Analysis and countermeasures of delayed action of generator stator grounding protection

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Abstract. The friction between the iron core and the wire rod caused insulation damage, which caused the wire rod to discharge to the ground, the generator stator ground protection action, and the generator stopped, through the analysis of the reasons, the generator operation preventive measures were formulated, and the delay time of the stator grounding protection was shortened and neutrality was adjusted. The improvement measures for shortening the delay time of stator grounding protection, adjusting the neutral point TV transformation ratio, increasing the impedance of the secondary load, and unified protection clock are proposed. These improvement measures provide useful experience for engineering and technical personnel to deal with related similar problems.

1. Introduction
Generator stator grounding refers to the single-phase grounding short circuit that occurs in the generator stator winding circuit and the primary system directly connected to the stator winding circuit. Stator grounding can be divided into instantaneous grounding, intermittent grounding and permanent grounding according to the length of grounding time; according to the grounding range, it can be divided into internal grounding and external grounding; according to the nature of grounding, it can be divided into metallic grounding, arc grounding and resistance grounding; according to grounding reasons can be divided into true grounding and false grounding.

2. Accident overview
At 19:03:16 on September 23, the protection of the No. 6 generator and transformer set A screen issued "stator grounding protection action" for 530ms, and the protection B screen issued a "stator grounding protection action" signal for 958ms, and the No. 6 generator transformer set was exported. The circuit breaker tripped and the No. 6 generator was disconnected from the system. When a fault occurs, the open triangle output voltage 3U0 at the generator end rises to 89.6V, the neutral point zero sequence voltage rises to 58.3V, and the generator neutral point ground current is 1.8A.

Doubtful point analysis: (1) The difference in the display action time of the two protection screens is too large. The screen A is 530ms and the B screen is 958ms. The difference is close to 500ms, which is a complete level difference; The wave protection delays action for 500ms, and the fundamental wave protection delays action for 1000ms, which is actually set as a backup protection for application; (3) The difference between the measured value of the secondary voltage of the generator end 3U0 and the neutral grounding transformer Large; (4) The third harmonic protection is not activated.
3. Inspection process

3.1. Fault information check
Check the recording status of the fault recorder screen and DCS, and the results are as follows.

The recording shows that the voltage of the two phases of generator A and B rises to 93.6V, the voltage of phase C drops to 4.1V, the open delta voltage rises to 89.6V, and the neutral point zero sequence voltage rises to 58.3V, and the generator neutral point is grounded. The current is 1.776A, so it is judged that the generator C is grounded. The data record is in good condition[1].

The above data are all secondary values, in which the secondary rated value of the generator outlet TV is 100V; the secondary rated value of the neutral grounded transformer is 120V; the ground current CT transformation ratio is 10/5A.

3.2. A systematic inspection

3.2.1. Inspection of generator peripheral equipment
A comprehensive inspection was conducted on the Gaochang transformer, public transformer, excitation transformer, main transformer, generator outlet TV, and closed bus, and no abnormalities were found.

Untie the soft connection of the generator outlet, and use a 2500V electric shaker to measure the insulation on the side of the enclosed bus, main transformer, high-tech transformer, and public transformer. The insulation resistance is 7000MΩ[2].

3.2.2. Inspection of generator body
The appearance inspection of the generator showed no abnormality.

Use a special shaker for water-cooled generators to measure the insulation on one side of the generator, and the insulation resistance is 0MΩ. Disconnect the neutral point connection line of the generator and measure the insulation of phase A, B and C. The values are as follows:

A: 350 MΩ (15s), 460 MΩ (60s), B: 660 MΩ (15s), 820 MΩ (60s), C: 0 MΩ.

Therefore, it is judged that the generator C-phase coil is faulty and grounded, which is consistent with the protection action result.

3.2.3. Generator inspection after hydrogen exhaust
Open the manhole door of the hydrogen cooler and the outlet manhole door at the generator end to enter the generator for internal inspection; open the end manhole door insulation partition to check the position of the coil end on the excitation side, and no faults are found.

Using the capacitive discharge detection method to add a DC voltage to the C-phase coil, a clear discharge sound can be heard at the manhole door of the hydrogen cooler on the excitation side and the end outlet manhole door, and the discharge spark can be seen. Enter the end of the excitation side and continue to test with the capacitor discharge method. It is found that there is a discharge spark at the 11 o'clock position. Finally, it is confirmed that the fault point is located at the slot 17 and 18 of the excitation side coil, that is, the fault point is at the machine end[3].

3.3. Inspection of protection matters
The inspection of generator stator grounding protection is as follows.

3.3.1. Fundamental zero sequence voltage stator grounding (95% stator grounding) protection inspection
(1)fixed value check
The control word "stator grounding protection input" has been set to 1; the zero-sequence voltage stator grounding protection plate is in the input position;
Fixed value setting: fundamental zero sequence voltage 10V, zero sequence voltage high value 20V, zero sequence voltage protection time limit 1000ms.

(2) Detection of protection action results

Add a zero sequence voltage 20V auxiliary voltage to the generator terminal, add an adjustable zero sequence voltage to the neutral point, and measure the sensitive segment action value $U_{dz} = 9.98V$; exit the sensitive segment, and measure the high value segment action value $U_{dz} = 20.08V$.

The measured fundamental zero sequence protection action delay is 1006ms.

3.3.2. 100% stator grounding protection

(1) Fixed value check

The control word "stator grounding protection input" has been set to 1; the 100% stator grounding protection pressure plate is in the input position.

Fixed value setting: the third harmonic voltage ratio before grid connection is 1.2, the third harmonic voltage ratio after grid connection is 1.2, and the third harmonic delay is 0.5s.

(2) Detection of protection action results

The third harmonic voltage ratio stator ground protection test result: $U_{3t}=2V$, $U_{3n}=1.772V$, ratio: 1.993.

After simulating grid connection, the circuit breaker contact input measured: $U_{3t}=2V$, $U_{3n}=1.771V$.

The measured third harmonic voltage ratio protection action delay: $t = 0.5s$.

4. Cause Analysis

According to the inspection of the generator, it is believed that the loose core is the direct cause of the failure. Because the iron core is loose, friction on the wire rod causes insulation damage, resulting in discharge to the ground, and grounding of the generator stator. After the generator stator ground fault, the grounding protection is activated, but the third harmonic grounding protection is not activated. The relevant problems are analyzed one by one.

4.1. The clock error caused a big difference in the action time of the two sets of protection

The reason for the delayed action of the B screen is caused by the clock error. The time difference between the action of the B screen and the A screen received by the fault recorder is only 2ms, that is, when the generator and transformer group protects the A screen 530ms, it is equivalent to the B screen 960ms time scale. Note that 530ms and 960ms are the moments of the action, not the action delay, they action almost simultaneously[4].

4.2. The input impedance of the measuring component causes a large difference between 3U0 and the neutral point voltage

When a single-phase grounding short circuit occurs at the generator outlet, the protection device requires the output voltage of the triangle side of the generator terminal TV to be 100V; the output voltage of the secondary side of the neutral point of the unit TV is 100V. However, in fact, there is a big difference between the two. The reason is analyzed according to the setting position of the neutral point TV tap of the stator grounding protection[5].

4.2.1. The output voltage of the secondary side of the neutral point TV of the unit

TV transformation ratio $n' = 20000/230$

When a phase A single-phase grounding short circuit occurs at the generator outlet, the system structure is shown in Figure 1. The output voltage of the generator neutral point TV secondary side is calculated as follows:
Figure 1. Generator voltage test wiring

The primary voltage at the neutral point of the generator is the phase voltage: $U_0' = 20000/\text{V}$

The secondary voltage at the neutral point of the generator is: $U_1 = U_0'/n = 230/\text{V} = 132/\text{V}$

The ratio coefficient of $U_1$ and $U_2$ is $n'' = 1.32/1$

Voltage at this time: $U_2 = U_1 / (1.32/1) = 100/\text{V}$

4.2.2. Output voltage on the triangle side of the TV opening at the generator end

When a phase A single-phase grounding short circuit occurs at the generator outlet, the output voltage of the generator outlet 1TV secondary side is calculated as follows:

The phasor analysis when a phase A single-phase grounding short circuit occurs at the generator outlet is shown in Figure 2.

(a) Primary side zero sequence voltage

The zero sequence voltage on the primary side is the phase voltage: $U_0 = 20000/\text{V}$

1TV transformation ratio $n_0 = (20000/\text{V})/(100/3)$

(b) Secondary zero sequence voltage

The secondary zero sequence voltage is $3U_0/2$: $3U_0/2 = 3U_0/\text{V} n_0 = 100/\text{V}$

4.2.3. Selection of generator neutral point TV transformation ratio

According to the output voltage of the triangle side of the TV opening of the generator terminal, 100V;

The output voltage of the secondary side TV at the neutral point of the unit is 100V.

$n'' = 20000/230$
That is, the tap of TV secondary 230 is selected, at this time \( n'' = \frac{U1}{U2} = \frac{230}{V}/100 \text{ V} = 1.32/1 \)

4.2.4. Analysis of the difference between the actual measured value and the theoretical value of 3U0
In fact, even if the rated output voltage of the secondary side TV at the neutral point of the generator meets the requirement of 100V, due to the difference between the actual measured value of 3U0 and the theoretical value, there is no guarantee that the output voltage 3U0 of the open triangle side of the generator terminal TV and the neutral point of the generator The output voltage of the TV secondary side is absolutely consistent.

The rated value of the secondary value of the neutral grounding transformer is set at 120V, and converted to when the rated output voltage of the TV secondary side meets 100V

\[ 59V/1.2=49V, \text{ the difference from 89V is close to 0.40 times, that is } (89V-49V)/100=40\% \]

Experience tells people that the secondary value of the neutral grounding transformer is closely related to the impedance value of the load. The higher the input impedance value of the secondary load, the smaller the difference between the actual measured value and the theoretical value.

4.3. Analysis on the Delay Time of Stator Grounding Protection
If the stator grounding protection is regarded as the main protection, in principle, it should be set to 0s action; if the stator grounding protection is regarded as the backup protection, a step delay should be set.

The analysis believes that the action delay can be shortened to avoid the influence of the transient process and the excessive process, which is enough to increase the delay by 200ms.

4.4. Analysis of the reasons for the failure of the stator grounding protection based on the third harmonic principle
From the principle analysis, the stator grounding protection based on the third harmonic principle only reflects the faults within 30% of the neutral point of the generator, and the protection should be able to start when the zero sequence voltage is 3U0≤30V.

According to the data displayed by the fault recorder, when the generator stator is grounded, the phase A and phase B voltages are both 94V, the phase C voltage is 4V, the 3U0 voltage is 89V, and the neutral point secondary voltage is 59V. It can be determined that the grounding point is not Within the protection range, it is normal that the stator grounding protection based on the third harmonic principle does not operate.

In addition, since the start-up protection is the third harmonic component, it belongs to the protection of the principle of small action quantity, its value is low and the error is large, and the measurement result will not be too accurate. Therefore, some units only put the third harmonic protection into signal operation.

5. Precautions

5.1. Shorten the delay time of stator grounding protection

5.1.1. Stator grounding 3U0 protection
For stator grounding 3U0 protection, shorten the action delay time of stator grounding 3U0 protection from 1000ms to 200ms. Set it as the main protection to apply.

b. Third harmonic voltage protection
For the third harmonic voltage protection, when the protection is switched on and tripped, the action delay time of the third harmonic stator grounding protection is shortened from 500ms to 200ms; when the protection signal is switched on, the delay of 500ms is maintained[6].
5.1.2. Adjust the neutral TV ratio
Make the rated output voltage of the neutral TV secondary side of the unit meet the requirements of 100V, and try to ensure that the output voltage of the generator terminal TV open triangle side 3U0 is theoretically consistent with the output voltage of the neutral TV secondary side of the unit.

5.2. Increase the impedance of the secondary load
Use high-impedance third-harmonic stator grounding protection to make up for the defects in principle.

5.3. Uniformly protected clock
In order to avoid the trouble caused by unsynchronized clocks, it is recommended to install a GPS device.
Due to the limitations of the site conditions, only one and two preventive measures have been taken. So far, the unit is operating normally.

6. The conclusion
The power plant’s management of generators is not thorough enough. Although it can carry out routine maintenance and regular overhaul, it has insufficient analysis of the deterioration of generator components; the training of generators is not in place, and the three measures and two cases do not reflect operating personnel’s precautions and emergency situations.

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