Analysis of Rotor Grounding Protection Action of Large Synchronous Condensers

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Abstract. Rotor Grounding protection of synchronous condensers in a converter station of Jiangsu province acted on September 24, 2018. The burning loss of primary side of synchronous transformer was found by accident investigation. Based on the theory of rotor grounding protection and fault cause, the correctness of rotor grounding protection of injection is verified. Meanwhile, the unstable grounding fault caused by the synchronous transformer was further studied. Based on the analysis of fault recording waveform of converter station, this paper proposes an improved scheme for the rotor grounding protection logic. Compared with the traditional rotor grounding protection logic, it can avoid the situation that the fault cannot be removed in time because of the unstable grounding fault. It can provide a reference for the protection of the excitation system of the new large-capacity synchronous condensers.

1. Introduction

With the large-scale construction of long-distance HVDC transmission, the voltage level and the transmission capacity are constantly improved, and the demand for reactive power compensation capacity of converter stations is also increasing. In particular, the dynamic reactive power compensation plays a very important role in the voltage stability of HVDC transmission system [1-4]. Synchronous condensers have the characteristics of higher reliability, larger capacity and strong dynamic voltage maintenance ability. It can output and absorb the reactive power in time through the over-excitation and the under-excitation in the case of voltage fluctuation [5-7]. Therefore, in order to ensure the safe, reliable and economic operation of the large power grid, the application of large capacity synchronous condensers has been put on the agenda [8,9].

Excitation system is an important part of synchronous condensers, and its main task is based on the running state of the synchronous condensers to provide an adjustable rotor winding dc excitation current, so as to meet the needs of operation mode of synchronous condensers. When the excitation system is in the event of failure and the fault cannot be removed promptly, the excitation system would be burned. At the same time, it will produce bad influence to power grid. Rotor circuit ground fault is one of the most common faults of synchronous condensers. Rotor one-point ground protection can not only detect the insulation drop of rotor winding itself, but also includes the cable between rotor winding and SCR, cable between rotor winding and protection device, carbon brush, collector ring and other parts. Therefore, it is more appropriate to call it the excitation circuit one-point grounding protection [10-11].
The synchronous transformer is a key device in the excitation system. In the SCR rectifier circuit, the SCR needs a trigger pulse to control its conduction. The synchronous transformer takes the voltage variation of the SCR anode as the control signal of the SCR [12-13].

In Ref. [14], the influence of shaft voltage absorption circuit and contact resistance on rotor grounding protection of generator is discussed, and corresponding Suggestions are put forward for the reliable work of rotor grounding protection. Ref. [15] discusses the influence of dc insulation monitoring circuit on rotor protection circuit during initial excitation through case analysis and theoretical derivation, and provides solutions to this problem. Ref. [16] introduces a generator stator over-load tripping accident caused by a fault of synchronous transformers of excitation regulator of generators. The cause and treatment process of the accident were analysed, and preventive measures were given. However, rotor grounding protection caused by the fault of the synchronous transformer in new large capacity synchronous condensers has not been reported publicly. Therefore, in response to injection rotor one-point grounding tripping accidents in a converter station of Jiangsu province, this paper analyses theories and trouble wave recordings, and proposes a method to improve the existing rotor grounding logic. This method can avoid existing logic which has difficulties to removing unstable grounding faults and provide references for subsequent projects.

2. Analysis of rotor one-point grounding protection principle

When a rotor has one-point grounding fault which cannot form a closed path, parameters of exciting winding remain the same and rotor will not have serious consequences. However, when a second point grounding fault occurs, the rotor ground fault current will burn the rotor body. Exciting winding will be shorted and gap flux will be imbalanced, which will cause vibration and shaft rotor magnetizing catastrophic consequences. These will result in a serious threat to the security of unit. For the safe operation of large generator sets, the rotor one-point grounding protection should be installed, whether it is hydro-generator, turbo-generator or modulator. At present, two kinds of rotor grounding protection principles are commonly adopted in synchronous condensers. The first one is the switching mode (ping-pong) and the second one is the injection mode which needs to inject low-frequency square wave voltage.

2.1. Switching mode

The principle of rotor grounding protection of switching mode is shown in Fig. 1:

Assuming that $U_r$ remains unchanged when S1 and S2 are switched, the one-point grounding resistance is calculated as follows:
When $R_g$ is less than the fixed value of grounding protection, the one-point grounding protection action of rotor is triggered.

2.2. Injection mode

Injection mode can monitor the insulation of rotor without excitation voltage, which is more suitable for large units to detect the insulation of rotor.

The principle of rotor grounding protection of square wave voltage type is shown in Fig.2 and Fig.3:

![Figure 2. Principle diagram of single-ended injection rotor grounding protection](image1)

![Figure 3. Principle diagram of double-end injection rotor grounding protection](image2)

$U_s$ is the amplitude of square wave power supply, $kV$; $R_c$ is the injection resistance, $k\Omega$; $R_m$ is the measuring resistance, $k\Omega$.

Power supply of square wave is injected between one end or two ends of rotor winding and the big shaft, and the one-point grounding protection of rotor is formed by calculating the value of grounding resistance. Injection mode is not affected by the grounding capacitance of rotor winding, which has high measurement accuracy. Protection sensitivity and rotor grounding position are independent. Because double-end injection can accurately measure the grounding position of winding, double-end injection is usually used.

Assuming that the rotor voltage remains unchanged in positive and negative states of square wave power supply, the one-point grounding resistance with double-end injection is calculated as follows:

$$R_g = \frac{U_s}{i - i'} - \frac{R_c}{2}$$

(2)

$i$ and $i'$ are respectively the measurement current when the square wave voltage is positive and negative, kA. When $R_g$ is less than the fixed value of grounding protection, the one-point grounding protection action of rotor is triggered.

2.3. Rotor ground protection of injection mode

Because the rotor ground protection of injection mode has faults, this paper focuses on the analysis of injection mode. The schematic diagram of rotor ground protection circuit of synchronous condensers is as follows:
V1~V6 are thyristors. L1 and L2 are inductors, H. The device adopts square wave voltage as the power supply, and the parameters of square wave are set according to the practical conditions, generally ranging from 0.5-1.5s. Rotor grounding protection reflects the grounding fault of the rotor circuit and its lead wire (with direct electrical connection). When the original edge C of synchronous transformer is healthy, thyristors turn on one by one. When the original edge C of synchronous transformer has faults, the three-phase winding of synchronous transformer is a direct electrical connection, so injecting square wave signal still can form a loop with the ground by the other two phase windings. Therefore, the injection rotor ground protection can reflect the grounding fault of the primary side winding in synchronous transformer.

3. Analysis of rotor grounding protection action process

The rotor grounding protection of a converter station in Jiangsu province is equipped with two sets of different principles, one is the injection mode, the other is the switching mode. In normal operation, the injection mode is put in, and the switching mode is standby. On September 24, 2018, the rotor one-point grounding protection of injection mode tripped. After the accident investigation by the staff, it was found that the C phase on the original side of the synchronous transformer was burnt out, and the B phase on the original side was blackened, and the C phase fuse on the original side of the synchronous transformer was blown out, and there were no other abnormalities in the cabinet.

The rotor one-point grounding protection was started for 4 times in total, and the starting time was 13:33:172ms, 13:33:41:562ms, 13:33:47:925ms and 13:34:00:391 ms, respectively. According to the recorded waveforms, the corresponding values of grounding resistance and action conditions at different operating times are counted, as shown in Table 1:

| Serial Number | Start-up Time of One-point Grounding of Rotor | Action Time /ms | Grounding Resistance Value/ kΩ | Action Situation |
|---------------|-----------------------------------------------|-----------------|---------------------------------|-----------------|
| 1             | 13:33:33:172ms                                | 0000 4279       | 1.38 5.39                       | One-point Grounding Start of Rotor Start Delayed Return |
| 2             | 13:33:41:562ms                                | 0000 2099       | 0.39 3.54                       | One-point Grounding Start of Rotor Start Delayed Return |
| 3             | 13:33:47:925ms                                | 0000 1039       | 0.77 3.56                       | One-point Grounding Start of Rotor Start Delayed Return |
| 4             | 13:34:00:391ms                                | 0000 5000       | 0.55 0.39                       | One-point Grounding Start of Rotor Tripping of Rotor Grounding Protection |

It can be seen from Table 1 that the grounding resistance is less than that value of the low fixed value section at the four start-up times, but the first three start-up times are 4279 ms, 2099 ms and 1039 ms (< 5s), respectively. That is to say, the grounding resistance value restores to more than 2.5 kΩ during the low fixed value period. Therefore, this fault belongs to unstable grounding fault, and cannot make the
rotor grounding protection action, until the fourth trigger of the rotor grounding protection successfully tripped.

4. Analysis of Synchronization Transformer Faults
There are two action values for one-point grounding, the sensitive section is used for alarm and the ordinary section is used for signal tripping. The alarm and delay are adjusted separately. From the previous analyses, it can be seen that the unstable grounding fault occurs in the synchronous transformer. Four rotor one-point grounding start-ups are separated by 8390 ms, 6363 ms and 12466 ms (the mean is 9073 ms). Because the first three start-ups failed to make the rotor grounding protection operate successfully, the synchronous transformer withstands a large current and burns down for a considerable period of time. Therefore, the logic diagram of one-point grounding protection adopted at present has disadvantages for unstable grounding. Therefore, considering adding a criterion in the logic diagram of rotor grounding protection, when the alarm of one-point grounding of the rotor is triggered repeatedly within 9 seconds, the unstable grounding of the excitation circuit should be considered to trigger one-point grounding protection. The improved logic of one-point grounding protection of the rotor is shown in Fig. 5.

5. Conclusion
In this paper, the tripping accident of rotor grounding protection during the operation of a new type of synchronous condensers with large capacity is analyzed, and the corresponding countermeasures are put forward.

a. In the operation of synchronous condensers, although the rotor one-point grounding protection can protect the original side of the synchronous transformer, the unstable grounding fault in the excitation circuit needs to be further studied, so it is proposed to add a section of protection in the logic criterion of the rotor protection to solve the existing drawbacks.

b. In the process of starting and returning delay of the first three times of rotor grounding protection, although the grounding resistance value is greater than 2.5 kΩ, it is still below 10 kΩ in the high fixed value section. At this time, the rotor grounding sensitivity section alarms, but this does not cause the vigilance of the duty personnel. Therefore, it is suggested that the staff on duty should pay attention to the alarm of the sensitive section to prevent the widening of the fault range caused by the damage of local components.

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