Generator

Major Caracteristics and Benefits

The electrical generator converts the mechanical energy of the turbine into electrical power. The electrical generator also serves as a starting motor for static start-up with a starting frequency converter from turning gear speed in case of a gas turbine application.

As one of the main international market leaders in manufacture of synchronous generators, Siemens Power Generation has decades of experience in production of reliable and high efficiency generators. Continuous improvement in materials, insulation systems, cooling systems, design tools and methods, production automation, project management, and innovation have resulted in a world-class line of air-cooled generators. Modular design concepts provide high efficiency and reliable operation with low maintenance requirements.

For simple-cycle gas turbine and multi-shaft combined-cycle power plants the air-cooled generator is Siemens standard.

The air-cooled series of generators **SGen5-1200A** for 50 Hz applications are designed according to IEC standards. These generators cover a wide rating range up to 370 MVA at line voltage levels up to 20 kV.

For the SGT5-4000F simple- and combined cycle applications the generator **SGen5-1200A** will be supplied as Totally Enclosed Water-to-Air Cooled (TEWAC) generator.

Detailed Description

Stator

The generator housing consists of a load-carrying base-frame and a cover. Both are welded steel-constructions. The base-frame supports the stator core and has horizontal walls for cooling air circulation. The generator cover houses the active stator components. The coolers are arranged in a separate cooler cover attached to one side of the generator.

The laminated core consists of insulated steel sheets with a low loss coefficient.

The three-phase stator winding is a fractional-pitch two layer type (transposed-bar). The winding is Global Vacuum Pressure Impregnated together with the stator core. This MICALASTIC® insulation system results in a high-voltage insulation, which is free of voids and possesses excellent electrical and mechanical properties.

The stator winding is dimensioned in accordance with class F insulation, IEC 34-1, but is not thermally loaded to more than the class B thermal limit.

The six winding ends are routed to the outside from the stator through bushings.

Rotor

The rotor shaft is machined from a vacuum-cast forging.

The field winding coils are manufactured from a copper alloy. They are inserted into the slots of the solid rotor body and locked in position by high-strength conductive slot wedges. The centrifugal forces on the end windings are accommodated by overhanging retaining rings.

These retaining rings are manufactured from non-magnetic, high-strength steel which is not susceptible to stress-corrosion cracking. They are shrunk onto the rotor body end and secured with a snap ring. The retaining rings and the slot wedges serve as a damper winding.

Bearings and Pedestals

The rotor is supported in pedestal bearings. These bearings are fitted on the stator base-frame on both the turbine and exciter side.

The two bearings are equipped with a hydraulic shaft jacking-device for start-up and turning operation.

Cooling

The generator is air-cooled. Indirect cooling is provided for the stator winding. The rotor winding is direct radially cooled. Under consideration of the magnetic requirements, the stator core is equipped with a system of radial cooling ducts and acts as a heat sink for the stator winding. This cooling system, together with the direct cooling system for the rotor winding, ensure uniform and low temperature levels along the entire slots.

All the cooling air is circulated by two symmetrically arranged axial-flow fans.

The generator cooling circuit is of a closed-loop design. The warm cooling air of the generator is recooled by means of a water to air cooler (TEWAC – totally enclosed water air cooler). These coolers are located under a cooler cover attached to one side of the generator cover.

Excitation

The rotor winding is supplied with power from a static excitation system via slip rings.

An excitation transformer is used to take the excitation current from the auxiliary power system. The digital voltage regulator is of two-channel design.

In case of a gas turbine application start-up frequency-converter is provided for starting the turbine generator unit. The generator acts as a motor in the converter mode to start the gas turbine-set without additional rotating prime mover. The converter forms part of the exciter unit (more details in relevant section).

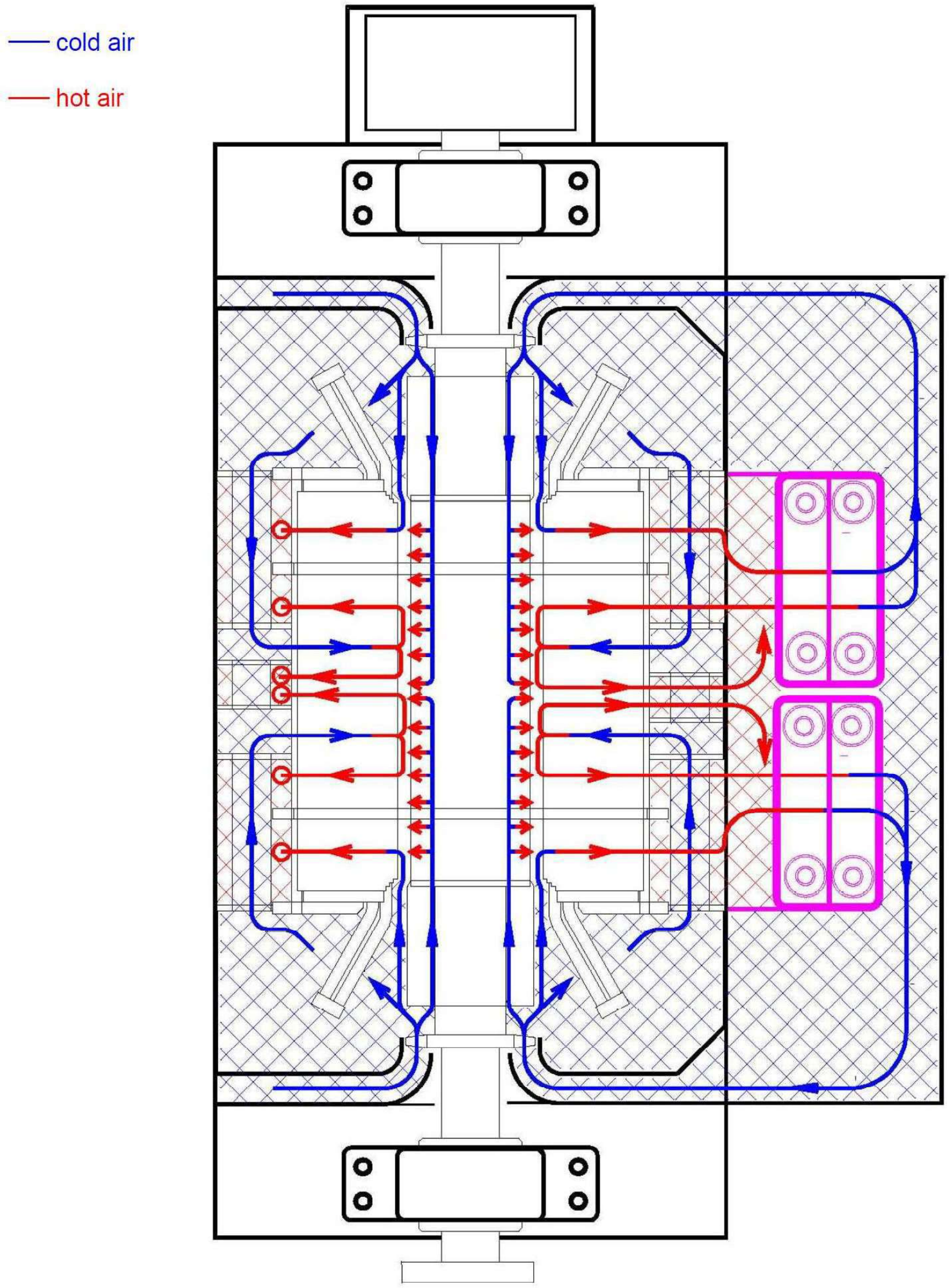


Figure: Electrical Generator - Air Cooled - Cooling Air System / cooler arrangement not binding for execution

Generator Electrical Systems

SEE and SFC including Transformer

Static Excitation Equipment

POWER SECTION

The exciter comprises an exciter transformer and a thyristor assembly in a three-phase fully controlled bridge connection.

For safe shut down the power section also includes a field suppressor which reduces the current in the bridge circuit after operating the power bridges in inverter mode. If energy feedback is not possible due to a grid fault, the field current will be reduced via a de-excitation resistor which is designed accordingly.

The thyristors in the bridge branches are protected by semiconductor fuses. Over voltage protection is provided by a crowbar installed on DC output side of the SEE.

The power section is forced air cooled by redundant fans.

CLOSED-LOOP CONTROL

The closed loop control for generator voltage comprises two redundant digital automatic voltage regulators. The inactive channel is always in hot standby and the set points will be adjusted via the automatic follow-up function. Each automatic channel includes its own manual controller for field current control.

The manual controller mode is used for commissioning purposes and generator protection tests. When the SEE is operated in manual controller mode, the permitted values of the excitation current are limited by the load condition of the generator (no load, on load). The operator has to ensure that the generator is operated within its capabilities.

When connected to the grid and automatic mode is selected, the generator voltage set-point will be held within the generator voltage regulation range of 95% to 105%, where 100% generator voltage represent generator rated voltage.

The generator terminal voltage will be maintained at the pre-set value with an accuracy of ±0.5% as long as the actual value of the generator terminal voltage can be obtained from voltage transformers with accuracy class 0.2.

The limiting functions of the automatic channel ensure that the generator is operated within its capability limits during grid operation. The following limiting and control functions are included:

- Stator current limitation
- Max. rotor current limitation (field forcing)
- Over excitation limitation (field current)
- Under excitation limitation
- V/f limitation

- Settable droop for reactive power
- Reactive power control
- Power System Stabiliser (PSS) as feature of the closed loop control

POWER SUPPLY

The SEE is fed via the SEE transformer from the medium-voltage supply of the power plant's auxiliary power supply system.

OPERATING ASPECTS

The Static Excitation Equipment (SEE) generates a magnetic field in the generator. The exciter energy is fed via collector rings to the rotor winding.

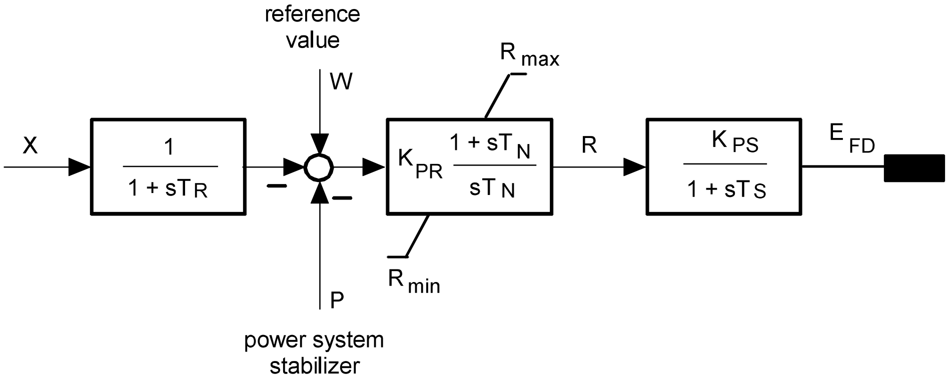
The communication interface between the SEE and TCS is a redundant PROFI bus DP connection. The standard telegram from the SEE to the TCS has a bidirectional design. Signal exchange to the SEE comprises all commands for SEE and SFC operation and the set-point values for different SEE closed loop controls. The opposite direction from the SEE to the TCS includes the feedback signals, actual values and several alarm signals.

An operator control panel as well as a measuring instrument panel are provided. The measuring instrument panel contains analog instruments to indicate exciter voltage/current and generator voltage/current. The analog instruments are located on the front door of the control cabinet. Local or remote operation can be selected by using the key switch at the control cabinet.

During normal generator operation, the set-points are set in the TCS control room. All actual values and status messages that are required for operation will be sent to the TCS control room. Additionally, all transmitted messages can be displayed more detailed on the local operator panel.

For the technical data of the SEE please refer to section 4.

BLOCK DIAGRAM VOLTAGE CONTROLLER POWER CONVERSION TYPE– (FOR INFORMATION ONLY)



Parameter	Symbol	Value
Generator terminal voltage (normalized)	X	
Time constant of the measuring device	T_R	5ms
Proportional factor of the controller	K_P	6 *)
Proportional factor of the controller (normalized)	$K_{PR} = K_P \frac{19}{8}$	14.25
Integration time of controller	T_N	2 s *)
Proportional factor of the thyristor bridge with generator	$K_{PS} = \sqrt{2}\,\frac{V_s}{V_{dAVn}}$	Plant specific
Time constant of thyristor bridge with pulse generator	T_S	1.8 ms
Upper limit	R_{max}	0.955
Lower limit	R_{min}	- 0.83

*) The value can be changed by the commissioning

with V_s the secondary voltage of the transformer of the thyristor bridge (RMS)
V_{dAVn} air gap excitation voltage (no-load of the generator)

AVR Block Diagram Power Conversion

Starting Frequency Converter

POWER SECTION

The power section of the starting frequency converter consists of the following components:

- Two fully controlled three-phase thyristor bridges, one line-side converter and one generator-side converter
- Current DC link reactor decouples the line side and generator side converters
- Surge arresters on the line side and generator side converter
- Radial fans for heat dissipation

CLOSED-LOOP CONTROL

The line-side converter is operated in rectifier mode and directs the active power taken from the power supply to the DC link. The closed-loop control consists of a closed-loop speed control with subsidiary closed-loop current control and a gating unit set which provides the ignition pulses that are required to control the converter.

The generator-side converter is operated in inverter mode in load-controlled operation. The maximum delay angle is altered as a function of the speed and the DC link current.

The current in the generator-side converter is commutated by the machine’s terminal voltage. The DC link current is switched from one stator winding to the next to establish a rotating field in the three-phase stator winding thus operating the generator as synchronous motor.

At start up and up to a minimum speed, the terminal voltage of the generator is not sufficient for commutation in the generator-side converter. By operating the line side converter in inverter mode, the DC link current will be reduced to zero in order to ensure correct commutation of the thyristors.

The rotor position is determined by the voltage induced in the stator winding. An additional rotor position detector is not necessary.

OPEN-LOOP CONTROL

The open-loop and closed-loop control for the SFC operates in coordination with the associated SEE equipment. During SFC operation, the SFC signal exchange with the TCS is realized via the existing PROFI bus communication interface with the SEE of the turbine set that will be started.

The SFC’s responds to faults in 3 different ways:

- Trip: Triggers the SFC to trip for critical faults
- Warning: Indicates faults without interrupting operation
- Not ready: Blocks the SFC from operating

The actual values for the turbine set speed and DC link current during start operation can be displayed locally.

POWER SUPPLY

The SFC is fed via the SFC transformer from the medium-voltage supply of the power plant's auxiliary power supply system.

OPERATING ASPECTS

The SFC is used to drive the generator in synchronous motor operation mode to accelerate the gas turbine set. Synchronous motor operation requires excitation power fed to generator field windings over the complete speed range. During SFC operation the SEE controls the excitation current according to the SFC requirements.

SFC operation is automatically controlled by the TCS sub group control for each operating mode, except washing mode.

The SFC is designed for four consecutive gas turbine starts with 2.5 minute pauses between starts. After 4 consecutive starts, a cooling down time of at least 2 h must be observed.

The starting frequency converter is designed for the following operating modes:

Unit Start	The SFC provides rated output power to start up the gas turbine set. The gas turbine will be fired at a low speed range and the SFC supports the acceleration until self-sustaining speed of gas turbine is reached and switches off at 70% of nominal speed.
Washing	The turbine is turned to clean the gas turbine compressor and turbine blades. Depending on turbine type, constant or variable speed operation can be provided at a low speed range. The gas turbine is not fired during this operation. This mode is initiated manually from the TCS.
Purging	The gas turbine must operate in purge mode prior to each gas turbine start. Residual ignitable gases are blown out of the stack and/or the heat recovery steam generator of simple-cycle or combined-cycle units. Depending on the turbine type, constant or variable speed operation can be provided at a low speed range. Purging operation for the stack / HRSG will be performed for 10 Minutes. The gas turbine is not fired during this operation.

CONNECTION TO GENERATOR CIRCUIT BREAKER

To perform a start-up of the gas turbine, the generator circuit breaker must be equipped with a start-up isolator, which gives the possibility to feed SFC power to the generator stator windings. During SFC operation, the generator stator voltage is limited to SFC nominal voltage. During generator operation, the external isolator must be kept open to avoid damage to the power section of the SFC caused by the higher generator voltage. In the arrangement of the isolator assembly, the fuses must be installed on the side of the isolator that connects to the SFC output. These fuses protect the power cables between the start-up isolator and the SFC power section against a generator-driven overcurrent, which can occur under certain fault conditions.

The fuses must be installed all 3 phases. The fuses and the necessary monitoring contacts (1 micro switch per phase necessary) are in the Siemens scope of supply. Depending on the SFC type, the following fuses must be installed in the start-up isolator assembly:

SFC Type	Fuse Type	Manufacturer	Number of fuses per phase
4.0 MW	25URC123TTF0600	MERSEN	3

For the technical data of the SFC please refer to section 4

Transformers for SEE and SFC

The low voltage transformers for the SFC and SEE are cast-resin transformers.

MAIN CHARACTERISTICS

The SFC and SEE transformers are three-phase, two-winding power transformers with following design:

- Iron core with three shanks
- Dry-type insulation
- AN cooling system
- Aluminum foil HV windings and aluminum strip LV windings.
- Temperature detectors in LV coils of each phase
- Temperature detector in the middle core shank
- Tapping links on the HV side which can be adjusted under de-energized condition
- For outdoor installation a metal enclosure is provided with IP23DHW protection degree.

For the technical data of the SFC and SEE transformers please refer to section 4.

Protection, Synchronization, Metering and Measuring

Generator Protection

TASK AND FUNCTION

The electrical generator protection serves to protect the generator.

CHARACTERISTICS

The protection relays are of the numerical type. The main features are as follows:

- Different protective and supervisory functions are implemented in each relay.
- Each housing contains a protective device that includes a DC/DC converter for the power supply, potential and current transformers, A/D converter, electronic unit, watch dog, binary inputs and trip relays.
- Fully digital measured value processing and control from data acquisition and digitalization of measured values up to the trip decision for the circuit breakers.
- The internal processing circuits are galvanically isolated from the measurement inputs, external control signals, shielded communication links and power supply circuit.
- Microcomputer based design provides self-monitoring functions to ensure proper functionality of the complete relay.
- Annunciation of malfunctions.
- Numerical processing eliminates drift of measured values, trigger thresholds or curve characteristics caused by temperature effects or ageing.
- In the event of faults, the current and voltage values are recorded and stored in the device to assist with trouble-shooting.
- The integrated clock management system stamps the time and date for each event including fault events. The time and date are synchronized with the turbine I&C system.
- Measured and calculated real time values can be shown on the integrated LC display.
- Integrated control and/or numeric keys in conjunction with the LC display facilitate local interaction with the protection device. A serial operator interface (PC port) on the front panel is provided for local communications through a personal computer using DIGSI® software.
- The menu-guided software (DIGSI®) provided allows convenient access to settings and parameterization as well as readout of process and fault signals and fault records.
- All application specific data is stored on EEPROMs, so that no information is lost even when the device is switched off (no batteries required).
- All operational alarms, global alarms as well as settings and self-monitoring alarms will be stored.
- Insensitive to voltage and current transformer errors, transient conditions and interference.

- The protection relays can be programmed to lock-out the trip commands. The signals can be reset manually. Outputs for tripping are directly hardwired to the circuit breaker trip coils or to devices which will be tripped.
- The protection cubicles are designed with a common 2 x 100% power supply, coming from independent DC supplies where possible. Loss of either power supply is announced.

PROTECTION FUNCTIONS

The protection functions are divided into protection group 1 and 2. Group 1 and 2 are implemented in different relays which are located in different panels. The complete partitioning of the protection functions is subject to adjustment by the contractor during project execution.

GENERATOR PROTECTION

Protection Group 1	ANSI No.		***Protection Group 2***	ANSI No.
Generator differential protection	87G		Generator differential protection	87G
			Rotor earth fault protection *(1-3 Hz voltage injection method)*	64F
Stator earth fault prot. (100%) *(20 Hz voltage injection method)*	64G			
Stator earth fault prot. (90%) *(rms value at secondary of neutral earthing transformer)*	51G		Stator earth fault prot. (90%) *(displacement method via open delta winding)*	59N
Reverse power protection	32R		Reverse power protection	32R
Impedance protection	21		Impedance protection	21
Definite time overcurrent prot. *(long time delay*: I_{tend}>*)*	51		Definite time overcurrent prot. *(long time delay*: I_{tend}>*)*	51
Underexcitation protection	40		Underexcitation protection	40
Overvoltage protection	59		Overvoltage protection	59
Overfrequency protection - stage 1 (grid disconnection) - stage 2 (turbine shut down)	81		Overfrequency protection - stage 1 (grid disconnection) - stage 2 (turbine shut down)	81
Underfrequency protection - stage 1 (grid disconnection) - stage 2 (turbine shut down)	81		Underfrequency protection - stage 1 (grid disconnection) - stage 2 (turbine shut down)	81
Breaker failure protection *(for units with Generator CB)*	50BF		Breaker failure protection *(for units with Generator CB)*	50BF
Inadvertent energization	50/27		Inadvertent energization	50/27
Generator unbalanced load prot.	46		Generator unbalanced load prot.	46
Out of step protection	78		Out of step protection	78
Overexcitation protection U/f	24		Overexcitation protection U/f	24
SFC earth fault monitoring *(for starting frequency converter)*	59NDC			
Generator voltage monitoring	60FL		Generator voltage monitoring	60FL
Trip circuit supervision Gen CB *(for units with Generator CB)*	74TC-G		Trip circuit supervision Gen CB *(for units with Generator CB)*	74TC-G
Trip circuit supervision Unit CB	74TC-U		Trip circuit supervision Unit CB	74TC-U

For further information concerning the protection functions, the protection relays and also for the synchronization device please refer to the internet www.siprotec.com.

Synchronization

APPLICATION

An automatic synchronization unit including an automatic paralleling device is furnished for connecting the generator to the grid with the generator circuit breaker or via the HV circuit breaker (if applicable). The length of the cables for synchronization between the HV circuit breaker and the offered synchronization system shall not exceed 700 meters. The earthing systems between the power plant and the HV switchyard shall be linked.

The automatic synchronization process is initiated by the start-up program of the I&C system or by a manually given operator command. The following synchronization sequence is controlled by the automatic synchronizing unit:

The synchronizing unit checks automatically whether the necessary conditions are met: phase angle, voltage and frequency on both sides of the open breaker.

Setpoint commands are given to the frequency and voltage balancing devices to adjust the speed of the turbine and the voltage of the generator until synchronous conditions are nearly achieved. Then the automatic paralleling device gives the CLOSE command to the respective circuit breaker so that the contacts of the circuit breaker are closed during synchronous conditions. The closing time of the relevant circuit breaker is taken into account.

A high degree of safety and reliability of the automatic paralleling device are guaranteed by virtue of its multichannel design. The device contains two independent analog voltage inputs, two analog to digital convertors, two logically independent measurement algorithms and two closing circuits controlled by different criteria. The device continuously monitors the measured values as well as the internal hardware and software. The two methods of measurement (envelope curve principle and zero crossing principle) are based on autonomous firmware blocks and make decisions independent of one another via the respective control circuit. The two closing contacts are connected in series to energize the breaker CLOSE command. The design is illustrated in the following scheme (Figure 1).

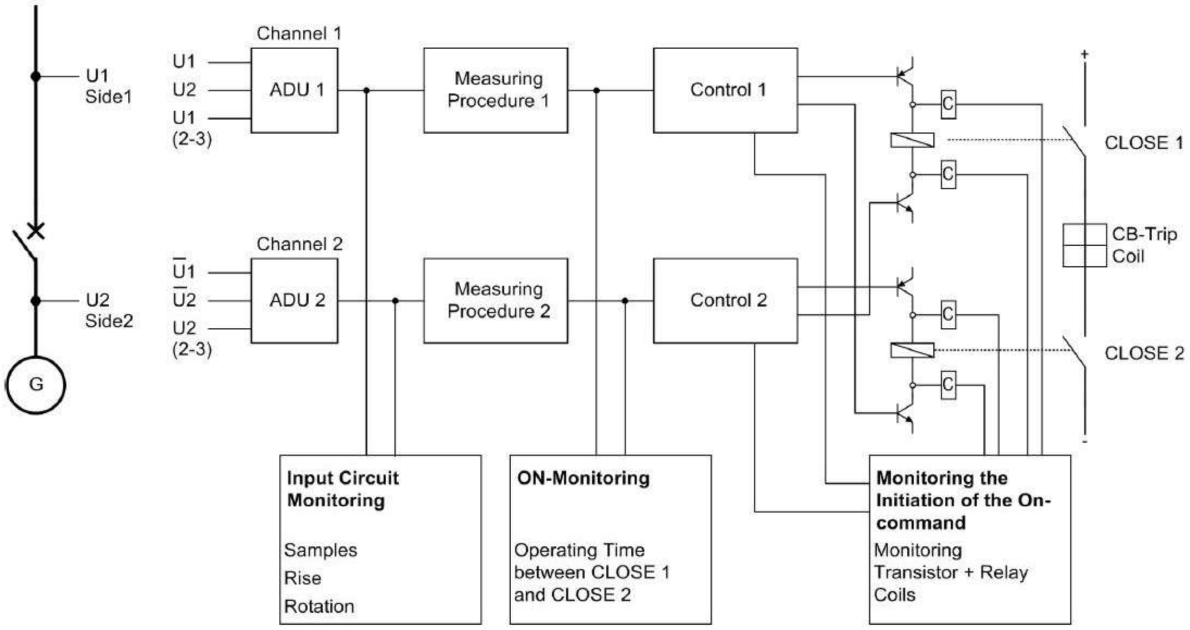


Figure 1

CHARACTERISTICS

The main features of the synchronizing unit are:

- Dual channel numerical type automatic paralleling device
- Automatic voltage balancing adjustment
- Automatic speed balancing adjustment
- Automatic angle adjustment
- Rack type enclosure for installation in the protection cubicles.

Metering and Measuring

The generator phase-to-phase voltages, generator phase currents, frequency, and generator active power are transmitted to the turbine I&C system for control and remote indication.

A digital meter for active energy (MWh) and reactive energy (MVarh,two directions of power flow) measures the gross output on each turbine generator.

The energy meter and transducers are installed in the protection cubicles.

Function Diagram Overview

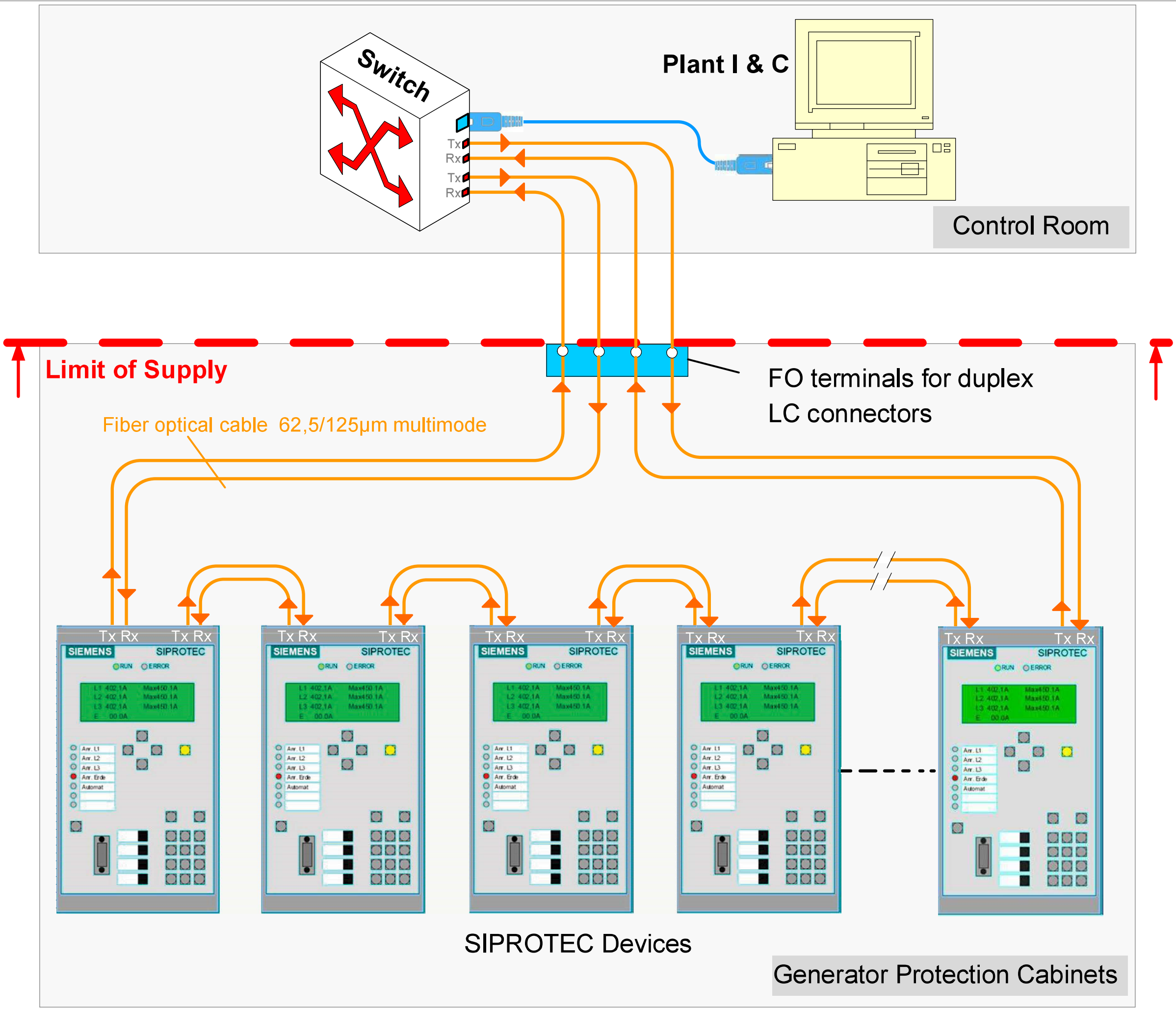
All functions mentioned above, the main interconnections of the electrical generator protection, synchronization and metering and measuring are shown in the function diagram.

(please refer to attachments “Electrical Equipment Design Information”).

Communication with IEC 61850

- In addition to the communication port on the front side, an optical interface module (EN100-O) is available on the rear side of the SIPROTEC® devices. The EN100-O includes an integrated switch so that the optical ring topology can be implemented (see also the below figure *Scheme IEC 61850 Bus)*. Based on the IEC 61850 Standard, a system wide solution can be implemented with regards to information exchange and data management. This standard is used for the relay communication interfaces, which includes:
- signalling to I&C
- actual value readout
- reading and writing access to relay setting values and internal parameters with password protection capabilities
- readout of fault records
- reading access to the operational buffer and trip log
- time synchronization

IEC 61850 configuration including the ICD-files of the SIPROTEC® devices is in Siemens scope of supply. The SIPROTEC® devices are provided with optical input and output connections. Fiber optic cables, configuration of addtional relays, generation of the SCD-file and integration of the IEC 61850 protocol into the I&C has to be done by a third party.



Topology with Ethernet and IEC 61850 network, fiber- optic ring

Optical Ethernet communication module *EN100-O* for IEC 61850 with integrated Ethernet switch.

Figure: Scheme IEC 61850 Bus

Generator Connection to the IPB, Neutral Earthing and Current Transformers

Line Side Connection to the IPB

The generator provides an interface for single phase encapsulated connection of the isolated phase busducts (IPB) (by others). It is recommended that the enclosure of the IPB (typically phase L2) is used as ground bus.

Connection of an Air-cooled Generator

The mechanical connection of the IPB enclosure fittings to the generator shall be realized via an insulated and sealed flange connection. A flexible, non-conductive compensator shall decouple the IPB from vibration of the generator. The connection between IPB conductor and generator terminal shall be realized via silver-plated flexible copper links. All these connection parts shall be within the scope of IPB supplier.

Neutral Tie Enclosure, Neutral Earthing Cubicle

The build-up of generator neutral is realized within a special generator neutral tie enclosure. The enclosure has to be mechanical fastened to the generator by means of insulated screws. The enclosure is linked to the generator housing via a specified earthing connection.

The short circuit bars and end connectors of the generator neutral terminals are installed in this enclosure.

The generator neutral point earthing equipment consisting of earthing transformer and secondary resistor is installed in a separate neutral earthing cubicle, located near the generator and directly connected to the generator neutral terminals by a cable with a maximum length of 20 meters.

The earthing cubicle is natural cooled and encapsulated in accordance with the protection class IP54.

The single phase dry type neutral earthing transformer has a rating of 135 kVA for 20 seconds (duty type S2).

Current Transformers

The generator current transformers for protection and measuring (ring type) are installed on the generator bushings at the neutral and at the IPB side. The CTs for protection are PR type (low remanence) and for measuring type 0.2FS10 according to IEC 61869-2. Details are shown in the Single Line Diagram.