

# EX2100e Excitation Control

100 mm, 77 mm, 53 mm, and 42 mm Thyristor Systems

## Product Description

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# 1 Overview

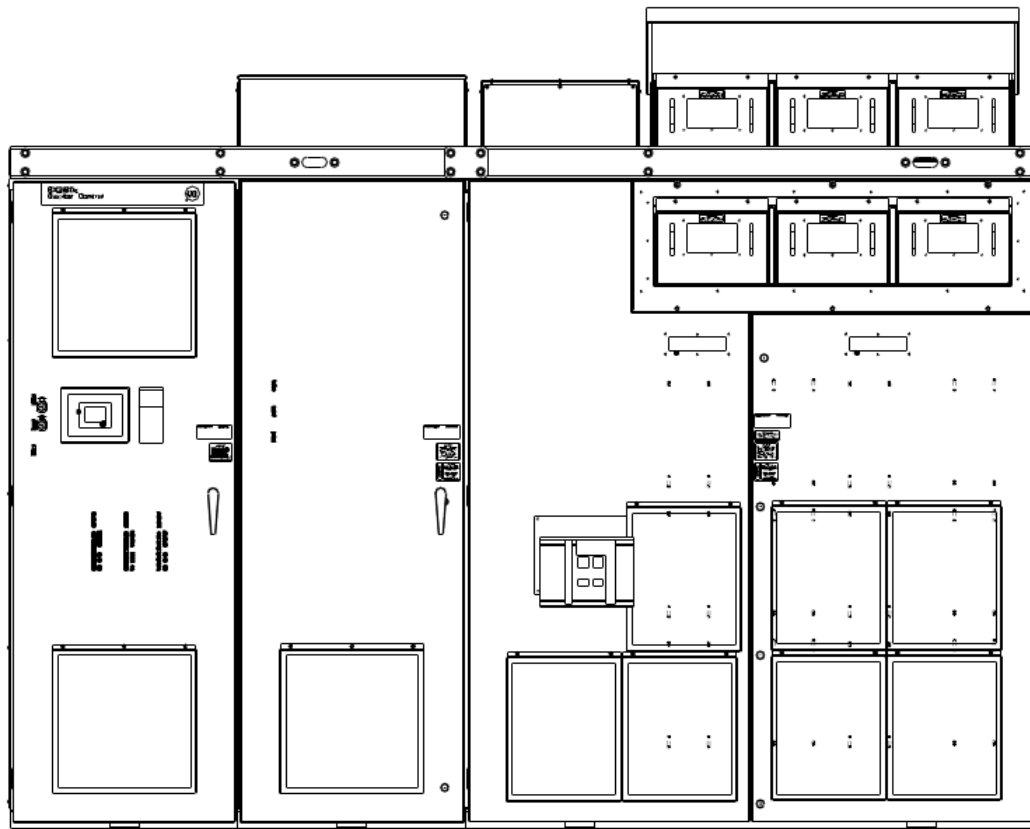
*The EX2100e control is GE's fourth generation digital excitation control system. There are over 4,000 first, second, and third generation GE digital excitation controls operating in 60 countries throughout the world.*

*Refer to GEA-S1301, EX2100e Excitation Control 35 A and 120 A Regulator Systems Product Description.*

The EX2100e Excitation Control is GE's latest state-of-the-art control for both new and retrofit steam, gas, and hydro generators. The control hardware and software design is closely coordinated between GE's system and controls engineering to ensure delivery of a true system solution. Integration between the EX2100e control, Mark\* VIe control, Mark VI Integrated Control System (ICS), LS2100e Static Starter, and human-machine interface (HMI) is seamless. For stand-alone retrofit applications, integration with customer distributed control systems (DCS) through ModBus® Ethernet is supported.

The EX2100e control system is available in several configurations to provide flexibility for full static and regulator control. The Thyristor silicon-controller rectifier (SCR)-based systems use cells sized at 42, 53, 77, and 100 mm to economically meet field current requirements in static applications. The pulse-width modulated (PWM) systems use Insulated Gate Bipolar Transistors (IGBTs) to provide up to 35 A or 120 A outputs for Regulator system applications. These systems can support the following applications:

- Static, potential source to 8000 A
- Static, compound source
- Alterrex\* Regulator system
- Saturable Current Transformers/Power Potential Transformer (SCT/PPT) Regulator
- Brushless Exciter Regulator
- Direct Current (dc) Rotating Exciter Regulator



**Typical EX2100e Excitation Control 77 mm Thyristor System**

## 1.1 Acronyms and Abbreviations

AVR	Automatic Voltage Regulator
COI	Control Operator Interface
CSLA	Compact PCI High-speed Serial Link Expansion Board
CT	Current Transformer
DCS	Distributed Control System
DPM	Dual-port memory
DRAM	Dynamic Random Access Memory
EAUX	Exciter Auxiliary I/O Interface Board
EBAC	Exciter Bridge AC Feedback Board
EBRG	Exciter Bridge Interface Board
ECTX	Exciter CT Expansion Board
EDEX	Exciter De-Excitation Control Board
EDFF	Exciter DC Fanned Feedback Board
EDIS	Exciter Power Distribution Board
EGD	Ethernet Global Data
ESYS	EX2100e System Interface Board for Customer I/O
EXAM	Exciter Attenuation Module
FCR	Field Current Regulator
FGD	Field Ground Detector
FPGA	Field Programmable Gate Array
FVR	Field Voltage Regulator
HMI	Human-machine Interface
HSLA	High-speed Serial Link Interface Board for Host Application Boards
ICS	Integrated Control System
IGBT	Insulated Gate Bipolar Transistor
I/O	Input and output
LAN	Local area network
LCD	Liquid Crystal Display
LVD	Low Voltage Directive
MTBFO	Mean Time Between Forced Outage
PCM	Power Conversion Module
PMG	Permanent Magnet Generator
PPT	Power Potential Transformer
PSS	Power System Stabilizer
PT	Potential Transformer
PTFD	Potential Transformer Fuse Failure Detection
PWM	Pulse-width Modulator
RC	Resistor/Capacitor Circuit
RCC	Reactive Current Compensation
SCL	Stator Current Limit
SCR	Silicon-controlled Rectifier
SCT	Saturable Current Transformer
SOE	Sequence of Events
SWC	Surge Withstand Capability
TMR	Triple Modular Redundant
UBC	Universal Building Code
UCSB	Universal Controller Stand-alone Microprocessor
UDH	Unit Data Highway
UEL	Underexcitation Limit control
VAR	Volt Amperes Reactive
V/Hz lim	Volts per Hertz Limiter

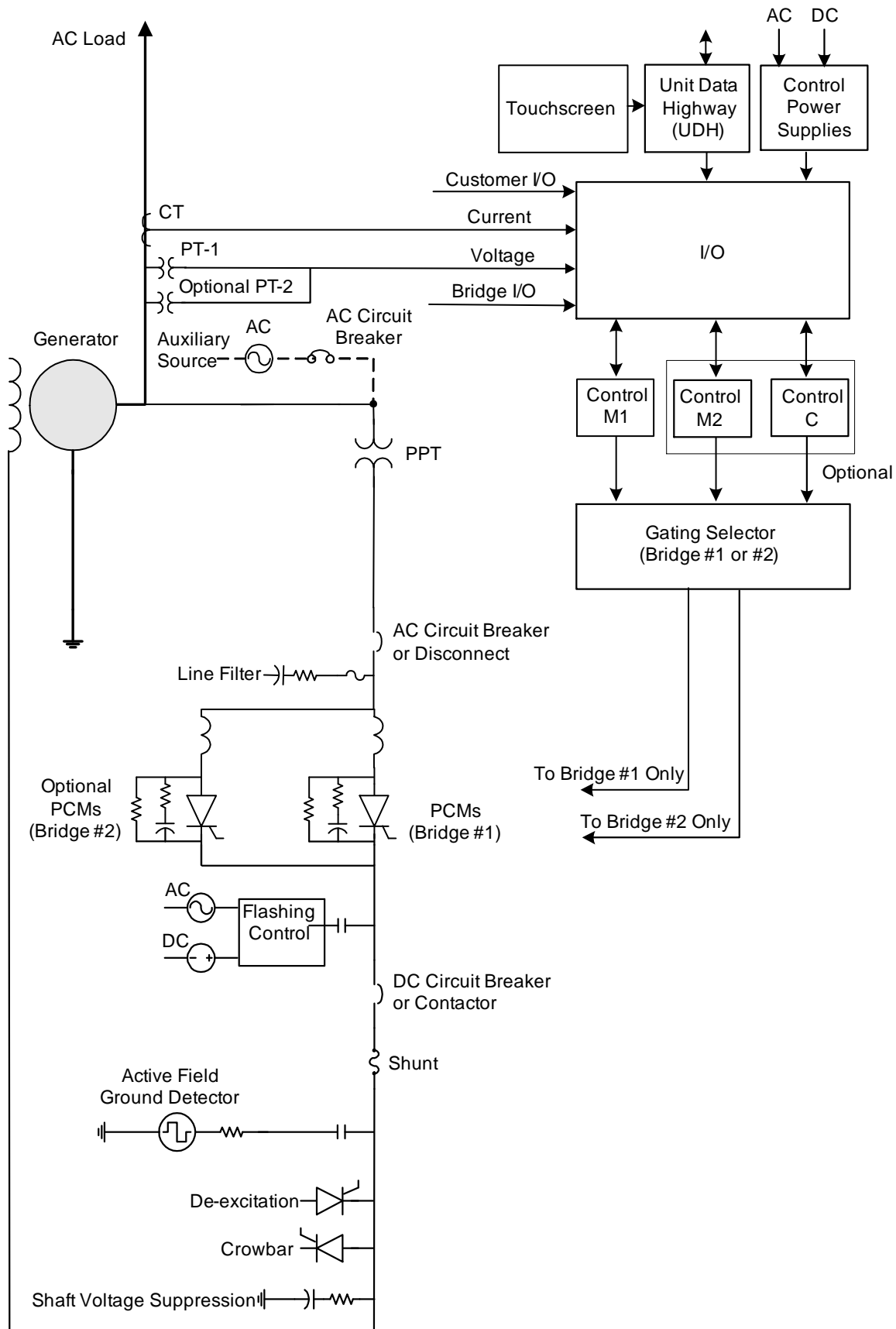
## 2 Control Hardware

*The EX2100e control incorporates a powerful diagnostic system and a control simulator to support rapid installation, tuning of control constants, and training.*

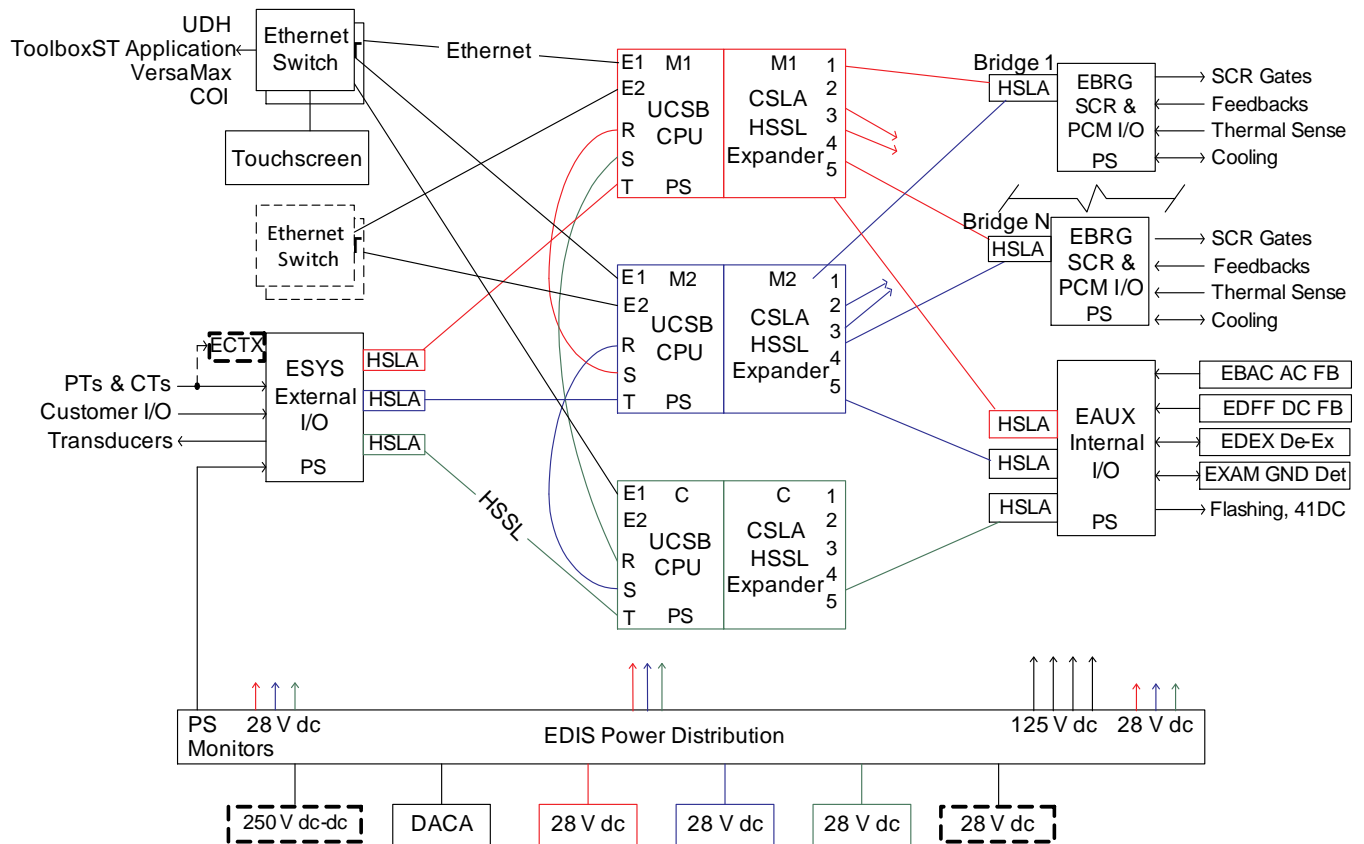
The EX2100e Thyristor system architecture is a simplex or redundant control configuration, customer I/O interface sub-system with an optional diagnostic interface local operator (touchscreen) or optional control operator interface (COI) remote touchscreen interface, control power supply input module, and power conversion module (PCM). The [PCM](#) consists of a bridge interface sub-system, power bridge, ac and dc filter networks, and ac and/or dc isolation devices.

The EX2100e Thyristor system supports Ethernet local area network (LAN) communication to the following:

- Turbine controls and ICS, HMI, Proficy\*-based Historian, Programming Interface (PI-based) Historian, Onsite Monitoring system (OSM), COI, and extended local input/output (I/O) VersaMax\* or Mark VIe control I/O modules using the Ethernet Global Data (EGD) protocol
- Customer DCS through Modbus remote terminal unit (RTU)
- ToolboxST\* application
- GE OnSite Support\* for monitoring and diagnostics



**Simplified EX2100e Control Major Functional Components (Maximum Case)**



**EX2100e Control Boards/Modules and Interconnection Overview (Maximum Case)**

## 2.1 Digital Controller (Thyristor-based Systems)

The EX2100e main control processor board is interconnected with the I/O boards and modules through High-speed Serial Link (HSSL) communication. The control and I/O boards and modules are as follows:

- Microprocessor-based Universal Controller Stand-alone (UCSB)
- Compact High-speed Serial Link Expansion (CSLA) board
- High-speed Serial Link Interface (HSLA) board for Host Application boards
- Exciter Auxiliary Interface (EAUX) board
- Exciter System Interface for Customer I/O (ESYS) module
- Exciter Bridge Interface (EBRG) board
- Exciter Bridge AC Feedback (EBAC) board
- Exciter Auxiliary Daughterboard (EAUD)
- Exciter DC Fanned Feedback (EDFF) board
- Exciter De-excitation Control (EDEX) board
- Exciter Power Distribution (EDIS) module
- Exciter CT Expansion (ECTX) board (Optional)

*Negative forcing provides fast response for load rejection and de-excitation.*

## 2.2 Power Conversion Module (Thyristor SCR)

For EX2100e Static exciter control systems, the 3-phase, full-wave, inverting thyristor (SCR) is the standard Power Conversion Module (PCM). The inverting bridge can provide both positive and negative forcing voltage for optimum performance. Each rectifier bridge includes thyristor protection circuitry, such as snubbers, filters, and fuses.

The thyristor bridge module is forced-air cooled. For most applications, redundant cooling modules that are normally energized during operation are used. A thermistor monitors the PCM temperature. A set of alarm and trip contacts trigger an alarm at a high temperature level, and a trip at a higher temperature level.

Depending on the application, the PCM may include protective components for the SCRs. A conduction sensing circuit, in coordination with the controller software, monitors each SCR bridge for blown fuses, missing gate pulses, or open/shorted SCRs. Reactors are located in the ac legs that are feeding the SCRs. The snubbers are a resistor/capacitor (RC) circuit from the anode to the cathode of each SCR. The cell snubbers, line-to-line filters, and line reactors together perform the following functions to maintain proper operation of the SCRs:

- Limit the rate of change of current through the SCRs and provide a current dump to aid in starting conduction
- Limit the rate of change in voltage across each cell
- Limit the reverse voltage that occurs across the cell during cell commutation

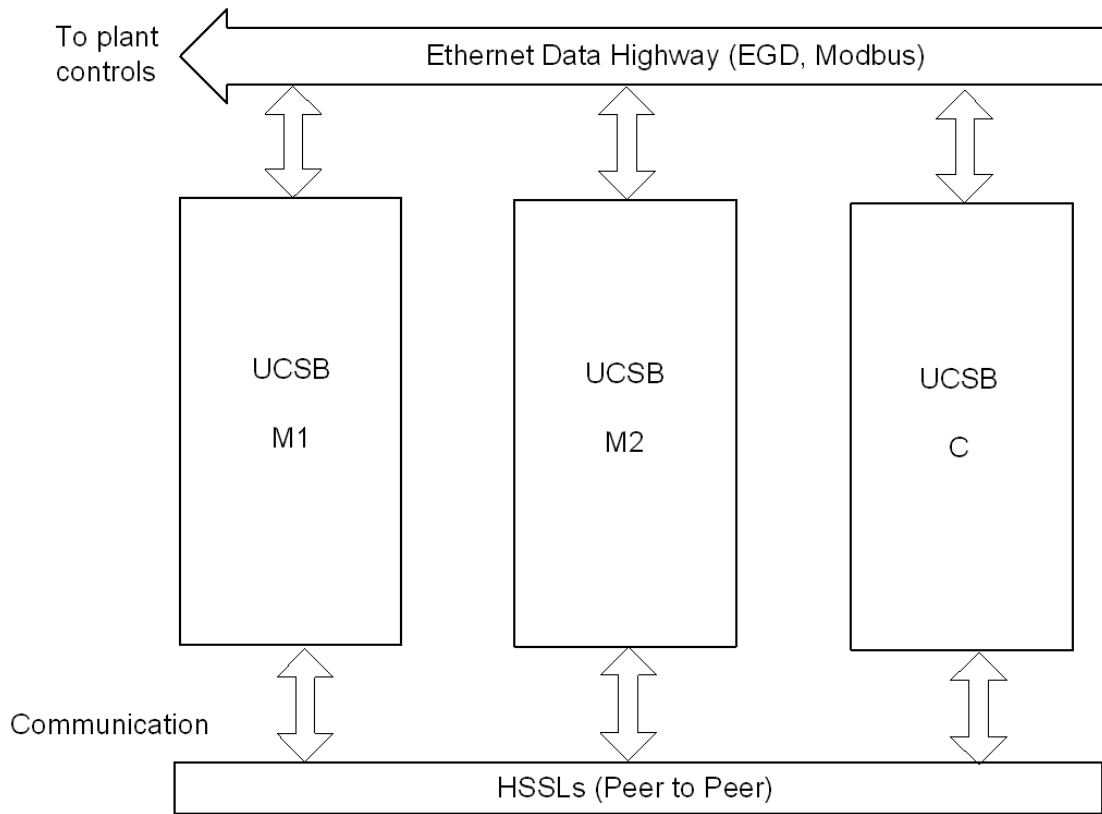
## 2.3 Controller Redundancy

*M1 and M2 are identical.*

In the warm backup ([WBU](#)) and [multi-bridge configurations](#), the EX2100e control features redundant control with triple modular redundancy (TMR) for voted I/O and protection, including the field ground detector (FGD) function. The control includes Master One (M1), Master Two (M2), and Controller (C) modules. M1 and M2 are independent controls, each with automatic and manual regulator functions. Either M1 or M2 can control the bridge firing, as determined by the operator, or a forced transfer by C. In the WBU configuration, M1 controls bridge #1, and M2 controls bridge #2. In the multi-bridge configuration, the Master in control fires all bridges. The M1 and M2 control modules each contain a UCSB controller for processing the application software. The C controller is responsible for M1/M2 transfer and provides the third element of TMR I/O and protection.

In the [redundant control, simplex bridge configuration](#), M1, M2, and C, are provided with a single bridge. In the simplex control configuration, only the M1 control and a single bridge are provided, and only a simplex FGD is available.





**Communication between Redundant Controllers**

### 2.3.1 Multi-bridge and Power Bridge Redundancy

The EX2100e control multi-bridge option is available for large static exciters. This option uses redundant controls (M1, M2, and C) with up to four full-wave SCR bridges that share common ac input and dc output circuits. The multi-bridge configuration is applicable to 8,000 A dc, 50/60 Hz, and may be configured as follows:

N+0, N = 2, 3

N+1, N = 2, 3

N+2, N = 1, 2

All power bridges receive gating commands from the active control (M1 or M2), and support the full field voltage and current needs of the generator field. The operator has full control to select which of the redundant controls are active or inactive. Bi-directional bumpless transfer between active and inactive controls is standard. In the N+1 and N+2 configurations, sophisticated monitoring and protection circuits detect a failure or misoperation of any single power bridge, and exciter operation continues while the faulty bridge is automatically shut down.

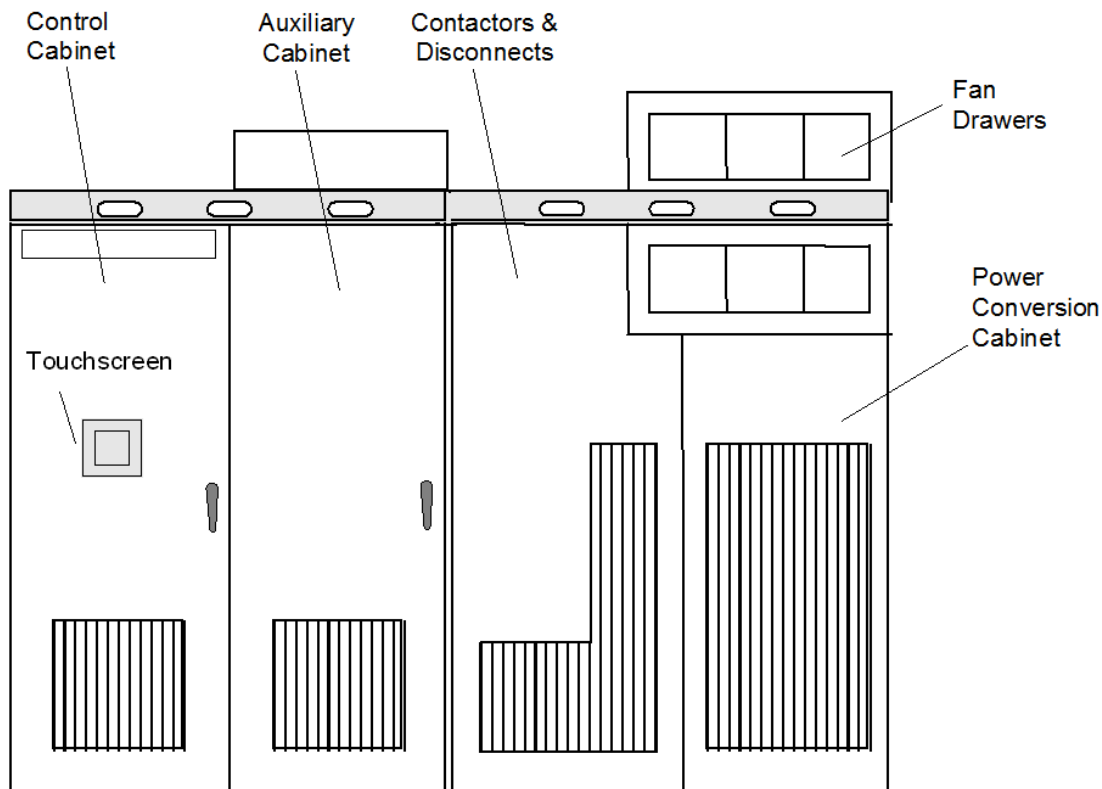
*A power bridge online maintenance feature that uses a 5-pole disconnect switch is available.*

### 2.3.2 Warm Backup and Power Bridge Redundancy

The EX2100e control WBU option is available for small to medium sized static exciters, which require power bridge redundancy, and the total power needs of the generator field can be supported within one PCM. This option uses redundant controls (M1, M2, and C) with two full-wave SCR bridges that share common ac input and dc output circuits.

*The WBU configuration is a cost-effective way to obtain N+1 bridge redundancy when N = 1.*

The active power bridge receives the gating commands from the active control (M1 or M2) and supports the full field voltage and current needs of the generator field while the backup power bridge's gating circuit is inhibited. The operator has full control to select which of the redundant power bridges is active or inactive. Bi-directional bumpless transfer between active and inactive bridges is standard. Sophisticated monitoring and protection circuits detect a failure or misoperation of the active power bridge, delays transfer (if needed to clear and SCR leg fuses), and activates the backup power bridge without operator intervention.



*Typical 77 mm or 53 mm WBU Cabinet Lineup*

### 2.3.3 Redundant Control and Simplex Bridge

The EX2100e redundant control, simplex bridge option is available for economical redundancy. This option uses redundant controls (M1, M2, and C) with a single full-wave SCR bridge. This system provides twice the mean time between forced outage (MTBFO) afforded by a simplex control with simplex bridge. Bi-directional bumpless transfer between active and backup controls is standard.

## 2.4 Control Cabinet

*An optional NEMA 12/IP54 rated control cabinet is also available. Refer to the section, [Specifications and Standards](#).*

The EX2100e Thyristor system is supplied in a NEMA® 1/IP20 freestanding, indoor metal cabinet for floor-mounting installation. The lineup consists of several cabinets bolted together with cable entry through the top or bottom. Each cabinet consists of a rigid, self-supporting, enclosed panel with a full-length door to provide easy access to the equipment. The standard cabinet color is ANSI™-70 (light gray) on both exterior and interior surfaces, but other colors are available. Each door is equipped with a suitable handle, three-point latch, and provisions for locking. The power bridge doors do not have handles, but are bolted closed to support code requirements. The equipment operates in an ambient temperature range of 0 to 40°C (32 to 104 °F). Depending upon the application, a current derating factor may apply at 50°C (122 °F).

The control cabinet may also be supplied detached from the power converter lineup to provide greater flexibility and safety in locating the equipment and to support Digital Front-end (DFE) applications of the EX2100e controls to other power converters.

### 3 **Control Software**

The EX2100e control software supports high performance and helps the customer and field engineers understand, install, commission, tune, and maintain the excitation control system. The exciter software is configured and loaded from the ToolboxST application and resides in the controllers. The software is represented on the ToolboxST Component Editor screen by control blocks that are linked together to display the signal flow.

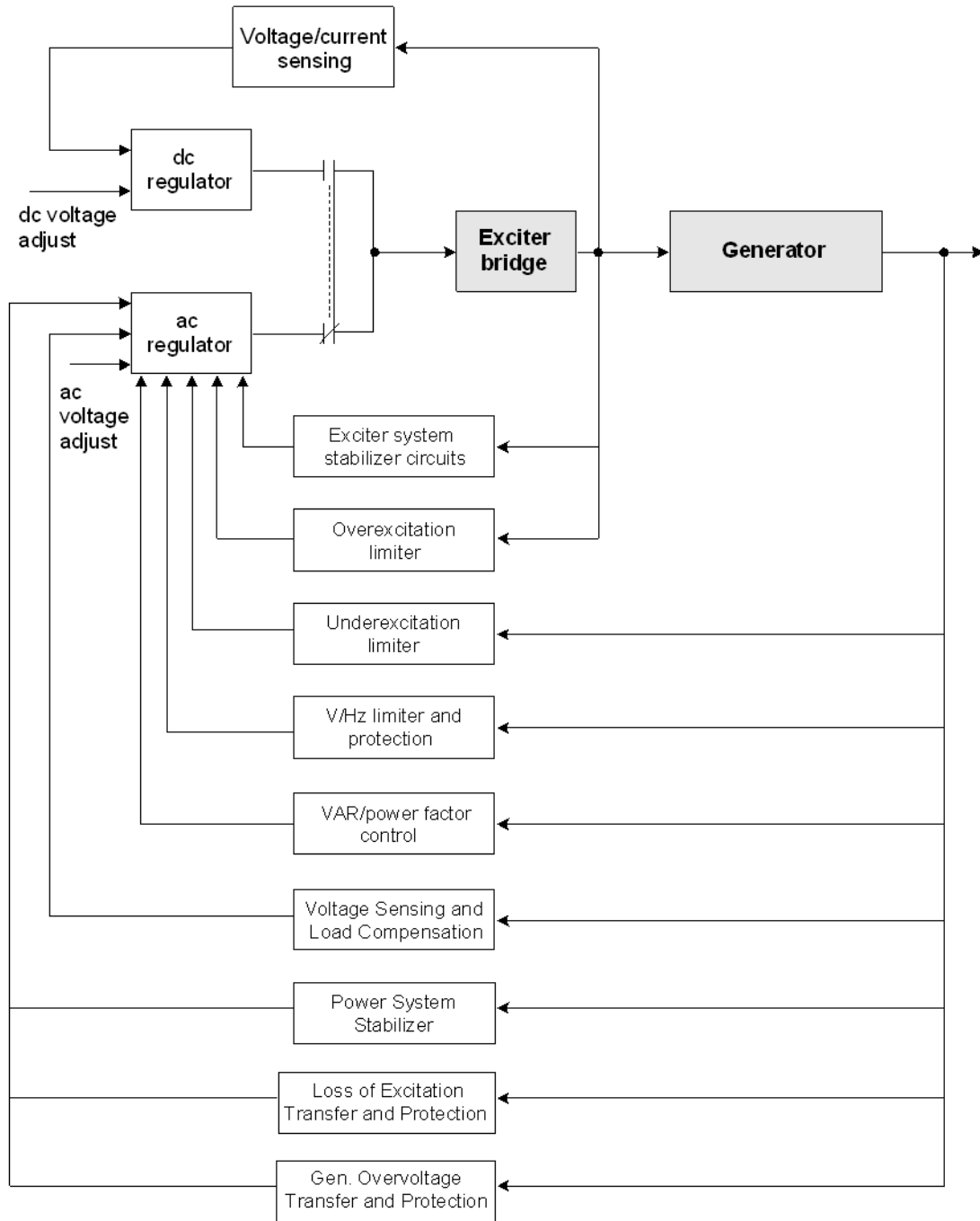
The output of the software transducer system includes the following:

- Generator voltage
- Generator active current (average in phase with watts)
- Generator reactive current (average in phase with reactive power, VARs)
- Generator frequency (current)
- Slip (signal representing the change in the rotor speed)

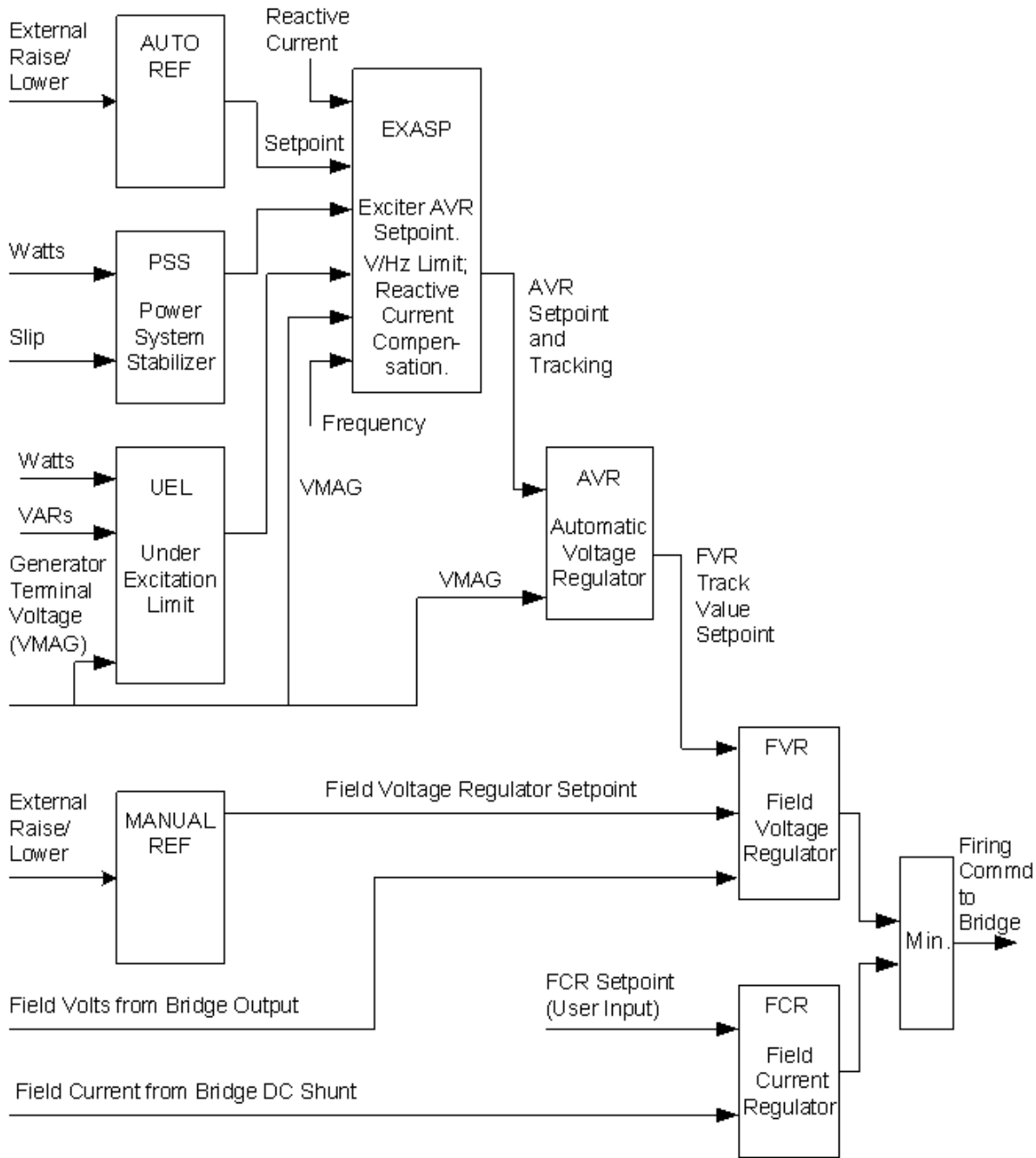
The transducer system uses the output to calculate the following:

- Generator power and VARs
- Magnitude of generator flux (V/Hz)
- Phase angle and power factor

The following figures provide a simplified overview of the exciter control system, displaying the main control functions. Both the generator field and stator currents and voltages are measured and input to the control system. In normal operation, the ac regulator is selected.



**Software Overview Block Diagram (1 of 2)**



**Software Overview Block Diagram (2 of 2)**

## 4 Specifications and Standards

Item	Description
<b>Physical Characteristics</b>	
Enclosure	NEMA 1/IP20 or IP21 freestanding, indoor metal cabinet, floor mounted Optional NEMA 12/IP54 available
Cabinet dimensions (W x H x D)	Cabinet dimensions vary depending on the SCR size (42 mm, 53 mm, 77 mm, 100 mm)
Paint	Exterior: ANSI®-70 (light gray) (other colors available) Interior: Galvanized steel
<b>Environmental Characteristics</b>	
Ambient temperature	0 to 40°C (32 to 104 °F); current derating at 50°C (122 °F)
AC input maximum	42 mm: 600 V rms 53/77 mm: 1000 V rms 100 mm: 1400 V rms
AC input frequency	50/60 Hz nominal
Nominal continuous output	42 mm: 165 A dc (convection), 465 A dc (fan cooled) 53 mm: 1000 A dc 77 mm: 2000 A dc 100 mm: 8000 A dc
<b>Supported Standards</b>	
Safety	UL508C Standard for Power Conversion Equipment CSA 22.2 No. 14 Industrial Control Equipment OSHA 29 CFR Part 1910 Subpart S, Electrical Safety Requirements
CE	Electromagnetic Compatibility (EMC) Directive 2004/108/EC: EN 55011: ISM equipment emissions (CISPR 11) EN 6100-6-4 & -6-2 Emissions and Immunity, Industrial Environment <ul style="list-style-type: none"> <li>• EN 61000-4-2 Electrostatic Discharge Susceptibility</li> <li>• EN 61000-4-3 Radiated RF Immunity</li> <li>• EN 61000-4-6 Conducted RF Immunity</li> <li>• EN 61000-4-4 Electrical Fast Transient Susceptibility</li> <li>• EN 61000-4-5 Surge Immunity</li> </ul> <p>Low Voltage Directive 2006/95/EC: EN 50178 Electronic equipment for use in power installations 1997</p>
IEEE™	421.1 Standard Definitions for Excitation Systems for Synchronous Machines (2007) 421.2 Guide for Identification, Testing, and Evaluation of the Dynamic Performance of Excitation Control Systems (1990) 421.3 High-Potential Test Requirements for Excitation Systems for Synchronous Machines (2004) 421.4 Guide for the preparation of Excitation Systems Specifications (2004) 421.5 Recommended Practice for Excitation Systems for Power Stability Studies (2005) C57.12.01 General Requirements
Seismic	IBC 2006/Universal Building Code (UBC) – Seismic Code section 2312 Zone 4

## 5 Testing

This section provides a brief description of the quality assurance tests performed on each exciter.

*All equipment goes through extensive testing with appropriate reviews and sign-offs.*

### 5.1 Routine Factory Tests

Each excitation control is subjected to routine factory tests including, but not restricted to, the following:

- Circuit continuity check
- Di-electric (hi-pot) tests in accordance with IEEE standard 421B
- Functional check of all components and devices for proper operation

### 5.2 Customer Witness Tests

After routine factory tests are complete, the customer can participate in a witness test. Two options are available:

*Customers are welcome to visit the GE factory to see how their equipment is engineered and manufactured.*

- **Option A:** The customer examines the appearance and workmanship of the equipment, then reviews the engineering and test paperwork. This is a standard service for no additional charge.
- **Option B:** The customer witnesses a demonstration of the hardware and software. This is an added-cost item to the customer.



# Glossary of Terms

**Auto Regulator Reference (AUTO REF)** generates the auto control (AC) setpoint variable for the automatic voltage regulator (AVR). Operator commands, (raise and lower inputs) come from direct inputs or over a data link from an HMI operator station, or from a plant DCS or remote dispatch system.

**Automatic and Manual Reference Follower (Tracking)** are software-implemented ramp functions that adjust the non-active regulator output to automatically track the active regulator. That is, when the auto regulator is controlling the generator, the manual regulator tracks, and when the manual regulator is controlling the generator, the auto regulator tracks. This provides for smooth transition when a transfer occurs from one regulator to the other.

**Automatic Voltage Regulator (AVR)** maintains the generator terminal voltage constant over changes in load and operating conditions.

**DCS Interface (ModBus RTU)** slave data link is supported to interface with customer DCS systems. This link uses TCP/IP support over Ethernet 10/100baseT hardware. Both commands and data can be supported.

**Exciter AVR Setpoint (EXASP)** combines a number of functions to produce the reference input to the AVR and the variables to support regulator tracking.

**Generator Field Temperature Calculation** measures the resistance by dividing the field voltage by the field current. From the known field resistance at 25°C (77 °F) and the linear resistance temperature change in copper, the algorithm calculates operating temperature. An adjustable high temperature alarm output contact is also included.

**Generator Overvoltage Trip (59G)** monitors the generator armature voltage and initiates a trip signal upon detecting an unacceptably high voltage.

**Generator Simulator (GEN SIM)** is a detailed generator model that is included as part of the excitation control system software. It can be configured to closely match the operation of the real generator. It can also be used for operator training, and can support the checkout of regulators, limiters, and protection functions while the unit is shut down.

**Hydrogen Pressure/Temperature Limiter** compensates the configuration parameters of key generator limiters and protection functions based on generator cooling. For hydrogen-cooled generators, the correct parameter is the internal hydrogen pressure, and for air-cooled generators, it is air temperature. The three limiters affected by pressure/temperature compensation are:

- Underexcitation limiter (UEL)
- Overexcitation limiter (OEL)
- Stator current limiter

**Loss of Excitation Protection (40)** detects a loss of excitation on synchronous machines using a two-zoned timed trip function that is based on resistance and reactance.

**Manual Regulator (FVR)** controls the generator field voltage or current, letting the generator output voltage. The manual regulator, like the AVR, uses a PPI regulator with integrator windup protection and its control output directly controls the firing command generator that controls the gating of the power bridge when enabled.

**Manual Regulator (FCR)** is a special application of the manual regulator and uses the generator field current as the feedback input. While it does regulate constant field current over varying field temperature, GE has not selected the FCR as its standard manual regulator because it inhibits the signal independence from the over excitation limiter.

**Manual Regulator Reference (MANUAL REF)** generates the manual setpoint variable for the manual voltage regulator (MVR). Operator commands, (raise and lower inputs) come in from direct inputs or over a data link from an HMI operator station or from a plant DCS or remote dispatch system.

**Manual Restrictive Limiter** limits the under-excited operation of the EX2100e while the manual regulator is selected (FVR or FCR). It also does not allow the manual regulator to track the automatic regulator when the unit is operating below the field voltage limit called for by the manual restrictive limiter.

**Overexcitation Limiter (OEL) and Offline Overexcitation Protection (OLOP)** protect the generator field from damage by events that require abnormally high field currents. These high currents, over an extended time, can overheat the field and cause damage. Generator fields are designed to ANSI standard C50.13, which specifies the overvoltage as a function of time that the field is designed to follow. This standard uses curves to describe the field overheating as a function of time and current.

**Potential Transformer Fuse Failure Detection (PTFD)** detects loss of PT feedback voltage to the voltage regulator. If the sensing voltage is lost or if it is single-phased, there is a transfer to the manual regulator and an alarm output is provided.

**Power System Stabilizer (PSS)** provides an additional input to the automatic regulator to improve power system dynamic performance. The PSS offered in the EX2100e control is a multi-input system using a combination of synchronous machine electrical power and internal frequency (which approximates rotor speed) to arrive at a signal proportional to rotor speed. This comes from the integral of accelerating power, but with shaft torsional signals greatly attenuated.

**Reactive Current Compensation (RCC/Line Drop)** has two modes: RCC and Line Drop. The RCC mode permits sharing reactive current between paralleled machines. Line Drop mode allows for better regulation of voltage at some point down stream from the generator terminals.

**Stator Current Limit (SCL)** determines the AVR/VAR control. When the generator stator current exceeds the rated value, the exciter changes from AVR control to a VAR control preset. Once the stator current is less than the rated value, the exciter returns to AVR control.

**Transfer to Manual Regulator upon Loss of PT** detects loss of PT feedback voltage to the ac voltage regulator. If the sensing voltage is lost, the regulator forces its output to ceiling for 0.5 sec and then transfers to manual. This is distinctly different from the PTFD function, which does not force the regulator to ceiling before transferring.

**Underexcitation Limiter (UEL)** is an auxiliary control to limit the AVR demand for underexcited reactive current. The UEL prevents reductions of the generator field excitation to a level where the small-signal (steady state) stability limit or the stator core end-region heating limit is exceeded. Performance is specified by identifying the region of the limiter action on the generator capability curve.

**Unit Data Highway Interface (UDH)** connects the exciter with the turbine control system, HMI or HMI viewer/data server, and GE controls. The UDH is based on EGD protocol. The UDH provides a digital window into the exciter where variables can be monitored and controlled. It also supports the ToolboxST application configuration and maintenance tool for the exciter.

**VAR/PF Control** is accomplished by slow ramping of the AVR reference setpoint. The VAR/PF is selected by operator command and the VAR/PF value is controlled using the raise/lower push-buttons. When the exciter interfaces with a Mark VIe turbine control system, this function is typically included.

**Volts per Hertz Limiter (V/Hz Lim)** limits the generator V/Hz ratio to the programmed setting in the EX2100e. This function uses two inputs from the software transducer, average generator voltage and generator frequency (its V/Hz ratio is configurable). Typically, the generator is considered to be operating acceptably within  $\pm 5\%$  of rated terminal voltage at rated frequency.

**Volts per Hertz Protection (V/Hz 24G)** serves as a backup to the V/Hz limiter. The protection scheme consists of two levels of V/Hz alarm and trip protection. Typically, one level is set at 1.10 per unit over V/Hz with an inverse time period, and the other level is set at 1.18 per unit with a two second time period.

When out-of-limit operation causes the exciter to trip, the controller stops gating the power converter IGBTs. The field current flows back into the dc link and rapidly collapses as its energy transfers into the dc link capacitors. To prevent overvoltage of the dc link, the dynamic discharge (DD) resistor is automatically connected across the dc link to dissipate the energy from the field.

