IEEE Guide for the Preparation of Excitation System Specifications

Sponsor

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Abstract: IEEE Std 421.4-1990, IEEE Guide for the Preparation of Excitation System Specifications, is intended to be a narrative description of items and functions that should be considered in the preparation of excitation system specifications. This guide applies to excitation systems for synchronous machines rated at 5000 kVA or larger.

Keywords: Excitation control systems, excitation system specifications, exciter, synchronous machine regulators, synchronous machines

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Foreword

(This Foreword is not a part of IEEE Std 421.4-1990, IEEE Guide for the Preparation of Excitation System Specifications.)

This guide is intended as resource material for specification writers preparing a specification for procurement of an excitation system for a synchronous machine. It is intended that IEEE Std 421.1-1986, IEEE Standard Definitions for Excitation Systems for Synchronous Machines;, IEEE Std 421.2-1990, IEEE Guide for Identification, Testing, and Evaluation of the Dynamic Performance of Excitation Control Systems; and IEEE Std 421B-1979, IEEE Standard for High-Potential Test Requirements for Excitation Systems, 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 rather is intended to be a narrative description of items and functions that should be considered in preparing excitation system specifications. Much of the information presented in this guide may be unnecessary for the writer’s particular specification. The writers should judge for themselves the applicability of information to be included in their specifications, and remove all inapplicable portions. Some tutorial material is included for the specification writer who may be relatively inexperienced in selecting parameters and requirements for each particular application.

It should be noted that although this guide is recommended for application to machines of 5000 kVA and above, there may be applications where the detailed requirements as proposed by this guide may be useful for smaller machines. 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 Std 100-1988, IEEE Standard Dictionary of Electrical and Electronics Terms.

This is a new guide. Suggestions for its improvement are welcomed. They should be sent to the Secretary, IEEE Standards Board, Institute of Electrical and Electronics Engineers, 345 East 47th Street, New York, NY 10017.

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IEEE Guide for the Preparation of Excitation System Specifications

1. Introduction

This guide is intended to provide to the specification writer the necessary material to prepare 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.

1.1 Purpose and Scope

The purpose of this guide is to aid in the preparation of procurement specifications for excitation systems for synchronous machines. This guide applies to excitation systems for synchronous machines rated 5000 kVA or larger. Some information presented in this guide may be inapplicable for a specific excitation system application, and 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 is a regulator that 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 421.1-1986 [9]).[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 power system.

1.2 References

This standard shall be used in conjunction with the following publications:

[1] ANSI C50.10-1977, General Requirements for Synchronous Machines.[2]

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

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[1] The numbers in brackets refer to the references that are listed in 1.2 in this guide. IEEE publications are available from the Institute of Electrical and Electronics Engineers, IEEE Service Center, 445 Hoes Lane, Piscataway, NJ 08855-1331, USA.

[2] ANSI publications are available from the Sales Department of the American National Standards Institute, 1430 Broadway, New York, NY, USA.

[3] ANSI C50.13-1989, Requirements for Cylindrical Rotor Synchronous Generators.

[4] ANSI C50.14-1977 (Reaff. 1989), Requirements for Combustion Gas Turbine Driven Cylindrical Rotor Synchronous Generators.

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

[6] IEEE C57.12.00-1980, General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers (ANSI).

[7] IEEE C57.12.91-1979, IEEE Test Code for Dry-Type Distribution and Power Transformers.

[8] IEEE Std 100-1988, IEEE Standard Dictionary of Electrical and Electronics Terms.

[9] IEEE Std 421.1-1986, IEEE Standard Definitions for Excitation Systems for Synchronous Machines.

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

[11] IEEE Std 421B-1979 (Reaff. 1984),, IEEE Standard for High-Potential Test Requirements for Excitation Systems.

[12] IEEE Committee Report. Excitation System Models for Power System Stability Studies, *IEEE Transactions on Power Apparatus and Systems*, vol. PAS-100, no. 2, Feb. 1981, pp. 494–509.

1.3 Definitions

The following definitions should be used in conjunction with this guide:

excitation control system: —is a feedback control system that includes the synchronous machine and its excitation system.

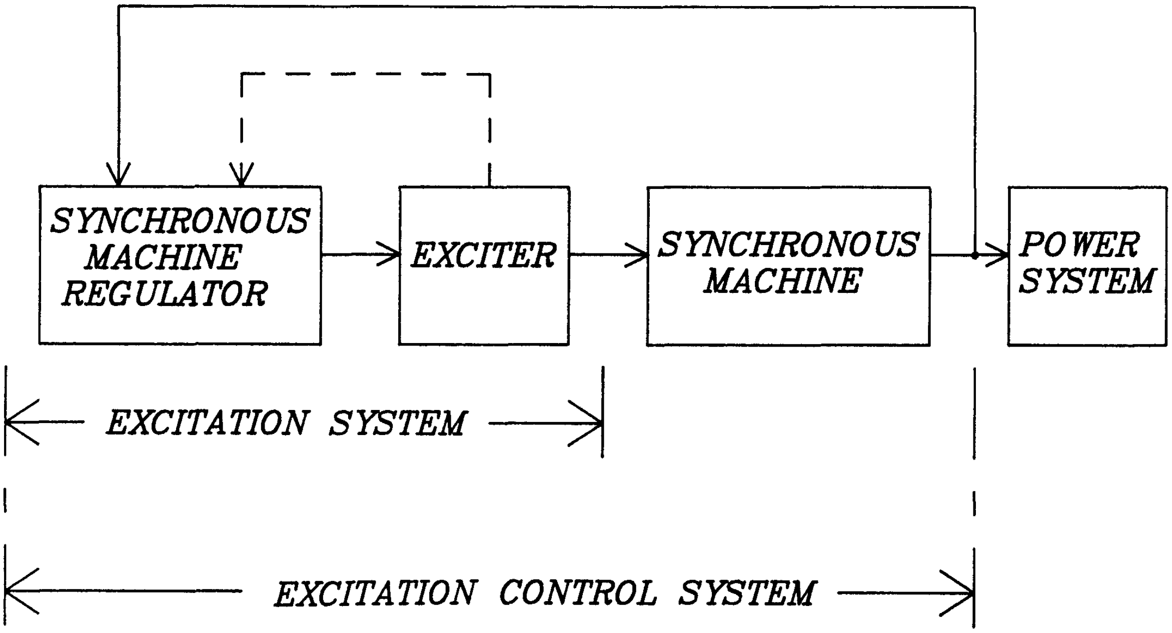

Figure 1—Block Diagram of the Components of an Excitation Control System

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

excitation system stabilizer: —is a control element that is used to stabilize the excitation control system.

exciter: —is the equipment that provides the field current for the excitation of a synchronous machine.

load regulation: —is the magnitude of voltage change resulting from a load change.

power system stabilizer (PSS): —is used to provide damping at power system frequencies associated with local and intertie modes of oscillation.

synchronous machine regulator: —is a regulator that 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 421.1-1986 [9]).

2. General

2.1 Basic

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 by a purchaser 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 also may identify the need for a power system stabilizer. Modern excitation systems may include various auxiliary control elements and protective devices in addition to a basic voltage regulator. The specification should functionally identify all the auxiliary excitation control equipment (compensators, limiters, power system stabilizer, 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, hydroelectric, etc.

2.2 Operating Modes

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, etc. The most severe duty cycle expected for each possible mode should be provided. In addition, the specification should indicate the extent of unattended operation, i.e., automatic startup, remote operation, etc.

2.3 Installation

The specification for an excitation system should clearly state whether the excitation control equipment is to be utilized as an outdoor or 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 specification could state the capacity and availability of cranes at the installation site.

2.4 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 written language for the installation, operation, maintenance, and repair manuals should be indicated. The specification may also define to what extent, if any, the excitation system must contain design, assembly, subsystems, parts, labor, etc., of domestic origin. The specification should describe the appropriate drawing standards to be used.

2.5 Insulation Systems

The specification for a rotating excitation system should specify an insulation system that meets Class B or Class F systems defined in ANSI C50.10-1977 [1]. Withstand of the dielectric tests in IEEE Std 421B-1979 [11] should be included.

2.6 Diodes and Thyristors

For diodes and thyristors, a voltage rating equal to a multiple (not necessarily integer) of the maximum anticipated duty should be specified. In critical applications devices in series, each with a full withstand rating, may be specified.

2.7 Availability

The reliability and maintainability of the excitation system should be compatible with the required reliability and service of the plant. Some plants require minimum downtime. 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 MTTR (minimum time to repair), MTBF (minimum time between failures), and MTTF (mean time to failure). If the 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.

2.8 Redundancy of Equipment

Sufficient redundancy should be allowed for device failure and replacement without compromising the required generator availability.

2.9 Spare Parts

The selection of spare parts should be carefully considered to ensure that an adequate number of required parts are available to support the required reliability and 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.

3. Exciter Rating Considerations

3.1 General

All parameters that affect the rating of the excitation system should be coordinated and unambiguously specified, since 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 sections 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.

3.2 Ratings

3.2.1 Rated Current

The continuous current rating should be specified to be equal to or larger than 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 [2], ANSI C50.13-1989 [3], and ANSI C50.14-1977 [4] allow all machines to operate at rated MVA and within ±5% of rated terminal voltage. Some machines may require an even wider operating range. The need for off-frequency operation must 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.

In the past, some excitation systems have had a small continuous negative current rating. This was utilized when the machine was operated as a synchronous condenser and the negative field current allowed a slightly greater transmission line charging capability. The negative current was relatively easily supplied from commutator-type exciters, with little additional complexity. Modern exciters employing solid-state rectfiers do not normally have inherent capability for negative currents. It could be obtained with great complexity, which cannot justify the associated minimal performance improvement (except for synchronous condensers). Some modern exciters will generate a transient negative voltage to force the decay of field current toward zero. This should not be confused with the concept of a continuous negative current rating, which is mentioned above.

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, since this is the normal operating mode.

3.2.2 Rated Voltage

The continuous voltage rating of a 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 ±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, including interconnecting bus or cable run voltage drop, up to the field winding terminals should be considered. Any brush drop voltage should be considered part of the synchronous machine field circuit.

3.3 Transient Requirements

3.3.1 Ceiling Current

Low ceiling voltage exciters, normally less than 150% of rated value, can usually be allowed to attain their ultimate ceiling current. Where high ceiling voltages are employed for improved transient performance, the ceiling current, if unrestricted, may reach high values and require excessive exciter capacity. An inclusion of a field current limiter should be considered to limit the ceiling current to a specified value. Ceiling voltage would then still be available to force the rapid change in current.

The ceiling current of the excitation system should have a transient time capability equal to or greater than the short-time overload capability of the synchronous machine to which it is connected. ANSI C50.13-1989 [3] and ANSI C50.14-1977 [4] give the field winding short-time thermal overload requirements. Note that these overloads are based on the voltage (rather than current) applied to the field windings. Presently there is no corresponding requirement in ANSI C50.12-1982 [2] for salient pole machines.

3.3.2 Ceiling Voltage

The ceiling voltage of an excitation system is normally not specified directly but is a function of the excitation system's nominal response requirement. This is one area where it is easy to specify conflicting requirements, and the specification writer is cautioned to be sure that some other reference to ceiling voltage does not conflict with the response requirement. The response should be specified by the user and the selection of the ceiling voltage left up to the manufacturer. For systems that obtain their energy from an ac source, the per unit voltage and (if applicable) current values of this source at which the nominal response requirement shall be met should be specified. Present standards base the rating of an exciter on its continuous output parameters and its time response to transient change. It is understood that the equipment must function in the transient mode and achieve ceiling output conditions without any detrimental effects. The ratio between ceiling and normal operation voltages will increase as higher nominal response systems are specified.

For certain special cases, a negative ceiling voltage may be required to control machine overvoltage conditions. Due to firing angle margin requirements of thyristor exciters, the negative ceiling is normally specified to be not more than 70% of the positive ceiling voltage, otherwise larger size equipment will probably be required.

3.3.3 Fault and Pole-Slipping Duties

The excitation system must withstand, without damage, any faults or abnormal operation of the synchronous machine. Faults on the synchronous machine ac terminals will induce large positive currents into the field (adding to the normal field current). In addition, the induced current will have an ac component at the power frequency. This is important when rectifier exciters supplied at the power frequency are involved since the peak current occurs at the same point each cycle and tends to overload one phase of the rectifier. The magnitude and time duration of this induced current is a function of machine and system reactances. Refer to IEEE C37.18-1979 (ANSI) [5] for a table of suggested values of induced currents for various types of machine construction. In addition to the positive induced field current under faults, there can be negatively induced currents (subtracting from the normal field current). These negative currents can be induced into the field circuit during pole-slipping events. When the negative induced current is so large that the total current becomes negative, and if the negative current is not allowed to flow, then the resulting voltage may become excessive. Excitation systems that employ solid-state rectifiers normally conduct current only in the positive direction. Some machines are inherently self-protecting due to additional current paths in the rotor. These may be damper windings or a solid steel structure. In machines where there is a possibility of large voltages, protective equipment may be supplied to protect both the exciter and machine field circuit. While the magnitude of the induced negative field current is a function of the machine design, the time the current flows is a function of the number of pole-slipping cycles, the system operating procedures, and the protective relay settings involved. The maximum time that any potentially damaging negative field current will flow should be specified in order to ensure there is sufficient energy capacity in any protective equipment.

4. Exciter Power Source Considerations

4.1 General

The exciter specification for new generators usually involves not only the selection of needed response characteristics and power ratings but also the selection of operator and station control interfaces, the kind of exciter power source, startup power requirements, equipment location, and reliability. The manufacturer will usually coordinate these latter activities. This is especially true in systems where generator enclosures may also enclose the entire exciter and where exciter power windings may actually be included in the generator winding slots.

Specifications for updating or rebuilding older excitation equipment are more difficult to prepare since the specifier must not only provide enough information to allow the excitation system to be coordinated with the generator, but also must ensure adequate control and protective systems are supplied. On many older systems, original design drawings of the excitation equipment and synchronous generator are either unavailable or are inadequate to provide the necessary data for the new excitation system. In these cases, some generator testing and examination may be required.

4.2 Rotating DC Generator-Commutator Exciters

Most rotating dc exciters are shunt generators, sometimes with series windings. The exciter output supplies the main generator slip rings. The exciters often have multifield windings for buck-boost regulator operation and field rheostat control, and some have windings to ensure continuous magnetic bias. Some exciters may be separately excited from a pilot exciter through a rheostat. Some exciters are motor driven rather than driven from the main generator shaft.

The replacement of these exciters is facilitated by the presence of the slip rings. Placing a new permanent magnet generator or an exciter alternator on the shaft may mean extensive reworking of the main generator to allow the connection of the new shaft and provide proper support. New static exciters can be located remotely from the generator and wired to the slip rings. The old exciter can then be removed from the generator, if desired. Reevaluation of the turbine-generator shaft dynamics may be necessary in such a case. An excitation power transformer should be provided whether the excitation power source is from the synchronous machine or from station service. The transformer provides electrical isolation, harmonic suppression, and fault limiting. When the excitation system supply is from the synchronous machine terminals, the excitation system must also be equipped with some form of startup power from station service or the station battery. The reliability of these systems must be considered since the old plant design assumed a self-starting exciter, and many control and protective schemes not directly a part of the excitation systems may have to be modified if the starting power is from station service. Finally, the physical location of a new exciter in an old plant must be carefully chosen.

4.3 Rotating AC Exciters

Rotating ac exciters may use rotating rectifiers or stationary rectifiers in a brush/collector ring system. The power converter may consist of controlled rectifiers. In most systems, however, the exciter terminal voltage is regulated through the control of the exciter field current. Power to operate the exciter field may come from a permanent magnet generator from the exciter itself or from an auxiliary source.

4.4 Static Exciters

4.4.1 Potential Source-Rectifier Exciter

The potential source exciter derives its power from a potential source (which may be the terminals of the synchronous machine) and uses stationary controlled rectifiers. Special consideration should be given to the selection of the exciter power source. The necessary bus duct or cable and transformer equipment may be part of the specification. If station service is used, the transient exciter loads and the transient effects of station service transfer schemes must be considered. The field flashing equipment is also important and adequate self-cooling capability may be specified for start up without the need for auxiliary cooling power.

The nominal response should be determined at a specified percentage of rated supply voltage. This value is best determined from power system simulation studies. In those cases where such studies are not feasible, this value can be based on the voltage during the first 0.5 second following a selected fault. A range of 70%–80% of rated supply voltage is not unusual.

The excitation system should operate during fault conditions down to a specified percentage of rated terminal voltage (25% of rated synchronous machine voltage is suggested). Following restoration of the supply voltage, the excitation system should be capable of immediate recovery and should be able to provide maximum available voltage to restore the system voltage.

4.4.2 Compound Source-Rectifier Exciter

The compound source exciter derives its power from both current and potential sources (depending on the synchronous machine terminal quantities). The nominal response should be determined at a specified reduction in the terminal voltage and increase in the terminal current. This system is frequently used when sustained short-circuit current is required from the synchronous machine. In this case, the value of sustained short-circuit current should be specified.

5. Excitation System Performance and Synchronous Machine Regulator Considerations

This section identifies the commonly used criteria for specifying performance of the excitation system. IEEE Std 421.2-1990 [10] contains detailed discussions of the parameters used. Most of the adjustable parameters that influence excitation control system performance are contained in the excitation control elements, including the voltage regulator error detector, compensators, and excitation system stabilizers and limiters.

The specification writer is cautioned to distinguish between these auxiliary control functions, which are a part of the automatic control of the excitation system and the control circuits associated with the interface between the excitation system and the power plant operation. Furthermore, many of the auxiliary control functions may easily be confused with closely related protective functions. The specification of auxiliary control functions is included within this section; the control requirements and protective requirements are discussed in the following two sections. It should be noted that the specification of the voltage regulator parameters alone is not sufficient to obtain the desired performance. Parameters such as ceiling voltage, excitation system stabilizer gains and time constants, synchronous machine parameters, and power system impedance greatly affect the performance of the excitation control system.

Control of the steady-state terminal voltage is the primary function of the synchronous machine regulator. The regulator may influence the stability of the synchronous machine at local mode or intertie frequencies depending upon the bandwidth, gain, and field-forcing capabilities of the excitation control system, which includes the synchronous machine regulator, the exciter, the synchronous machine, and the power system. Stabilizers such as the power system stabilizer may be included as supplementary control functions within the synchronous machine regulator.

Performance can be specified only to the terminals of the equipment package being purchased. The supplier of the equipment can only be responsible for the performance that does not extend beyond the terminals of the equipment to be supplied. For example, the terminal voltage excursions of the synchronous machine for large disturbances cannot be entirely controlled by either the synchronous machine regulator or by the exciter.

5.1 Manual Control Performance

The manual controller typically regulates synchronous machine field voltage over a range from 30% of no-load field voltage to the maximum field voltage required by the synchronous machine on load. The manual controller typically provides excitation during start up until terminal voltage reaches a preset value. It also serves as a backup controller should the automatic controller fail.

The performance requirements for manual control are traditionally quite minimal. The controller is usually quite simple in order to provide a highly reliable backup control system. The manufacturer typically defines the parameters and the associated control system response.

5.2 Automatic Control Performance (Including the Synchronous Machine)

The synchronous machine regulator, including its limiting and stabilizing functions, regulates the synchronous machine terminal voltage by applying a control signal to the exciter. The regulator, exciter, machine, and power system all influence the terminal voltage response. The control system that includes all of these influences is referred to as the “excitation control system.“ Only the performance of those portions of this system that are being purchased can be specified. The specification writer must determine the dynamic performance requirements of the equipment being purchased. Dynamic performance classification is discussed in IEEE Std 421.2-1990 [10]. The material contained in this section is general in nature. Detailed model studies may be required to determine the performance requirements for a specific system. To assist manufacturers in providing systems that meet the user’s needs, “worst-case” excitation system operation and special conditions should be specified.

5.2.1 Steady-State Performance

The response of the excitation system to slow variations in load, frequency, and ambient temperature constitutes the steady-state performance. The term “load regulation” is the magnitude of voltage change resulting from a load change; the assumed load change is from synchronous machine no-load to full load, unless otherwise specified. Load regulation of ±0.5% of rated terminal voltage is typical. Frequent changes in power system operating schedules and allowable variation in voltages are normally such that load regulation is not critical. Allowable variations in voltage caused by frequency and ambient temperature excursions are stated separately.

5.2.2 Small Signal Performance

Small signal characteristics refer to those responses where nonlinearities in excitation control system operation can be neglected. The transient and frequency responses associated with feedback control systems are the basis for specifying small signal performance. Rise time, overshoot, and settling time are the principal characteristics of interest in specifying transient response. The opened-loop frequency response characteristics provide an indication of stability margins and the primary characteristics of interest are the low frequency gain, crossover frequency, phase margin, and gain margin. On the other hand, the closed-loop frequency response characteristics are related to the transient response characteristics and provide an indication of small signal response. The characteristics of interest are the bandwidth, the peak value of the amplitude response, and the frequency at which the peak occurs. IEEE Std 421.2-1990 [10] contains a detailed description of the transient response and frequency response characteristics including a tabulation of typical values. In order to tune the excitation control system for specific application requirements and allow retuning at periodic intervals for changes in power system requirements, most synchronous machine excitation systems are designed with adjustable parameters.

If the synchronous machine, exciter, and regulator are purchased together from the same manufacturer, then the offline dynamic performance of the excitation control system could be specified using transient and frequency response parameters. However, if only a portion of the excitation control system is purchased, then the dynamic performance of that portion being purchased must be specified in a manner that permits the manufacturer to demonstrate compliance with the specification at the factory where the remaining portion of the excitation control system is not available. For example, it is current practice to replace older regulators while retaining the exciter and synchronous machine. In this case, the regulator parameters or the regulator transient and frequency response requirements may be specified. These parameters or responses must be determined from model studies. Usually, a range of parameters or responses is specified. For most applications, one of the manufacturer’s standard equipment packages can be specified by comparing model study requirements with manufacturer’s literature.

In certain simple power system applications, it may be advisable that the required dynamic performance criteria for the complete excitation control system be provided to the manufacturer to possibly permit a better understanding of the requirements for a specific element within the system.

5.2.2.1 Systems with High Initial Response

A high initial response excitation system is capable of attaining 95% of the difference between the available ceiling voltage and rated load field voltage in 0.1 second or less. When these systems are required, their performance may be specified in terms of the frequency response characteristics from terminal voltage reference to the resulting exciter output. They inherently have an essentially flat frequency response from dc to some specified frequency at which the gain is 3 decibels down from the dc value. The phase response is a small angle up to a specified frequency where a maximum phase angle is identified. Frequently, the use of high initial response characteristics may be desirable for stability of a generator or system in critical power system applications. This characteristic can be included in ac exciters and compound source exciters and is a characteristic of potential source static exciters. The frequency response may be modified by the application of an excitation stabilizer as explained in 5.2.2.3 below.

5.2.2.2 Systems without High Initial Response

Although some excitation systems employing rotating exciters may have slower response than a high initial response excitation system, the primary difference is in the large signal performance rather than in the small signal performance. Rated feedback or transient gain reduction is used to increase loop gain and phase margin. The specification is normally in terms of frequency response similar to high initial response units.

On machines with rotating dc exciters, especially original exciters retained in an excitation system upgrade, the performance may be limited by the excitation system time constants. The frequency response of these systems is difficult to predict and a frequency response specification may not be practical. Specification of overshoot and settling time to a step change is more practical.

5.2.2.3 Excitation Stabilizer (Rated Feedback)

For many excitation control systems designed and installed currently, the small signal response is determined by settings of the synchronous machine regulator gain and the excitation stabilizer gain and time constant. Traditionally, systems have used some form of rated feedback to provide the stabilizing action, especially when rotating exciters are employed.

5.2.2.4 Excitation Stabilizer (Transient Gain Reduction)

In some excitation systems, the excitation stabilizer function is accomplished by transient gain reduction. It is not common for both rated feedback and transient gain reduction to be employed at the same time. Transient gain reduction is used to reduce the gain within the specific band of frequencies where power system instability is of concern.

5.2.3 Large Signal Performance

The large signal performance characteristics refer to those responses of terminal voltage to the sudden large changes in system loading that are characterized by nonlinear operation of the excitation control system. The extent to which the excitation system can contribute positively to first swing or transient stability is dependent upon the difference of the excitation system positive forcing voltage capability, the countering effect of the synchronous machine field current, and the delaying effect of the machine field time constant. Normally, the parameters to be specified for high initial response systems are the excitation system nominal response and the source voltage level for potential source exciters and, additionally, the source current level for compound source exciters. In determining the specified parameter, the effect of current limiters should be considered. These parameters, if specified, should be under the most adverse conditions. For nonhigh initial response systems, only the specification of the excitation system nominal response is necessary. It should be noted that, if both ceiling voltage and excitation system nominal response are specified, a potential for conflicting requirements exists.

In certain specific applications, the response of the excitation control system under certain likely operations should be considered. Load rejection and the resulting overspeed is one such operation, especially for hydro machines. The excitation control system should maintain the terminal voltage within acceptable limits in spite of the off-frequency operation resulting from overspeed. For systems with rotating dc exciters, the regulator power amplifier may need to provide negative voltage and current capability to provide required field forcing by the rotating exciter during load rejection.

Start up and shutdown are considered routine operations. Specific requirements related to these operations should be specified. Power system fault conditions, underfrequency operation, and their impact on the requirements of the excitation supply should be considered. A case where this is especially important is in specifying potential source-rectifier systems. (Cases where fault current must be sustained were previously described in 4.4.2).

5.3 Auxiliary Control Functions

There are a number of auxiliary control functions that affect the performance of the excitation control system. They are auxiliary in that they may not be included in all applications or they may be active only under specific conditions. They are generally included as components within the synchronous machine excitation system and they are not protective functions, although they may perform roles closely associated with certain protective functions. Modern excitation systems frequently include both auxiliary control and synchronous machine protective functions. In some cases, both functions may be integrated into the same enclosure. Frequently incorporated functions are overexcitation, underexcitation, and volts/hertz limiters.

5.3.1 Compensators

Several types of compensation are available on most excitation systems. Synchronous machine active and reactive current compensation are the most common. Either reactive drop compensation or line drop compensation connections may be used, simulating an impedance drop and effectively regulating at some point other than the terminals of the machine. The impedance or range of adjustment and type of compensation must be specified.

5.3.2 Power System Stabilizers

There are several types of stabilizers in use with excitation systems. The excitation system stabilizer refers to a control element (previously described in 5.2.2) that is used to stabilize the excitation control system. The power system stabilizer (PSS) is used to provide damping at power system frequencies associated with local and intertie modes of oscillation. Explanation of the PSS parameters is described in detail in the IEEE Std 421.2-1990 [10]. The specification should include a description of the application, including the frequency range of concern. The source of input to the power system stabilizer, i.e., PT's, CT's, tachometers, etc., should be identified. The specification writer should be aware of the possible and undesirable interaction of the PSS with the torsional natural frequencies of the machine mechanical shaft system. To prevent such an occurrence, filters and protective devices may be needed to attenuate torsional signals and trip the PSS for control circuit failure.

5.3.3 Torsional Stabilizers

The use of series capacitors in transmission lines creates electrical tuned circuits whose natural frequencies may coincide with the natural mechanical shaft torsional resonant frequencies of the synchronous machine. Excitation systems with sufficiently wide frequency response may be equipped with control systems to provide positive damping torques at these frequencies. These control (frequently termed “subsynchronous excitation damper controls”) are generally quite complex. They must incorporate control, monitoring, and protective circuits because of the hazard of severe machine damage should the control misoperate.

5.3.4 Underexcitation Limiter

The underexcitation limiter is included in most applications to prevent operation that would cause overheating in the stator end region of the synchronous machine or instability and loss of synchronism. Its performance is usually specified by identifying the region of limiter action on the synchronous machine capability curve. Its performance should be coordinated with the loss of excitation protection provided for the synchronous machine.

5.3.5 Overexcitation Limiter

The overexcitation limiter is used primarily to avoid overheating of the synchronous machine field winding. The permissible thermal overload of this winding is inversely proportional to time and, therefore, limiter action may be delayed. However, very high ceiling exciters may be provided with an additional instantaneous limiter action. This limiter is often incorporated in a multistep control and protective package for the field winding.

5.3.6 Volts/Hertz Limiter

The volts/hertz limiter is used to prevent overheating that may arise from excessive magnetic flux due to underfrequency operation or overvoltage operation, or both. It is commonly used where a synchronous machine is connected to a power system through a transformer and circuit breaker in such a manner that the transformer is energized during start up and shutdown of the synchronous machine, thereby subjecting the transformer to low frequency operation. It is also used to protect the synchronous machine from flux levels, as they may occur when the machine is not loaded. Furthermore, it is also used when two synchronous machines are used or started together, one as a motor and the other as a generator. In this type of operation, the volts/hertz limiter acts to raise the terminal voltage as frequency increases. The volts/hertz ratio at which the limiter is to become active must be specified.

5.3.7 Exciter Auxiliary Control Functions

Auxiliary functions, which similar in operation to those described above, may be provided for the exciter control as well as the synchronous machine. Exciter low voltage limiter, volts/hertz limiters, and other limiters may be provided if they are deemed necessary by the manufacturer.

6. Control Considerations

Many devices associated with control of the excitation system must be considered. If the manufacturer is to provide all of the devices, then they should be included in the specification. Generally, the objective is to obtain from the manufacturer a complete package requiring only installation and wiring at the station. Coordination of the control equipment design with the manufacturer, with the supervisory control hardware and with the excitation system performance specification is essential.

6.1 De-excitation

An effective and dependable means of de-energizing the synchronous machine is necessary. A main field breaker with a discharge resistor may be used for those synchronous machines equipped with slip rings. For ac and dc rotating exciters, an exciter field breaker with a discharge resistor can be used. An ac power breaker may be appropriate for some potential source static exciter designs. Some configurations of the compound source static exciter permit the use of a shorting breaker. Special exciter control circuits to force the output to zero can be used on most systems. Redundant shutdown methods are frequently employed to guard against breaker failure.

6.2 Unit Manual Control

Manual control may be implemented using a field rheostat in the case of dc rotating exciters. A base adjuster system is frequently used in rotating rectifier exciters. In most other types of exciters, some form of dc regulator is included to provide control of the exciter voltage. Automatic transfer to manual control may result from overspeed protection on motor-driven exciters, or overexcitation (overvoltage, overcurrent). Manual transfer by the operator is useful for maintenance, i.e., of the ac regulator, replacement of rectifiers or fuses.

6.3 Unit Automatic Control

If automatic control is specified, the interface between the user-supplied and manufacturer-supplied equipment should be defined. A typical requirementfor the manufacturer would be to provide a specified change in terminal voltage or reactive power for each closure of a contact. The duration of each contact closure should also be specified. If the excitation system set-point is an analog or digital quantity rather than a raise or lower contact input, then a specified change in terminal voltage or reactive power for a specified change in the set-point should be defined. In this case, a reliable set-point signal supplied by the user is necessary.

Consideration should be given to the need for control and monitoring of excitation system operation from a remote site. Even in fully automated systems, it may be prudent to have some form of remote manual operation capability. Provision for verifying the integrity of the communication link can be of value. It is also common to provide for local operation at the site of the excitation equipment, including indicating lights and metering.

Online testing of the excitation system operation, from either local or remote sites, may be desirable. In such a case, the purchaser should designate the parameters that are to be measured, and the manufacturer should provide convenient access points in the control circuitry.

6.4 Unit Automatic Start/Stop

If automatic start and/or stop is specified, the interfaces between user-supplied equipment and manufacturer-supplied equipment should be specified. A typical specification would require the manufacturer to provide all equipment necessary to place the excitation system into operation (or to remove it from operation) upon closure of a contact.

Automatic positioning of all adjustable control set-points should be addressed. It is generally necessary for the controls to be pre-set either before automatic startup or after automatic shutdown.

Retention of a local method of manual control is very important and provision for selection of remote automatic operation, local automatic operation, or local manual operation is valuable.

6.5 Unit Automatic Voltage Matching

It is common to include automatic voltage adjusting capability in conjunction with automatic synchronizing equipment. Consideration should be given to the interface requirements between the automatic synchronizer and the excitation equipment.

6.6 Set-Point Adjusters

The operation of the excitation equipment to raise or lower voltage or reactive power can be accomplished in several ways. The most commonly used method is motor-operated set-point adjusters. Analog or digital signals from automated supervisory equipment may be required in some applications. Provision for this interface between user-supplied and manufacturer-supplied equipment must be specified. It is important to specify the range of set-point operation in terms of the terminal voltage. In raise and lower contact operation, this may take the form of a specified closure time or number of closures to provide a specified change in terminal voltage or reactive power. The need for remote operation of the set-point should be considered along with the need for local operation at the site of the excitation equipment. In automated systems, the need for manual as well as automatic operation should be considered.

6.7 Set-Point Tracking

In many applications, it is important to consider the need for set-point tracking equipment. This equipment causes the manual set-point to track the excitation requirements for the operating point of the synchronous machine, so that, in the event of automatic control failure, the excitation system would have an appropriate manual set-point.

6.8 Control Circuit Interface to Power Plant Circuits

The interface between the excitation control circuits and power plant circuits can be at a variety of voltages and currents. Coordination between the user and manufacturer is necessary to facilitate the design.

A wide range of dc voltages are in use in control circuits including the standard battery circuits of 48, 125, or 250 volts dc. The nominal range of the dc voltage should be specified. A typical range is 80% to 115% due to loading and battery charge conditions.

A wide range of ac voltages are also used in control circuits including the standard voltages of 120, 240, 480, or 600 volts. Both single phase and three phase are used. Again, the range should be specified and a typical range is 110% to 90%.

Some user philosophies allow a momentary interruption of the control power supply while others require that a continuous supply be provided. Historically, such contingencies were addressed by specifying mechanically latched relays. The recent practice of using solid-state switching necessitates that users specify the maximum duration of power supply interruption. Field flashing may be essential to some installations. AC or DC voltages may be used and may be the same as the voltages for the control circuits or may come from a separate supply. The current and the maximum time duration of this current should be specified. The specification should also reflect the troubleshooting and maintenance of the user's plant technical personnel, such as the procedure of briefly de-energizing control circuits to isolate grounds.

Consideration should be given to the type and number of instrumentation transformers required to provide ac voltage and current signals for the excitation system. Consideration should also be given to the type and number of transducers required to monitor excitation system parameters. If circuit breakers are required in the control circuit supply, they should be specified, including placement if appropriate.

7. Protection Considerations

7.1 General Requirements

Modern excitation systems require a higher degree of protection than older excitation systems. Protection is generally divided into two categories: protection of the excitation system itself and protection of equipment external to the excitation system. Annunciation of abnormal conditions should be considered so that the operator is apprised of the impending equipment protective action.

7.2 Protective Action

The excitation system specification should be coordinated with devices capable of detecting conditions external to the equipment that may cause damage to the excitation equipment and the synchronous machine. Such conditions may include generator overvoltage, generator loss of field, generator field overexcitation, pole-slip reverse current, field ground, and excessive volts/hertz in the synchronous machine and step-up transformer.

Internal conditions within the excitation system that may require protective devices include loss of rectifier cooling and exciter phase imbalance. Protection circuits in the excitation system may be considered, which return excitation to a predetermined level after some period of overexcitation. This may include transfer of excitation to the manual control mode.

7.3 Annunciation Action

Annunciation within the excitation system to alert operators to potential problems should be considered, to aid in the determination of conditions that may have caused the excitation system to trip, and to minimize equipment troubleshooting time. In addition to annunciation of those protective actions noted in 7.2, annunciation is sometimes provided for loss of control power supplies, loss of regulator sensing, and failure of thyristors, diodes, fuses, and high temperatures within the excitation cubicle. Although several of these functions may be grouped together for annunciating to operators in a remote location, independent annunciation should be made locally.

8. Environmental and Enclosure Considerations

8.1 Environmental

The environment in which the excitation system will be placed must be clearly defined and appropriate requirements specified. Environments that expose the excitation system to electrical transients, radio interference, temperature extremes, humidity, altitude, vibration, corrosive atmospheres, or any unusual conditions should be specified. Consideration should also be given to interference generated by the excitation system. Any special requirement, such as tropicalization (encapsulation, protection from humidity, rodents, insects) or seismic requirements should also be indicated. Detailed cooling information should be spelled out to the manufacturer, including primary cooling media, maximum and minimum coolant temperatures and pressure, cooling tube material, cathodic protection, and any necessary plant interface.

8.2 Enclosure

When the final location in the plant has been determined, an appropriate enclosure should be specified by the user. Its suitability is dependent on several factors, an extreme example of which could be that the enclosure is against a wall with limited accessibility. Specifics should be mentioned as to the ease of access and removal of particular equipment items within the enclosure. If the enclosure has access to all sides, it may be desirable to specify doors on all sides for ease of maintenance. Depending on temperature limitations, suitable cooling vents or louvers should be included for necessary cooling or ventilation or both, particularly if cooling fans are used. Other considerations should include dust filters and rodent-proof screened louvers. Additional considerations, depending upon the specific power plant, may be some of the following:

1) User-mounted monitoring instruments for operation, testing, and adjustment
2) User mounted push buttons and switches for manual/automatic controls
3) Paint/finish
4) Construction
    a) Terminals/connectors
    b) Wiring/wire marking
        i) Insulation flammability
        ii) Dangerous materials, i.e., asbestos, PVC, etc.
    c) Nameplates
    d) Fire protection
    e) Outdoor/indoor (NEMA type)
        i) Tightness, dripproof, dustproof, splashproof, etc.
        ii) Heat exchangers, air conditioning
    f) Dimensional constraints
    g) Seismic
    h) Heaters/thermostats
    i) Doors/panels/accessibility
    j) Handles/locks/latches
    k) Cable entry location, sealing methods
    l) Mounting and anchoring
    m) Breaker interlocks
    n) Grounding
    o) Personnel protection
    p) Circuit isolation/barriers
    q) Interior lighting/receptacles/communication
    r) Noise level-Audible, EMI (electromagnetic interference), RFI (radio frequency interference), TIF (telephone influence factor)

8.3 Instruments and Controls for Remote Mounting

Instruments, switches and push-buttons, or controls, are required for remote mounting on a switchboard that has been furnished by others. If excitation system equipment is to be designed for remote control, it may include the following functions:

1) Control of the generator voltage set-point adjuster
2) Control of the manual set-point adjuster
3) Placing the excitation system in or out of service
4) Testing excitation system operation
5) Indication of excitation system voltage, field current, and all other parameters that the manufacturer considers pertinent to the operation of the excitation system
6) All indicating lights, as necessary, for the user and recommended by the manufacturer

During the review of the manufacturer's drawings, sufficient data should be provided by the excitation system manufacturer to ensure proper coordination, if remote equipment is to be supplied or mounted by others. That data will include:

1) Parameters to be instrumented, i.e., control voltage and current requirements, in addition to the type and range of signals
2) Control switch functions
3) Control, start, stop, and shutdown control circuits
4) Number and kind of circuits for indicating lights

9. Information to Be Provided by the Manufacturer

9.1 General Requirements

Excitation system information that is necessary to efficiently conduct the project engineering, erection, testing, troubleshooting and operation of all excitation components is required. The specification requirements should be specific to the project, including "due times" allowed for drawings, data, and submission of descriptive information as stipulated in the paragraphs below. A delivery schedule should be submitted by the manufacturer following the award of contract and should be coordinated with the overall equipment and plant design schedule.

9.2 Information That May Be Provided at the Time of Submission of Proposals

If requested, the manufacturer should furnish performance data of the excitation system with a written description of the principles of operation. Usually, such requests might include typical outline drawings of excitation components showing approximate dimensions.

9.3 Information Provided Prior to Delivery of the Equipment

The manufacturer should submit drawings and descriptive material to the purchaser for review as follows:

1) After the award of contract and release for engineering, drawings showing actual overall dimensions and weights of the principal excitation system components should be provided within a designated time.
2) After the award of contract and release for engineering, drawings show full details of foundation requirements, bus drawings (as applicable), wiring drawings, mathematical models for use in dynamic computer studies, and schematic diagrams for all parts of the excitation system, including all necessary interfacing components and auxiliary devices to required make a complete system should be provided within a designated time.

9.4 Information to Be Provided with Equipment When It Is Delivered

The manufacturer should provide instruction and /or operating and maintenance manuals describing the equipment in detail and the recommended procedures for assembling, erection provisions, dismantling, maintaining, diagnosing trouble, and operating the excitation system and its components. Purchasers should clearly define whether they require these manuals to be submitted for approval, or if they are satisfied to accept the manufacturer's standard manuals.

In general, the manuals should include at least the following:

1) Technical data including weights of all major components
2) All pertinent vendor bulletins, instruction manuals, and drawings, or both, prepared by the various components sub-suppliers
3) Procedures for assembling, disassembling, adjusting, operating, troubleshooting, and maintaining the excitation system, including the recommended complement of spare parts
4) Lubrication requirements, including a list of recommended lubricants for all components requiring lubrication
5) A manufacturer-specified selected set of the component physical arrangement, schematic, and excitation system wiring drawings that may be reduced in size to suit the page format of the instruction manuals
6) A set of assembly drawings or printed bulletins that show all individual equipment components and that indicate and identify each component item number, including the common commercial designation

9.5 Photographs

Photographs of entire or partial equipment may be part of the instruction or maintenance manual, or both, whenever available or practical. Photographs may not be an essential requirement if their only purpose is to aid in the interpretation of outline drawings by operating and maintenance personnel.

9.6 Drawing Review Procedure During Project Stage

The manufacturer should submit the drawing and descriptive material described in 9.3 to the purchaser in a timely manner in accordance with the time schedule stipulated. The purchaser should review the submitted drawings, mark them appropriately, and return them to the manufacturer within a designated period of time after their receipt.

9.7 Drawing Review After Erection Is Completed

The manufacturer should implement all field changes onto the relevant drawings and either provide an addendum to or a revision of the relevant drawings previously designated as "as shipped" drawings. These drawings should then receive the status of "as installed."

10. Tests

The tests described in the following sections are intended to verify that all excitation system elements are functioning properly and are capable of performing their specified function.

10.1 Routine Factory Tests

Routine factory tests may not require the complete factory assembly of the excitation system; however, it is advisable that each element of the excitation system be subjected to the following routine tests.

10.1.1 Excitation Control Equipment

1) Visual examination to verify major component or subassembly identity, location, and mounting conformance to manufacturer's drawings.
2) Dielectric tests specified in IEEE Std 421B-1979 [11].
3) Verification of proper electrical and mechanical operation of all control switches; control, protective, and transfer relays; cam switches; contactors; and circuit breakers. Also continuity measurements of related wiring.
4) Verification of input-output static transfer characteristics of each excitation control element.
5) Operation of regulator power amplifier(s) at rated supply, voltage, and as much current as practical into the resistive-inductive load to verify input-output static transfer characteristics, ceiling voltage capability, stability of control, and voltage and current sharing.
6) Burn-in, if specified, is performed with the regulator power amplifier operating at rated load current and voltage at a specified ambient temperature for a specified time.

10.1.2 DC Commutator Exciter

The routine tests should include measurement or verification of the following:

1) Insulation resistance (meggering)
2) DC resistance of all windings at a specified temperature
3) Resistance of all external current limiting resistors and field rheostats, where applicable
4) Air gap
5) No-load saturation curve, from residual to exciter ceiling
6) High potential test in accordance with IEEE Std 421B-1979 [11]

10.1.3 Alternator-Rectifier Exciter

The routine tests should include the measurement or verification of the following:

1) Insulation resistance
2) Resistance of all windings at a specified temperature
3) Resistance of all external current limiting resistors and field rheostats, where applicable
4) Air gap
5) No-load saturation curve, from residual voltage to ceiling voltage of exciter rated voltage
6) Phase rotation
7) Pilot exciter no-load voltage and phase rotation, where applicable
8) Continuity of rectifier fuses
9) Rectifier leakage
10) Range and stability of rectifier phase control, where applicable
11) High potential test in accordance with IEEE Std 421B-1979 [11]
12) Momentary overspeed

10.1.4 Potential Source-Rectifier Main Exciter

10.1.4.1 Excitation Power Potential Transformer(s)

Routine factory tests should be made on each transformer in accordance with IEEE C57.12.91-1979 (ANSI) [7] or other standards as applicable.

Routine tests should include measurement of the following:

1) Winding resistance
2) Ratio

3) Polarity and phase relationships
4) No-load loss (if applicable)
5) Excitation current at rated voltage
6) Applied potential (dielectric)
7) Induced potential

10.1.4.2 Controlled Rectifier Assembly

Routine tests on each controlled rectifier assembly should be made. Routine tests should include measurement or verification of the following:

1) Continuity of rectifier fuses
2) Rectifier leakage
3) Polarity and phase relationships
4) Range and stability of rectifier phase control
5) Dielectric tests
6) Burn-in, 48 hours unless otherwise specified (designate if current or voltage burn-in is required)

10.1.5 Compound Source-Rectifier Exciter

10.1.5.1 Excitation Power Potential Transformer(s)

Routine factory tests should be made on each transformer in accordance with IEEE C57.12.91-1979 (ANSI) [7] or other standards, as applicable. Routine tests should include the measurement of the following factors:

1) Winding resistance
2) Polarity and phase relationships
3) No-load loss (if applicable)
4) Excitation current at rated voltage
5) Applied potential (dielectric)
6) Induced potential

10.1.5.2 Excitation Power Current Transformer(s)

Routine factory tests should be made on each transformer in accordance to IEEE C57.12.00-1987 (ANSI) [6], where applicable and unless otherwise specified, or other standards, as applicable.

1) Winding resistance
2) Ratio
3) Polarity and phase relationships
4) No-load loss
5) Excitation current at rated voltage
6) Applied potential (dielectric)
7) Induced potential

10.1.5.3 Linear Reactors

Routine factory tests should be made on each reactor in accordance with IEEE C57.12.00-1987 (ANSI) [6] or other standards, as applicable. Tests should include measurement or verification of the following:

1) Winding resistance
2) Impedance, including taps, if any, and losses
3) Linearity, to 110% of normal rated voltage unless otherwise specified
4) Dielectric tests (applied potential tests)
5) Induced potential

10.1.5.4 Power Converter

Routine tests should be made on the power converter assemblies (either controlled or uncontrolled) and should include measurements or verification of the following:

1) Resistance of rectifier fuses
2) Rectifier leakage
3) Polarity and phase relationships
4) Range and stability of rectifier phase control, where applicable
5) Dielectric tests

10.2 Special Factory Tests

Unless otherwise specified by the purchaser, special tests should only be made on a prototype design excitation system element, and then on only one element of a number of duplicate elements. Except for tests to measure excitation system voltage time response and nominal response, the excitation system does not need to be completely assembled at the factory. The tests could include measurement or verification of the following:

10.2.1 Excitation Control Equipment

1) Routine factory tests specified in 10.1.1 above
2) Input-output static transfer characteristics of each excitation control element over specified ranges of supply voltage, frequency, and operating temperature. Verify gain, linearity, maximum and minimum outputs, and stability to be within tolerance.
3) Time constants of all excitation system elements by frequency response testing techniques described in IEEE Std 421.2-1990 [10].
4) Temperature and cooling air flow; i.e., heat runs at rated load and at specified overloads.
5) Burn-in, if specified, is performed with the regulator power amplifier operating at rated load (current and voltage) at a specified ambient temperature for a specified period of time.

10.2.2 DC Commutator Main Exciter

1) Routine tests specified in 10.1.2 above
2) Load saturation curve, up to 110% of normal ceiling voltage
3) Exciter regulation curve
4) Pilot exciter regulation curve, where applicable
5) Efficiency test to determine segregated losses
6) Operating temperature, i.e., heat run
7) Excitation system voltage time response and nominal response
8) Audible noise
9) Commutation
10) Exciter time constant(s)
11) Operation at momentary overspeed, if the anticipated overspeed exceeds 125%
12) Purchasers' witness tests

10.2.3 Alternator-Rectifier Exciter

1) Routine factory tests as specified in 10.1.3 above
2) Audible noise
3) Load saturation curve, up to 110% of nominal ceiling voltage
4) Main exciter regulation
5) Pilot exciter regulation, where applicable
6) Heat run

7) Exciter time constant
8) Excitation system voltage response time and response in accordance with IEEE Std 421.2-1990 [10], where applicable
9) Operation at momentary overspeed, if the anticipated overspeed exceeds 125%
10) Purchasers' witness tests

10.2.4 Potential Source-Rectifier Main Exciter

10.2.4.1 Excitation Power Potential Transformer(s)

1) Routine tests specified in 10.1.4.1 above
2) Impedance, load loss, and regulation
3) Computing reactance
4) Temperature rise, i.e., heat run
5) Impulse test(s)
6) Purchasers' witness tests

10.2.4.2 Controlled Rectifier Assembly

1) Routine tests specified in 10.1.4.2 above
2) Rated current, forward, and reverse losses
3) Temperature rise, i.e. heat run
4) Burn-in, 48 hours unless otherwise specified (designate if current or voltage burn-in is required)
5) Power factor and displacement factor, efficiency, and voltage regulation
6) Verify current balance
7) Purchasers' witness tests

10.2.5 Compound Source-Rectifier Exciter

10.2.5.1 Excitation Power Potential Transformer(s)

1) Routine tests specified in 10.1.5.1 above
2) Impedance, load loss, and regulation
3) Temperature rise, i.e., heat run
4) Impulse test(s)
5) Purchasers' witness tests

10.2.5.2 Excitation Power Current Transformer(s)

1) Routine tests specified in 10.1.5.2 above
2) Impedance and load loss
3) Temperature rise, i.e., heat run
4) Impulse test(s)
5) Average (not rms) saturation voltage, at specified overload current
6) Purchasers' witness tests

10.2.5.3 Linear Reactors

1) Routine tests specified in 10.1.5.3 above
2) Temperature rise, i.e., heat run
3) Saturation curve to specified overload voltage
4) Impulse test(s)
5) Purchasers' witness tests

10.2.5.4 Rectifier Assemblies

1) Routine test as specified in 10.1.5.4 above
2) Rated current, forward and reverse losses
3) Temperature rise, i.e., heat run
4) Burn-in, 48 hours unless otherwise specified (designate if current or voltage burn-in is required)
5) Power factor and displacement factor, efficiency, and voltage regulation
6) Verify current balance
7) Purchasers' witness tests

10.3 Field Tests

The following tests can serve as a guide in placing excitation control equipment in service and to verify that all excitation system control and protective elements are operating properly and are capable of performing their intended function.

10.3.1 Tests with Synchronous Machine Not Running

These should be executed or supervised by the manufacturer's field service engineering personnel.

1) Verify external wiring to be in accordance with contract drawings.
2) Verify operation of all relays, contractors, circuit breakers, and voltage adjusters.
3) Verify operation of manual control means and regulator power amplifiers using station supply and simulated load per manufacturer's instruction books.
4) Verify operation of all excitation system control and protective devices using simulated input signals and station power supply per manufacturer's instruction books.

10.3.2 Tests with Synchronous Machine Running at Rated Speed and Offline

These should be done or supervised by the manufacturer's field service engineering personnel.

1) Energize machine with excitation system in the manual control mode.
2) Verify operation of excitation control elements using machine voltage signal per manufacturer's instruction books.
3) Verify satisfactory transfer of excitation control from manual to automatic mode and vice versa.
4) While in automatic control mode, check stability and adjust the excitation system stabilizer for satisfactory performance per manufacturer's instruction books and guidelines given in IEEE Std 421.2-1990 [11].

10.3.3 Test with Synchronous Machine Connected to Power System

These tests are the responsibility of the user with the participation of the manufacturer's representative, if specified by the user.

1) Verify that polarity and phase relationships of machine terminal voltage and current signals to the excitation system are in accordance with the contract drawings and the manufacturer's instruction books.
2) Verify satisfactory transfer of excitation control from the manual to automatic control mode and vice versa.
3) Verify settings and operation of compensators, limiters, and protective devices using machine terminal current and voltage signals per manufacturer's instruction books.

NOTES:

Test settings may be used if power system conditions preclude testing with final in-service setting.

1 — Final determination of suitable settings for some devices is the responsibility of the user; however, the manufacturer may provide suggested settings when specifically requested.

2 — Verify settings and operation of power system stabilizers, where applicable, per instructions in manufacturer's instruction books and guidelines given in IEEE Std 421.2-199 [10] or alternately in accordance with user's test procedure.

3 — Where feasible, verify final setting and operation of all excitation control and protection elements with machine operating in normal and "worst-case" system configurations.

4 — Verify small signal transient response, and where applicable (for high-initial response systems) excitation system voltage time response, ceiling voltage, and response ratio according to guidelines given in IEEE Std 421.2-1990 [10].

10.4 Routine Tests of Other Components

All other electrical parts, i.e., bus ducts, regular rheostats and similar devices, should be tested individually in accordance with the applicable IEEE and ANSI Standards.

In the event parts are mass produced and the routine tests performed on them are in accordance with the above noted standards, individual tests of such parts will not be required.

It may be more practical to test these individual components in the factory as applicable. However, in any event, the contractor should submit certified test data covering each part.

Annex A AC-DC Power Converters (Informative)

(This Appendix is not a part of IEEE Std 421.4-1990, IEEE Guide for the Preparation of Excitation System Specifications, and is included for information only.)

Naturally commuted power converters are produced in a variety of configurations of thyristors and diodes. The operation of these converters is frequently explained with reference to the four quadrants of an xy coordinate system. The coordinates are voltage (x) and current (y). There are four possible modes of operation depending upon the polarity of the voltage and the current.

Quadrant 1 is for voltage and current, both of which are positive. Power flow is from the ac source to the dc load. An example of this type of operation is a diode bridge that supplies a dc load. The dc voltage is adjusted by controlling the ac supply voltage to the rectifier. A bridge composed of thyristors in one set of legs and diodes in the other set will also operate in quadrant 1. In this case, the ac supply voltage can be fixed and the dc voltage adjusted from zero to maximum by controlling the firing angle of the thyristors.

Quadrant 2 operation is when the voltage is negative but the current is still positive. In this case, the power flow is from the dc system to the ac system. A full thyristor bridge can operate in this mode. For firing delay angles of 0 to 90°, this bridge functions as a quadrant 1 rectifier (ac power to dc). With firing delay angles of 90° to 180°, it functions as a quadrant 2 inverter (dc power to ac). An inductive load is necessary to maintain positive current flow during negative voltage excursions.

Quadrant 3 and 4 operations are similar to quadrant 1 and 2 operations, respectively, except that both the current and voltage are reversed. This type of operation is implemented by a reverse polarity connection of quadrant 1 and 2 equipment.

Excitation systems employing solid-state rectification are normally supplied either as one-quadrant or two-quadrant devices.

Unusual applications requiring both positive and negative current must be supplied as four-quadrant devices. A four-quadrant device may be made up of two two-quadrant devices in anti-parallel. The ratings of the positive and negative section can be different. Four-quadrant converters are not normally justified for excitation systems since the improvement resulting from the negative current is minimal. They are primarily used on dc reversing motor drives or ac cycloconverter drives where current as well as voltage must be reversed.