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Control and Configuration of Generator Excitation System as Current Mainstream Technology of Power System

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ABSTRACT: An Integral part of generator is Excitation System and new technology of Excitation System has been developed utilizing a power sources. The most important a portion of electric power system is synchronous generator due to it is the source of electrical energy and energy transformation is possible only when generator excitation exists. The generator excitation systems work when generator excitation system operates a dc charge to the generator heads to energize the field of magnetic around them to enable the electricity that should be generated. There are brushless and brush-type exciters and generators are built in exciters or charge can be established from any external source. This paper presents the control and configuration of synchronous generator excitation system as current mainstream technology, which is widely designed for feeding of turbo generator excitation winding with auto- regulated DC in generator operation, control normal and emergency modes. In this paper discuss appended on excitation system models of synchronous generator and emphasis on drawbacks, different possibilities to regulate generator excitation, de-excitation systems and overvoltage Protection with special newly developed nonlinear system regulation. And also append short descriptions of functions, compositions, Structure and Working Principle of Generator Excitation System.

KEYWORDS: Generator, Excitation System, De-excitation System, Overvoltage Protection, Function, Working principle.

1 INTRODUCTION

Synchronous generator excitation system is key part of the power system [1]. The excitation system of a synchronous generator makes it possible to supply the energy generated by an engine (turbine) to the power grid. As a result, high priority is assigned to the reliability and availability of excitation equipment when choosing systems [7]. This paper looks at the issue of current mainstream technology of generator excitation system and brief introduce is done of technical levels of generator excitation and de-excitation system for the industrial technical communication.

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2 FUNCTIONS OF GENERATOR EXCITATION SYSTEM

The function of generator excitation system contributes stable operation of power system which is included in three mainstream steps [2]. First is maintaining the voltage of generator or other control points at reference value. Second is Control the reasonable distribution of reactive power of parallel operation unit and third is improve the stability of power system. 1st step is ensure the safety of operating equipment of power system, Ensure the economical operation of generator and the requirement for improvement of capability of maintenance generator voltage is consistent with that for improvement of power system stability in many respects. 2nd step is droop/ voltage-droop compensation, droop expressed as percentage of rated generator voltage when the reactive current of generator changes to rated value from zero under such conditions that voltage-drop compensation unit is switched on, reference value of voltage is fixed and power factor is zero and drop of generator is calculated according to the following formula:

D(%)=[(Ug0-Ug)/Ug]×100%

In which, Ug0 --- voltage value when the reactive current of generator is zero

Ug --- voltage value when the reactive current of generator equals to rated reactive current

3rd step cases the Parallel connection at high voltage side of generator-transformer unit: droop of transformer (positive droop) + droop of generator (negative droop), droop of long power transmission line (positive droop) + drop of generator (negative droop), expanded unit connection of 2 generators with 1 transformer: Positive droop

3 STRUCTURE AND WORKING PRINCIPLE OF GENERATOR EXCITATION SYSTEM

Composition of Generator Excitation System: Composition of generator concluded in the following technical levels

- Excitation transformer
- Thyristor rectifier bridge
- Automatic excitation regulator
- Field flashing device
- Rotor overvoltage protection and de-excitation device

3.1 CONTROL ALGORITHM OF GENERATOR EXCITATION SYSTEM

PID regulator for control as per proportion, integral and differential is one of the most widely used regulators with mature technology in continuous system control. Proportional regulation can reduce the inertia time constant of control system, but will lower its stability and cannot eliminate the steady-state error; Integral regulation can eliminate the steady-state error; Differential regulation can improve the stability of control system and accordingly increase the amplification factor of proportional regulation.

$$Gc(s) = \frac{Y(s)}{E(s)} = Kp \bullet \frac{1+Tc1\bullet s}{1+Tb1\bullet s} \bullet \frac{1+Tc2\bullet s}{1+Tb2\bullet s} \quad (1)$$

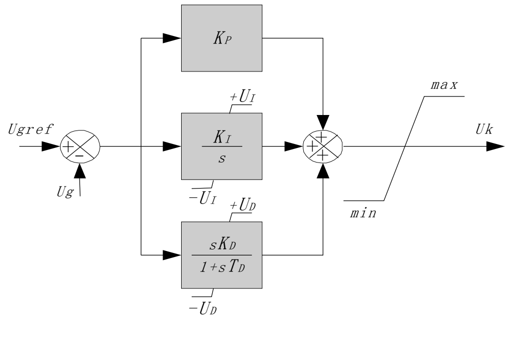

Fig. 1. Model of Parallel PID Regulation

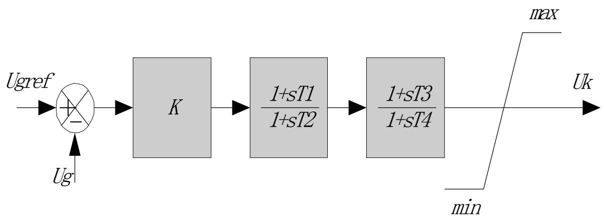

Fig. 2. Model of Series PID Regulation

3.2 POWER SYSTEM STABILIZER (PSS)

To solving the dynamic instability problem in power systems is widely installed Power system stabilizer (PSS) [9]. With the development of power system, occurrence and expansion of interconnected power system and application of fast automatic excitation regulator and fast excitation system, the low-frequency power oscillation occurs in power system, seriously affecting the safe and stable operation of power system, which has been one of the most important restriction factors for improvement of transmission power limit of tie line. The power system stabilizer, PSS for short, designed according to F.D. Demello and C. Concordia principle, is just set to suppress the low-frequency oscillation and improve the dynamic stability of power system.

At present, the control mode PID+PSS has been widely applied in excitation system [3]. The electromagnetic torque of generator can be classified into synchronous torque and damping torque. Synchronous torque (PE) has same phase with Δδ and damping torque with Δω. Insufficient synchronous torque will lead to sliding step-out and insufficient damping torque to oscillation step-out. An additional control input has to be introduced to counterbalance the negative damping torque caused by fast excitation regulation and increase the positive damping of unit. Make the additional torque produced by the additional input have the same phase with Δω through design and calculation. ΔMex=DAΔω+KAΔδ, producing negative damping DAΔW.

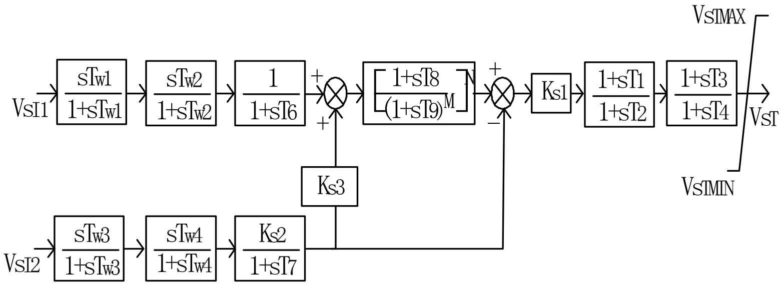

Fig. 3. Model-Block diagram PSS2A Model

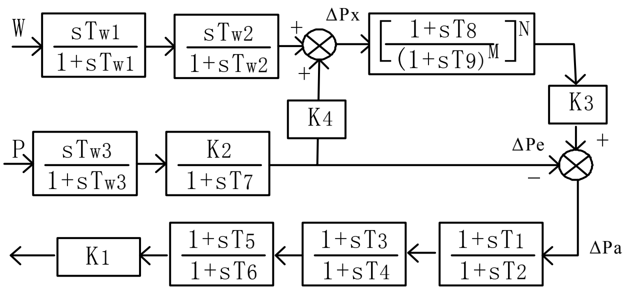

Fig. 4. Model-Block diagram PSS2B Model

4 THYRISTOR RECTIFIER OF GENERATOR EXCITATION SYSTEM

Firstly, discuss the case when controlling angle α=0. Within ωt0-ωt1, the potential of phase A is the highest and that of phase B is the lowest, which may form access. If the trigger pulse Ug6 of SCR6 of common anode group still exists before ωt0, trigger the pulse ug1 of SCR1 of common cathode at the time of ωt0 (α=0). In this way, SCR1 and SCR6 can form access: phase A of AC power →SCR1→R→SCR6→return to phase B of power supply. Obtain line voltage (Uab) from load resistance (R). Then, trigger pulse of each bridge arm in order to convert current successively. The waveform of 3-phase fully-controlled bridge rectifier circuit output voltage (Ud) is of 6 equal segments in one period, i.e. the period of output voltage (Ud) is one sixth of AC voltage period. Therefore, for calculation of its average voltage Ud, we only have to determine the average value of AC voltage U1cosωt within (-π/6+α)- (π/6+α). When α<90°, the output average voltage Ud is positive value and 3-phase fully-controlled bridge is in state of rectifier, which converters AC to DC.

$$U_d = \frac{1}{\frac{2\pi}{6}} \int_{\frac{2\pi}{6}+\alpha}^{\frac{2\pi}{6}+\alpha} \sqrt{2U_1} \cos \omega t d\omega t \quad (1)$$

$$U_d = \frac{3}{\pi} \sqrt{2U_1} \times 2\sin\frac{\pi}{6}\cos\alpha \quad (2)$$

$$U_d = 1.35U_1 \cos\alpha \quad (3)$$

4.1 INVERSION WORKING CONDITION

When α> 90°, the output average voltage Ud is negative value and 3-phase fully-controlled bridge is in state of inverter, which converts DC to AC. With 3-phase full-wave fully-controlled rectifier circuit, inverted de-excitation can be carried out when there is fault inside generator, which quickly feeds the energy originally stored by generator rotor field to AC power, so as to lower the damage extent of generator. The inversion of separate-excitation wiring can be finished quickly with good performance; while the inversion of self-excitation wiring is of poor performance. Besides, during excitation regulation, when α>90°, the excitation voltage of generator rotor becomes too negative value and reducing excitation quickly.β=180°-α is often called as inversion angle in fully-controlled bridge. Since inversion occurs only when α>90°, the inversion angle β is always less than 90°. The reverse DC average voltage of 3-phase fully-controlled bridge in state of inversion working can be expressed with following formula, Uβ=-1.35U1 COS (180°-β) =1.35U1COSβ. For 3-phase fully-controlled bridge rectifier circuit, the conduction angle of thyristor is fixed. The inversion angle is usually expressed with β, which varies within 0°-90°with the controlling angle α.

4.2 PROTECTION OF THYRISTOR

The performance of silicon element to withstand overvoltage and overcurrent is poor. The thyristor has limited capacity to bear forward voltage and current rate of rise. And the insulation of excitation winding of rotor has limited voltage-withstand capability. If no proper protection and suppression measures are taken, the tolerance range may be exceeded in operation, resulting to damage of related components in semiconductor excitation system. The overvoltage protection and overcurrent protection are two important basic part of protection of thyristor.

5 DE-EXCITATION AND OVERVOLTAGE PROTECTION OF GENERATOR EXCITATION SYSTEM

The safe and reliable de-excitation of synchronous generator not only concerns to self-safety of excitation system, but also has a direct bearing on the safe operation of whole power system. When generator stops normally: invert de-excitation.

When generator stops due to accident: de-excitation due to accident stop when there are faults inside generator, the relay protection activates to cut off main circuit breaker. In this case, quick de-excitation is required to be carried out; when electrical accident happens in generator, the de-excitation system quickly cuts off excitation circuit of generator and consumes the energy of magnetic field stored in excitation winding rapidly in de-excitation circuit.

5.1 REQUIREMENTS OF DE-EXCITATION

The requirements of de-excitation are involved in Time for De-excitation shall be as short as possible, The inverse voltage of De-excitation cannot exceed the specified multiple, The circuit and structure of de-excitation device shall be simple and reliable, The field circuit breaker shall have sufficient capacity to break the current of generator rotor and The de-excitation system shall have enough capacity.

Fig. 5. De-excitation of synchronous generator

5.2 CLASSIFICATION OF DE-EXCITATION SYSTEM

- Classification as per breaker function:
- Energy-consumed de-excitation: the field circuit breaker consumes energy of magnetic field.
- Energy-transferred de-excitation: the field circuit breaker doesn't consume energy of magnetic field.
- Classification as per breaker position:
- De-excitation of DC field circuit breaker: the field circuit breaker is installed at DC side.
- De-excitation of AC field circuit breaker: the field circuit breaker is installed at AC side.
- De-excitation of crowbar: use crowbar rather than field circuit breaker
- Classification as per type of de-excitation resistance:
- De-excitation of zinc oxide nonlinear resistance
- De-excitation of silicon carbide nonlinear resistance
- De-excitation of linear resistance

5.3 PRINCIPLE OF DC DE-EXCITATION

Principle for de-excitation of DC breaker: trip DC breaker MK at the time of de-excitation. Electric arc is produced at the break of DC breaker. The arc voltage plus SCR output voltage of rectifier equals to rotor induction against potential. The induction against potential is added to both ends of de-excitation resistance at the same time. When UR is more than the break-over voltage of de-excitation resistance, the de-excitation resistance circuit is conductive, which consumes energy of magnetic field for the purpose of de-excitation [6].

$$U_R = U_K - U_{SCR} \quad (4)$$

In De-excitation conditions of DC breaker: It is necessary to ensure that the sum of arc voltage at switch break and voltage output by rectifier exceeds the break-over voltage of de-excitation resistance when carrying out de-excitation in all operating conditions of generator. De-excitation features of DC breaker: Advantage: external logic cooperation is not required for de-excitation, ensuring simple operation. Disadvantage: high requirement for arc voltage at break of DC breaker, resulting to difficult breaker manufacturing.

5.4 DE-EXCITATION OF CROWBAR

The crowbar refers to rotor overvoltage protection device. Its basic circuit and principle are as follows: a group of thyristors forward and reverse paralleled connects with one discharge resistance firstly and then connects to two ends of excitation winding in parallel. When the trigger circuit of thyiristor detects rotor over-voltage, it sends out trigger pulse immediately to make thyristor be conductive and absorbs overvoltage energy through making use of discharge resistance. Advantage of crowbar: No breaker in main circuit, simple structure and high reliability; Disadvantage of crowbar: The maximum break-over voltage of crowbar circuit cannot be more than the peak voltage of AC line and the time for de-excitation is longer accordingly.

5.5 DE-EXCITATION RESISTANCE

The resistance for de-excitation can be linear resistance, nonlinear zinc oxide resistance or nonlinear silicon carbide resistance. For de-excitation of turbo generator, the solid generator rotor has strong damping effect. Although the current in excitation winding is rapidly reduced to zero, fast voltage attenuation of generator cannot be realized as the current in damping winding cannot be reduced quickly. And the current in damping winding is uncontrollable. Therefore, most generator units with strong damping effect use linear resistance for de-excitation and ones with weak damping effect use nonlinear resistance for de-excitation. For de-excitation of hydro generator, the generator rotor is not solid and its damping effect is also not strong. Besides, the generator voltage will raise a lot in failure conditions. Therefore, it is recommended to use nonlinear resistance for de-excitation, so as to effectively prevent accident expansion. The nonlinear resistance is classified into zinc oxide and silicon carbide.

5.6 SELECTION OF DE-EXCITATION CIRCUIT BREAKER

Rated voltage of de-excitation circuit breaker: shall be more than the maximum operational voltage of rotor; Rated operational current of de-excitation circuit breaker: shall be more than maximum long-term continuous operational current of rotor; Current breaking capacity of de-excitation circuit breaker: shall be more than ceiling current of rotor; Voltage breaking capacity of de-excitation circuit breaker: shall be more than the sum of voltage on field suppressing resistance and voltage output by thyristor rectifier.

5.7 DESIGN OF DE-EXCITATION

According to the stipulation of excitation national standard, the design multiple of de-excitation voltage shall not exceed 5 times of rated excitation voltage and is usually 3-5 times .According to the stipulation of excitation national standard, the design multiple of overvoltage shall not exceed 7 times of rated excitation voltage and is usually 5-7 times.

Problems taken into considerations for design of excitation system

1. Calculation of de-excitation capacity
2. Selection of de-excitation valve plate
3. Residual voltage and chargeability of de-excitation resistance
4. Average energy and current of nonlinear resistance

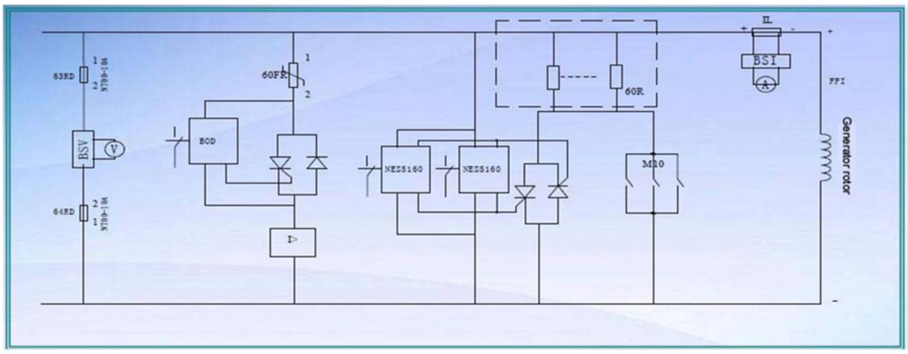

Fig. 6. Schematic Circuit Diagram of De-excitation

Main Circuit Design of De-excitation concluded in Crowbar is composed of mechanical corwbar M10, electronic corwbar and thyristor trigger module; Adopt linear or nonlinear resistance forde-excitation; the main element inside overvoltage trigger module is BOD; the overvoltage nonlinear resistance adopts ZnO resistance.

5.8 OVERVOLTAGE SOURCE

In addition to atmospheric overvoltage, the overvoltage is mainly caused by the mutual conversion and transfer of electromagnetic energy excited in circuit during circuit breaker operation in system and commutation and switch-on/off of thyristor element. The latter two kinds of overvoltage are respectively called as commutation overvoltage and operation overvoltage. The suppressing overvoltage protection is classified into AC side protection, DC side protection and element protection. The commonly used overvoltage protections are as shown in the figure (1—4RC is resistance-capacitance protection.

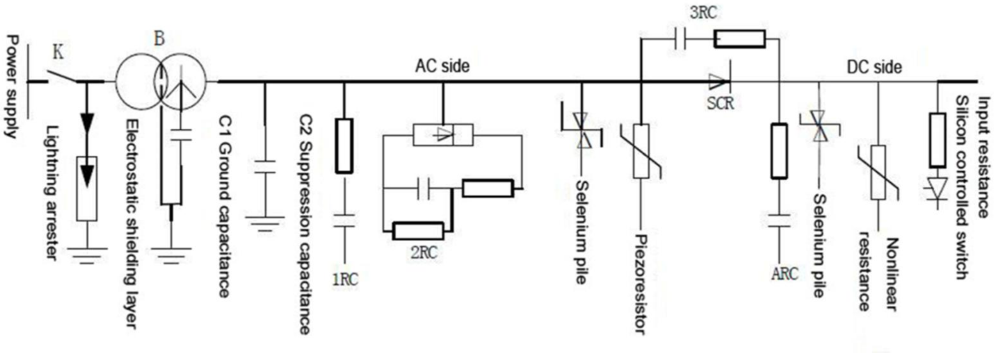

Fig. 7. Measures for Suppression of Overvoltage

In overvoltage protection, In order to limit the discharging current of capacitor, reduce the forward current increase rate di/dt caused by capacitor discharging current at the moment of thyristor switch-on and avoid oscillation produced by capacitance and circuit inductance, we usually connect proper resistance in capacitance circuit in series to form resistance-capacitance absorption protection. Usually, the transient voltage can be suppressed to such effect that not exceeding some permissible value, so as to realize the overvoltage protection of AC side, DC side and silicon element. Since the voltage at two ends of capacitor cannot sharply change, but can store electric energy, the transient surge energy can be absorbed to limit overvoltage.

6 CURRENT MAINSTREAM TECHNOLOGY AND CONFIGURATION OF GENERATOR EXCITATION SYSTEM

6.1 EXCITATION TRANSFORMER

The excitation transformer provides excitation source for excitation system. In early days, the excitation transformer usually adopts oil immersed transformer. Recently, with the development of dry-type transformer manufacturing technology and considerations for influence of fire protection, maintenance and other factors, the epoxy dry-type transformer is often used for excitation. The exciting transformer of large capacity is usually composed of 3 single phase dry-type transformers. The connection group of exciting transformer is usually of Y/△-11. Like common distribution transformer, the short-circuit voltage drop of exciting transformer is also 4%～8%.

6.2 THYRISTOR RECTIFIER

The thyristor bridge rectifier is a reliable productive topology and relative to the cost usually employed in medium voltage applications [8]. All large power rectifiers in self-excitation system are wired in 3-phase bridge mode, which ensures low voltage on semiconductor element and high use ratio of exciting transformer. Most self-excitation systems adopt fully-controlled bridge. The generator rotor is inductive load. When the controlling angle within 0°-90°, the 3-phase fully-controlled bridge is in rectifier state (produce forward voltage and forward current); when the controlling angle is within 90°-165°, the 3-phase fully-controlled bridge is in inversion state (produce reverse voltage and forward current). Therefore, when generator loads changes, we can regulate the field current through changing the controlling angle of thyristor, so as to ensure the constant generator voltage. Multiple rectifier bridges in parallel are usually adopted for excitation system of large unit, so as to ensure sufficient field current. The number of parallel branches of Rectifier Bridge is determined by the principle "(N+1) bridges". N stands for number of rectifier bridges required for normal excitation of generator. One rectification bridge faulted has no influence on normal excitation of excitation system.

6.3 EXCITATION CONTROL DEVICE

The excitation control device includes automatic voltage regulator and field flashing control circuit. For the automatic voltage regulator in self-excitation system of large unit, the regulation of PID (proportion, integral and differential) is carried out as per deviation. Voltage closed-loop regulation: measure generator voltage and compare it with given value. When the generator voltage is more than reference value, increase the controlling angle of thyristor and reduce field current, making the generator voltage return to setting value; when the generator voltage is less than reference value, reduce the controlling angle of thyristor and increase field current, maintaining generator voltage at setting value. At present, the regulator of NARI Electrical Control Company which has been put into operation mainly includes: SJ800 (no longer produced); SAVR2000 (no longer produced); NES5100.

6.4 DE-EXCITATION AND ROTOR OVERVOLTAGE PROTECTION DEVICE

De-excitation and rotor overvoltage protection device can be configured with field circuit breaker (must meet the breaking requirement under all extreme working conditions), linear de-excitation resistance and nonlinear resistance (flexibly select de-excitation resistance according to unit characteristics, unit capacity and difference of concrete requirement). When linear de-excitation resistance is configured, it has to be used together with the normally closed contact of field circuit breaker and be configured with independent rotor overvoltage protection device. When nonlinear resistance is used Forde-excitation, it can also ensure the rotor overvoltage protection. Therefore, the nonlinear resistance for de-excitation is widely applied in large generator unit, especially in hydro generator. Domestic companies mostly use high-energy zinc oxide valve plate and foreign companies mainly adopt silicon carbide resistance. At present, some domestic large units also adopt mechanical switch + silicon carbide Forde-excitation.

6.5 INTRODUCTION TO NES-HMI EXCITATION INTELLIGENT MONITORING INTERFACE

NES-HMI excitation intelligent monitoring interfaces Software is widely using in the industrial projects at China. NES5100 field regulator is equipped with 1 set of liquid crystal industrial control computer, 1 set of D-LINK exchange, and 3 pieces of network lines. The operating system is Windows XP. Here, the 3 pieces of network lines are connected with the industrial control computer, regulator A, and regulator B respectively. Well connect the network line of the regulator and D-LINK exchange, and of D-LINK exchange and industrial control computer. Input all power supply on the field regulator cabinet in the following sequence: D-LINK exchange, industrial control computer, regulator A and regulator B, and input and output power supply. In system topology, there are the schematic diagram of system connection, and visual graphic marks. If a graphic clicked is highlighted or brightened, it shows that the internal related data of this graphic may be observed. The interface is divided into upper part and lower part. Where, the upper part is the analogy pointer meter for generator unit stator sampling analog and the lower part is the real-time digital quantity of analogy sampling.

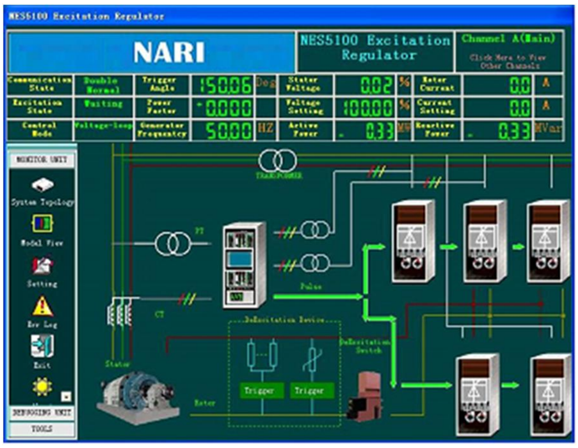

Fig. 8. Topology of NES-HMI excitation intelligent monitoring interface Software made by NARI Group of Corporation, China

The curve includes over-excitation and under-excitation curve; and the main interface includes graphic simulation zone and numerical value setting zone. The graphic simulation zone includes 5 buttons as shown in fig. 9. The vernier determines the “Starting Point Determination” and “End Point Determination” through moving vertical rectangular coordinate, and “Automatic Analysis” to automatically calculate the maximum value and the minimum value.

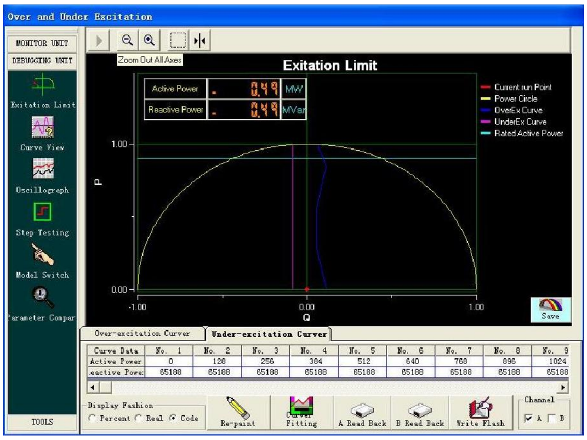

Fig. 9. Over/under-excitation parameter interface

7 CONCLUSION

The generator excitation system is most maintenance intensive subsystems in various kinds of power plants and improves the dynamic stability of power systems [4], [5]. The conclusion comes up with the discussion of the aspects current mainstream technology of generator excitation system and the short review of their function operation and control, principle and structuring of excitation system. And topology of NES-HMI excitation intelligent monitoring interfaces software is introduced which keeps operation and control of generator excitation system.

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