



IEEE Standard Definitions for Excitation Systems for Synchronous Machines

STANDARDS

IEEE Power and Energy Society

Developed by the
Energy Development and Power Generation
Committee

IEEE Std 421.1™-2021
(Revision of IEEE Std 421.1-2007)



IEEE Standard Definitions for Excitation Systems for Synchronous Machines

Developed by the

Energy Development and Power Generation Committee
of the
IEEE Power and Energy Society

Approved 8 December 2021

IEEE SA Standards Board

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Abstract: Defined in this standard are elements and commonly used components in excitation systems. Also contained are 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, IEEE 421.1, synchronous generator controls

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Introduction

This introduction is not part of IEEE Std 421.1–2021, IEEE Standard for 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 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 *IEEE Standards Dictionary Online* but to clarify or more fully define terms as related specifically to excitation of synchronous machines.

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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

1.2 Purpose

This standard provides a common base for terminology in common usage related to excitation control systems. The definitions given in this standard assist in describing terms specifically related to excitation systems. With the advent of new excitation systems and changes in common terminology and usage, there are revisions required to keep this standard relevant.

1.3 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall* equals *is required to*).^{1,2}

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should* equals *is recommended that*).

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may* equals *is permitted to*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can* equals *is able to*).

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained) ~~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.

¹The use of the word *must* is deprecated and cannot be used when stating mandatory requirements, *must* is used only to describe unavoidable situations.

²The use of *will* is deprecated and cannot be used when stating mandatory requirements, *will* is only used in statements of fact.

IEEE Std 421.3TM, IEEE Standard for High-Potential Test Requirements for Excitation Systems for Synchronous Machines.^{3,4}

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

3. Definitions

For the purposes of this ~~document~~ ~~standard~~, the following terms and definitions apply. The ~~Authoritative Dictionary of IEEE Standards~~ ~~Dictionary Online~~ ~~Terms [B11]~~³ should be ~~consulted~~ ~~referenced~~ for terms not defined in this clause.⁵

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**.

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

adjuster: A device or function by which the setpoint is determined.

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.

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⁵~~IEEE Standards Dictionary Online is available at: http:// dictionary.ieee .org. An IEEE account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.~~

²~~The numbers in brackets correspond to those of the bibliography in Annex B.~~

NOTE—This defines one per unit excitation system voltage for use in computer representation of excitation systems.⁶⁴

air-gap line: The extended straight line part of the no-load saturation curve of the synchronous machine, [which neglects magnetic saturation and remanent flux](#).

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.

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.

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**.

autotracking: A function that causes the output of a control channel in the standby mode to follow the action of an active control channel [to facilitate bumpless transfer under steady state conditions](#); for example, autotracking of the manual control to follow the automatic control. Also called a follower. *See also:* [bumpless transfer and null balance](#).

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

⁶⁴ Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

NOTE—See Figure A.10.

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.

bumpless transfer: A transfer between two control modes that results in negligible change in synchronous machine output [under steady state conditions](#). *See also:* **null balance** and [autotracking](#).

ceiling current: The maximum field current that the excitation system is designed to supply [or permitted to supply by limiting action](#). Typically, this is related to the thermal capability of the excitation system equipment or the synchronous machine field circuit capability. *See also:* **overexcitation limiter**.

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

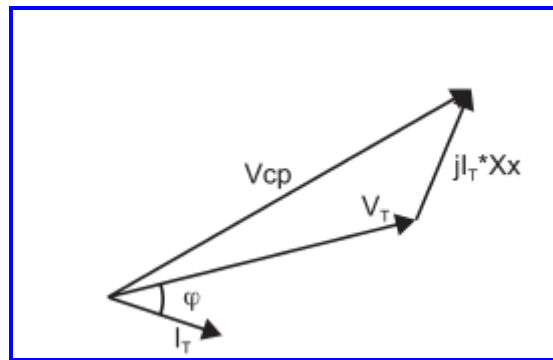
NOTE 1—The no-load ceiling voltage is determined with the excitation system supplying minimal current.

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.

compensated frequency: An approximated angular speed variation signal used for the formation of the speed input signal in some power systems stabilizers. The compensated frequency signal is an approximation of the synchronous generator air-gap voltage frequency that is proportional to the rotor angular speed deviation. The compensated frequency is obtained by calculating frequency of the phasor $V_{cp} = V_T + jI_T * X_x$ as shown in Figure 1:



(New)

Figure 1— Vcp phasor used for compensated frequency calculations

X_x is typically adjustable and should be related to the effective quadrature reactance applicable for the frequency range of the oscillations. Refer to IEEE Std 1110 [B13].

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.

control error: Difference between the setpoint and the controlled variable. There is a separate control error for each closed-loop mode, such as a voltage control error when operating in AVR.

crowbar: In excitation system usage, a circuit designed to limit the maximum field voltage by providing a low impedance ~~provide a conduction~~ path for the 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.~~

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.

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 rectifiers that may be either noncontrolled ~~rectifiers~~ or controlled, including ~~rectifiers, with~~ gate circuitry. It is exclusive of input control elements.

NOTE—See Figure A. ~~15~~ 14 and Figure A. ~~16~~ 15.

~~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.

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

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.

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

de-excitation: The process ~~removal~~ of removing the excitation and discharging the field ~~discharge~~ of the synchronous machine, main exciter, or pilot exciter.

NOTE—See IEEE Std 421.6™ [B12].

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

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 [Digital Excitation Technology—A Review of Features, Functions and Benefits \[B5 B6\]](#).

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.

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.

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 [2 1](#).

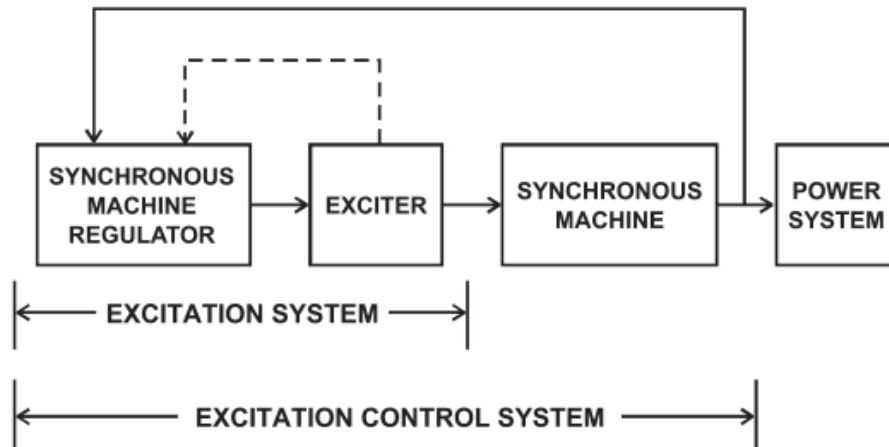


Figure 2—Block diagram of excitation control system

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

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.

excitation system negative ceiling voltage V_n : Most negative (direct) voltage, if any, which the excitation system is able to provide from its terminals under defined conditions. See also: **ceiling voltage.**

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 32.

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.

[NOTE 8—The nominal response was also referred to as response ratio.](#)

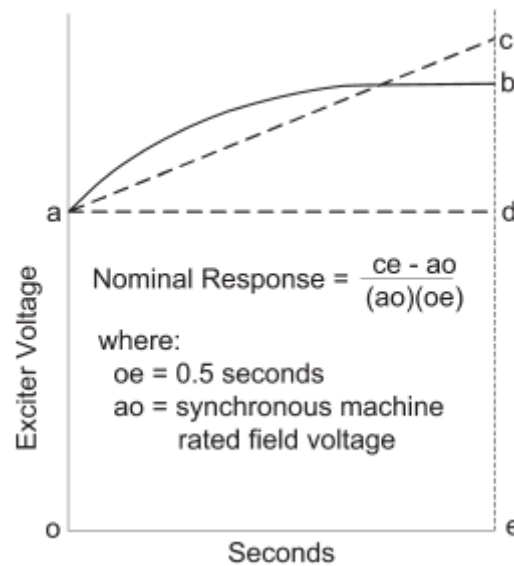


Figure 3—Excitation system nominal response

excitation system on-load negative ceiling voltage V_{nL} : Most negative (direct) voltage, if any, which the excitation system is able to provide at initial current equal to rated field current at rated conditions of the synchronous machine. *See also: ceiling voltage.*

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.

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).