the possibility to measure the exhaust gas emissions and must be provided in the exhaust line in accordance with the requirements and specifications. The following points provide an overview:

- The required nominal widths of the exhaust gauge connections, the mutual alignment of the exhaust gas connections and the respectively required straight inlet section and outlet sections before and after the exhaust gauge connections must be observed.
- When positioning, make sure that the exhaust gauge connections can be used in accordance with their intended purpose during later operation and that, for example, no component hinders the introduction of measuring lances.

- Access to the measuring points must be possible and safe for personnel. If exhaust gauge connections are provided in the upper section of the exhaust stack, a stationary or mobile climbing aid is required. The version of the climbing aid must be clarified with the person who performs the measurement.
- The installation of the exhaust gauge connections in the exhaust line must always take place at a right angle to the exhaust line. Exhaust gauge connections must not be facing down (below the horizontal) so that condensate cannot accumulate.

12.4 Components and parts

12.4.1 Oxidation catalytic converter

All gas engines operate on the lean-burn principle. Depending on the engine type and emissions requirements, an oxidation catalytic converter is required for the carbon monoxide and formaldehyde exhaust components.

Safety

If fuels with a hydrogen content of more than 1 vol.% are used, fuel mixture can enter the exhaust system in the event of a failure of the ignition system. There, an unacceptable temperature increase can occur in the oxidation catalytic converter as a result of hydrogen oxidation.

WARNING

Explosive combustion of fuel mixture in exhaust system in case of engine ignition failure due to hydrogen oxidation

This can lead to severe injury or even death.

- Hydrogen oxidation already occurs at normal exhaust temperatures. If the exhaust temperature reaches 590 °C, explosive ignition of the entire fuel system is possible. To prevent this, suitable measures for explosion protection must be taken into account and implemented during planning

Storage

- If the catalytic converter is wet, it must be protected from the effects of freezing.
- The catalytic converter must be stored such that it is protected from dust.

Assembly

- The catalytic converter is usually the first component in the exhaust system after the exhaust turbocharger.
- Anchor points or crane or crane rails can be helpful for the installation and removal of catalytic converters.

- The catalytic converter insulation must be designed in such a way that it can be easily dismounted in order to clean or replace the catalytic converter.
- Always install catalytic converter housings free of tension if possible to prevent damage to the catalytic converter. Expansion joints absorb the length changes in the exhaust line caused by heat and reduce axial and radial applications of force.
- The catalytic converter is installed before the muffler, in order to prevent obstruction due to the detachment of absorbent wool.
  - **Note:** Mineral wool occupies the inlet openings in the catalytic converter channels and leads to an increase in the exhaust back pressure and to reduced harmful substance reduction performance. It is not easy to remove the mineral wool from the ducts of the catalytic converter.
- Installation after a pure reflection muffler is permissible provided that exclusively stainless steel parts are used in the exhaust path.
- In order to protect them against overheating, the catalytic converters should only be installed in the exhaust system when the engine has been adjusted and is running trouble free. This applies to both initial commissioning and subsequent maintenance work.

Operation

- Misfiring must be avoided as non-combusted fuel in the catalytic converter can lead to undesired after-burning with unduly high exhaust temperatures.
- Temperatures above approx. 600 °C may lead to premature aging and also to damage to the catalytic converter as the temperature increases.
- The catalytic converter is usually destroyed above 700 °C.
- A temperature-monitoring device must be provided after the catalytic converter, which will cut off the fuel supply if the exhaust temperature is too high.
  - **Note:** In particular with fuel gases with a high content of long-chain hydrocarbons or carbon monoxide, this can lead to oxidation of the hydrocarbons at the catalytic converter if combustion is incomplete in the engine. If there is no temperature monitoring with shutdown of the fuel gas supply, this can lead to a rapid rise in the temperature. Above 590 °C, the methane contained in the exhaust gas can oxidize at the catalytic converter and overheat to the point of its destruction.
- Deflagration in the exhaust pipe can lead to the mechanical destruction of the catalytic converter if the client has not provided explosion flaps.
  - Required information: Deflagration [▸ 222]
- Low-ash, low-alloy engine oils must be used in order to minimize deposits of lube oil ash in the catalytic converter. Blockages of the ducts caused by lube oil incineration ash can significantly impair the functioning of the catalytic converter.

- Moisture or solvents must be prevented from affecting the catalytic converter; passing through the dew point when starting up and shutting down the engine is an exception to this rule.
- Usually, the use of oxidation catalytic converters is only permissible if the fuel gas has been finely desulfurized beforehand. When using exhaust heat exchangers after an oxidation catalytic converter, desulfurization is especially important.
  - Required information: Fuel gas system [▷ 165]
  - Required information: Sulfur oxide in the exhaust gas [▷ 215]
- The use of oxidation catalytic converters is only possible if the exhaust gas is free of organosilicon hydrocarbons.
  - Required information: Silicon oxide in the exhaust gas [▷ 221]
- The following elements are harmful to the catalytic converter and must be avoided in the fuel gas: silicon, sodium, calcium, lead, bismuth, mercury, manganese, potassium, iron, arsenic, antimony, cadmium, zinc, phosphor, halogen.

Maintenance

- In larger engines, the catalytic converter housing weighs far more than 100 kg, so this must be taken into account during planning. Anchor points or crane or crane rails can be helpful for the installation and removal of catalytic converters.
- If the flange connections are opened to clean the catalytic converter or exchange the catalytic converter, new seals must be fitted.
- The catalytic converter can be cleaned when a dust or fiber coating is the cause of the lowered reduction performance

NOTE

Suitable and permissible cleaning procedures must be selected. When doing so, compliance with health measures must be observed. Dust can be respirable. The dust layer must not be blown off. Dust must only be extracted using a suitable industrial vacuum cleaner with a fine dust filter.

12.4.2 SCR catalytic converter with integrated oxidation catalytic converter

The required nitrogen oxide emissions cannot always be reached through engine settings. With the aid of an SCR catalytic converter, nitrous oxides in the exhaust gas can be limited below the required limit value. Usually, the reduction of carbon monoxide and formaldehyde takes place in the oxidation catalytic converter installed after the SCR level. Furthermore, the reducing agent ammonia is made harmless in the case of overdosage of reduction agent in the oxidation catalytic converter due to oxidation.

The specifications for oxidation catalytic converters must be taken into account with regard to storage, assembly, operation and maintenance.

- Required information: Oxidation catalytic converter [▶ 227]

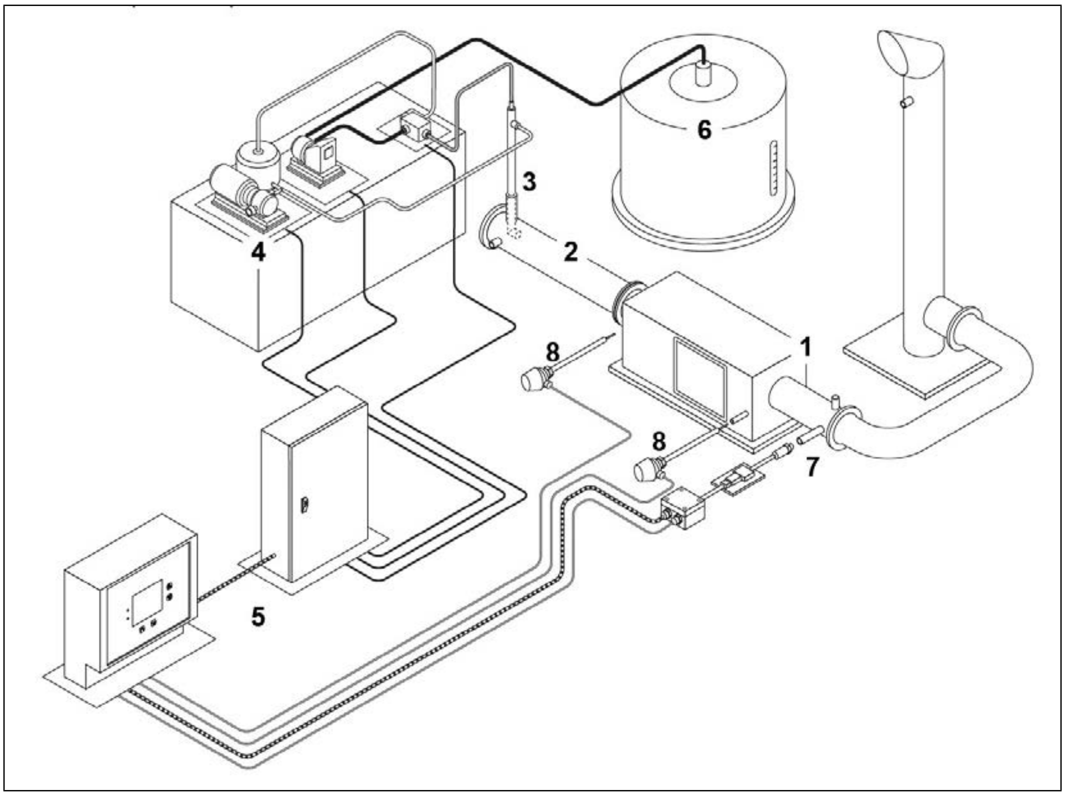
In deviation from this, the following limits apply for the exhaust temperature:

- Temperatures above approx. 500 °C may lead to premature aging and also to damage to the catalytic converter as the temperature increases.
- The catalytic converter is usually destroyed above 530 °C.
- Temperature monitoring before an SCR catalytic converter is required if it is technically possible to exceed 500 °C. A controlled shutdown is required when exceeding 500 °C to protect the catalytic converter.

The exhaust temperature limits specified above can deviate depending on the project and depending on the catalytic converter manufacturer.

Design of an SCR catalytic converter with integrated oxidation catalytic converter

An SCR system essentially consists of the components shown:



3761766283: Example illustration

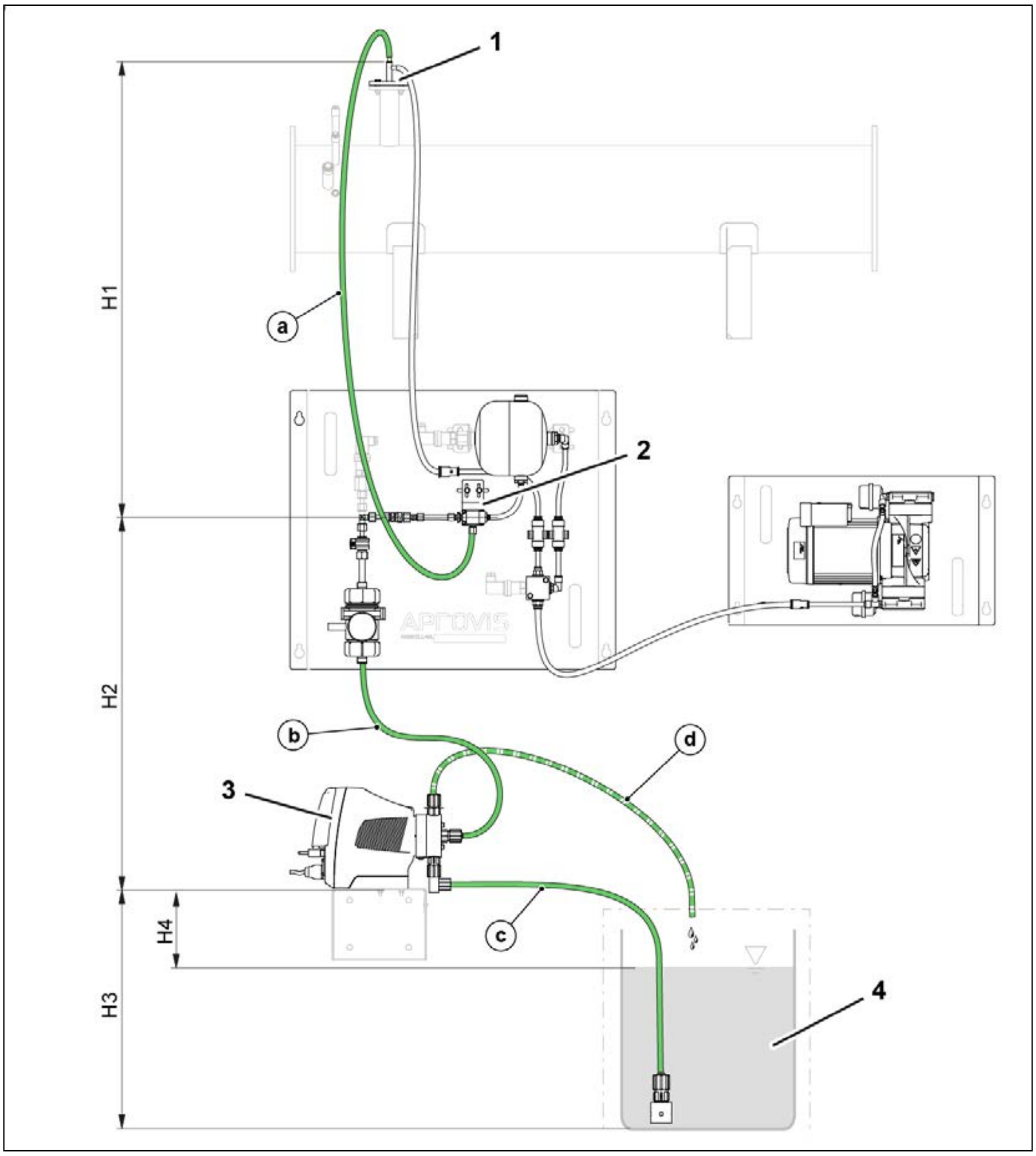
1	Catalytic converter housing with catalytic converter blocks	2	Injection line

3	Injection lance	4	Urea dosing unit
5	SCR control	6	Urea tank
7	Measuring lance with NO_x sensor	8	Temperature sensors

Urea tank and metering technology

For the operation of an SCR catalytic converter, an aqueous urea solution is usually required as the reaction agent. This urea solution must be kept in reserve in sufficient quantity and quality and injected into the exhaust pipe upstream of the SCR catalytic converter by means of a urea dosing unit. The metering technology components must be positioned in such a way that the resulting hose line lengths and discharge heads do not exceed the permissible limits.

The following illustration shows the basic layout and the permissible hose lengths.



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Component	
1	Injection lance
2	3-way valve (mounted on urea dosing unit)
3	Dosing pump
4	Urea tank
Hose[1)]	
a	3-way valve to injection lance
b	Dosing pump to urea dosing unit

c	Urea tank to dosing pump (the condensate drain valve must be laid with a constant incline without trapped air bubbles).
d	Dosing pump return line to urea tank[2)]
[1)] The hoses must be laid with a constant incline without trapped air bubbles.	
[2)] The return line must be laid with a steady downward incline or horizontal (parallel) to the suction line (d). The end of the return line must never be immersed in the urea solution.	

Maximum vertical clearances	
H1	≤10 m
H2	≤10 m
H3	≤2 m
H4	>0 m
Maximum hose lengths	
a	<10 m
b	<30 m
c	<10 m
d	≤10 m

A urea tank must be provided for reserves. This must at least be equipped with level monitoring and, if necessary, heating if there is a risk of frost. The urea solution must be protected from direct sunlight and high temperatures, as urea decomposes at high temperatures and when exposed to sunlight.

The urea metering device, which is always included in the scope of delivery of the SCR catalytic converter, must be installed according to the specifications in the following overview to enable reliable operation of the SCR catalytic converter. If the limits of hose lengths and/or discharge heads cannot be complied with for specific orders, individual solutions must be implemented in consultation with CES.

12.4.3 SCR catalytic converter without integrated oxidation catalytic converter

The use of SCR catalytic converters without an oxidation catalytic converter is possible, but rare. It only serves to reduce the NO_x content in the exhaust gas.

- Required information: The general descriptions in chapter SCR catalytic converter with integrated oxidation catalytic converter [▷ 229]

The specifications for oxidation catalytic converters must be taken into account with regard to storage, assembly, operation and maintenance.

- Required information: Oxidation catalytic converter [▸ 227]

In deviation from this, the following limits apply for the exhaust temperature and sulfur dioxide in the exhaust gas:

- Temperatures above approx. 505 °C may lead to premature aging and also to damage to the catalytic converter as the temperature increases.
- The catalytic converter is usually destroyed above 530 °C.
- Temperature monitoring before an SCR catalytic converter is required if it is technically possible to exceed 500 °C. A controlled shutdown is required if a temperature of 500 °C is exceeded in order to protect the catalytic converter.
- Special catalytic converters that withstand higher temperatures can be used with exhaust temperatures above 500 °C.
- In the case of an SCR catalytic converter without an oxidation catalytic converter, slightly higher values of sulfur dioxide can be tolerated in the exhaust gas
  - For more information: Sulfur oxide in the exhaust gas [▸ 215]

The exhaust temperature limits specified above can deviate depending on the project and depending on the catalytic converter manufacturer.

12.4.4 Exhaust muffler

The task of an exhaust muffler is to dampen the exhaust noise to a required level. The mufflers used take the form of reflection mufflers, absorption mufflers, or combination mufflers. Reflection mufflers achieve their maximum damping in the lower 125 Hz to 500 Hz frequency range. Absorption mufflers reach their maximum damping effect in the frequency range of 250 Hz to 1000 Hz.

In the case of combination mufflers, the first part is designed as a reflection muffler and the second as an absorption muffler. The combination muffler brings together the characteristics of both muffler types and thereby achieves a significant silencing effect over a broad frequency range.

If the required damping of the exhaust gas noise cannot be reached with a muffler, then usually an additional muffler must be installed in series. An expansion joint must be installed between the mufflers to reduce structure-borne noise.

- For more information: General [▸ 299]

Operation

- The exhaust mufflers expand at operating temperature. Floating bearings and expansion joints must be provided accordingly.

12.4.5 Exhaust flaps

In most applications, the exhaust systems are designed separately for each engine. In these systems, exhaust flaps are used for bypassing exhaust components.

With exhaust systems where multiple engines must be connected to one common exhaust line, exhaust flaps are used to disconnect the individual engine from the common exhaust line. This is, for example, the case if the exhaust gas of several engines is combined for the operation of a common absorption chiller.

Exhaust flaps are not completely tight in the fully closed position, there is always a small amount of leakage flow. The requirements concerning the tightness of exhaust flaps have to be considered with the individual application demands.

By-passing components in the exhaust system

For by-passing exhaust components, such as exhaust heat exchangers and/or steam generators, exhaust flaps are used. They are driven by an electric or pneumatic actuating drive. A manual drive is also possible. They simply have an open/close function and no control function. Preferably, butterfly valves combinations are used, for which two butterfly valves are opened and closed in the opposite direction via a coupling rod.

Multi-engine plants with common exhaust line

For multi-engine plants with a common exhaust manifold, exhaust gas must be prevented from uncontrolled backflow. Uncontrolled backflow of exhaust gas to an engine currently not in operation causes corrosion. There are different options to avoid backflow of exhaust gas by a corresponding arrangement of exhaust flaps. They are described in the following.

Exhaust flap arrangement with separate exhaust pipe

With this version of the exhaust system, an exhaust flap is arranged behind the engine in the line. Using a bypass flap combination, the exhaust gas is either led to the common exhaust manifold or into the open air via a separate exhaust pipe (see next illustration). When the engine is at standstill, the exhaust flap behind the engine (butterfly valve 1) and the butterfly valve to the common exhaust manifold (butterfly valve 2) are closed. The butterfly valve in the line to the outlet to the open air (butterfly valve 3) is open. The common exhaust manifold is overpressurized when the other engines are running. There is a slight leakage flow via exhaust flap 2 into the space between. As the leakage flow is comparably small and free cross section of the exhaust line to the open air comparably large (butterfly valve 3 open), the leaking gas flows to the open air. The engine is protected by closed butterfly valve 1. Before starting the engine, exhaust flap 1 behind the engine is opened. The exhaust gas first flows through the open exhaust flap 3 into the open air.

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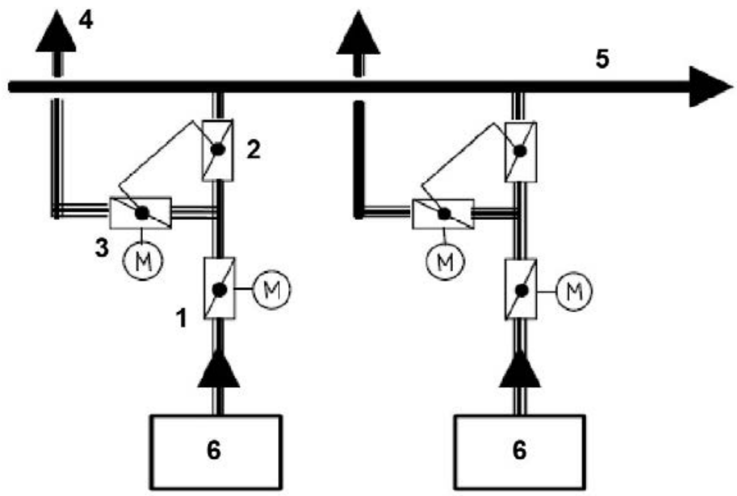
When the engine is started up, the exhaust path to the open air is closed by switching the exhaust bypass flap combination. At the same time, the path to the common exhaust pipe is opened. This structure has the following advantages:

- Each engine can be operated individually, i.e., it is independent of the conditions in the common system.
- Each engine can be started without exhaust back pressure.

With power-driven operation, the exhaust heat can be adjusted to the active demand by switching the bypass to the open air. This arrangement is highly recommended with several engines connected to one common exhaust system.



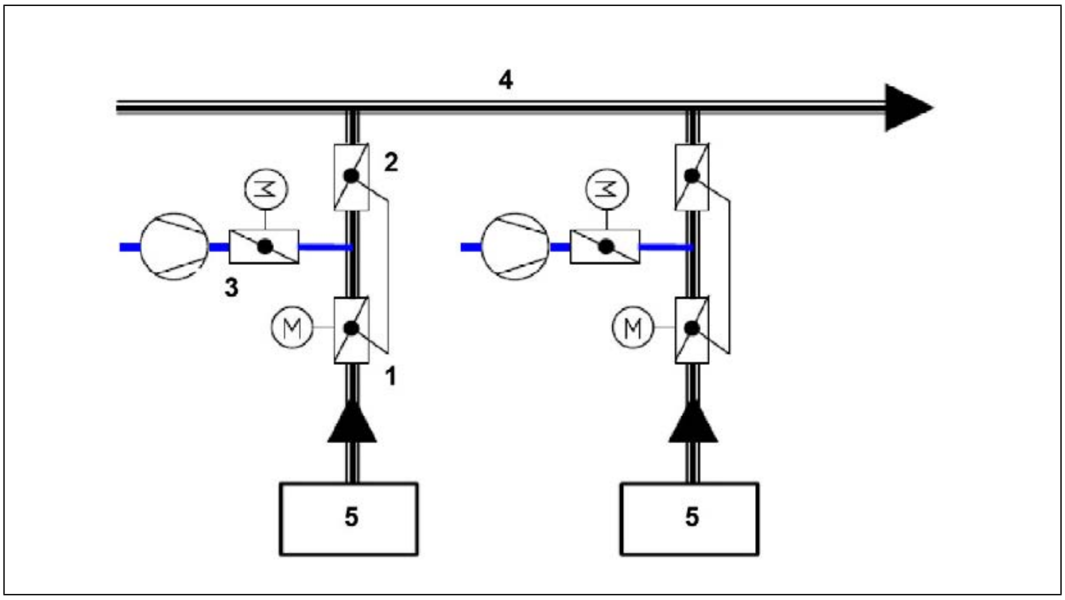
3761792267: Common exhaust system with bypass to the open air

1	Exhaust flap 1	2	Exhaust flap 2
3	Exhaust flap 3	4	Bypass to open air
5	Exhaust manifold	6	Gas engine

Exhaust flap arrangement with air lock

With this system, there are two shut-off flaps in the exhaust line to the common exhaust pipe. The flaps can be opened and closed simultaneously via an actuating drive. The sealing air line is connected in the space between both butterfly valves. Sealing air is supplied via a fan with a downstream shut-off flap (see next illustration). When the engine is at a standstill, both exhaust flaps (butterfly valves 1 and 2) are closed. Sealing air is blown into the space between the butterfly valves. The pressure of the locking air must be higher than the maximum exhaust back pressure in the exhaust manifold. The volume flow of the sealing air must be greater than the leaking rate of the exhaust flaps. There is no possibility of exhaust backflow from the exhaust manifold to the engine when the engine is not running. Before starting the engine, both exhaust flaps are opened, shut-off flap 3 after the fan is closed and the sealing air fan is switched off. The engine has to start at the increased exhaust back pressure present in the exhaust manifold.

Advantage: No additional line to the open air is necessary.



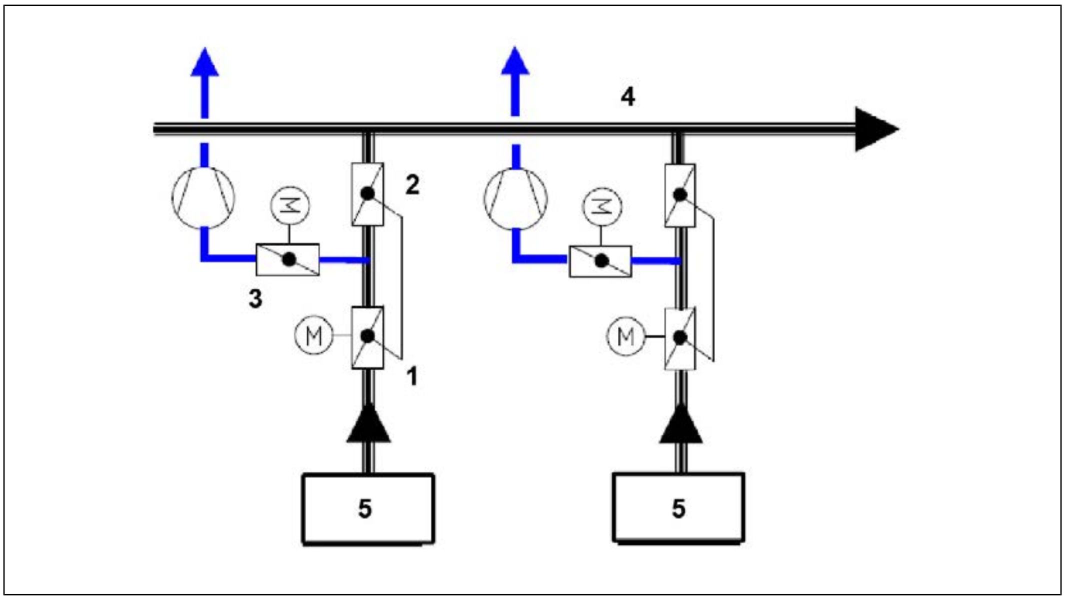
3762870155: Common exhaust system with air lock

1	Exhaust flap 1	2	Exhaust flap 2
3	Air flap	4	Exhaust manifold
5	Gas engine		

Exhaust flap arrangement with intermediate venting

Also with this system, there are two shut-off flaps in the exhaust line to the common exhaust pipe. The flaps can be opened and closed simultaneously via an actuating drive. The venting line is connected in the space between both butterfly valves. The leakage gas in the space between the exhaust flaps is extracted by an extractor fan with an upstream shut-off flap and routed into the open air (see next illustration). When the engine is at a standstill, both exhaust flaps (butterfly valves 1 and 2) are closed. A slight negative pressure is maintained in the space between the butterfly valves by the extractor fan. The leakage gas flowing via the exhaust flaps is routed to the open air via the extractor fan. Leakage gas flowing into the engine when not running is avoided. Before starting the engine, both exhaust flaps are opened, shut-off flap 3 before the fan is closed and the extractor is switched off. The engine has to start at the increased exhaust back pressure present in the exhaust manifold.

Disadvantage: A separate line to the open air must be provided, but the cross section is comparably small in relation to an exhaust line as shown in the illustration below.



3762872843: Exhaust flap arrangement with intermediate venting

12.4.6 Exhaust stack

Especially in the vicinity of residential areas, it is necessary to avoid impermissible engine exhaust gas emissions. Exhaust stacks are used to transport the exhaust gas up to a high level in the atmosphere.

The exhaust stacks must be insulated to avoid condensation in the exhaust system. If the exhaust stack is not or not completely isolated, this can lead to undercutting the dew point and therefore the formation of condensation during operation. This can cause considerable corrosion.

The speed of the exhaust gas in the exhaust stack should be between 15 m/s and 20 m/s. Above 20 m/s, there is a risk of resonance vibrations with undesired noise emission. A high outlet speed leads to a dynamic increase in effective stack height and improves the dispersal of the gases, but it also increases the flow noise.

The draft effect of the exhaust (depending on the stack height) decreases the back pressure in the exhaust system. However, installing deflector hoods at the mouth of the exhaust stack can partially or even entirely offset the exhaust stack draft. In unfavorable cases a back pressure should also be expected in the exhaust stack.

Exhaust stacks must be equipped with a continuous condensate drain valve and rainwater runoff. The amount of rain, ice and snow that enters must be minimized.

13 Compressed air system

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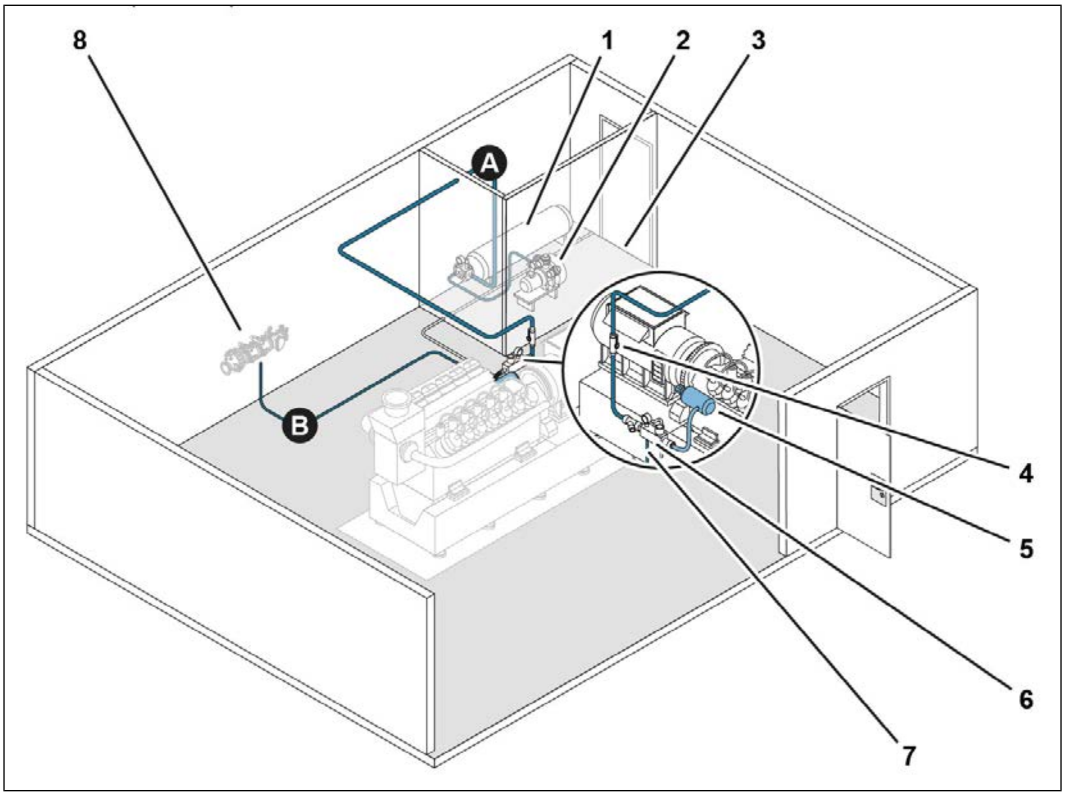
13.1 System overview

The schematic illustration shows and lists typical components and interfaces to help you get started. Proportions are therefore not to scale and the arrangement is just an example.



3619792523: Simplified example illustration

A	Starting system (high pressure)	B	Low pressure system (option)
1	Compressed air container	2	Compressed air compressor
3	Condensate drain	4	High-pressure shut-off valve
5	Compressed air control line and compressed air starter on the genset	6	Connection fittings
7	Outflow for low pressure system (option)	8	Gas train with compressed air connection (only for certain fuel gases)

13.2 Structure and function

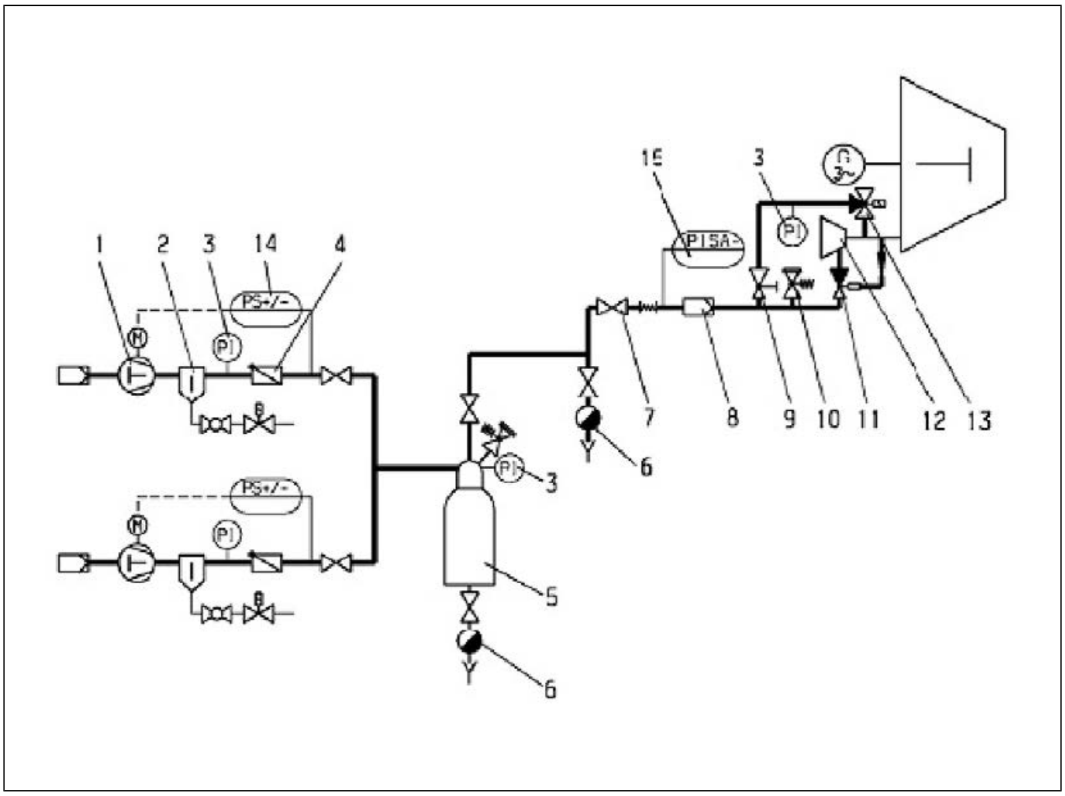
13.2.1 Starting system

Compressed air starter

Some engine models start with compressed air. The start is carried out with a compressed air starter via a gear ring on the flywheel. The table below shows the starting systems used for the various series.

Engine series	Compressed air starter	Electric starter
TCG 3016		X
TCG 2020	X	X (Default)
TCG 3020		X
TCG 2032	X	

Table 29: Series and starting systems



3881224075: Starting air system for an engine with compressed air starter

1	Compressor	2	Oil separator
3	Pressure gauge	4	Non-return valve
5	Compressed air container	6	Condensate drain valve
7	High-pressure shut-off valve	8	Dirt trap
9	Pressure controller	10	Safety valve
11	Starting valve	12	Starter
13	Control valve	14	Pressure switch for compressor ON/ OFF

15 Pressure sensor for display and evaluation in the TEM system and TPEM system

As shown in the illustration, the compressor (1) fills the compressed air container (5) via the non-return valve (4) and the oil separator (2). The compressed air container (5) is equipped with a water separator (6). The filling pressure of the container is read from the pressure gauge (3). Compressed air gets to the starter valve (11) via the high-pressure shut-off valve (7) and the dirt trap (8). When the start command is initiated, the control valve (13) opens the starter valve and the starter (12) is pressurized with compressed air. The engine starts.

Low-pressure air system

In the gas train of TCG 2032 series engines, the pneumatic shut-off valves are supplied with compressed air at max. 10 bar. The starter group is equipped by default with a low-pressure connection for supplying a gas train with pneumatic valves. If gas trains with solenoid valves are used, the low-pressure connection is not used.

13.3 Requirements and guide values

Compressed air quality

The compressed air must be free from dust and oil. The compressors and air filtration must be designed accordingly.

13.4 Compressed air system components

13.4.1 Compressors

Redundant diesel or electric compressors are provided with the appropriate equipment for pressure released starting. Compression generally takes place in two stages with intermediate cooling. The compression pressure is 30 bar. The design must be matched to the total volume of the connected compressed air containers.

13.4.2 Compressed air container

Compressed air containers are designed as either vertically or horizontally installed containers. The container volume depends on the number and types of the connected engines. Other factors include the required number of starts to be achieved without refilling the air containers. Compressed air containers must be drained regularly. A drain facility must be fitted at the lowest point of the compressed air containers. Horizontal containers must be installed with a slope towards the base of the container, so that they can be properly drained through the base. Generally automatic drainage facilities must be provided. These must always be arranged beneath the container; the condensate line from the container to the drain must always be laid with a continuous slope.

13.4.3 Compressed air pipes

An oil and water separator must be installed in the filling pipe between the compressor and the compressed air container if this is not provided on the compressor.

The starting line between the compressed air container (head of container) and the main starter valve of the engine must be as short as possible and must have as few elbows as possible. Dependent on how the pipes are laid, an automatic drain facility must be fitted at the lowest points. It is recommended that a dirt trap with drain-off valve be installed in the starter line. When fitting the dirt trap, pay attention to the orientation (sieve always to be removed from below) and the direction of flow. The dirt trap is a component of the start system for gensets with a compressed air starter.

In the case of multi-engine plants, a ring circuit may increase the starting availability of the system.

Welding deposits and any other contamination must be avoided in the compressed air line. The starting air lines must always be stainless steel pipes.

Required information

- Material for piping [▹ 340]

13.5 Safety notes

When carrying out work on the engine, it is essential to shut off the compressed air supply to the engine to prevent the engine from being started unintentionally.

14 Control systems and switchgear

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14.1 System overview

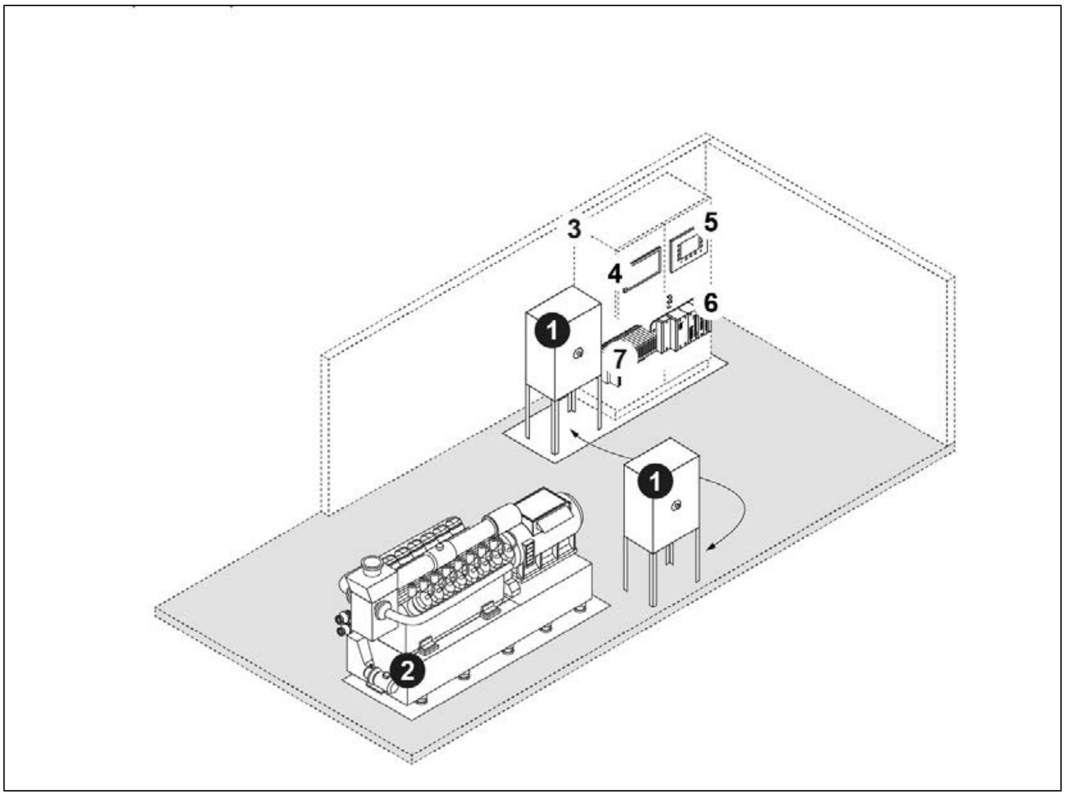
14.1.1 Control systems

The genset and auxiliary systems are controlled by the TEM system or the TPEM system, depending on the series. Both control systems have a very different structure and function.

The following illustrations show a selection of typical control components for a genset with a TEM system or TPEM system as examples. They serve as an overview of the most important differences in the arrangement of components and operation between TEM and TPEM systems.

14.1.2 TEM system

Important components for genset control



3597238155: Simplified example illustration

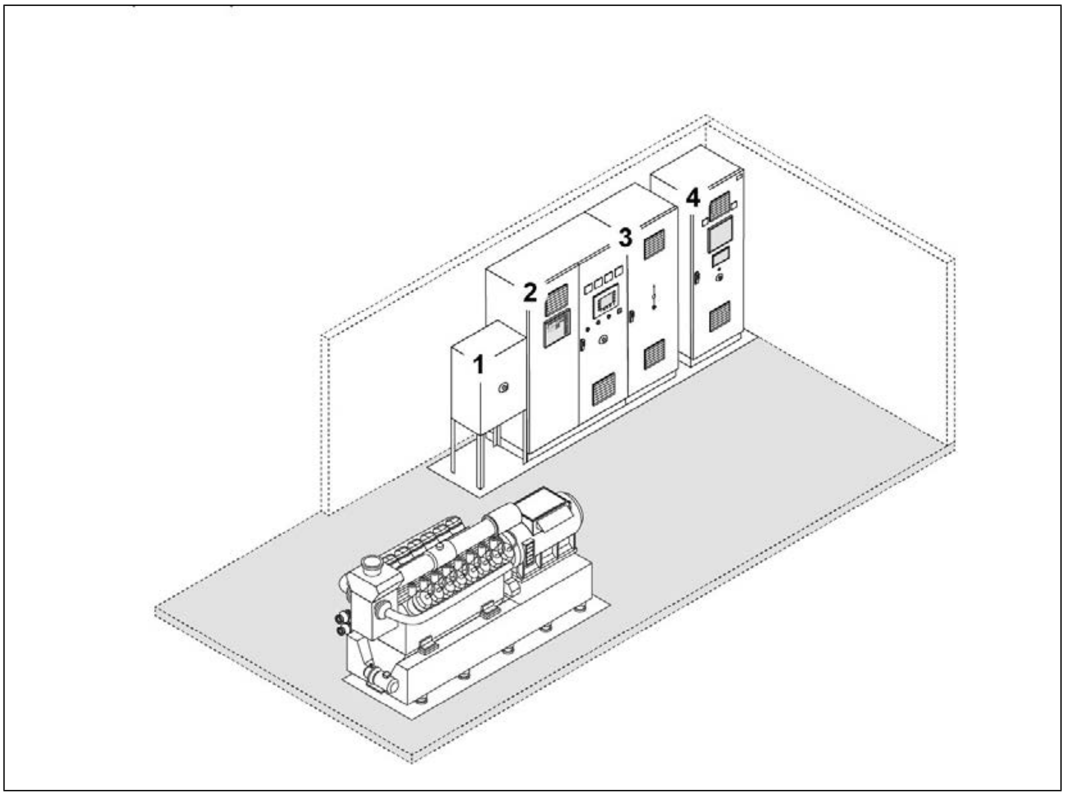
1	Genset control (AGS), short connection line (positioned close to the genset or switchgear room if a short distance away)	2	Genset with actuators and sensors
3	Auxiliary cabinet (HAS)	4	Operating computer as the central HMI for installation in a switchgear cabinet

5 Multi Function Relay (TEM MFR) with operating elements as the interface to the power input for installation in a switchgear cabinet

6 Grid Demand Interface (GDI) for grid code applications

7 TEM I/O Controller as the interface to various auxiliary systems for installation in a switchgear cabinet

TEM system with switchgear



3703325451: Simplified example illustration

1 Genset control (AGS)

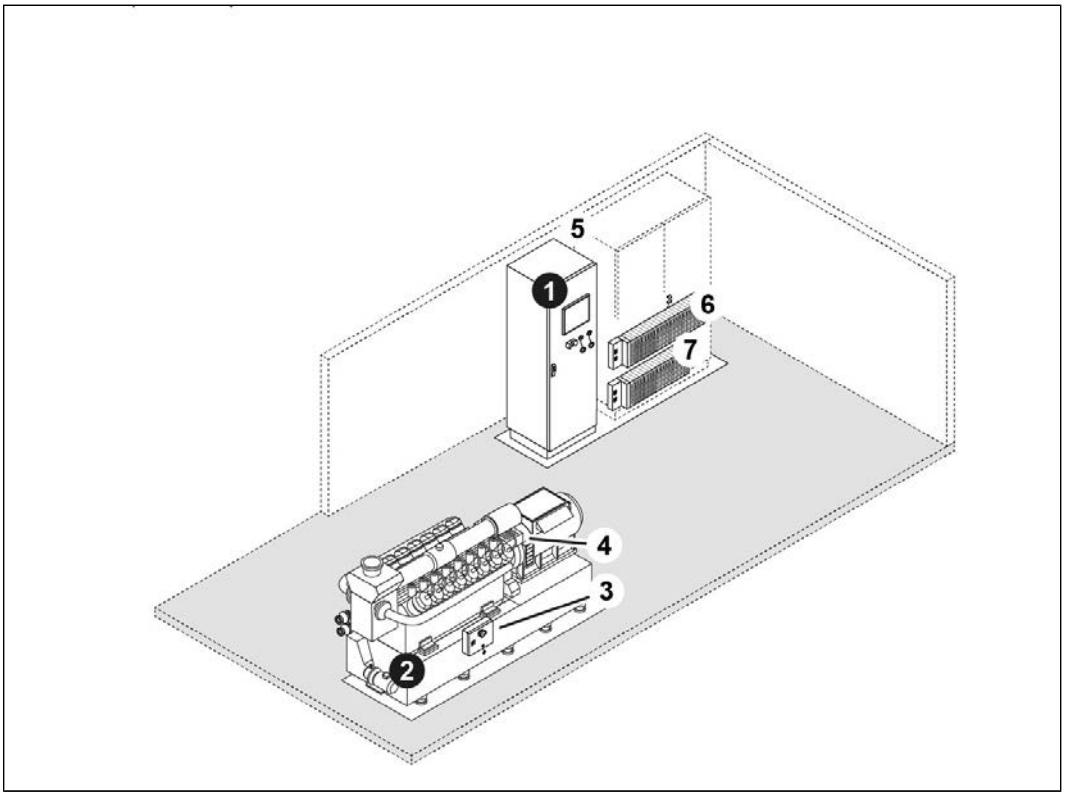
2 Auxiliary cabinet (HAS)

3 Generator circuit breaker cabinet (GLF) for low-voltage power output

4 Master control cabinet (ZAS) as the superior switchgear cabinet for multi-module plants

14.1.3 TPEM system

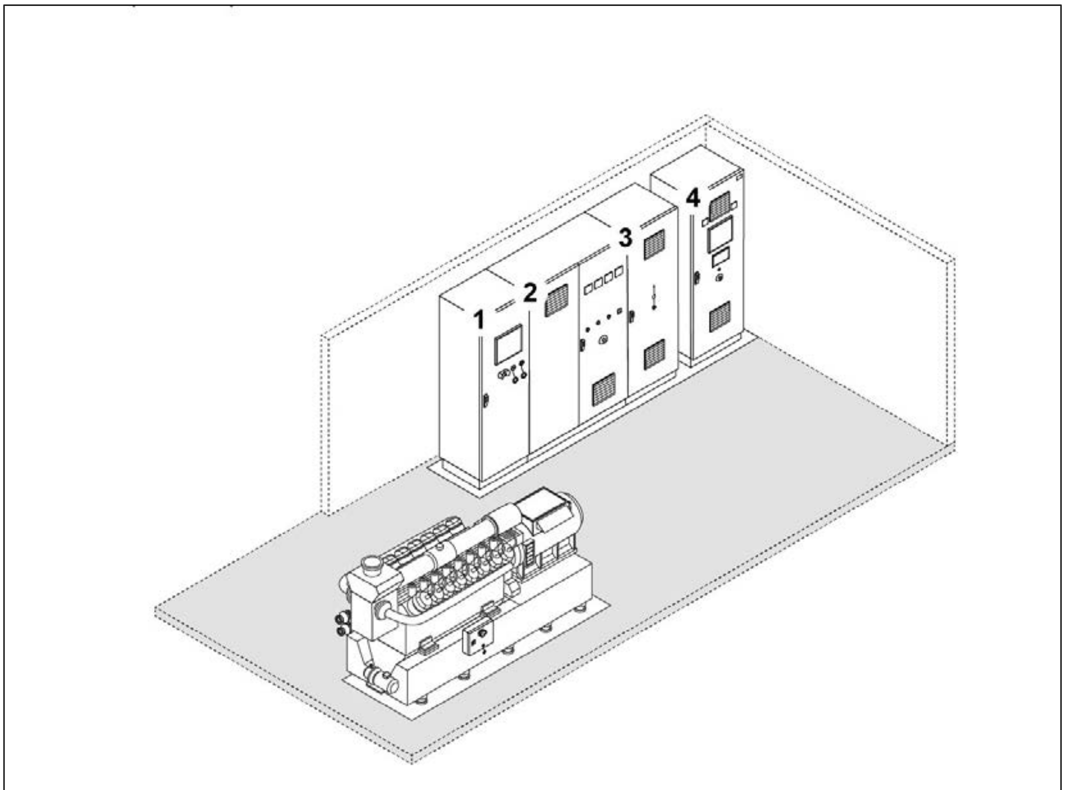
Important components for genset control



3671902859: Simplified example illustration

1	TPEM Control Cabinet (TPEM CC) with TPEM Touch Panel as the central HMI, long connection line possible (positioning in switchgear room recommended)	2	Genset with actuators, sensors, and one or more controllers (TPEM CU), depending on the genset series
3	TPEM Connection Box for assembly-friendly connection to the TPEM CC	4	Controller for engine control (TPEM CU)
5	Auxiliary cabinet (HAS)	6	TPEM I/O Controller as the interface to various auxiliary systems for installation in the auxiliary cabinet (HAS)
7	TPEM Grid Code I/O Controller for grid code applications		

TPEM system with switchgear



3703324939: Simplified example illustration

1	TPEM Control Cabinet (TPEM CC)	2	Auxiliary cabinet (HAS) for TPEM system
3	Generator circuit breaker cabinet (GLF) for low-voltage power output	4	Master control cabinet (ZAS) as the superior switchgear cabinet for multi-module plants

14.2 Structure and function of the TEM system

14.2.1 Structure and function

Components

The TEM-EVO system comprises the following components:

- Genset control cabinet (AGS) complete with connected cables to the genset; contains the genset control and the safety chain. The length of cable between the gas engine and genset control cabinet (AGS) is 8 m (optionally 15 m). For the TCG 2032, the cable length is 8 m.
- I/O Controller for installation in the auxiliary cabinet (HAS), with max. 250 m distance from the genset control cabinet (AGS); data transfer via a fail-safe CAN bus connection

- Grid Demand Interface (GDI) for installation in the auxiliary cabinet (HAS) for the implementation of specific requirements of the grid code that applies at the operating site
- Operating computer with touch screen for installation in the auxiliary cabinet (HAS) or external control cabinet. Max. 100 m distance from genset control cabinet; cabling to comprise shielded 3-core line.
- Multi Function Relay (TEM MFR) for installation in the auxiliary cabinet (HAS) for communication with the generator controller and the generator circuit breaker (GCB)

This layout minimizes the time it takes for cabling in the plant. The genset control cabinet (AGS) is mounted in immediate proximity to the genset. Together with the factory-tested engine cabling, the cables fitted and tested on the genset control cabinet (AGS) and connected to the genset (with plug connections on the genset end) ensure smooth commissioning and a high level of operational reliability.

Signals relating to the power part are exchanged with the TEM-EVO system directly in the auxiliary cabinet (HAS) via the I/O Controller. Data is transferred to the genset control via a fail-safe CAN bus connection.

The operating computer can be located on the plant as desired, if required in the auxiliary cabinet (HAS) or in the control room. The max. distance to the genset control cabinet (AGS) is 100 m.

Function

The TEM system is the brain of the entire gas engine module. The TEM system contains:

- Control functions, regulation functions and monitoring functions for the genset gas engine and generator
- Optional control functions, regulation functions and monitoring functions for compatible auxiliary equipment (e.g., dump cooling, heating circuit control)
- HMI for operation and monitoring by the operator

The TEM system regulates and optimizes the combustion of gas in the cylinders. Through its monitoring functions, it protects the genset against impermissible boundary conditions and guarantees long service life. Thanks to the integrated regulatory functions, it ensures optimum, reproducible engine status values in all operating conditions.

The integral short-term history and long-term history store the relevant measured values on retentive data storage media and provide a transparent view of its own procedures.

The functions described in the following chapters are integrated in modular form in the TEM-EVO system. In addition, thanks to a wide range of options, the TEM-EVO system can optionally be adapted to specific application cases. For example, the anti-knock control (AKC), genset room ventilation, open-loop control and closed-loop control of the radiators in the heating circuit, engine circuit, dump cooling circuit and mixture cooling circuit can be adapted. Further adjustments are possible by using parameterizable measured values, counter values and control loops, CH_4 value guided operation, etc. Simple operation, a high level of operational reliability and optimized economic efficiency is the result.

14.2.2 Operation log and history

The recording functions of the electronic operation log kept by the TEM-EVO system take the place of a manual operation log. All operating messages and operationally relevant switching actions as well as all parameter changes are recorded with a precise time stamp (date and time).

As a whole, the TEM-EVO system can monitor and distinguish between over 600 different events. The TEM-EVO system makes it possible to provide fast and detailed analyses of genset operation, including TEM-EVO-controlled auxiliary functions.

The history function records up to 84 measured values. Up to 20 measured value curves can be jointly illustrated in one graph. The user can compile the measured value curves themselves. TEM-EVO records histories at three speed stages.

History	Speed stages
Operating cycle history	Records actual values in each operating cycle (1 operating cycle = 2 crankshaft revolutions)
6 min. history	Records current values at one second intervals
40 h history	Records 6 min. measured values

Table 30: History function

14.2.3 Diagnostics and service functions

In addition to the history and operation log, the basic TEM-EVO system also includes further diagnostic functions and service functions. Diagnostic functions and service functions aid the early detection of abnormalities and make it possible to optimize plant operation. Error situations can be remedied faster. Commissioning becomes easier and faster using these functions. This contributes decisively towards the overall economic efficiency of the gas engine set.

The following service and diagnostic functions are available:

- Auxiliary genset test mode
- Digital speed governor
- Electronic ignition system
- Parameterization
- Oil change
- Electronic operating hour meter

- Selection of language and selection of printer
- System setup (software versions, serial numbers, color settings, screen saver, etc.)
- Other diagnostic masks and service masks for some options (e.g., anti-knock control, dual gas operation)

The service masks and diagnostic masks, like all other masks, can also be transmitted optionally by analog modem, radio modem, or IP modem (internet). In this way, remote diagnostics and remote repair can be provided with very short response times via our Customer Service or the operator's own on-call staff. It is possible to operate several TEM-EVO systems via a central operating computer, if one is available.

14.2.4 Technical data (AGS)

Genset control cabinet		
	Cable inlets from below	
	Standard dimensions (H x W x D)	1200 × 800 × 300 mm
	Degree of protection	IP54
	Permissible operating temperature	5 °C to 45 °C

Table 31: Technical data for the genset control cabinet

I/O Controller		
	Dimensions (H x D)	112 × 114.5 mm
	Width depending on number of options	
	Degree of protection	IP20
	Permissible operating temperature	5 °C to 45 °C

Table 32: Technical data for the I/O Controller

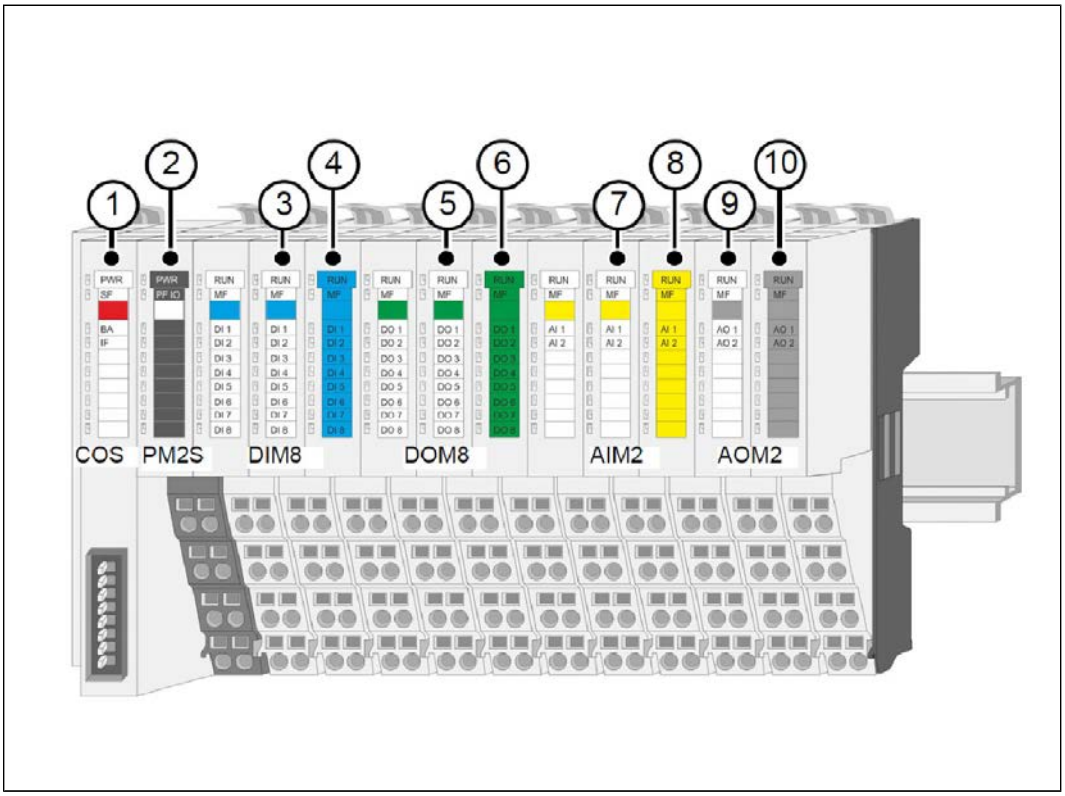
Operating computer		
	Dimensions (H x W x D) including front plate	311 × 483 × 101 mm
	Installation depth	95 mm
	Mounting cutout (H x W)	282 × 454 mm
	Degree of protection (front-side)	IP 65
	Permissible operating temperature	5 °C to 40 °C

Table 33: Technical data for the operating computer

Customer Level (CL) / 18014401340850699 - EN / 2025-12

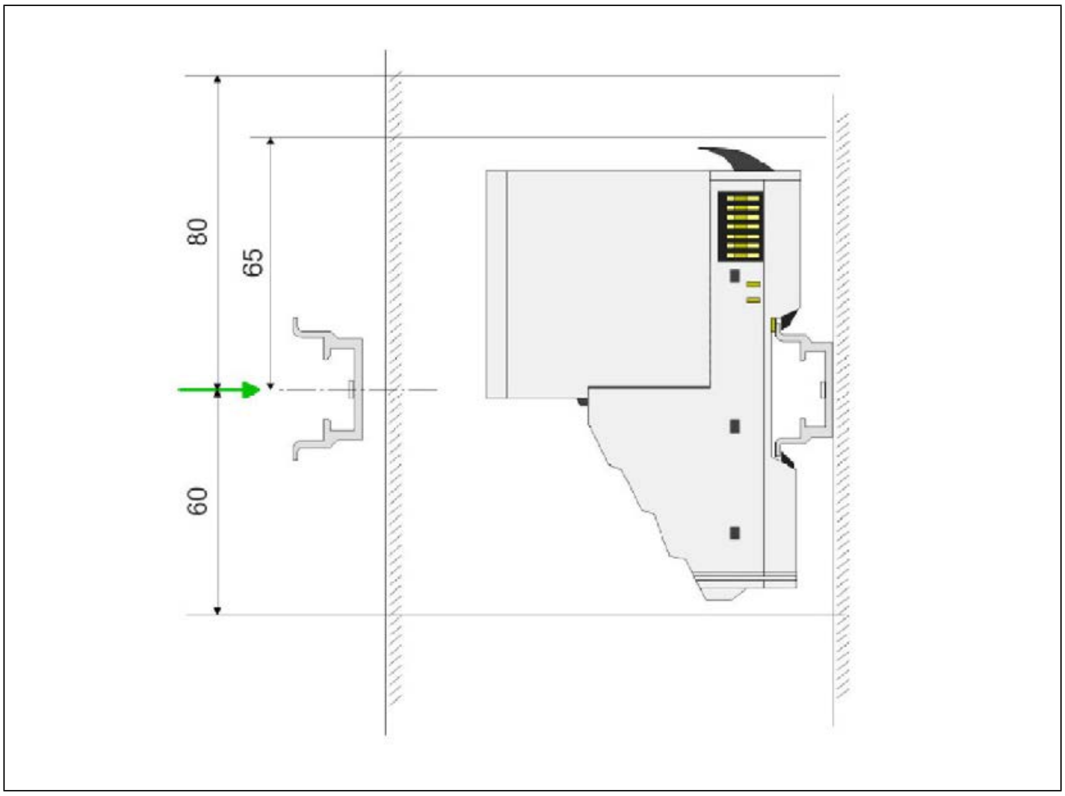
14.2.5 Installation notes for the I/O Controller

The I/O Controller must be installed in a horizontal 35 mm top-hat rail (DIN EN 60715) in a switchgear cabinet. The modules must be installed vertically (see next illustration), so that sufficient ventilation is guaranteed. The distance between two cable ducts should be 200 mm (at least 160 mm). Along with the IO module, space is provided for possible retrofitting of other IO modules. This space must not be blocked by other components when installing the controller in the switchgear cabinet.



3693538443: I/O Controller

1	red: bus coupler module COS	2	black: power module PM1S and PM2S, PM2S shown
3	blue: I/O module DIM8	4	blue: spare parts module DIM8
5	green: I/O module DOM8	6	green: spare parts module DOM8
7	yellow: I/O module AIM2	8	yellow: spare parts module AIM2
9	gray: I/O module AOM2	10	gray: spare parts module AOM2



3695392395: Installation of the I/O Controller in the switchgear cabinet

14.2.6 Advantages for the user

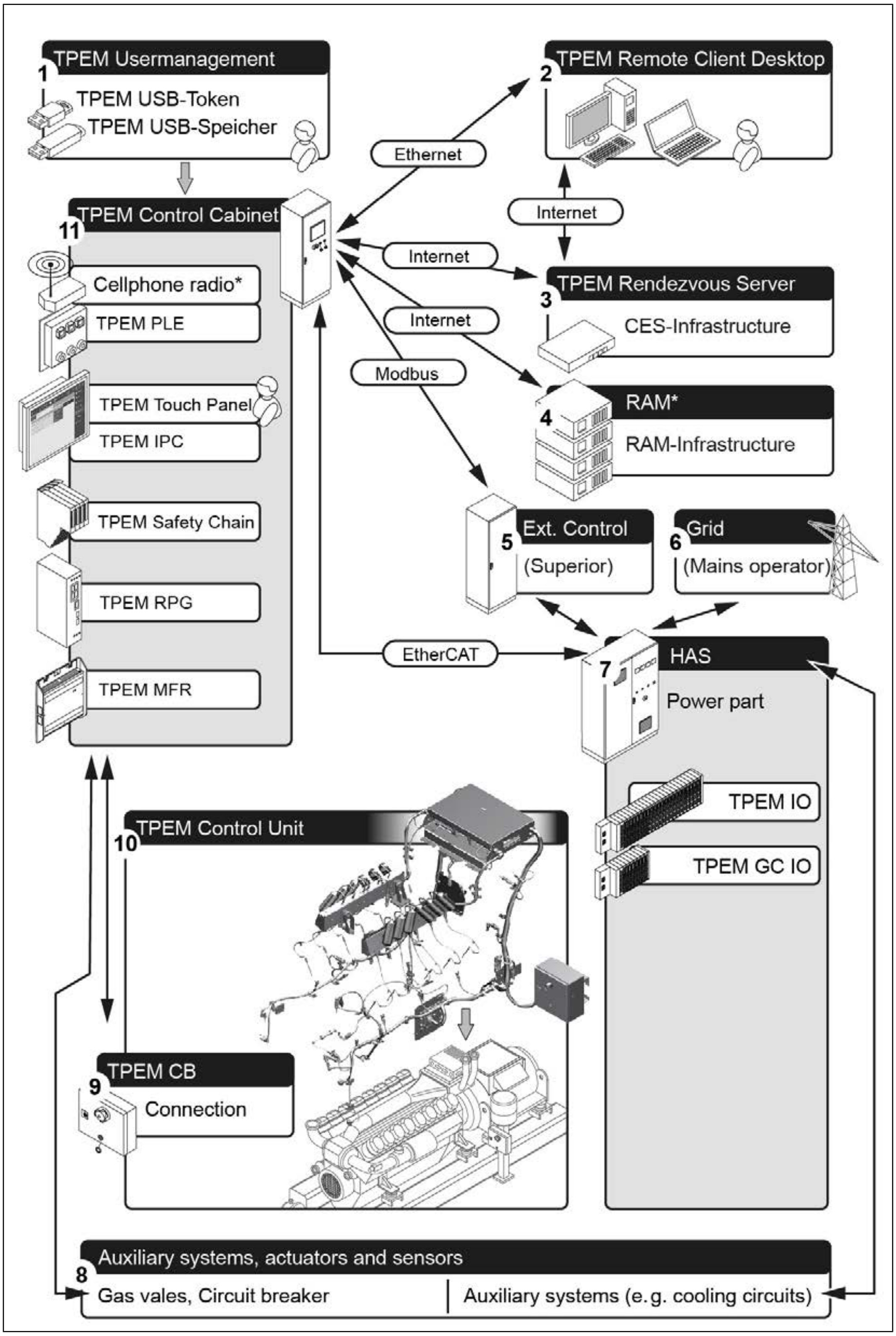
TEM-EVO offers the user the following advantages:

- Compact structure and integration of numerous additional peripheral functions such as heat recovery, etc.
- High engine efficiency by controlled operation at optimum operating point.
- Permanently low exhaust emissions.
- High level of plant reliability thanks to automatic plausibility checks.
- Rapid elimination of faults thanks to the display of measured values and warning messages and fault messages.
- Fast, cost-effective service thanks to extended diagnostics options backed up by short-term history and long-term history.
- Effective remote operation and remote diagnostics via the central control room or other external computers by telephone modem or radio modem (option).
- Additional remote diagnostics options from the Service via telephone modem (option).

14.3 Structure and function of the TPEM system

14.3.1 Structure and function

Structure



4815731595: Structure of the TPEM system using a TCG 3016 as an example

* Optional

1	TPEM USB token and TPEM USB storage	2	TPEM Remote Client Desktop (TPEM RC DT)
3	TPEM Rendezvous Server (TPEM RVS)	4	Remote Asset Monitoring (RAM) with optional monitoring services
5	External control, e.g., the operator's superior energy supply plant (EZA) control	6	Communication line to the grid operator
7	Auxiliary cabinet (HAS)	8	Connected auxiliary systems, actuators and sensors
9	TPEM Connection Box (TPEM CB)	10	TPEM Control Unit (TPEM CU)
11	TPEM Control Cabinet (TPEM CC)		

The TPEM system is the newly developed control system and regulation system for operating an energy generation plant with gas engine gensets. TPEM is the abbreviation for "Total Plant & Energy Management". Comprehensive monitoring functions protect the gas engine genset and the plant components associated with it from exceeding impermissible limits. The monitoring functions thus guarantee ready availability and long service lives. The TPEM system is structured in modules and can be flexibly adjusted to the local conditions.

The system is initially available for the TCG 3016 and TCG 3020 series.

The TPEM system comprises the following main components:

- TPEM Control Unit (TPEM CU)
  - The TPEM Control Unit includes the components of the TPEM system that are mounted on the gas engine genset. The interface to the TPEM control system forms the TPEM Connection Box mounted on the genset. The maximum possible distance between the TPEM Connection Box and the TPEM control system is 100 meters. The cable bundle between TPEM CC and TPEM CU can be ordered from CES or must be performed by the customer according to the cable specification provided by CES.
- TPEM Control Cabinet (TPEM CC)
  - The TPEM Control Cabinet is the control cabinet with hard-wired 15" touch panel for operation. The TPEM Control Cabinet controls and regulates the gas engine, the generator and the auxiliary drives as well as the generator circuit breaker and mains circuit breaker. The interfaces for it are the TPEM I/O Controller and the TPEM Multi Function Relay. The TPEM Control Cabinet still includes the TPEM Remote Plant Gateway for remote access and the safety chain certified by TÜV.
- TPEM I/O Controller (TPEM I/O)

- The TPEM I/O Controller creates the interface between the TPEM system and the auxiliary drives. The I/O Controller is installed in the auxiliary cabinet (HAS). The signals for controlling the auxiliary drives are supplied, the power supply for the auxiliary drives is to be provided separately. The distance between the TPEM Control Cabinet and TPEM I/O Controller must not exceed 100 meters.

- TPEM Rendezvous Server (TPEM RVS)
  - The TPEM Rendezvous Server enables access to the TPEM system with a TPEM Remote Client via the internet.
- TPEM Remote Client (TPEM RC)
  - The TPEM Remote Client is the piece of software used for visualization of the TPEM system on a computer. It differentiates between two access modes:
  - a) for the Caterpillar Energy Solutions service: remote diagnostics and remote maintenance of the plant
  - b) for the operator: remote operation and remote monitoring of the plant
- TPEM USB token
  - The TPEM USB token regulates authentication for local access and remote access to the TPEM system.
- TPEM PLE
  - The TPEM PLE permits the integration of the TPEM system into the technologies and services of Remote Asset Monitoring (RAM).

Function

The TPEM system comprises all functions that are required to ensure a reliable, comfortable regulation and control of the gas engine genset and the plant associated with it. These functions are:

- Control of the actuators and signal analysis of the sensors on the TPEM I/O Controller in the auxiliary cabinet (HAS); data transfer to and from the TPEM Control Cabinet (TPEM CC).
- Test mode for verification of connected actuators, sensors and auxiliary drives.
- Recording of measured values (history) for checking and diagnostic purposes.
- Integrated data processing and monitoring of the sensors and actuators for electrical faults such as cable break and short-circuit.
- Recording of alarms, warnings, operating messages and parameter changes with their dates and times of occurrence. The recordings are used for detailed monitoring of the operation.

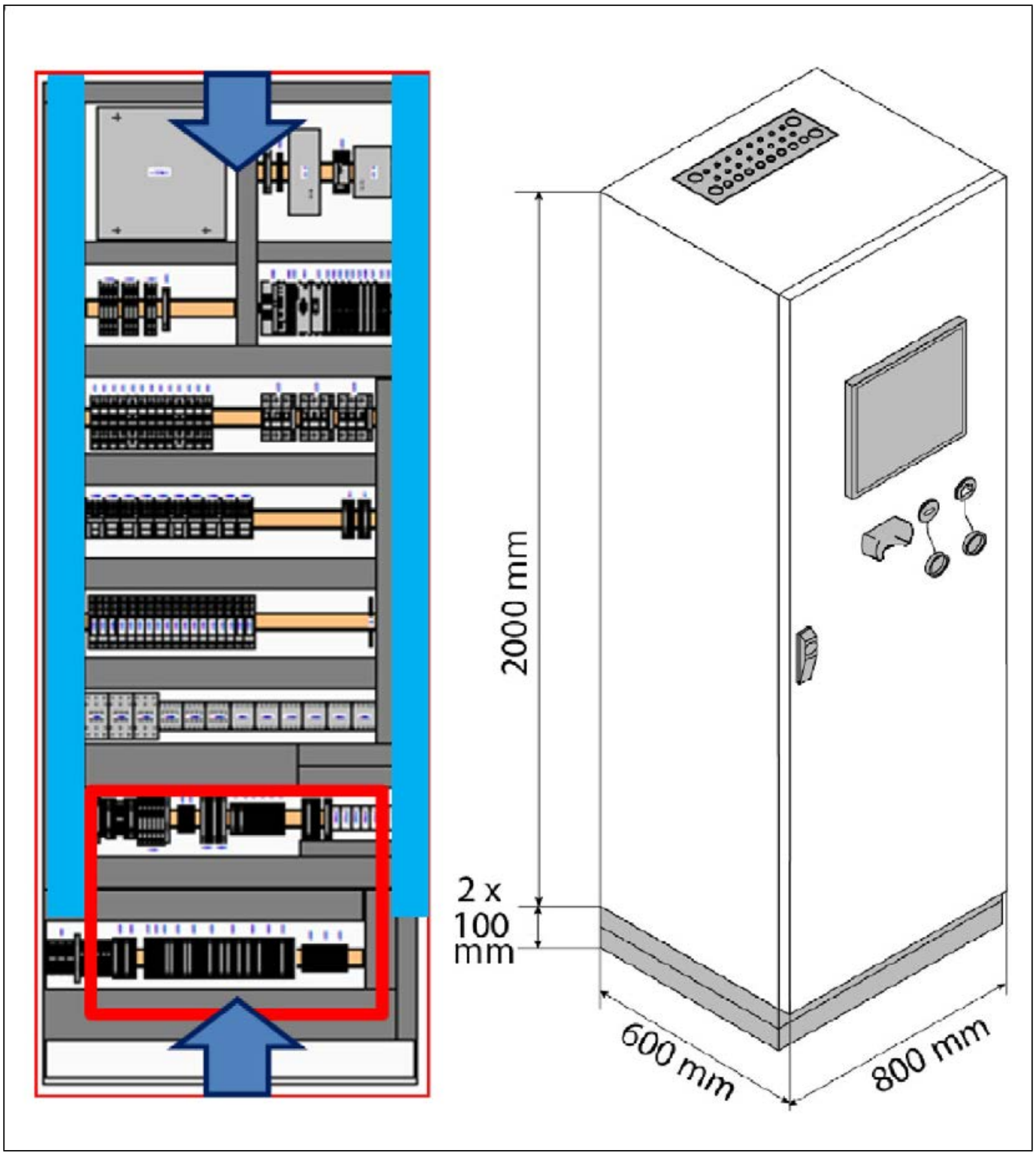
- Possibility for the connection of a service laptop to a service PC interface directly on the TPEM Control Cabinet.
- Operator access to the TPEM control via Rendezvous Server and TPEM Remote Plant Gateway e.g., for remote diagnostics, remote maintenance and connection to a local network.

Depending on plant-specific features, the TPEM system can be expanded and flexibly adjusted with special functions.

14.3.2 TPEM Control Cabinet (TPEM CC)

The following illustration shows the TPEM CC. All the necessary terminal strips for connecting the TPEM CC are in the bottom of the switchgear cabinet (see area marked red in the illustration).

Furthermore, the TPEM CC allows for cables to the connection terminal to enter from above. A pre-punched perforated plate is fitted in the ceiling of the switchgear cabinet (see upper gray arrow in the illustration). The cables connected from above are guided to the connection terminals in the lower part of the switchgear cabinet via the cable ducts installed on the side walls (see lower markings in the illustration). The relevant cable specification must be taken into account for the wiring from the TPEM CC to the TPEM CB.



3693569163: TPEM Control Cabinet (TPEM CC)

TPEM MFR

The MFR (Multi Function Relay) contained in the TPEM Control Cabinet controls the generator circuit breaker and, when necessary, the mains circuit breaker. Except in island operation and island-parallel operation, information on the status of the mains circuit breaker must be available for the MFR. Furthermore, the MFR supports the following generator protection functions and mains protection functions in accordance with the ANSI standard.

Generator protection function	
Number as per ANSI/IEE C37-2	Function
81O/U	Overfrequency and underfrequency
59/27	Overvoltage and undervoltage
51 V	Time-dependent overcurrent
50	Present overcurrent
46/47	Unbalanced load (not permissible in Germany)
32/32 R	Overload and reverse power
25	Synchronization check

Table 34: Generator protection function

Mains protection function	
Number as per ANSI/IEE C37-2	Function
81O/U	Overfrequency and underfrequency
59/27	Overvoltage and undervoltage
78	Time-dependent overcurrent
25	Synchronization check

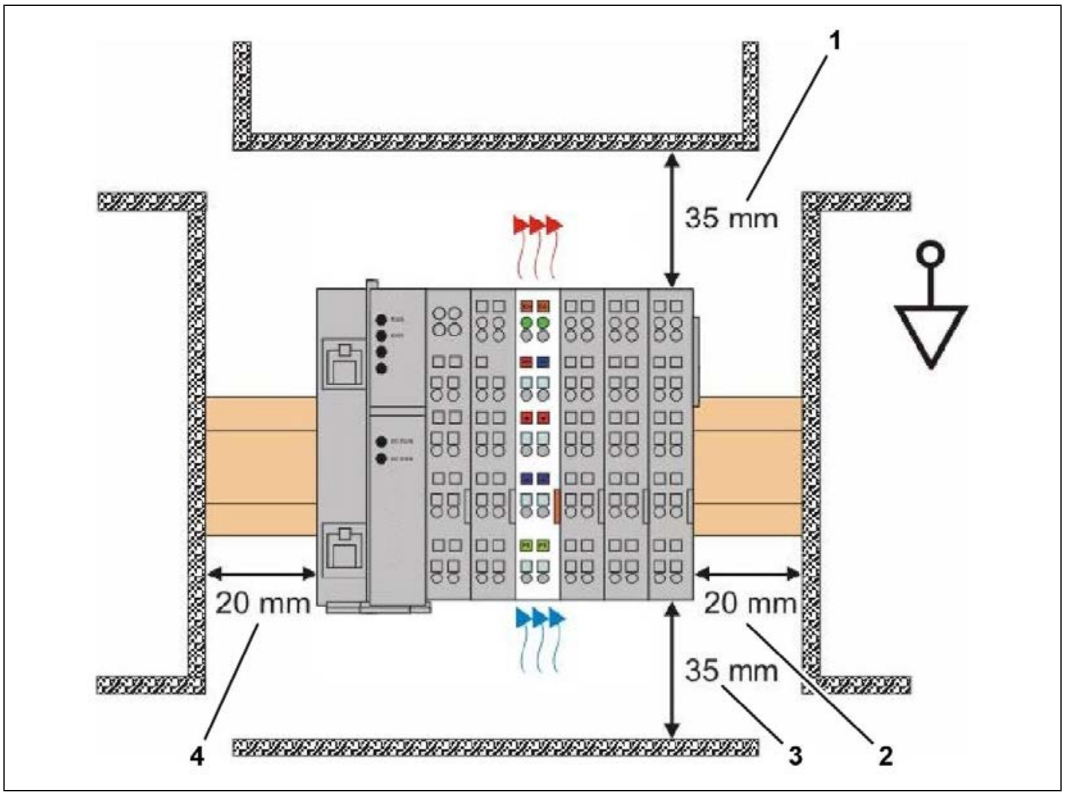
Table 35: Mains protection function

Notes on TPEM Control Cabinet

- The base of the TPEM Control Cabinet can be split up to reduce its height. This can produce base heights of 100 mm and 200 mm (see illustration above).
- It is recommended that the TPEM Control Cabinet be set up in an air-conditioned switchgear room.
- The maximum distance from the gas engine genset (TPEM Connection Box) is 100 meters.
- Pre-assembled cables with lengths of 25, 50, 75 and 100 meters are available as order options for connecting the TPEM Connection Box and the TPEM Control Cabinet. If necessary, a further adjustment of the length of the cables can be carried out. The cable specification is provided by Caterpillar Energy Solutions.

14.3.3 Installation notes for the TPEM I/O Controller

The I/O Controller must be installed in a horizontal 35 mm top-hat rail (DIN EN 60715) in a switchgear cabinet. The modules must be installed vertically (see next illustration). In order to guarantee sufficient ventilation, the distances shown in the following illustration must be observed.



3693639819: TPEM I/O Controller - Installation dimensions

1	Clear space above I/O modules	2	Distance from side panel
3	Clear space below I/O modules	4	Distance from side panel

14.3.4 Technical data

TPEM Control Cabinet (TPEM CC)		
	Dimensions (H x W × D)	2200/2100 × 800 × 600 mm
	Degree of protection	IP45
	Permissible operating temperature	5 °C to 45 °C
	Cable inlet alternatively from the bottom or from the top	

Table 36: TPEM system technical data

TPEM I/O Controller		
	Dimensions **without** grid code (W × H × D)	340 × 100 × 70 mm
	Dimensions **with** grid code (W × H × D)	500 × 100 × 70 mm
	Degree of protection	IP20
	Permissible operating temperature	5 °C to 45 °C

14.3.5 Operation of the TPEM system

Easy operation of the TPEM system is ensured by an intelligent operating computer with a 15" touch panel that can be used intuitively to access all functions. The operator can use the navigation bar to quickly and directly change the mask displayed to operate the genset. Each operating mask informs the operator of the current status of the connected genset. All regulation functions, service functions, control functions, and monitoring functions can be operated conveniently without a lengthy training period. Communication with the user can take place in English, German, and over 20 other system languages. The language can be changed at any time by pressing a button. Service work may be temporarily performed in a different language to that used by the site staff.

14.3.6 Logbook

The operating logbook of the TPEM system ensures transparent operation of the gas engine genset, its peripheral components and the mains connection. All operating messages and operationally-relevant switching actions as well as all parameter changes are recorded with a clear time stamp (date and time). As a whole, the TPEM system is able to monitor and distinguish between over 600 different events. This makes it possible to provide a fast and detailed analysis of the genset operation, including the TPEM-controlled auxiliary functions.

14.3.7 History

The History function records all measured values. These can be displayed together in a single diagram when needed. The user can compile the measured value curves themselves.

14.3.8 Diagnostic functions and service functions

In addition to the history and operating messages, the TPEM system contains additional diagnostic functions and service functions that contribute significantly to the high availability of the gas-engine module. Commissioning also becomes easier and faster using these functions.

Masks for service and diagnostics are available for:

- Auxiliaries test mode
- Electronic ignition system
- Parameterization
- Oil change
- Operating hour counter

14.4 Switchgear cabinets and modules

14.4.1 Auxiliary drives control and supply - Auxiliary cabinet (HAS)

In addition to the TEM system and TPEM system, a typical plant includes one cabinet for auxiliary drives, synchronization and generator protection for each genset, as well as the appropriate charging equipment. Auxiliary drives include all power supplies for pumps, control valves, butterfly valves, fans, radiators etc. The synchronization function ensures synchronous connection to the mains by precision balancing. Control of engine speed is balanced to the mains frequency under consideration of voltage and phase relation. Generator protection covers all necessary and recommended monitoring facilities for generators as per ISO 8528-4.

Multi Function Relay

For TEM systems, the TEM MFR is located in the auxiliary cabinet (HAS). The TEM MFR corresponds to the TPEM MFR in TPEM plants.

- For more information: TPEM Control Cabinet (TPEM CC) [▸ 258]

Buffer battery

A separate voltage supply with 24 V must be ensured via a buffer battery. Among other things, this serves to keep the plant sensor system and plant control system active even in the event of a power failure. Furthermore, it ensures that the ignition can still be active in the event of a power failure. This is usually necessary when the genset runs down so that residual amounts of ignitable mixture in the engine are completely burned off and no ignitable mixture enters the exhaust pipe.

14.4.2 Power part - Generator circuit breaker cabinet (GLF)

GLF for voltages in the low voltage range

The power part includes the generator circuit breaker (GCB). The current transducers are also located in the power part. In the case of voltages < 1 kV, the voltage is tapped directly from the rail.

We recommend fitting the GCB with an undervoltage coil to ensure more reliable triggering of the circuit breaker if the supply voltage in the On/Off circuit switch fails, for example.

In accordance with the control technology monitoring concept, an undervoltage coil opens the GCB in response to the situation.

GLF for MV voltage plants in the medium voltage range

The power part includes the generator circuit breaker and the corresponding transformers to protect the generator. The current and voltage transducers are likewise located in the power part.

14.4.3 Central plant control - Master control cabinet (ZAS)

The ZAS is used for central control of several gensets. The functionality depends on the project engineering. The ZAS includes:

- Integrated PLC (Programmable Logic Controller)
- Local operating level via touch panel

Functions of the ZAS for the individual gensets:

- Automatic or manual selection and deselection
- Genset power demand
- Specification of the operation mode (grid-parallel operation, island operation, back-up power mode)
- Mains consumption control
- Load share

Possible additional functions of the ZAS:

- Controlling the different operation modes
- Gas type selection
- Mains failure monitoring
- Controlling and monitoring the lube oil supply and waste oil disposal (lube oil service tank, waste oil tank)
- Controlling and supplying central pumps
- Controlling and supplying central dump cooling facilities
- Monitoring and controlling a heat storage tank

- Gas tank level-dependent operation
- Controlling and supplying the ventilation system
- Controlling and supplying the gas warning system
- Controlling and supplying fire safety facilities, etc.

In addition, a manual operating level must also be provided to allow local control of the plant in the event of a failure of the process management system.

14.4.4 Grid Demand Interface (GDI) module and TPEM Grid Code I/O Controller

The Grid Demand Interface (GDI) PLC module implements the control functions stipulated in the grid code regarding active power, reactive power and connection in TEM systems and TPEM systems at the energy supply unit level. It provides the required interfaces to the genset, operator of the energy supply plant and grid operator. Control of the entire energy supply plant (EZA controller) by the GDI is not provided. It is a closed system whose functionality may not be modified or extended by anyone outside Caterpillar Energy Solutions.

The functions for fulfilling the grid connection regulations include, for example:

- Checking the connection conditions for voltage and frequency in the normal state
- Checking the connection conditions for voltage and frequency after mains decoupling
- Active power limitation by grid operator via digital and analog specifications (as part of the grid safety management)
- Frequency-dependent active power adjustment at overfrequency and underfrequency (Limited frequency sensitive mode - underfrequency and over frequency, LFSM-U and -O)
- Selection of required active power ramps at various grid conditions (normal operation, setpoint value specification by third party (direct sales), active power limitation by grid operator, LFSM, connection after mains decoupling of the energy supply unit) operating modes for the provision of reactive power, such as:
  - Cos(f) specification
  - Q(U) characteristic curve
  - Q(P) characteristic curve
  - Reactive power specification with voltage limitation
- Parameterizable switchover of the reactive power mode or relevant setpoint as reaction upon failure of the telecontrol connection to the grid operator

14.5 Notes for planning and implementation

When equipping and installing switchgear systems, in addition to the generally acknowledged rules of engineering, particular attention should be paid to the following regulations:

- Low Voltage Directive 2014/35/EU
- EMC Directive 2014/30/EU
- DIN EN 50156-1:2016-03
- DIN VDE 0100 Part 0410 (IEC 60364-4-41)
- VDE 0660-600-2 (DIN EN 61439-2, IEC 61493-2)
- If applicable DIN EN 602014-1 and DIN EN 60204-1
- DGUV regulation 3, Electrical installations and equipment
- UL 508, CSA 22.2

When working in control cabinets and switchgear cabinets with electric assemblies, DIN EN 61340-5-1 (IEC 61340-5-1) must be observed. Handling electrostatically sensitive components (e.g., circuit boards) is set out in the service bulletin (explicit reference is made here to DIN EN 61340-5-1).

The switchgear systems must be designed for ambient temperatures of 0 °C to 40 °C and for a relative humidity of 5 % to 70 %. An exception to this is the TEM control cabinets. In these, the internal temperature of the switchgear cabinet may rise to 45 °C.

If necessary, the lost heat of the switching device combinations must be dissipated by means of thermostatic controlled ventilators in order to avoid exceeding the permissible internal temperatures. Switchgear rooms must always be air-conditioned. The air conditioning keeps the temperature and relative humidity at a constant level. Direct sunlight contact on the cabinets is to be avoided by means of an appropriate arrangement. Condensation in the switchgear cabinet must be prevented by taking appropriate measures.

15 Power grids and genset connection

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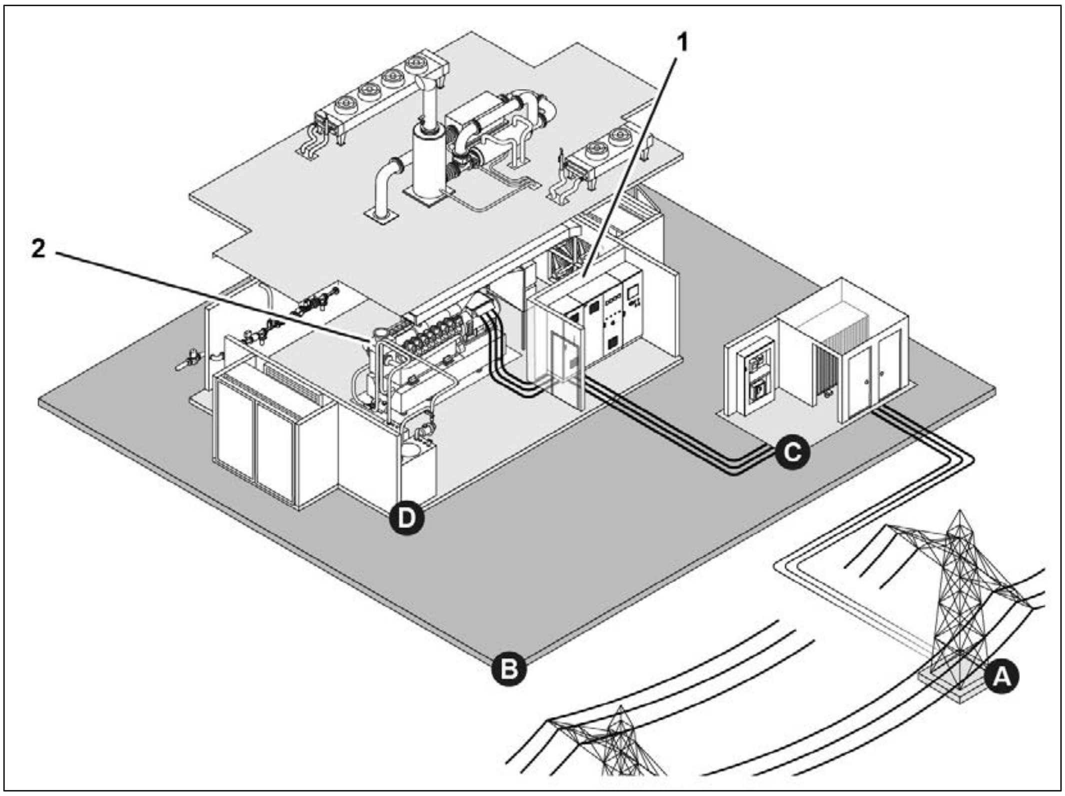
15.1 Grid-parallel operation

15.1.1 System overview

The schematic illustration shows and lists typical components and interfaces to help you get started. Proportions are therefore not to scale and the arrangement is just an example.



3620530571: Simplified example illustration of a typical energy supply plant with grid-parallel connection

A	Power grid of a mains operator	B	Energy supply plant (EZA) of a plant operator with grid-parallel connection to the power grid
C	Closed-loop control or open-loop control of the entire energy supply plant and communication with grid operator	D	Complete energy supply unit (EZE) from CES
1	Switchgear with generator circuit breaker (GCB), auxiliary cabinet (HAS) and TPEM Control Cabinet (TPEM CC) or genset control cabinet (TEM-AGS), depending on the control system	2	Genset for generating power and heat

15.1.2 Structure and function

The participation of central large power stations, decentralized energy supply plants (EZA) and many consumers is characteristic of an interconnected grid (e.g., a medium-voltage network). All power generators are connected in parallel (grid-parallel operation) and generate their AC voltage in the interconnected grid synchronously to the phase position and frequency.

An energy supply plant consists of one or more energy supply units and a superior control. The open-loop and closed-loop control is subdivided according to functionality into:

- Switchgear components for open-loop and closed-loop control of the energy supply unit (EZE) which ensure the desired quality of the voltage for the demanded electrical power
- Switchgear components for energy distribution or energy infeed of the superior energy supply plant (EZA) into an interconnected grid

In order to connect an energy supply plant (EZA) with its energy supply units (EZE) electrically to an interconnected grid, comprehensive specifications from the grid operator and higher-level authorities must be complied with. Specific proof of conformity is required for a grid connection authorization. The type of proof differs from region to region, and should be coordinated with the manufacturer of the energy supply unit during the project planning phase.

15.1.3 Grid code requirements

15.1.3.1 General

Grid codes regulate, among other things, the behavior of power generation plants on the public power grid and, in some cases, on island grids under certain operating conditions. The relevant grid operator specifies the grid code according to the demands of the mains in consideration. For this, the grid operator takes into account regulations coordinated and laid out in associations, as well as national, European, or international committees.

15.1.3.2 Grid code in Germany: Energy supply plants' connection to and parallel operation with the medium-voltage network and high-voltage network

General

Photovoltaic plants, wind power plants, hydroelectric plants and plants with gas engine gensets are becoming increasingly important. The increasing significance is based on the progressive decentralization of power generation through these plants within the mains power supply. The connection requirements of power generators in the medium-voltage network or high-voltage network in Germany are specified in the following directives:

- Energy supply units in the medium-voltage network: VDE-AR-N 4110
- Energy supply units connected to the high-voltage network: VDE-AR-N 4120

According to this new directive, gas engine gensets shall also engage in the static and dynamic grid support alongside photovoltaic plants, wind farms and hydroelectric power plants. Further requirements for active power output, mains feedback, protection settings and connection conditions, for example, must be complied with. In this context, gensets from Caterpillar Energy Solutions are counted as type 1 energy supply units (EZE) due to their synchronous generators being directly coupled to the grid.

Static voltage stability

Static voltage stability refers to voltage stability in the medium-voltage network or high-voltage network for normal instances of operation. Slow voltage changes in the distribution grid are kept within tolerable limits.

Dynamic grid support

In the medium-voltage network or high-voltage network, dynamic grid support refers to voltage maintenance in the event of short-term voltage dips and voltage rises. Voltage stability prevents large feeder lines from disconnecting and the network from collapsing.

Requirements for the gas engine genset

With the technical conditions described above, the requirements for the gas engine genset have changed. Static and dynamic grid support requires a change in the operation of the plant.

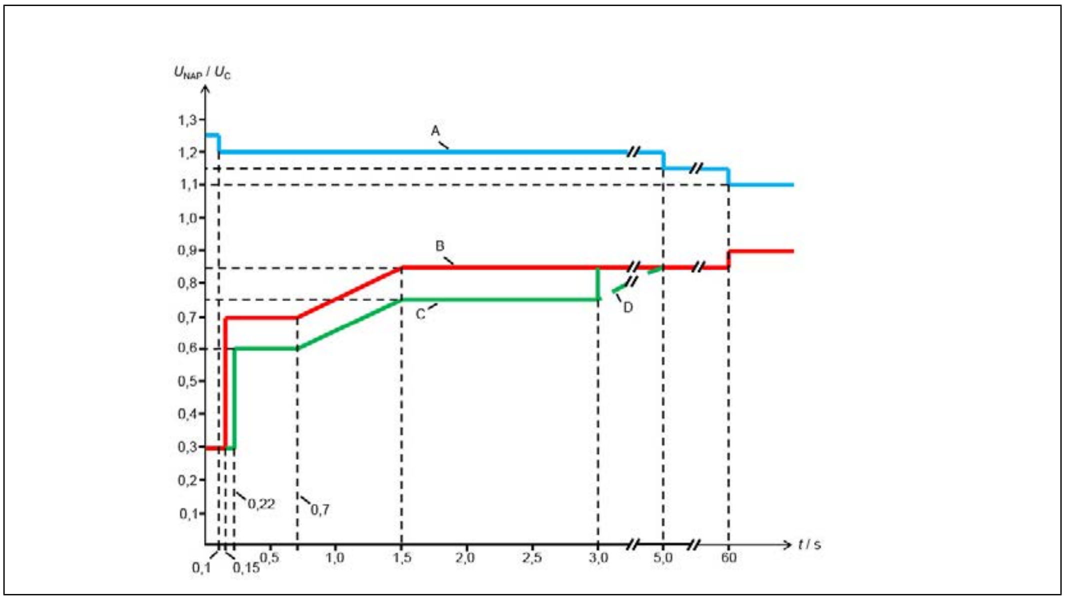
In accordance with the new medium-voltage directive/high-voltage directive, other requirements have to be taken into account:

- Increased voltage range and frequency range
- Power change over frequency
- Power limitation by grid operator
- Variable cos(φ), variable reactive power and reactive power curves
- Dynamic grid support
- Decoupling protection on the energy supply unit
- Connection conditions in normal operation and after mains decoupling

Fault Ride Through (FRT) capability

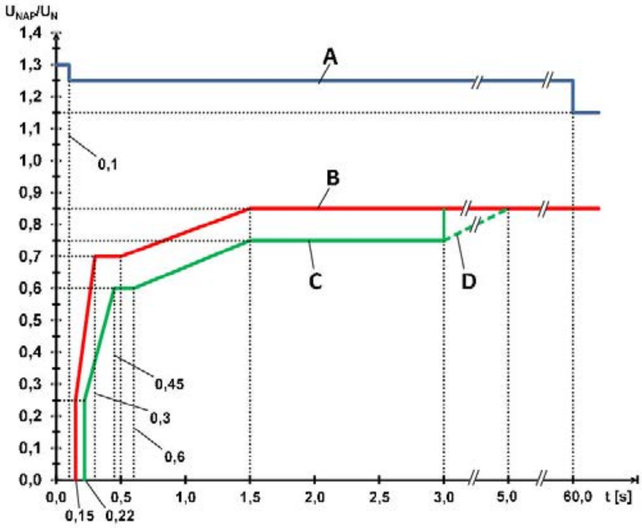
During a sudden change in voltage, the Fault Ride Through (FRT) capability of an energy supply plant or an energy supply unit maintains the grid connection for a certain time and backs up the grid during this time by feeding in reactive power.

The borderlines in the following illustrations describe this type of dynamic grid support. Outside the limit curves, immediate disconnection from the mains is permitted.



3691240587: Borderline for the voltage profile at the grid connection point (in the event of FRT) for a type 1 energy supply plant (medium-voltage network)

A	Upper FRT limit curve	B	Lower FRT limit curve for triple pole errors (type 1)
C	Lower FRT limit curve for double pole errors (type 1)	D	According to ability (dashed line)
t	Time in seconds	U_{NAP}/U_C	Ratio of actual mains voltage to agreed supply voltage



3691242251: Borderline for the voltage profile at the mains connection point (in the event of an FRT) for a type 1 energy supply plant (high-voltage network)

A	Upper FRT limit curve	B	Lower FRT limit curve for triple pole errors (type 1)
C	Lower FRT limit curve for double pole errors (type 1)	D	According to ability (dashed line)
t	Time in seconds	U_{NAP}/U_N	Ratio of actual mains voltage to mains rated voltage

In many cases, the agreed supply voltage U_C is equal to the rated voltage U_N of the grid, but a different supply voltage can also be defined by the grid operator.

The dynamic grid support lays down high technical requirements for the gas engine genset. The genset control and the components (e.g., moment of inertia of the generator) must be adapted for safe operation in the event of an FRT. It is important to ensure that auxiliaries installed in the energy supply plant comply with the requirements.

For a complete overview of the applicable requirements, please refer to the above-mentioned guidelines. During the planning, construction and commissioning of the energy supply plant (EZA), it is important to ensure that all requirements are implemented. This concerns requirements for the individual EZE as well as for the entire EZA.

In each individual project, it is necessary to check which directives must be complied with by the main operator's subscriber at the designated installation site of the gensets, which requirements thus apply to the genset as an EZE controller and which must be implemented on a higher level, e.g., by an EZA controller, a central control system or higher-level decoupling protection. Accordingly, it is necessary to check to what extent the scope of delivery of Caterpillar Energy Solutions can comply with the requirements imposed on it, as this can vary on a project-specific basis between a pure energy supply unit and an energy supply plant within the meaning of the grid connection rules.

Certification of the gas engine gensets

The suitability of the energy supply plant (EZA) for operation in the medium-voltage network or high-voltage network must be validated and confirmed with a certificate by a certification body accredited according to DIN EN ISO/IEC 17065.

The certifier issues a type-specific EZE certificate for the energy supply unit (EZE), in which the relevant technical properties of the EZE are described and evaluated and instructions are given for the integration of the EZE in an EZA and for the EZA certification. These must be complied with. If the properties of the relevant safeguards are not identified in the EZE certificate, the conformity validation is fulfilled by a component certificate of the relevant manufacturer. However, this is only the case if all framework conditions are fulfilled.

Following completion of the complete EZA, the certifier issues an EZA certificate. In a final EU declaration of conformity, the certifier checks the correspondence between the properties of the plant actually installed and the properties of the plant specified in the EZA certificate after commissioning and the associated commissioning declaration.

A calculation model carries out validation of the capacity for dynamic grid support of the gensets. The calculation model is created in commercial grid calculation software as part of the EZE certification and validated by the certification body using measurement data. The measuring results for selected gensets are recorded in a type test: A test device designed for this causes voltage changes according to the illustrations in chapter Requirements for the gas engine genset [▸ 270] with a defined residual voltage and a specified duration. The test device records representative electrical and mechanical variables occurring before, during and after the fault. These variables are thus available for comparison with the results of a simulation of these tests. Finally, stability investigations follow with a worst-case variation of the simulation parameters in order to investigate the most critical cases that can occur in reality.

Further details on the verification process and the IBN, including forms, can be found in the aforementioned guidelines. The EZE certificate is part of the customer documentation. The associated evaluation report, other attached documents and the calculation model are made available by Caterpillar Energy Solutions to the certification body entrusted with EZA certification directly after conclusion of a non-disclosure agreement.

15.1.3.3 International grid code

In addition to Germany, there are country-specific regulations in other countries, both within and outside the EU, which specify requirements for energy supply plants of different power classes with connection to certain grid levels. In view of the increase in decentralized power input and supply with renewable energy, more and more countries are revising or have already revised these regulations.

In Europe, a comprehensive set of regulations for electricity grids has been drawn up by the European Network of Transmission System Operators for Electricity ENTSO-E. The regulation “Network Code Requirements for Generators (NC RfG)” defines the framework conditions and limits for requirements for energy supply plants as an EU directive. Country-specific directives and regulations define the connection of energy supply plants to the public grid in accordance with the NC RfG. Since the adoption of the NC RfG, this provision has to be taken into account in the country-specific directive of the grid code.

A standard for the grid code applicable in Europe was prepared by CENELEC (European Committee for Electrotechnical Standardization). EN 50549 formulates requirements for the connection of energy supply plants to the low and medium voltage distribution grid. An associated standards section, which describes the tests on energy supply units that are necessary for the verification procedure is also available.

Both the requirements for energy supply units and plants and the respective verification process differ, in some cases considerably, from country to country. Therefore, it is important to check in each individual case which guidelines must be complied with at the designated installation site of the gensets by the grid operator's subscriber, which requirements thereby apply to the genset as an EZE and which must be implemented on a higher level, e.g., by an EZA controller, a central control system or higher-level decoupling protection. Accordingly, it is necessary to check to what extent the scope of delivery of Caterpillar Energy Solutions can comply with the requirements imposed on it, as this can vary on a project-specific basis between a pure energy supply unit and an energy supply plant within the meaning of the grid connection rules.

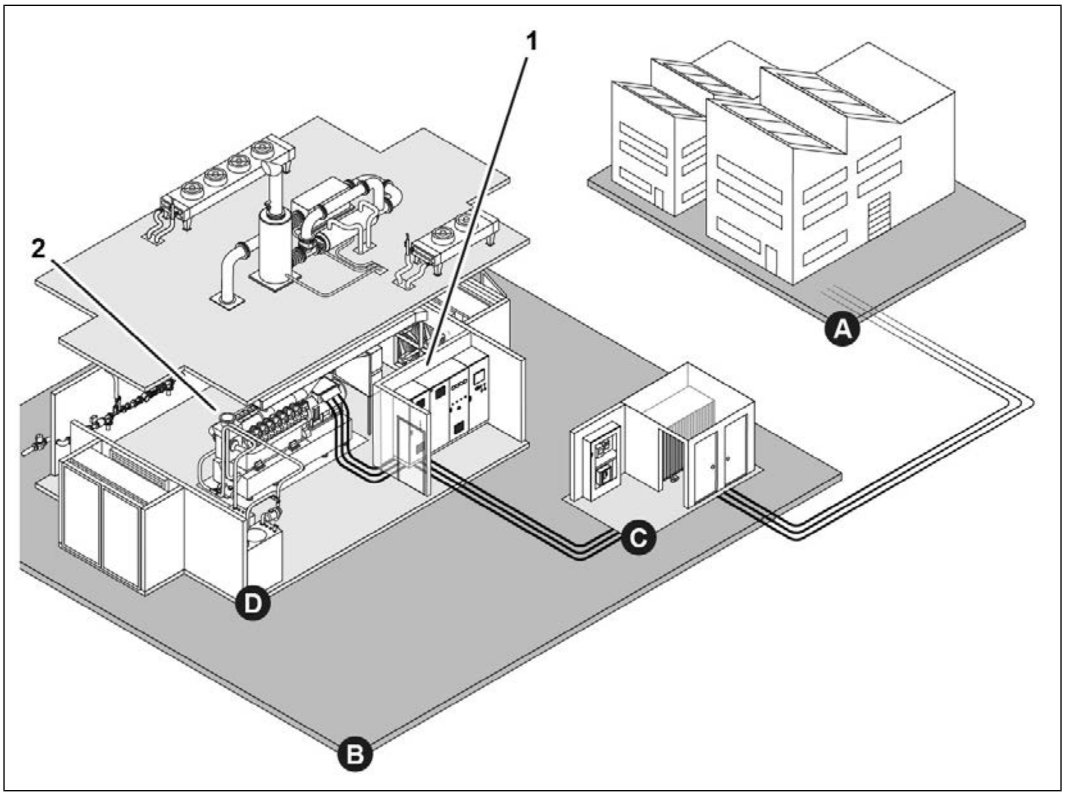
Available guideline-specific disclaimers or manufacturer's declarations from Caterpillar Energy Solutions must be observed.

15.2 Island operation and island-parallel operation

15.2.1 System overviews

15.2.1.1 Island operation

The schematic illustration shows and lists typical components and interfaces to help you get started. Proportions are therefore not to scale and the arrangement is just an example.

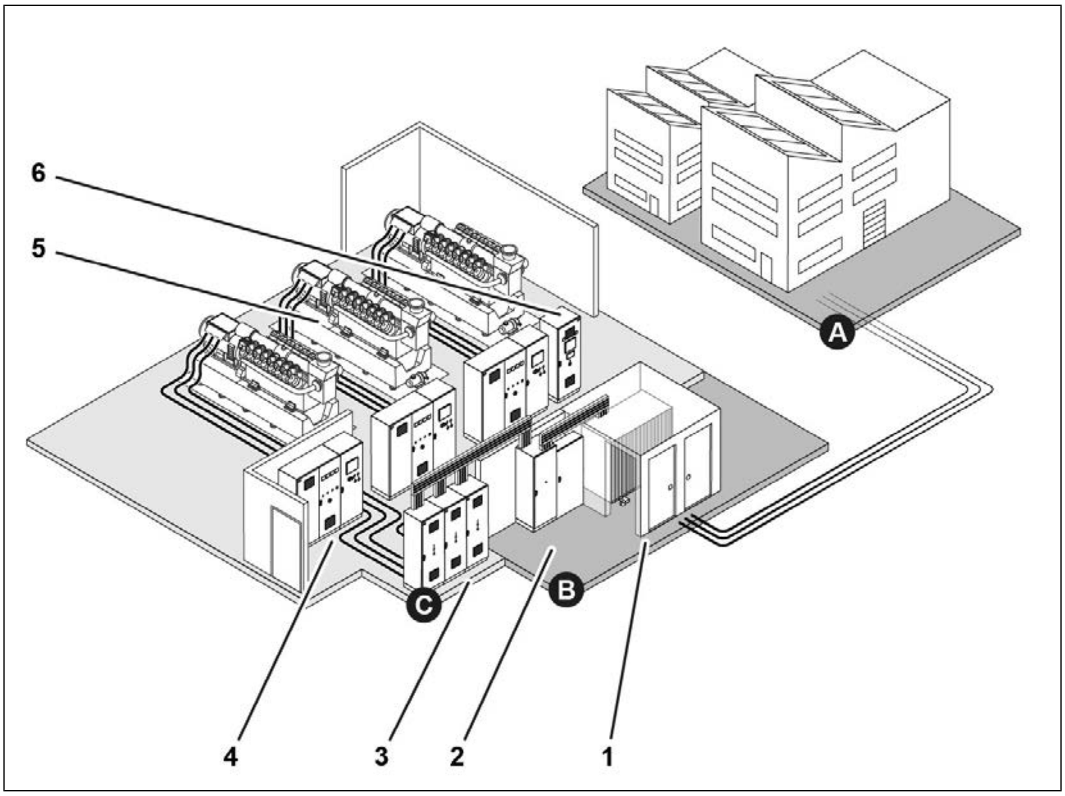


3903076875: Simplified example illustration of a typical energy supply plant with island operation

A	Island grid with equipment for energy distribution and load control	B	Energy supply plant (EZA)
C	Closed-loop control or open-loop control of the entire energy supply plant and communication with the island grid	D	Energy supply unit (EZE) from CES with gensets and switchgear
1	Switchgear with generator circuit breaker (GCB), auxiliary cabinet (HAS) and TPEM Control Cabinet (TPEM CC) or genset control cabinet (TEM AGS), depending on the control system	2	Genset for generating power and heat

15.2.1.2 Island-parallel operation

The schematic illustration shows and lists typical components and interfaces to help you get started. Proportions are therefore not to scale and the arrangement is just an example.

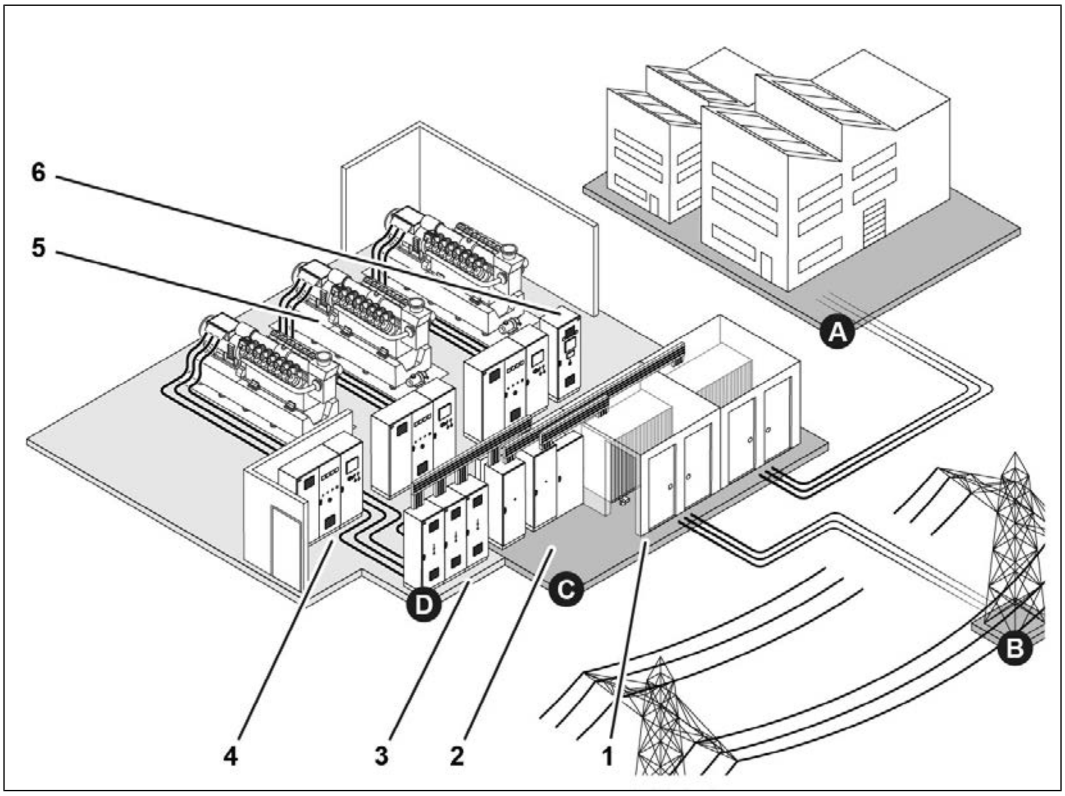


3903077387: Simplified example illustration of a typical energy supply plant with island-parallel operation

A	Island grid with equipment for energy distribution and load control	B	Closed-loop control or open-loop control of the entire energy supply plant and communication with the island grid
C	Modular energy supply units (EZE) from CES with gensets and switchgear		
1	Island connection point with transformers, etc.	2	Mains circuit breaker (MCB) for the island connection with measurement devices, etc.
3	Generator circuit breaker cabinet (GLF) for every energy supply unit	4	Switchgear with auxiliary cabinet (HAS) and TPEM Control Cabinet (TPEM CC) or genset control cabinet (TEM AGS), depending on the control system
5	Gensets for generating power and heat	6	Master control cabinet (ZAS) for controlling the gensets

15.2.1.3 Island-parallel operation with grid connection

The schematic illustration shows and lists typical components and interfaces to help you get started. Proportions are therefore not to scale and the arrangement is just an example.



3903078283: Simplified example illustration of a typical energy supply plant with island-parallel operation and grid connection

A	Island grid with equipment for energy distribution and load control	B	Power grid of a mains operator
C	Closed-loop control or open-loop control of the entire energy supply plant and communication with grid operator and island grid	D	Modular energy supply units (EZE) from CES with gensets and switchgear
1	Mains and island connection points with transformers, etc.	2	Mains circuit breaker (MCB) for the grid connection and island connection with measurement devices, etc.
3	Generator circuit breaker cabinet (GLF) for every energy supply unit	4	Switchgear with auxiliary cabinet (HAS) and TPEM Control Cabinet (TPEM CC) or genset control cabinet (AGS), depending on the control system
5	Gensets for generating power and heat	6	Master control cabinet (ZAS) for controlling the gensets

15.2.2 Structure and function

15.2.2.1 General

On the electrical side, there are different possibilities for operating gas engines. In the majority of cases, the engines run parallel to the public mains. The public mains is viewed as a large system with very high inertia. Load acceptance and load rejections of individual consumers do not cause any drop or increase in the level of voltage or frequency. Gas engines were developed and designed for grid-parallel operation with optimized efficiency. However, in some cases, the customer has no or no continuous public mains access available. For this reason, island operation or island-parallel operation is available as an optional feature.

Two possibilities of island operation are classified:

- Island operation or island-parallel operation after a switchover from grid-parallel operation
- Island operation without public mains access

15.2.2.2 Island operation

In island operation with a gas genset, it is not possible to control the power of the gas genset via the TEM system or the TPEM system. In this case, the power controller is deactivated and the speed control maintains a constant frequency. In island operation, the TEM system or the TPEM system on its own can have no effect on the load of the genset. For this reason, the boundary conditions such as inlet air temperature and engine cooling water inlet must be followed. Therefore, the load acceptance to any gas genset and the load rejection – especially for the highly turbocharged gas gensets (TCG 3016, TCG 2020, TCG 3020, TCG 2032) – must be controlled by the customer's load management system. For this case, maximum permissible load steps for each gas genset have been defined.

Required information

- Transient performance capability (island operation) [▸ 59]

15.2.2.3 Island-parallel operation

For island-parallel operation with gas gensets, the whole plant concept must be planned in detail from the beginning of the planning process. Therefore, the single line diagram and the knowledge of the customer's consumers (real starting power and start-up characteristic) are required in order to achieve a good project status. This applies especially to the starting power and start-up characteristic of large consumers like pumps and ventilators. Another important measure is to analyze the grounding concept for the whole plant.

For island-parallel operation a digital or analog (recommended) load share is required. It is strongly recommended that these are also ordered through Caterpillar Energy Solutions Mannheim. Plants with the TPEM system, load share is possible via the internal TPEM MFR CAN bus. A start-up and shutdown of the gensets must be implemented higher-level in the ZAS or in the customer control room.

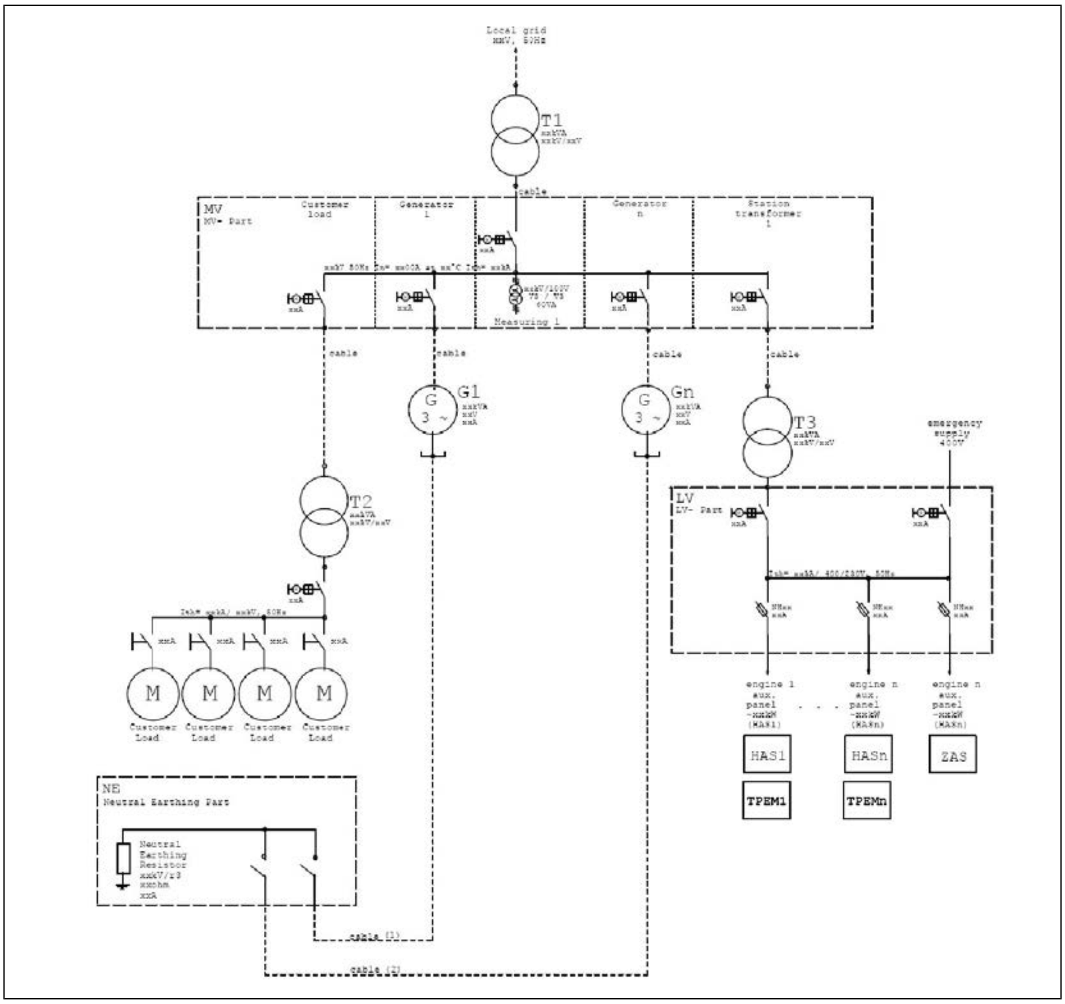
15.2.2.4 Island-parallel operation after a switchover from grid-parallel operation

In normal operation, the gas gensets run parallel to the public mains. The gensets are controlled by the power controller of the TPEM system. The frequency and voltage level of the gensets is set by the public mains. The single line diagram in the illustration below shows a typical layout for an emergency power supply.

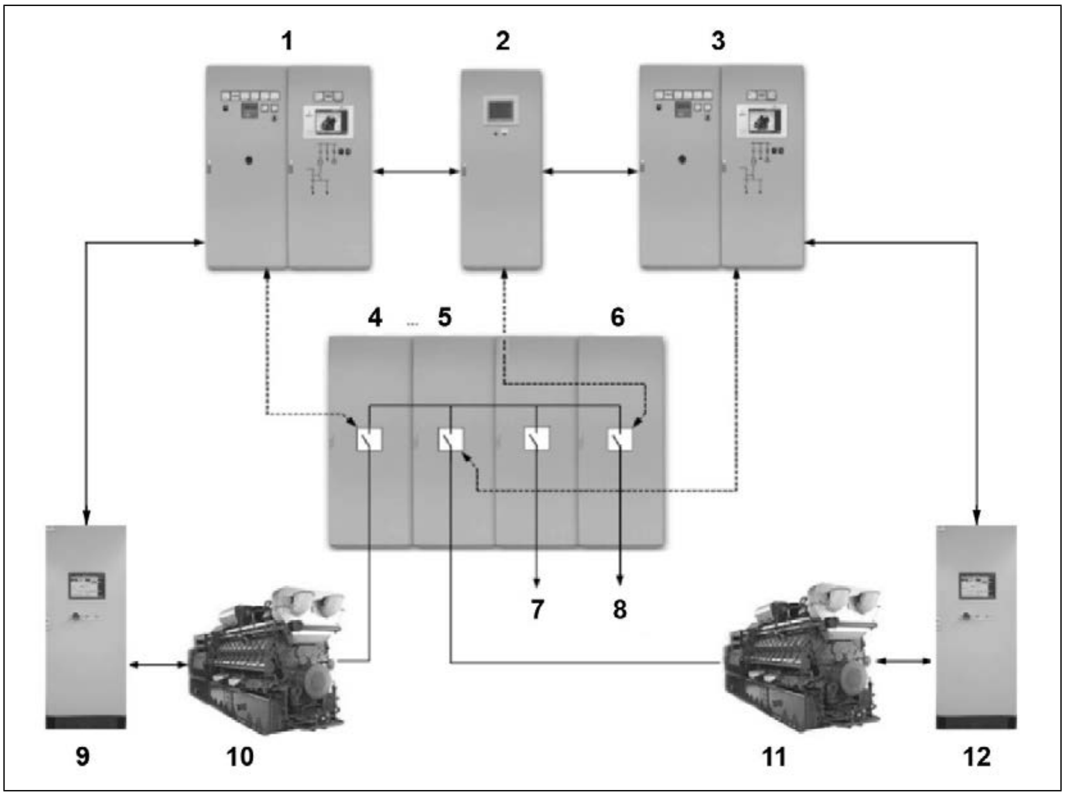
In the event of a mains failure, the mains circuit breaker is immediately opened. In the best-case scenario, the gas gensets will continue to supply the consumers of the customer plant without interruption, otherwise there is a risk of a shutdown with total power failure for the entire system:

- If there is a mains failure, the mains circuit breaker is opened and the gas genset will supply the consumers on the plant.
- The gas engine auxiliary drives are supplied by an auxiliary drive transformer (voltage supply provided by the operator).
- Normally, this transition from grid-parallel operation to island operation causes rapid load changing.
- If this load changing exceeds the relevant load steps, the exhaust turbocharger of the gas engine starts to pump and, in extreme cases, the gas engine is switched off.

To solve this problem, various solutions are available which will be coordinated according to the requirements of the whole plant during project planning. It is important to analyze the behavior of the gas engines together with the consumers to create an suitable concept.



3691467403: Island-parallel operation and grid-parallel operation (TPEM system)



3691469067: Island-parallel operation and grid-parallel operation (TPEM system)

1	Auxiliary cabinet (HAS) for genset 1	2	Master control cabinet (ZAS)
3	Auxiliary cabinet (HAS) for genset 2	4	Generator power field (GLF) genset 1
5	Generator power field (GLF) genset 2	6	Mains circuit breaker (MCB) public access
7	Power supply with internal grid	8	Power supply with public mains access
9	TPEM Control Cabinet (TPEM CC) for genset 1	10	Genset 1
11	Genset 2	12	TPEM Control Cabinet (TPEM CC) for genset 2

15.2.2.5 Island-parallel operation without a public mains

In island operation, it is important to analyze the start procedure and the load acceptance as well as the load rejection. In some cases, it is necessary to provide an emergency diesel or an uninterruptible power supply system (UPS system) to supply the auxiliary drives for prelubrication and aftercooling.

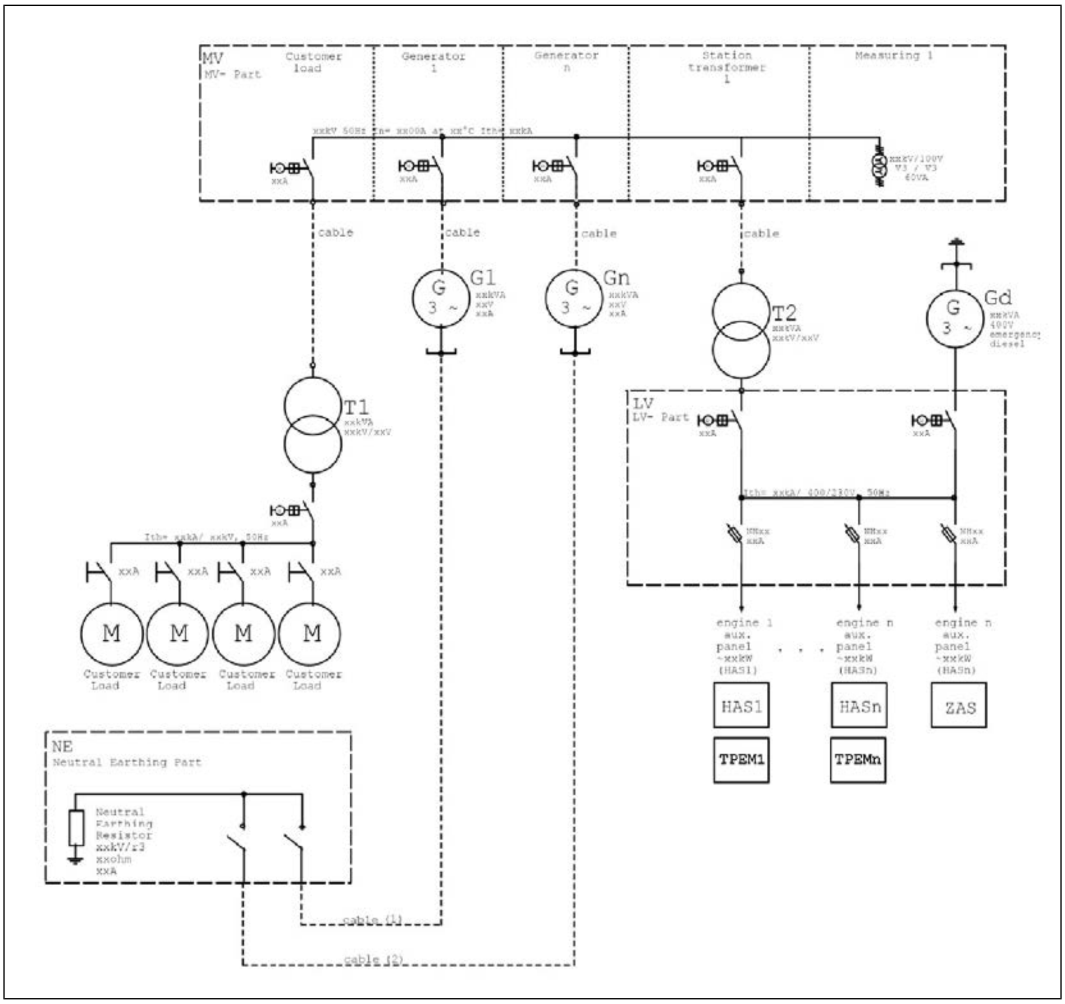
Further information

- Transient performance capability (island operation) [▸ 59]

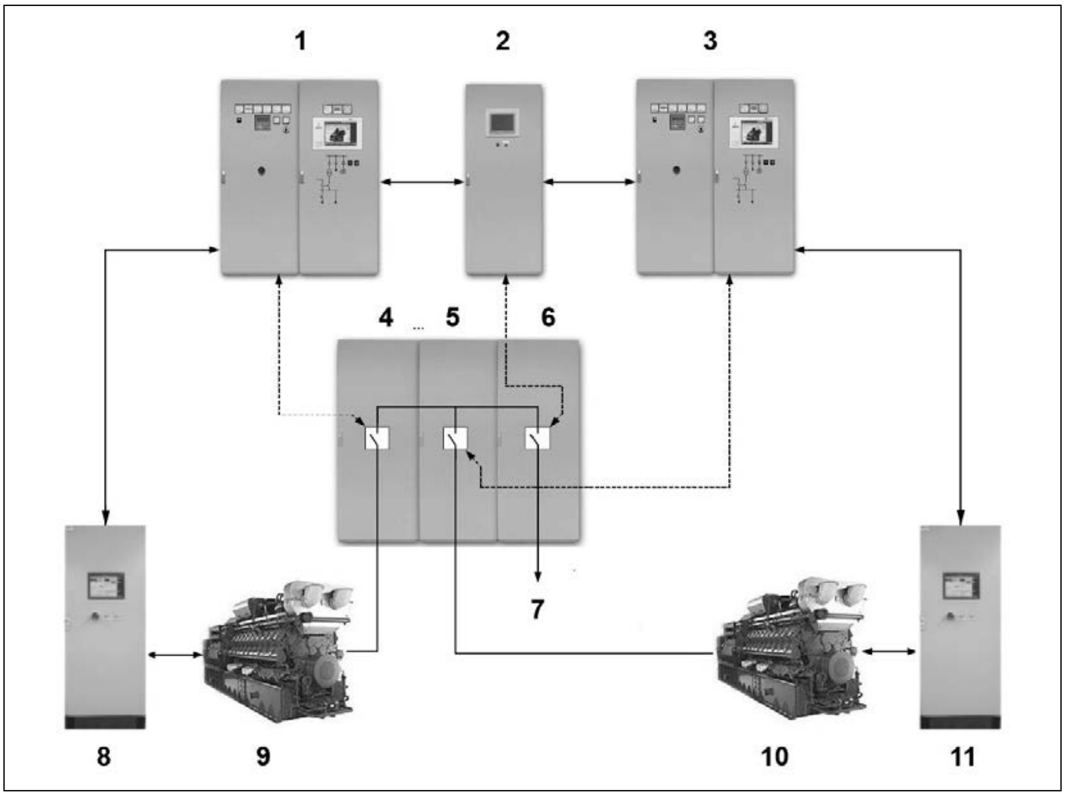
The single line diagram in the illustration below shows a typical layout for this island-parallel operation. The functionality is as follows:

- An emergency diesel distribution is connected to the 400 V distribution, which is started first to supply the auxiliary drives
- Then the first gas genset starts and supplies the customer's consumers and the auxiliary drives via the auxiliary transformer. The load share and load-dependent starting and stopping is implemented via the ZAS
- Now the diesel genset can be stopped. If the operator wants to stop the whole plant, all gas gensets except one are stopped one after another. The stopped gas engines are cooled down
- The diesel genset is now started and synchronized with the auxiliary busbar
- After this, the switch of the auxiliary drive transformer can be opened
- The last gas genset can then be stopped and also cooled down. The heat discharge after the genset is switched off is primarily to prevent the exhaust turbocharger from overheating
- When the after-cooling period has elapsed, the TEM system or TPEM system will stop the genset auxiliary drives and the diesel genset can be stopped as well

The switchover of the power supply for the auxiliary drives can be obtained via an ATS (Automatic Transfer Switch).



3693384843: Island-parallel operation without a public mains



3693386507: Island-parallel operation without a public mains

1	Auxiliary cabinet (HAS) for genset 1	2	Master control cabinet (ZAS)
3	Auxiliary cabinet (HAS) for genset 2	4	Generator power field (GLF) genset 1
5	Generator power field (GLF) genset 2	6	Mains circuit breaker (MCB) public access
7	Power supply with internal grid	8	TPEM Control Cabinet (TPEM CC) for genset 1
9	Genset 1	10	Genset 2
11	TPEM Control Cabinet (TPEM CC) for genset 2		

15.2.3 Notes for planning and operation

15.2.3.1 Fundamentals of project planning for island operation

To design fault-free island operation, the design of the whole plant and the associated customer requirements must be known during the project planning stage.

With the following customer specifications, the necessary requirements can be defined in accordance with the gas engine requirements (load steps, for example) and coordinated with the customer:

- Single line diagram of the whole plant
- Actual starting power and starting conditions of large consumers
- Operating mode of the plant

16 Buildings and installations

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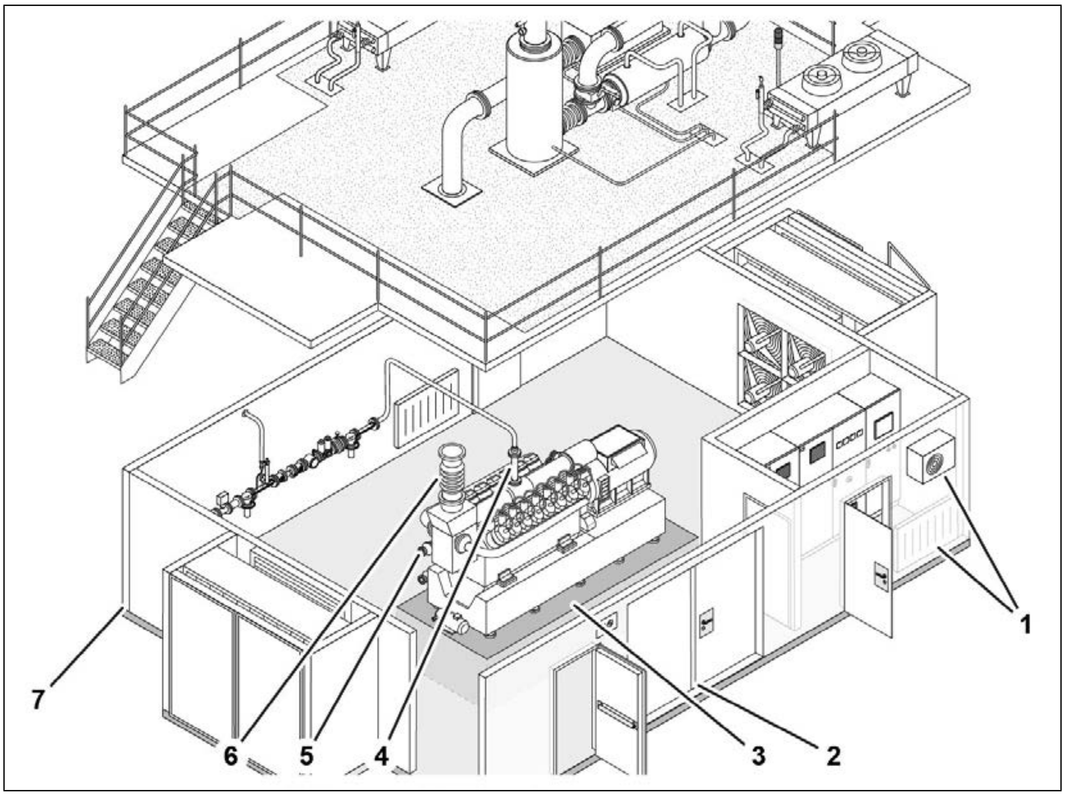
16.1 Overview of buildings and installations

The schematic illustration shows and lists typical components and interfaces to help you get started. Proportions are therefore not to scale and the arrangement is arbitrary.

For clarity, one structure is shown as the machine enclosure. The arrangement is similar in the compact containerized power stations, but the access points to the genset are more restricted.



4064822027: Simplified example illustration

1	Air conditioning equipment	2	Transport opening for the genset
3	Foundation block for the genset	4	Fuel gas expansion joint or gas hose
5	Rubber expansion joint	6	Exhaust expansion joint
7	Machine enclosure (as a structure or container)		

16.2 Requirements for genset installation

16.2.1 Genset room

16.2.1.1 General

Having carefully selected and established the power of the genset, there are a series of preconditions which must be fulfilled by the client. This will achieve a safe, low-maintenance, and fault-free operation.

The most important questions must therefore be clarified at the time when buildings intended to house the energy generation gensets are being planned. In particular these are questions associated with the setup and installation of the genset. Alterations and special solutions introduced at a later date are generally expensive and often unsatisfactory.

Right from the start, consideration should be given to possible future expansion.

16.2.1.2 Requirements for the genset room

The genset room must be of adequate size. Spatial design requirements for operation and maintenance must be observed.

For the TCG 3016, TCG 2020, and TCG 3020, a clear space of approx. 1 m in width should be available all around the genset, increasing to approx. 2 m in width for the TCG 2032. Care must be taken to ensure that the starter batteries are installed as close as possible to the electric starter. For the TCG 2032, an open area (pre-assembly area for the cylinder units) of 2 m x 5 m suitable for cranes is required. Ideally this area is located close to the engine. This means that the pre-assembly area and the genset can be lifted using the same crane. Along with the genset, the other components arranged in the genset room determine the required size of the genset room. Other components include heat utilization unit, switchgear, gas train, fuel tank, oil tank, starter battery, exhaust line and mufflers. The mufflers for the supply air and outlet air also require a considerable amount of space. It is essential to design large enough openings for installing the genset and for venting the plant.

- Required information: Machine room ventilation [▷ 115]

Either permanently installed lifting equipment must be available, or defined lifting points or slide rails must be provided for supporting the lifting equipment. Supporting installations and equipment for lifting processes must be designed and selected at least for the heaviest individual component to be lifted. The maximum permissible load must be clearly indicated on all load-bearing installations. Depending on the engine type, it must be guaranteed that, when carrying out maintenance work, e.g., pistons, con-rods, cylinder heads or even a complete engine can be lifted. Both assembly and subsequent maintenance can then be performed more quickly and more practically.

The genset room must be of sufficient height to allow pistons and connecting rods to be withdrawn upwards, taking the lifting equipment into account. The length and width of the genset room must be of adequate size to allow unimpeded work on all points of the genset. Space for putting down individual genset parts and spare parts must also be available.

For TCG 2032 series engines, maintenance platforms must be provided on both sides for reaching the cylinder units and other engine components during maintenance work. Mobile work platforms are also suitable provided they are designed in such a way that all planned work can be carried out safely.

Together with the planning of the genset room, the anti-vibration mounting and the design of the foundation block must be clarified. Furthermore the laying of piping and cable ducts requires careful planning. The implementation of any special noise protection and anti-vibration isolation measures must also be considered in the early stages.

Generally for smaller genset outputs, the genset and the switchgear can be set up in one room. For larger plants, it may be more practical to set up the switchgear in a separate, sound-proofed operating room.

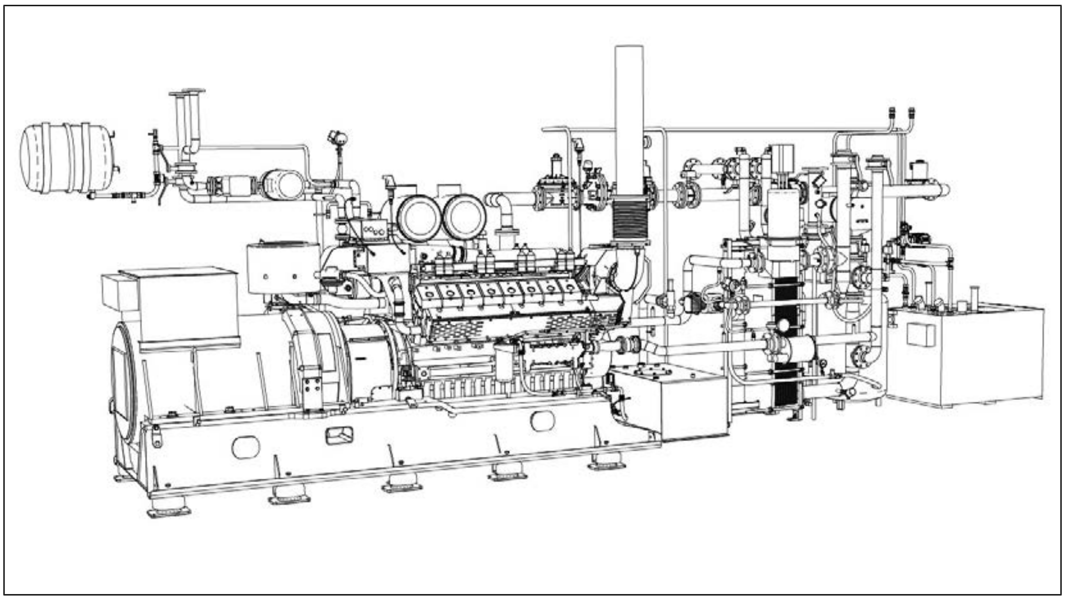
When planning the genset room, consideration must also be given to the transport route, so that, if necessary, an engine or generator can be removed and reinstalled. In particular, the load bearing capacity of the floor must be adequate and there must be sufficient space available.

The following illustration shows a practical and proven genset installation.

If access to the genset and its components is heavily restricted, e.g., due to the genset room not being designed large enough, additional costs may be incurred when working on the genset. For work involving commissioning, maintenance or modifications, additional expenditure and high costs may be incurred because of poor accessibility. There is no flat-rate cover for these additional costs and they must therefore be borne by the contracting party.

When operating and when performing maintenance work on the genset, lube oil and/or coolant can enter the genset room under certain circumstances. Retention devices must be provided in the genset room drainage system to reliably prevent environmental damage from these substances.

As a rule, the entire room in which systems with water-hazardous liquids are located should be designed as a water-resistant and oil-resistant sump. This sump should always be able to contain the largest possible leaks.



3720786827: Installation example

16.2.1.3 Site

The planning process begins with the selection of the setup site for the genset. In order to minimize losses in the transmission of energy to the consumer, it makes practical sense to arrange the genset in the vicinity of the consumer. The fuel gas supply, connection to the mains, noise requirements and exhaust emissions are some important aspects that are of great importance for determining the location and must therefore be considered.

Where a building is designed solely for supplying energy, the problems of ventilation, vibration damping, fuel supplies and storage, and also of installation and accessibility are generally easier to resolve than for existing buildings that were previously used for different purposes.

In the case of large buildings such as department stores, hospitals and administration buildings, genset rooms must be located as near as possible to an outside wall. This allows the cooling air and ventilation air to be supplied and discharged without any difficulties. The genset room can be designed at ground level, below ground, or in the case of smaller gensets, even on one of the upper floors.

The choice of building materials must take account of the need for sound and vibration damping.

16.2.2 Maintenance area

16.2.2.1 General

A maintenance area must be provided around the genset in the machine enclosure. The following specifications provide orientation for the planning of the size, setup and statics of the machine enclosure and its rooms.

In order to design the genset so that the necessary maintenance work can be performed safely, professionally and properly, at least the following is required:

- Sufficient free space to be able to safely and properly move and put down components
- The possibility to work safely and properly with load handling equipment

In addition, there are the customary energy supply, lighting, steps, protective devices, etc., which will not be further described.

16.2.2.2 Spatial design

NOTE

It must be possible to safely access the maintenance points on the genset. In addition, a minimum free space must be provided to ensure safe working.

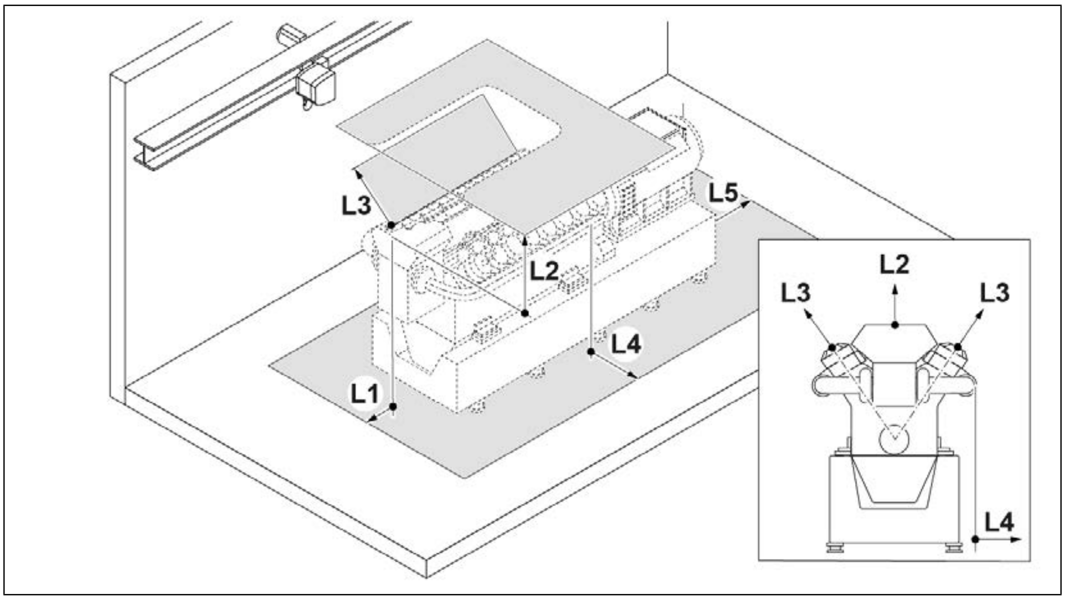
Various specifications apply depending on the region, for example for safe access to the maintenance points or the ergonomic design of the workstation. These can deviate from the specified values and must then be complied with.

Free space around the genset

The specified dimensions apply for machine enclosures realized as a building. The free spaces consider the dimensions of the components and the required routes for the removal and installation and the possibility to perform work quickly. They apply only for single components (e.g., flywheel) or assembled components (e.g., cylinder units) in accordance with the procedure specified by the manufacturer for maintenance work.

The following free spaces shown in the illustration below must be provided during planning:

- A freely accessible, open and walkable area with a width L4 must be provided on both longitudinal sides of the genset. For the TCG 2032 series, permanently installed maintenance platforms must be provided on both sides in this area
- On the free end of the genset (gas engine), an accessible area with width L1 for the dismantling and servicing of components installed on the genset
  - Depending on the situation, components that supply the genset must be arranged in this area (for example, circulating pumps, filters, mixing coolers). In this case, sufficient interspace for hands and tools must be provided on the free end to make work easier. In the case of extensive maintenance work (for example removal of vibration dampers, camshafts), it must be possible to quickly disassemble the components located in the free space.
- A freely accessible, open and walkable area with width L5 must be provided on the free end of the genset (generator)
- A freely accessible, open space with height L2 over the genset
- A freely accessible open space with length L3 in the extension of the cylinder axes
- Lengths L2 and L3 are the minimum distances from the top side of the component to be lifted to the bottom edge of the anchor point. The resulting height of the room depends on the type of anchor points, their structure and fastening as well as the general specifications for the room heights



3720791051: Simplified example illustration

Item	TCG 3016	TCG 2020, TCG 3020	TCG 2032
L1	500 mm	500 mm	500 mm
L2	1200 mm	1200 mm	2200 mm
L3	1200 mm	1200 mm	2500 mm
L4	1000 mm	1000 mm	2000 mm
L5	1000 mm	1000 mm	1000 mm

Table 37: Genset free spaces

Exceptions

Compact machine enclosures (containerized, for example) do not always offer enough space to comply with the specifications listed here. Smaller free spaces are possible to a limit extent, but they can lead to greater maintenance effort and longer work times.

The following applies for the passage widths:

- Wider than 600 mm, preferably 800 mm

If this passage width cannot be complied with in narrow points, the following applies:

- A documented risk assessment indicates the reason and determines the safe passage width for each narrow point
- The passage width in narrow points is wider than 500 mm

16.2.2.3 Possibility to move components

NOTE

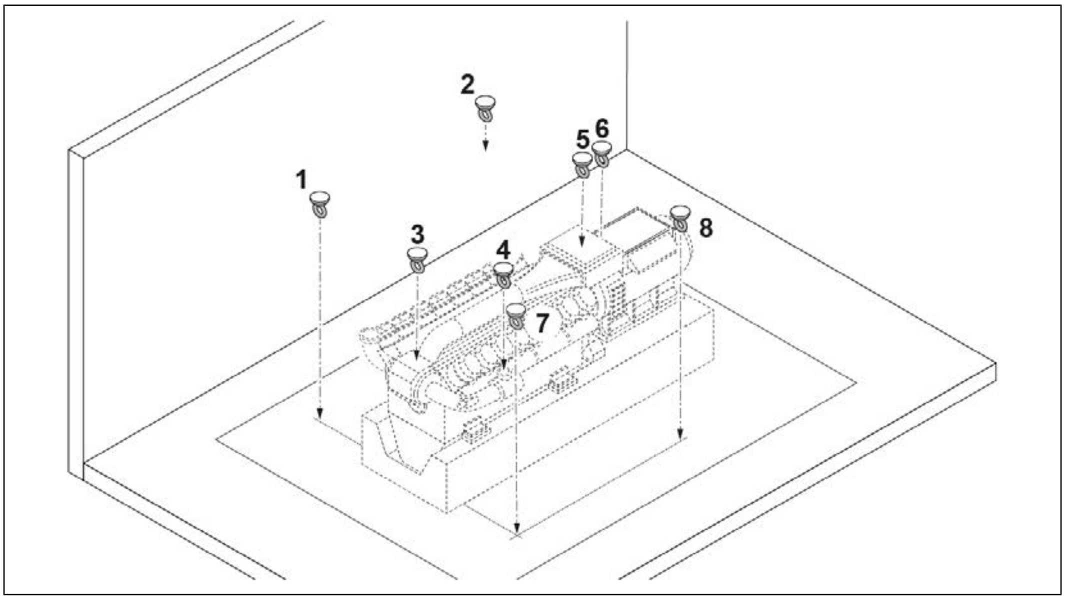
The specified loads are minimum values for the selection of lifting equipment. They apply only for single components (e.g., flywheel) or assembled components (e.g., cylinder units) in accordance with the procedure specified by the manufacturer for maintenance work.

The loads are determined for a vertical and static load of the anchor point. If it is not possible to transport the components with the transport equipment in the lateral free space, the component must be fastened in both anchor points and moved such that the load angle deviates as little as possible from the vertical. Larger deviations must be considered during the design phase.

Depending on the region, different safety margins apply for the load in order to determine the maximum permissible load of the load handling equipment.

For gas engine TCG 3016

The following illustration shows a schematic representation of the main arrangement of the fastening possibilities above the free area. The actual position depends on the concrete order. A drawing with the genset measurements is available from the manufacturer.



3720795275: Simplified example illustration TCG 3016

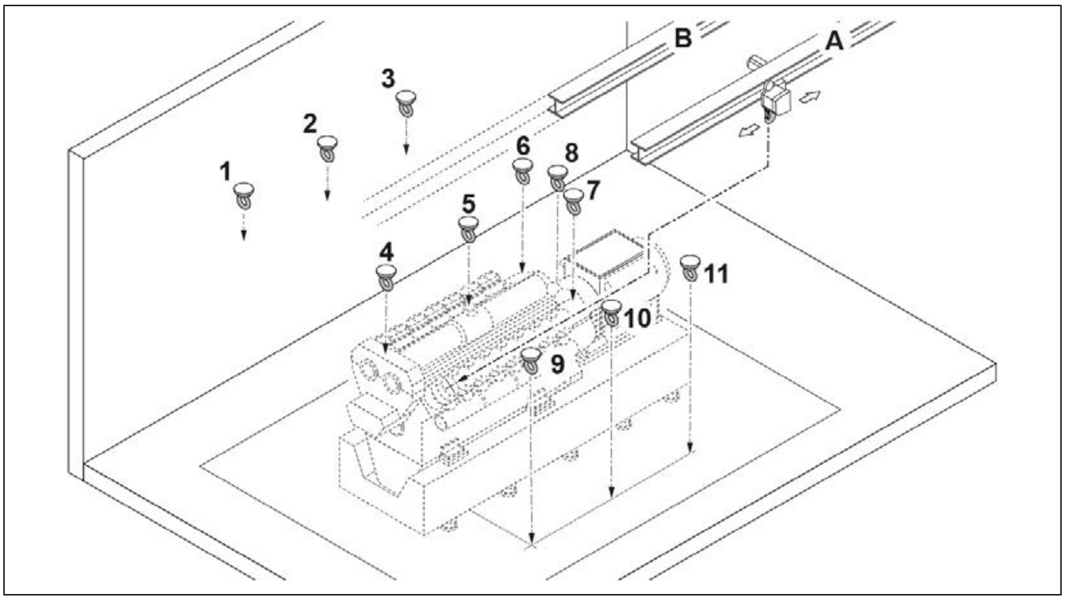
Item	Location	Loads (minimum)	Type
1 - 2	Above the free space on cylinder side B	250 kg	Minimum single anchor points in the structure, for example on the ceiling. The lateral anchor points lie aligned and
3	Above the exhaust turbocharger		

Item	Location	Loads (minimum)	Type
4	Above the gas-air mixer		perpendicular to the anchor points above the genset. Alternatively, the single anchor points 1 – 2, 3 – 6 and 7 – 8 can be replaced with profile rails for mobile lifting equipment.
5	Above the mixture cooler		
6	Above the flywheel		
7 - 8	Above the free space on cylinder side A		

Table 38: Loads TCG 3016

For gas engine TCG 2020, TCG 3020

The following illustration shows a schematic representation of the main arrangement of the fastening possibilities above the free area. The actual position depends on the concrete order. A drawing with the genset measurements is available from the manufacturer.



3720810763: Simplified example illustration TCG 2020, TCG 3020

Item	Location	Loads (minimum)	Type
1 - 2	Above the free space on cylinder side B	250 kg	Minimum single anchor points in the structure, for example on the ceiling. The lateral anchor points lie aligned and
3		500 kg	
4	Above the exhaust turbocharger	250 kg	
5	Above the gas-air mixer	250 kg	

<table>
<tr><th>Item</th><th>Location</th><th>Loads (minimum)</th><th>Type</th></tr>
<tr><td>6 - 7</td><td>Above the mixture cooler</td><td>250 kg</td><td rowspan="4">perpendicular to the anchor points above the genset.
Alternatively the single anchor points 1 – 3, 4 – 5 and 8 as well as 9 – 10 can be replaced with profile rails for mobile lifting equipment.</td></tr>
<tr><td>8</td><td>Above the flywheel</td><td>500 kg</td></tr>
<tr><td>9 - 10</td><td rowspan="2">Above the free space on cylinder side A</td><td>250 kg</td></tr>
<tr><td>11</td><td>500 kg</td></tr>
<tr><td>A – B</td><td>Above the cylinder units</td><td>250 kg</td><td>Minimum profile rails for mobile lifting equipment.</td></tr>
</table>

Table 39: Loads TCG 2020, TCG 3020

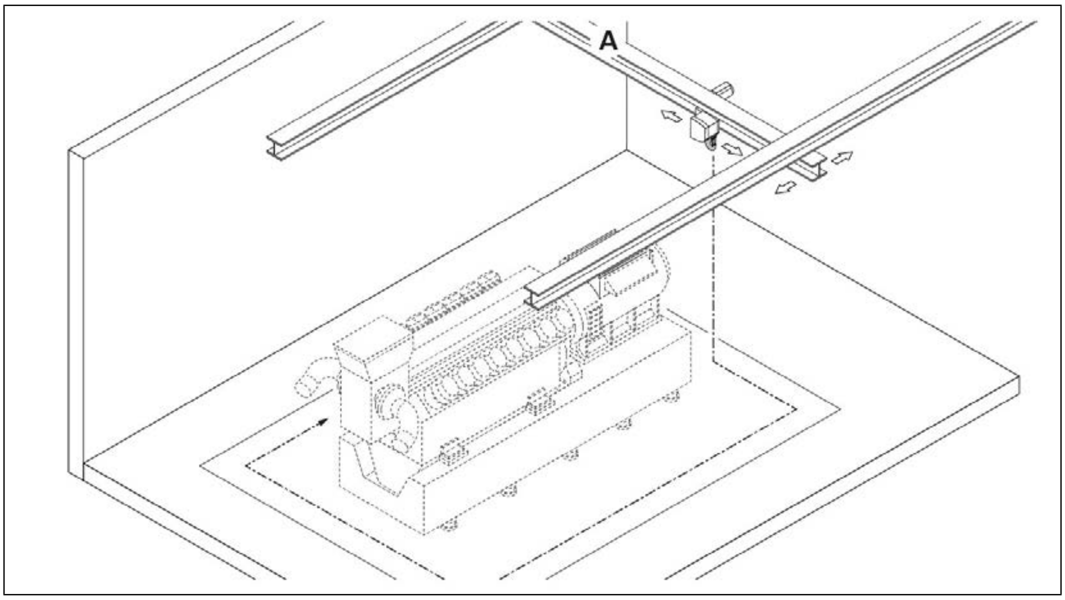
NOTE

Type and source of the danger

A crane system is recommended with an electrically driven traverse and electric chain hoist. The lifting capacity should be at least **250 kg**. In this case, only the positions with a higher lifting capacity remain as stationary anchor points.

For gas engine TCG 2032

The following illustration shows a schematic representation of the main arrangement of the fastening possibilities above the free area. The actual position depends on the concrete order. A drawing with the genset measurements is available from the manufacturer.



3720813451: Simplified example illustration TCG 2032

Item	Location and route	Loads (minimum)	Type
A	Above the genset and the free space around the genset	1000 kg	Crane system with electrically driven traverse and electric chain hoist.

Table 40: Loads TCG 2032

16.2.3 Foundation and vibration damping

16.2.3.1 General

In the case of gensets with piston engines, inertial forces and moments of inertia are not, in all cases, completely balanced. The transmission to the foundation of the vibration and noise thus created can be significantly reduced by the use of anti-vibration mountings.

The exception to this is gensets of the TCG 3016 series. These gensets are equipped with an anti-vibration mounting between the coupled unit comprised of the engine and generator and the base frame. The genset is installed without any additional mounting elements on the foundation block. Rubber mats must be provided between the base frame and foundation.

16.2.3.2 Foundation block

The base of the foundation must be implemented with special care.

Sinking and basing the foundation are the responsibility of the construction company or architect.

For calculation purposes, clients can be provided with the data on the foundation load imposed by the genset and the natural frequencies of the anti-vibration mountings.

The foundation surface must not exceed a tolerance of +/- 2 mm in the area of the installed anti-vibration mountings and in the cooling module installation area. The remainder of the foundation surface can be designed according to the standard building regulations for foundations.

16.2.3.3 Anti-vibration mounting

In the TCG 3016 series gensets, the engine and generator are connected rigidly via a flange housing. The unit of engine and generator is elastically mounted on the base frame with rubber elements.

16.2.3.4 Uneven foundation surfaces and foundation inclines

Before installing the genset, it is absolutely essential that you check the foundation evenness and, if necessary, place filler plates under the spring elements before lowering the genset into place. The thickness of the plates must be adapted to the required height compensation at the relevant spring element. Caterpillar Energy Solutions (CES) provides suitable plates in the thicknesses 1.2 mm and 5 mm for the relevant bearing types. The height adjustment of the bearings themselves is only utilized for the fine alignment of the genset.

The procedure for ascertaining the foundation evenness and determining the washers that might be required is a component of the customer documentation.

16.2.4 Noise emissions

16.2.4.1 General

The acoustic requirements for the installation of gensets with combustion engines are defined by various laws and standards. Below is some information on the contexts and possible solutions in case of noise problems.

Noise sources mainly include the combustion noise of the engine. Other noise sources are mechanical engine noises, air intake noises and exhaust noises from the engine. The ventilators, pumps and other auxiliary drives also contribute to noise emissions.

Air speeds that are too high can also cause noises.

There is little that effective resources themselves can do to reduce the source of noise. Thus most measures to mitigate noise are directed towards reducing the transmission of noise outside of the genset room.

Further information

- Notes on ventilation system planning and operation [▶ 126]

16.2.4.2 Acoustic dependencies

Noise consists of pressure waves of varying frequencies. All measurements of noise are thus frequency dependent pressure measurements. Lower-frequency noises are more easily tolerated by human beings than those of higher frequencies. Sound waves with frequencies above 16 000 Hz to 20 000 Hz, on the other hand, are generally beyond detection by the human ear.

The need to compare the loudness of sound events at different locations has led to the development of objective measurement methods. Assessments are conducted in accordance with specific frequency curves, as defined in DIN EN 61672-1 and DIN EN 61672-2. This involves analysis curves A, B, C and D (see next table). The assessment curves replicate in a somewhat simplified manner the frequency response of the ear to narrow-band noises. Curve A applies to the low-volume range, Curves B and C cover the range of loud and very loud noises. D applies to aircraft noises.

Frequency in Hz	Assessment curve in dB			
	A	B	C	D
31.5	-39.4	-17.1	-3.0	-16.5
63	-26.2	-9.3	-0.8	-11.0
125	-16.1	-4.2	-0.2	-6.0
250	-8.6	-1.3	0.0	-2.0
500	-3.2	-0.3	0.0	0.0
1000	0.0	0.0	0.0	0.0
2000	1.2	-0.1	-0.2	8.0
4000	1.0	-0.7	-0.8	11.0
8000	-1.1	-2.9	-3.0	6.0

Table 41: Assessment curves for the human ear

Engine noises are normally assessed in dB(A).

A value measured at 125 Hz is, for example, perceived as 16.1 dB quieter than the same value at 1000 Hz.

The strength of the noise is dependent on the range at which it is measured and on the installation site. When measured a short distance from the source, the sound pressure level is higher, and at long distance it is lower. This reduction in sound level is referred to as dispersion damping.

For point sources, the following applies:

$$L_{(r2)} = L_{(r1)} - 10 \times \log\left(\frac{r_2}{r_1}\right)^2$$

3720819211: Sound pressure level formula

$L_{(r1)}$	= sound pressure level 1
$L_{(r2)}$	= sound pressure level 2
r_1	= distance 1
r_2	= distance 2

Example

$$L_{(r2)} = 70 - 10 \times \log\left(\frac{20}{10}\right)^2 = 64\ \text{dB}$$

3720834699: Example sound pressure level

$L_{(r1)}$	= 70 dB
$r1$	= 10 m
$r2$	= 20 m

If the distance doubles, the sound pressure level falls by 6 dB.

For plants with several gensets, the total noise level may be determined according to the laws of acoustics:

$$L_{(r2)} = L_{(r1)} - 10 \times \log\left(\frac{r_2}{r_1}\right)^2$$

3720837387: Total noise level formula

L_{Σ}	= total level
L_i	= individual level

Example

$$L_\Sigma = 10 \times \log\left(10^{\frac{70,5}{10}} + 10^{\frac{71,5}{10}} + 10^{\frac{72,5}{10}} + 10^{\frac{75,5}{10}} + 10^{\frac{77,0}{10}}\right) = 81,1 \text{ dB}$$

3720840075: Example

L_1	= 70.5 dB
L_2	= 71.5 dB
L_3	= 72.5 dB
L_4	= 75.5 dB
L_5	= 77.0 dB

In simplified terms, when adding *n* equal levels *L*, the following applies:

$$L_\Sigma = L + 10 \times \log(n)$$

3720842763: Simplified total noise level formula

When two equal sound levels are added, the level rises by 3 dB.

Where a genset is erected in a closed room, the noise level is greater as a result of the impeded dispersal of the noise. A higher noise level is recorded than when measuring in the free field. In small rooms with no acoustic material, the noise distribution is equal almost everywhere.

Large rooms with sound-absorbent walls offer acoustic benefits; tiles or similar construction materials should be avoided.

16.2.4.3 Possible means of mitigating noise

Normal wall thicknesses of 24 cm or 36 cm already dampen the noise coming from within by 40 to 50 dB. Muffler sections of 2 m to 3 m in length must be provided for the air inlet ducts and exhaust ducts. These soundproofing baffles dampen the noise by approx. 40 dB. Taking into account the volume of cooling air, the air speed in the muffler section should not exceed approx. 8 m/s on the delivery side and approx. 6 m/s on the extraction side.

- For more information: Machine room ventilation [▸ 115]

If acoustic materials such as sound insulating panels are installed in the genset room, the noise level can be reduced by approx. 3 dB. A noise level reduction of approx. 10 dB can be achieved with thicker sound insulation. Particular care must be taken to control the exhaust noise. Reductions in noise levels of up to approx. 60 dB can be achieved with suitable mufflers.

Questions of sound insulation can only be solved on an individual basis, as they are highly dependent on local circumstances. By way of assistance, the manufacturer provides one-third octave spectra or octave spectra of exhaust gas noises and engine noises.

Sound insulation measures must be designed in collaboration with specialist firms.

Such measures might, for example, include:

- Exhaust silencing with the aid of reflection mufflers, absorption mufflers, active sound deadening
- Installing the genset so as to insulate against structure-borne noise
- Arrangement of absorption baffles for the genset room air inlet openings and air outlet openings
- Housing the genset inside a sound-insulating enclosure
- Fitting the genset room with sound insulation and installing a floating floor (tasks for specialist firms)

No fiber materials (e.g., Heraklit) must be used to clad the interior of the space. Vibrations in the air cause particles to be released which then block the air cleaners and can even destroy the engine.

When sound-proofing the building, it is necessary to consider not only the walls but also the windows, doors etc.

Technical sound-proofing considerations should also extend to additional sound sources such as auxiliary drives or radiators which are located outside of the genset room. Noise sources also include gas trains, pre-pressure gas trains or zero pressure gas trains, which are installed outside the genset room or outside a sound capsule. These additional noise sources must be considered in the technical sound design.

16.2.4.4 Sound data in genset data sheets

The genset data sheets indicate the sound values for airborne sound and exhaust gas sound as sound power levels. For airborne noise there are one-third octave spectra; for exhaust noise there are one-third octave spectra and in some cases octave spectra. The specified levels in the one-third octave bands and octave bands are linear levels, meaning that no correction was made according to one of the assessment curves A, B, C or D.

The overall noise levels are specified as total levels with an A assessment of the individual levels.

Noise data for a TCG 2020 V12

Frequency band	Airborne sound emission[4)]	Exhaust sound [5)]
f in Hz	$L_{W,Terz}$ in dB(lin)	$L_{W,Octave}$ in dB(lin)
25	94	
31.5	95	
40	98	
50	100	128
63	106	128
80	109	128
100	108	135
125	109	135
160	106	135
200	115	134
250	115	134
315	115	134
400	109	131
500	110	131
630	109	131
800	109	123
1000	109	123
1250	108	123

Frequency band	Airborne sound emission[4]	Exhaust sound [5]
1600	108	122
2000	108	122
2500	107	122
3150	109	120
4000	103	120
5000	102	120
6300	114	119
8000	107	119
10000	101	119
12500	104	121
16000	98	114
L_{WA}/dB(A)	121	132
S/m^2	114	15.5

[4] DIN EN ISO 3746

[5] DIN 45635-11 Appendix A (±3 dB)

L_W = sound power level

S= measuring area at the distance x from the sound source with S_0 = 1 m^2

Table 42: Noise data

Correction values for the individual levels according to the assessments A, B, C, and D

Frequency in Hz	Assessment curve in dB			
	A	B	C	D
25	-44.7	-20.4	-4.4	-18.5
31.5	-39.4	-17.1	-3.0	-16.5
40	-34.6	-14.2	-2.0	-14.5
50	-30.2	-11.6	-1.3	-12.5

Frequency in Hz	Assessment curve in dB			
63	-26.2	-9.3	-0.8	-11.0
80	-22.5	-7.4	-0.5	-9.0
100	-19.1	-5.6	-0.3	-7.5
125	-16.1	-4.2	-0.2	-6.0
160	-13.4	-3.0	-0.1	-4.5
200	-10.9	-2.0	0.0	-3.0
250	-8.6	-1.3	0.0	-2.0
315	-6.6	-0.8	0.0	-1.0
400	-4.8	-0.5	0.0	-0.5
500	-3.2	-0.3	0.0	0.0
630	-1.9	-0.1	0.0	0.0
800	-0.8	0.0	0.0	0.0
1000	0.0	0.0	0.0	0.0
1250	+0.6	0.0	0.0	+2.0
1600	+1.0	0.0	-0.1	+5.5
2000	+1.2	-0.1	-0.2	+8.0
2500	+1.3	-0.2	-0.3	+10.0
3150	+1.2	-0.4	-0.5	+11.0
4000	+1.0	-0.7	-0.8	+11.0
5000	+0.5	-1.2	-1.3	+10.0
6300	-0.1	-1.9	-2.0	+8.5
8000	-1.1	-2.9	-3.0	+6.0
10000	-2.5	-4.3	-4.4	+3.0

Table 43: Correction values for the individual levels

Conversion of sound power levels into sound pressure levels

The sound power is a variable that is independent of the distance and room and is suitable as a starting point for all technical sound calculations. The sound power is not directly measurable, but instead is established via specified measurement methods.

The sound power level L_W is the identifying technical sound variable for a sound source. In contrast to the sound pressure level L_p, the sound power level L_W is fully independent of the sound field. This means it is independent of the size of the room and the distance from the source. The emitted sound power of a noise source is determined by measuring the sound pressure in several points of a closed measuring area *S*. The sound power of a source is calculated with the sound pressures measured on the defined enveloping surface. The ascertained sound power can be used to calculate the sound pressure levels at any distance from the sound source.

The following correlation applies to the sound pressure level at a distance of *x* from the sound source:

$$L_p = L_W - 10 \times \log\left(\frac{S}{S_0}\right)$$

3720860299: Formula for the sound pressure level without assessment

The following results from specification with A-assessed levels:

$$L_{pA} = L_{WA} - 10 \times \log\left(\frac{S}{S_0}\right)$$

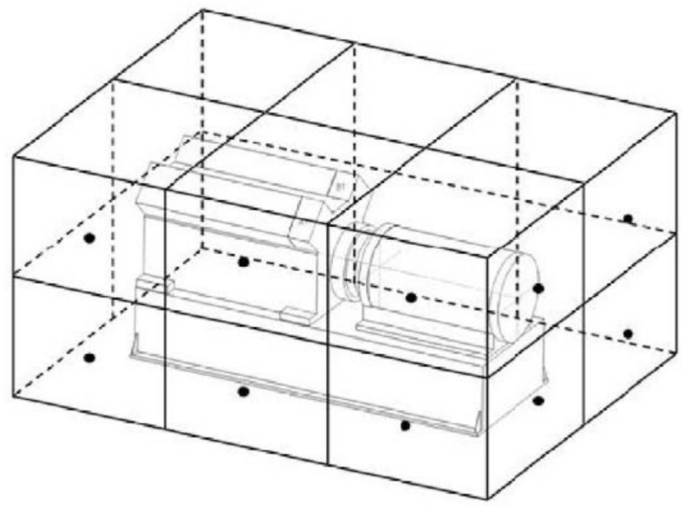
3720862987: Formula for the sound pressure level with assessment

The following apply here:

L_p	= sound pressure level, linear (without assessment)
L_{pA}	= sound pressure level, assessment according to curve A
L_W	= sound power level, linear (without assessment)
L_{WA}	= sound power level, assessment according to curve A
S	= measuring area at the distance x from the sound source
S_0	= reference area, always 1 m^2

Measuring areas for the genset

When determining the sound power level for the genset, a cuboid measuring area at a distance of one meter from the genset is implied (see next illustration). The measuring surface is divided into a grid with a measuring point in the center of each individual grid surface. This procedure corresponds to DIN EN ISO 3476.



3720865675: Cuboid measuring area for the genset

Measuring areas for the exhaust sound

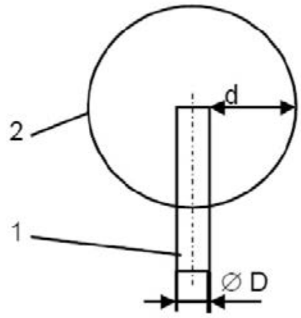
With exhaust sound, a spherical measuring area at a distance of one meter from the outer edge of the exhaust pipe is implied. The measuring area is calculated with the equation:

$$S = 4 \times \pi \times \left(\frac{D}{2} + d\right)^2$$

3720868363: Measuring area formula

The following apply here:

S in m²	= measuring area
D in m	= diameter of the exhaust pipe
d	= measurement distance in 1 m



3720871051: Spherical measuring area for the exhaust gas

1	Exhaust pipe	2	Measuring area *S*

Examples of conversion sound power level - sound pressure level

Example 1

How high is the sound pressure level for a TCG 2020 V12 genset at a distance of 1 meter and 10 meters?

- The sound power level of the genset is specified in the data sheet as 121 dB(A)
- The measuring area *S* at a distance of 1 meter is specified in the data sheet as 114 m^2
- The basic dimensions of a TCG 2020 V12 genset are:
  - Length *l* = 5.7 m
  - Width *w* = 2.1 m
  - Height *h* = 2.5 m

An equivalent cuboid at a distance of 10 meters has the dimensions:

- Length *l* = 5.7 m + 2 x 10 m
- Width *b* = 2.1 m + 2 x 10 m
- Height *h* = 2.5 m + 10 m

This results in a measuring surface *S* of approx. 1763 m^2 at a distance of 10 meters. The following calculations are obtained with the equation mentioned above:

- Sound pressure level at a distance of 1 meter:
  - $L_{pA} = L_{WA} - 10 \times \log (S / S_0)$
  - $L_{pA} = 121 - 10 \times \log (114 / 1)$
  - $L_{pA} = 121 - 10 \times \log 114 = 121 - 10 \times 2.06$
  - $L_{pA} = 100.4$ dB(A)

- Sound pressure level at a distance of 10 meters:
  - $L_{pA} = L_{WA} - 10 \times \log (S / S_0)$
  - $L_{pA} = 121 - 10 \times \log (1763 / 1)$
  - $L_{pA} = 121 - 10 \times \log 1763 = 121 - 10 \times 3.25$
  - $L_{pA} = 88.6$ dB(A)

Example 2

How high is the exhaust gas sound pressure level for a TCG 2020 V12 genset at a distance of 1 meter and 10 meters from the exhaust outlet?

- The sound power level for the exhaust gas is specified in the data sheet as 132 dB(A).
- The reference area *S* for a spherical surface with a radius of 1 m is specified in the data sheet as 15.5 m^2

The surface area S of a sphere with a radius of 10 meters is 1257 m^2. The following calculations are obtained with the equation mentioned above:

- Sound pressure level at a distance of 1 meter from the pipe outer wall:
- $L_{pA} = L_{WA} - 10 \times \log (S / S_0)$
- $L_{pA} = 132 - 10 \times \log (15.5 / 1)$
- $L_{pA} = 132 - 10 \times \log 15.5 = 132 - 10 \times 1.19$
- $L_{pA} = 120.1$ dB(A)

Sound pressure level at a distance of 10 meters:

- $L_{pA} = L_{WA} - 10 \times \log (S / S_0)$
- $L_{pA} = 132 - 10 \times \log (1257 / 1)$
- $L_{pA} = 132 - 10 \times \log 1257 = 132 - 10 \times 3.1$
- $L_{pA} = 101$ dB(A)

16.3 Rubber expansion joints

16.3.1 Function

Rubber expansion joints are used in the plant to elastically decouple connection pipes carrying fluids from the elastically mounted genset. They reduce structure-borne noise that would otherwise be transferred unhindered into the building through the connected piping and compensate for the heat expansion.

Additional expansion joints may also be required in the piping in the plant.

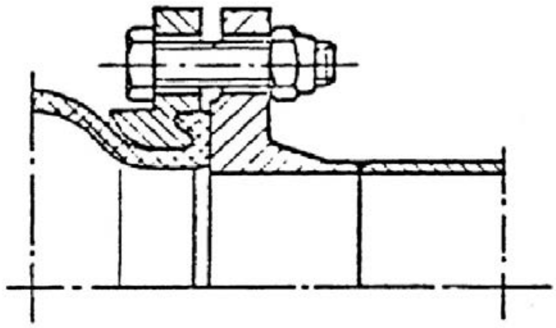
16.3.2 Notes for planning

Installation position

The installation position must be planned in such a way that it is accessible and can be monitored even after assembly.

Types of expansion joints, bellows material and their markings

Only DIN welding neck flanges or VG flared flanges must be used as counter flanges. No additional seals are required for these as the rubber lip is sufficient. Other flange designs are not permissible owing to the risk of damage to the rubber lip.



3726746379: Expansion joint with rubber lip and flange with smooth sealing surface through to internal diameter

Expansion joints with the bellows material EPDM (Ethylene Propylene Diene Rubber) are used for installation in the cooling water systems. In these types the bellows are provided with an orange/blue marking. When this bellows material is used, only oil-free cooling water additives may be used.

When used in lube oil systems, expansion joints with the bellows material NBR (nitrile butadiene rubber) are used, with this only applying to the TCG 2032 series. In these types, the bellows have a red-and-blue marking.

Specific values for rubber expansion joints with flanges in accordance with EN 1092-1

		1					2					3				4
5 DN	6	PN	ØD	ØK	nxØd2	b	BL	Ødi		8 ØC	9 W	10	11	12	13	14
	[mm]	[bar]			[mm]							[mm]			[°]	[kg]
32	42,4x2,6	16	140	100	4xØ18	16	125	31		72	78	30	10	15	25	3,3
40	48,3x2,6	16	150	110	4xØ18	16	125	39		81	86	30	10	15	25	3,8
50	60,3x2,9	16	165	125	4xØ18	16	125	49		95	97	30	10	15	25	4,4
65	76,1x2,9	16	185	145	8xØ18	18	125	65		115	113	30	10	15	25	5,6
80	88,9x3,2	16	200	160	8xØ18	20	150	77		127	135	40	10	15	20	7,2
100	114,3x3,6	16	220	180	8xØ18	20	150	100		151	160	40	10	15	15	8,1
125	139,7x4	16	250	210	8xØ18	22	150	127		178	184	40	10	15	15	10,8
150	168,3x4,5	16	285	240	8xØ22	22	150	153		206	212	40	10	15	12	13,2
175	193,7x5,4	16	315	270	8xØ22	22	150	176		230	236	40	10	15	10	15,8
200	219,1x5,9	16	340	295	8xØ22	25	175	202		260	265	45	15	15	8	19,819,6

3726969739: Expansion joints with flanges according to EN 1092-1

1	Flange dimensions as per DIN 1092-1*	2	Bellows
3	Movement absorption (without overlay)	4	Expansion joint
5	Nominal diameter	6	Pipe as per DIN 2448
7	-	8	Sealing surface
9	Shaft diameter (depressurized)	10	Suppression
11	Extension	12	Lateral
13	Angular	14	Weight

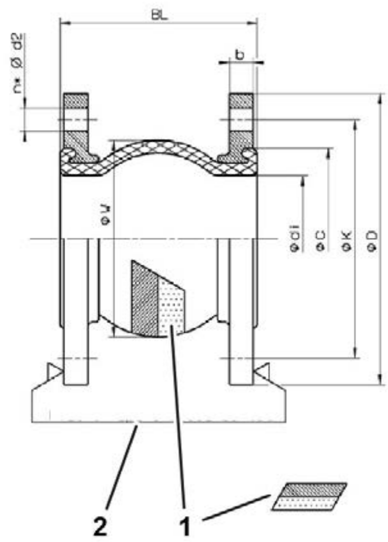
* Counter flanges as per E 1092-1-PN 16 with screws and self-locking nuts as per DIN 985, but without any seals. For DN 200, counter flanges as per EN 1092-1-PN10. Assembly notes No.: 6.000.9.000.242 sheet 1-4

Pressure stages				
Temperature load up to	°C	+60	+100	+110
Max. permissible operating pressure*	bar	16	10	6
Test pressure at +20 °C	bar	23	23	23
Burst pressure	bar	≥ 48	≥ 48	≥ 48
Vacuum at installation length ≤ BL	Special measures are necessary in this connection and must be asked for.			
* In case of loads produced by jerks, the max. operating pressure must be set 30 % lower				

Table 44: Pressure stages for expansion joints

Bellows material	**Operating medium**
EPDM	Cooling water with oil-free additives for frost protection and corrosion protection
NBR	Lube oil

Table 45: Bellows material for certain operating media



3726737931: Expansion joint

1	Rating plate orange/blue (EPDM), red/blue (NBR)	2	Surfaces machined by cutting

Specific values for rubber expansion joints with flanges in accordance with VG 85356

		1					2					3				4
5 DN	6	PN	ØD	ØK	nxØd2	b	BL	Ødi		8 ØC	9 W	10	11	12	13	14
[mm]		[bar]	[mm]							[mm]					[°]	[kg]
40	42	16	108	84	6xØ11	16	125	32		71	74	30	10	15	25	1,9
50	50	16	120	96	6xØ11	16	125	40		83	88	30	10	15	21	2,3
65	60	16	140	116	8xØ11	18	125	61		103	113	30	10	15	17	3,0
80	80	16	150	126	8xØ11	18	150	72		113	137	40	10	15	14	3,4
100	100	16	172	148	10xØ11	18	150	93		135	145	40	10	15	11	4,2
125	120	16	200	176	10xØ11	18	150	117		163	178	40	10	15	9	5,7
150	159	16	226	202	12xØ11	18	150	143		189	201	40	10	15	7	6,6

3726976779: Expansion joints with flanges according to VG 85356

1	Flange dimensions as per VG 85356 Part 1	2	Bellows
3	Movement absorption (without over-lay)	4	Expansion joint
5	Nominal diameter	6	Pipe diameter, external
7	-	8	Sealing surface
9	Shaft diameter (depressurized)	10	Suppression

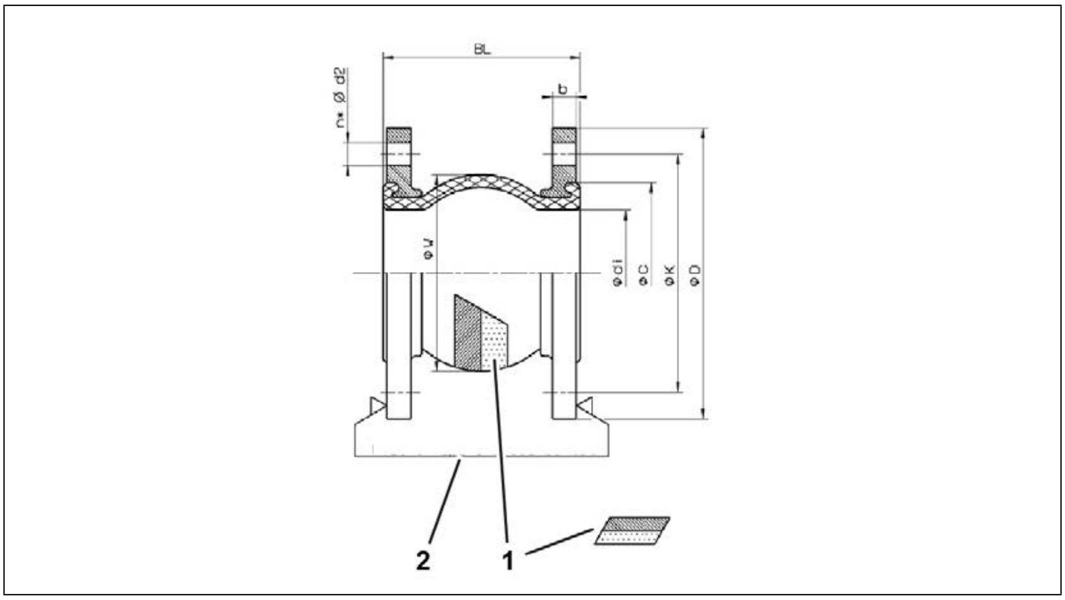
11	Extension	12	Lateral
13	Angular	14	Weight

Pressure stages				
Temperature load up to	°C	+60	+100	+110
Max. permissible operating pressure*	bar	16	10	6
Test pressure at +20 °C	bar	23	23	23
Burst pressure	bar	≥ 48	≥ 48	≥ 48
Vacuum at installation length ≤ BL	Special measures are necessary in this connection and must be asked for.			
* In case of loads produced by jerks, the max. operating pressure must be set 30 % lower				

Table 46: Pressure stages for expansion joints

Bellows material	**Operating medium**
EPDM	Cooling water with oil-free additives for frost protection and corrosion protection
NBR	Lube oil

Table 47: Bellows material for certain operating media



3726742155: Expansion joint

1 Rating plate orange/blue (EPDM), red/blue (NBR)

2 Surfaces machined by cutting

Number

The number of expansion joints depends on the piping routing itself and the heat expansion caused by the temperature of the media inside the pipe.

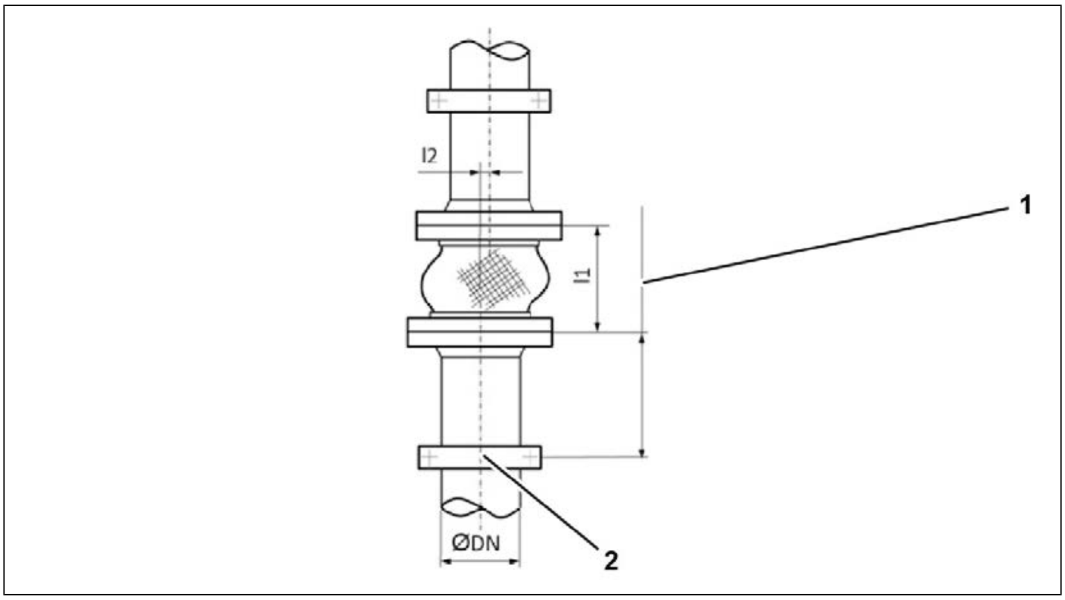
The following applies to the installation location:

- The installation position of an expansion joint must be accessible and must facilitate monitoring.
- The expansion joint should preferably be compressed.
- The installation gap for the expansion joint must be defined so as to guarantee the correct installation length.

Installation gap at the installation position

The values for permissible suppression, stretch, and lateral and angular movement absorption specified above are all maximum specifications for non-overlaid deflections.

When installing the expansion joints on the gas engine genset, the values specified in the illustration “Installation of expansion joints” must be observed. Adhering to these installation dimensions guarantees that the genset deflections can be absorbed both during operation and during start procedures and stop procedures without overstraining the expansion joints.



3726815755: Installation of expansion joints

1	Maximum 3 x DN	2	Fixed point

Maximum permissible installation dimensions	l1	l2
Nominal diameter DN 32 to DN 65	125 ± 5 mm	3 mm
Nominal diameter DN 80 to DN 175	150 ± 5 mm	3 mm
Nominal diameter DN 200	175 ± 5 mm	3 mm

Table 48: Rubber expansion joint installation dimensions

Load types

Overlaid movements

In the case of overlaid movements, the values specified above must be requested from the manufacturer.

Negative pressure

If an expansion joint is to be subjected to negative pressure (vacuum), it must under no circumstances be stretched when it is installed. It is better to compress the expansion joint slightly, making it more vacuum-resistant. However, special measures will be called for here, which must be queried separately. The assembly instructions of the expansion joint manufacturer must be complied with here.

Pipe brackets

When arranging expansion joints, always provide pipe brackets or pipe guides before and after the expansion joint. For expansion joints that are only installed for the decoupling of vibrations (e.g., expansion joints of an elastically mounted genset), apply fixing points before and after the expansion joint. Expansion joints installed for the compensation of heat expansions in the piping generally have a pipe bracket as a fixing point on one side and a pipe guide as a free-running point on the other side. The distance between the fixed or free-running point and the expansion joint should not exceed 3 × DN.

- Required information: Assembly, insulation and surface treatment of pipes [▷ 343], Pipe brackets and supports

Equipotential bonding

Since the rubber bellows is not electrically conductive, a suitable elastic bridge is required.

- Required information: Technical documentation on the relevant rubber expansion joint

16.3.3 Storage

Store rubber expansion joint in a clean and dry condition, protect from all damage, do not roll using the bellows. In the case of storage and installation in the open air, protect against intense sunlight, such as through the use of a covering sheet.

16.3.4 Checks

Before the expansion joint is installed, it must be checked in its consistency and, with regard to the state of the rubber bellows, if for example a strong embrittlement caused by the high temperature during storage has occurred.

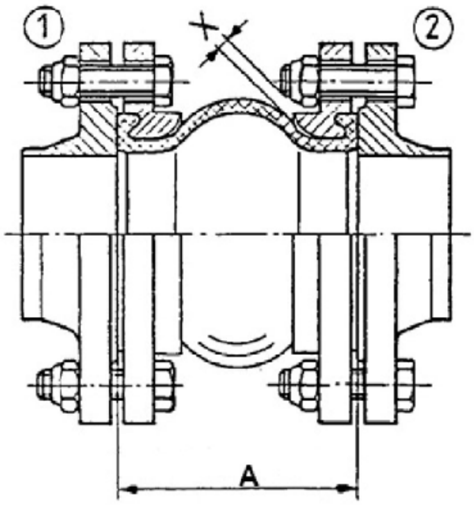
The higher the operating temperature on the expansion joint, the faster the elastomer will age and embrittle (in other words, harden) and the rubber bellows will tend to form cracks. If a strong crack formation has occurred on the surface, the expansion joint should be replaced for safety reasons.

16.3.5 Assembly

This is a general description. The assembly notes provided by the expansion joint manufacturer and the planning notes must be observed.

Generally

- Before welding on the counter flanges, disassemble rubber expansion joints that are already installed.
- Always check the effect of external heat radiation!
- The bellows must remain clean during assembly and even afterwards!
- Never paint the bellows!
- The expansion joint should preferably be compressed during assembly and when installed.
- Noting the maximum permissible amount of movement which may be accommodated (and which must not be exceeded in operating state), install the expansion joint **free of torsional stress** (without rotation) in the installation gap.
- The boreholes in the connection flanges must line up and the sealing faces must be parallel to each other.
- Only use DIN welding neck flanges or VG flared flanges as counter flanges.
- Do not use any additional seals as the rubber lip seals the expansion joint.
- Use normal hexagon screws and self-locking hexagon nuts as per DIN 985 for securing the expansion joint and connection flange.
- To avoid damaging the bellows with tools, only turn the wrench on the counter flange side and counter the wrench away from the bellows on the bellows side. Do not crush the bellows!
- Use installation type 1 for the screw connection. If this is not possible, installation type 2 with screws is permissible as an exception, where the distance is less than the safety distance X of 15 mm.



3726813067: Installation types

1	Nuts on the outside of the counter flange, screw heads inside the expansion joint flange
2	Screw heads on the outside of the counter flange, nuts inside the expansion joint flange
X	Safety distance between end of screws and bellows
A	Overall length. The installation length (BL) depends on the planned and permissible movement of the expansion joint

Tightening specification for flanges

In order not to destroy the rubber seal by overtightening the flanges, the tightening torques indicated in the next table, for example, must be observed.

Tightening specification	
Nominal diameter DN 40	90 Nm
Nominal diameter DN 50	90 Nm
Nominal diameter DN 65	90 Nm
Nominal diameter DN 80	90 Nm
Nominal diameter DN 100	90 Nm
Nominal diameter DN 125	90 Nm
Nominal diameter DN 150	145 Nm

Table 49: Tightening specifications for rubber expansion joints

The tightening torques listed apply to new expansion joints. The values can be exceeded by 30 % if necessary.

Genset

Before assembly, the genset must be aligned on the foundation in accordance with the specifications.

The external piping is connected without filling the engine previously with water and lube oil. After filling with water and lube oil, the genset moves down only an additional 1 to 2 mm on the engine side. If necessary, the height-adjustable anti-vibration mounting elements can be readjusted.

- For more information: Anti-vibration mounting [▶ 113]

Procedure

- Install the pipe brackets (without expansion joint) at the installation position in such a way that the specifications for the installation gap are complied with (free-running and fixed points, flanges are aligned and parallel, compensating movements). Observe the distance of max. 3 × DN for fixed points
- Measure the installation gap as per the requirements determined during planning and adjust pipe brackets if necessary. The required movement of the expansion joint when heated during operation and when cooled down after switching off the genset must be ensured!
- Fit the expansion joint free of torsional stress and with the correct installation length by compressing it and screw in fastening screws (screw head on the bellows side). Loosely install nuts on the counter flange
- Close the pipe brackets in such a way that the pipe is fixed at the fixed point and the pipe can slide at the free-running point
- Tighten nuts evenly several times crosswise only slightly until the expansion joint flanges are touching the connection flanges. Then tighten according to the specified tightening torque. Excessive tightening can crush the rubber lip!
- Since the connection will settle during initial commissioning or after 24 hours of operation, check the connection point, check the tightening torque of the screw connection and re-tighten if necessary

Protective measures after assembly

After assembly, the expansion joints must be covered as protection against welding heat (e.g., weld spatter, beads) and external damage.

16.4 Exhaust expansion joints

16.4.1 Function

Axial expansion joints and axial double expansion joints are used in the plant to elastically decouple connection pipes carrying exhaust gas from the elastically mounted genset. They reduce structure-borne noise that would otherwise be transferred unhindered into the building through the connected piping and also compensate for the heat expansion.

Additional expansion joints may also be required in the piping in the plant.

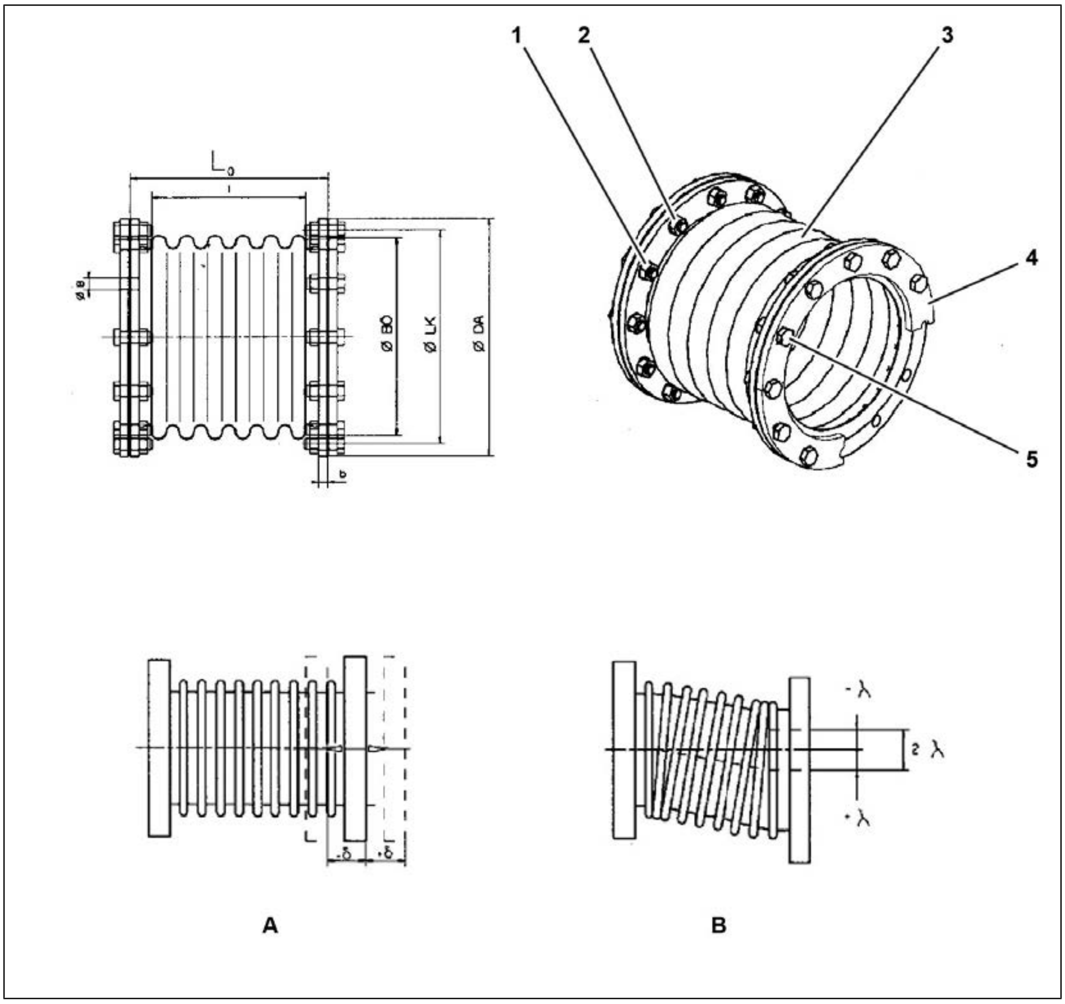
16.4.2 Notes for planning

Installation position

The installation position must be planned in such a way that it is accessible and can be monitored even after assembly.

Specific values for exhaust expansion joints

Dimensions and connection sizes are shown in the next two illustrations.



3726926987: Movement of bellows

A	Axial movement of bellows	B	Lateral movement of bellows

1						2							*1)
3	4			5	6	7					8		9
	10	11	12			13	14	15	16	17	18	19	
DN	2δN	2λN	â	L0	l	DA	LK	B	BÖ	b	N	-	G
	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	Stück	M	kg
100	50	6	1,0	118	60	210	170	18	147	14	4	M16	5,4
100	80	12	2,5	184	2x47								5,9
125	50	7,7	0,2	140	75	240	200	18	178	10	8	M16	5
125	200	114	2,0	340	272								6
150	50	6,9	0,2	145	78	265	225	18	202	10	8	M16	6
150	200	101,1	2,0	350	286								7
200	50	5,1	0,2	150	73	320	280	18	258	16	8	M16	11
200	200	81,2	2,0	370	291								14
250	50	3,6	0,1	150	65	375	335	18	312	16	12	M16	14
250	200	64,5	1,9	370	286								17
300	50	3,3	0,1	150	69	440	395	22	365	16	12	M20x2	18
300	200	54,4	1,6	365	285								21
350	50	3,3	0,1	155	74	490	445	22	415	16	12	M20x2	24
350	200	48,1	1,4	355	272								28
400	60	4,4	0,1	180	84	540	495	22	465	16	16	M20x2	29
400	180	39,2	1,2	365	279								35
450	60	4,1	0,1	185	98	595	550	22	520	16	16	M20x2	33
450	180	34,1	1,0	355	272								40
500	60	3,8	0,1	190	100	645	600	22	570	16	20	M20x2	36
500	180	30,4	0,9	360	270								44
600	60	2,8	0,1	190	89	755	705	26	670	20	20	M24x2	53
600	180	25,2	0,8	370	267								63
700	60	2,6	0,1	200	95	860	810	26	775	20	24	M24x2	63
700	180	21,3	0,6	365	262								74
800	60	1,9	0,1	185	79	975	920	30	880	20	24	M27x2	77
800	180	18,3	0,5	365	257								90

3726929675: Expansion joint, dimensions and design

1	Technical data - axial expansion joint	2	Flanges DIN EN 1092 PN 6
3	Nominal size	4	Nominal accommodated movement over 1000 load cycles
5	Overall length, unstressed [L0]	6	Corrugated length [l]
7	Diameter	8	Screws
9	Weight	10	Axial [2dN]
11	Lateral [2lN]	12	Axial/Radial [â]
13	Outer diameter [DA]	14	Bolt circle [LK]
15	Bore [B]	16	Flared tube end [BÖ]
17	Sheet thickness [b]	18	Quantity [N]
19	Thread		

The specified values apply at room temperature; in operating state, lower values are to be expected. At temperatures of up to 300 °C, deviations may be disregarded for practical purposes.

For correction values $K_{\Delta\vartheta}$ for higher temperatures, see the next table "Temperature influence on the available movement of exhaust expansion joints".

The sum of all relative stresses must not exceed 100 % of the temperature factor KΔϑ.

Where heat expansion and vibration coincide, the travel element and amplitude element must each be considered separately. As per the following formula:

$$\left(\frac{2 \times \delta_{\text{axial,Design}}}{2 \times \delta_{\text{axial,Nominal}}}\right) + \left(\frac{2 \times \lambda_{\text{lateral,Design}}}{2 \times \lambda_{\text{lateral,Nominal}}}\right) + \left(\frac{\hat{a}_{\text{Design}}}{\hat{a}_{\text{Nominal}}}\right) \leq K_{\Delta\vartheta} \times 100\ \%$$

3726932363: Travel element and amplitude element formula

$2\times\delta_{\text{axial,Design}}$	axial movement, design
$2\times\delta_{\text{axial,Nominal}}$	axial movement, rated value
$2\times\lambda_{\text{lateral,Design}}$	lateral movement, design
$2\times\lambda_{\text{lateral,Nominal}}$	lateral movement, rated value
$\hat{a}_{\text{Design}}$	all-round movement, design
$\hat{a}_{\text{Nominal}}$	all-round movement, rated value
$K_{\Delta\vartheta}$	Correction value

Nominal: Rated value (nominal) from the table in the illustration above "Expansion joint, dimensions and design"

Design: Maximum movement during operation.

An expansion joint comprising multi-wall bellows 1.4541 (X6 CrNiTi 18 9) and flared flange RST 37-2 may be used at operating temperatures of up to 550 °C.

The expansion joint only fully undertakes one of the indicated movements. The operating pressure may be up to 1 bar (PN1).

The installation length (overall length + pre-tension) depends on the total system-side expansion. The overall length L_o refers to the neutral position.

Temperature influence on the available movement*			
	Material	KDJ	ϑ
	1.4541	1	100 °C
		0.9	200 °C

Temperature influence on the available movement*			
		0.85	300 °C
		0.8	400 °C
		0.75	500 °C
		0.7	600 °C
* Witzenmann, "Kompensatoren" (Expansion joints) page 99, edition 1990			

Table 50: Temperature influence on the available movement of exhaust expansion joints

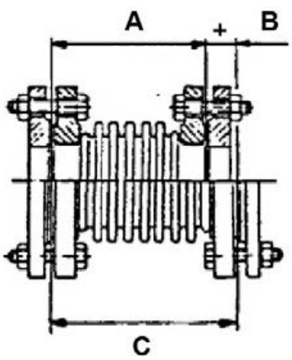
Installation gap at the installation position

For assembly, the installation gap for the expansion joint must be defined so as to guarantee the correct installation length. Connection pipes must be perfectly aligned.

Noting the maximum permissible amount of movement which may be accommodated (and which must not be exceeded in operating state), the expansion joint must be installed so that it is not subjected to torsional stresses either during installation or during operation due to adverse pipe tension.

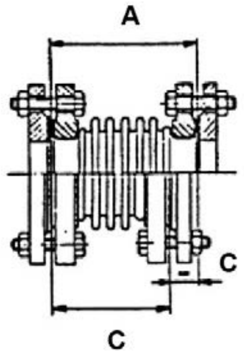
When specifying the length of the expansion joints, please note these different terms.

The overall length is the length of the expansion joints as generally supplied by the manufacturer (delivered length). The overall length is indicated on the rating plate of the expansion joint. The installation length comprises the overall length with pre-tension (stretch "+" or compression "-") as shown in the next two illustrations.



3726895371: Expansion joint, installation length > overall length

A	Overall length	B	Extension
C	Installation length		



3726898059: Expansion joint, installation length < overall length

A	Overall length	B	Extension
D	Compression		

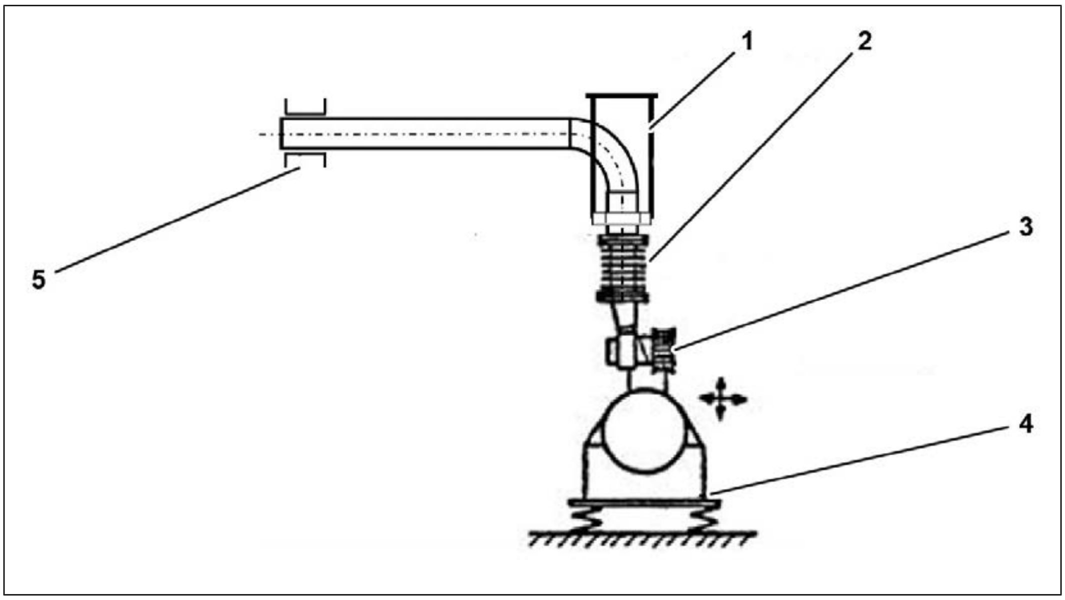
In a cold condition, the expansion joint should be installed half pre-tensioned (stretched "+" or compressed "-"), depending on how the expansion joint is to be used. This is recommended even if the axial movement of the expansion joint is not to be fully utilized.

Exhaust piping requires the use of an expansion joint that can expand by 30 mm during operation, for example. The expansion joint used in the example allows a max. expansion of 66 mm. In terms of the expansion joint's service life, it is better to preload the expansion joint to ± 15 mm expansion or compression than just to 30 mm expansion.

Installation situation on the gas engine (exhaust turbocharger)

Alignment is necessary when connecting the exhaust pipes on the plant side to the exhaust expansion joint on the engine side after the exhaust turbine. A poor alignment of the engine-side exhaust expansion joint leads to impermissible forces acting on the housing of the exhaust turbocharger. Assembly instructions for the relevant exhaust expansion joints are supplied in the documentation with each order under the chapter Assembly note.

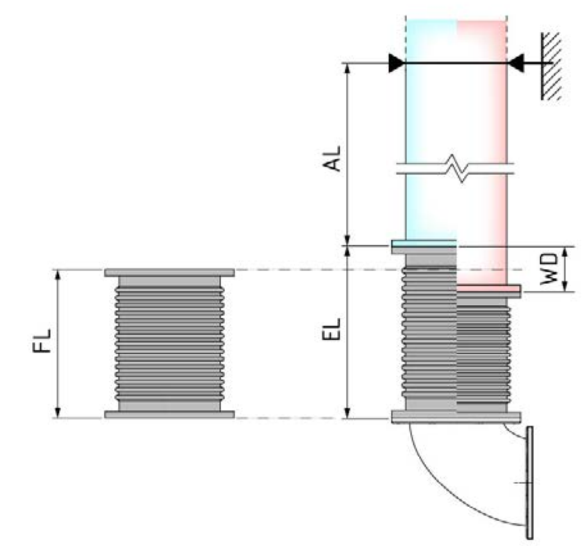
If possible, expansion joints should be installed without lateral offset. Expansion joint torsion must be avoided at all costs. The first exhaust line bearing point on the engine after the expansion joint must be designed as a fixed point and should be as close as possible to the exhaust expansion joint (see next illustration).



3726900747: Arrangement of the fixed point after the engine in the exhaust line

1	Fixed point	2	Axial expansion joint
3	Exhaust turbocharger	4	Genset on anti-vibration mountings
5	Free-running point (pipe guide)		

It is not always possible to have the fixed point immediately after the expansion joint in the exhaust line, as in the above illustration. The assembly notes specify the maximum possible distances from the expansion joint to the fixed point for each genset. The exhaust pipe expands during genset operation due to the high exhaust temperatures. This thermal expansion, which has a determining influence on the expansion joints on the engine, depends on the distance of the expansion joint to the fixed point. Other parameters that influence thermal expansion of the exhaust pipe include respective exhaust temperatures and exhaust pipe material. In these cases, the expansion joint must be installed with pre-tension (see next illustration).



3726916235: Length change of the exhaust line (principle diagram)

The following installation length-expansion joint correlation applies:

$$EL = FL + \frac{WD}{2}$$

3726918923: Installation length of expansion joint

AL	Length of the exhaust line from expansion joint to fixed point [mm]	EL	Installation length of expansion joint [mm]
FL	Free length of the compensator in unloaded state [mm]	WD	Thermal expansion of the exhaust pipe [mm]

The expansion joint is slightly compressed during genset operation. Compliance with these specifications ensures that the stress on the turbine housing of the turbocharger is kept low due to the restoring forces of the expansion joint. This applies to both the cold state when the genset is at a standstill and to the warm state when the genset is in operation.

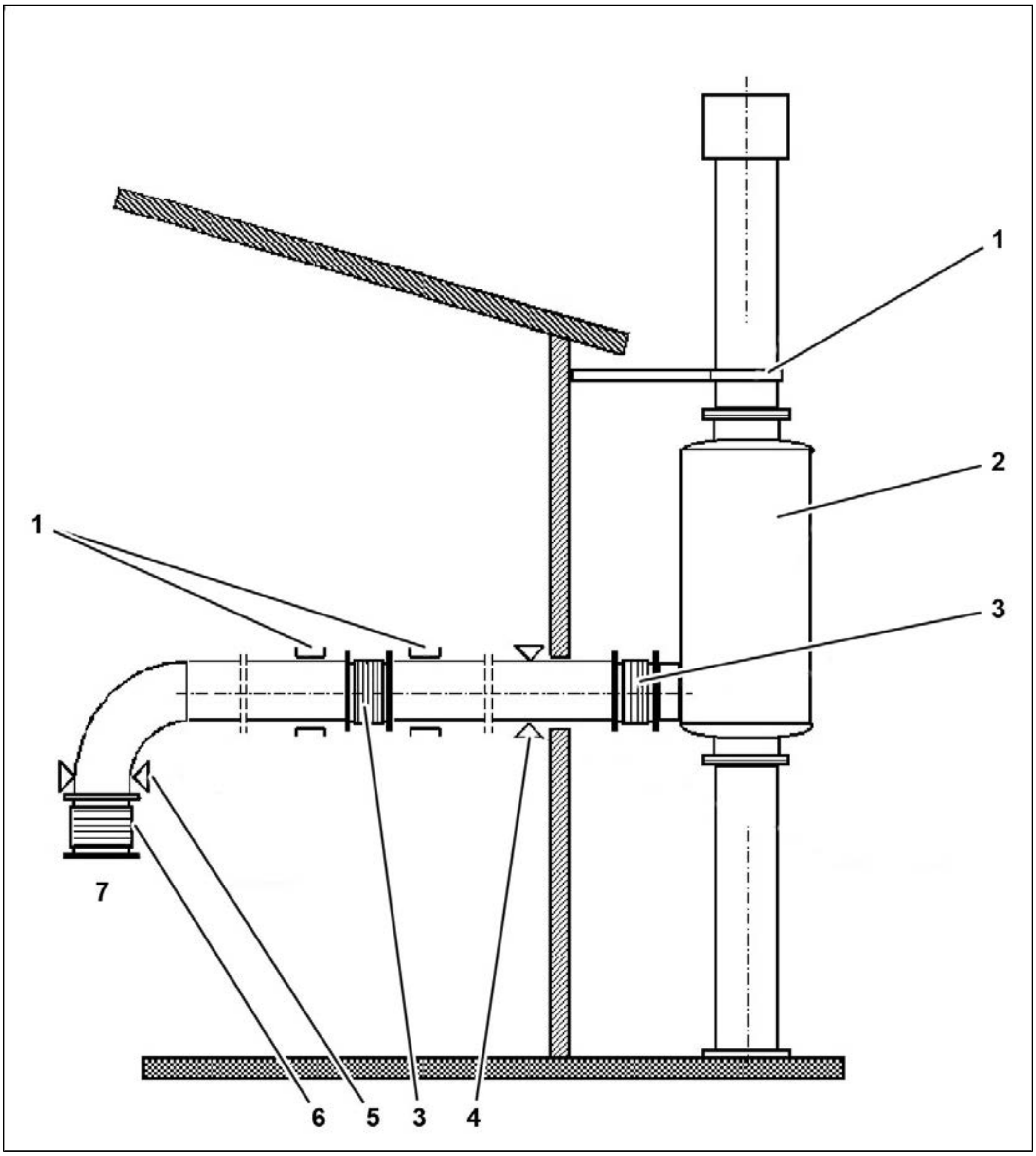
Installation situation in the pipeline section of the exhaust system

To determine heat expansion in piping, the following rule of thumb applies:

- For mild steel approx. 1 mm heat expansion per meter of pipe and per 100 °C.
- For stainless steel approx. 2 mm heat expansion per meter of pipe and per 100 °C.

That means that, for example, for a 1 meter section of pipe at 500 °C, the heat expansion is approx. 5 mm for mild steel and 10 mm for stainless steel.

Normally, axial expansion joints are fitted in exhaust piping to accommodate the heat expansion. The arrangement of the expansion joints will be shown on the installation plan for the respective order, whereby the installation directives laid down by the manufacturer must be observed. It will generally be adequate to continue the exhaust line as shown in the next illustration.



3726921611: Fixed supports, loose supports and expansion joints in an exhaust line

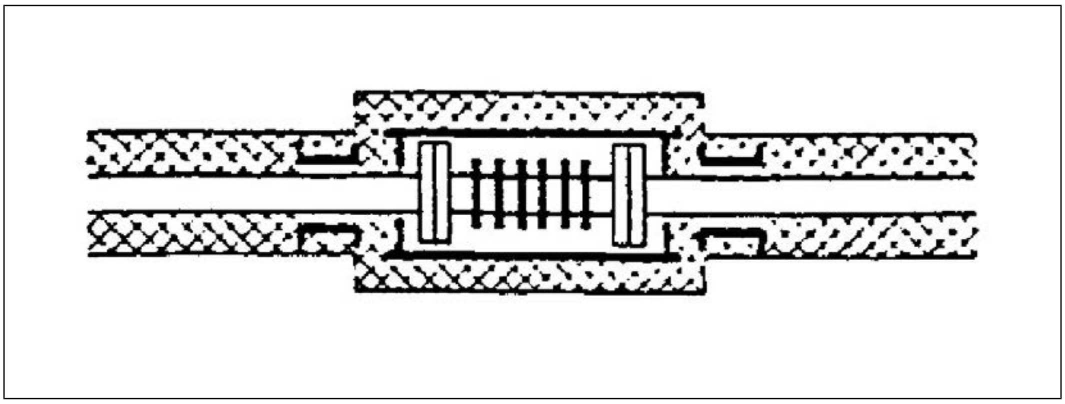
1	Free-running point or pipe guide	2	Muffler
3	Expansion joint	4	Fixed point
5	Fixed point after engine	6	Expansion joint after engine
7	Engine		

Pipe brackets

When arranging expansion joints, pipe brackets shall always be provided before and after the expansion joint, otherwise the pipeline may bend out sideways. Depending on the installation situation, the pipe brackets can be arranged as fixed and/or free-running points. The distance between the fixed point and the expansion joint must not exceed 3 × DN of the piping. Free-running points provide secure support for the piping system, allow flexible but controlled linear expansion of the piping in response to temperature changes, and thus prevent jamming or undesirable shifts in forces. Fixed points keep the entire system stable by introducing the forces and events that occur into the structure. Shifting, twisting or kinking of the piping cannot occur if fixed and free-running points are installed correctly. Depending on the weight and size of the pipe, it may be necessary to fit extra pipe brackets.

Insulation

Because of the considerable heat radiation, it may under circumstances be advisable to insulate an expansion joint particularly inside the engine house. For this purpose, a sliding pipe or sheet-metal sleeve should be laid around and at some short distance from the expansion joint, to prevent the insulation material from resting directly on the expansion joint (see next illustration). Otherwise there is a risk that the insulation material will jam between the sides of the bellows corrugations. For the insulation, it is recommended to use asbestos-free plaited insulation strands or matting; glass wool or diatomite should not be used because of glass wool's and diatomite's tendency to produce dust.



3726935051: Insulation, expansion joint

16.4.3 Storage

Axial expansion joints must be stored in a clean and dry condition, protected from all damage, and must not be rolled using the bellows. Always lift expansion joints for transportation.

16.4.4 Assembly

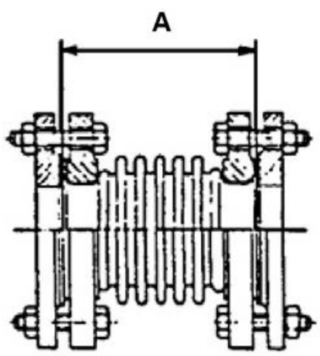
This is a general description. The assembly notes provided by the expansion joint manufacturer and the planning notes must be observed.

Generally

- Before welding on the counter flanges, disassemble expansion joints that are already installed
- The bellows must remain clean during assembly and even afterwards!
- Never paint the bellows!
- Noting the maximum permissible amount of movement which may be accommodated (and which must not be exceeded in operating state), install the expansion joint **free of torsional stress** (without rotation) in the installation gap.
- The boreholes in the connection flanges must line up and the sealing faces must be parallel to each other.
- Check that the bellows corrugations are free of foreign bodies (dust, cement, insulation material), first inside before assembly and then outside after assembly.
- Use normal hexagon screws and self-locking hexagon nuts as per DIN 985 for securing the expansion joint and connection flange.
- To avoid damaging the bellows with tools, only turn the wrench on the counter flange side and counter the wrench away from the bellows on the bellows side. Do not crush the bellows!

Installation and tightening specifications for flanges

The expansion joints are fitted using normal hexagon screws and nuts. Smooth flanges or flared flanges are used as counter flanges. The nuts must be fitted on the counter flange side (see next illustration).



3726924299: Expansion joints, overall length

A Overall length

Genset

Before assembly, the genset must be aligned on the foundation in accordance with the specifications.

The external piping is connected without filling the engine previously with water and lube oil. After filling with water and lube oil, the genset moves down only an additional 1 to 2 mm on the engine side. If necessary, the height-adjustable anti-vibration mounting elements can be readjusted.

- For more information: Anti-vibration mounting [▷ 113]

Procedure

- Install the pipe brackets (without expansion joint) at the installation position in such a way that the specifications for the installation gap are complied with (free-running and fixed points, flanges are aligned and parallel, compensating movements). Observe the distance of max. 3 × DN for fixed points
- Measure the installation gap as per the requirements determined during planning and adjust pipe brackets if necessary. The required movement of the expansion joint when heated during operation and when cooled down after switching off the genset must be ensured!
- Fit the expansion joint free of torsional stress with the installation length determined during planning and screw in fastening screws (screw head on the bellows side). Loosely install nuts on the counter flange
- Close the pipe brackets in such a way that the pipe is fixed at the fixed point and the pipe can slide at the free-running point
- Tighten nuts evenly several times crosswise in accordance with the manufacturer’s specifications.
- Since the connection will settle during initial commissioning or after 24 hours of operation, check the connection point, check the tightening torque of the screw connection and re-tighten if necessary

Protective measures after assembly

After assembly, the expansion joints must be covered as protection against welding heat (e.g., weld spatter, beads) and external damage.

16.5 Hose lines

16.5.1 Function

Rubber hose lines allow the flexible connection of lines carrying fluids and fittings on the genset.

16.5.2 Notes for planning

Installation position

The installation position must be planned in such a way that it is accessible and can be monitored even after assembly.

Materials and requirements

Hose lines must be flame resistant (flame-proof) and must meet the requirements of all classification organizations (Approval test). The following specifications apply to rubber hose lines DN 8 to DN 40.

Bending radius

The smallest bending radii specified in the following illustration refer to rigidly laid hose lines.

If the movement in the hose line (where the bending radius is tight) is repeated very often (continuous operation), it is recommended that an attempt be made to increase the bending radius (if necessary, by using turning knuckles). This will prevent the hose from kinking and extend its service life.

1	DN [mm]	L [mm]	rmin. *1 [mm]	L2 [mm]	2 ØD [mm]	t [mm]	3 [bar] 7	 8	4 [bar]	5 [°C] 9	6
10	8	300	75	12,5	10x1,0	5	25	10	38	70	GCNA 2277
	10	300	80	16,5	14x1,5	6	25	10	38		
11	20	500	130	21,5	25x1,5	8	25	10	50	80 (14) 90 (15) 125 (16)	OLNWV 2298
	32	700	180	21,5	35x2,0	8	25	10	50		
12	32	700	240	23,5	40x2,0	10	22	10	45	80	OLNWV 2298
	20	500	130	21,5	25x1,5	8	25	10	50		
	32	700	180	21,5	35x2,0	8	25	10	50		
13	8	300	115	12,5	10x1,0	5	215	170	510	90 (14) 100 (17) 100/125 (16)	1STT 2432
	10	300	130	16,5	14x2,0	6	180	150	435		
	20	500	240	21,5	25x2,0	8	105	80	255		
	32	700	350	21,5	35x2,0	8	63	60	150		
	40	700	450	23,5	45x2,5	10	50	40	120		

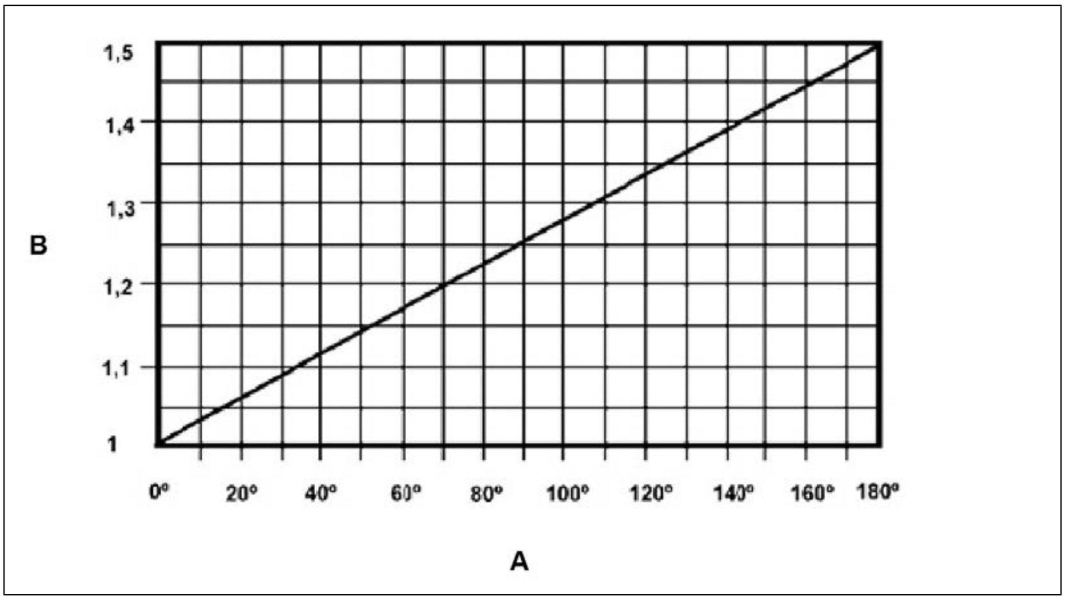
3726869387: Hose line overview

1	Operating medium	2	Pipe diameter
3	Nominal pressure	4	Test pressure
5	Temperature max.	6	Hose designation

7	Normal	8	Upon acceptance
9	Short-term	10	Diesel fuel
11	Diesel fuel, water and lube oil	12	Sea water
13	Lube oil, compressed air and water	14	Diesel
15	Water	16	Lube oil
17	Compressed air		

*1 Smallest bending radius

The diagram in the following illustration shows – depending on the bending angle of the hose line – the bending factor by which the minimum bending radius must be multiplied to determine the permissible bending radius for continuous operation.

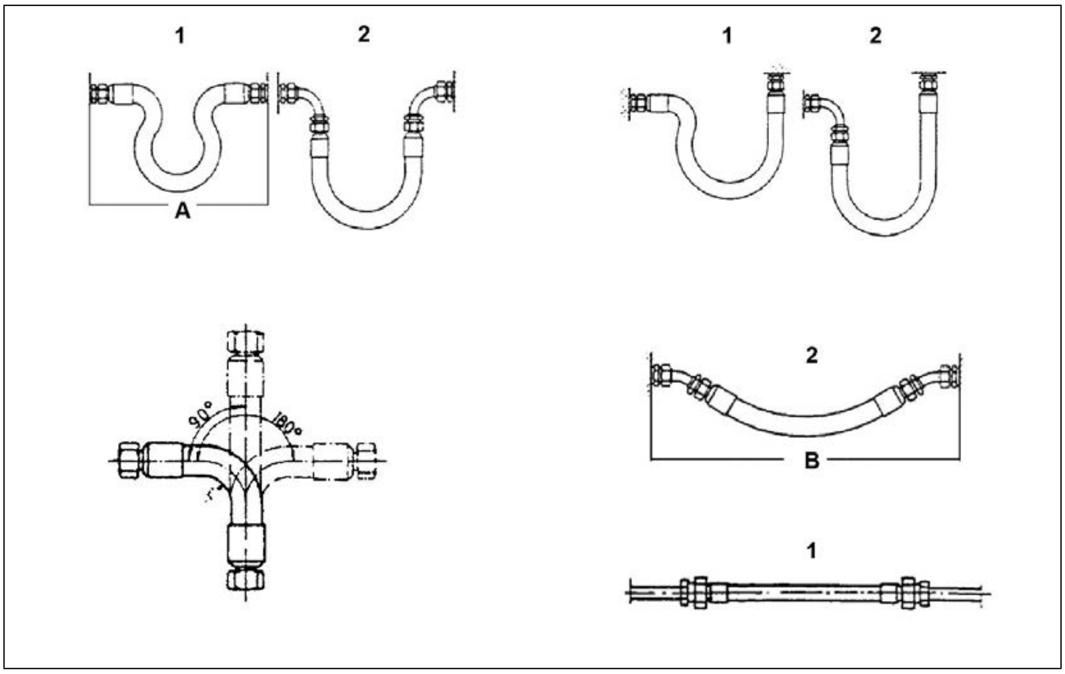


3726874763: Bending factor

A	Bending angle	B	Bending factor

Installation situation

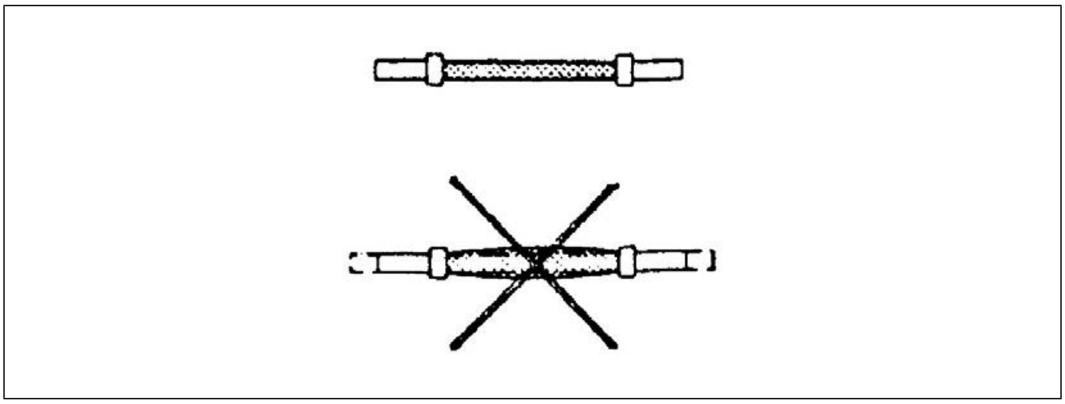
Hose lines shall not come into contact with one another or with other objects during operation. The permissible bending radius should not be undershot. It is not permissible to overbend or stretch the hoses.



3726822923: Arrangement and installation

1	Incorrect	2	Correct
A	Installation length too short	B	Installation length satisfactory

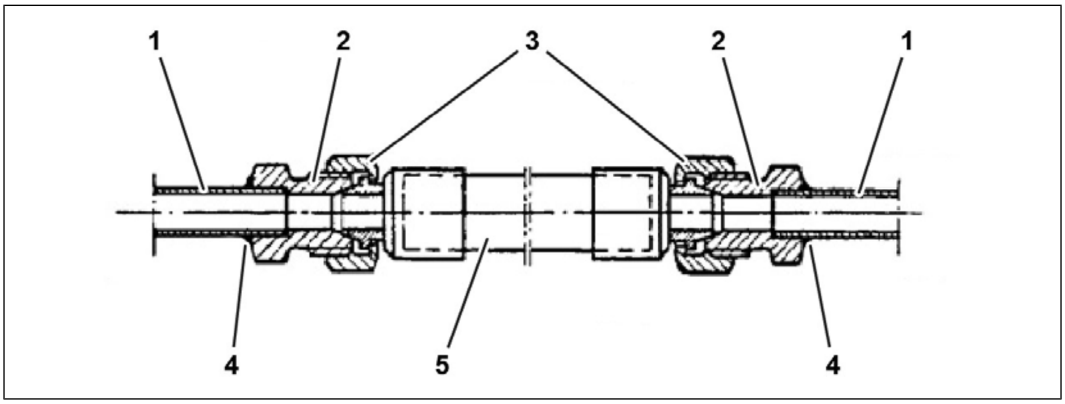
Install hose without tension. Axial compression is not permissible. The braiding detaches itself from the hose and pressure resistance is no longer guaranteed.



3726864011: Axial compression

Hose lines shall not be bent at sharp angles or buckled, i.e., the hose shall not be kinked. No movement stresses or bending stresses must act directly on connections (screw connections). The so-called neutral part of the hose ends must be of adequate size.

If necessary, standard commercially available elbows, manifolds or ring-type screw connections must be provided at the connection ends. When selecting the connecting parts, the stress from pressure, temperature, and type of media must be observed. In the event of movement, the hose line must be mounted so that its axis lies in the same plane as the direction of movement in order to prevent torsion.



3726866699: Soldered connector

1	Connection pipe	2	Soldered connector
3	Union nut	4	Braze
5	Hose line		

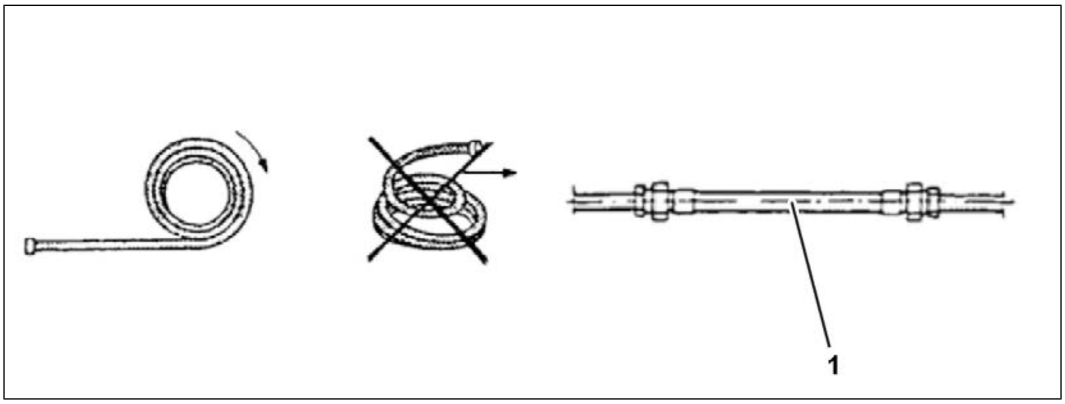
The So Ms 59 F 50Z (special brass) soldered connectors on the hose line screw connections can be removed from the screw connections and connected by means of hard-soldering to the respective pipe end. After determining the gap in which to install the joint between the pipes to be connected, first solder the connector in place on one side, then check the possible bending radius for the hose line before soldering the connector on the other side. The ends of the connection pipes must be cut off precisely at right-angles to the axis of the pipe. The permitted bending radii must be observed.

Pipe brackets

When arranging hose lines, fixed points shall always be provided upstream and downstream of the hose line. The distance between the fixed point and the hose line should not exceed 3 x DN.

16.5.3 Storage

Store hoses in a clean and dry condition and protect against all external damage. Do not drag the container along the ground or over sharp edges. Uncross hose by unwinding the hose ring. Pulling on one end of the hose ring will bend the hose beyond its minimum permissible bending radius and subject it to an impermissible torsional stress.



3726820235: Storage of hose lines

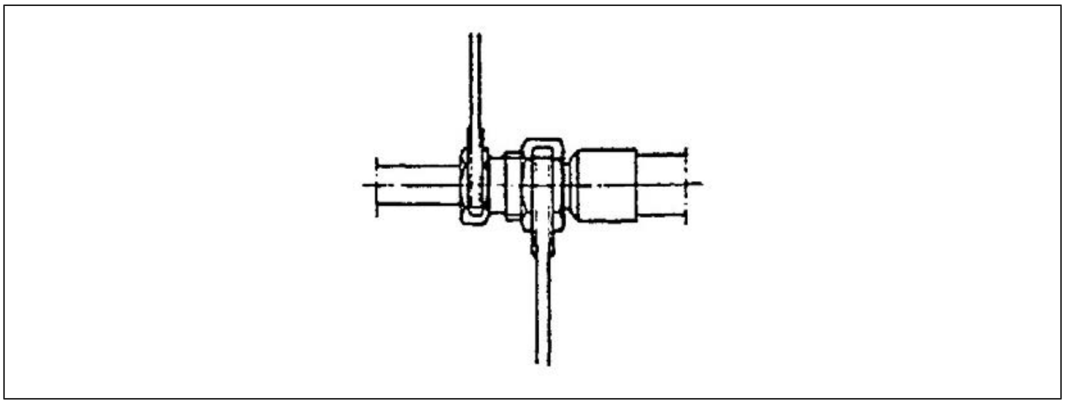
1 Optimum storage = straight

16.5.4 Assembly

This is a general description. The assembly notes provided by the hose line manufacturer and the planning notes must be observed.

Generally

- The hose line must remain clean during assembly and even afterwards!
- Do not paint the hose line!
- When installing the hose line, tighten the connection on one side only. To begin with, leave the connection at the other side loosely fixed.
- Move the empty hose 2 or 3 times in the desired direction to allow it to align itself without twisting, then tighten it also on this side.
- Noting the required freedom of movement (which must also be observed in operating state), install the hose line so that it is **not subjected to torsional stresses** (without rotation), **with no tension and no axial compression**.
- For hose lines with screw connections, use a second wrench to counter the connection (see next illustration).



3726890251: Screw fittings

Procedure

- Connect the hose line without tension
  - Use a second wrench to counter rotating threaded connections.
  - Comply with permissible bending radii

Protective measure after assembly

After assembly, the hose lines must be covered as protection against welding heat (e.g., welding spatter, brazing beads) and external damage.

16.6 Fuel gas expansion joints and gas hoses

The requirements for the installation of fuel gas expansion joints and flexible gas hoses on the gas-air mixer of the genset must be observed.

- Required information: Section “Notes on installing gas trains” in Notes on assembly of gas trains [▹ 176]

The general instructions for expansion joints specified above also apply to fuel gas expansion joints and gas metal corrugated hoses.

- Required information: Rubber expansion joints [▹ 310] and Exhaust expansion joints [▹ 322]

16.7 Piping

16.7.1 General assembly notes

- Piping must be manufactured in accordance with nationally applicable regulations.
- After manufacturing the piping and at the latest before assembly of the plant, thoroughly clean all piping (inside) from dirt, scale and chips. No foreign bodies are allowed to enter the pumps, valves, heat exchangers, sensor systems or combustion engine etc.
- Preserve piping depending on the storage period.
- Where pipe diameters do not match the connections to components (pumps, compressors, mixing coolers, etc.), adapt by fitting reducers or reducer connectors. For the location and size of the connections to this apparatus, please refer to the individual component drawings.
- When installing measuring instruments (e.g., heat meter, gas meter, etc.), the guidelines specified by the manufacturer must be observed. This applies in particular to the installation location and the inlet section and outlet section.
- In systems which are to be filled with fluids, make connections for draining and filling at the lowest points. At the low points, install taps with end caps and hose connections for filling and draining. At all high points, air vents must be provided. At the high points, attach bleeding taps or automatic vents.

- In the case of pipes carrying gaseous media, fit condensate collectors with drain cocks at the lowest points. Lay pipes with a slope to the condensate collector.
- Copper piping is permissible for fresh oil filling lines. Solder pipe connections using silver solder. As an alternative, use unsheathed “ERMETO” steel piping for the lines. Generally assemble pipe connections using special screw connections, do not weld! After being laid, thoroughly purge the fresh oil lines with new oil.
- Compress fresh oil lines made of copper or steel with oil-resistant fittings. Since the sealing material is not oil-resistant, it is not permissible to use standard fittings for the sanitary area.
- Pickle and passivate stainless steel lines after production. Tarnish must be removed. Chromate burnout must be prevented by forming.

16.7.2 Material for piping

The following table shows an overview of the piping materials for the different media:

Operating medium	Subdivision	Pipe material
Natural gas, mine gas (for gas quality High according to TR 3017)		Steel, galvanized steel, between gas train and engine. Steel lines or stainless steel lines; these lines must be absolutely “clean”.
Biogas, sewage gas, landfill gas, associated petroleum gas		Standard stainless steel
Water	Engine circuit, mixture cooling circuit, charge air circuit, heating circuit, dump cooling circuit, raw water circuit	Standard steel: depending on the water quality, higher-quality materials may have to be used, e.g., seawater in the dump cooling circuit or raw water circuit.
Lube oil. Hot lube oil bypass lines		Stainless steel
Fresh oil filling lines and waste oil lines		Steel, copper, stainless steel
Compressed air	Starter pipes	Stainless steel
	Filling pipes	Steel

Operating medium	Subdivision	Pipe material
	Control air pipes (low pressure)	Steel, copper
Exhaust gas	Operation with natural gas, mine gas	Before EHE and interior installation: heat-resistant steel (e.g., 15 Mo 3) After EHE and outdoor installation: stainless steel
	Operation with biogas, sewage gas, landfill gas, associated petroleum gas	Stainless steel (e.g., 1.4571)
	Upstream of catalytic converter	Always stainless steel (e.g., 1.4571)
Condensate	With content of acid components	Stainless steel
	Residual	Steel, copper, galvanized steel

Table 51: Overview of piping materials and operating media

When using materials other than those specified in the table, always consult Caterpillar Energy Solutions GmbH (CES).

16.7.3 Notes on welding piping

Welded connections guarantee absolute impermeability during operation. Welded connections form a homogeneous part of the piping. A welded pipe connection is the most economical connection method and its use is therefore preferred. The quality of the weld joint is dependent on how the pipes are fitted together, the ends being perfectly centered, the edges being properly prepared for welding and the chosen welding method.

Risk of destruction of components

Risk of destruction of components

Components can be damaged by heat, flying sparks, etc., as well as by the welding current in the case of electric welding

- When performing welding work in the pipe system, disconnect all electrically conductive connections to the genset.
- Remove the steel expansion joints on the genset when welding.
- In the case of E welds, place the electrode mass close to the welding point. Ensure a good ground connection.
- When welding, weld sparks can damage the rubber expansion joints and steel expansion joints. Cover rubber expansion joints and steel expansion joints (see Chapter Protecting the genset [▸ 113]).

Welding steel pipes

The following points should be noted here:

- Roughness of the cut-offs according to the applied WPQR / WPS
- Approved welding processes shielded metal arc welding, metal inert gas welding or tungsten inert gas welding according to DIN EN ISO 15607 to 15614
- Weld seam preparation as per DIN EN 9692-1
- Directive on assessment categories for irregularities DIN EN ISO 5817, evaluation group C
- Welding spatter must be removed completely
- Filler metals according to applied WPQR / WPS

16.7.4 Releasable piping connections

Flange connections

Flange connections are notable for their ease of assembly and are generally used for the piping connections at engines, pumps, heat exchangers, tanks, etc. Preference shall be given to flanges which comply with DIN EN 1092, PN10 or PN16; for high-pressure media (e.g., compressed air), they should have a correspondingly higher nominal pressure.

When servicing or maintaining engines or plant components, it is often necessary to dismantle piping to improve accessibility. In such cases, it is particularly recommended that flange connections be installed at suitable locations.

The materials used to seal between the flanges should be selected to suit the load imposed by the operating media itself as well as the pressure and temperature of the media. In order to avoid leaks, flange connections need to be monitored. Therefore, as far as possible, flange connections should be accessible in order to replace the seals or retighten the screws. The facility to check the connections visually must, under all circumstances, be guaranteed.

Screw connections with sealed thread

Preferably use Whitworth pipe threads as per DIN EN 10226 for connections to threaded pipe. Use pipe threads with cylindrical, internal threaded connections on mountings, fittings, etc. and with tapered external threads. Before fitting, pack the threads with sealant to increase the sealing tightness.

Screw pipe connections

Establish the sealing tightness with a progressive ring for the screw pipe connection. The screw pipe connection is a positive-fit, leak-proof pipe connection. For these lines, use exclusively precision steel pipes, preferably with external diameters of between 6 mm to 38 mm. Depending on the wall thickness and external diameter, use reinforcing sleeves. Take care in tightening the progressive ring.

16.7.5 Assembly, insulation and surface treatment of pipes

Pipe brackets and supports

Fasten pipes to consoles or walls with clamps, round steel clips, etc. In the case of pipes running horizontally, select the mounting span according to the pipe diameter. In the case of pipes subject to expansion because of the high temperature of the operating media they carry, adjust the bearings to the conditions. Implement bearings as fixed mounts and free-running mounts. Where appropriate, consider the possibility of structure-borne noise.

Insulating pipes

Depending on the temperature of the operating media they carry, fit pipes with heat insulation to provide contact protection. Select the insulation thicknesses to avoid the surface temperature of the insulation exceeding 60 °C. Alternatively, achieve contact protection by other means, for example by fitting perforated metal sheeting or wire mesh at an appropriate distance from the object.

Surface treatment, coloring

Always paint all piping, with the exception of stainless steel pipes. Thoroughly clean pipes. Provide piping with a primer and top coat, for the required corrosion protection class and protection duration.

Coat pipes provided with heat insulation in primer only.

Provide high-heat resistant coatings for steel exhaust pipes.

Insofar as no particular colors are otherwise specified, select the colors in accordance with DIN 2403. This standard lays down the requisite colors for pipes dependent on the media they carry.

Leak tightness

Check piping for leaks during filling and commissioning.

16.8 Measuring devices, monitoring devices, and limiting devices

16.8.1 General specifications

16.8.1.1 Basic principles

The measuring devices, monitoring devices, and limiting devices are used to protect and control the CHPS module. Moreover, they are needed to fulfill the safety requirements for heat generators.

An EU declaration of conformity and CE marking are necessary for measuring devices, monitoring devices and limiting devices. The EU declaration of conformity confirms fulfillment of the Low Voltage Directive 2014/35/EU and the Electromagnetic Compatibility Directive 2014/30/EU.

When installing the measuring devices, monitoring devices, and limiting devices, the manuals for operation, , use, and maintenance must be taken into account. When installing, it is essential to take account of the following:

- Permissible ambient temperature
- Permissible operating media
- Permissible operating media temperature
- Permissible operating pressure
- Permitted position for installation
- Permissible flow speed
- Required minimum immersion depth
- Selection of cables according to chapter Overview of cabling [▸ 347]

16.8.1.2 Monitoring as per DIN EN 12828

In order to limit temperature, pressure, flow and low water level, the devices must fulfill the following requirements:

- Temperature monitors and limiters must be tested according to DIN EN 14597 (limiters with reactivation lock)
- Pressure limiters must be component-tested according to VdTÜV Technical Leaflet "Pressure 100/1" with reactivation lock
- Flow limiters must be component-tested according to VdTÜV Technical Leaflet "Flow 100"
- Fill level limiters must be component-tested according to VdTÜV Technical Leaflet "Fill level 100/2"

16.8.2 Components and parts

16.8.2.1 Temperature measurement

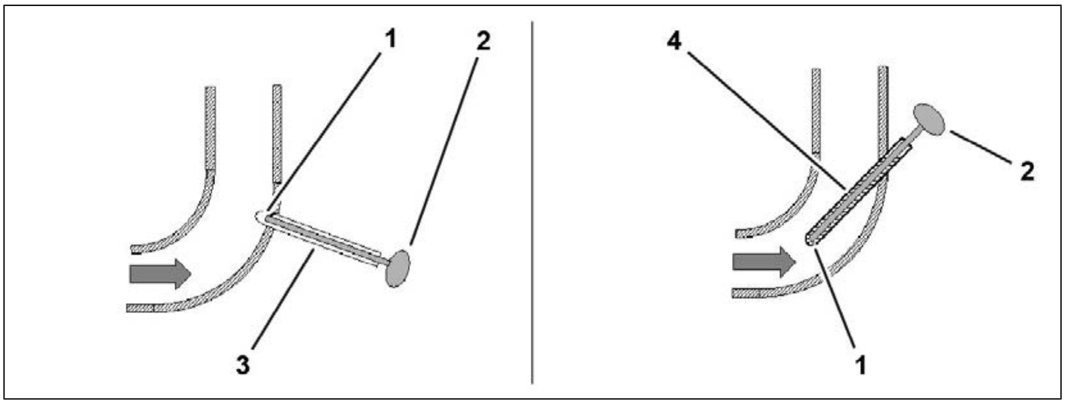
Water circuit temperatures are recorded with temperature sensors and exhaust gas temperatures are recorded with thermocouples. The temperature-dependent changes in resistance and thermoelectric voltage are converted via transmitters in the sensor head into a standardized 4 – 20 mA signal.

Installation notes for temperature sensor

Fast measuring of dynamic temperature changes is an absolute requirement for a good control system. The installation position has a great influence on the response times and measuring errors.

The following illustration shows good and bad examples of installation in piping. The length of the immersion sleeves has to be adapted to the piping so that the sensor tip measures the temperature in the core of the flow. The sensor has to be connected to the immersion sleeve thermally by a conductive medium. Temperature-proof oils and heat-conductive pastes are suitable for this. Insulating air gaps between the immersion sleeve and sensor have to be avoided in all cases.

Example: bad (sensor not in the core of the flow)	Example: good (sensor in the core of the flow)



3694933771: Installation of the temperature sensor

1	Pt100 sensor	2	4 to 20 mA transmitter
3	Immersion sleeve with air gap	4	Gap filled with thermally conductive medium

16.8.2.2 Exhaust back pressure monitoring

A gas pressure monitor specially designed according to VdTÜV Technical Leaflet “Pressure 100/1” is used to monitor the exhaust back pressure. The measuring line must always slope upwards towards the sensor.

16.8.2.3 Differential pressure monitoring

Differential pressure switches are used to monitor differential pressures.

16.9 Cabling

16.9.1 Overview of cabling

The cabling for a CHPS plant comprises power cables, supply lines for auxiliary drives, control cables and signal lines.

The power cables must be laid separately from the control cables and signal lines. It is essential to use flexible, oil-resistant, fine-wire gas trains (e.g., H05VV5-F).

Analog signals shall also be shielded (shielding to be composed of tinned copper braid with a minimum of 85 % coverage such as H05VVC4V5-K, not aluminum foil).

For the supply lines to the auxiliary drives, flexible, oil-resistant, fine-wire engine connection lines must be laid (e.g., H05VV5-F).

Cables for outside installation need to be suitable for installation in open air (weatherproof, UV-resistant, e.g., ÖLFLEX classic).

The supply lines for frequency controlled drives need additional shielding (e.g., TOPFLEX EMV-UV-2YSLCYK-J). For frequency controlled drives, the total length of 100 m for the pipeline may not be exceeded.

Flexible single-core cables made of copper with rubber sheathing, e.g., NSGAFÖU, should be used for connecting starter batteries to the electric starters.

For the generator power cables, flexible multi-wire power cables (25 mm^2 and upwards) made of copper must be used (e.g., NSGAFÖU for low voltage and NTMCWOEU for medium voltage).

As protection against overload and short circuit, the lines must be fitted with miniature circuit breakers as per DIN VDE 0641 and/or DIN EN 60898; circuit breakers as per DIN EN 60947-2 (IEC 60947-2) must be provided for the engines. The layout of the cabling should always be based on the currently applicable version of DIN VDE 0100. The cables must be routed through appropriate installation ducts and cable support systems. The cables must be laid in such a way as to prevent damage to the cable sheathing. This is of particular importance where cables are laid on a cable support system. That is, adequate edge protection must be provided. As a matter of principle, cables must be fixed or secured in such a manner as to prevent tension on the terminals (strain relief).

When laying cables, attention must be paid to the measures designed to safeguard electromagnetic compatibility.

- Required information: General [▷ 352]

Cable glands with integral strain relief must be used. The size must be selected to suit the external diameters of the cables.

Power cables must be laid short circuit-proof and must be selected according to bundling, type of laying and ambient influences.

When choosing and laying lines, the following points must be considered:

- Avoid possible mechanical or electrical interference between neighboring circuits.
- Consider the heat given off by lines or the chemical and physical effects of the line materials on adjacent materials such as structural materials or decorative materials, insulating conduits, fastenings.
- Consideration of the effect of the current heat on the materials used for conductors, connections, and couplings.

16.9.2 Safety requirements for cables and lines

16.9.2.1 Boundary conditions for the safe use of cables and lines

Operating conditions

The lines selected must be suitable for the operating conditions and the respective protection class of the equipment concerned.

The operating conditions include, among others:

- Voltage
- Current
- Protective precautions
- Bundling of lines
- Type of laying
- Accessibility

The lines selected have to be suitable to withstand all external influences which may arise.

These external influences include, among others:

- Ambient temperature
- Rain
- Water vapor or accumulated water
- Chemicals and operating media (e.g., lube oil)
- Mechanical stresses (e.g., fluctuations and vibrations)
- Animals (e.g., rodents)
- Radiation (e.g., sunlight)

Voltage

The rated voltage of a line is the voltage for which the line is designed and which is used as a definition for electrical tests. The rated voltage is specified in Volts using two values U_o / U:

- U_o is the r.m.s. value of the voltage between an external conductor and ground (metal sleeves of the line or surrounding medium).
- U is the r.m.s. value of the voltage between two external conductors of a multi-core line or a system of single-core lines.
- In an AC voltage system, the rated voltage of a line must at least correspond to the U_o and U values of the system.

Current carrying capacity

The nominal cross-section of a conductor should be selected so that its current carrying capacity is not less than the maximum continuous current flowing through the conductor under normal conditions. The limit temperatures to which the current carrying capacity relates must not be exceeded either for the insulating sleeve or sheathing of the respective line type. Among the defined conditions is also the manner in which the line is laid. Attention should be paid here to the specified permissible current loads.

The conditions to be taken into account include, among others:

- Ambient temperature
- Bundling of lines
- Type of overcurrent protection
- Heat insulation
- Rolled or coiled lines (should be avoided)
- Frequency
- Effects of harmonics.

The conductor cross-section shall not be selected simply in accordance with the requisite current carrying capacity (DIN VDE 0298-4). Rather, the requirements for protection against hazardous shock currents, overload currents, short-circuit currents, and voltage drop should be considered. Where lines are to be operated for extended periods at temperatures higher than those specified, they may suffer serious damage. This damage can lead to premature failure, to a significant impairment of their characteristics and life threatening situations.

Thermal influences

Lines should be selected, laid and installed so as to ensure that the anticipated release of current-induced heat is not obstructed and there is no risk of adjacent materials catching fire. The limit temperatures for the individual line types are specified by the manufacturer. The specified values must, under no circumstances, be exceeded due to the interaction between internal current-induced heat and ambient conditions. The typical temperature range for permanently laid standard cables is from -40 °C to +80 °C. If higher temperatures occur, cables with greater heat resistance must be used.

Mechanical influences

When assessing the risks of mechanical damage to the lines, consideration must be given to all mechanical stresses which might arise.

Tensile load

The strain values specified for the cables must not be exceeded. Typical values are 50 N/mm² for permanently installed lines and 15 N/mm² for flexible lines. In cases in which the above-mentioned values are exceeded, a separate strain relief element or similar should be fitted. Such strain relief elements should be connected to the line in such a way that they do not damage the line.

Bending stresses

The minimum bending radius must always be checked and complied with for the particular lines and cables used.

The specified bending radii apply at ambient temperatures of 20 °C (±10 K). For other ambient temperatures, account must be taken of the manufacturer's specifications. Bends should be avoided in the immediate vicinity of external or internal fixing points.

Pressure load

Lines should not be subjected to such pressure as might damage them. For example, lines must not be driven over or subjected to other loads.

Torsional stresses

Flexible lines are not intended to support torsional stresses. Where such torsional stresses are unavoidable, this must be clarified on a case-by-case basis with the cable manufacturer.

Types of use and stress

Electrical lines may be divided between the following types of use:

- Cables for use in interior rooms, e.g., CHPS room
- Cables for use in the open air, e.g., supply line for radiators

16.9.2.2 Safety requirements for the safe use of cables and lines

Fundamental requirements

When used in the manner intended, cables and lines should be regarded as safe. Cables and lines present no unacceptable risk to life or property.

General Requirements

Lines should be chosen such that they can withstand the occurring voltages and currents. This applies to all operating states, to which lines are exposed in an operating medium, plant or parts of a plant. The lines must be structured, laid, protected, deployed, and maintained in such a way as to avoid hazards as far as possible.

Power cables must be laid short circuit-proof and must be selected according to bundling, type of laying and ambient influences.

Cable design for normal operation

The conductor cross-section must be selected to ensure that, at the current load specified for the conductor, the permissible operating temperature is not exceeded at any time or at any point. The heating or the current carrying capacity of a cable or line is dependent on its structure, material characteristics and operating conditions.

The additional heating effect of heating ducts, solar radiation, etc. on bundled cables or lines should be considered and avoided. Where covers are used, it is important to ensure uninterrupted air circulation.

Operation mode

Continuous operation represents constant current operation, the duration of which is at least sufficient for the operating equipment to reach thermal steady-state, but is not otherwise limited in time. The design values for cables and lines are based on continuous operation, whereby the permissible operating temperature of the conductor is reached.

Ambient conditions

Ambient conditions are marked by, among other things, the ambient temperature, heat loss and heat radiation. The ambient temperature is the temperature of the ambient air when the cable or line concerned is not under load. The reference temperature is +30 °C. The operating conditions for cables and lines may vary both in the case of heat loss, for example in closed rooms, underfloor cable ducts, etc., and under the influence of radiated heat, e.g., the effects of the sun.

Conditions and requirements for permanently laid lines

Requirements for lines which are to be permanently laid are as follows:

- Lines must not come into contact with nor be laid in immediate proximity to hot surfaces, unless they are suitable for it.
- Lines must not be laid directly in the soil.

- Lines must be secured in an appropriate manner. When selecting the distance between fixings, the weight of the line must be considered.
- The line must not be damaged by the mechanical means of fixing employed.
- Lines which have been in use for some time can be damaged if changes are made to the manner in which they are laid. This is due to the natural effect of aging on the physical characteristics of the materials used for insulating sleeves and sheathing. This process is accelerated by higher temperatures.

Requirements for flexible lines

- The length of connecting lines must be selected so as to be certain that the short-circuit protection devices will respond.
- The lines should not be subjected to excessive stresses due to strain, pressure, friction, twisting or kinking.
- Strain relief devices and connections must not be damaged.
- The lines must not be laid beneath covers or other operating equipment. There is a risk that they may suffer damage due to excessive heat build-up or mechanical damage due to being walked on.
- The lines shall not come into contact with nor be laid in the immediate proximity of hot surfaces.
- Observe the permissible bending radii.

16.9.3 Measures to safeguard EMC

16.9.3.1 General

The line arrangement contributes to an essential part of the EMC of a plant. The lines are graded in four groups:

Group I	Very interference-susceptible (analog signals, measuring lines)
Group II	Interference-susceptible (digital signals, sensor cables, 24 V_{DC} switch signals)
Group III	Fault source (control cables for inductive loads, unswitched power cables)
Group IV	Strong fault source (output cables of frequency converters, switched power cables)

Table 52: EMC and line routing

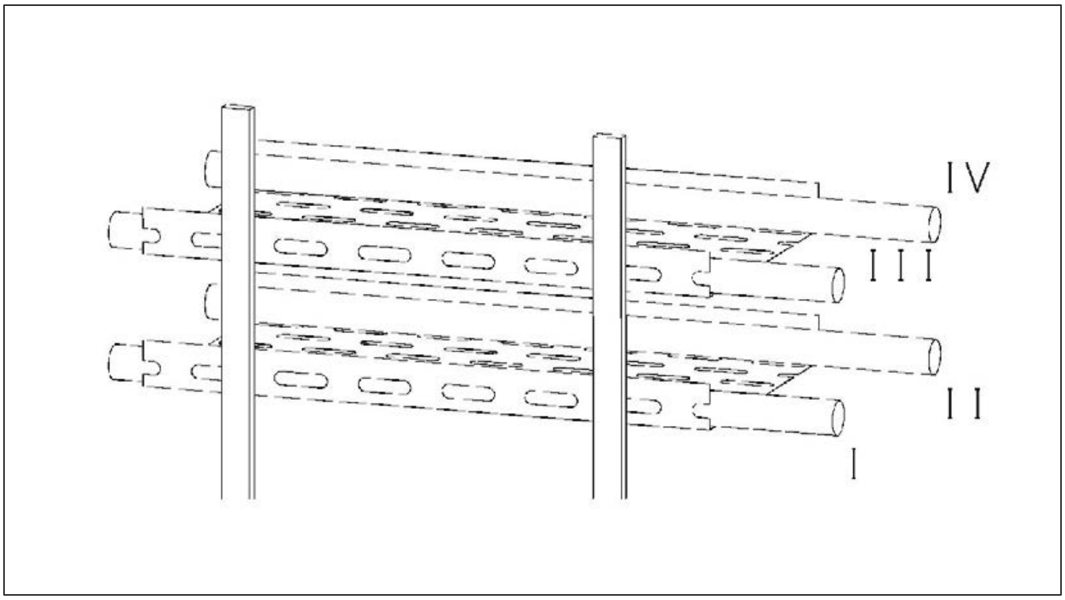
Crossing should be avoided when arranging the cables. If there are unavoidable crossings, the lines of the different groups must cross at right angles.

16.9.3.2 EMC instructions for use of frequency converters

Depending on the EMC requirement (environmental class 1 or environmental class 2) and type of frequency converter, EMC filters are required. Attention must be paid to the cabling instructions and EMC instructions in the operating manual.

16.9.3.3 Cable ducts

- Metallic cable ducts must be included in the grounding concept and connected continuously
- Reduction of the magnetic field through distance of the cable troughs (see next illustration)
- Lines are installed in various cable ducts
- Power cables and control cables are separated by a metallic separator



3698873867: Cable troughs

The recommended minimum distance between cable troughs is 0.15 m. The troughs should be electrically connected to the vertical carriers. The cable duct for the signal transmission lines should be covered. In general, the power cables of generators should be laid separately. In the case of power cables, it must be noted that the type of routing has a significant influence on the current carrying capacity of the line. The correction factors in the standards must be observed here.

The correction factors in the standards must be observed here. The standard VDE 0298 specifies a distance of 0.3 m between the cable conductors and to the ceiling when routing cables on cable conductors.

16.9.3.4 Cable glands

In the case of particular EMC requirements, EMC-type cable fittings should be used. In general, chromed brass fittings are used. Separate specifications must be observed for fittings for generator power cables.

Required information

- Generator power cables [▶ 354]

16.9.4 Generator power cables

The standards and directives applicable at the installation site must always be observed for the layout and routing of generator cables. The cable layout based on the German regulations is described in the following sections.

16.9.4.1 Cable layout

NOTE

The specifications relate to the standard DIN VDE 0298-4: 2023-06 (IEC 60364-5-52:2009) which applied when this document was created, and may have to be updated. If different rules and regulations apply on site, these must be observed.

This chapter contains a general description of the procedure for the planning of the required power cables for connecting the generator to the power supply mains.

The typical energy distribution systems from Caterpillar Energy Solutions (CES) are required. The following description is based on the specifications in the standard DIN VDE 0298-4. As this is very comprehensive, the following information is focused on the relevant content of the standard

Required information

- Standard DIN VDE 0298-4: 2023-06 (IEC 60364-5-52:2009) Application of cables and insulated lines in power installations – Part 4: Recommended current load ratings of cables and lines for fixed routing in and on buildings and of flexible lines

Calculation method

The calculation method is based on the maximum and permanently permissible operating current that flows through the cables connected to the genset when used as intended. A cable type and its cable size must be selected for this. For this selection, the cable manufacturer or the standard that applies for the cable specifies a current carrying capacity under standard conditions which must be transferred to the actual situation on site. This is transferred by classifying the on-site situation (temperature, type of laying) into various classes with their specific correction factors. For the final cable layout, the number of required cables with the selected cable size and planned type of laying is calculate from this, or the layout is optimized using a different cable size or type of laying.

Step	Task	Comment
1	Define the maximum operating current of the genset	See Technical data for the genset or values defined during project planning
2	Select cable type and select cable size	See "Notes on cable selection" below
3	Determine the theoretical current carrying capacity of the cable type	See Technical data provided by the cable manufacturer
4	Determine the correction factor for the expected ambient temperature on site	See Standard specified above, Table 17[1]
5	Determine the correction factor for the generally planned type of laying	In containerized power stations from CES, this is generally the value for cables laid in bundles in the air (see Standard specified above, Table 14[2])
6	Determine the correction factor for the actual implementation of this type of laying	In containerized power stations from CES, this is generally the value for cable conductors in draft-ventilated rooms (see Standard specified above, Table 24[3])
7	Calculate the current carrying capacity of the cable type in practice and the required number of cables	See Formula in the standard or Example calculation [▸ 361]
8	Final cable selection or optimization	

Table 53: Calculation method steps

[1] Table 17 – Conversion factors for ambient temperatures above or below 30 °C for the current load ratings of cables and lines in air

[2] Table 14 – Operating conditions for lines with rated voltages of 0.6/1 kV or higher in column 4 for bundling in three-phase current circuits

[3] Table 24 – Conversion factors for bundling of single-core cables or lines on

cable troughs and cable conductors

Notes on cable selection

Caterpillar Energy Solutions (CES) recommends the following cables, which are also used in the CES switchgear systems:

- Low-voltage applications: Cable NSGAFÖU
- Medium-voltage applications: Cable NTMCWOEU

Other cable types can also be used. It must be ensured that these involve flexible cables, as only limited space is available in the generator connection boxes. It is also necessary to check whether the cables can be used at the installation (for example USA and Canada require special cables).

Notes on ambient temperature

The ambient temperature has an effect on the current carrying capacity of the power cable. A relatively high temperature is produced in the genset room due to the heat dissipated from the engine. Therefore the cable types used should have a permissible operating temperature at the conductor of at least 90 °C.

Notes on type of laying (laying conditions and cable bundles)

The load-bearing capacity of the cables also depends on whether direct current circuits, alternating current circuits or three-phase current circuits are involved. The specifications in the standard for three-phase current networks are relevant for the energy supply plants from CES.

Correction factor for the general laying type

The values for the laying of bundled or touching lines are relevant for the energy supply plants from CES. Correction factors are available for selection for:

- Laying on surfaces (e.g., floor, wall)
- Laying free in the air (e.g., cable conductors)
- Laying in tubes or channels

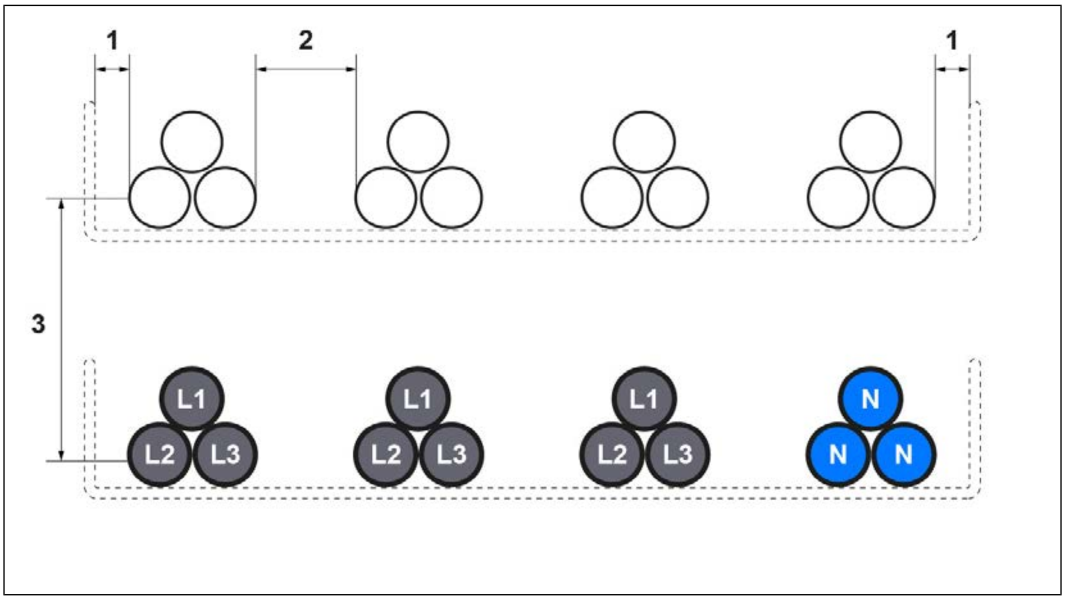
Correction factor for the special laying type

In addition to this factor, the correction factor specified in the standard must be considered for the special laying type.

It must be ensured during the laying that the heat resulting due to the load on the cables can be dissipated. Various factors play a role here, for example the substrate, the spacing between the cables themselves as well as the distance to the surrounding parts.

When using a cable conductor where the cables are surrounded by air on all sides, the heat can be dissipated significantly better than, for example, on a cable trough. The CES containerized power stations are therefore designed with cable conductors as standard.

The correction factors for the laying of cables on cable conductors and cable troughs specified in the standard relate, for example, to laying cables in bundles of three (see next illustration).



3698877067: Example illustration for laying in bundles of three

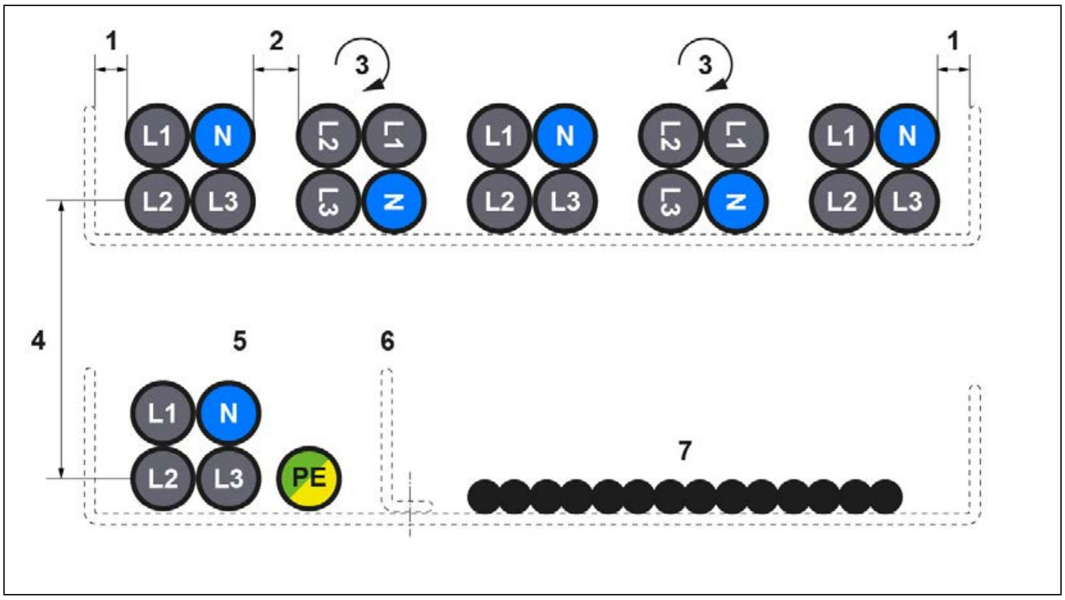
1 Distance of cable bundles from the side wall: > 20 mm

2 Distance between cable bundles: at least twice the cable diameter

3 Distance between the cable level and the ceiling: at least 300 mm

Designations: (L) Phase, (N) Neutral conductor

For standard containerized power stations from CES, it is safe to assume that there is continuous ventilation, and as a result, there is no accumulated heat. Cables can therefore be laid as shown in the following illustration. This type of laying can also be used for draft-ventilated genset rooms in compliance with the ambient conditions.

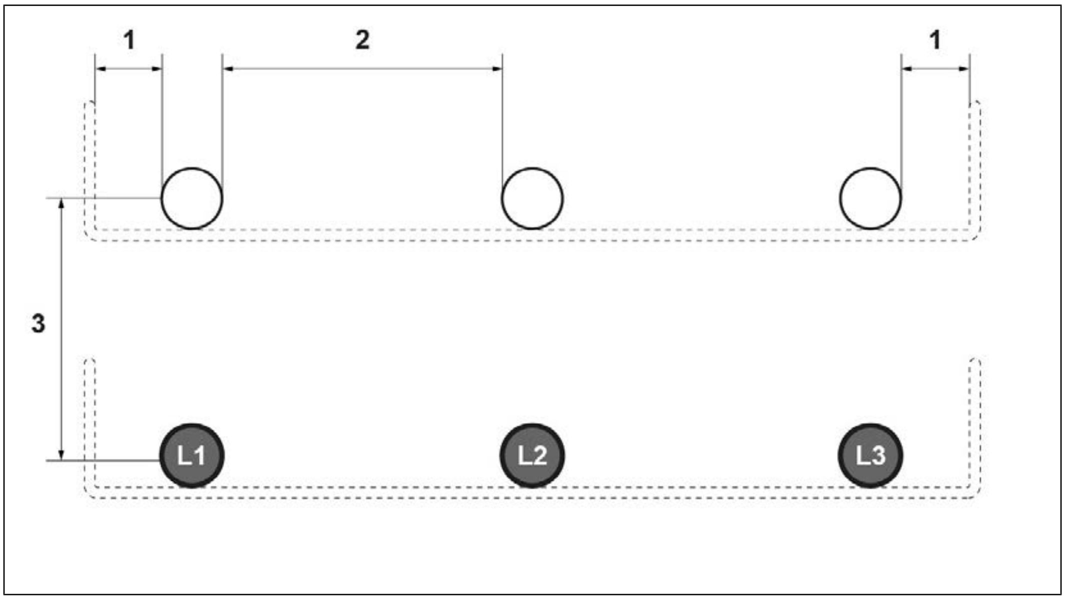


3698880267: Example illustration of laying cables in bundles of four

1	Distance of cable bundles from the side wall: > 20 mm	2	Distance between cable bundles: at least the cable diameter
3	Cable bundle rotated 90°	4	Distance between the cable level and the ceiling: at least 300 mm
5	Power cable and PE cable	6	Metallic separator
7	Control cables		

Designations: (L) Phase, (N) Neutral conductor, (PE) Protective conductor

Alternatively, single cables can also be laid with spacing between them, but this will increase the amount of space required (see next illustration).



3698881931: Example illustration of unbundled laying of single cables (medium voltage)

1 Distance between cables and the side wall: > 20 mm

2 Distance between cables: at least the cable diameter

3 Distance between the cable level and the ceiling: at least 300 mm

Designations: (L) Phase

The correction factors in the standard must be observed for other types of laying.

Recommendation

In order to keep the correction factors as low as possible, laying on a cable conductor is recommended. All power cables are arranged horizontally in groups of four on a cable conductor. If several cable conductors or cable troughs have to be laid over one another for space-related reasons, the correction factors specified in the standard apply. The cable conductors must have a minimum distance of 300 mm from the ceiling and between one another.

When you compare the correction factors specified in the standard for the laying type shown in the illustration “Laying cables in bundles of three on cable troughs and cable conductors” above, we see that:

- laying cables on cable conductors gives a more favorable correction value as the heat is dissipated better
- laying cables on a cable conductor will not reduce the current carrying capacity of the cable (this is the case even if the number of three-pole current circuits is higher than 3)
- even arranging eight cables per phase on one cable conductor works well as long as the specified distances are observed.

The same applies for laying cables as shown in the previous illustration “Example illustration of laying cables in bundles of four” in draft-ventilated rooms.

Assembly notes for making cable bundles

- The cable bundles must be wrapped every 0.5 m with five wraps and fixed every 2 m with cable clamps on the cable conductor.

16.9.4.2 Neutral conductor

According to the current guideline, the N-conductor can be designed with half cross section, given that the harmonic content in the current is less than 10 %. As the harmonic currents depend on the load, in other words the consumers, these vary specific to the plant. The N-conductor is therefore listed with complete cross section in the overview table.

Required information

- Table “Cable layout overview” in chapter Overview of cabling [▸ 347]

16.9.4.3 Short-circuit-proof laying

In the event of a short-circuit, enormous forces result, which can cause the power cables to move considerably. In order to prevent damage to the insulation of the cables or to surrounding parts, short-circuit-proof laying must be ensured. The cable bundles are wrapped with five wraps of cable bundle tape every 0.5 to 1 m for this purpose. To prevent the cable bundles from moving, they are fastened to the cable conductor with a cable clip every 2 m. The minimum bending radii of the cables used must always be observed for the laying. Failure to comply can result in damage to the insulation.

16.9.4.4 Screw fittings

Screw connections with integrated strain relief must be used for introducing the power cables in the generator terminal boxes. These prevent forces from acting on the connecting terminals in the generator. In addition, the screw connections should not exhibit any edges where the cable chafes, thereby damaging the insulation. In this case, Caterpillar Energy Solutions recommends using so-called bell-mouth screw connections (see next illustration).

3698897931: Bell-mouth screw connection

16.9.4.5 Cable connection

The power cables must be laid and connected in accordance with the relevant standards and technical regulations. It is important to ensure that suitable cable lugs and cable end locks are used and that these meet both the electrical and mechanical demands of the power cables used as well as the connection requirements of the generator terminals. Technical details and specifications for the generator connection boxes are available on request.

16.9.4.6 Cable outlet

The cable outlet can be realized on both sides (right or left) upwards or downwards out of the generators. The low-voltage generators are connected upward and the medium-voltage generators are connected downward as standard.

The cables must be held with a suitable device at a relatively close position downstream of the outlet from the generator (see illustrations below). The cables must be fastened with cable clamps. Fastening with cable ties is not permissible as this results in damage to the insulation. It must also be ensured that the cables are not laid with tension but instead provided with a curvature, which prevents the genset from vibrating.

16.9.4.7 Example calculation

NOTE

The specifications relate to the standard DIN VDE 0298-4: 2023-06 (IEC 60364-5-52:2009) which applied when this document was created, and may have to be updated.

The cable calculation is based on a TCG 2020 V12 with 400 V ± 10 %, 50 Hz as an example.

Cable type and current carrying capacity

The recommended cable NSGAFÖU with a cross section of 300 mm² is selected.

The current carrying capacity for a single laid line is:

- 898 A*

* as per data sheet or the applicable standard for the selected cable type

Correction factor for ambient temperature

The example should also apply to containerized power stations from CES. Since temperatures of up to 45 °C in summer are possible there in the standard version, this ambient temperature is assumed as the basis for the calculation.

Since the selected cable type must be suitable for a permissible operating temperature at the conductor of at least 90 °C, this results in the following correction factor:

- 0.87*

* Table 17 in the standard specified above

Correction factors for laying type

In the containers, the low-voltage power cables are laid in bundles of four on the cable conductors as standard.

For the laying of bundled lines in air, this results in the following correction factor:

- 0.7*

* Table 14 in the standard specified above

Since this is three-phase current, all cables are laid on one cable conductor and the containers are draft-ventilated, this results in the following correction factor:

- 1.0*

* Table 24 in the standard specified above

Result

Applying the above correction factors yields a current carrying capacity per cable of:

898 A × 0.87 × 0.7 × 1.0 = 547 A

The maximum permanently permissible operating current of the genset flows at a power factor cos(phi) of 0.8 % and 10 % undervoltage and is calculated as follows:

$$I = \frac{P}{\cos(phi) \times \sqrt{3} \times 0{,}9 \times U_{\mathrm{N}}}$$

$$= \frac{1200\ \mathrm{kW}}{0{,}8 \times \sqrt{3} \times 0{,}9 \times 400\ \mathrm{V}}$$

$$= 2406\ \mathrm{A}$$

3698905099: Operating current formula

The number of cables to be used per phase is calculated from the maximum current and the current carrying capacity of the cable:

- 2406 A / 547 A = 4.4
- 5 cables per phase must be selected

NOTE

This calculation method can be adapted to all genset combinations. If different rules and regulations apply on site, these must be observed. If different cable types are selected, their correction factors apply.

16.9.5 Starter cables and starter batteries

Risk of destruction of components

If the requirements for starter batteries and their cables are not observed

Overloading of the starting system due to the high drive power of the starter

As previously mentioned, the starter cables are flexible single-wire rubber lines made of copper, e.g., NSGAFÖU in accordance with VDE 0250-602. The required line cross section is derived from the power of the starter, the battery capacity, and the cable length for the feed and return line to the starter battery. The cable cross sections required for the different cable lengths can be found in the terminal connections diagram for the respective genset.

Further information

- Overview of cabling [▸ 347]

Starter batteries

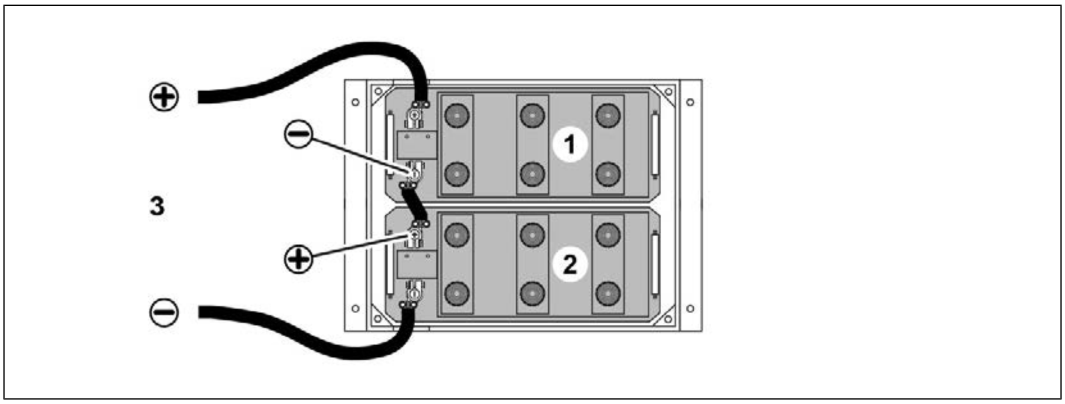
Caterpillar Energy Solutions supplies lead accumulators with capacities of 143 Ah/12 V and 225 Ah/12 V as starter batteries. The battery capacity required for the respective genset is specified in the respective data sheet as well as in the terminal connections diagram. Arranging in individual cases, double cases, or quadruple cases are possible for installation of the starter battery.

The size of the battery supply used must be matched to the size of the starter on the engine. The starters on the engine require a voltage of 24 V_{DC}. The voltage and the required capacity are shown on the corresponding circuit of the standard commercially available 12 V lead batteries.

Genset	Starter version	Number of batteries	Voltage/capacity
		Units	V/Ah
TCG 3016 V08	Single starter	2	12/143
TCG 3016 V12			24/143 (Fig. "Wiring of 2 batteries each with 12 V")
TCG 3016 V16	Single starter	4	12/143
			24/286 (Fig. "Wiring of 4 batteries each with 12 V")
		2	12/225

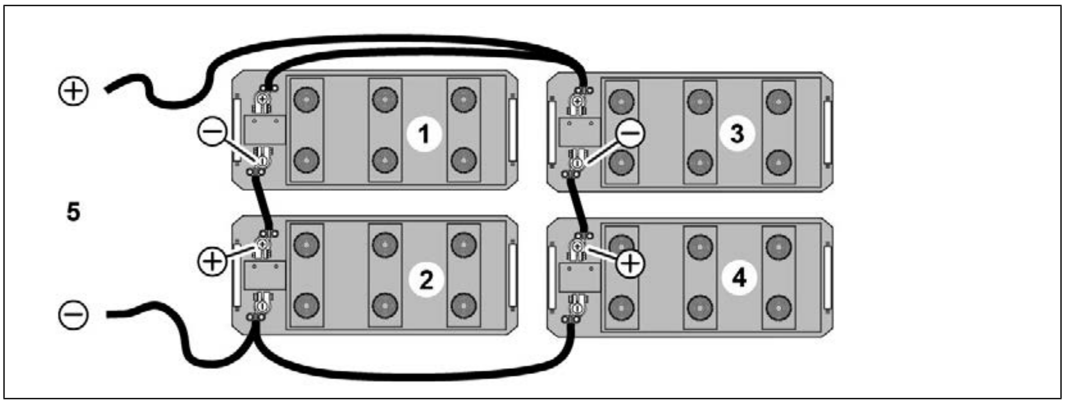
Genset	Starter version	Number of batteries	Voltage/capacity
			24/225 (Fig. “Wiring of 2 batteries each with 12 V”)
TCG 2020 / TCG 3020	Double starter	4	12/225
			24/450 (Fig. “Wiring of 4 batteries each with 12 V”)

Table 54: Recommended battery supply



3699247115: Wiring of 2 batteries each with 12 V

1 - 2 12 V_{DC} 3 24 V_{DC}



3699249675: Wiring of 4 batteries each with 12 V

1 - 4 12 V_{DC} 5 24 V_{DC}

An important parameter in determining the suitability of a starter battery is the cold cranking amp rating (CCA rating). CCA rating definitions can vary according to DIN, IEC, SAE and DIN EN.

DIN 43539-2 provides the following definition:

To measure the CCA rating, a fully charged 12 V battery is discharged at a temperature of -18 °C until it reaches a voltage of 6 V. After 30 seconds, the battery must maintain a voltage of at least 9 volts and at least another 150 seconds must pass before a voltage of 6 V is reached.

IEC, SAE and DIN EN definitions differ from the DIN definition. According to the different regulatory bodies' definitions of CCA ratings, there are fixed conversion calculations.

According to the above standards, CCA ratings for 143 Ah and 225 Ah batteries supplied by Caterpillar Energy Solutions are given in the following table.

	CCA rating in A according to definition by			
Battery	**DIN 43539-2**	**DIN EN 50342**	**SAE J537**	**IEC 60095-1**
12 V/143 Ah	560	950	1000	645
12 V/225 Ah	675	1150	1200	775

Table 55: CCA rating for starter batteries

Starter cables

Correct dimensioning of the starter cables is necessary for the fault-free functioning of the battery and starter system. Cable lengths and cross-sections must fit to the battery system and starter size. The cable dimensions of the starter main lines for the gensets are given in the following tables.

		Cable length* of starter main line in m
		1 – 8
Genset	**Battery package**	**Cable cross section in mm²**
TCG 3016 V08 / TCG 3016 V12	24 V/143 Ah	95

		Cable length* of starter main line in m
	(2 x 12 V/143 Ah)	
* Sum of the lengths of the supply line from the battery to the starter and the return line from the starter to the battery		

Table 56: Starter main line for 143 Ah batteries

		Cable length* of starter main line in m		
		4 – 6	**6 – 18**	**18 – 24**
Genset	**Battery package**	**Cable cross section in mm²**		
TCG 3016 V16	24 V/286 Ah (4 x 12 V/143 Ah)	70	95	120
* Sum of the lengths of the supply line from the battery to the starter and the return line from the starter to the battery				

Table 57: Starter main line for 143 Ah batteries

		Cable length* of starter main line in m		
		1 - 8	**8 - 14**	**14 - 18**
Genset	**Battery package**	**Cable cross section in mm²**		
TCG 3016 V16	24 V/225 Ah (2 x 12 V/225 Ah)	95	120	160
TCG 2020 / TCG 3020	24 V/450 Ah (4 x 12 V/225 Ah)	185	240	-
* Sum of the lengths of the supply line from the battery to the starter and the return line from the starter to the battery				

Table 58: Starter main lines for 225 Ah batteries

The optimal positioning of the batteries is as close as possible to the starter, since the required cross sections of the starter cables are small in this case. Positioning in the area of the generator's cooling air inlets is not permissible, since acidic vapors that escape from the starter batteries can cause damage to the generator.

The starter batteries are charged while dry. They are filled with battery acid at the installation site.

The safety instructions given in the operating manuals must be observed for the maintenance of the starter batteries.

All-pole fuse protection of the battery charging voltage must be provided. Grounding of the starter battery ground terminal is also recommended.

Connection terminals

Tightening torques for the connection terminals of the engine starter: (extract from Bosch: “manual Basis - TKU [page 39]”)

- Terminal 31 (battery minus) M10 or M12 steel with Sn surface coating 24 ±4 Nm
- Terminal 30 (battery plus) M12 copper, with optional Ag surface coating 26 ±4 Nm
- Terminal 50 (control line) M6 steel 3.7 ... 4.6 Nm

16.9.6 Starter cable when using a mains starting device

The gensets can be started with a mains starting device as an alternative to starter batteries. Starting the genset is then possible only with mains voltage.

Delivery conductor and return conductor	Cable cross section
1 m to 10 m	185 mm^2 or AWG[1)] 350 MCM[2)]
10 m to 14 m	240 mm^2 or AWG[1)] 500 MCM[2)]
[1)] American Wire Gauge [2)] Mille Circular Mils	

Table 59: Starter main line for mains starting device

16.9.7 Grounding system

The grounding system for the plant design must also be considered in good time. This means it must be studied according to the customer single line diagram of the whole plant. Due to the complexity of some plants, the grounding concept must be adapted to the individual requirements. The grounding concept and the implementation of the equipotential bonding is the responsibility of the customer or the operator.

Required notes on the grounding system and equipotential bonding

- Concept for protective grounding, protective conductor and protective equipotential bonding [▶ 29]

16.9.8 TEM, TPEM and PLC power supply

The power supply of the TEM system or the TPEM system is provided by one or multiple switching power supplies in combination with batteries. The batteries provide sufficient voltage in the case of a mains failure so that the plant can be shut down in a controlled manner.

The following demands apply for the power supply of the TEM system or the TPEM system as well as optional PLC, measurement devices or some actuators installed in the auxiliary cabinet (HAS):

- Power supply to genset control cabinet (AGS):
  - 24 V_{DC} ± 5 % - residual ripple < 0.5 V_{SS}
- Power supply to TPEM Control Cabinet (TPEM CC):
  - 24 V_{DC} ± 10 % - residual ripple < 0.2 V_{SS}

Customer Level (CL) / 18014401340850699 - EN / 2025-12