

VOITH

Thyricon™ Excitation System





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Excitation System

The Thyricon Excitation Family represents the extensive experience and knowledge of Voith Hydro as one of the major hydropower generator manufacturers. Our excitation product line offers best-in-class technology to feed the hydro generator's field winding, as well as to reliably control the stator voltage and reactive power.

Voith Hydro is a global leader in hydropower plant equipment and services for both new and modernization projects. For more than 140 years, our name has been synonymous of excellence in the hydropower industry, with nearly 40,000 generators and turbines installed worldwide.

Throughout our history, we have continuously set new records in performance and size of hydropower machines and components, as well as having a high understanding of solutions from our staff around the world. This combination has supplied best designs and solutions, based on state-of-the-art engineering and manufacturing expertise.

Thyricon, the Voith Hydro excitation product line, ensures excellence in generator control. This modular system can be customized to provide an optimized solution for hydropower generators and motors from 0.5 to 800 MW.

Many configurations are available, including redundant controllers and fully or $n + 1$ redundant thyristor bridges. All parts of the Thyricon Family are factory-tested prior to shipment. The comprehensive controller software includes special features like data logging function and special modules for the service and commissioning teams.



From the simplest system to the complex redundant programmable controllers and redundant rectifier bridges.

Selection of references (left page):

- 1 Omkareshwar, India
- 2 Cannelton, Smithland, Willow Island, USA
- 3 Picote, Portugal

Thyricon Family

An excitation system comprises all the devices responsible for delivering the field current to a synchronous generator along with the equipment responsible for regulating the stator voltage, including the limiting and protecting functions. Voith provides excitation systems for a wide range of hydro generators.

Excitation systems for a wide range of hydropower generators.

The Thyricon Family consists of the following members:

Family	Thyricon 300	Thyricon 400	Thyricon 500	Thyricon 600
Nominal field current range ¹	up to 90A	up to 450A	up to 4000A	up to 4000A
Redundancy (optional)	1 + 1	No	No	N + 1 or 1 + 1
Human-machine interface	Touch Panel TP 1200	Touch Panel TP 1200	Touch Panel TP 1200	Touch Panel TP 1200
Excitation circuit breaker	AC, DC or AC+DC	AC	AC, DC or AC+DC	AC, DC or AC+DC
PLC	Siemens S7 300	Siemens S7 300	Siemens S7 300	Siemens S7 300 Siemens S7 400
Digital communication	Profibus DP	Profibus DP	Profibus DP	Profibus DP
Cubicle layout	Mounting plate/wall chest	1 cubicle	2 or more	2 or more
Cooling	Natural	Natural/Forced	Natural/Forced (Option redundant)	Natural/Forced (Option redundant)

¹Upper limits depend also on the ceiling current and ceiling voltage requirements.

Digital Voltage Regulator

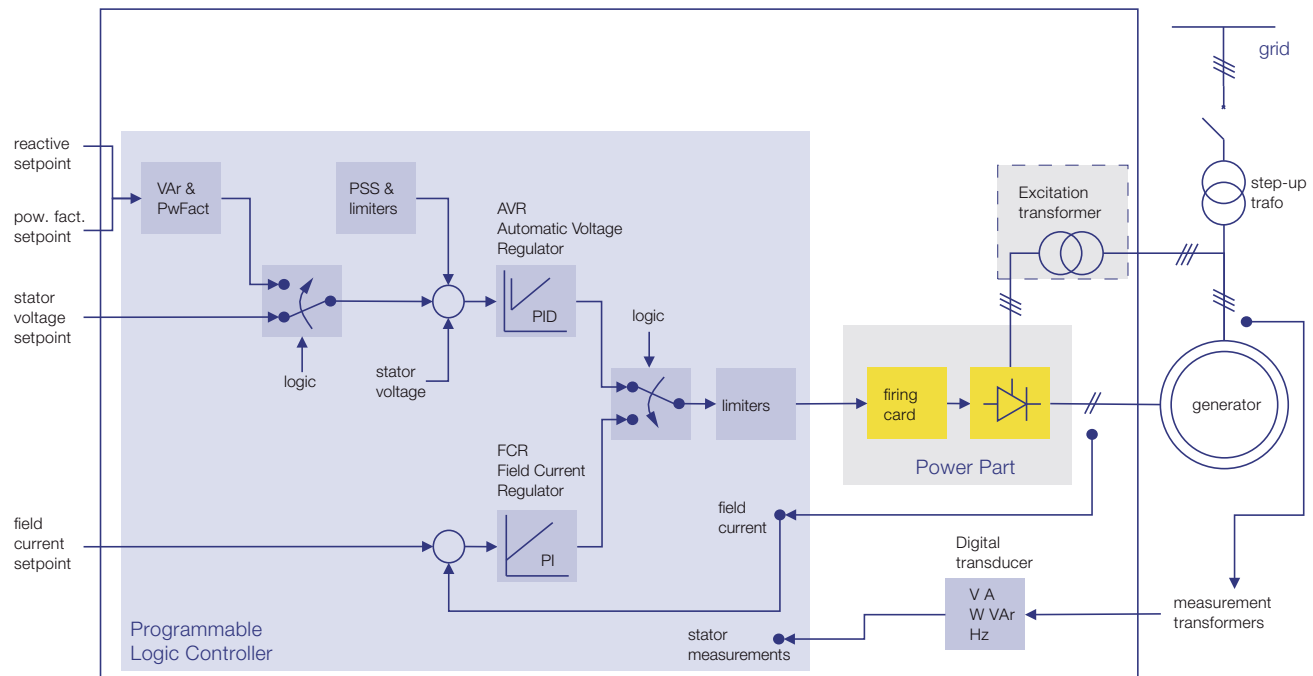
Control Features

The voltage regulator's primary task is to keep the voltage of the generator constant. The voltage regulator is also required to maintain the stability of the generator in steady-state conditions, as well as during transient disturbances. The voltage regulator covers all control functions needed for excitation systems. The micro processing capacity makes it possible to realize accurate control functions, and the digital technology provides good long-term stability.

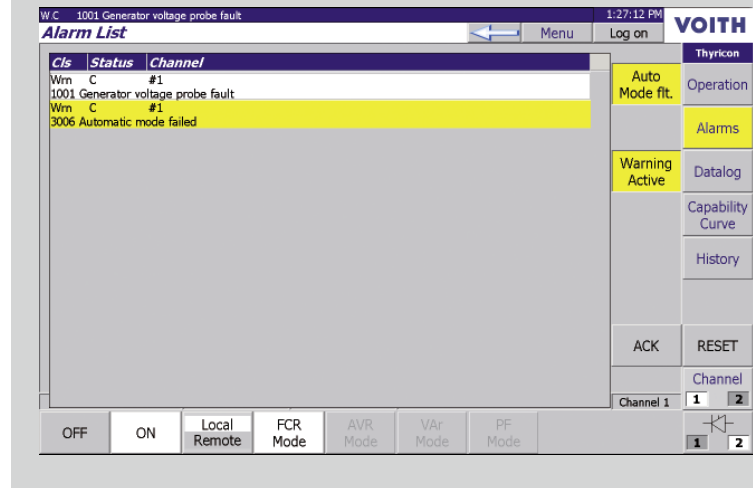
The basic and standard functions may easily be complemented with extra features. By adding software and, in certain cases, hardware, customized control functions can be implemented.

Thyristor Excitation System

Simplified diagram of a static excitation system and the generator unit



The alarm and event list are exportable as text files to USB or SSD cards directly from the Operator Panel.



Digital Measuring Transducers

Measuring of stator voltage and current is done by fast A/D conversions of each phase value several times per period. True RMS value is calculated by the measuring device.

Automatic Voltage Regulator (AVR)

The AVR control algorithm of PID characteristic regulates the stator voltage to the desired value.

Field Current Regulator (FCR)

Field Current Regulation fulfills the usual requirement of manual control. FCR is a backup to the AVR in case of e.g. fault in the stator voltage measuring circuits.

Reactive Power Controller (VAr)

The VAr controller keeps the reactive power constant. The reactive power is regulated by a slow operating three-state controller that adjusts the AVR's reference value. This maintains the favourable effects of the fast AVR during transient power line disturbances.

Power Factor Controller (PF)

The PF Controller keeps the power factor constant. The power factor is regulated by a slow operating three-state controller that adjusts the AVR's reference value. This maintains the favourable effects of the fast AVR during transient power line disturbances.

Transfer between Control Modes

The commutation between VAr Controller, PF Controller, AVR and FCR can be requested by the operator or is accomplished automatically in case of specific faults. Any transition is smooth, so there are no perceptible generator terminal voltage transients ("bumpless transition")*.

Monitoring, Control and Supervision

The regulator includes all necessary logical functions for control and supervision of the excitation equipment during start-up, service and shut-down.

This includes for example:

- Field flashing, DC and/or AC
- Natural cooled or fan-cooled thyristor converter
- Redundant thyristor bridge (option)
- Auto adjustment of reactive power after synchronism
- Reactive load shedding before disconnection from the grid
- Pre-synchronizing
- Handling of external set points
- Selection of the control mode with follow-up and bumpless transfers

Voltage Supervision

The voltage measuring signal and the supply voltage to the rectifier bridge can be supervised by mutual comparison. At low measuring signal, automatic change-over to FCR is initiated.

Fault Signal Indication

Each individual internal and external fault signal is indicated in a local Human-Machine Interface. They can also be indicated with LEDs, relay contacts or on a remote control panel. The fault signals are grouped into 'Warning', 'Block' or 'Trip'; these three signals are available via potential-free contacts. 'Warning' and 'Block' faults allow continuous operation, but a 'Block' fault prevents restarting the Excitation System (i.e. field flash voltage missing).

Self Monitoring and Diagnose

The programmable logic controller self-monitoring functions cover the power supply system, processor, memories, I/O-units and communication system. Some of the alarms are time-delayed, and this is necessary to obtain a good voltage regulation during temporary network faults.

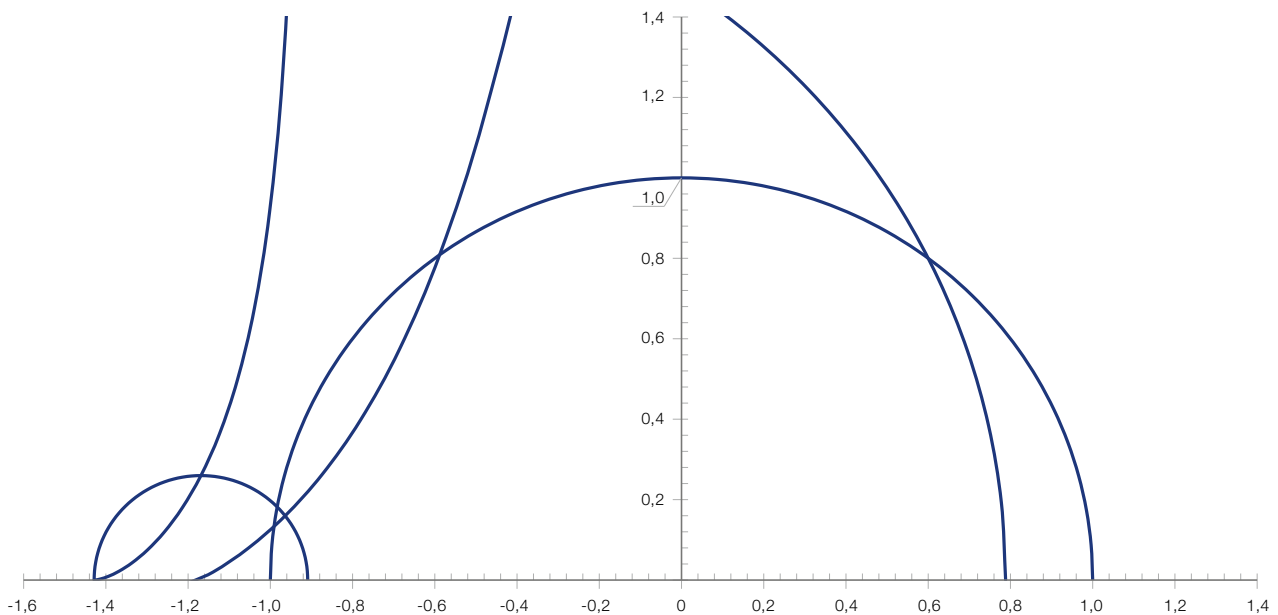
*Follow-up and bumpless transitions between control modes.

Limiters and Control Features

Upon voltage changes in the power system, the AVR will restore the stator voltage by increasing or decreasing the excitation current of the machine, and thereby also the reactive power. The higher the short circuit power of the electrical system compared with the machine's, the higher the risk of overloading the generator; this due to high amounts of produced (overexcited) or consumed (under excited) reactive power.

At unmanned stations, or when it is desired that the machine's contribution to maintaining the grid's voltage is not to be reduced, the need for limiters is increased. The limiters have the task of preventing outages of the machine due to operation of the protection relays caused by reactive overloading, underexcitation, or overloading of the exciter.

Thyristor ensures the operation of the generator inside its capability curve



Reactive and Active Compensation or Droop

In addition to the AVR structure, there are Reactive and Active Droop Compensators. These features compensate for active and reactive voltage drops in the step-up transformer and/or transmission line. The Reactive Droop Compensation also helps in balancing the reactive power among synchronous machines that are connected in parallel or directly to the grid without a transformer in between.

Frequency Compensation

Frequency Compensation is used to help weak grids during transients. The generator voltage is changed in phase with the deviation of the frequency. The changes in the active power delivered to the weak grid due to the voltage changes help to damp the oscillations.

Volts per Hertz Limiter (V/Hz)

The limiter, also called the flux limiter, reduces the voltage during under-frequency conditions. It protects the generating unit, especially the step-up transformer, against magnetic saturation.

Time-delayed Overexcitation Limiter (OEL)

The Time-delayed Overexcitation Limiter primarily avoids overheating of the synchronous machine field winding. The OEL also prevents overheating of the excitation system's power part.

The permissible duration of the field current overload is inversely proportional to the overload current level. The OEL allows time-delayed overloads of the generator unit that are required for the stability of the electrical system.

Instantaneous Overexcitation Limiter (OELf)

The Instantaneous Overexcitation Limiter keeps the field current below a predetermined value. The OELf is mainly used to prevent the thyristor converter from overheating, because of its short thermal time constant.

Underexcitation Limiter (UEL)

The Underexcitation Limiter avoids operation conditions that would cause stator overheating or instability and loss of synchronism.

The UEL action is determined by identified regions on the synchronous machine capability curve. The limiter region is programmed in the Thyristor's logic controller, and is coordinated with the loss of excitation function of the generator protection relay.

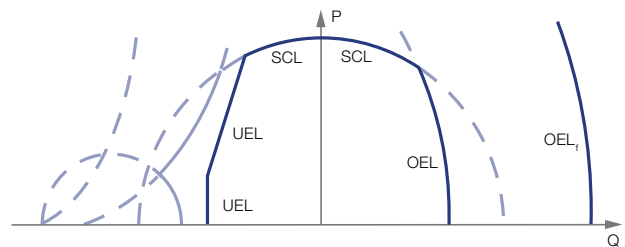
Stator Current Limiter (SCL)

Stator Overcurrent Limiter avoids overheating of the stator due to a rise in the generator current. SCL detects the overcurrent and compares it with the reactive current to determine how the voltage regulator should act. A time delay allows short overcurrents, providing space for the AVR and the PSS to act, and therefore increase the grid stability.

The SCL is very convenient after upgrading of turbine runners where the active power output is significantly increased while the generator rated apparent power is unchanged.

Safe operation of the Excitation System and of the generator

guaranteed by the Thyristor limiters



Pre-synchronizing

Pre-synchronizing means that the line (bus) voltage is used as a reference value for the voltage regulator during synchronizing. The voltage regulator will then keep the stator voltage equal to the line voltage during the synchronizing period. This facilitates synchronization and reduces VAR peaks when the generator breaker closes.

Power System Stabilizer

Thyricon features the dual-input integral of the accelerating power PSS2B described by the IEEE 421.5 Standard.

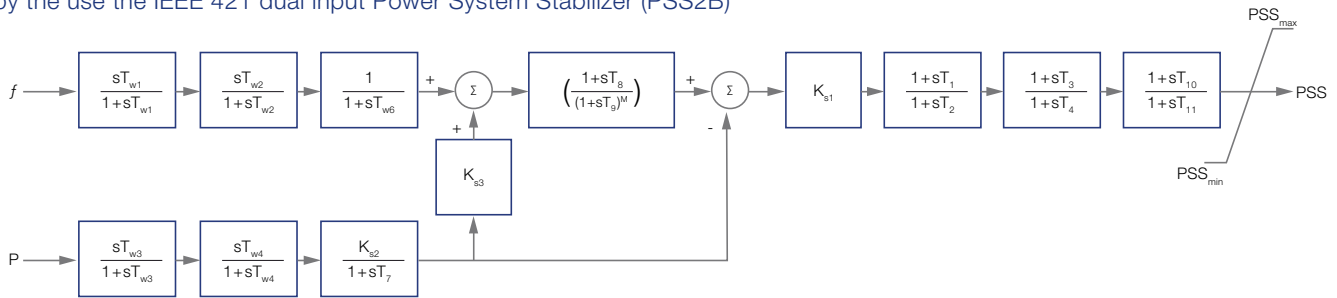
The PSS is not a limiter; it is an additional function that enhances the damping of low frequency oscillations on the synchronous machine. Such oscillations can be observed in the turbine speed, voltage frequency and active power.

In order to identify the low frequency oscillations, the PSS2B synthesizes the integral of the accelerating power which is the net result of transient unbalances between the mechanical power delivered by the turbine to the generator, and the electrical power delivered by the generator to the power system.

The PSS treats the integral of the accelerating power signal and introduces a disturbance into the Automatic Voltage Regulator PID controller. These “PSS disturbances” cause the damping of the low frequency oscillations. As a benefit of the action of several PSSs at several synchronous machines, the stability of the whole power system increases.

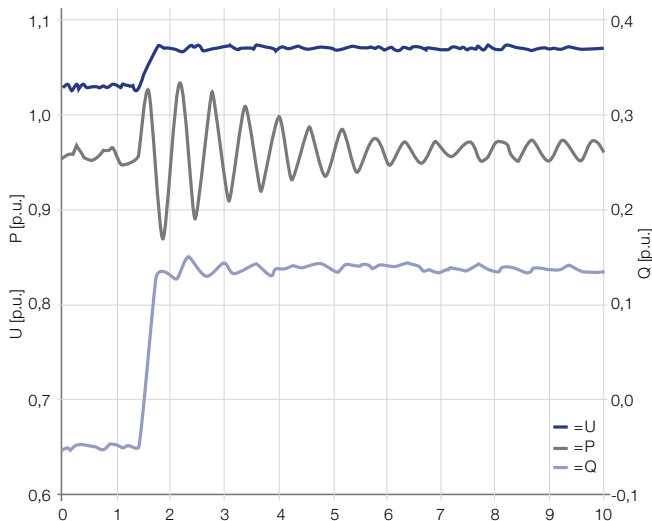
Thyricon enhances the stability of the electrical system

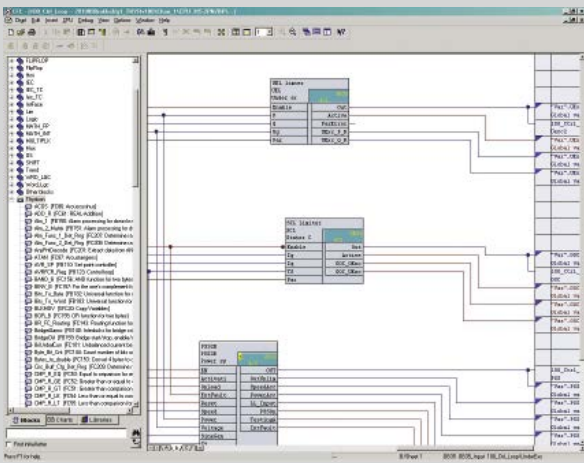
by the use the IEEE 421 dual input Power System Stabilizer (PSS2B)



Step response in the stator voltage

and the resulting step in Q and the oscillation in active P





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- 1 Graphical user friendly programming tool.
- 2 User friendly operator panel with touch sensitive colour LCD screen.

Programmable Logic Controller – PLC

Thyricon's hardware platform is based on Programmable Logic Controllers, PLC. The PLC has an interface to the surroundings comprising digital and analogue inputs/outputs and communication units for serial communication. The equipment is normally mounted in a cubicle together with power supply units, transducers and interface relays.

Application Software

The software modules incorporated in the voltage regulator are structured to provide a very clear and detailed view of the modules included. All analogue signals are scaled in the per unit system (1 pu = 100 %).

The software modules are built up from function blocks from a library according to the Standard IEC 61131-1. Examples of function blocks are AND-gates and SR-flip-flops, arithmetic blocks, control and filter blocks, timers and oscillators. The function blocks are interconnected to obtain the required functions in the program module. The function blocks contain parameter inputs for setting of gains, limit values, time delays etc.



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Industrial off-the-shelf programmable logic controllers guaranteeing worldwide access to maintenance and spare parts.



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Industrial off-the-shelf programmable logic controllers guaranteeing worldwide access to maintenance and spare parts.

Human-Machine Interface

The voltage regulator can operate as a stand-alone unit with communication to all types of joint control and remote control equipment via parallel digital and analog signal interface. Series communication with different types of protocols can be included. The programmable logic controller takes care of the Excitation System and only a few input/output signals are needed.

The standard Thyricon is fitted with the Siemens Touch Panel (Standard 12" screen), usually mounted in one of the cubicles' front doors. The operator panel features a touch sensitive colour LCD screen.

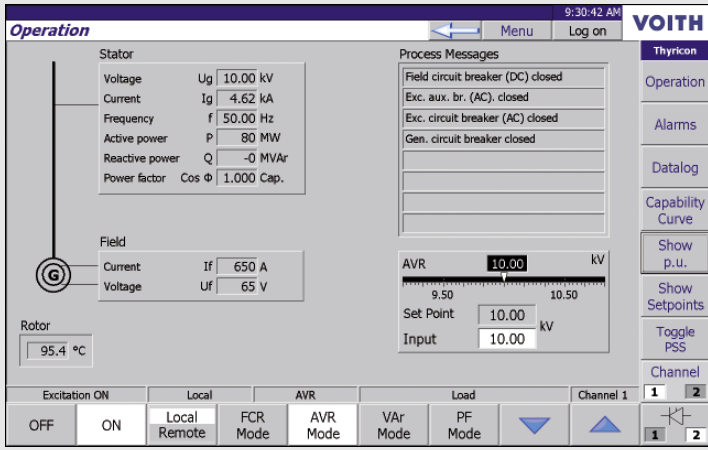
Different user levels with different passwords allow access to the different functions of the operator panel.

As a safety precaution, Thyricon incorporates a command confirmation system. All frequently used commands that directly affect the status of the system are subject to a two-stage operation sequence.

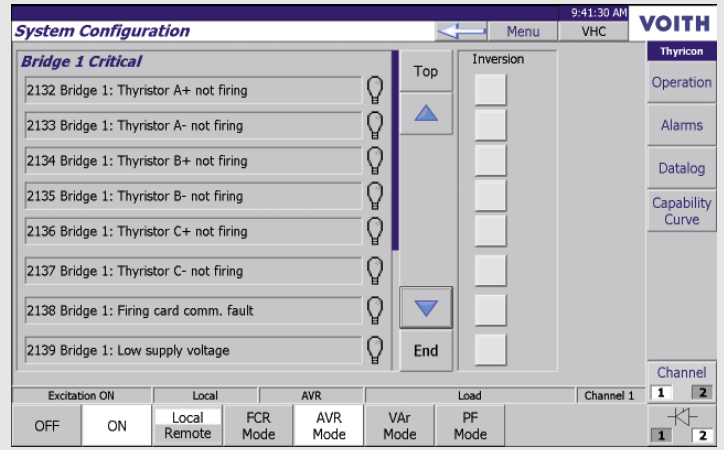
Safety increased by a two-stage command confirmation system incorporated in the operator panel.

Typical input and output signals

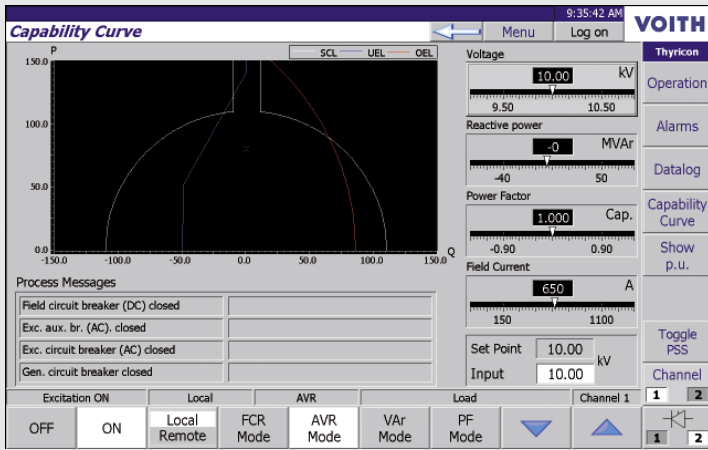
- Excitation off / on
- Selection of mode of regulation
AVR / VAr-controller / PF-controller
- Decrease / Increase signals for reference setting of the regulators
- Signal for closed generator circuit breaker
- Limiter in operation
- Common signal 'Warning'
- Common signal 'Block'
- Common signal 'Trip'



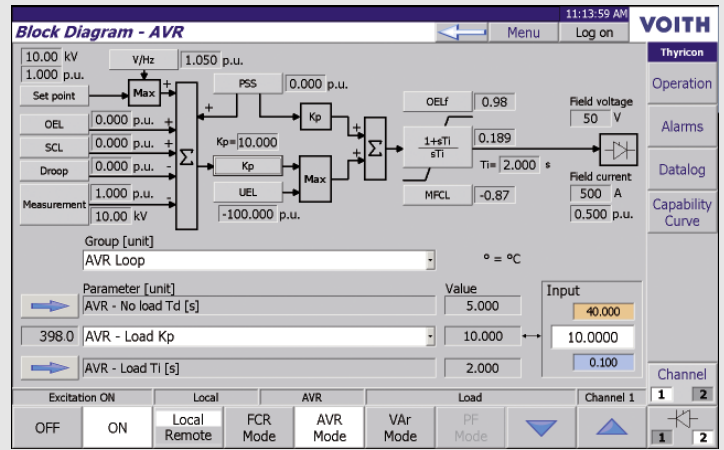
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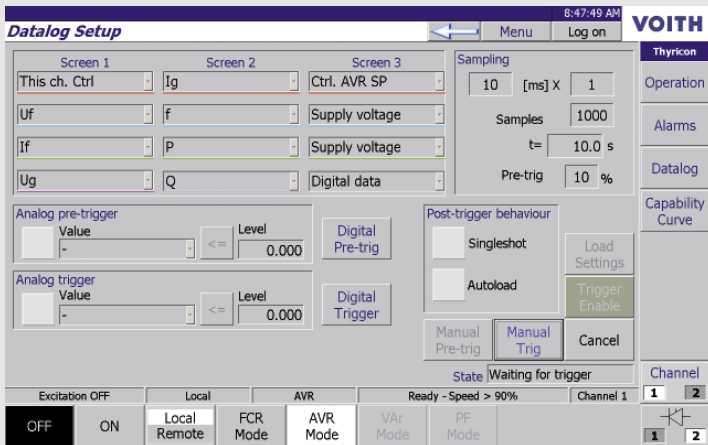
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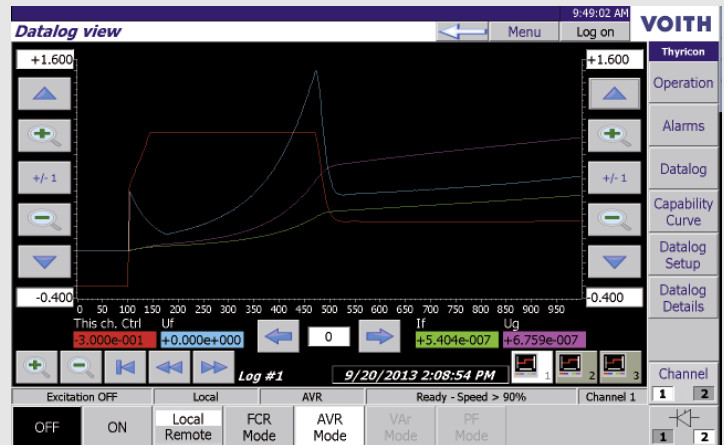
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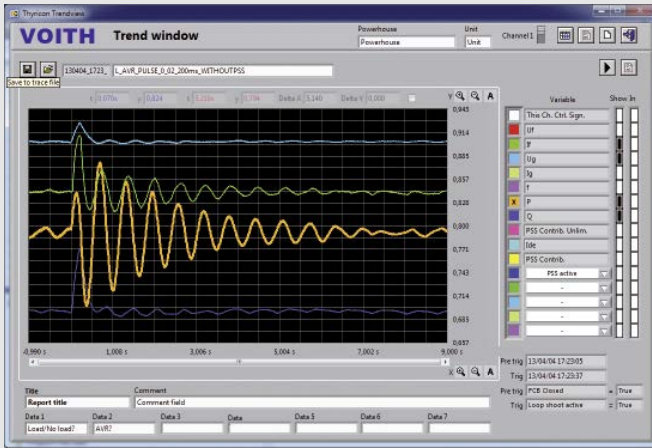
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- 1/2 Powerful testing and maintenance tools incorporated in the operator panel.
- 3 Dynamic capability curve with the indication of the operation point and Thyricon limiters.
- 4 Parameter changing is accessible from the operator panel.
- 5/6 Built-in data logging and parameter changing from the operator panel allow the testing of the system without external loggers or computers.
- 7 PC based tool to retrieve, analyse, store and report the test results.

User Friendly Operator Screen

Thyricon user friendly human-machine interface provides information about the general status of the Excitation System and the measured generator data. Active control and operation mode, as well as the current state of the system, can be seen in the corresponding output fields.

Local and Remote Interlocking of Commands

Thyricon can be operated remotely from the control room or locally from the human-machine interface. The set points of the control modes can be locally changed, if necessary. Local and remote modes commands are safely interlocked so the maintenance staff is protected from dangerous remote commands during inspections and service.

Monitoring and Forcing Values

Thyricon incorporates powerful commissioning, testing and maintenance tools into the human-machine interface. Monitoring of digital and analogue inputs and alarms is accessible to all users. Forcing of input and output signals is protected by password.

Block Diagram and Parameter Changing

Thyricon parameters are accessible through the operator panel. The parameters are organized in self-explanatory groups. Accidental changes are avoided by minimum and maximum limits, command confirmation and/or password protection.

Data Logging

Thyricon's human-machine interface incorporates a powerful data logging tool. The number of samples, the sampling time and the number of analogue values to be logged are configurable. Various events and analogue values can be selected as trigger to the data logger.

The data logging configuration is performed through the human-machine interface, but the actual data is stored in the PLC. Power outages will not destroy the last data trends stored. The data logging tool can be adjusted to permanently store the events related to the last emergency shut-down.

The stored data can be viewed in the operator panel. The parameter changing and the data logging capabilities enable the commissioning of Thyricon without any external tool. The recorded analogue and digital values can be exported as text file to an USB or SSD card directly from the operator panel.

The number of data logs stored in the PLC is limited. A PC-based software tool is available on request for retrieving, analysing, reporting and storing the data logs.

Static Excitation System

Static exciters are used for synchronous generators in all types of power generating plants: hydro, thermal, gas, diesel and wind, as well as for synchronous condensers and motors.

The advantages are summarized in the following main points:

- Superior dynamic control characteristics
- Low losses
- The size is not dependent on the speed of the machine for a given excitation power

The Power Circuit

The main power circuits included in the Static Excitation System consist of:

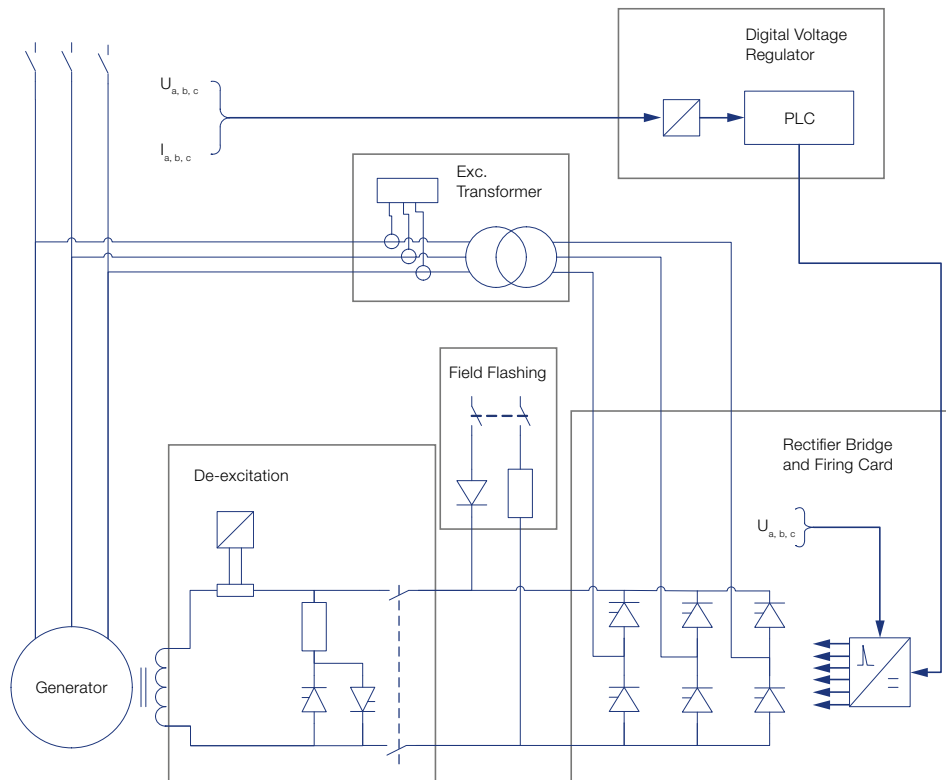
- Excitation transformer
- Thyristor Rectifier Bridge
- Equipment for de-excitation
- Equipment for field flashing

The excitation power is normally derived from the machine terminal bus and is conducted via the rectifier bridge into the field winding of the synchronous machine. Power necessary for voltage build-up at start is supplied via the field flashing equipment.

The excitation power can also be derived from the local power supply or from a suitable point outside the machine circuit breaker. As the connection point is normally energized, no field flashing equipment is required. During de-excitation, the field breaker is opened and the field of the machine is de-energized.

High ceiling voltage capacity and a wide-range operating voltage of the firing card guarantee that Thyristor continues to work even during severe voltage drops in the electrical system.

In most of the Static Excitation Systems, the rectifier bridge is fed by the generator itself.





Example of a Thyristor Static Excitation System.

Excitation Transformer

The purpose of the Excitation Transformer is to adapt the power supply voltage to the converter and to isolate the field winding from the power supply.

The secondary voltage is dimensioned according to the required ceiling voltage. The current rating of the transformer is determined by the maximum continuous field current of the synchronous machine. The transformer is normally dry of cast resin type. Temperature supervision by means of Pt100 elements can also be supplied.

Thyristor Rectifier Bridge

The converter, a fully controlled bridge, consists of a thyristor stack, firing card and the necessary equipment for supervision and cooling. Each thyristor stack is connected as a three-phase, six-pulse bridge. This connection allows the converter to operate as a rectifier as well as an inverter.

The thyristors are protected against short circuits by means of a quick-acting fuse in each branch or phase. Protection against voltage transients is achieved by RC circuits (snubbers). For efficient cooling, the thyristors are clamped into heat sinks that can be natural or forced air cooled (by ventilators). The thyristor converter is controlled by the digital voltage regulator via the firing card. This card converts the output signal from the regulator to trigger pulses, with correct phase shift compared with the supply voltage.

The supply voltage is determined by the required ceiling voltage from the thyristor converter, and is adapted to machine data in each individual case. The ceiling voltage is critical for the speed of regulation of the generator voltage, and thereby the contribution from the generator to the voltage stability in the power line during disturbances. Typical ceiling voltage is 2.0 times the nominal field voltage.

The thyristor converter is sized for the continuous field current necessary for maximum long-term load on the machine. It should also be able to carry the field forcing current received at ceiling voltage as described above. The normal field forcing time is 5 – 10 seconds.

To achieve higher reliability, the excitation equipment can be supplied with redundant thyristor bridges. Redundancy is either performed as a 1 + 1 system with one bridge in operation and the other one in hot stand-by or as an N + 1 system from which one bridge can be disconnected. In case of a 1 + 1 system, each bridge is designed for rated load. In case of an N + 1 system, the bridges are designed for rated load with one bridge out of service.

Field Flashing

When the excitation equipment is supplied from the generator terminals, it is necessary to supply the field winding of the machine with a small current for a few seconds to initiate the voltage build-up. The special circuit for field flashing feeds about 5-10% of the no-load excitation current into the field winding until the voltage of the generator through the excitation transformer is sufficient to supply the converter.

The start-up energy is normally provided by the station battery. Another solution available is to obtain the start-up energy from the station AC power supply via a transformer and a diode rectifier bridge.

The wide-range operating voltage of the firing card practically enables Thyristor to start only with the remanent voltage. Nevertheless, field flashing is a must as the remanent voltage may be zero after long periods without operation.

De-excitation

Special measures have to be taken to break the DC current and discharge the energy stored in the field winding of the machine. If not, very high voltages occur which can damage both the excitation equipment and the rotor winding. If a generator electrical fault should occur, it is also very important to de-excite the generator as fast as possible.

Two different methods can be offered:

- De-excitation is performed by an excitation circuit breaker connected on the AC side of the converter, and a de-excitation thyristor connected in series with the de-excitation resistor on the DC side.
- De-excitation is performed by a field circuit breaker connected on the DC side of the converter, and a controlled thyristor discharge circuit. The breaker disconnects the rectifier from the field winding, and the discharge thyristor closes a circuit through the de-excitation resistor for the field current. Optionally, a make-before-break contact on the field breaker in parallel with the discharge thyristor ensures a safe de-excitation.

The de-excitation resistor can be delivered both as linear and non-linear type. The non-linear type is voltage dependant and de-excites the last third of the field energy faster than a linear resistor.

De-excitation during normal unit shutdown is achieved by reversing the field voltage. The excitation breaker is opened when the field current is zero, saving the contact surfaces for unnecessary wear.

Field circuit breaker from worldwide know manufacturers.

Field Circuit Overvoltage Protection

The purpose of the Field Overvoltage Protection (crowbar) is to prevent excessive voltages in the field circuit that might otherwise arise during certain unfavourable transient fault conditions, such as incorrect synchronization or loss of synchronism.

The overvoltage protection is incorporated in the de-excitation equipment. It consists of two thyristors connected in anti-parallel in series with the discharge resistor. The thyristors fires when the voltage in either direction across the field winding exceeds the protection level chosen with the triggering unit, and short-circuits the field winding through the discharge resistor. The resistor limits the de-excitation current and the resistance is calculated so that the voltage across the field does not exceed the maximum allowed level even at the highest induced field current occurring.

Protection

In addition to the protection for different parts of the main circuit described above, devices or relays protecting against the following are available:

- Excitation transformer overcurrent/short circuit
- Temperature rises in the excitation transformer
- Rotor earth fault
- Overload in the field circuit
- Non-conducting thyristor branch
- Fan fault



Highly reliable cast-iron linear de-excitation resistors (top left). Non-linear resistors are also available.

Brushless Excitation System

On smaller generating units, the static exciter is replaced by a direct-driven AC exciter machine with the rectifier mounted on the generator shaft. The main advantage of this solution compared to DC exciters, is that the problems associated with the commutator and brushes can be completely eliminated. The brushless system eliminates the slip rings and thus all current-carrying brushes.

The Brushless Excitation System is used for high speed synchronous machines with horizontal shaft, as well as for hydro-power generators.

The Power Circuit

The main Power Circuits included in the Brushless excitation System consist of:

- Power supply
- Thyristor converter
- Main exciter

The excitation power is normally derived from a PMG (a pilot AC exciter of permanent magnet type) and is conducted, via the controlled converter equipment, into the field winding of the main exciter.

The excitation power can also be derived from the local power supply or the generator terminal bus via a suitable transformer for isolating and voltage adaptation. With supply from the generator terminals, power for voltage build-up at start must be supplied via field flashing equipment.

The controlled rectifier supplies adequate excitation power to the field winding of the synchronous generator. The rotating diode rectifier does not allow the main exciter to supply negative voltage or current to the generator field.

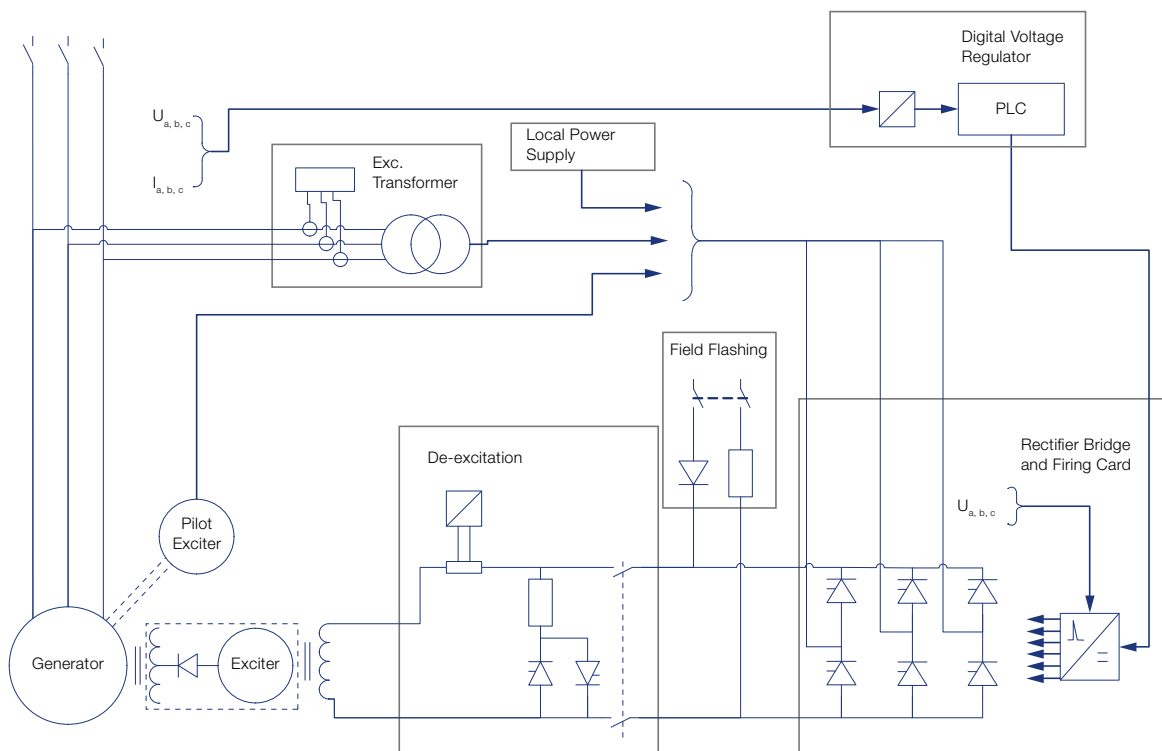
During de-excitation, the exciter field breaker is opened and the field of the main exciter is de-energized through the discharge circuit. The field winding of the synchronous generator is then de-energized through the diode rectifier mounted on the generator shaft.

Protection

Common protections and supervisions which are available:

- Detection of diode faults in the rotating rectifier of the main exciter
- Protection against overload in the exciter field winding
- Earth fault protection. To be connected to an auxiliary slip ring in the main generator field
- Thyristor converter failure

Typical diagram of a Brushless Excitation System



Documentation and Quality Assurance

The excitation system is described in a set of instructions and drawings:

- Function description
- Operation and maintenance instruction (including Troubleshooting guide)
- Cubicle mechanical layout
- Circuit diagram
- List of apparatus
- Test report

The specification, design, manufacturing, testing and commissioning of the voltage regulator as well as the complete excitation system are executed under high quality standards and requirements. Prior to delivery each system is subjected to a test and verification procedure. The verification covers all the functions and units according to a pre-defined inspection and test plan.

Technical Data

General data for control and regulation circuits. Concerning data for main circuit, please see specification available for the project.

Technical Data

Auxiliary supply voltage	DC	24V or 48 – 250 Vdc
	AC	110 – 240 Vac
Measuring circuits	Voltage 1, 2 or 3 phases	100 – 120 V
	Current, 1, 2 or 3 phases	1 or 5A
	Frequency	50/60 Hz
	Load	< 0.1VA/phase
Regulating accuracy		< ±0,5 %
Ambient temperature	Storage	-40 – + 70 °C
	Operation	0 – + 50 °C
Protection degree	With self-cooled bridges	Max. IP32
	With forced cooling	Max. IP43
	With air-water heat exchanger	Max. IP54
Environment conditions	No condensation permitted	Humidity < 85 % (higher humidity requires heaters and thermostats/hygrostats)
	Rodents and termite free	
	Oil dust and carbon dust free	
	up to 1000 m. a. s. l.	Higher altitudes on request
Thyristor bridge control	Voltage interval	5 – 1000 V
	Frequency	5 – 500 Hz
Applicable codes	IEEE Std. 421.1-1986	Criteria and Definitions
	IEEE Std. 421.2-1990	Guide for Identification of Dynamic Performance
	IEEE Std. 421.3-1997	Standard for High-Potential Test Requirements for Excitation
	IEEE Std. 421.4-2004	Guide for the preparation of Excitation System Specification
	IEEE Std. 421.5-2005	Excitation System Models for PSS-Studies
	IEC 34-16-1 (1991)	Excitation Systems for Synchronous Machines

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