Fast fault diagnosis strategy of the main loop of excitation power unit

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Abstract. The power unit is an important component of the main circuit generators excitation system, when the power unit of the main circuit failure, failure can be found fast, accurate, timely troubleshooting and stable operation of the excitation system is very important. This paper summarizes the fault type of generator excitation power unit and common fault analysis, through the simulation of MATLAB power unit is the main circuit fault types, fault spectrum analysis focuses on the quantitative fault feature extraction and fault classification, proposes a truth table method for fast fault diagnosis strategy of the main loop of power unit, the experiment platform verify fault categories, provide the basis for excitation system power unit failure diagnosis.

Key words: the power unit of the main loop; fault diagnosis; generator excited system; thyristors.

1. Introduction
Excitation system is a very important part of the generator set. The excitation system with good performance is inseparable from the stable operation of its power unit. An excellent excitation system power unit can not only guarantee the safety and reliability of the excitation system, but also significantly improve the technical indicators of the whole generator set. However, in the normal operation of power unit, the operation of its main circuit plays a decisive role. Through a large number of field data summary and research, it is found that the most common fault of the main circuit of the power unit excitation system of the generator set is the fault of the thyristor of the rectifier circuit. Through the summary and analysis of the thyristor fault, it is divided into thyristor direct fault and thyristor open fault. Thyristor through fault refers to when the thyristor in any phase circuit in the three-phase main circuit fails to make the phase circuit through, thus causing a short circuit in the phase circuit, causing a sharp rise in the current of the phase circuit, leading to the system protection action to remove the short circuit fault, usually the thyristor through fault includes the thyristor is short circuit; Thyristor open circuit fault is when the main loop of the three-phase bridge arm any thyristor failure occurs, the phase bridge arm circuit can still work normally, but the output of excitation voltage waveform distortion...
and pulsation are increased, the average output voltage is decreased obviously, make the whole generator set can not be normal and stable work, the common faults of thyristor damage, fuse, etc. Therefore, the effective fault diagnosis of the main loop of the power unit of the excitation system will be particularly of practical significance.

At present, when most of the power units of the generator set fail, the fault diagnosis is usually not able to find out exactly which one or more thyristors fail. At present, there are mainly the following methods for the diagnosis of the main loop of the generator set: Reducing voltage waveform by fast Fourier analysis, and then build, such as pattern recognition, fuzzy fault diagnosis, information fusion fault diagnosis, intelligent fault diagnosis, BIT of fault diagnosis, neural network fault diagnosis, fault diagnosis expert system, network fault diagnosis, such as integrated fault diagnosis algorithm to establish mathematical model, Then, a fault diagnosis system is built on the basis of virtual instrument. The model of this method is complex, and the real results often need a lot of programming and debugging. Finally, the fault diagnosis results are not fast and accurate. In addition, the traditional fault diagnosis algorithm such as fuzzy diagnosis model is too complex. The fault diagnosis of agent often needs to be applicable under specific environment. The fault element localization of neural network fault diagnosis is not accurate. When a fault occurs in a certain part or a certain equipment in the information fusion fault diagnosis system, it will be shown as a fault of the whole system through information conduction. Expert system fault diagnosis is sometimes used at the expense of performance, in order to ensure that the system runs normally within the specified time. At the same time, the fault diagnosis of analog circuit has been the focus of research in the electronic industry. Considering the lack of fault models, nonlinear circuit elements and other factors, analog circuit is regarded as the most unstable and measurable system, and there are still many problems in fault diagnosis. For example, the random interference of external noise, the unknown degree of fault-free components deviating from their tolerance and the uncertainty of soft faults bring great difficulties to accurately diagnose the faults of analog circuits.

In this paper, the three-phase rectifier circuit of the power unit is taken as the key research object. By analyzing and summarizing the fault types and common faults of the power unit of the excitation system, the simulation model of the power main circuit of the excitation system is established to simulate the main fault phenomena. Then according to the structure and fault characteristics of three-phase rectifying loop of power unit of excitation system, such as nonlinearity, time-varying parameters and real-time diagnosis method, the quantitative fault feature extraction and fault classification based on spectrum analysis are studied, which provides a fast and effective fault diagnosis method for the main loop of power unit.

2. Working principle and fault type of power unit main loop

Fig. 1 Simplified circuit of main circuit of power unit

The rotor circuit of the generator set can be regarded as a large inductance. The main part of the main circuit of the power unit of the excitation system is a three-phase fully controlled rectifier circuit. The three-phase bridge fully controlled circuit can not only work in the state of rectification, but also convert AC to DC, which is used to supply excitation to the rotor winding of the generator set. It can also work
in the inverting working state, converting DC to AC, and feeding it back to the generator set to realize its demagnetization.

As shown in figure 1 of the generator excitation system of power unit primary loop three-phase circuit controlled thyristor rectifier bridge, half bridge by a total of three Yin group controlled thyristor T1, T3, T5, conduction when working in the positive half cycle, the second half of the bridge by the anode of three controlled thyristor T4 and T6, T2, conduction when working in the negative half cycle. If the natural commutation point is used as the starting point for calculating the trigger Angle, that is, when the trigger Angle is triggered between 0 and 90o, the main loop of the power unit is in the state of rectifying operation. When the trigger Angle is triggered at 90-180o, the main circuit of the power unit is in the inverting working state. When the rectifier loop is working normally, the output excitation working voltage pulsates six times in each cycle, and each power frequency periodic pulsation waveform is composed of six identical wave heads. The conduction sequence of the thyristor is: T6, T1, T3, T4, T5, T6. In the generator excitation system operation process of the main loop of the power unit, controlled thyristor disconnect or trigger pulse missing is the most common fault, when such fault occurs, the port output waveform excitation voltage produce certain regularity, through summary analysis of the law can be concluded that controlled thyristor whether failure fault information. By summarizing all kinds of fault information, thyristor faults can be roughly divided into three types, namely: single tube fault, double tube fault and triple tube fault. A large number of data [21-24] show that, in general, the probability of simultaneous failure of three thyristors is very small when the main loop of excitation system is working. Therefore, in the fault diagnosis and analysis, the situation of three-tube fault is eliminated, and the fault diagnosis of single-tube fault and double-tube fault is analyzed with emphasis. Single pipe fault is VT1, VT3, VT5, VT4, VT6, VT2; Dual-tube faults are divided into two thyristor faults VT1VT4, VT1VT6, VT1VT2, VT3VT4, VT3VT6, VT5VT2 of the upper arm, and two thyristor faults VT1VT3, VT1VT5, VT3VT5 of the upper arm. The two thyristors of the lower axle arm failed VT4VT6, VT4VT2, VT6VT2. Among them, thyristor short circuit, trigger signal loss and other faults are the corresponding thyristor faults. Therefore, the single-tube fault and dual-tube fault modes mentioned above can represent all the faults of the main loop fault of the power unit excitation system of the generator set.

3. Method of fault diagnosis of power unit main loop
Matlab Simulink module is used to simulate the main loop of the power unit excitation system of the generator set. In the simulation model, only the fault location unit needs to be changed to obtain a group of image spectrum curve images of the thyristor of the main loop of the power unit. Spectrum analysis of the fault unit is the main research strategy in fault diagnosis. The fault thyristor location can be quickly and conveniently diagnosed by establishing the diagnosis rule through the secondary location.

It is very convenient to use Simulink module to model the main circuit of the power unit of the generator set. The modules needed in the modeling process are put into the modeling window, and the various modules are connected correctly and the appropriate parameters are set. When setting the simulation parameters, it includes the start time, end time, simulation algorithm, maximum relative error, fixed step size and so on. The specific parameter setting needs to be decided according to the nature of the main loop model and the simulation requirements. The selection of algorithm in the main loop model construction plays a decisive role in the correctness and simulation time of the following simulation to a large extent. When the parameters selection of simulation model components, must take into account the voltage, frequency level need to match the problem, in choosing a silicon controlled thyristor need to pay attention to its range of parameter setting, reasonable adjust various parameters values can make the whole of the main loop of the power unit output correct full waveform in a row. Resistors, inductors, capacitors and other impedance components can directly refer to the original value, and the components that do not need to set parameters can be set to zero. Fig. 2 is the main circuit model of the power unit of a generator set after each module is properly connected [26-28]. A three-phase sinusoidal AC power supply composed of three AC power sources is used in the model. The amplitude is 380V, the frequency is 50Hz, and the phase difference is 120o in turn, respectively, as follows: U(A)
$U_A = 220\sin(\omega t - 120^\circ)$, $U_B = 220\sin(\omega t)$, $U_C = 220\sin(\omega t + 120^\circ)$, Synchronized 6-Pulse Generator trigger pulses are provided by the thyristor in the main circuit of the module. Alpha _deg is the trigger Angle. The trigger Angle of the SCR is set through alpha _deg to provide the trigger pulses for the Synchronized 6-pulse Generator with a difference of 60o between the wide pulses and the narrow pulses generated.

Fig. 2 Simulation model of power unit main loop

Through the simulation analysis of single arm fault and two arm fault, the sensor collects the excitation variable secondary side AC current. By summarizing and analyzing the waveforms of AC current, the truth table of fault parts is obtained, which contains the one-to-one correspondence of all current waveforms and corresponding faults.

First of all, the simulation of the failure of a single silicon controlled thyristor is waveform, the closed loop current size of 300 a, by setting the thyristor delay time to simulate fault state, respectively set up silicon controlled thyristor VT1, VT3, VT4, VT6 single delay time, get as shown in figure 3 to figure 6 single pipe failure closed loop current waveform figure, through the waveform, It can be clearly seen that when the single tube in the upper half of the rectifier bridge fails, the upper wave head of the fault thyristor current waveform is missing, and when the single tube in the lower half of the rectifier bridge fails, the lower half wave head of the fault thyristor current waveform is missing.

Fig. 3 Waveform of SCR VT1 failure
Fig. 4 Waveform of SCR VT3 failure

Fig. 5 Waveform of SCR VT4 failure

Fig. 6 Waveform of SCR VT6 failure
Figure 7 to Figure 8 are the current waveform when a SCR fault occurs at the same time in the upper and lower bridge arms. The current closed-loop 300A simulates the faults of VT1VT4 and VT1VT6 respectively. Through the analysis of the simulated closed-loop current waveform, we can clearly see: When VT1 and VT4 fail at the same time, the upper and lower waveheads of the first waveform are lost at the same time, which is in a straight line. When VT1 and VT6 fail simultaneously, the upper half of the first waveform and the lower half of the second waveform are missing.

![Fig. 7 Waveforms when SCR VT1 and VT4 fail](image1)

![Fig. 8 Waveforms when SCR VT1 and VT6 fail](image2)

Fig. 9 to Fig. 10 are the current waveform when two SCR thyristor faults occur at the same time with the upper bridge arm or the lower bridge arm. The closed loop current is 300A, and two pipe faults VT1VT3 and VT1VT5 are simulated respectively. When VT1 and VT3 fail at the same time, the upper half of the first wave and the second wave are missing, and the lower half of the third wave is missing. When VT1VT5 fails simultaneously, the upper half of the first wave and the third wave is missing, and the lower half of the second wave is missing.

![Fig. 9 Waveforms when two SCR thyristor faults occur](image3)

![Fig. 10 Waveforms when two SCR thyristor faults occur](image4)
Through modeling of the main loop of the generator set power unit, delay the malfunction of the silicon controlled thyristor time simulating single silicon controlled thyristor fault, cross two silicon controlled thyristor bridge arm up and down fault, ditto bridge arm, or with the silicon controlled thyristor bridge arm under fault closed-loop current waveform, proposed the main loop of the generator set power unit silicon controlled thyristor the fault truth table, As shown in Table 1, the normal current is represented by 0, only the positive current is represented by 1, only the negative current is represented by -1, and the * current is 0. This table covers all the SCR fault information. Through this truth table, specific problems of SCR fault location can be quickly and accurately found.
Table 1. SCR fault truth table

| Current value fault | Ia | Ib | Ic |
|---------------------|----|----|----|
| A single tube       |    |    |    |
| VT1                 | -1 | 0  | 0  |
| VT3                 | 0  | -1 | 0  |
| VT5                 | 0  | 0  | -1 |
| VT4                 | 1  | 0  | 0  |
| VT6                 | 0  | 1  | 0  |
| VT2                 | 0  | 0  | 1  |
| Two tubes in the upper and lower axle arms respectively |    |    |    |
| VT1 VT4             | *  | 0  | 0  |
| VT1 VT6             | -1 | 1  | 0  |
| VT1 VT2             | -1 | 0  | 1  |
| VT3 VT4             | 1  | -1 | 0  |
| VT3 VT6             | 0  | *  | 0  |
| VT3 VT2             | 0  | -1 | 1  |
| VT5 VT4             | 1  | 0  | -1 |
| VT5 VT6             | 0  | 1  | -1 |
| VT5 VT2             | 0  | 0  | *  |
| Two pipes on the upper axle arm |    |    |    |
| VT1 VT3             | -1 | -1 | 1  |
| VT1 VT5             | -1 | 1  | -1 |
| VT3 VT5             | 1  | -1 | -1 |
| Two pipes on the lower axle arm |    |    |    |
| VT4 VT6             | 1  | 1  | -1 |
| VT4 VT2             | 1  | -1 | 1  |
| VT6 VT2             | -1 | 1  | 1  |

4. Example analysis and verification
Verifying and analyzing the failure of a single thyristor and two cross-controlled thyristors of the upper and lower bridge arms, and the two thyristors of the same upper or lower bridge arms: Assume that a single silicon controlled thyristor VT5 fails, as shown in table 1, if VT5 pipe failure, Ia current value is 0 (normal), the Ib's current value is 0 (normal), Ic current value is 1, namely the third waveform simulation and closed loop current after failure occurs on the wave head is missing, closed loop current waveform is obtained by simulation as shown in figure 11, The correctness of the truth table in the case of single SCR failure is accurately verified by the current waveform in Fig. 11.

Fig. 11 Waveform when SCR VT5 fails
Assuming that VT1VT2 of the two cross-controlled thyristors of the upper and lower bridge arms fail, as shown in Table 1, if the VT1VT2 tube fails, the current value of IA is -1, the current value of IB is 0 (indicating normal), and the current value of IC is 1, that is, the upper wave head of the first waveform of the simulated closed-loop current is missing after the failure. The lower half of the third waveform is missing, and the closed-loop current waveform is obtained through simulation, as shown in Figure 12. The current waveform in Figure 12 accurately verifies the correctness of the truth table when the two cross-controlled thyristors of the upper and lower bridge arms fail.

![Fig. 12 Waveforms for failure of SCR VT1VT2](image12)

Under the same as above or with two silicon controlled thyristor bridge arm fault VT3VT5 fails, as shown in table 1, if VT3VT5 pipe failure, IA current value is 1, the Ib's current value to 1, Ic current value is 1, the simulation loop current after the first wave in the event of a failure of the second half of the wave front is missing, the second wave half wave head is missing, The upper half of the third waveform is missing, and the closed-loop current waveform is obtained through simulation, as shown in Fig. 13. The current waveform in Fig. 13 accurately verifies the correctness of the truth table when the two SCR thyristors with the same upper or lower bridge arm fail.

![Fig. 13 Waveform when SCR VT3VT5 fails](image13)
5. Conclusion
Because the generator excitation system power unit is prone to failure, the form of the fault is complex and diversified, and the existing methods can not be simple, effective and rapid to find and diagnose the fault, so the generator power unit fault diagnosis research is very necessary. This paper uses the Simulink module in the simulation software Matlab to simulate the main circuit of the power unit of the generator set. The current waveform obtained through the simulation is clear and accurate. By simulating the single crystal thyatron faults, two of the same phase power thyristor fault, with the two half bridge thyristor fault, cross two thyristor, three-phase bridge arm in each have a thyristor or arbitrary two phase fault and the fluctuation cross bridge arm of the communist party of China three fault, three-phase thyristor bridge arm in each have a thyristor fault, At the same time, the current waveform of a bridge thyristor fault when the two Bridges are parallel is given, and the characteristics of the closed-loop current waveform under the fault state are analyzed. The SCR fault truth method proposed in this paper is used to quantitatively analyze and diagnose the typical faults in the main loop of the power unit of the excitation system. The correctness of this method is proved by the simulation experiment, which makes the fault diagnosis of SCR more rapid and practical. Of course, this method is only verified in the simulation experiment, and the improved diagnosis method made in the existing complex diagnosis method needs to be further studied and discussed in the actual fault.

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