Research on fault monitoring system for collector ring and carbon brush of generator rotor

Jianlong Zhao*, Xi Zhou and Wei Hou

NR Electric Co., Ltd., Nanjing, Jiangsu, 211102, China

Abstract. The operating status of the generator rotor's collector ring and carbon brush determines the safe and stable operation of the generator. It is critical to promptly detect and handle any abnormalities or faults in the collector ring and carbon brush to prevent accidents from expanding. At present, the status monitoring of the collector ring and carbon brush mainly relies on manual inspection, which has low efficiency and cannot discover faults in real-time. This article studies the establishment of a fault monitoring system for collector ring and carbon brush of the generator rotor. Through real-time collection and analysis of arc light, temperature, and electrical data, abnormalities and faults can be detected and alerted in a timely manner. This system can improve the accuracy and effectiveness of monitoring, and ensures the safe operation of the generator.

1. Introduction

The collector ring and carbon brush of the generator are important components for normal power generation and conduction of current. The good working of the collector ring and carbon brush directly determines the safe and stable operation of the generator. Discharge, vibration, uneven wear, and surface oil stains between the collector ring and carbon brush are prone to occur during the operation of the generator, which will cause local heating of the carbon brush and collector ring[1~5]. If the temperature exceeds a certain value, the performance of the insulation material will deteriorate, accelerating the aging of the insulation and leading to arc faults. If the anomalies can not be detected and manually intervened in a time, it may bring about the shutdown of generator or even primary equipment damage accident. At present, the monitoring of the collector ring and carbon brush is mostly based on a single state, such as magnetic field [6], temperature [7], carbon brush length [1, 2], etc. However, the method based on a single state variable is difficult to comprehensively monitor various faults of the collector ring and carbon brush, and when the collection sensor of a single state is abnormal, all functions of the monitoring system will fail, resulting in low system reliability.

Therefore, it is necessary to establish a real-time fault monitoring system for the generator rotor collector ring and carbon brush based on multiple sensors to improve the level of abnormal monitoring and avoid catastrophic faults.

*Corresponding author's e-mail: zhaojl@nrec.com

2. Overall system scheme

As shown in Figure 1, the real-time fault monitoring system for the collector ring and carbon brush of generator rotor adopts a layered and distributed structure design, consisting of station layer, bay layer and process layer.

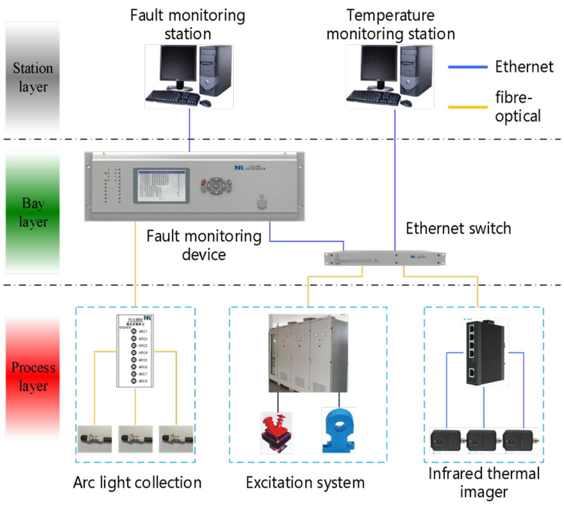

Figure 1. Network structure diagram of collector ring carbon brush fault monitoring system.

2.1. Station layer

The main function of station layer equipment is to achieve device monitoring, alarm, and information exchange, in order to complete data collection, monitoring, management, and storage. The station layer equipment includes the fault monitoring station and the temperature monitoring station. The fault monitoring station displays the data and discrimination results submitted by the fault monitoring device, and storing the data in a history database. The temperature monitoring station analyse and works with the data from the infrared thermal imager, displays temperature images, stores historical data and images, transmitting key data to the fault monitoring device through ethernet communication.

2.2. Bay layer

The bay layer equipment is used for gathering real-time data information from process layer and completing data analysis and logical operation discrimination. The equipment mainly includes fault monitoring device and ethernet switch. Fault monitoring device receives sampling data such as arc light, electrical quantities of the excitation system and temperature. Through analysing and calculating the data, the working status of collector ring and carbon brush is distinguished, which will be sent to fault monitoring station.

2.3. Process layer

The process layer equipment which includes arc light acquisition unit, excitation system and infrared temperature measurement unit is applied to collect real-time operating electrical quantities, monitor equipment operation status and so on.

a) The arc light collection unit consists of arc light sensors and the distributed arc light collection units. The arc light sensors collect the arc light signal of collector ring and carbon brush in case of a fault, and then transmit the signal to arc light collection units through fibre-optical; The distributed arc light collection units are responsible for collecting the sampling signals of all arc light sensors on site and sending them to fault monitoring devices.
b) The electrical datas of the generator, such as excitation voltage and current, active and reactive power, are connected to the excitation system controller and transmitted to the fault monitoring device.
c) The infrared temperature measurement unit is composed of infrared temperature measurement probes and dedicated ethernet switch. The probes collect real-time temperature information of collector ring and carbon brush in the excitation room and the dedicated switch gathers the temperature information and transmits it to the temperature monitoring station.

3. Fault monitoring discrimination methods

The real-time fault monitoring device for collector ring and carbon brush adopts an embedded hardware architecture, which supports arc signal acquisition, infrared temperature measurement data access and electrical quantity access. The arc energy accumulation model and the collector ring and carbon brush temperature rising model are established by arc, temperature, and electrical quantity data. The working condition of collector ring and carbon brush is identified based on the analysis results of arc energy, temperature rise rate, and excitation resistance changes. Independent fault monitoring criteria are designed and optimized according to various sampling signals.

3.1. Fault monitoring criteria based on arc light

During the operation of the generator, the imbalanced current often leads to the over current through some of the carbon brushes. As the operation time increases, the temperature of the carbon brushes, rising up with the strengthening of current, damages the surface structure of the carbon brushes, and causes arcing or fire between the carbon brushes and the collector ring. In severe cases, it can also form a ring fire, posing a direct threat to the safety and stability of the generator.

The fault monitoring system detects the arc light generated during the arc of collector ring and carbon brush via the reasonable arrangement of arc sensors, and extracts the characteristic quantities of equipment status through data analysis. When the characteristic quantities of the arc signal exceeds the threshold, an alarm signal is given. The logic is shown in Figure 2.

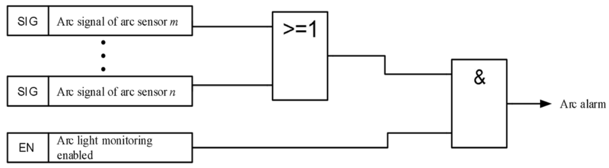

Figure 2. Arc light monitoring logic diagram.

3.2. Fault monitoring criteria based on temperature

When the current distribution of carbon brushes is uneven or even ring fire occurs, the temperature of some carbon brushes will be higher than the temperature during normal operation. The fault monitoring area covers all carbon brushes through the reasonable arrangement of temperature measuring instruments, and monitors the temperature of carbon brushes in real time. By analysing the temperature of carbon brushes within each interval, combined with characteristics such as maximum temperature and temperature rise rate, the operating conditions of the collector ring and carbon brushes are judged using the following criteria.

a) Overtemperature alarm: By recording the temperature characteristics of the collector ring and carbon brush during the entire operation process of the generator, and analysing the historical temperature data, the operating temperature range of the collector ring and carbon brush during normal motor operation is determined, and the overtemperature alarm threshold is rationally set. When the temperature of the carbon brush of the collector ring is detected to be higher than the overtemperature alarm threshold, an overtemperature alarm signal is issued.

b) Abnormal temperature rising alarm: Analysing historical temperature data to determine the safe rising rate and duration of collector ring and carbon brush temperature during normal operation of the generator. When it is detected that the temperature rising rate of the carbon brush is significantly higher than the safety threshold, or when the combined temperature rising rate and duration are significantly higher than normal, an abnormal temperature rising alarm signal is issued.

The logic is shown in Figure 3.

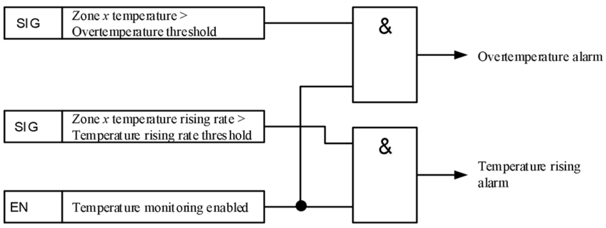

Figure 3. Temperature monitoring logic diagram.

3.3. Fault monitoring criteria based on electrical quantity

The excitation current of the generator is transmitted to the excitation winding through carbon brushes and collector rings. The equivalent circuit of the excitation system is shown in Figure 4.

Where, R_{P1}, …… , and R_{PN} respectively represent the positive electrode of the contact resistance between each carbon brush and the collector ring; R_{Q1}, …… , and R_{QN} is the negative electrode of the contact resistance individually; The resistance of the carbon brush and collector ring, which can be ignored, is much smaller than the contact resistance; R is the excitation winding resistance; U is the excitation voltage, and I is the excitation current. The total resistance of the excitation circuit is:

$$R_{\Sigma}=R_{P1}||...||R_{PN}+R+R_{Q1}||...||R_{QN}=\frac{U}{I} \quad (1)$$

If all carbon brushes are in normal condition and have a good contact with the collector ring, the excitation current can be evenly distributed by each carbon brush current:

$$I_{P1}=...=I_{PN}=I_{Q1}=...=I_{QN}=\frac{I}{N} \quad (2)$$

When a fault occurs in the collector ring and carbon brush, such as improper compression force and looseness of carbon brush, insufficient or uneven pressure of constant pressure spring, mixed use of different types of carbon brushes, poor contact between carbon brush and slip ring, weak connect between brush braid and carbon brush and so on, which expand the contact resistance between the faulty carbon brush and collector ring, leading to an increase in the total resistance of the excitation circuit. In order to maintain the stability of the excitation current, the excitation system will adjust and raise the excitation voltage in real time.

Considering the analysis above, it is apparent that when some carbon brushes experience errors, an increase in the total resistance of the excitation circuit will come together. Via excitation voltage and current data, the total resistance can be calculated in real-time. When it exceeds the safety threshold, an alarm signal of abnormal excitation resistance will be issued. The logic is shown in Figure 5.

In addition, intelligent learning is conducted on the correlation between the collected active and reactive power of the generator, excitation voltage, and excitation current, so a history database is established. After sufficient data samples are available, whether there is a significant difference in the electrical correlation between the abnormal state and normal state of collector ring and carbon brush can be determined, which contributes to the establishment of relevant fault criteria.

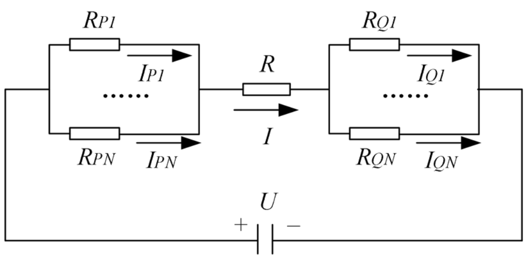

Figure 4. Equivalent circuit diagram of excitation system.

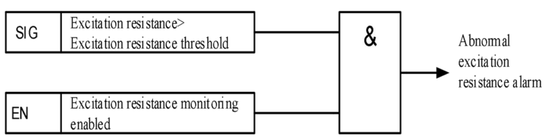

Figure 5. Excitation electrical quantity monitoring logic diagram

3.4. Optimizing fault monitoring criteria

Based on the above analysis, when the carbon brush malfunctions, it will exhibit fault characteristics in arc light, temperature, electrical quantity and other information. By estimating these characteristics in conjunction with the operating conditions of the generator, a single criterion can be optimized to improve the reliability of fault monitoring criteria.

During the initial stage of applying excitation when the generator starts, the temperature of the carbon brush will gradually increase from room temperature to operating temperature, which will have an impact on the monitoring criteria based on temperature rise rate described in section *3.2*. By monitoring the excitation current, this process can be distinguished, and one can choose to temporarily exit the temperature rise anomaly detection function during this process, or establish a temperature rise feature model for the generator excitation stage based on the temperature data of this process, which can be distinguished from the fault temperature rise feature and improve the sensitivity of fault monitoring. The logic is shown in Figure 6.

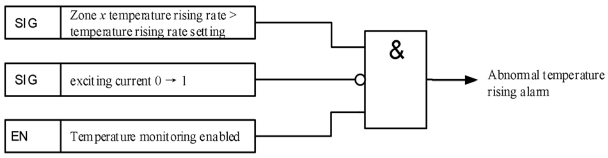

Figure 6. Temperature rise anomaly monitoring optimization logic diagram.

4. Signal acquisition schemes

4.1. Arc light signal acquisition

The earliest arc light sensor used in China was a visible light sensor with a wide spectrum of light response. Although visible light sensors can effectively monitor arc signals, daily light such as lighting, sunlight, and strong electric light during inspections can trigger arc alarm signals.

The energy of arc light is mainly concentrated in the ultraviolet range of 300 - 380nm and the visible range of 380 - 700nm, with over 70% of it being ultraviolet light. Based on this characteristic, arc light sensors based on ultraviolet light sensing technology have been developed in recent years, which can effectively detect ultraviolet light in the wavelength range of 300 - 380nm.

In order to ensure reliable detection of arc light signals and effectively prevent the interference of natural light and strong flashlights during inspection from affecting the normal operation of the device, ultraviolet light sensors are used in this design scheme.

According to the arrangement of the collector ring and carbon brush in the excitation compartment of a thermal power plant, the installation plan of the arc light sensor is shown in Figure 7.

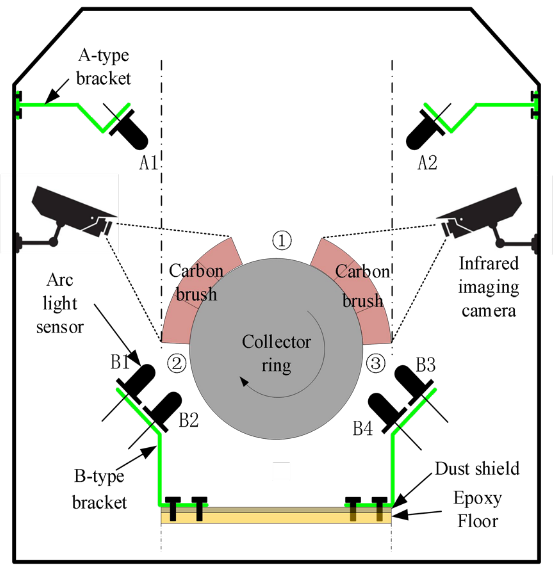

Figure 7. Schematic diagram of side view of equipment installation.

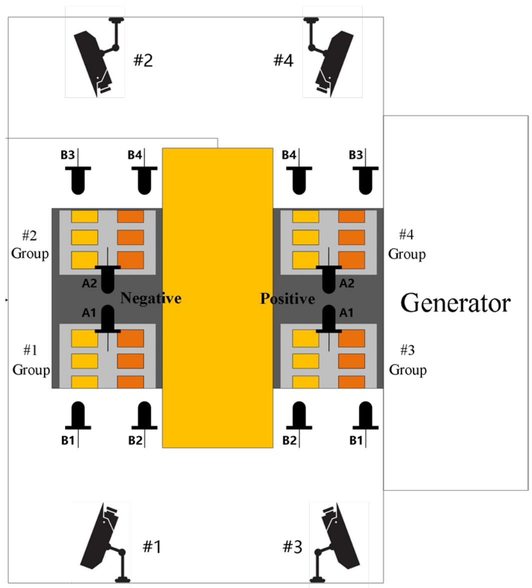

Figure 8. Schematic diagram of look down of equipment installation.

a) Install an A-type bracket symmetrically on the inner wall of the small chamber above the carbon brush side of the collector ring, and install one arc light sensor on each bracket, totally two, numbered A1 and A2, to detect the arc light signal at the contact surface ① of the collector ring and carbon brush.

b) Install a B-type bracket symmetrically on the brush holder base below the carbon brush side of the collector ring, and install 2 arc light sensors on each bracket, totally 4, numbered B1, B2, B3, and B4, to detect the arc light signals at the contact surfaces ② and ③ of the collector ring and carbon brush.

In summary, 6 arc sensors need to be installed for the arc detection of the collector ring and carbon brush of each excitation pole, and a total of 12 arc sensors need to be installed for the positive and negative electrodes of each excitation chamber.

4.2. Temperature signal acquisition

The temperature signal of the collector ring and carbon brush is collected using infrared imaging cameras. For example, a thermal power plant symmetrically installs two infrared imaging cameras above the carbon brush, and the monitoring area is the entire carbon brush group, as shown in Figure 7. The number and location of cameras installed for positive and negative electrodes are consistent, with a total of 4 infrared imaging cameras installed.

The top view diagram of the installed equipment is displayed in Figure 8. The temperature measurement system divides all carbon brushes monitored by each infrared imaging camera into 3 - 6 temperature measurement areas. With each temperature measurement area is independently monitored and analyzed, the system extracts information such as the highest, the lowest, and average temperatures of each area, generates temperature images, and sets various alarm thresholds.

The fault monitoring device obtains the main temperature signals and alarm information from the temperature monitoring workstation through the communication method, such as analog information of the maximum temperature, minimum temperature, average temperature, predicted temperature, etc. in each temperature measurement area, as well as switch information like alarm signals and warning signals.

4.3. Electrical quantity signal acquisition

The collector ring and carbon brush fault monitoring system needs to collect electrical information such as excitation voltage and current of the excitation system, as well as active and reactive power of the generator, to extract fault features and achieve the electrical quantity based collector ring and carbon brush fault detection.

The electrical quantity data of general generators has been connected to the excitation system. In this scheme, the fault monitoring device obtains electrical quantity information from the excitation system in the way of communication.

5. Conclusions

By installing arc sensors and infrared imaging cameras at specific locations to collect arc and temperature information, and using the communication method to obtain electrical information from the excitation system, the fault monitoring system conductes comprehensive logical analysis to detect faults of the collector ring and carbon brush of generator rotor. Compared to the traditional manual inspection method, the fault monitoring system for collector ring and carbon brush of generator rotor has the advance of real-time and reliability, providing strong support for the safe operation of generators.

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