IEEE Standard Definitions for Excitation Systems for Synchronous Machines

IEEE Power Engineering Society

Sponsored by the
Energy Development and Power Generation Committee

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Approved 8 March 2007

IEEE-SA Standards Board

Abstract: This standard defines elements and commonly used components in excitation systems and contains definitions for excitation systems applied to synchronous machines. An included annex contains one-line block diagrams of some typical excitation systems. These are presented to illustrate the defined terminology referenced in this standard and clarify the understanding of the excitation control system.
Keywords: definitions of excitation controls, excitation block diagrams, excitation control systems, excitation systems terminology, synchronous generator controls

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Introduction

This introduction is not part of IEEE Std 421.1-2007, IEEE Standard Definitions for Excitation Systems for Synchronous Machines.

This standard defines elements and commonly used components in excitation systems and contains definitions for excitation systems applied to synchronous machines. For general requirements of a synchronous machine refer to IEEE Std C50.12™ and IEEE Std C50.13™.[a]

A synchronous machine excitation control system operating under automatic control is a feedback control system. Thus, the Terminology of the Excitation System Subcommittee Working Group of the Energy Development and Power Generation (ED&PG) Committee adopted definitions that had a common basis to excitation systems. Efforts were made not to conflict with terms found in the most recent edition of *The Authoritative Dictionary of IEEE Standards Terms* [B11], but to clarify or more fully define terms as related specifically to excitation of synchronous machines.[b]

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[a] For more information on references, please refer to Clause 2.

[b] The numbers in brackets correspond to those in the bibliography in Annex B.

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Contents

IEEE Standard Definitions for Excitation Systems for Synchronous Machines

1. Overview

This standard contains definitions and terminology specifically related to elements and commonly used components in excitation control systems for synchronous machines. Clause 1 is an overview of the standard and provides an outline of the scope of the standard. Clause 2 lists references to other standards that are relevant to definitions presented here. Clause 3 is a listing of the relevant definitions covered in this standard.

This standard also has two annexes. Annex A is an outline of some excitation system diagrams that are referred to in some of the definitions. Annex B provides bibliographical references.

1.1 Scope

This standard defines elements and commonly used components in excitation control systems and contains definitions for excitation systems as applied to synchronous machines. These definitions should be useful in the following areas:

— Writing excitation systems specifications

— Evaluating excitation system performance

— Specifying methods for excitation system tests

— Preparing related excitation system standards

— Serving as an educational means for those becoming acquainted with excitation systems

— Modeling excitation systems

2. Normative references

The following referenced documents are indispensable for the application of this standard. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

IEEE Std C50.12™, IEEE Standard for Salient-Pole 50 Hz and 60 Hz Synchronous Generators and Generator/Motors for Hydraulic Turbine Applications Rated 5 MVA and Above.[1, 2]

IEEE Std C50.13™, IEEE Standard for Cylindrical-Rotor 50 Hz and 60 Hz Synchronous Generators Rated 10 MVA and Above.

IEEE Std. 421.2™, IEEE Guide for Identification, Testing, and Evaluation of the Dynamic Performance of Excitation Control Systems.

IEEE Std 421.3™, IEEE Standard for High-Potential Test Requirements for Excitation Systems for Synchronous Machines.

IEEE Std 421.4™, IEEE Guide for the Preparation of Excitation System Specifications.

IEEE Std 421.5™-2005, IEEE Recommended Practice for Excitation System Models for Power System Stability Studies.

3. Definitions

For the purposes of this standard, the following terms and definitions apply. *The Authoritative Dictionary of IEEE Standards Terms* [B11][3] should be referenced for terms not defined in this clause.

3.1 ac field breaker: A circuit breaker used to disconnect the excitation system from the power potential transformer (PPT) or ac supply. *See also:* **de-excitation**.

3.2 ac regulator: *See:* **voltage regulator**.

3.3 adjuster: A device or function by which the set point is determined.

3.4 air-gap field voltage: The synchronous machine field voltage required to produce rated voltage on the air-gap line of the synchronous machine with its field winding at 1) 75 °C for field windings designed to operate at rating with a temperature rise of 60 °C or less; or 2) 100 °C for field windings designed to operate at rating with a temperature rise greater than 60 °C.

NOTE—This defines one per unit excitation system voltage for use in computer representation of excitation systems.[4]

3.5 air-gap line: The extended straight line part of the no-load saturation curve of the synchronous machine.

3.6 alternator-rectifier exciter: An exciter whose energy is derived from an alternator and converted to direct current by rectifiers. The exciter includes an alternator and power rectifiers that may be either noncontrolled or controlled, including gate circuitry. It is exclusive of input control elements. The alternator may be driven by any type of prime mover, most commonly the shaft of the synchronous machine. The rectifiers may be stationary or rotating with the alternator shaft.

3.7 automatic control: In excitation control system usage, automatic control refers to maintaining synchronous machine terminal voltage at a predetermined level without operator action, over the operating range of the synchronous machine.

NOTE—Voltage regulation may be modified by the action of load current compensators, power factor or var controllers, power system stabilizers, or may be constrained by the action of various limiters included in the excitation system.

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[3] The numbers in brackets correspond to those of the bibliography in Annex B.

[4] Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

3.8 automatic voltage regulator (AVR): A term often used to designate either the voltage regulator alone or the complete control system comprised of limiters, etc. *See also:* **synchronous machine regulator**.

3.9 autotracking: A function that causes the output of a control channel in the standby mode to follow the action of an active control channel; for example, autotracking of the manual control to follow the automatic control. Also called a follower.

3.10 auxiliary winding excitation system: An excitation system whose energy is derived from a separate dedicated power winding in the main generator's stator.

NOTE—See Figure A.10.

3.11 brushless exciter: An alternator-rectifier exciter employing rotating rectifiers with a direct connection to the synchronous machine field, thus eliminating the need for brushes.

NOTE—See Figure A.6.

3.12 bumpless transfer: A transfer between two control modes that results in negligible change in synchronous machine output. *See also:* **null balance**.

3.13 ceiling current: The maximum field current that the excitation system is designed to supply. Typically, this is related to the thermal capability of the excitation system equipment or the synchronous machine field circuit capability. *See also*: **overexcitation limiter**.

3.14 ceiling voltage: The maximum direct voltage that the excitation system is designed to supply from its terminals under defined conditions.

NOTE 1—The no-load ceiling voltage is determined with the excitation system supplying minimal current.

NOTE 2—The ceiling voltage under load is determined with the excitation system supplying synchronous machine rated field current.

NOTE 3—For an excitation system whose supply depends on the synchronous machine voltage and (if applicable) current, the nature of power system disturbance and specific design parameters of the excitation system and the synchronous machine influence the excitation system output. For such systems, the ceiling voltage is determined considering a specified supply voltage (usually rated voltage) and (if applicable) synchronous machine current.

NOTE 4—For excitation systems employing a rotating exciter, the ceiling voltage is determined at rated speed.

3.15 compound source-rectifier exciter: An exciter whose energy is derived from the currents and potentials of the ac terminals of the synchronous machine and converted to direct current by rectifiers. The exciter includes the power transformers (current and potential), reactors (if required), and rectifiers that may be either noncontrolled or controlled, including gate circuitry. It is exclusive of input control elements.

3.16 crowbar: In excitation system usage, a circuit designed to provide a conduction path for field current flow to prevent excessive field voltage. Triggered semiconductors with series resistors or inductors are commonly used. Non-linear resistors may alternatively provide this function.

NOTE—See Figure A.17b.

3.17 current boost: An excitation system auxiliary supply that acts to increase the available power supplied to the field winding, typically during fault conditions where the terminal voltage is lower and current is higher than normal.

3.18 current boost exciter: An exciter whose energy is derived from currents at the ac terminals of the synchronous machine and converted to direct current by rectifiers. The current boost system output is added directly with a potential source exciter rectifier as a separate rectifier system. The current boost system may include power current transformers, and either noncontrolled rectifiers or controlled rectifiers, with gate circuitry.

NOTE—See Figure A.14 and Figure A.15.

3.19 dc field breaker: A circuit breaker used to disconnect the excitation system from the generator or exciter field. *See also:* **de-excitation**.

3.20 dc generator-commutator exciter: An exciter whose energy is derived from a dc generator. The exciter includes a dc generator with its commutator and brushes. It is exclusive of input control elements. The exciter may be driven by a motor or any type of prime mover, most commonly by the shaft of the synchronous machine.

3.21 dc regulator: *See:* **manual control**.

3.22 de-excitation: The removal of the excitation and field discharge of the synchronous machine, main exciter, or pilot exciter.

NOTE—De-excitation may be accomplished by various means, such as a field discharge circuit breaker, dc field breaker, ac field breaker, crowbar, free wheeling diode, phase-back control of controlled rectifiers, or a combination of these.

3.23 digital excitation system: A common nomenclature for describing an excitation system for a synchronous machine where some, if not all, of the functionality is implemented in a digital processor. As a minimum, the AVR control function would be expected to be implemented digitally in such a system. It is likely that the limiter functions and optional var/pf or PSS controls are also implemented in the same digital-based control.

NOTE—See [B6].

3.24 discharge resistor: A resistor that, upon interruption of excitation source current, is connected across the field winding of a synchronous machine or an exciter to limit the transient voltage in the field circuit and to hasten the decay of field current of the machine.

3.25 discontinuous excitation control: A control function that acts to rapidly change synchronous machine excitation to a level different than that called for by the voltage regulator and power system stabilizer, for a period of time following a system fault or disturbance. Also known as discrete field forcing or transient excitation boosting.

3.26 excitation control system: The feedback control system that includes the synchronous machine and its excitation system. The term is used to distinguish the performance of the synchronous machine and excitation system in conjunction with the power system from that of the excitation system alone.

NOTE—See Figure 1.

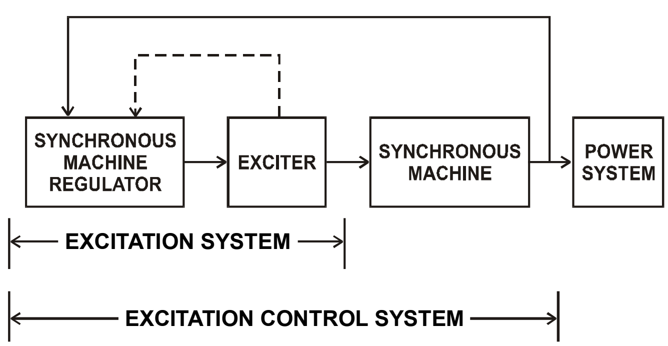

Figure 1—Block diagram of excitation control system

3.27 excitation system: The equipment providing field current for a synchronous machine, including all power, regulating, control, and protective elements.

3.28 excitation system duty cycle: An initial operating condition and a subsequent sequence of events of specified duration to which the excitation system will be exposed.

NOTE—The duty cycle usually involves a three-phase fault of specified duration that is located electrically close to the synchronous machine. Its primary purpose is to specify the duty that the excitation system components can withstand without incurring mis-operation or damage.

3.29 excitation system nominal response: The rate of increase of the excitation system output voltage determined from the excitation system voltage response curve, divided by the rated field voltage. This rate, if maintained constant (curve ac), would develop the same voltage-time area as obtained from the response (curve ab) over the first half-second interval (unless a different time interval is specified).

NOTE 1—Refer to Figure 2.

NOTE 2—The excitation system nominal response shall be determined with the excitation system voltage initially equal to the rated field voltage of the synchronous machine, after which the excitation system ceiling voltage is rapidly attained by introducing a specified voltage error step.

NOTE 3—The excitation system nominal response shall be determined with the excitation system loaded with a resistance equal to the field resistance under rated load conditions and adequate inductance so that voltage drop effects and current and voltage waveforms are reasonably duplicated.

NOTE 4—For excitation systems whose supply depends on the synchronous machine voltage and (if applicable) current, the nature of the power system disturbance and specific design parameters of the excitation system and the synchronous machine influence the excitation system output. For such systems, the excitation system nominal response shall be determined considering a specified supply voltage (usually rated voltage) and (if applicable) synchronous machine current.

NOTE 5—If, for practical considerations, tests can only be made on individual components or the entire excitation system but only at partial or no-load, analytical methods may be used to predict performance with rated field voltage (see NOTE 1).

NOTE 6—For excitation systems employing a rotating exciter, the excitation system nominal response shall be determined at rated speed.

NOTE 7—Not normally used in the specification of static excitation systems. There is a potential conflict if ceiling voltage is also specified.

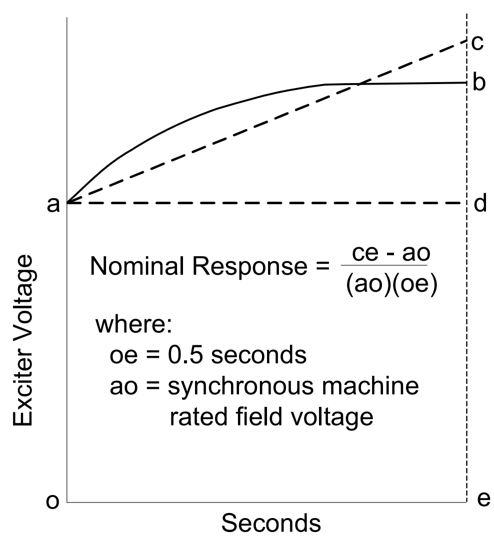

Figure 2—Excitation system nominal response

3.30 excitation system output terminals: The place of output from the equipment comprising the excitation system. These terminals may be identical with the field winding terminals.

3.31 excitation system rated current: The direct current at the excitation system output terminals that the excitation system can supply under defined conditions of its operation. This current is at least that value required by the synchronous machine under the most demanding continuous operating conditions (generally resulting from synchronous machine voltage, frequency, and power factor variations).

3.32 excitation system rated voltage: The direct voltage at the excitation system output terminals that the excitation system can provide when delivering excitation system rated current under rated continuous load conditions of the synchronous machine with its field winding at 1) 75 °C for field windings designed to operate at rating with a temperature rise of 60 °C or less; or 2) 100 °C for field windings designed to operate at rating with a temperature rise greater than 60 °C.

3.33 excitation system stabilizer: A function that serves to modify the voltage regulator forward signal by either series or feedback compensation to improve the dynamic performance of the excitation control system.

3.34 excitation system voltage response time: The time in seconds for the excitation voltage to attain 95% of the difference between ceiling voltage and rated field voltage under specified conditions.

3.35 exciter: The equipment that provides the field current for the excitation of a synchronous machine.

3.36 fault current limiter: A function that acts to prevent the stator current from exceeding a preset value during steady-state operation of the generator with a short-circuit applied to its output. The limiter acts to limit fault current by decreasing excitation. Also known as line current limiter.

3.37 field current/voltage limiter: A control function that acts to prevent the field current or voltage from exceeding a preset value. *See also:* **overexcitation limiter**.

3.38 field discharge circuit breaker: A circuit breaker having main contacts for energizing and de-energizing the field of a synchronous machine or rotating exciter and having discharge contacts for short-circuiting the field through a discharge resistor prior to the opening of the circuit breaker main contacts. The discharge contacts also disconnect the field from the discharge resistor following the closing of the main contacts.

NOTE 1—When used in the main field of a synchronous machine the circuit breaker is designated as a main field discharge circuit breaker.

NOTE 2—When used in the field circuit of a rotating exciter of the main machine, the circuit breaker is designated as an exciter field discharge circuit breaker. See [B1].

3.39 field flashing: Momentary application of dc power to the field of a synchronous machine for the purpose of building up terminal voltage.

3.40 field forcing: A control action that rapidly drives the field voltage of a synchronous machine in the positive or in the negative direction.

3.41 field voltage/field current regulator: A regulator that functions to maintain the field voltage/field current at a predetermined value.

3.42 field winding: A winding on either the stationary or the rotating part of a synchronous machine whose sole purpose is the production of the main electromagnetic field of the machine.

3.43 field winding terminals: The place of input to the field winding of the synchronous machine. If there are brushes and slip rings (collectors), these are considered to be part of the field winding.

3.44 freewheeling diode: A diode connected across the controlled bridge of a static excitation system to provide a path for field current to flow if the normal bridge path is not available. Also called flyback diode.

NOTE—See Figure A.1c.

3.45 high initial response: An excitation system capable of attaining 95% of the difference between ceiling voltage and rated field voltage in 0.1 s or less under specified conditions.

3.46 impedance compensator: *See*: **line drop compensator; reactive droop compensator**.

3.47 large signal performance: Response of an excitation control system, excitation system, or elements of an excitation system to signals that are large enough that nonlinearities must be included in the analysis of the response to obtain realistic results.

3.48 line drop compensator: A function that modifies the machine terminal voltage to compensate for the impedance drop to a fixed point external to the synchronous machine terminals.

3.49 load current compensator: A function that acts to influence the voltage regulator action to control voltage at a point other than where the synchronous machine voltage is measured. Specific uses are reactive droop compensation, reactive differential compensation, and line drop compensation.

3.50 manual control: In excitation system usage, manual control refers to direct control of the synchronous machine excitation by operator action. *See also*: **field voltage/field current regulator**.

NOTE—Manual control may include open or closed loop control of the exciter output, or any other means that does not directly control the synchronous machine output variables.

3.51 no-load field current: The direct current in the field winding of synchronous machine required to produce rated voltage at no-load and rated speed.

3.52 no-load field voltage: The voltage required across the terminals of the field winding of the synchronous machine under conditions of no-load, rated speed, and rated terminal voltage, and with the field winding at 25 °C.

3.53 null balance: A circuit or action designed to match the output of the automatic voltage regulator and the manual control to minimize the transient upon transfer of regulator control. *See also*: **bumpless transfer**.

3.54 overexcitation limiter (OEL): A control function that limits the field current of the synchronous machine or excitation equipment to permissible values with regard to thermal overload. Action may be immediate or time delayed. Also called a maximum excitation limiter. *See also:* **field current/voltage limiter.**

3.55 permanent magnet generator (PMG): An auxiliary synchronous machine with permanent magnet field. Used to supply the power requirements of a portion of the excitation system. Also known as permanent magnetic alternator (PMA).

NOTE—See Figure A.2, Figure A.4, and Figure A.6.

3.56 pilot exciter: The equipment providing the source of field power for the excitation of another exciter.

3.57 potential source-rectifier exciter: An exciter whose energy is derived from a stationary ac potential source and converted to direct current by rectifiers. The exciter includes the power potential transformers and power rectifiers that may be either noncontrolled or controlled, including gate circuitry. It is exclusive of input control elements. The source of ac power may come from the machine terminals or from a station auxiliary bus or a separate winding within the synchronous machine.

3.58 power current transformer: A transformer in a compound source-rectifier excitation system that transfers electrical energy from the synchronous machine armature current to the excitation system at a magnitude and phase relationship required by the excitation system. Also used in current boost configuration.

NOTE—See Figure A.7 and Figure A.8.

3.59 power factor controller: A control function that acts through the adjuster to modify the voltage regulator set point so as to maintain the synchronous machine steady-state power factor at a predetermined value.

3.60 power factor regulator: A synchronous machine regulator that functions to maintain the power factor at a predetermined value. Commonly used on synchronous motors. *See also:* **power factor controller**.

3.61 power potential transformer (PPT): A transformer in a potential source-rectifier excitation system that transfers electrical energy either from the machine terminals or from an auxiliary bus to the excitation system at a magnitude level required by the excitation system. Also, a transformer in a compound source-rectifier excitation system that transfers electrical energy from the synchronous machine armature terminals to the excitation system at a magnitude and phase relationship required in the excitation system.

3.62 power system stabilizer (PSS): A function that provides an additional input to the voltage regulator to improve the damping of power system oscillations.

NOTE—A number of different quantities may be used as input to the power system stabilizer, such as shaft speed, frequency, electric power, etc., or a combination of these signals.

3.63 rated field current: The direct current in the field winding of the synchronous machine when operating at rated voltage, current, power factor, and speed. Rated field current of any other rotating exciters is based on the synchronous machine rated field current at a specified temperature.

3.64 rated field voltage: The voltage required across the terminals of the field winding under rated continuous load conditions of the synchronous machine with its field winding at 1) 75 °C for field windings designed to operate at rating with a temperature rise of 60 °C or less; or 2) 100 °C for field windings designed to operate at rating with a temperature rise greater than 60 °C. Rated field voltage of any other rotating exciter is based on the synchronous machine rated field current at a specified temperature.

3.65 reactive differential compensator: A function used to obtain reactive current sharing among synchronous machines operating in parallel without causing reduction of terminal voltage. Requires interconnection of voltage regulators or current transformers of the machines.

3.66 reactive droop compensator: A function that causes a reduction of terminal voltage proportional to reactive current. Generally used to obtain reactive current sharing among synchronous machines operating in parallel.

3.67 set point: The reference signal to which the controlled variable is to be compared.

3.68 shaft voltage suppressor: A filter device, usually consisting of a symmetrical RC network, connected from each side of the field to ground. The filter is designed to eliminate common mode voltage that is caused by power semiconductors used to supply the field circuit. The filter minimizes shaft voltages that would otherwise lead to shaft currents, which could damage bearing surfaces.

3.69 small-signal performance: The response of an excitation control system, excitation system, or elements of an excitation system to signals that are small enough that nonlinearities can be disregarded in the analysis of the response, and operation can be considered to be linear.

3.70 stator current limiter: A function that acts to prevent the stator current from exceeding a preset value. If the generator is operating overexcited, the limiter will decrease excitation, while in underexcited operation the limiter increases excitation.

3.71 synchronous machine regulator: A general term applied to a regulator that couples the output variables of a synchronous machine to control the exciter output through forward and feedback elements for the purpose of regulating the synchronous machine output variables. *See also:* **automatic voltage regulator**.

3.72 terminal voltage limiter: A function that acts to prevent the terminal voltage from exceeding a preset level.

3.73 underexcitation limiter (UEL): A function that either overrides the voltage regulator action (takeover type) or adds to terminal voltage setpoint (summing type), to maintain synchronous machine excitation such that synchronous machine output remains above a preset level. Various terms have been applied, often descriptive of the measured variable; minimum excitation limiter, underexcited reactive ampere limit, and rotor angle limiter.

3.74 var controller: A function that acts through the adjuster to modify the voltage regulator set point so as to maintain the synchronous machine steady-state reactive power at a predetermined value.

3.75 var regulator: A synchronous machine regulator that functions to maintain the reactive component of power at a predetermined value. Commonly used on synchronous motors. *See also:* **var controller**.

3.76 voltage regulation accuracy: The band or zone, expressed in percent of the rated value of the regulated voltage, within which the excitation system will hold the regulated voltage of the synchronous machine during steady or gradually changing conditions, in the absence of the action of any compensators or limiters. Unless otherwise specified, the range will be assumed from no-load to rated kVA and power factor.

3.77 voltage regulator: A synchronous machine regulator that functions to maintain the terminal voltage of a synchronous machine at a predetermined value, or to vary it according to a predetermined plan.

3.78 volts per hertz limiter: A function that acts to prevent the ratio of terminal voltage to frequency from exceeding a preset level. The purpose is to prevent excessive magnetic flux in the synchronous machine and connected transformers.

Annex A

(normative)

Typical elements and components of excitation control systems

The following figures are included only to aid in the understanding of the excitation control system and to illustrate some typical systems terminology referenced and defined in this standard.

Figure A.1 is a generalized block diagram identifying excitation system control and protective elements. The symbols used in Figure A.1 are taken directly from IEEE Std 421.5-2005, "Computer Representation of Excitation Systems" [B15], and "Excitation System Models for Power System Stability Studies" [B16], and are defined in Table A.1.

Table A.2 shows the correlation between the diagrams of this standard and the excitation model types used in IEEE Std 421.5-2005 and "Excitation System Models for Power System Stability Studies" [B16]. Table A.2 also shows a further breakdown of the three basic exciter types, as well as the source of exciter power.

Figure A.2 through Figure A.16 show typical configurations of the principal excitation systems currently in use. These single line diagrams identify the source of the excitation power with control circuits shown for clarity and general understanding.

Figure A.17a through Figure A.17d represent the typical three-phase rectifier bridge circuits that may be used in excitation control systems. The rectifier bridge circuit is shown in Figure A.3 and Figure A.6 through Figure A.15 as a single rectifier or controlled rectifier in a block. These rectifiers are the main source of the field current for an exciter or generator main field.

The potential source and compound source systems have *power* PTs and *power* CTs. These transformers supply power to the rectifier bridge circuits; they should not be confused with the instrument transformers supplying intelligence to the automatic control circuit, or used for protection and metering functions.

Table A.1—Nomenclature for Figure A.1

E_{FD}	–	Exciter output voltage (generator field voltage)
I_{FD}	–	Exciter output current (generator field current)
V_F	–	Excitation system stabilizer signal
V_{FE}	–	Signal proportional to exciter field current
V_L	–	Limiters and protective elements feedback
V_R	–	Regulator output
V_S	–	Power system stabilizer output
V_{SI}	–	Power system stabilizer inputs (shaft speed, frequency, synchronous machine electric power, and others)
V_T,I_T	–	Generator terminal voltage and current, respectively
V_{REF}	–	Voltage regulator, reference signal

Table A.2—Excitation system characteristics

Exciter category	Type of exciter	Exciter power source	Figure	High initial response	Computer model type*
DC	DC generator commutator exciter	Motor-generator set or synchronous machine shaft	A.2, A.4 A.3 A.5	no no no	DC1A DC2A DC3A
AC	Alternator-stationary noncontrolled rectifier	Synchronous machine shaft	A.7	no	AC3A
	Alternator-rotating noncontrolled rectifier (brushless)	Synchronous machine shaft	A.6	no yes	AC1A AC2A
	Alternator-stationary controlled rectifier	Synchronous machine shaft	A.8	yes	AC4A
ST	Potential source controlled rectifier	Synchronous machine voltage or auxiliary bus voltage	A.9 A.10	yes yes	ST1A ST3A
	Compound source noncontrolled rectifier	Synchronous machine voltage and current	A.11, A.14	no	ST2A
	Compound source controlled rectifier	Synchronous machine voltage and current	A.12, A.13 A.15, A.16	yes	ST3A

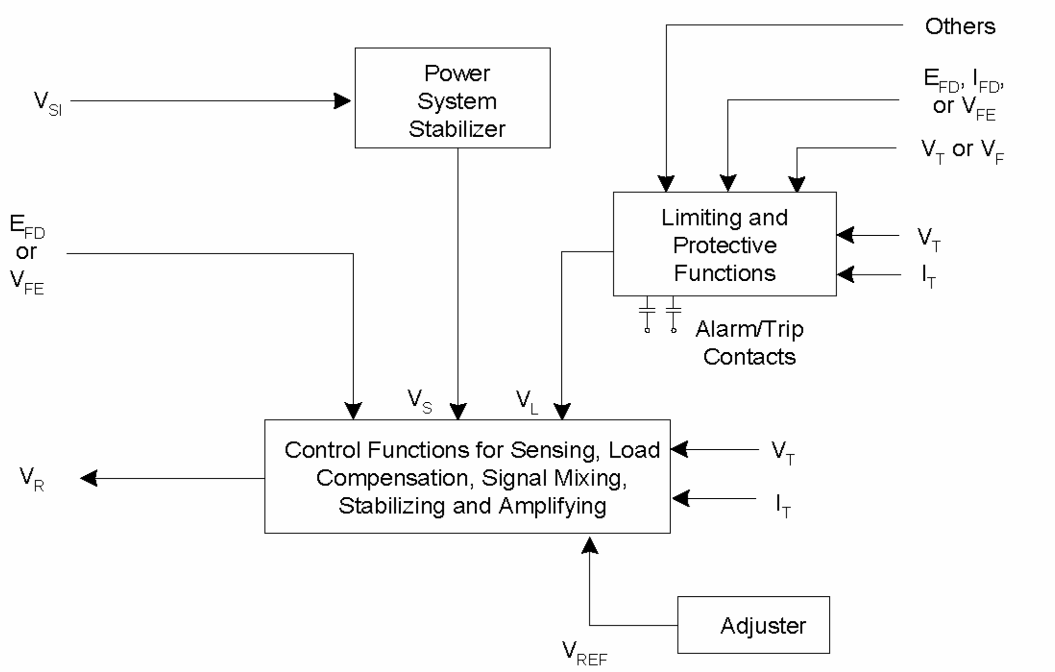

Figure A.1—Automatic control functions

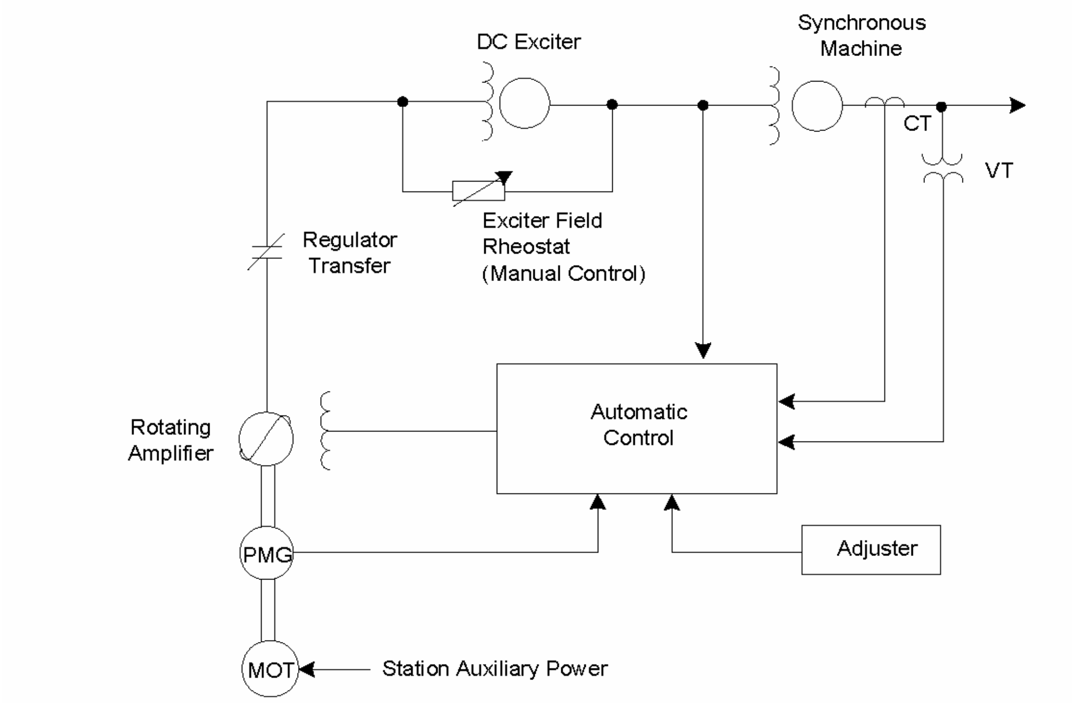

Figure A.2—DC generator-commutator exciter with rotating amplifier

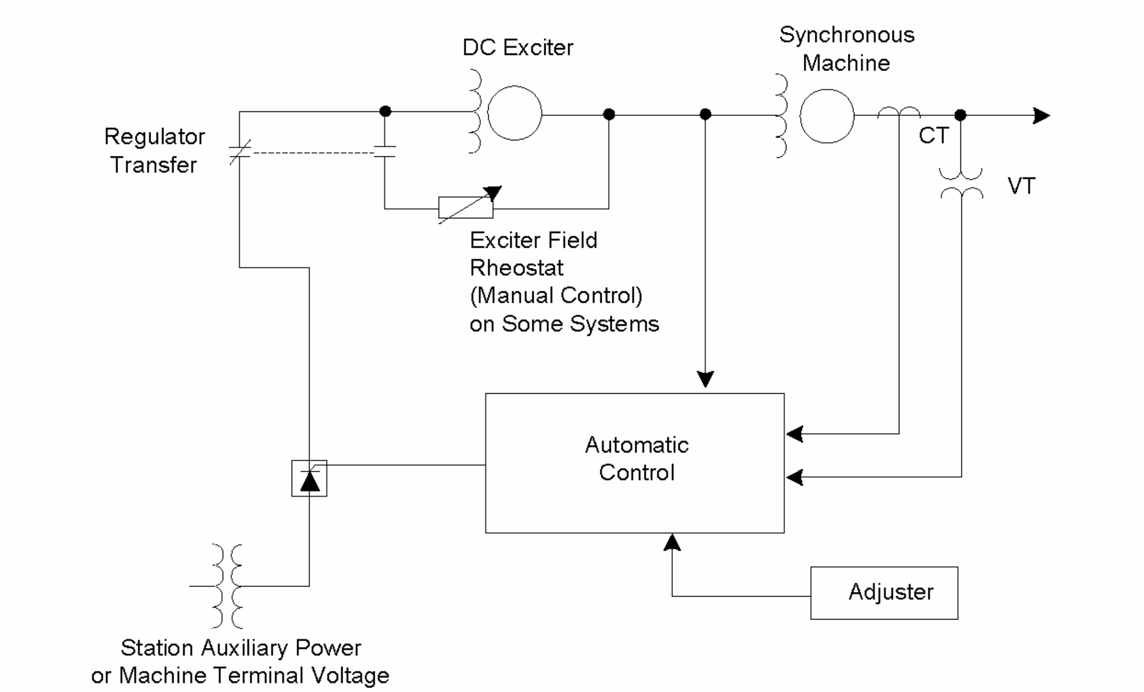

Figure A.3—DC generator-commutator exciter with static amplifier

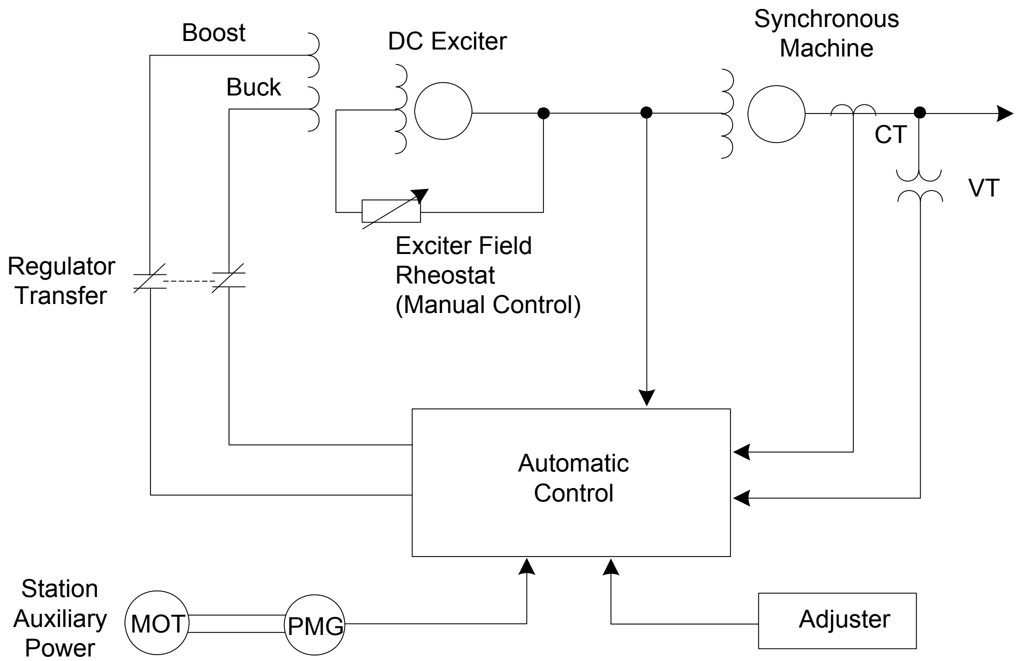

Figure A.4—DC generator-commutator exciter with continuously acting regulator employing static amplifiers

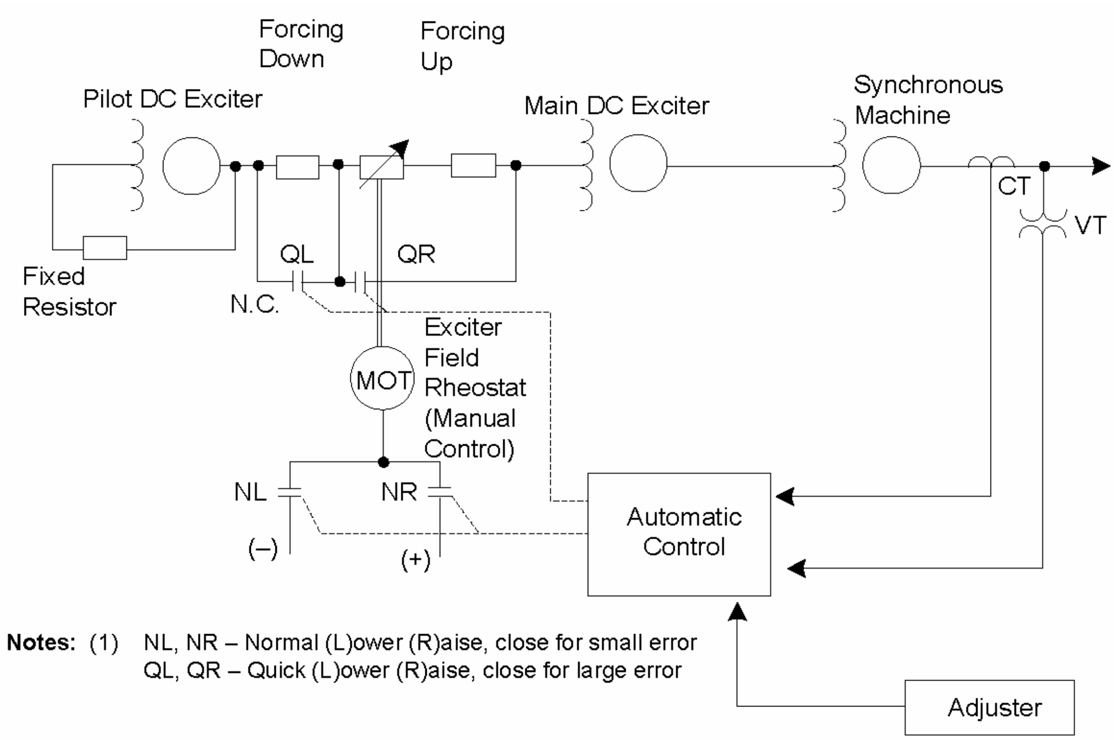

Figure A.5—DC generator-commutator exciter separately excited with noncontinuously acting rheostatic regulator

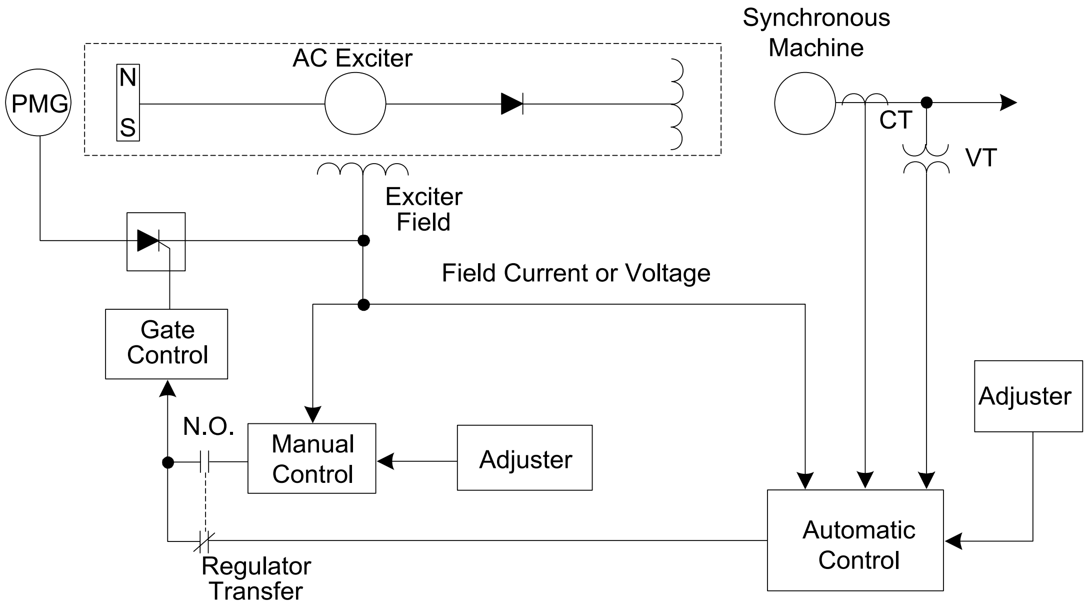

Figure A.6—Alternator-rectifier exciter employing rotating noncontrolled rectifiers (brushless exciter)

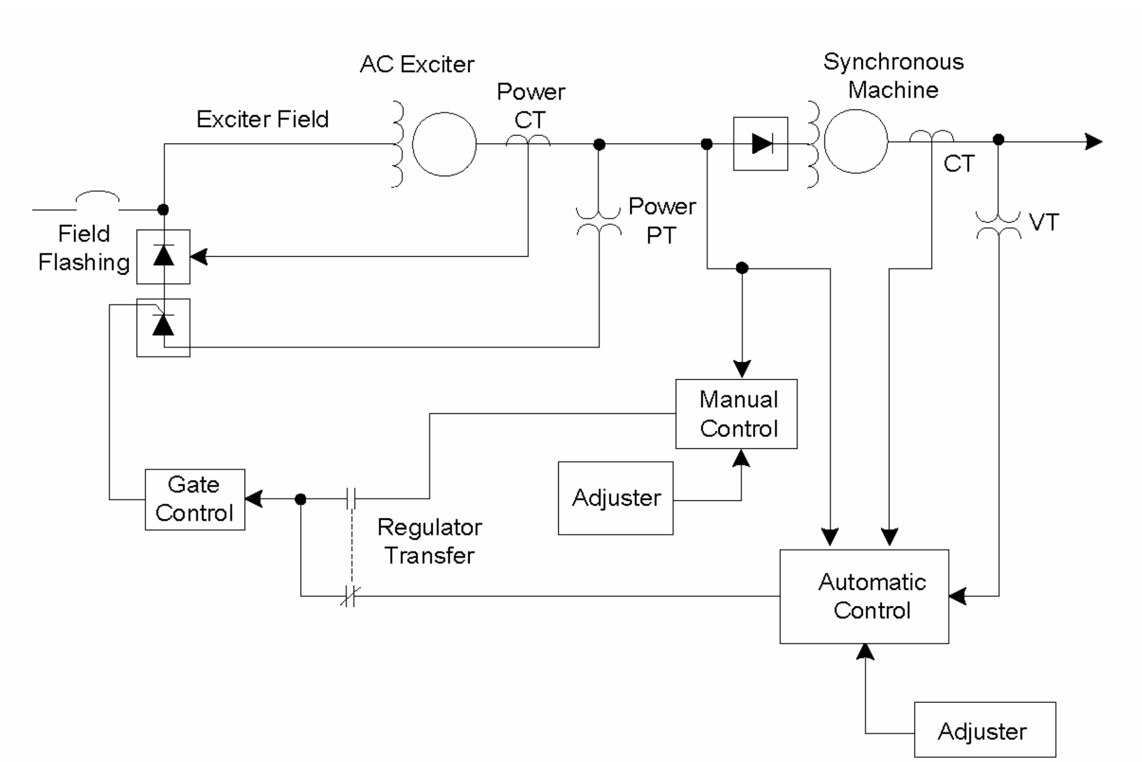

Figure A.7—Alternator-rectifier exciter employing stationary noncontrolled rectifiers

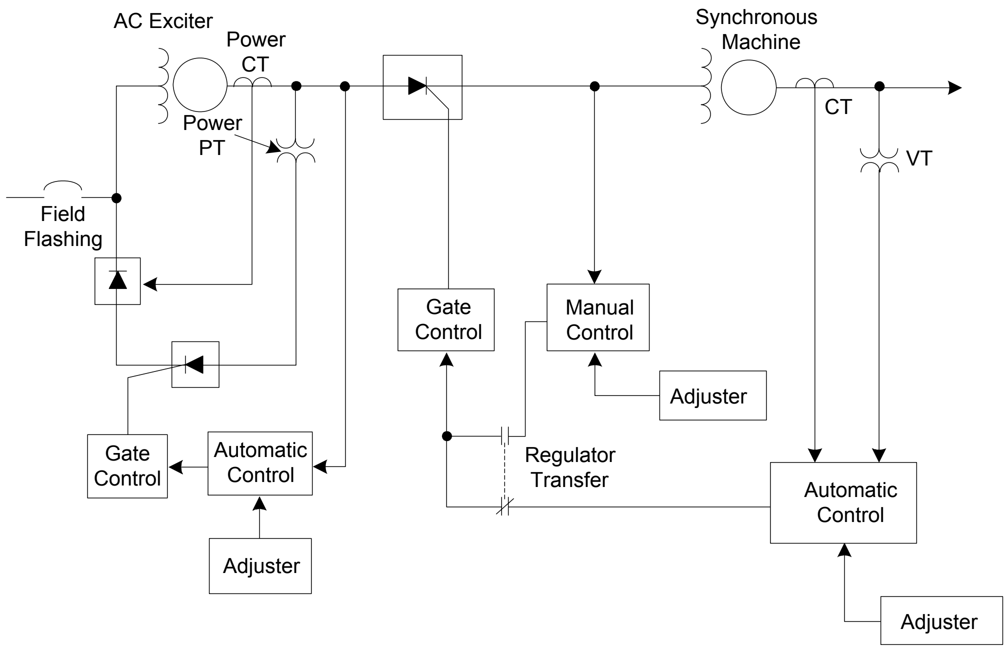

Figure A.8—Alternator-rectifier exciter employing controlled rectifiers

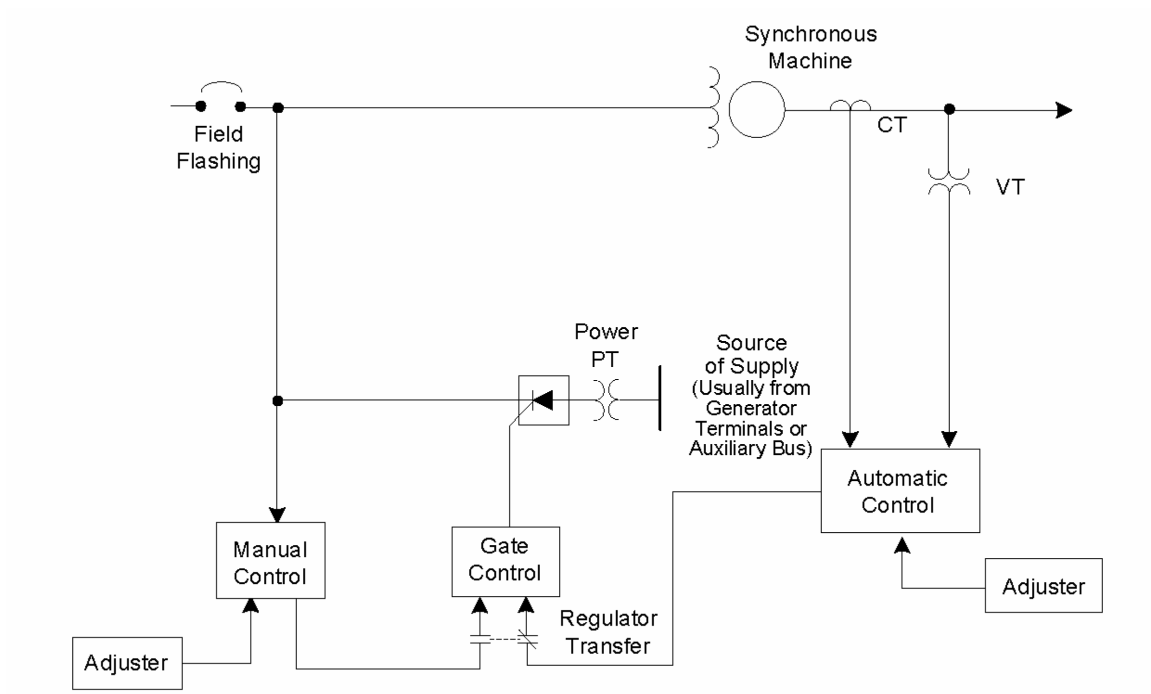

Figure A.9—Potential source-rectifier exciter employing controlled rectifiers

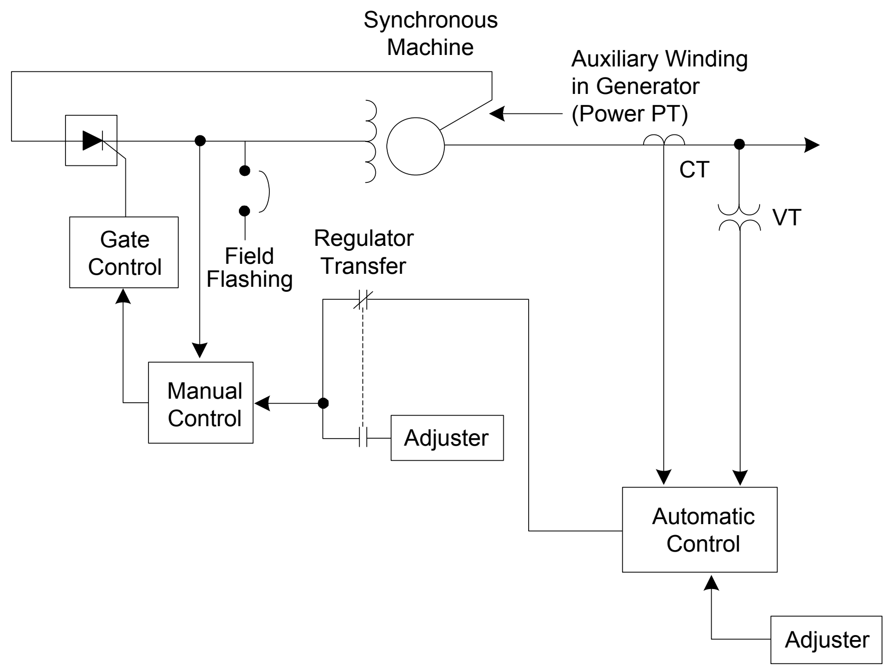

Figure A.10—Potential source rectifier exciter employing controlled rectifiers (with generator auxiliary power source)

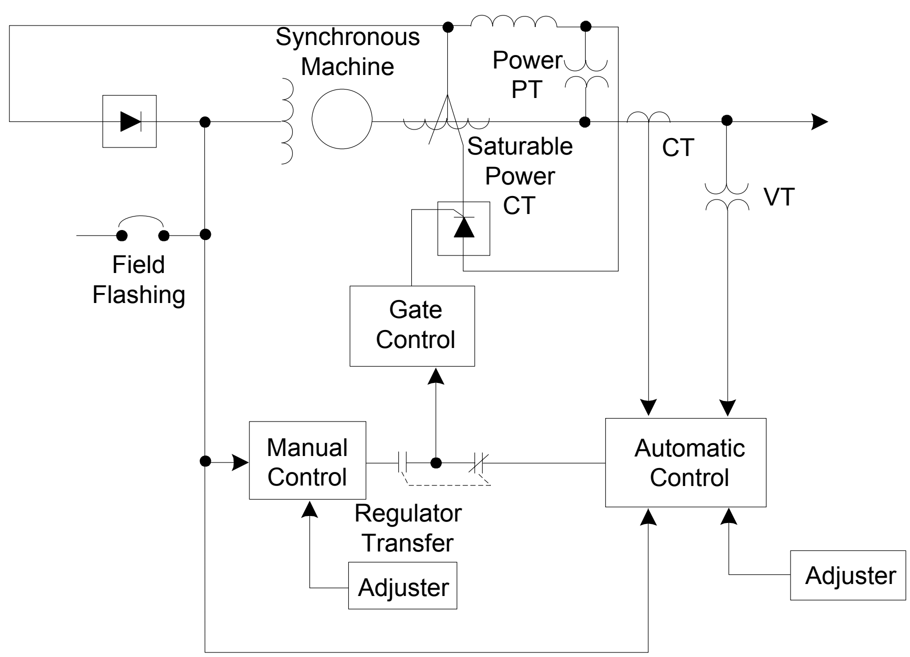

Figure A.11—Compund source-rectifier exciter employing noncontrolled rectifiers

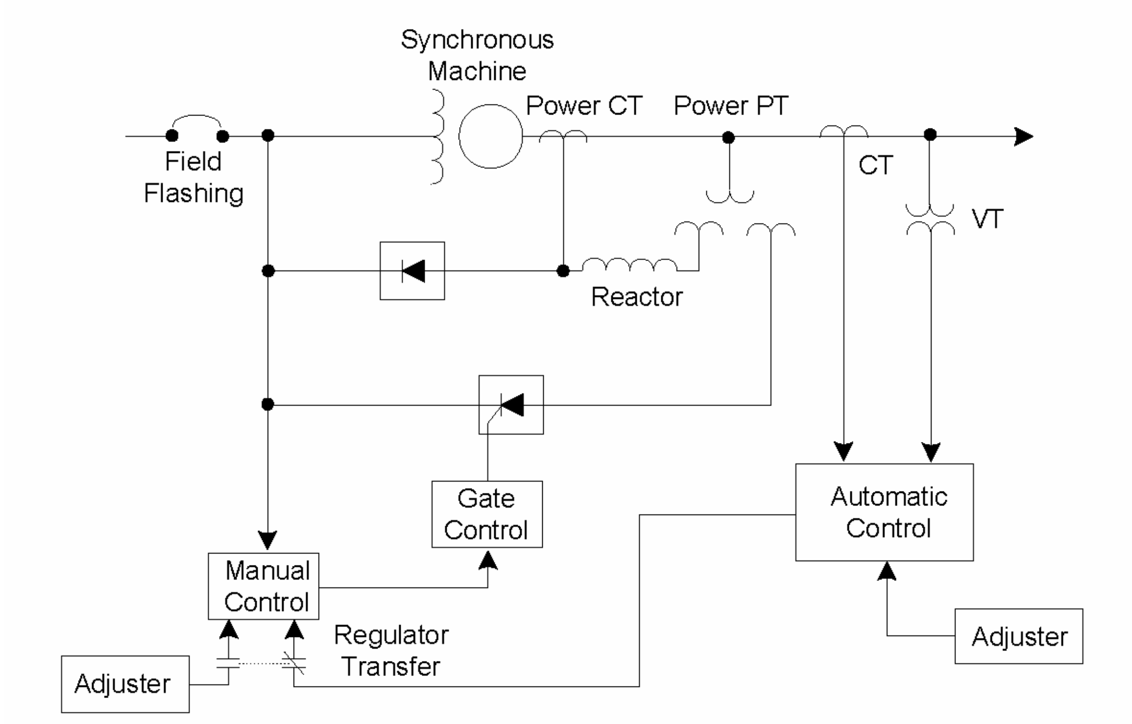

Figure A.12—Compund source-rectifier exciter employing controlled rectifiers

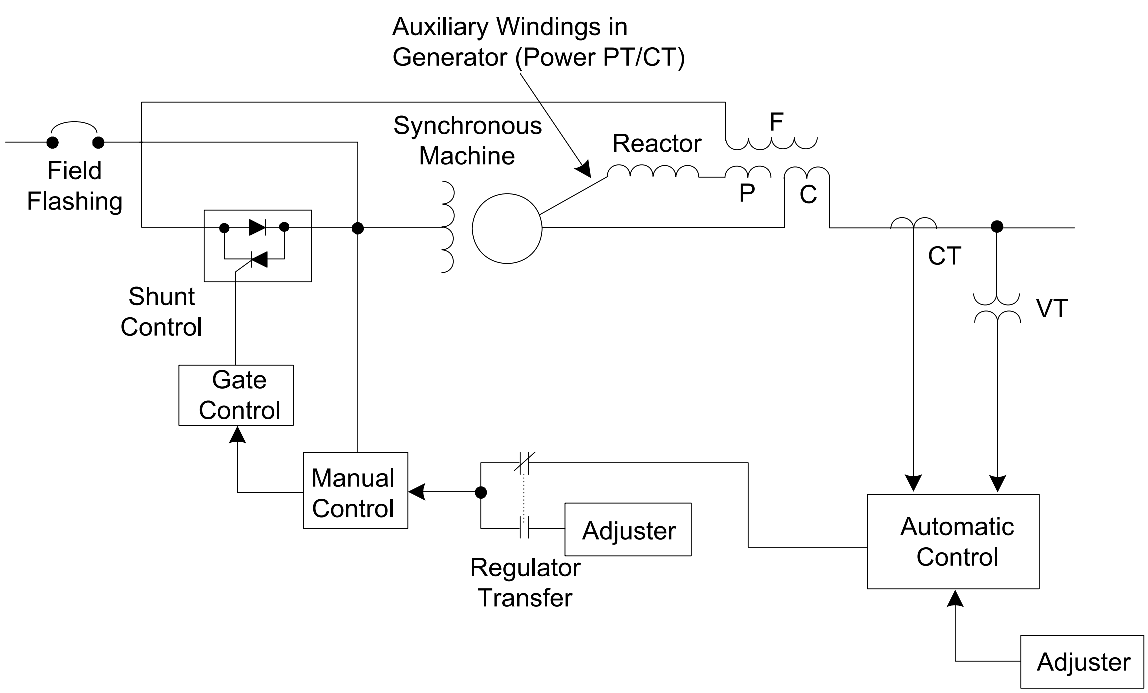

Figure A.13—Compound source-rectifier exciter employing shunt controlled rectifiers

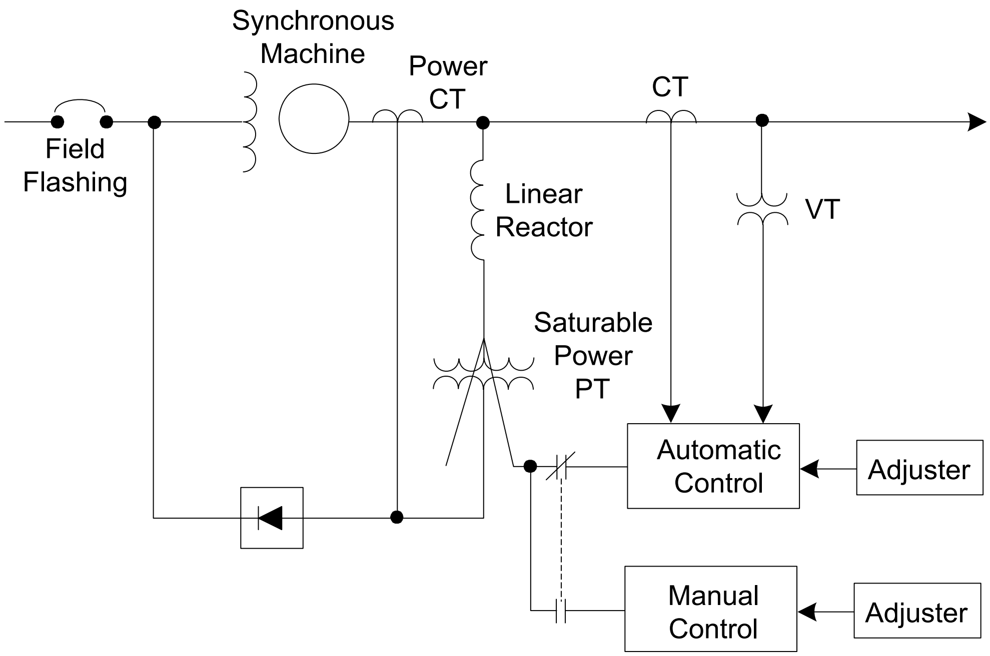

Figure A.14—Compound source-rectifier exciter employing noncontrolled rectifiers and saturable potential transformers

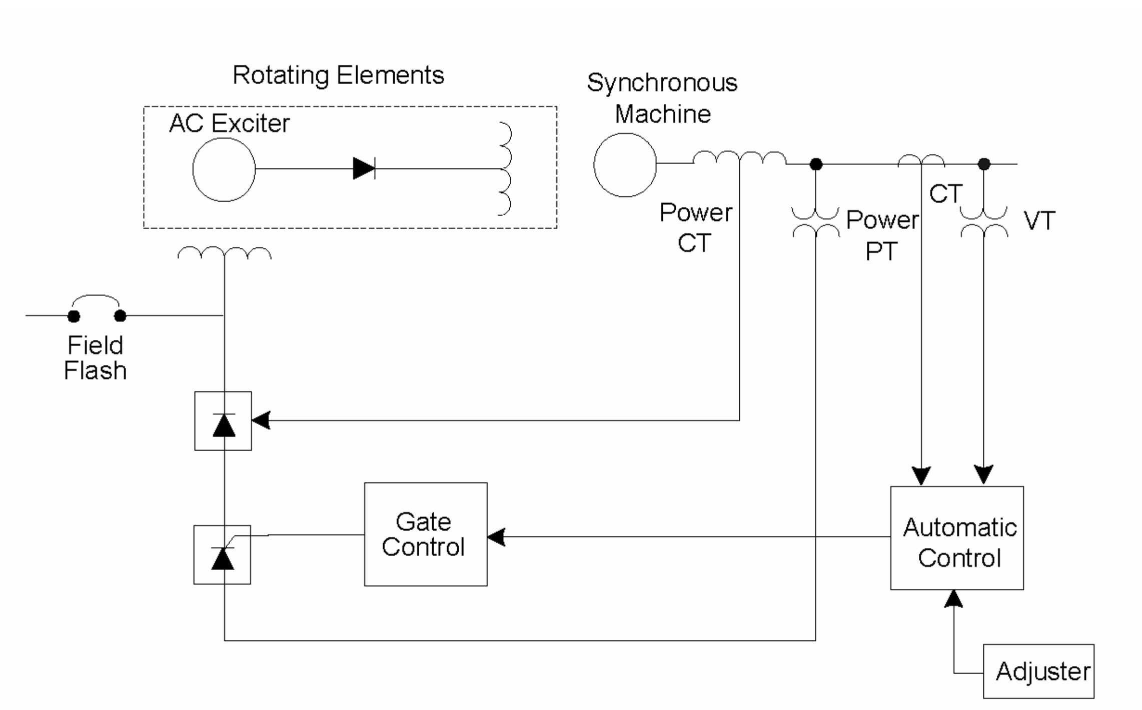

Figure A.15—Rotating exciter rectifier with current boost excitation system

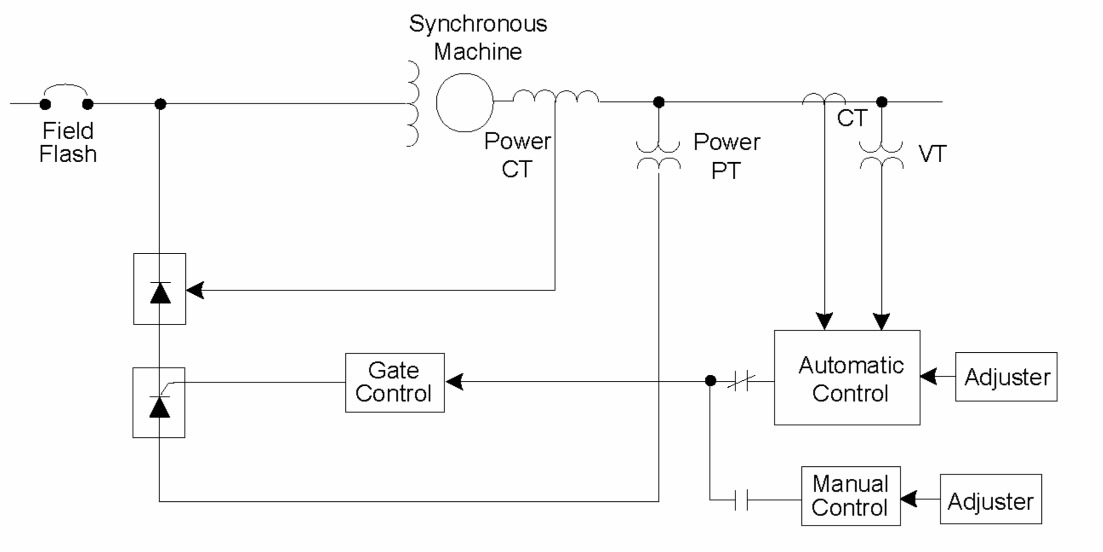

Figure A.16—Potential source exciter with current boost excitation system

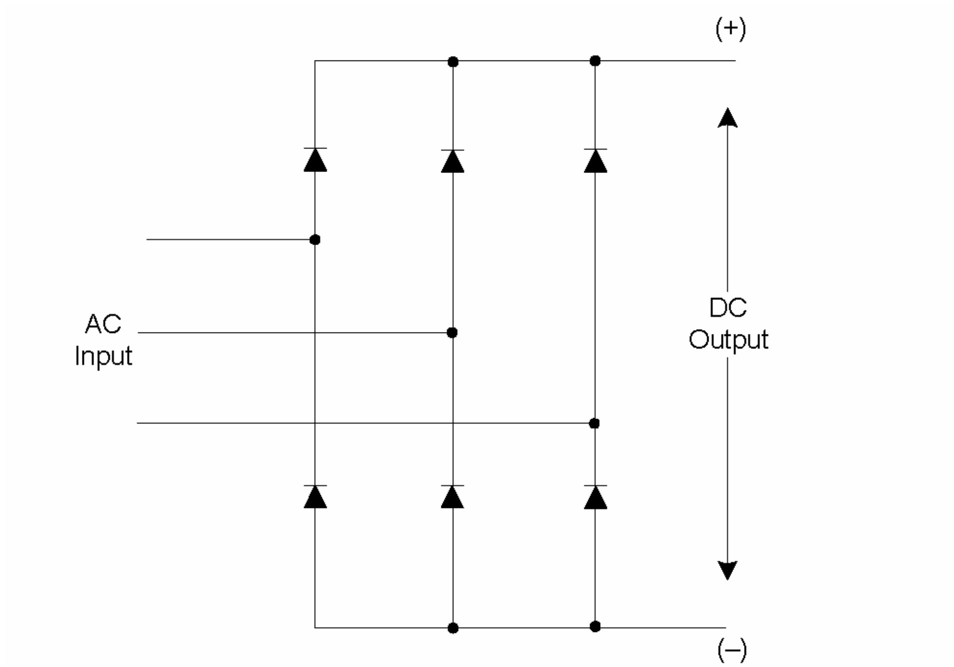

Figure A.17a—Three-phase full wave diode bridge (noncontrolled rectifier)

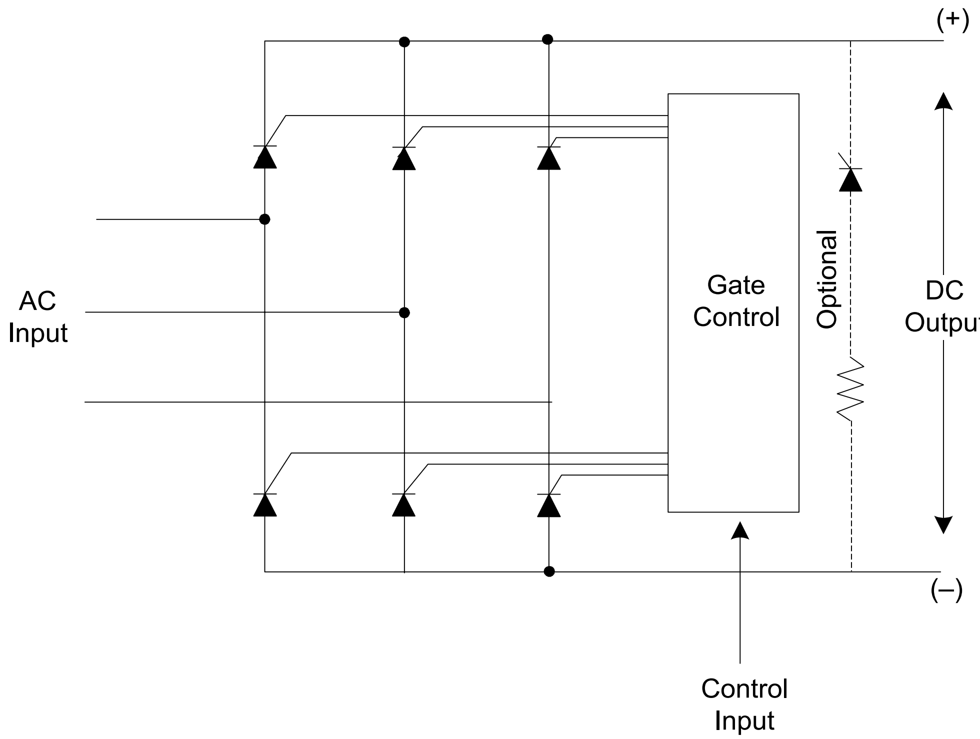

Figure A.17b—Three-phase full wave diode bridge (controlled rectifier)

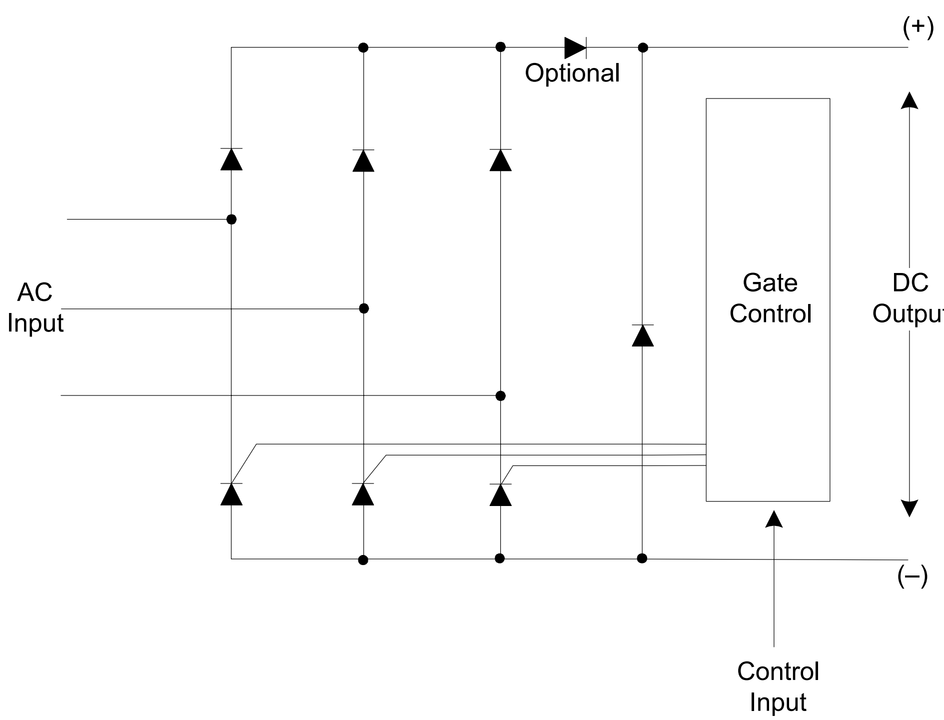

Figure A.17c—Three-phase full wave diode bridge (hybrid controlled rectifier)

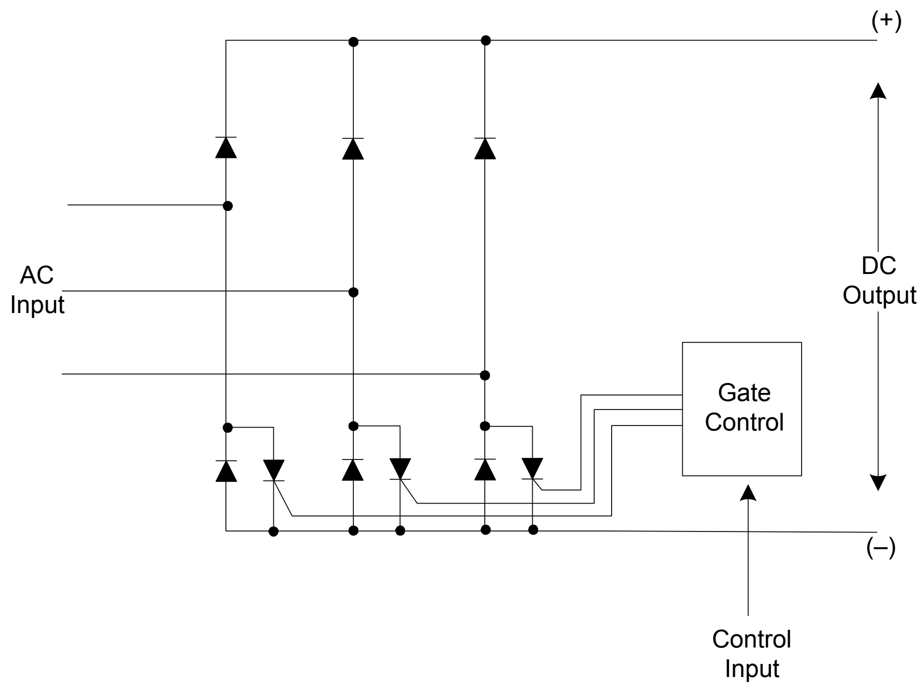

Figure A.17d—Three-phase full wave diode bridge (shunt controlled rectifier)

Annex B

(informative)

Bibliography

[B1] ANSI/IEEE C37.18-1979 (Reaff 1996), IEEE Standard Enclosed Field Discharge Circuit Breakers for Rotating Electric Machinery.

[B2] Barnes, H. C., Oliver, J. A., Rubenstein, A. S., and Temoshok, M., "Alternator-Rectifier Exciter for Cardinal Plant 724-MVA Generator," *IEEE Trans. Power App. Syst.*, vol. PAS-87, Apr. 1968, pp. 1189–1198.

[B3] Chambers, G. S., Rubenstein, A. S., and Temoshok, M., "Recent Developments in Amplidyne Regulator Excitation Systems for Large Generators," *AIEE Trans. Power App. Syst.*, vol. 80, 1961, pp. 1066–1072.

[B4] Cotzas, G. M., Crenshaw, M. L., and Richardson, G.L., "GENERREX-PPS (Potential Power Source) Excitation System for Wisconsin Power and Light," Edgewater 5, *Proceedings of the Forty-Third American Power Conference*, Apr. 1981.

[B5] Cotzas, G. M., Drexler, K. F., Dvorscak, J. J., and Gerlitz, R. L., "Descriptions and Tests of the GENERREX Excitation System for Large Steam Turbine-Generators," *IEEE Trans. Power App. Syst.*, vol. PAS-95, May/June 1976, pp. 803–810.

[B6] Digital Excitation Applications Task Force of the Excitation System Subcommittee, "Digital Excitation Technology—A Review of Features, Functions and Benefits," *IEEE Trans. Energy Convers.*, vol. 12, no. 3, Sept. 1997, pp. 255–258.

[B7] Digital Excitation Task Force of the Equipment Working Group, "Computer Models for Representation of Digital-Based Excitation Systems," *IEEE Trans. Energy Convers.*, vol. 11, no. 3, Sept. 1996, pp. 609–615.

[B8] Dillman, T. L., Keay, F. W., Raczkowsi, C., Skooglund, J. W., and South, W. H., "Brushless Excitation," *IEEE Spectrum*, Mar. 1972, pp. 58–66.

[B9] Domeratzky, L. M., Rubenstein, A. S., and Temoshok, M., "A Static Excitation System for Industrial and Utility Steam Turbine-Generators," *AIEE Trans. Power App. Syst.*, vol. 80, Feb. 1962, pp. 1072–1077.

[B10] Hurley, J. D, Bize, L. N., and Mummert, C. R., "The Adverse Effects of Excitation System Var and Power Factor Controllers," Paper PE-387-EC-0-12-1997.

[B11] IEEE 100, *The Authoritative Dictionary of IEEE Standards Terms*, *Seventh Edition*, New York, Institute of Electrical and Electronics Engineers, Inc.

[B12] IEEE Task Force on Excitation Limiters, "Recommended Models for Overexcitation Limiting Devices," *IEEE Trans. Energy Convers.*, vol. 10, no. 4, Dec. 1995, pp. 706–713.

[B13] IEEE Task Force on Excitation Limiters, "Underexcitation Limiter Models for Power System Stability Studies," *IEEE Trans. Energy Convers.*, vol. 10, no. 3, Sept. 1995, pp. 524–531.

[B14] IEEE Tutorial Course, "Power System Stabilization Via Excitation Control," 81-EHO 175-0 PWR.

[B15] IEEE Working Group of the Excitation Subcommittee, “Computer Representation of Excitation Systems,” *IEEE Trans. Power App. Syst.*, June 1968, pp. 1460–1464.

[B16] IEEE Working Group on Computer Modelling of Excitation Systems, “Excitation System Models for Power System Stability Studies,” *IEEE Trans. Power App. Syst.*, vol. PAS-100, no. 2, Feb. 1981, pp. 494–509.

[B17] Keay, F. W., and South, W. H., “A Solid-State Regulator for Electric Utility Applications,” *IEEE Trans. Power App. Syst.*, vol. PAS-90, no. 4, July/Aug. 1971, pp. 1527–1547.

[B18] Kundur, P., Klein, M., Rogers, G. J., and Zywno, M. S., “Application of Power System Stabilizers for Enhancement of Overall System Stability,” *IEEE Trans. Power Syst.,* vol. 4, no. 2, May 1989, pp. 614–626.

[B19] Lane, L. J., Rogers, D. F., and Vance, P. A “Design and Tests of a Static Excitation System for Industrial and Utility Steam Turbine-Generators,” *AIEE Trans. Power App. Syst.*, vol. 80, Feb. 1962, pp. 1077–1085.

[B20] Lee, C. H., and Keay, F. W., “A New Excitation System and a Method of Analyzing Voltage Response,” *1964 IEEE International Convention Record*, vol. 12, pt. 3, pp. 5–14.

[B21] Lee, D. C., Beaulieu, R. E., Service, J. R. R., “A Power System Stabilizer Using Speed and Electrical Power Inputs—Design and Field Experience,” *IEEE Trans. Power App. Syst.*, PAS-100, no. 9, Sept. 1981, pp. 4151–4157.

[B22] McClymont, K. R., Manchur, G., Ross, R. J., and Wilson, R. J., “Experience with High-Speed Rectifier Excitation Systems,” *IEEE Trans. Power App. Syst.*, vol. PAS-87, June 1968, pp. 1464–1470.

[B23] Murdoch, A., Owen, E. L., Sanchez-Gasca, J. J., D’Antonio, M. J., and Lawson, R. A., “Excitation Systems—The Use of var/pf Control—A System Stability Perspective,” IEEE Paper 99-WM-025.

[B24] Rubenstein, A. S., and Temoshok, M., “Underexcitation Reactive Ampere Limit for Modern Amplidyne Voltage Regulator,” *AIEE Trans. Power App. Syst.*, PAS-15, vol. 73, Dec. 1954, pp. 1433–1438.

[B25] Rubenstein, A. S., and Walkley, W. W., “Control of Reactive KVA with Modern Amplidyne Voltage Regulators,” *AIEE Trans. Power App. Syst.*, Dec. 1957.

[B26] Watson, W., and Manchur, G. S., “Experience with Supplementary Damping Signals for Generator Static Excitation Systems,” *IEEE Trans. Power App. Syst.*, Jan./Feb. 1973, pp. 199–203.

[B27] Whitney, E. C., Hoover, D. B., and Bobo, P. O., “An Electric Utility Brushless Excitation System” *AIEE Trans. Power App. Syst.*, vol. 78, 1959, pp. 1821–1824.

[B28] Woolridge, P. A. B., and Blythe, A. L., “Considerations Affecting the Design Philosophy of Solid-State Exciters,” *IEEE Trans. Power App. Syst.*, vol. PAS-87, May 1968, pp. 1288–1299.