SIPOL
Transistorized Excitation Systems for Synchronous Generators
Operating Characteristics

- High availability
- Reliability
- Digital control facilities
- Very good control characteristics
- Compact design and easy installation
- Low maintenance
- Short delivery times
- Small space requirements

Standard circuit

SIPOL is an excitation system for synchronous generators with exciters and rotating-rectifier diodes. It can also be connected directly to the sliprings of the generator. Thanks to its versatile usability and easy installation, this excitation system is suitable for use in small industrial-, steam- and hydro power plants and lends itself especially to the modernization of existing plant.

The power part exists of a transistorized chopper and is connected to the field winding of the exciter or the generator sliprings. The rotor circuit is protected against overvoltage with a protection feature connected in parallel to the rotor.

The excitation power of the standard excitation systems is supplied either from a permanent-field pilot exciter (AC or DC), from a separate excitation transformer or from an auxiliary winding. The clamping bolts of the laminated stator core form the auxiliary winding, e.g. The excitation transformer may be connected either to the terminals of the synchronous generator or to the station service system. Further redundant incoming feeders are possible, e.g. through station battery or an uninterrupted power supply.

The low mounting space and the various standard software functions of the digital open- and loop control make the SIPOL system particularly suitable for the modernization of existing excitation systems.

That is how the modernization of existing excitation systems can be done very quickly.

Mechanical Design

The SIPOL excitation system is completely wired, fully tested and fitted on a metal mounting plate ready for installation in a suitable cubicle. Optionally possible is an installation in a standard cubicle specially designed for equipment comprising open loop and closed-loop controls and power electronics devices.

Modular design and easy accessibility of all components facilitate all setting and optimizing operations. The dimension of the mounting plate is 580 mm wide by 350 mm deep, at a height of 700mm.
Main components:

Transistor chopper (1)
Automatic voltage regulator (2) for controlling the voltage at the generator terminals and the field current regulator (3) for the manual channel.
The station battery can provide the excitation power (E) by the station service system, by an auxiliary winding, by a separate excitation transformer or by a permanent-magnet pilot exciter. Optional redundant feeders, e.g. from the station battery to the excitation system ensure high availability of the excitation system.

The excitation system SIPOL is suitable for various types of engines: brushless exciter with rotating-rectifier diodes (5) and (7), direct current exciter (6) and for direct excited engines (8). The input power for the transistor chopper regulator comes from a rectifier and DC link. De-excitation of the generator is by means of the integral field discharge resistor.
Mode of operation

Closed-loop control

Automatic Voltage Regulator
(Automatic control system)
The actual value of the generator voltage is compared with an adjustable generator voltage setpoint. The resulting signal is compared with the output of the excitation limiter and taken to the input of the PI voltage controller. The PI voltage controller with adjustable gain and time response provides an output signal which is applied to the setpoint input $I_{ref}$ of the secondary field current controller. The output of this controller governs the generation of the frequency-modulated driving pulses for the power transistors of the associated output stage, which is operated with a clock frequency of about 2.5 kHz. The DC current flows through the phase U and W of the transistor power circuit.

Automatic cos $\varphi$ or reactive power regulator at the generator leads
(Automatic control system)
The cos $\varphi$ regulator compares the actual value with an adjustable cos $\varphi$ reference value. In case of a deviation the reference value of the voltage regulator is adjusted until the deviation is reduced to zero. In isolated or no-load operation of the generator the operation mode of the automatic control system is switched over from cos $\varphi$ regulation to voltage regulation.

Manual control system
(Excitation current regulator)
The P-action control amplifier of this regulator receives a filtered setpoint signal that is compared with the actual value of the field current. The output signal controls the frequency-modulation drive circuit for the power transistors of the associated output stage.

Of the three control systems the automatic one is normally in operation, even during starting and stopping of the electric set. The automatic control system includes the measuring and setpoint devices and the control and monitoring circuits for the following functions:

- Generator voltage regulation
- Fast secondary control and limitation of the output current of the field current chopper regulator and/or field-forcing limiter.
- Limiting controller for the under-excited range (minimum-excitation limitation)
- Delayed high limiting control for the over-excited range (maximum excitation limitation)
- Delayed generator current limiter (stator current limitation)

Options
- Redundant power supply
- Mounting in a cubicle
- Cos - $\varphi$ - or reactive power regulator at the supply point
- Reactive Power Joint Control of several generators
- Diode failure detection

Commissioning mode
The manual control system is designed as excitation current regulator which permits generator characteristics to be recorded during commissioning and inspections, and also short-circuit operation of the generator to be carried out for setting the protective relays. When the automatic voltage regulator is faulted, it can also be used for the operational adjustment of the generator excitation.

Follow-up control
The setpoint value of the field current controller is continually updated during operation on the automatic control system, thus ensuring rapid and nearly bumpless changeover to manual control in the event of a fault. Automatic switchover takes place when the internal excitation supervision operates or on cases of a fault in the generator voltage aquisition.
Limiting controllers

During generator operation, it is necessary to observe the permissible combinations of active and reactive power, which can be seen from the capability diagram.

LMO  Limit characteristic of the underexcited range
OP   Limit set by the stator temperature rise
PQ   Limit set by the rotor temperature rise

Similar characteristics with reversed active-power flow apply to motor operation of the generator.

For ensuring the operation of the generator within the limits the function over- and underexcitation limiter can define 10 pairs of value. This pairs (X= reactive power actual value and Y= associated permissible active power value) reproduce the characteristic data of the generator.

The underexcitation limiter corrects the reactive power by raising the machine voltage as necessary to ensure that, in case of an excursion beyond the limit characteristic L-M-O, the operating point is returned to that characteristic before the machine is tripped by the underexcitation protection.

The overexcitation limiter ensures that, in the overexcited range, the operating point always keeps within capability curve section P-Q of the generator. In response to system voltage drops caused by high reactive power requirements, switching manipulations or faults, the voltage regulator raises the excitation level so as to keep the generator voltage constant. The overexcitation limiting device acts as a safeguard against thermal overloading of the rotor.

The overexcitation limiter admits excitation current values between the maximum continuous current and the maximum excitation current (field forcing) for a limited period of time so that the generator can back up the system in response to short-time system voltage dips.

The secondary excitation current limiter (field-forcing limiter), in contrast, has the task of limiting the excitation current to the maximum permissible value as quickly as possible.

The stator current limiter ensures the delayed limitation onto working points, within the N-P range of the generator power diagram. The main task of the stator current limiter is to prevent the generator stator from thermal overload, which can be caused by a high reactive power at increased active power. The stator current limiter also permits increased excitation values for a limited period so that the generator can back up the system.
Automatic control

Each operating condition of the excitation system are all supervised and indicated.

The internal monitoring routine makes the following signals available at the cubicle terminals:

- Fault with Protective Off command
- Fault in automatic control system and switchover to manual control system
- Group alarm triggered by various internal fault signals causing starting lockout.

Additionally following operating signals are available for external indication.

- Excitation is on
- Excitation is off
- Automatic Voltage Regulator is on
- Excitation Current Regulator is on
- Cos $\phi$ – or VAR Regulator is on
- Limiters are active

Further more detailed signals are optionally possible.

Overexcitation and field-forcing limiter

When driven to maximum output, the chopper regulators provide a voltage higher than required for exciting the generator to its ceiling current. This overvoltage on the field winding shortens the time required for reaching the ceiling current in that it substantially accelerates the excitation build-up.

The output current of the chopper regulator for the manual control system is limited by the maximum value of the setpoint setter.

The output current of the chopper regulator for the automatic control system is influenced by the integration limit of the PI voltage controller. This reference variable corresponds to the voltage that gives the required field current.

Driving the transistor chopper to a high output voltage in order to obtain faster exciter response.

- $U_E$ = Chopper output voltage (equivalent to excitation voltage)
- $I_E$ = Chopper output current (equivalent to excitation current)
- $I_{EO}$ = No-load excitation current
- $I_{EN}$ = Rated-load excitation current
- $I_{Emax}$ = Ceiling current
- 1 = Output current without field-forcing limitation
- 2 = Output current without overdriving
Power circuit

The power circuit uses transistor chopper regulators, which provides the necessary excitation power via a DC link.

The field voltage is adjusted by varying the pulse/pause ratio and the field circuit resistance causes the field circuit to vary accordingly. The field current is measured in the output stage and the signal is converted for the field current controller.

De-excitation

De-excitation of the synchronous generator is necessary for shutdown and when a protective device of the machine itself or of the unit transformer operates. Therefore the transistor chopper is blocked. The magnetic energy stored in the field is returned to the DC link via the diodes in the chopper circuits. Additionally the power circuit is disconnected from the power supply. This ensures very rapid de-excitation of the generator.

Principle connection of the transistor power part

Clock frequency about 2.5 kHz. Variable pulse/pause ratio. Chopper output voltage as affected by the driving pulses.

Excessively high voltages are prevented by parallel-connected varistors.
PC Tools

The operator friendly software tool SIMOVIS/DriveMonitor guarantees simply commissioning of the SIPOL. Through a serial interface the voltage regulator can be connected with the PC for easy configuration.

Customer friendly Configuring

The SIMOVIS/DriveMonitor software for Microsoft Windows 9x/2x/NT allows the complete parameterization of the SIPOL. Actual values can be monitored in the parameter list and parameters can be changed easily by selecting the corresponding parameter in the parameter list. It is possible to choose between a complete parameter list, pre-defined parameter lists with selection of parameter for a special application (e.g., input/output) or a user defined parameter list by entering the interesting parameter numbers. A complete upread of parameters allows easy documentation.

<table>
<thead>
<tr>
<th>P No</th>
<th>Name</th>
<th>Ind</th>
<th>Index text</th>
<th>Parameter value</th>
<th>Dim</th>
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<td>Menu Select</td>
<td>001</td>
<td></td>
<td></td>
<td></td>
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<td>0148</td>
<td>Special Access</td>
<td>001</td>
<td></td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>0711</td>
<td>Line Volt</td>
<td>001</td>
<td></td>
<td>90</td>
<td>V</td>
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<tr>
<td>1011</td>
<td>Motor Ref Volt</td>
<td>001</td>
<td>MDS1</td>
<td>300</td>
<td>V</td>
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<td>1012</td>
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<td>V</td>
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<td>MDS1</td>
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<td>A</td>
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<tr>
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<td>Current Reg Timer</td>
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<td>MDS1</td>
<td>200.0</td>
<td></td>
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</table>
Trace

Trace is an add-on for SIMOVIS/Drive Monitor that permits visualization of recorded data. You can also store the data read out of the device and open it again later. It is also possible to import such data into text processing programs, such as Microsoft Word, or into spreadsheet programs, such as Microsoft Excel.

You can perform simple measurements of amplitudes and instants using two moveable cursors.

The trace recording function contains following features:

- Monitoring of up to 8 analog signals
- Monitoring of 16 binary signals per unused analog signal (e.g. 32 binary and 6 analog signals)
- Maximum recording time of 280s at a maximum sampling rate of 280ms or 1.4s at minimum sampling rate of 1.4ms
- Freely adjustable sampling rate between 1.4 and 280ms in stepps of 1.4ms
- Fault recording is automatically triggered by programmable fault signals (triggered by binary signals e.g. faults or by comparing an analog value (condition: <\>/=/>=) with a predefined value)
- Adjustable pre-trigger between 0% (no pretrigger, only future) and 100% (only past, no future)
**Function Plan**

- **Generator voltage setpoint**
- **Generator actual voltage**
- **Static active and reactive power**
- **Limiter VAR/PF-regulator**
- **M2L+**
- **Excitation current setpoint**
- **Tracking of setpoint**

**Switchover AVR/ECR**

- **Automatic Switchover**
- **Transistor controller**

**Automatic voltage regulator (AVR)**

- **Deexcitation**
- **Field current regulator**

**PG scope of supply**

**Control room**

**Battery**

**Control room**

**Main exciter**

**Pilot exciter (DC/AC)**

**Power plant battery or station service**

**Current transformer**

**Voltage transformer**

**Generator protection**

**Current transformer**

**Control room**

**24V DC**

**Power supply**

**Control room**

**Control room**

**Control room**

**Automatic voltage regulator (AVR)**

**Excitation current regulator (ECR)**

**Field current regulator**

**Transistor controller**

**Deexcitation**

**Automatic Switchover**

**Transistor chopper**

**DC-intermediate circuit**

**UG**

**IG**

**Side View**

**Front View**

**Dimension Drawing**

- **L1, L2, L3**
- **Voltage transformer**
- **Current transformer**
- **Main exciter**
- **Control room**
- **Generator protection**
- **Power supply Pilot exciter (DC/AC)**
- **Power plant battery or station service**

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- **Power supply Pilot exciter (DC/AC)**
- **Power plant battery or station service**
Technical Data

**SIPOL**

### Auxiliary Power

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC voltage</td>
<td>24VDC</td>
</tr>
<tr>
<td>Maximum power consumption</td>
<td>&lt; 100 W</td>
</tr>
<tr>
<td>Insulation test voltage</td>
<td>500 V/1 min</td>
</tr>
</tbody>
</table>

### Main Power

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC voltage 1- or 3 phase</td>
<td>approx. 90...400 V&lt;sub&gt;AC&lt;/sub&gt;</td>
</tr>
<tr>
<td>Range of frequenz</td>
<td>up to 400 Hz</td>
</tr>
<tr>
<td>DC voltage</td>
<td>approx. 90...300 V&lt;sub&gt;DC&lt;/sub&gt;</td>
</tr>
<tr>
<td>Insulation test voltage</td>
<td>1500-2500 V/1 min</td>
</tr>
</tbody>
</table>

### Measuring input

<table>
<thead>
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<th>Parameter</th>
<th>Specification</th>
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</thead>
<tbody>
<tr>
<td>Generator voltage, 3-phase</td>
<td>100...120 V</td>
</tr>
<tr>
<td>Power consumption</td>
<td>max. 3 VA</td>
</tr>
<tr>
<td>Generator current, 1-phase</td>
<td>1 A</td>
</tr>
<tr>
<td>Max. power consumption</td>
<td>0.5 VA</td>
</tr>
<tr>
<td>Generator current, 1-phase</td>
<td>5 A</td>
</tr>
<tr>
<td>Max. power consumption</td>
<td>1.5 VA</td>
</tr>
<tr>
<td>Insulation test voltage</td>
<td>2500 V/1min</td>
</tr>
</tbody>
</table>

### Current output

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<th>Parameter</th>
<th>Specification</th>
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</thead>
<tbody>
<tr>
<td>Continuous current</td>
<td>15 A&lt;sub&gt;DC&lt;/sub&gt;</td>
</tr>
<tr>
<td>Short time (10s)</td>
<td>20 A&lt;sub&gt;DC&lt;/sub&gt;</td>
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</table>

### Analog output

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
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</thead>
<tbody>
<tr>
<td>Output range</td>
<td>0...10 V oder 0/4...20 mA</td>
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### Control accuracy

<table>
<thead>
<tr>
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<th>Specification</th>
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<tbody>
<tr>
<td>Voltage regulation</td>
<td>0.5%</td>
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</table>

### Customs tariff no.:

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
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<tbody>
<tr>
<td>8537 10 10</td>
<td>AL: N; ECCN: N</td>
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</table>

### Maximum ambient temperature

<table>
<thead>
<tr>
<th>Condition</th>
<th>Temperature Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>During operation</td>
<td>0°C bis +40°C</td>
</tr>
<tr>
<td>During storage / transport</td>
<td>-25°C bis +70°C</td>
</tr>
</tbody>
</table>

### Site altitude

<table>
<thead>
<tr>
<th>Condition</th>
<th>Maximum Site Altitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without power reduction</td>
<td>≤ 1000m above NN</td>
</tr>
</tbody>
</table>

### Standards

The SIPOL excitation system is rated and designed according to IEC-, EN-, DIN-, VDE-, IEEE-421- standards. Service and maintenance of the excitation system SIPOL can be executed according to VGB4- instructions.

Gersthofen hydroelectric power plant; Lech Elektrizitätswerke AG: 5 x 3MVA generators. Although the space was very restricted, the SIPOL technology was integrated without any problems into the existing facility.
Subject to change without prior notice

The information in this document contains general descriptions of the technical options available which do not always have to be present in individual cases. The required features should therefore be specified in each individual case at the time of closing the contract.