Analysis on burning failure of main transformer in 220kV substation

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Abstract. Neutral point ungrounded three-phase system is widely used in 10kV and 35kV low-voltage systems because of its higher power supply reliability. When the single-phase grounding short-circuit fault occurs in the system, the other two phases can continue to operate for a period of time to ensure the reliability of power supply. However, when the system operates under single-phase grounding fault, arc grounding overvoltage is easy to occur, which may damage electrical equipment or develop into phase-to-phase short circuit. This paper analyses a burning accident of main transformer caused by arc grounding overvoltage in 220kV substation, obtains fault recording information, points out fault causes and puts forward corresponding preventive measures.

Keywords: transformer, arc grounding, fault recording, insulator string aging.

1. Introduction
Neutral ungrounded three-phase system is widely used in 35kV and below voltage level power grid, which is mainly used to improve the power supply reliability of low-voltage system [1]. Usually, when the single-phase grounding short-circuit fault occurs in the three-phase system with ungrounded neutral point, the short-circuit current is only the capacitance current to ground of the three-phase system because the system has only one grounding point, the short-circuit current is only the capacitance current to ground of the three-phase system. At this time, the voltage of the grounding short-circuit phase is 0, and the voltage of the other two-phase is increased to 1.73 times loss of load.

The arc grounding over-voltage fault studied in this paper is: when the single-phase grounding short-circuit occurs in the three-phase system with ungrounded neutral point, because the short-circuit point is often not metallic contact, unstable intermittent arc will be generated at the short-circuit point [2]. In the process of arc extinguishing and re igniting for many times, it will lead to high-frequency oscillation over-current on the inductance and capacitance circuits of the fault phase and non-fault phase the over-voltage amplitude of the non-fault phase can reach 3.15-3.5 times of the phase voltage [3]. At this time, the over-voltage of the non-fault phase will lead to insulation breakdown, which will lead to the development of the system from single-phase short-circuit fault to three-phase short-circuit fault [4].
2. System operation status before failure
Before the fault, the 220kV and 110kV double bus operation of the substation, No.1 and No.2 main transformers are in parallel operation, the 35kV side bus is in single bus section (only section knife switch) with bypass operation mode, No.2 main transformer with 35kV full load, No.1 main transformer with 35kV side hot standby. There are 5 35kV lines in total, all of which operate on 35kV side I section bus, including Qigao line, Qihe line, qiguang line, Qimin line and Qihua line.

The model of faulty insulator is zsw-40.5/10-4, which is produced by Mudanjiang electric porcelain factory, and put into operation on November 3, 2015.

The model of the main transformer with fault is sfsz11-120000 / 220, which is produced by Huludao power equipment plant of China energy construction group, and put into operation on September 29, 2015.

3. Fault event process, monitoring information and protection action
At 15:29 on May 28, 2020, the monitoring center found that there was single-phase grounding in phase B of 35kV system in the substation. At 15:31, the three-side switch of 220kv2 main transformer in the substation tripped, the I section of low-voltage side of I and II protection acted, ratio differential action, differential quick break action. The non-electric quantity protection signal lamp of No.2 main transformer showed light gas action, pressure relief valve action, and this weight At 15:45, the operation and maintenance personnel opened the 0345 switch of 35kv2 substation according to the local dispatching order, opened the 35kV section 0340 knife switch at 16:39, and closed the 0301 switch on the 35kV side of No.1 main transformer at 16:51. The 35kV system of the substation was grounded, and the 35kV outgoing line switches were pulled one by one, and the 35kV Qihua line switch was opened. The system grounding phenomenon disappeared, and the user Haohua was informed at 16:54, the 0318 switch, 0317 switch and 0316 switch of Qihe high-speed railway were switched on; at 17:36, the 35kV Qihua line 0312 was transferred from hot standby to maintenance, and the line side grounding switch was closed. At 18:04, the No.2 main transformer and 35kV section II bus were transferred from hot standby to maintenance. In case of fault, the waveform of current recording at 110kV side of No.2 main transformer is as follows:

Figure 1. current recording and broadcasting waveform at 110kV side in case of fault
4. Failure cause analysis and treatment

4.1. On site inspection

During the field inspection, it was found that phase a at the side of 0345 West knife switch of 35kv2 substation was suspended and fell off. Many pieces of original four insulator strings had fallen off, and the porcelain fragments were scattered under the crossing line between 0345 West knife switch and 0345 circuit breaker, and the two-phase B and C cross-line did not fall off. However, discharge burn marks were found on the surface of corresponding insulator and the tail end of tension clamp, and the porcelain bottle on phase a wire side of 0345 West knife switch fell off along with the wire. Oil was sprayed at the pressure relief valves on the north and south sides of No. 2 main transformer. The porcelain bushing of 220kV zero phase bushing of main transformer shifted with the flange plate, and the insulating oil of bushing leaked. Gas was found inside the gas through the observation port. The on-site inspection pictures are as follows:

![Figure 2. phase a cross line and its insulator string falling behind](image1)

![Figure 3. burning trace of phase B insulator string](image2)

![Figure 4. burn marks of phase B and C clamps and insulator strings](image3)

![Figure 5. scattered A-phase insulator string](image4)
4.2. Field test
The test items include dissolved gas analysis in oil, insulation resistance of iron core and clamp, insulation resistance of winding, DC resistance of winding and winding deformation test. The insulation resistance of iron core and clamp and winding insulation resistance are normal. The abnormal test data are as follows:

1. Acetylene in insulation oil chromatographic test is 19.5 μL/L, which is 0 in routine test in 2019. Professional judgment shows that there is high energy arc discharge in transformer.
2. The phase-to-phase unbalance of DC resistance of medium voltage side winding exceeds (regulations ≤ 2%), and the three-phase unbalance degree is 3.4%.
3. The phase-to-phase unbalance of DC resistance of low-voltage side winding exceeds (regulations ≤ 2%), and the three-phase unbalance degree is 443.1%.
4. The frequency response curve after the main transformer winding deformation test fault does not coincide with the original curve during handover acceptance.

4.3. Failure cause analysis
1. The faulty insulator string is composed of four insulators connected by fittings. Each insulator unit is fixed and connected by the upper part of the insulating porcelain piece and the hardware cup head through cement adhesive. However, the cement adhesive is deteriorated, and the normal deterioration rate shall not exceed 0.02%. Once the deterioration rate is accelerated, there will be a gap between the cup head and the insulating porcelain piece, resulting in large leakage of the insulator string. According to the on-site breakdown of insulator string, the poor manufacturing process and high degradation rate are the direct reasons for the breakdown fault of the insulator string.
2. The B-phase single line grounding of Qihua line occurred before the fault, which directly caused the voltage rise of a and C phases in the 35kV system of Qiyi primary transformer substation. After the
overvoltage impulse, the degradation speed of insulator string was further accelerated, which is another reason for the breakdown of faulty insulator string.

3. After the A-phase insulator string is broken down, the A-phase and B-phase short-circuit are formed during the falling process. Due to the arc light and air thermal effect, the A-phase and B-phase short-circuit are formed, and then the three-phase arc light short-circuit is formed.

5. Preventive measures and suggestions
   1. Strengthen the importance of insulator string products, and actively explore the inspection technical means for similar equipment problems;
   2. Strengthen the tracking and supervision of the user's equipment operation status;
   3. Some effective measures such as installing current limiting reactor are adopted to make up for the insufficient short-circuit resistance of transformer, and some links such as transformer return to factory for overhaul, new transformer design participation and on-site supervision are used to actively promote the improvement of short-circuit resistance ability of transformer.

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