



## APPLICATION

Basler Electric has expanded its excitation product offering with the addition of the ECS2100 excitation control system. The ECS2100 is a multi-microprocessor excitation control system that provides advanced technology to precisely control, protect, and monitor synchronous generators, including new and existing applications that are driven by all types of prime movers, such as steam, gas, hydro, and diesel. Its multifunctional design allows the ECS2100 to operate as a voltage regulator or as a static exciter, providing excitation currents up to 10,000 Adc. Since the introduction of the ECS2100, it has been successfully applied to generators ranging from 1 to 1300 MW.

## FEATURES

- Multi-Microprocessor based ECS2100 Digital Controller
- +0.2% Voltage Regulation Accuracy
- Performance response < 20 ms
- Redundant Controllers with Independent Supervisory Channel (options)
- Six-SCR Power Rectifier Bridges Fixed and Drawer Type (options)
- Multi-Bridge paralleling schemes up to 10,000 Adc
- Patented Active Current Balance Algorithm
- Multiple Excitation Limiters with on-line and off-line settings
- · Generator optimization by real-time limiter set point recalibration
- Integrated Dual Input Power System Stabilizer IEEE Type 2 (optional)
- Negative Field Forcing for highest system performance
- Multiple Operating Modes with Auto-following
- Multiple protection functions with on-line and off-line settings
- Programmable input/output terminations
- Programmable Sequencing provisions
- Built-in Field Ground Protection (64F)
- High Initial Response Per IEEE 421.2
- Color Touch Screen for local and/or remote monitor and control
- · ccTools, a sophisticated software configuration program for setup and testing
- Continuous self diagnostic capabilities
- Transient event recording and data logging (options)
- · Incorporates fiber optics for critical signals
- Provisions for Field Flashing from Station Service

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## **BASLER DIGITAL EXCITATION SYSTEMS - Type ECS2100**

#### Background

Type ECS2100 static excitation control systems have evolved from years of experience that originated with the original Westinghouse Distribution & Controls group. Under Westinghouse, many products dating back into the 1920's were developed for the generator excitation market. In 1994, Cutler-Hammer purchased the Distribution & Controls business from Westinghouse and carried the tradition and expertise to support this same market. In June of 2006, Basler Electric acquired Cutler-Hammer's Excitation Control product line to complement Basler's existing DECS product offering. Basler Electric has been committed to the generator excitation market since the mid 1960's and is dedicated to support this continued effort.

#### **Product History**

As part of the acquisition, Basler Electric inherited a substantial amount of history dating back to the 1920's that is associated with the original Westinghouse excitation products line. The following provides a brief historical description of the Westinghouse and Cutler-Hammer excitation system now in service in many power plants.

#### MGR (Introduced in the late 1980's)

The MGR (Medium Generator Regulator) was an analog static excitation and voltage regulating systems that covered small and medium size generators in utility, cogeneration, industrial and hydro applications. The MGR was designed as a replacement for existing Westinghouse voltage regulators and other manufacturers' single field regulators. Typically, the MGR provided excitation levels up to 600 Adc. As an update to the MGR, Basler can provide a "Front End" Digital solution that utilizes our DECS-400 Digital Excitation Control System. This digital upgrade uses many of the existing components of the MGR, but it adds many new features and functions. Contact Basler Electric for more details or download the DECS-400 product bulletin (SZF) from www.basler.com.

#### WTA-300B (Introduced in the mid 1990's)

The WTA-300B (Westinghouse Trinastat Amplifier), is the latest of the WTA family of solid-state analog static exciter/voltage regulators which were standard equipment on large utility and industrial generators typically sized greater than 100,000 kVA. The first WTAs were introduced in the mid 1960's. Typically, the WTA-300B was utilized for excitation currents greater than 500 Adc.

#### WDR-2000 (Introduced in the early 1990's)

The WDR-2000 (Westinghouse Digital Regulator) was Westinghouse's first microprocessor designed excitation system. Primarily, it was applied on medium to large generators requiring 1000 to 10,000 Adc of excitation. Today, the WDR-2000 can be retrofitted with the latest technology by replacing the WDR rack module with a drop-in ECS-RW. The ECS-RW provides advanced communication capabilities and many of the same features and functions as specified in this product bulletin. Contact Basler Electric for more details.

### DESCRIPTION

The Basler ECS2100 Digital Excitation System is designed to provide digital voltage regulation, control, protection, and monitoring functions for a synchronous generator. The ECS2100 Digital Excitation System is a multiple microprocessor-based control system. ECS2100 uses a digital signal processor for required computational speed of advanced control functions and algorithms and an integrated 32-bit communications controller for implementation of event recording, data logging, and communications to external control systems and to a user-friendly PC interface for maintenance and analysis functions. The ECS2100 can be scaled to generation units of all sizes with minimal changes except to the power electronics and the excitation power potential transformer. A software tool, ccTool, is used to change settings for the various limiting and protection functions, download new system firmware, and retrieve diagnostics information.

The Basler system consists of one or more thyristor power converters, each with its own digital firing control. A single converter or multiple converters operate with single-channel or multi-channel control logic for increased reliability. Operator control can be provided through a single-cable interconnection to a local and/or remote PanelMate operator panel, interface to PLC, SCADA, or plant DCS (Distributed Control System), or traditional discrete switches and meters.

Power to the ECS2100 can be supplied via a power potential transformer (PPT) from the generator terminals. A field flashing option will be added for black start when the generator terminals are used for the excitation power source. Alternately, power to the ECS2100 Digital Excitation System can be taken from a reliable threephase, 50 or 60 Hz station auxiliary source.



Figure 1 - Typical Dual Channel Two Power Drawer ECS2100 with Breaker and Auxiliary Cubicle

## STANDARD SYSTEM FUNCTIONAL DESCRIPTION

#### General

The design of the ECS2100 Digital Excitation System permits flexibility in the system architecture that is the most appropriate for your application. Proposed configurations include a single-channel system and alternates for a dualchannel or three-channel system with each type of system capable of using redundant power converters. A typical control channel consists of microprocessor-based modules for digital sensing, regulation, SCR firing control and sequence control algorithms. The cabinet lineup includes a logic cabinet and the required number of cabinets for the power converters and auxiliary devices (See Fig. 1). It should be noted that not all items will be utilized in all applications; therefore, some components may only be applicable to certain applications. It is recommended to discuss options with respect to the application with Basler Electric's Applications Specialists.

#### **CONTROL CHANNEL OPTIONS**

#### Single-Control Channel System

The Single-Control Channel System is the most basic configuration in the ECS2100 line. The regulator automatic and manual controls with associated limiter, protection, sequence control, and firing control are implemented on one set of printed circuit modules. The control channel includes the Excitation Control Module (ECM), Firing Control Interface Module (FCIM), and Sensor Input Module (SIM). The control channel interfaces through fiber optic cable to the firing control (Bridge Control Module) of one or more thyristor power converters. Redundant internal power supplies provide power for the single control channel. Each power converter is equipped with its own Bridge Control Module (BCM) that provides digital firing pulses to fire the bridge (See Figs 2 and 5). Generator





#### **CONTROL CHANNEL OPTIONS, continued**

#### **Dual-Control Channel System**

The dual-channel capability of the ECS2100 Digital Excitation System is configured with two identical sets of printed circuit modules. Each of the two sets has the capability of performing the voltage regulation, limiter, protection, sequence control, and firing functions. Both sets are connected to control the firing time of a Bridge Control Module (BCM) associated with its own power converter bridge. Signals from both control channels are sent to each BCM. Each BCM has a state-select contact that determines which channel controls the BCM. The system initially is set up such that the main channel controls the BCM. Should the internal diagnostics in the main channel detect a failure, an external relay will be energized, which in turn will direct the BCM to ignore the control signal from the other channel. A remote switch may be used to transfer control from the main to redundant channel for maintenance (See Fig 3).



#### Figure 3 - ECS2100 One-Line Diagram, Dual Channel Control Scheme

#### **Dual-Control Channel with Supervision**

A dual-channel configuration with a third supervisory channel is available for additional reliability for protection of the generator.

The three-channel system consists of the dual-channel configuration plus a third channel that supervises the other two. All three channels monitor limiting and protection functions. When conditions call for a unit trip, the combined logic of the three controllers using two-of-three voting logic determines when the unit is tripped. This two-out-of-three voting process with the third channel (Supervisory) is also used to determine which of the dual channel controllers is selected to be in control and regulate the generator's output.

#### **Power Converter Assembly**

The power converters use thyristors in a three-phase full converter bridge configuration. This configuration applies positive and negative forcing voltage to the generator field for dual-directional forcing of field voltage. The field current, however, cannot be reversed. The thyristors conduct current once each cycle at a variable angle in the cycle as determined by the amplified error signal from the regulator. The earlier in the cycle that the thyristors conduct, the greater the amount of energy delivered to the field. Thus, the regulator controls excitation by varying the output of the power amplifiers by controlling the time of the firing pulses. Each power converter is equipped with conduction monitoring and thyristor overtemperature protection.

The power converters will be supplied in adjacent cubicles as required for the application. The power converter section features either drawout thyristor bridges or fixed bridge assemblies.

The power converter features a compact design. If optional power converter redundancy is purchased with drawout power converters, the converters may be isolated under full load. Redundant power converters can be added to both single and dual-channel configurations.

With drawout converters, the power section features a forced air-cooling system with a main fan and a backup spare fan for each power cubicle. The fan control circuits including automatic transfer to the backup fan are grouped together in one convenient location in each power cubicle. With fixed bridge assemblies, the cooling can be either convection or forced.



Figure 4 - 1100 Adc Power Drawer

#### **Active Current Balance**

The patented active current balancing algorithms (known as "Skip Firing") may be provided in multi-bridge schemes. By monitoring the temperature of each SCR in the Power Converter, this special algorithm facilitates an electronic method for rectifier bridge current sharing. This unique approach allows excitation currents to reach up to 10,000 Adc continuously.

#### SYSTEM OPERATION

The ECS2100 Digital Excitation System for a static exciter includes the ECS2100 Digital Voltage Regulator for automatic and manual control. In the automatic mode, the digital regulator controls generator terminal voltage by supplying a digital control signal to the firing circuits. The bridge control module (BCM) generates firing pulses for the power amplifiers in response to the ac regulator signal so as to control the power amplifier output current. In the manual mode, the dc field current regulator controls the system by sending a signal through the firing circuits to control the output current of the power amplifiers.

#### **Regulation Modes**

A variety of feedback control functions can be implemented. The purpose of these functions is to hold the particular regulated quantity at a set point. The set point is adjustable by operator action. The regulator gain, range of the set point, and the slew rate of the set point are adjustable for all regulators. Transient gain reduction is included with each regulator channel for the static exciter application. Another feedback control function is an Excitation System Stabilizer. This method is typically used in rotary exciter applications. In addition, a Proportional, Integral, and Derivative (PID) type controller is also available.

Each regulator has its own adjuster to provide a reference signal for that regulator. The slew rate, which can be set by the operator, is adjustable between minimum and maximum set points. The minimum and maximum set points can vary from 1 to over 200 seconds. The set point adjusters have position indication capability. There are 5 regulation modes of operation that can utilize the various feedback control functions.

#### Automatic Voltage Regulation Mode

In Automatic Voltage Regulation mode, the ECS2100 maintains the generator's voltage to <0.2% of the set point from no load to full load of the generator. The generator voltage adjustment range is 40 to 110% of nominal.

#### **Manual Regulation Mode - Generator Field Current**

When the system is in the Manual Regulation-Generator Field Current mode, generator field current is regulated by the ECS2100 to within  $\pm 0.5\%$  of the generator no load field current. The adjustment range is 20% to 125% of the generator full load rated field current.

**Manual Regulation Mode - Generator Field Voltage** When the system is in the Manual Regulation-Generator Field Voltage mode, generator field voltage is held to within  $\pm 0.5\%$  of the generator no load field voltage. The adjustment range is from 20% to 125% of the generator full load field voltage.

#### VAR Control Mode

In VAR Control mode, the system maintains the average VAR output of the generators output to an adjustable dead band setting (0.5%-10% or rated generator MVA). The time delay is adjustable from 0.02 to 10 seconds. The adjustment range of the VAR's set point is between 100% Overexcited to 100% Underexcited.

#### **Power Factor Control Mode**

In Power Factor (PF) Control mode, the system holds the average power factor within an adjustable deadband of 0.01-0.1 PF with a delay of 0.02-10 seconds as the generator load changes. Below an adjustable set point or when the voltage is outside a settable range, the power factor controller is automatically turned off and the system functions as an automatic or manual regulator. The range of adjustment is from 10 percent to 100 percent load. The range over which the power factor can be controlled is adjustable between 0.1 PF lead and 0.1 PF lag.

#### **Operating Mode Set Point Followers**

The Set point Followers function provides a virtually bumpless change in the newly regulated quantity when a transfer is made from automatic voltage regulation to manual regulation and from manual regulation to automatic regulation under steady conditions. The bandwidth between the controlling regulator-firing command and the following regulator firing command is adjustable from 0.1 percent to more than 10 percent. The time delay during which that bandwidth can be exceeded is adjustable from .02 to more than 10 seconds. During transients, the transfer may be made from one regulator to a second one even if that transfer will result in a bump.

The var/power factor controller takes raise or lower signals and generates the referenced set point for the automatic var/ power factor regulator. The adjuster followers (when enabled) operate to raise or lower this reference set point until the difference between the automatic voltage regulator and automatic var/power factor regulator error signals is within a desired deadband. If that signal is outside the deadband for longer than an adjustable deadband delay in seconds, a raise or lower output is activated. The output remains activated until the balance signal returns to within the deadband value.

#### **Programmable Sequence Control (PSC)**

Programmable Sequence Control is the function that performs startup, running, and shutdown control of the ECS2100 Digital Excitation System. The function is implemented in the software of the ECM. All control is provided in PSC. When the power requirements of the devices being operated, such as the 41A device, require them or when a customer interface requires dry contacts, discrete relays are added.

Programmable Sequence Control is made up of a series of logic blocks or gates that can be constructed using ccTool. Sequence control is displayed in ladder logic or ladder diagram fashion using ccTool.

#### HARDWARE AND SOFTWARE FEATURE DESCRIPTION

## Digital Voltage Regulator Channel Control Logic (Hardware)

#### **Excitation Control Module (ECM)**

The Excitation Control Module (ECM) is the central control card in a control channel for the excitation control system.

The ECM contains the intelligence to implement all of the regulators, limiters, protection, communication, and system control functions.

Each system utilizes one ECM module per channel. The function of a module as a main controller or a redundant controller is selectable in the software in its microprocessors. Each module contains the hardware needed to implement the software functions/settings and is stored in nonvolatile flash memory.

The ECM board has the capability to synchronize the system clock with an Arbiter Systems 1084B GPS satellite clock. Currently, the software is capable of synchronizing the controller clock to within 1ms of the satellite clock. The system has been designed to allow the GPS satellite clock signal to be brought in to the ECM board through the serial port (RS-232 DB-9 pin connection or RS-485 port).

#### Firing Control Interface Module (FCIM)

The Firing Control Interface Module (FCIM) is the interface between each Bridge Control Module (BCM) and the Exciter Control Module (ECM). See Fig. 5. The FCIM receives a firing command signal from the ECM and signals from Field Isolation Transducers (FIT) for field voltage and the excitation transformer (PPT) secondary voltage. Based on this information, the FCIM supervises the firing control for a single bridge or multiple thyristor-controlled bridges. The module receives information regarding bridge status from each BCM. The FCIM indicates loss of any one thyristor, a bridge low temperature alarm, and a bridge high temperature alarm. The FCIM also responds to phase-up, phaseback, and turn-off-pulse commands.

#### Sensor Input Module (SIM)

The Sensor Input Module (SIM) has high-speed analog inputs that collect data from regulation and metering potential transformers and current transformers connected to the generator's output, as well as other analog signals. The SIM receives signals from transformers that isolate it from analog inputs. The PT signals can be in the range of 20 to 160 Vrms. The CT signals are converted to a voltage through a 0.3 ohm resistor yielding voltages in the range of 0 to 1.8 Vrms. The input frequency can vary in the range of 20 to 70 Hz. The continuous line current can be in the range of 0.1 to 6 A in the CT secondary. During faults, transit signals as high as 25 A can be sensed without clipping.

The SIM contains 12 analog-to-digital converters for making measurements from these transformers and other inputs. Each analog-to-digital converter has a 12-bit resolution. The high-speed analog inputs sample the incoming signals simultaneously and are updated every millisecond.

The SIM is also the controller for serial input/output links to the ECM. Fiber optic connections are made from the SIM to expansion low-speed analog (AIOM) and digital (DIOM) input/output modules.



Figure 5 - Typical Single Channel Control Scheme

#### Digital I/O Module (DIOM)

The purpose of the Digital Input / Output Module (DIOM) is to provide a means to interface the ECS2100 excitation control system with external devices. Each DIOM has the capability to sense twelve digital inputs ( $\pm$ 24 - 125Vdc or 120Vdc) which are sampled every 8 ms. These inputs are commonly used to provide an interface to the excitation control system from pushbuttons, control switches, and relay auxiliary contacts.

Eight digital form C relay outputs are also provided on each module. The digital outputs are each connected to form C relays with ratings of 10A, 120Vac or 10A, 30Vdc. The ECM updates the outputs at an 8 ms rate. These outputs are commonly used to drive external relays and indicator lights, or to interface with DCS's and PLC's. Each ECS2100 control channel may be equipped with a maximum of four DIOMs that are connected in daisy chain fashion using an isolated bi-directional fiber optic communication link. Utilizing the ccTool software, the digital input and output data can be connected to any control software block input or output in the ECM.

These may be included in the original system or may be added by the customer in the field as the need for additional I/O arises. Because the fiber optic link is immune to electrical noise, the boards may be mounted in close proximity or up to 22 meters from the cubicle. This results in reduced wiring to the excitation cubicle.

#### Analog I/O Module (AIOM)

The purpose of the Analog Input / Output Module (AIOM) is to provide a means to interface the ECS2100 excitation control system with external devices such as meters, resistance thermal devices (RTD), transducers, chart recorders, distributed control systems (DCS), and programmable logic controllers (PLC). Each AIOM has the capability to sense two analog inputs (±10 Vdc) that could be used to interface the ECS2100 to PLC's or DCS systems. The AIOM

also has one 100 ohm Platinum RTD input that is commonly used to provide temperature and hydrogen gas pressure feedback to the system for use in the generator optimization functions associated with compensated excitation limiting.

The AIOM provides four individually configurable ( $\pm 10$  Vdc / 4-20 mAdc) analog outputs on each module with 16 bit resolution. Each ECS2100 control channel may be equipped with a maximum of four AIOMs that are connected in daisy chain fashion using an isolated bi-directional fiber optic communication link. These outputs are commonly used to drive existing panel meters or to interface with DCS systems or chart recorders. Utilizing the ccTool software, the analog input and output data can be connected to any control software block input or output in the ECM. Because the fiber optic link is immune to electrical noise, the boards may be mounted in close proximity or up to 22 meters from the cubicle. This results in reduced wiring to the excitation cubicle.

#### **Power Supplies Dual Source**

The excitation system can operate under extreme ranges of supply voltage. The Digital Excitation System contains dualsource power supplies that provide reliable control power from both the 120 Vac excitation source and the 125 V battery. Thus, control power is available regardless of machine speed or terminal voltage.

A dc-dc converter will be supplied for applications where a 250 Vdc supply voltage is used. dc control power is taken from both the customer's 125 V or 250 Vdc source and auctioneered with rectified 125 Vdc from 120 V, single-phase ac taken from the secondary of the excitation transformer.

#### **Generator Field Ground Detection**

A ground in the field of a synchronous machine should be detected since the occurrence of a second ground might short circuit part of the field winding, and the resultant unbalance and vibration may damage the machine.

The function of the exciter ground detector panel is to detect a ground current flowing from the machine dc field winding to the grounded machine shaft. The ground detector continuously monitors the machine field and detects ground currents ranging from 0.1 mA to 15 mA. A remote alarm is available for annunciation whenever a ground is detected. Provision is also made for checking the operation of the ground current sensing circuitry by applying a "simulated ground" to the PC card. The ground detector panel may be applied to brush excitation systems at rated generator field voltages up to 1,250 Vdc.

#### **Rapid De-Excitation**

A dc field breaker is not required with the ECS2100. Consequently, there is no need for a field discharge resistor or dc field breaker. An ac supply contactor or drawout circuit breaker, electrically operated with six (6) auxiliary contacts, will be supplied. The exciter power amplifier is a full converter (with thyristors in all legs of the three-phase bridge) with the ability to force down excitation quickly. The field is de-excited by phasing back the firing pulses to the static exciter amplifier. This action causes stored energy in the field to be inverted back to the source, which quickly reduces the field excitation to zero. Upon opening the ac field contactor, the remaining field energy will be dissipated very rapidly in a nonlinear resistor permanently connected across the field. Under emergencies when the ac field contactor is opened without de-exciting the field, the field current is discharged through the last two conducting thyristors or the nonlinear resistor.

In larger static excitation systems, rapid de-excitation is accomplished by a combination of electronically inverting the field voltage and triggering the DX module that shorts the field through a discharge resistor. The energy stored in the field is dissipated quickly in the discharge resistor that reduces the field excitation to zero. The ac field breaker is then opened to complete the shutdown.

#### **De-excitation Module (DX)**

The DX module is a thyristor-controlled circuit that provides an alternate path for the generator field current when the normal path is not available. The normal path is through the PPT, 41A-supply breaker, and the generator field. Should this path be interrupted, the DX circuit provides the safe alternate path to dissipate the field energy. To provide the alternate path, the DX thyristor is triggered by a control signal and/or excessive negative field voltage.

Control firing of the thyristor is implemented when the excitation system provides a de-excitation signal, typically when device 41A, the ac supply breaker, is opened. Voltage firing triggers the thyristor when the field voltage exceeds a preset negative voltage value. Feedback to the excitation system is provided when current is present in the DX module. A current sensing circuit in the module provides a logic signal to the excitation system whenever the current in the DX exceeds a minimum preset level.

#### Crowbar Module (CB)

The Crowbar module (CB) protects the generator field and exciter power converter from excessive high positive field voltages. Generator pole slip is a source of positive high voltage. The Crowbar self-triggers any time a high voltage occurs. The system automatically recovers once the voltage starts to go negative.

Since the power converter thyristors are likely to be phased on when the Crowbar operates, a resistor is placed in series with the module to limit the bridge current and provide a pole-slip current path. Feedback to the excitation system is provided when current is present in the Crowbar.

#### Field Flashing (Optional)

Field flashing is required when the static exciter receives all of its energy supply from the machine terminals and the machine terminal voltage is zero at startup. It is necessary to flash the machine field to raise the machine terminal voltage to a suitable level that is sufficient for the static exciter to begin to build up the machine voltage.

In order to ensure positive buildup of the ac generator voltage on startup, a reliable dc source of power is required for momentary field flashing. This source of power is applied momentarily to the generator field during startup by means of contacts on the field flash contactor. Field flashing after the a-c contactor closes by automatic or manual implementation, which may be supplied as an option. The field flash contactor has a momentary action and is supplied as standard equipment. In manual if the operator releases the switch, the momentary action permits the field to be disconnected from the dc source. The field flashing circuit includes a timer to prevent overflashing the field and a phase-up circuit that minimizes the load on the station battery source. The field flash is turned off when either the terminal voltage builds up or the field current exceeds a settable minimum value. The range of settings is from 1 percent to 100 percent of no-load field current.

Optionally, an ac, single-phase field-flashing source can be used. In that case a rectifier circuit is added to the assembly.

#### SOFTWARE CONTROL FUNCTIONS

#### **Reactive Compensation**

Reactive compensation, either droop or rise, is included with the ECS2100 system. These functions modify generator voltage by regulator action to compensate for the impedance drop from the machine terminals to a fixed point in the system. Action is accomplished by inserting into the regulator a reference voltage equivalent to the settable impedance drop time's reactive current. Three types of reactive compensation are available with the ECS2100.

- Generator Reactive Current Compensation Using One Set of CTs
- Generator Cross-Current Compensation Using Two Sets of CTs (Optional)
- Line Drop Compensation Using a Line CT Responds to both Resistive and Reactive currents (Optional)

#### Power System Stabilizer (Optional)

The Power System Stabilizer (PSS) provides a supplementary control signal input to a synchronous machine voltage regulator that improves system dynamic performance. The stabilizing signal provides positive damping of the electromechanical oscillations that occur as a result of system disturbances. Without supplementary control, a continuously acting voltage regulator can contribute negative damping to system swings, and these oscillations may be sustained or may even increase in amplitude.

The ECS2100 has only one predefined PSS algorithm. Implementation of the IEEE Type 2 "Integral of Accelerating Power" Dual Input PSS (power and frequency) power system stabilizer model PSS is standard. The function produces a stabilizing signal derived from two inputs: the deviation in synchronous machine speed and electrical power. The polarity of the signal is in the direction to increase excitation for terminal frequency deviations above normal frequency. This dual input PSS includes a ramp-tracking filter: one or two stages of high pass (washout) filters, and two or three lead-lag stages. Ramping output limiters are included to minimize the adverse effects of the PSS on system voltage. The Type 2 PSS requires inputs from three line CTs to achieve the best accuracy. The PSS also incorporates a low power threshold and will automatically disable the PSS function when the generators power drop below a predetermined level.

#### LIMITERS

The purpose of limiters is to take away control from any of the regulators, either manual or auto, then regulate the particular quantity at the pickup point of the limiter. The limiters provide an alternate feedback control loop to the regulators, and each limiter is provided with its own adjustable gain, adjustable transient gain reduction, or damping algorithm as needed to provide stable loop operation when the limiter is in control. Limiters operate whether the unit is in automatic or manual regulation modes.

All limiters have alarms associated with them. The first alarm is generated when the pickup has been exceeded. A second alarm, for limiters with time delays, is generated after the limiter has timed out. A third alarm is generated when the limiter has taken control from the regulator.

# Minimum Excitation Limiter- Steady State Stability Limit (MEL)

The Minimum Excitation Limiter (MEL) is based on generator stability. The limiter keeps the operating point of the generator within adjustable MW and Mvar curves. The operating curve, in terms of MW and Mvar will vary proportionally to the square of the generator terminal voltage. The shape of the MW and Mvar operating curves is constructed in a piecewise-linear fashion made up of five straight-line segments. Both Summing Point and Takeover style limiter is available with the MEL.

## Under Excitation Limiter- Generator Capability Curve (UEL) - Optional

The Under Excitation Limiter (UEL) prevents excitation reduction in the ac generator to levels that would result in damage to the generator while it is operating in an underexcited mode. The UEL is based on the generator capability curve. The limiter keeps the operating point of the generator within adjustable MW and Mvar curves. The shapes of the MW and Mvar operating curves are constructed in a piecewise-linear fashion made up of five straight-line segments. The inputs to the limiter are taken from machine potential and current transformers. The limiter output auctioneers against the voltage sensing signal output in an auctioneering function for control of the power amplifiers. The control of the power amplifiers by the limiter prevents the auto or manual regulator elements from decreasing machine excitation to levels below the desired set characteristic value. Both Suming Point and Takeover style limiter is available with the UEL.

Note: The following pickup modification (recalibration functions are available as options to the UEL:

Hydrogen Gas Pressure Recalibration for UEL (Optional)

Hydrogen Gas Pressure Recalibration modifies the UEL operating curve. The curve varies as a function of the generator hydrogen pressure and is reduced as the hydrogen pressure is reduced. The system receives either a 4-20 mA signal or a  $\pm 10$  V signal.

#### **Temperature Recalibration for UEL (Optional)**

Temperature Recalibration modifies the UEL operating curve. The modified curve varies as a function of the generator temperature measured by an RTD. The curve is proportional to the temperature.

#### **Over Excitation Limiter (OEL)**

The Over Excitation Limiter (OEL) acts through the regulator to return the value of excitation to a preset value after an adjustable time delay during which overexcitation is permitted for field forcing. The limiter operates on an inverse time characteristic that permits lower values of overexcitation for longer time intervals and limits higher values of over-excitation for shorter time intervals. This limiter's output auctioneers with the output of the auctioneering function in a signal mixer such that reduced excitation is sent to the firing circuit. The Over Excitation Limiter keeps the generator field current or voltage below a desired value of field voltage or field current that is adjustable. This limiter functions with the Instantaneous Limiter to provide a two step operation. The first operation is the instantaneous limiter. The second operation is the time-delayed limiter.

The OEL provides a "memory" of the time-dependent nature of the residual and cumulative effects of rotor heating. If the field quantity drops below the inverse limiter pickup, the inverse timer immediately begins to reduce the accumulated time over pickup to zero with a cool-down characteristic curve. An alarm is indicated when the limiter picks up.

Note: The following pickup modification (recalibration) functions are available as options to the Over Excitation Limiter:

#### Hydrogen Gas Pressure Recalibration for OEL (Optional)

The Hydrogen Gas Pressure Recalibration function modifies the pickup point of the inverse delay portion of the OEL. The pickup point varies as a function of the generator hydrogen pressure. The curve is proportional to the absolute pressure. The proportionality constant is adjustable. The system can receive either a 4-20 mA signal or a  $\pm 10-20$  mA signal or a  $\pm 10$  V signal.

#### **Temperature Recalibration for OEL (Optional)**

Temperature Recalibration modifies the OEL operating curve. The modified curve will vary as a function of the generator temperature measured by a 100-ohm RTD. The curve is proportional to the temperature. If a thermocouple or another size RTD is used, a separate transducer with either a 4-20 mA output or  $\pm 10$  V signals is required. Instantaneous Field Current Limiter

The Instantaneous Field Current Limiter keeps the generator field current or voltage below a desired level. That level may correspond to a ceiling limit for the generator field voltage in a brushless excitation system, to the instantaneous current limit of a thyristor bridge, or to a low level of current required during startup operation. The instantaneous limiter setting is automatically changed based on the status of the generator 52 breaker. When the 52 breaker is open and the unit is off line, the instantaneous limiter has an adjustable setting. When the 52 breaker is closed and the unit is on line, the instantaneous limiter has a second adjustable setting and a short adjustable delay.

#### Volts/Hertz Limiter (HXL)

The Volts/Hertz Limiter keeps the ratio of generator terminal voltage to line frequency below a desired value. The limiter is applied to the excitation system when the station must operate under adverse circumstances with the system frequency below normal operating range. In such cases, the reason for operating at reduced voltage during under-frequency conditions is to avoid the heating effects of excessive magnetic flux in the generator, transformers, or other magnetic devices. The limiter uses an inverse curve that coordinates with the sample volts/ Hertz curves shown in ANSI C37.102. The input to the volts/Hertz limiter is machine terminal voltage, and its output is a signal that auctioneers with the positive auctioneering output signal in the signal mixer in such a manner that whichever signal that reduces excitation is sent to the firing circuit.

#### Generator Overvoltage Limiter (OVL)

When the Generator Overvoltage Limiter is in control, the generator voltage is regulated to a pickup point below a desired line voltage. The limiter uses a selectable fixed time delay.

#### Generator Line Current Limiter (Optional)

The Generator Line Current Limiter keeps the generator line current below a desired level. The limiter is disabled when the power factor is near unity between 0.99 PF lag and 0.99 PF lead. The limiter is bidirectional. When the generator is operating overexcited, this limiter reduces the field current. When the generator is operating underexcited, the limiter raises the field current. The operation of the limiter occurs following a fixed time delay after the current has exceeded the pickup point. When the limiter is operating, it regulates the generator line current to within  $\pm 1.0\%$  provided that the power factor is either less than 0.99 pf lead or less than 0.99 PF lag.

#### Hydrogen Gas Pressure Recalibration for Generator Line Current Limiter (Optional)

Hydrogen Gas Pressure Recalibration modifies the Line Current Limiter operating curve. The curve will be varied as a function of the generator hydrogen pressure and is reduced as the hydrogen pressure is being reduced. The system receives either a 4-20 mA signal or a ±10 V signal.

#### PROTECTION

Protection functions operate whether in manual or auto. These functions provide alarm indications or trip commands when they operate. Protection functions do not tend to regulate or limit the signal, although some of them may

phase back the power bridges. For every Limiting Function, there is an associated Protection Function. The protection elements are intended to back up the Limiting Functions in an effort to take control and attempt to avoid a system trip.

**MONITORING FUNCTIONS via Color Touch Screen** The monitoring functions include a variety of items that are determined by the inputs to the control modules. Values can

be displayed on a color touch screen locally and/or remotely, if included. An alarm is generated whenever one of the monitored quantities exceeds an adjustable value.

**Field Values** - Displays field current, field voltage, and balance signal associated with the operating modes/ channels.

**Generator Field Temperature Monitor -** Monitors and displays the rotor temperature. There are two levels of alarm, low and high. An alarm is generated when either temperature exceeds a time delay.

#### **Generator Megawatts and Megavars**

Displays Generator Megawatts and Megavars function determines the real and reactive power output of the generator for display. These values are available whether one, two, or three CT signal(s) are utilized once programmed.

#### Analog Signal Outputs Using AIO Module (Meter Drivers)

The Analog Signal Outputs function sends an equivalent analog signal to a meter or chart recorder. As a minimum, the following signals are selectable to send to the analog outputs termination point: generator or exciter field current, generator or exciter field voltage, terminal voltage, terminal voltage deviation, line frequency, line frequency deviation, line current, generator real power, generator reactive power, accelerating power, PPT voltage on static systems, any error detector output, any set point adjuster signal, any limiter output, a firing command, any field temperature, the power system stabilizer output, or the balance meter output. The user can select the analog output channel for any of the quantities. The output range is  $\pm 10$  V or 4 to 20 mA.

#### Alarm Outputs Using DIO Module

A variety of alarm indications is available. The individual alarms can be indicated on the ccTool screen at the remote or local personal computer. An alarm (exciter trouble) relay is available to indicate that an alarm has occurred. Up to three additional individual relay contacts are available for annunciation.

# Excitation Transformer Temperature Monitor Using a DIO Module - (Optional)

The Excitation Transformer Temperature Monitor monitors the dry contacts of the temperature alarm of the excitation transformer coils. An alarm is generated if the temperature exceeds an adjustable value.

#### **Alarms Displayed on CCTools**

These alarms are documented functions viewed through Level 1 of the ccTool program. The purpose of this is to detect an internal problem or fault in the ECS2100 system. If the problem is non-critical, an alarm is generated and a short description of the fault is displayed. If the problem is critical, the main controller either automatically transfers control to another ECM, if present and prior to tripping the unit, or it trips the unit if no backup controller is available. A critical problem is one that may result in tripping the turbinegenerator off line or, if left uncorrected, could result in damage to the turbine-generator unit. All other problems will be defined as non-critical.

#### POWER SECTION DESCRIPTION

#### **Digital Firing Logic**

Digital firing control of the thyristor bridges in the ECS2100 utilizes field programmable gate arrays that are supervised by a microprocessor located on each Bridge Control Module (BCM). A separate microprocessor on the Firing Control Interface Module (FCIM) controls all of the Bridge Control Modules (BCM). The use of a microprocessor at each bridge provides bridge intelligence and diagnostics at each individual bridge. The use of an FCIM permits simultaneous firing of multiple bridges.

The ac error signal feeds a PID controller in the ECM and is then sent to the microprocessors in the FCIM of the digital firing circuits, and the resultant timing command, then, is sent to the field programmable gate arrays in the BCM. Then, the BCIM initiates the pulses being sent to the thyristors of the power converters. Each power converter is a three-phase, six-pulse, thyristor-controlled full converter whose ac input line frequency can be in the range of 20 to 480 Hz. The firing circuits are synchronized with the ac supply voltage and the associated thyristors or Silicon-Controlled Rectifiers (SCR). A linear relationship is established in a firing circuit between the regulator output signal voltage and the dc output voltage of the associated power converter.

#### **Thyristor Bridge Control**

The bridge control function supports the power converters in the ECS2100 Digital Excitation System. In multiple-bridge systems any one of the power converters can be turned off and repaired without affecting the operation of the other bridges. In systems utilizing pullout drawers when a redundant drawer is present, any drawer can be removed under full load by cranking out the drawer.

#### **Bridge Control Module (BCM)**

The ECS2100 systems are configured with one or more Bridge Control Modules (BCM). A BCM is located in each converter bridge assembly. The BCM generates the firing pulses needed to fire the SCRs in the full converter. A stateselect port on the BCM is used to select which channel is to be in control.

Monitoring functions of each BCM include the conduction of thyristors, the temperature of the bridge, and an optional magnitude of bridge current feature.

#### **Power Converter Assembly**

Each power converter for this application is packaged in a three-phase, six-thyristor, full-wave bridge configuration that includes a BCM module. The power converter applies positive and negative forcing voltage to the exciter field for dual directional forcing of field voltage. The field current, however, is not reversed. The thyristors conduct current once each cycle at a variable angle in the cycle as determined by the amplified error signal from the regulator. The earlier in the cycle that the thyristors conduct, the greater the amount of energy delivered to the field. Thus, the regulator controls excitation by varying the output of the power amplifiers by controlling the associated firing circuits.

Some of the power converter bridges are constructed of drawout, compact module subassemblies that can be electrically isolated to facilitate maintenance under load or fixed bridge assemblies. Drawout power converters permit easy removal of a complete power converter for bench testing. These modular bridges can be stacked to limit the cubicle floor space required for the ECS2100 Digital Excitation System.

#### **Power Redundancy**

The ECS2100 is configured to optionally add a spare operating power converter and associated BCM. With redundancy, maintenance can be performed under full load. This redundancy is important to assure that the failure of one of these modules or components does not cause a unit trip.

The ECS2100 Digital Excitation System has the capability to add redundancy in a single channel or in multiple channel configurations. This redundancy permits generator operation at rated load with one power converter assembly deactivated.

#### **Thyristor Protection**

RC snubber networks protect the thyristors against excessive rate of change of current and voltage. Nonlinear resistor assemblies protect against excessive transient reverse voltage. For large static exciter systems, ac line filters are typically used. Protection against loss of pulse in a firing circuit and loss of conduction in any converter bridge assembly is provided. Volt-Traps or MOVs (Metal Oxide Varistors), used as line surge protection devices, are included across the input lines to the converter input. Thyristor overtemperature is monitored by thermal sensors (RTD's) embedded in the heatsinks. The thermal sensors provide heatsink temperature indication. Typically, only the hottest heatsink is displayed.

#### **Cooling System**

For drawout converters, a main fan with a backup fan supplies forced-air cooling. The fan is designed to provide adequate cooling for the entire power cubicle. An automatic fan transfer circuit is included should the main fan fail. The fans are located in the top front and top back of the power cubicle. The fan assembly is designed to allow removal under load. A motor protection circuit is included, as well as a loss of airflow alarm. A fan selector switch is provided which allows the main fans to be alternated between the two fans.

For fixed bridge assemblies, the power converters may be either convection cooled or fan cooled depending on the combination of power converter rating required and converter size. If fans are used, they are mounted on each heat sink of the three-phase power converter or on the cubicle door depending on the field current requirements. The current rating is reduced without the fans, and the converter may be operated at reduced load without them. Many application requirements can be met with convection cooing only.

#### **CONTROL AND MAINTENANCE FEATURES**

#### **Operator Interface**

Flexibility in the ECS2100 control room interface capability permits the operator to monitor status, perform control operations, and make routine adjustments in the voltage regulator. For replacement installations, the customer may choose to use an existing control room panel. In that case, the system is operated with traditional switches, lights, and meters connected to programmable I/O terminals. For new installations or for sites where the customer chooses to replace existing controls, the ECS2100 can be connected to the control room by a single cable. Control then may be done through the Color Touch Screen Operator Control Module (See Fig. 6). This module can be mounted locally on the excitation cubicle or remotely in the control room, or it can be mounted at both locations. Critical switches such as the ac supply breaker can be direct connected to a relay via a terminal block.

Alternately, control may be done through the plant digital control system via a communication processor in that system.

The excitation control system can also be interfaced to a SCADA remote terminal unit, a process controller, or a backup set of control room switches, lights, and meters.



Figure 6 - Color Touch Screen Operator Control Module

#### Controller Configuration Tool (ccTool)

The ccTool is an easy-to-use software tool for configuring, monitoring, and maintaining the ECS2100 Digital Excitation Control System purchased. It provides operators and maintenance personnel with password access to the operational parameters and optional configuration management of the ECS2100 Digital Excitation System through a laptop or desktop PC.

Level 1: View, the basic access capability, includes the ability to monitor generator system values, digital regulator operating parameters such as gains, time constants, and limiting and protective set points, and view job-specific drawings, instruction books, help menus and help screens.

Level 2 (includes Level 1): Settings allows a user to modify selectable and adjustable parameter settings.

Level 3 (includes Levels 1 and 2): Configuration Management includes capabilities for the reconfiguration of software regulator function blocks and sequence control connections.

The ccTool can be accessed locally or from a remote location through the RS232 port on the ECM module.

The access capability also includes the ability to view the data collected by the ECS2100 Transient Event Recorder. The Transient Event Recorder is a software package that includes the standard Event and Alarm recorder that is accessed through Level 1: View of ccTool. Special features include the optional Single Event Recorder and Analyzer, and the optional Data Logger applications programs, both of which are accessed through optional Level 3: Configuration Management of ccTool. All events are time and date-tagged.

ccTool is compatible with industry standard software such as Embedded Windows NT and Windows XP.

#### **Transient Event Recorder**

The Transient Event Recorder is a software package that consists of three applications programs for recording and processing transient events.

#### **Event and Alarm Recorder**

The Event and Alarm Recorder generates a time and date stamped list of events. The events and alarms included in the list are pre-selected. The following items are included:

- Pickup of limiters
- Operation of limiter
- Pickup of protection functions
- Operation of protection functions
- Internal failure in the controllers



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Up to 2000 events may be recorded, then uploaded to a personal computer file using ccTool. An ACCESS spreadsheet may be used for viewing or printout.

#### **Single Event Recorder and Analyzer**

The Single Event Recorder records up to eight simultaneous signals. These signals can be selected from any input or output signals and selected internal signals. The record shows both pre-trigger and post-trigger information. The system provides a time that the event trigger occurred. A selectable remote trigger or an internal one can initiate the event recording. The Single Event Recorder can accept a time synchronization command from an external source such as a personal computer or plant digital control system.

Each record contains up to 9600 points per channel. The resolution is sufficient to allow a cycle-by-cycle analysis for an event. Up to 4 records are stored. The time between recorded points, as well as the number of recorded points, is adjustable. The minimum time between recorded points is one millisecond.

These data points can be viewed using a personal computer that can be directly connected to the ECM or connected via a modem to the ECS2100 Digital Voltage Regulator. Using ccTool, data for the event can be uploaded to a text file and viewed directly. The output file from the transient event is compatible with commercially available software such as Microsoft EXCEL<sup>™</sup>. Using such commercially available software, one can also view and plot the recorded information without being connected to the excitation system.

#### Data Logger

The Data Logger is a log of the value of selected inputs. The items to be logged are selectable from 1 to 12 items. The last 1000 samples of an item that is contained in a circular buffer are logged. The following is a list of items that, as a minimum, may be logged:

- · Generator output such as watts, vars, power factor
- · Excitation cubicle output, amps, and volts
- · Field temperature

The time between value readings is selectable in onesecond increments starting at one second. When requested, the last 1000 values logged may be uploaded using ccTool. The log can be stored on disk or printed.



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