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Research on AC Excitation Regulation Control System for Synchronous Generators

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Abstract: Although there are many methods for classifying the excitation systems of synchronous motors, there are three types of excitation systems for synchronous motors based on the numerous methods of providing excitation power to synchronous generators. One is a DC excitation system, the second is an AC excitation system, and the other is a static excitation system. This paper mainly studies the AC excitation system. The rotor speed of AC excited generators is variable and has excellent characteristics such as improving power system stability, allowing for deep operation without losing step. AC excitation generators not only have variable speed and constant frequency power, but also have independent adjustment functions for speed, reactive power, and effective power. The use of high-performance variable frequency excitation power supplies and appropriate excitation control methods can maximize the reliability, operational flexibility, and exceptional adjustment performance of AC excitation generators. The excitation system is an important part of synchronous generator operation. A good excitation system not only ensures the stable and reliable operation of the generator, but also greatly improves the stability of the motor and power system.

Keywords: Synchronous generator, AC excitation system, Stability.

1. Introduction

(1) Background and significance of this study

The increasing scale of modern power systems ensures the reliability and stability of system operation. High quality electricity energy supply plays a particularly important role in improving people's economic development and living standards, and is of great significance. The excitation control system of synchronous generators plays a very powerful role, and it is a particularly important part in power control. It can not only maintain a certain range of reactive power adjustment for a certain generator terminal voltage, but also ensure dynamic and transient stability in power operation. Its optimization and development are very important for the application of generators and power systems.

(2) Development Status of AC Excitation Generators at Home and Abroad

AC excitation generators have many excellent working performance. In daily work, if you want to improve some of the generator's working performance, you can choose appropriate excitation control methods. Therefore, whether in China or abroad, there have been a large number of scholars learning and understanding this aspect. As early as the 1950s, countries such as Europe and the United States began exploring new methods to solve power system stability and reactive power problems, proposing AC excitation generators and starting research.

The research on AC excited generators began with dual axis motors, as the name suggests, which are motors with two shafts. The use of three-phase AC excited rotors has attracted more attention from scholars. After 1980, Japan learned AC excitation power generation technology and invested it in flywheel energy storage and pumped energy storage power plants, with considerable results. Two Japanese companies collaborated in 1987 and 1993 to start two units. In 1990, two power stations also jointly started one unit and developed a higher power unit. [1] Two power stations and one company in Japan continuously adopt three-phase AC excitation power generation technology. The situation shows that the variable speed operation of the waterwheel improves the operational efficiency of the waterwheel, enhances the automatic frequency adjustment ability of the pump under operating conditions, and improves the stability of the system through rapid adjustment of active and reactive power.

Western Europe and some other countries have also conducted many practical and experimental discussions on AC exciters and their systems. For example, a French scholar conceived a new type of generator with constant frequency and variable speed, and validated it using MATLAB software to perform simulations.

The domestic research on AC excitation generators began in the mid-1980s. The electrical engineering major at Chongqing University conducted a lengthy discussion on the principle data and electromagnetic design application of d-axis and q-axis excitation asynchronous generators.[2] Teachers from Huazhong University of Technology learn and understand the control system of dual axis excitation synchronous generators.

2. Basic Knowledge and Structure of Synchronous Generators

(1) Basic working principle of synchronous generators

The energy conversion of a motor is performed by the back and forth movement of the relative position between the charged conductor and the magnetic field. Therefore, from a structural perspective, a rotating motor consists of two parts, one of which is static and called the stator; The other part is dynamic, and the rotating part is called the rotor. There is a space between the stator and rotor, called an air gap, which constitutes the main magnetic circuit of a synchronous motor. Ferromagnets are the materials of the stator and rotor in the motor, and the air gap between the stator and rotor becomes the main magnetic path in the synchronous motor. [3] The circuit of a synchronous motor mainly consists of the following parts: one is the excitation circuit, and the coil that makes up the circuit is called the excitation winding. Because the magnetic conductivity of the ferromagnetic coil is relatively good, the excitation winding is connected to the direct current to generate the main magnetic flux, and the excitation winding is usually installed on the rotor; One is an armature circuit, which can sense electromotive force on its coil. It is not installed on the rotor, but on the stator, and is generally in the form of three-phase. A synchronous generator can be regarded as a generator or as an electric motor. When it operates as a generator, the motor will also drive the rotor and input direct current. When it passes through the space air gap, it will generate a repeatedly rotating magnetic field, causing it to move back and forth. When the armature conductor of the stator is blocked by the magnetic field, AC electromotive force will occur. If the air gap magnetic flux density is sinusoidal, then a sinusoidal three-phase electromotive force will appear in the stator three-phase winding. The frequency f of alternating current electromotive force is determined by the number of pole pairs p of the motor and the speed n of the rotor. When the motor has a pair of poles, the electromotive force induced by the conductor will undergo a periodic change when the rotor rotates once; In the case of a motor with p opposite poles, if the rotor rotates once, the electromotive force induced by the conductor will undergo p periodic changes.

(2) Basic structure of synchronous generators

A synchronous generator consists of two parts: a rotor and a stator.

The stator has a stator coil, iron core, shell, etc. The stator coil outputs electrical energy through induced electromotive force, the iron core provides a magnetic circuit, and the shell provides protection.

The rotor has a coil, iron core, and slip ring, and the rotor coil is used for excitation. The iron core provides magnetic circuits and rotating shafts. The slip ring and brush form a dynamic and static combination. The excitation control part outside the rotor is used for excitation and control of output voltage of the generator.[4]

3. Excitation System

(1) Excitation method of synchronous generator

The synchronous generator excitation system can be divided into DC excitation system, AC excitation system, and self-excited static excitation system according to the difference in excitation power supply of the output unit:

DC exciter system: The generator has a special DC generator called a DC exciter. The exciter generally has the same axis as the generator, and the excitation winding of the generator inputs DC current from the exciter end by changing the position of the fixed brush installed on the main shaft.

AC exciter system: After the current is emitted from the exciter, it is transmitted to the rectifier. The rectifier can convert the input AC power into DC power and then transmit it to the generator rotor, thus achieving excitation. Meanwhile, due to the use of static rectification equipment, it is also known as separate excitation static excitation.

Self excited static excitation system: When power is converted into the generator itself to achieve excitation, it is called self excited static excitation. Self excited static excitation can be divided into self parallel excitation method and self compound excitation method.

(2) Principle of excitation system

The rotor of a generator has two parts: a coil and an iron core. The rotor coil needs to be energized to form a certain magnetic field. The DC power is supplied by the excitation system. Therefore, if you want the excitation system to produce a rotating magnetic field, you only need to input DC power to the generator rotor. The magnetic field moves relative to the stator, and the stator can sense the electromotive force, so the generator generates electricity.

(3) Composition of excitation system

Power section: This includes the power supply and power rectifier (without rectifier). This is a very important unit of the excitation system, which supplies appropriate excitation current to the generator rotor. Based on the function of the power unit, determine the main circuit style and the device with the highest function of the excitation system.

Automatic excitation regulator: Automatic excitation regulator is an intelligent device in the excitation system. The performance of the automatic excitation regulator plays an extremely important role, as it can control the entire excitation system.

Automatic adjustment excitation device: When measuring signals such as current and voltage, the transmitter is sent to the measurement unit for conversion, facilitating comparison with the given value. The result of this comparison is a deviation, which is increased by the amplifier to facilitate the control of the opening angle of the thyristor, thereby changing the magnitude of the excitation current.

The excitation control, protection, and signal loop consists of an excitation suppression switch, auxiliary circuit, fan in the cabinet, implicit triggering of the excitation suppression switch, failure of the regulator, variable excitation overcurrent, abnormal generator operating state, power transmitter, etc. When there are related problems with synchronous generators, demagnetization is necessary to quickly reduce the rotor magnetic field. The main function of the demagnetization device is to shorten the demagnetization time as much as possible without applying pressure to the rotor. According to the specified excitation voltage, demagnetization methods can be linear or nonlinear.

(4) Principle of excitation current regulation

The excitation current of a generator usually does not change through the rotor circuit. In the rotor circuit, the current is very large and difficult to adjust. The usual method is to adjust the excitation current to change the magnitude of the rotor current.

The commonly used methods include: changing the resistance of the excitation circuit of the excitation device, changing the additional excitation current of the excitation device, and changing the conduction angle of the thyristor. However, the conduction angle of the thyristor rectifier will fluctuate accordingly due to changes in generator voltage,[5] current, and power. After the conduction angle changes, the excitation current will also change accordingly. The assembly of this device is generally composed of transistors and silicon controlled electronic components, which have the advantages of sensitivity, fast speed, fault free area, large output power, small size, and light weight. If a fault occurs, it can not only suppress the excessive voltage of the generator, but also achieve rapid deexcitation.

4. Basic Theory of AC Excitation Generators

(1) Mathematical model of AC excitation generator in A-B-C three-phase coordinate system

AC excitation generators have a structure similar to three-phase winding motors, which provides convenience for the learning of AC excitation machines. When deriving the mathematical model of AC excitation generators, the following assumptions are often made:

1. If the generator does not have a damping coil, then it has a pair of electrodes; 2. Negligent saturation magnetic circuit, with constant self inductance and mutual inductance between each coil; 3. The three-phase windings differ by 120 degrees from each other in space, and the generated magnetoelectric potential is distributed in a sinusoidal shape around the periphery of the air gap; 4. Negligent consumption of iron cores; 5. Do not consider the interference of temperature and frequency.

Firstly, it is necessary to specify the positive direction of current, voltage, and flux chain, as shown in the following figure. The three-phase winding of the stator is a_s, b_s, c_s the axis evenly divides 360 degrees in space, with a difference of 120 degrees between the two. Rotor winding shaft a_r, b_r, c_r like the stator winding circumference, the two are 120 degrees apart from each other and rotate together with the rotating rotor, a_r axis and a_s there is an angle difference between the axes, assuming that θ Corner, θ The angle can be changed, and the positive direction of the winding axis of each phase plays a more important role, and is selected as the positive direction of the magnetic linkage of each phase winding.

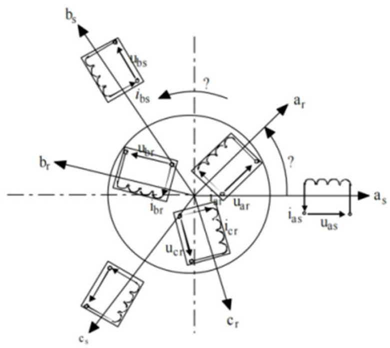

Figure 1. Physical Model of AC Excitation Generator

(2) Mathematical Model of AC Excitation Generator in D-Q-O Coordinate System

In addition to the A-B-C coordinate system with real changes, the motor equation can also be represented by various coordinate systems such as fixed coordinate systems in space, coordinate systems with rotor motion, and constant synchronous rotation speed.[6] AC exciter has the following operating characteristics:

The rotor speed may not be equal to the synchronous speed;

The rotor speed has a composite magnetic electromotive force, and the rotor winding is probably not zero above this;

The angular rate of the rotor magnetic potential in the space after the stator end is connected to the power system is similar to the angular frequency of the power grid, and is almost stable.

Therefore, in the D-Q-O coordinate, select a variable that synchronizes with the speed ω_0 rotation is used to replace the actual variable in the A-B-C coordinates. In a stable state, each electromagnetic quantity is combined into a space vector that is stationary relative to the coordinate axis, and is a direct flow in the D-Q-O coordinate system. The equation form in an AC exciter is a nonlinear and time-varying coefficient differential equation, while in the D-Q-O coordinate system, it is a constant coefficient differential equation, which includes other quantities such as current and magnetic flux links that exist in both DC and DC modes.

5. Simulation and Results

(1) Simulation Model of AC Exciter

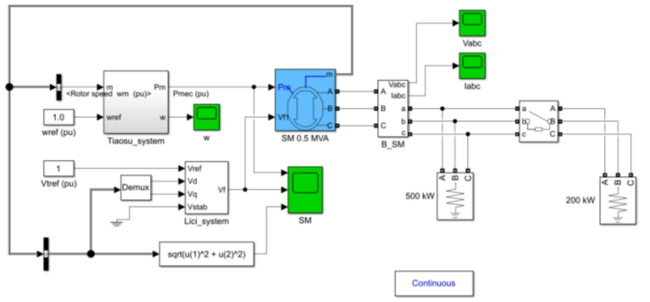

Figure 2. Simulation Model of AC Exciter

On the left side of the model, there is a speed regulation system and an excitation system. The speed regulation system ensures a stable output frequency of voltage, and the output of the excitation system is the magnetic field voltage vfd (in pu), which is used to apply the Vf Simulink input to the Synchronous Machine module. There are two three-phase parallel RLC loads on the right side, and the initial load power of the system is 500kW. The load power of 200kW is set and cut off through the circuit breaker module in the upper right corner to observe the dynamic performance of the system. And through the B-SM module, three-phase AC voltage and three-phase AC current can be measured. This part is connected to the electrical terminal of the synchronous generator, and the output terminal of the synchronous generator outputs the rotor speed and AC excitation voltage. The rotor speed is then fed back to the speed control system and excitation system. In the speed control system, the reference speed is set to 1 unit, with the rotor speed as the input and the output mechanical power as the input of the synchronous motor. In the excitation system, the reference voltage is set as a unit, with vd and vq as inputs, and the output excitation voltage is used as the input of the synchronous motor.

(2) Simulation analysis of AC exciter

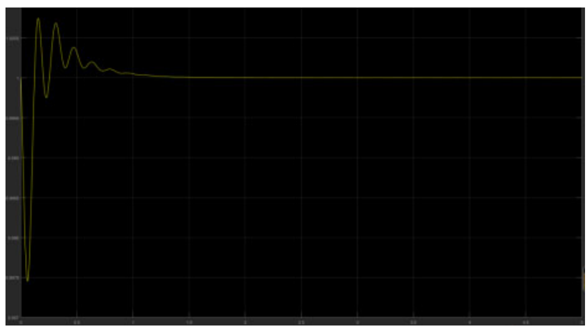

Figure 3. Angular velocity of the generator

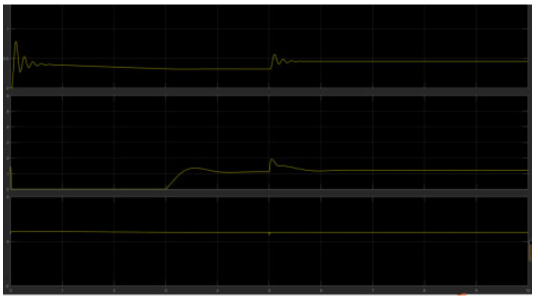

Figure 4. Oscilloscope Output (from top to bottom: Output Power, Excitation Voltage, Output Voltage)

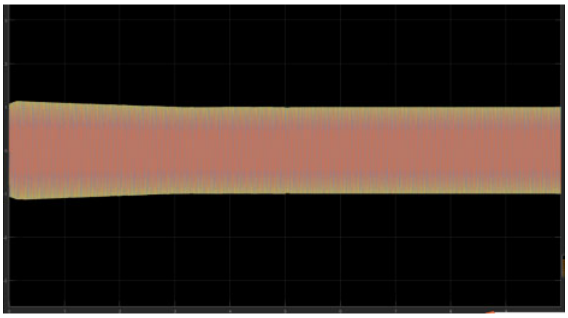

Figure 5. Output three-phase AC voltage

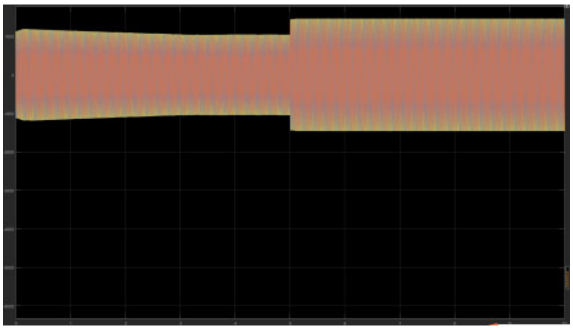

Figure 6. Output three-phase AC current

From Figures 3, 4, 5, 6, it can be seen that when the load power of 200kW is set at the fifth second, it can be observed that there is a significant increase in output power, and the output amplitude is attenuated oscillation, which then remains stable; The output amplitude of the excitation voltage decreases monotonically and then tends to stabilize; The output voltage remains unchanged and unaffected; The output three-phase AC voltage also does not change; The amplitude of the output three-phase AC current increases and remains unchanged.

It can be seen that by changing the magnitude of the excitation current, the variable speed and fixed frequency power generation operation of the AC exciter can be achieved, and the stability of the power system can be improved.

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