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IEEE Guide for the Preparation of Excitation System Specifications

IEEE Power Engineering Society

Sponsored by the
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IEEE Guide for the Preparation of Excitation System Specifications

Sponsor

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

Approved 24 June 2004

IEEE-SA Standards Board

Abstract: This guide is intended to provide to the specification writer the information to prepare a specification for the purchase of an excitation system. This guide is presented in narrative form with descriptions of functions typical of excitation systems. Narrative is provided describing types of excitation systems and information required for sizing the excitation system.

Keywords: communications, compound exciters, digital, excitation guide, exciter types, potential, integral, derivative (PID), potential source exciters, power system stabilizers, redundant controllers, rotating exciters

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Introduction

(This introduction is not part of IEEE Std 421.4-2004, IEEE Guide for the Preparation of Excitation System Specifications.)

This guide is intended as resource material for writers preparing a specification for procurement of an excitation system for a synchronous machine. It is intended that IEEE Std 421.1TM-1986, IEEE Std 421.2TM-1990, IEEE Std 421.3TM-1997, and IEEE Std 421.5TM-1992 be used in conjunction with this guide in preparing the specification. This guide is not intended to be a fill-in-the-blanks guide but a narrative description of items and functions that should be considered in preparing excitation system specifications. Some of the information presented in this guide may be unnecessary for the writer's particular specification. One should judge the applicability of information to be included in the writer's specification and remove all inapplicable portions. Some tutorial material is included for the user who may be relatively inexperienced in selecting parameters and requirements for each particular application.

It should also be noted that this document defines an excitation control system as one that includes the synchronous machine. The definition is included here for clarity as the term is not defined in IEEE Std 421.1-1986; however, it is included in IEEE 100, *The Authoritative Dictionary of IEEE Standards Terms*, Seventh Edition.

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IEEE Guide for the Preparation of Excitation System Specifications

1. Overview

This guide is intended to provide to the specification writer the necessary material for preparing a specification for the procurement of an excitation system for a synchronous machine. The information presented in this guide is given in narrative form with the descriptions and functions of particular items that should be examined in preparing the specifications. Some information presented in this guide may be inapplicable for a specific excitation system application, and it may be omitted in the writer's specification.

The term *excitation control system* is used throughout this guide. An excitation control system is a feedback control system that includes the synchronous machine and its excitation system. Figure 1 contains a block diagram of an excitation control system. An excitation system is the equipment providing field current for a synchronous machine, including all power, regulating, control, and protective elements. An exciter is the equipment that provides the field current for the excitation of a synchronous machine. A synchronous machine regulator couples the output variables of the synchronous machine to the input of the exciter through feedback and forward controlling elements for the purpose of regulating the synchronous machine output variables (see IEEE Std 421.1TM-1986).¹ The influence of the power system upon the operation of the excitation control system must be considered when the synchronous machine is connected to the utility grid.

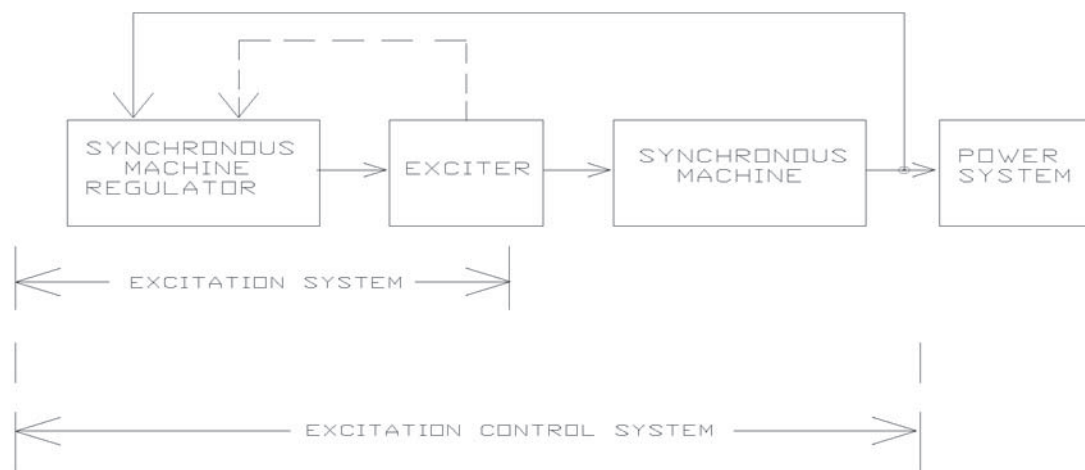


Figure 1—Block diagram of the components of an excitation control system

¹Information on references can be found in Clause 2.

2. References

This guide shall be used in conjunction with the following publications. When the following specifications are superseded by an approved revision, the revision shall apply.

ANSI C50.12-1982 (Reaff 1989), American Standard Requirements for Salient-Pole Synchronous Generators and Generators/Motors for Hydraulic Turbine Applications.²

ANSI C50.13-1989, American Standard Requirements for Cylindrical-Rotor Synchronous Generators.

IEEE Std 421.1-1986, IEEE Standard Definitions for Excitation Systems for Synchronous Machines.^{3, 4}

IEEE Std 421.2TM-1990, IEEE Guide for Identification, Testing, and Evaluation of the Dynamic Performance of Excitation Control Systems.

IEEE Std 421.3TM-1997, IEEE Standard for High-Potential Test Requirements for Excitation Systems for Synchronous Machines.

IEEE Std 421.5TM-1992, IEEE Recommended Practice for Excitation System Models for Power System Stability Studies.

IEEE Std C37.18TM-1979 (Reaff 2003), IEEE Standard Enclosed Field Discharge Circuit Breakers for Rotating Electric Machinery.

IEEE Std C57.12.00TM-2000, IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers.

IEEE Std C57.12.91TM-2001, IEEE Standard Test Code for Dry-Type Distribution and Power Transformers.

3. Definitions

For the purposes of this guide, the following terms and definitions apply. *The Authoritative Dictionary of IEEE Standards Terms*, Seventh Edition, should be referenced for terms not defined in this clause.

3.1 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 automatic voltage regulator (AVR) control function would be expected to be implemented digitally in such a system. It is likely that the limiter functions and optional var/power factor (pf) or power system stabilizer (PSS) controls are also implemented in the same digital-based control.

3.2 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.

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

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⁴IEEE publications are available from the Institute of Electrical and Electronics Engineers, Inc., 445 Hoes Lane, Piscataway, NJ 08854, USA (<http://standards.ieee.org/>).

3.4 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.

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

3.6 line drop compensator: A function that modifies the machine terminal voltage to compensate for the impedance drop to a fixed point in the external network.

3.7 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, and so on, or a combination of these signals.⁵

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

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

3.10 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.

3.11 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 kilovoltampere and power factor.

4. Introduction

This guide applies to excitation systems using rotating and static exciters. In many cases, equipment maintenance, associated with the older excitation systems, and obsolescence of parts may make maintainability cumbersome and involved. Today, many older excitation systems such as rotating or pilot exciter type are being replaced with new solid state excitation systems to improve or simplify the operation and control of the synchronous machine. New excitation systems can enhance the performance of the synchronous machine by eliminating deadbands and delays inherent in older type excitation systems.

4.1 Basics

The primary function of an excitation system is to provide the field current required by a synchronous machine to meet a specified range of power system operating conditions. In addition to fulfilling this requirement, there are a number of other factors that should be considered when writing specifications for an excitation system. Power system stability studies have been found to be useful in identifying dynamic performance requirements. These performance evaluations help establish the required response characteristics and may identify the need for other control functions, e.g., a power system stabilizer. Modern excitation systems may include various auxiliary control elements and protective devices in addition to a

⁵Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the guide.

basic voltage regulator. The specification should functionally identify all auxiliary excitation control equipment (compensators, limiters, power system stabilizers, etc.) and protective equipment (volts/Hertz protection, overexcitation protection, etc.), which are to be included in the excitation system.

The specification should include items relevant to the excitation system design even though they do not directly affect the performance of the voltage regulation task. To assist the manufacturer in identifying applicable standards and possible design constraints, a description of the type of installation should be included, i.e., nuclear, fossil fueled, hydro turbine, and so on.

4.2 Operating models

An important consideration in the design of an excitation system is the identification of the operating mode or modes of the plant. The specification should clearly state all possible modes of operation, i.e., generation, pumped storage, synchronous condenser, and so on. The most severe duty cycle expected for each possible mode should be provided. In addition, the specification should indicate any requirements for unattended operation, i.e., automatic startup, remote operation, and so on.

4.3 Installation

The specification for an excitation system should clearly state whether the excitation control equipment is to be used as an outdoor or as an indoor installation. Special storage requirements for the system before installation should be included in the specification, as well as special handling and shipping instructions. If there is a preferred method of shipping, it should be stated in addition to all known minimum clearances and maximum weight limitations. In addition, the specifications should state the capacity and availability of cranes at the installation site.

4.4 Conventions

The specification for an excitation system should reference any desired conventions and applicable standards for the system. It should include copies of all local laws and codes that apply to the design, construction, and installation. Any desired units of measurement should be stated, and the appropriate language, appropriate standard and form of media information (drawings, manuals, etc.) as stipulated in Clause 11 should be provided. The specification may also define to what extent, if any, the excitation system should contain design, assembly, subsystems, parts, labor, and so on, of domestic origin.

4.5 Insulation systems

The specification for a rotating excitation system should specify an insulation system that meets Class B, Class F, or Class H systems defined in ANSI C50.12-1982 and ANSI C50.13-1989. Withstand of the dielectric tests in IEEE Std 421.3-1997 should be included.

4.6 Diodes and thyristors

For diodes and thyristors, a voltage rating equal to a multiple (not necessarily integer) of rated root mean square (rms) input voltage should be specified, e.g., three times the rms input voltage to the rectifier bridge. In critical applications, devices in series, each with a full withstand rating, may be specified.

4.7 Availability

Availability is defined to be the fraction of time that a system is available for service. It can be found by taking the ratio of the time the system is available for service to the total time. The reliability and maintainability of the excitation system should be compatible with the required reliability and service of the unit. Some units require maximum availability. In such applications, the use of redundant elements should be considered. In extremely critical applications, the specification writer may wish to establish associated excitation system requirements such as *mean time to repair* (MTTR), *mean time between failures* (MTBF), and *mean time to failure* (MTTF). If that unit or plant has more scheduling flexibility, the consequences of a failure and its associated cost may not justify the establishment and specification of MTTR, MTBF, and MTTF.

4.8 Redundancy of equipment

In systems where reserves of machine/system capacity is available and machine startup cost is low, the failure of an excitation device and lost generation may not compromise the required generation needed to support the system load. For these systems, repair can often be made in a timely fashion to return the machine back to operation without the complexity and cost of redundant excitation equipment. In other cases, the loss of generation capacity or other economic factors may be significant. The need for equipment redundancy is often associated with minimum downtime requirement and the critical importance of the generation for the system load. Varying degrees of redundancy in the excitation system are often available.

Some of the approaches used to increase the security of online generation in the event of a problem involving the excitation system are described in 4.8.1–4.8.6.

4.8.1 Manual control as a backup

Today, manual control is used as a commissioning tool to assist startup of the excitation system or a means to maintain excitation in the event of loss of a fuse in the instrument transformers used for voltage regulator sensing. This feature is a standard function in most excitation systems. Where backup is required, it is best to use redundant excitation controllers, which includes the voltage regulator. See 4.8.2.

Manual control provides the means to maintain excitation to the field of the generator as an alternative control to the automatic voltage regulator. Transfer to manual is performed either automatically or manually.

In some systems, a transfer to manual control automatically occurs in the event of a system abnormality such as a blown fuse in the instrument transformer circuit to the voltage regulator. Protective functions may be used to monitor the operating parameters of the system to determine the transfer. Where automatic transfer to manual is used, a tracking scheme is recommended if bumpless transfer is required.

4.8.2 Redundant automatic voltage regulator

A redundant voltage regulator provides the means to maintain voltage regulation of the generator in the event of an internal voltage regulator component failure. Redundancy can be in the form of a standby voltage regulator monitoring the primary voltage regulator. If a detectable failure occurs, a transfer to the standby voltage regulator results.

In some systems, the redundant voltage regulator can be continuously operating. When a detectable failure occurs with one of the operating voltage regulators, the defective unit will be tripped by a monitoring system used to determine which voltage regulator is defective. The redundant voltage regulator system may include, for example, manual control, under/overexcitation limiting, and a power system stabilizer.

Isolating hardware may be specified in some applications to provide a means to repair the defective components while the excitation system remains in service.

4.8.3 Power rectifier bridge redundancy

A fault in a power rectifier bridge may result in a loss of capability and possible overload of the excitation power components. Two approaches are commonly used to maintain online operation:

- a) Two separate bridges with transfer to the redundant bridge. Redundant coolers should also be considered to ensure adequate cooling.
- b) Three or more parallel rectifier bridges of which at least one is redundant. Redundant coolers should also be considered to ensure adequate cooling.

4.8.4 Online maintenance of power rectifier bridge

Online maintenance for redundant power rectifiers may further increase availability of the system. This feature allows trained electrical technicians to physically isolate the defective rectifier bridge and repair the excitation system while the unit continues to operate.

4.8.5 Redundant static excitation systems

Another type of exciter redundancy is a fully redundant static excitation system consisting of a complete duplication of the electronic control circuits, including limiters, transducers, and power system stabilizers as required, as well as two sets of voltage transformers (VTs) and current transformers (CTs). The control electronics are duplicated all the way to the firing pulse generation circuits for the static bridges. Sensing circuits cause a transfer at the firing pulse output for failures in any part of the controlling channel. The following schemes have been used to implement redundant static excitation systems:

- a) Two or more thyristor bridges where any one or more may be faulty at any time and still allow continuous rated field current output. There is only one exciter power transformer.
- b) Two complete static exciters with forced current sharing where either of which may be faulty at any time while allowing continuous rated field current output. The two static exciters are fed from separate power transformers, which in turn are fed from separate buses, for complete redundancy.

4.8.6 Other redundant features

More complex excitation systems may incorporate multiple features in the redundant scheme. Some of these features may include

- a) Firing circuit.
- b) Power supplies.
- c) Input devices (VTs, CTs).
- d) Sensing (measuring devices).
- e) Communication ports.
- f) Power rectifier bridge (see 5.2).
- g) Triple modular redundant (2 of 3 voting). The user should specify which parts of the excitation system must be capable of being isolated, disconnected, and repaired while the system is operating.

4.9 Spare parts

An adequate number of spare parts should be kept in stock to support the expected availability. Prospective suppliers may be contacted for recommendations prior to writing of the specifications. The inclusion of spare parts in the bidding process needs special attention so that all bidders will be evaluated consistently.

5. Exciter rating considerations

5.1 General

All parameters that affect the rating of the excitation system should be coordinated and unambiguously specified, because the rating determines the cost of the major components. The writer is cautioned to specify a rating only once and avoid having conflicting information in other clauses of the specification. Some parameters refer to steady-state operation and others to transient operation. When the excitation system and synchronous machine are ordered at the same time from the same manufacturer, many of the design parameters are automatically coordinated and need not be specified in as much detail as when equipment is ordered from different suppliers.

5.2 Steady-state ratings

5.2.1 Rated current

The continuous current rating should be specified to equal or exceed the maximum required by the synchronous machine field under any allowed continuous operating conditions. Note that some machines have a continuous overload rating. In addition, ANSI C50.12-1982, and ANSI C50.13-1989, allow all machines to operate at rated megavolt ampere and within $\pm 5\%$ of rated terminal voltage. Some machines may require an even wider operating range. The need for off-nominal frequency operation, especially in hydro, should also be considered in establishing the rating. Some machines, such as combustion-turbine-drive units, have a variable rating depending on ambient air temperature. The excitation system for these machines may require a variable rating based on ambient air temperature.

Some excitation systems may require a small continuous negative current rating when the machine is operated as a synchronous condenser. The negative field current allows a slightly greater transmission line charging capability. The negative current was relatively easily supplied from commutator-type exciters, with little additional complexity. Exciters employing solid-state rectifiers do not normally have inherent capability for negative currents, but they can be obtained with some complexity. Most static excitation systems can develop a transient negative voltage to force the decay of field current toward zero. This process should not be confused with the concept of a continuous negative current rating, which is previously mentioned.

For exciters that are specified with redundant current paths or cooling elements, the continuous rating should apply with the redundant parts out of service. The exciter efficiency and losses should be measured at the rated current and voltage point with all redundant parts in service because this is the normal operating mode.

5.2.2 Rated continuous voltage

The continuous voltage rating of an excitation system should be such that the voltage is sufficient to supply the necessary continuous current to the synchronous machine field, with the field at its maximum temperature under rated load conditions. In addition, the continuous voltage capability should allow operation of the synchronous machine at rated MVA and within $\pm 5\%$ of rated terminal voltage unless otherwise specified. In determining the required voltage for the continuous as well as the transient ratings mentioned later, all voltage drops up to the field winding terminals should be considered. Any brush drop voltage should be considered part of the synchronous machine field circuit.