

Synchronous machines essay sample



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A synchronous machine rotates at a constant speed in the steady state. Unlike induction machine the rotating air gap field and the rotor in the synchronous machine rotate at the same speed called the synchronous speed. A synchronous machine can operate as both motor and generator. They are used primarily as electrical power generators. They are usually large machines generating electrical power at hydro, nuclear or thermal power stations. Synchronous generators with power rating of several hundred MVAs are quite common in generating stations. Synchronous generators are the primary energy conversion devices of the world's electrical power systems today. Because the rotor speed is proportional to the frequency of excitation, synchronous motors can be used in situations where constant speed drive is required. In industry, synchronous motors are used mainly where constant speed is desired. In industrial drivers, therefore synchronous motors are not as widely used as induction or dc motors a linear version of the synchronous motor (LSM) is being considered for high speed transportation systems of the future. An important feature of the synchronous motor is that it can drop either lagging or leading reactive current from the ac supply systems. A synchronous machine is a doubly excited machine.

Its rotor poles are excited by a dc current and its starter buildings are connected to the ac supply. The air gap flux is therefore the resultant of the fluxes due to both rotor current and stator current. In a synchronous motor if the rotor field winding provides just the necessary excitation, the stator will draw no reactive current; that is the motor will operate at a unity power factor. If the rotor excitation current is decreased, lagging reactive current

will be drawn from the ac source to aid magnetization by the rotor field current and the machine will operate at a lagging power factor. If the rotor field current is increased leading reactive current will be drawn from the ac source to oppose magnetization by the rotor field current and the machine will operate at a leading power factor. Thus by changing the field current the power factor of the synchronous motor can be controlled. If the motor is not loaded but is simply floating on the ac supply system it will thus behave as a variable inductor or capacitor as its rotor field current is changed.

A synchronous machine with no load is called a synchronous condenser. It may be used in power transmission systems to regulate line voltage. In industry synchronous motors are sometimes used with other induction motors and operated in an over-excited mode so that they draw leading current to compensate the lagging current drawn by the induction motors, thereby improving the overall plant power factor. The field excitation of a synchronous machine may be provided by means of permanent magnets, which eliminate the need for a DC source for excitation. This can not only save energy for magnetic excitation but also dramatically simplify the machine structures, which is especially favorable for small synchronous machines, since this offers more flexibility on machine topologies. The diagram below illustrates the cross sections of two permanent magnet synchronous machines

SYNCHRONOUS MACHINE STRUCTURES

Stator and Rotor

The armature winding of a conventional synchronous machine is almost invariably on the stator and is usually a three phase winding. The field

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winding is usually on the rotor and excited by dc current, or permanent magnets. The dc power supply required for excitation usually is supplied through a dc generator known as exciter, which is often mounted on the same shaft as the synchronous machine. Various excitation systems using ac exciter and solid state rectifiers are used with large turbine generators. There are two types of rotor structures: round or cylindrical rotor and salient pole rotor as illustrated schematically in the diagram below. Generally, round rotor structure is used for high speed synchronous machines, such as steam turbine generators, while salient pole structure is used for low speed applications, such as hydroelectric generators. The pictures below show the stator and rotor of a hydroelectric generator and the rotor of a turbine generator.

EXCITATION SYSTEMS IN SYNCHRONOUS MACHINE

The basic function of the excitation system is to provide d. c. current to the synchronous machine field winding. It also performs protective and control functions essential to the satisfactory performance of the power system by controlling the field voltage and thereby the field current. The control functions include the control of voltage and reactive power flow, and the enhancement of system stability. The protective functions ensure that the capability limits of the synchronous machine, excitation system and other equipment are not exceeded. Arrangement of and Requirements for an Excitation System.

The direct current required to energize the field winding of a synchronous machine is taken from what is known as an exciter. Most frequently, this is a d. c. generator whose shaft is mechanically coupled to that of the associated

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synchronous machine. Apart from the main exciter, the system contains a pilot (or auxiliary) exciter to energise the field winding of the separately excited main exciter, adjusting rheostats, contactors, remote control facilities, automatic voltage regulators, and some other items. (1)Field current control. In large synchronous machines , the d. c. field current , I_f , runs into hundreds or even thousands of amperes. Therefore, it would be wasteful of power to adjust it with a rheostat connected in the field (armature) circuit of the exciter. The losses in the rheostat would markedly reduce the efficiency of the synchronous machine. The field current is therefore adjusted solely by varying the exciter field voltage, V_f , because the field current varies

Elements of an Excitation System

1)Exciter : Provides dc power to the synchronous machine field winding, constituting the power stage of the excitation system. 2)Regulator : Processes and amplifies the input control signals to a level and form appropriate for control of the exciter. This includes both regulating and excitation system stabilizing functions. 3)Terminal voltage transducer and load compensator : Senses generator terminal voltage, rectifies and filters it to dc quantity, and compares it with a reference which represents the desired terminal voltage.

In addition, load (or line-drop, or reactive) compensation may be provided, if it is desired to hold constant voltage at some point electrically remote from the generator terminal (for example, part way through the step-up transformer). 4)Power system stabilizer: Provides an additional input signal to the regulator to damp power system oscillations. Some commonly used input signals are rotor speed deviation, accelerating power and frequency

deviation. 5) Limiters and protective circuits : These include a wide array of control and protective functions which ensure that the capability limits of the exciter and synchronous generator are not exceeded. Some of the commonly used functions are the field-current limiter, maximum excitation limiter, terminal voltage limiter, volts-per-Hertz regulator and protection, and underexcitation limiter. These are normally distinct circuits and their output signals may be applied to the excitation system at various locations as a summing input or a gated input.

Types of Excitation Systems

DC excitation system: This is the traditional method. A DC generator mounted on the main shaft may be of either the shunt-wound or the separately-excited type. The output current is fed to the rotor of the synchronous machine through slip-rings. • Static excitation system: Here, DC excitation can be obtained by means of a rectifier and a suitable AC supply. This method eliminates the commutation limits inherent in DC exciters. The rectifier unit has no moving parts, requires very little maintenance, and is immune to hazardous or dusty atmospheres. • AC excitation system: The AC exciter is mounted on the main shaft. Its field is fed from a pilot exciter, whose field in turn is obtained from a permanent-magnet generator. The AC exciter output voltage is rectified and fed to the field of the synchronous machine via slip-rings.

DC excitation system:

Source of excitation power: DC generators.

The system provides current to the rotor of the synchronous machine through the slip rings. The exciter may be driven by a motor or the shaft of

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the generator. It may be self-excited or separately excited. When separately excited, the exciter field is supplied by a pilot exciter comprising a permanent magnet generator. AC excitation system:

Source of excitation power: Alternators (ac machines)

The ac output of the exciter is rectified by either controlled or non-controlled rectifiers to produce the direct current needed for the generator field. The rectifiers may be stationary or rotating. The different forms of AC excitation systems are:

1) Stationary rectifier systems: With stationary rectifiers, the dc output is fed to the field winding of the main generator through slip rings. When non-controlled rectifiers are used, the regulator controls the field of the ac exciter, which in turn controls the exciter output voltage. 2) Rotating Rectifier Systems: With rotating rectifiers, the need for slip rings and brushes is eliminated, and the dc output is directly fed to the main generator field. The armature of the ac exciter and the diode rectifiers rotate with the main generator field. A small ac pilot exciter, with a permanent magnet rotor rotates with the exciter armature and the diode rectifiers. The rectified output of the pilot exciter stator energises the stationary field of the ac exciter.

The voltage regulator controls the ac exciter field, which in turn controls the field of the main generator. Such a system is referred to as a Brushless Excitation System. It was developed to avoid problems with the use of brushes that were perceived to exist when supplying the high field currents of very large generators. However with well maintained brushes these

problems did not actually develop. AC excitation systems with and without brushes have performed equally well. High initial-response performance of brushless excitation can be achieved by special design of the ac exciter and high voltage forcing of the exciter stationary field winding. These systems do not allow direct measurement of generator field current or voltage. Manual control of main generator voltage is provided by an adjustable dc input setting to the thyristor gating circuits.

Static Excitation Systems:

Components in these systems are static or stationary. Controlled or uncontrolled, static rectifiers supply the excitation current directly to the field of the main synchronous generator through slip rings. The supply of power to the rectifiers is from the main generator (or the station auxiliary bus) through a transformer to step down the voltage to an appropriate level, or in some cases from auxiliary windings in the generator. The forms of static excitation systems: 1) Potential-source controlled-rectifier systems: The excitation power is supplied through a transformer from the generator terminals or the station auxiliary bus, and is regulated by a controlled rectifier. This type of excitation system is also commonly known as a bus-fed or transformer-fed static system. This system has a very small inherent time constant. The maximum exciter output voltage (ceiling voltage) is, however, dependent on the input ac voltage. Hence, during system fault conditions causing depressed generator terminal voltage, the available exciter ceiling voltage is reduced.

This limitation of the excitation system is, to a large extent, offset by its virtually instantaneous response and high post-fault field-forcing capability.

In addition, it is inexpensive and easily maintainable. For generators connected to large power systems such excitation systems perform satisfactorily. Compounding ancillaries, such as those described below, are not normally justified; they are likely important for generators feeding power directly into small industrial networks with slow fault-clearing. 2)Compound-source rectifier systems: The power to the excitation systems in this case is formed by utilizing the current as well as the voltage of the main generator. This may be achieved by means of a power potential transformer (PPT) and a saturable-current transformer (SCT). Alternatively the current and voltage sources may be combined by utilizing a single excitation transformer, referred to as a saturable-current potential transformer (SCPT).

The regulator controls the exciter output through controlled saturation of the excitation transformer when the generator is not supplying the load, the armature current is zero and the potential source supplies the entire excitation power, under loaded conditions, part of the excitation power is derived from the generator current. During a system fault condition, with severely depressed generator terminal voltage, the current input enables the exciter to provide high field-forcing capability. 3)Compound-controlled rectifier excitation systems: This system utilizes controlled rectifiers in the exciter output circuits and the compounding of voltage and current-derived sources within the generator stator to provide excitation power. The result is a high initial-response static excitation system with full “ fault-on” forcing capability. Since the source of power to a static excitation system is the main generator, it is in effect self-excited. The generator cannot produce any voltage until there is some field current. It is therefore necessary to have

another power source of power for a few seconds to initially provide the field current and energise the generator. This process of build-up of generator field flux is called field flashing. The usual field-flashing source is a station battery.

Recent Developments and Future Trends:

The advances in excitation control systems have been influenced by developments in solid-state electronics and the latest development has been the introduction of digital technology. Developments in analog-integrated circuitry have made it possible to easily implement complex control strategies. Thyristors continue to be used for the power stage. The control, protection and logic functions have been implemented digitally. Digital controls provide a cheaper and possibly more reliable alternative to analog circuitry. They have the added advantage of being more flexible allowing easy implementation of more complex control strategies, and interfacing with other generator control and protective functions.

Dynamic performance measures:

The effectiveness of an excitation system in enhancing power system stability is determined by some of its key characteristics. In this section, we identify and define performance measures which determine these characteristics and serve as a basis for evaluating and specifying the performance of the excitation control system. Following Figure shows the representation of the overall excitation control system in the classical form used for describing feedback control systems.

The performance of the excitation control system depends on the characteristics of excitation system, the generator, and the power system. Since the system is nonlinear, it is convenient to classify its dynamic performance into large-signal performance and small-signal performance. For large-signal performance, the nonlinearities are significant; for small-signal performance, the response is effectively linear.

Large Signal Performance Measures: Large signal performance measures provides a means of assessing the excitation system performance for severe transients such as those encountered in the consideration of transient, mid-term and long-term stability of the power system. Such measures are based on the quantities defined below. To permit maximum flexibility in the design, manufacture, and application of excitation equipment, some of the performance measures are defined “under specified conditions”; these conditions may be specified as appropriate for the specific situation. (a) **Excitation system ceiling voltage:** The maximum direct voltage that the excitation system is able to supply from its terminals under specified conditions. Ceiling voltage is indicative of the field-forcing capability of the excitation system; higher ceiling voltages tend to improve transient stability. For potential source and compound source static excitation systems, whose supply depends on the generator voltage and current, the ceiling voltage is defined at specified supply voltage and current. For excitation systems with rotating exciters, the ceiling voltage is determined at rated speed. (b) **Excitation system ceiling current:** The maximum direct current that the excitation system is able to supply from its terminals for a specified time.

When prolonged disturbances are a concern, the ceiling current may be based on the excitation system thermal duty. (c) Excitation system voltage time response: The excitation system output voltage expressed as a function of time under specified conditions. (d) Excitation system voltage response time: The time in seconds for the excitation voltage to attain 95% of the difference between the ceiling voltage and rated load-field voltage under specified conditions. The rated load field voltage is the generator field voltage under rated continuous load conditions with the field winding at (i) 75°C for windings designed to operate at rating with a temperature rise of 60°C or less; or (ii) 100°C for windings designed to operate at rating with a temperature rise greater than 60°C. (e) High initial-response excitation system: An excitation system having a voltage response time of 0.1 seconds or less.

It represents a high response and fast-acting system. (f) Excitation system nominal response: The rate of increase of the excitation system output voltage determined from the excitation system voltage response curve, divided by the rated field voltage. This rate, if maintained constant, would develop the same voltage-time area as obtained from the actual curve over the first half-second interval (unless a different time interval is specified) The nominal response is determined by initially operating the excitation system at the rated load field voltage (and field current) and then suddenly creating the three-phase terminal voltage input signal conditions necessary to drive the excitation system voltage to ceiling. It should include any delay time that may be present before the excitation system responds to the initiating disturbance.

Excitation System Nominal Response.

Referring to above figure the excitation response is illustrated by line ac.

This line is determined by establishing area acd equal to area abd: Nominal

$$\text{response} = (cd)/(ao)(oe)$$

Where, $oe = 0.5 \text{ s}$

$ao =$ rated load field voltage

The basis for considering a nominal time span of 0.5 s in the above definition is that, following a severe disturbance, the generator rotor angle swing normally peaks between 0.4 s and 0.75 s. The excitation system must act within this time period to be effective in enhancing transient stability. Accordingly, 0.5 s was chosen for the definition time period of nominal response. In the past, the nominal response has been a well-established and useful criterion for evaluating the large-signal performance of excitation systems. With older and slower excitation systems, this was an acceptable performance measure, but it is not adequate to cover many of the modern excitation systems. In particular, it is not a good figure of merit for excitation systems supplied from the generator or the power system, due to the reduced capability of such systems during a system fault. For high initial-response excitation systems, the nominal response merely establishes the required ceiling voltage. The ceiling voltage and voltage response time are more meaningful parameters for such systems.

Small-Signal Performance Measures

Small-signal performance measures provide a means of evaluating the response of the closed-loop excitation control systems to incremental changes in system conditions. In addition, small-signal performance

characteristics provide a convenient means for determining or verifying excitation system model parameters for system studies. Small-signal performance may be expressed in terms of performance indices used in feedback control system theory:

- Indices associated with time response; and
- Indices associated with frequency response

The typical time response of a feedback control system to a step change in input is shown in figure below. The associated indices are rise time, overshoot, and settling time.

Typical Time Response to step input.

Typical open-loop frequency response of an excitation control system with the generator open-circuited

A typical open-loop frequency response characteristic of an excitation control system with the generator open-circuited is shown in figure above. The performance indices associated with the open-loop frequency response are the low frequency gain G , crossover frequency ω_c , phase margin and gain margin M_g . Larger values of G provide better steady-state voltage regulation, and larger crossover frequency indicates faster response. Larger values of phase margin and gain margin provide a more stable excitation control loop. (The reference here is to excitation control system stability and not power system synchronous stability.) In timing the voltage regulator, an improvement to one index will most likely be to the detriment of other indices. For example, an increase in regulator gain will shift the gain curve in figure above upward. This has the beneficial effect of increasing the low-frequency gain and crossover frequency, but has the undesirable effect of

decreasing the gain and phase margins. In general, a phase margin of 40° or more and a gain margin of 6 dB or more are considered a good design practice for obtaining a stable, non-oscillatory voltage regulator system.