Discussion on Explosion of 66kV Electromagnetic Voltage Transformer

Wang Tao, Shi Xiao, Zhang Wei, Han Lu, Yang Songhan, Wang Shuai, Zhang Wenguang, Zhang Hua, Zhao Chuanzong, Hu Yang

Fushun Power Supply Company, Liaoning Electric Power Company Limited, State Grid, China

Keywords: voltage transformer, fault, ferromagnetic resonance, frequency division resonance, single phase grounding

Abstract: Through the analysis of the fault of 66kV electromagnetic voltage transformer, it is clarified that the cause of the explosion of electromagnetic voltage transformer is the frequency division resonance of the system. The occurrence conditions and types of ferromagnetic resonance and the hazards to voltage transformers are introduced. In order to avoid the ferromagnetic resonance accident of the same type of voltage transformer again, an effective countermeasure is scientifically proposed.

1. Introduction

In the distribution system where the neutral point is not grounded, the internal overvoltage accident caused by the saturation of the electromagnetic voltage transformer is frequent, which seriously affects the safety of the power system and should be paid special attention. The performance of this overvoltage may be that the two-phase or three-phase voltage rises, and the phase voltage oscillates at a low frequency of about once per second, which may cause insulation damage, explosion arrester explosion, may cause virtual grounding, or in a voltage transformer. An over current is caused to blow the fuse and the voltage transformer is burnt.

At present, the 66kV system is a non-effective grounding of the neutral point, that is, the arc-suppression coil grounding system. When the system is improperly operated or has ground fault disturbance, etc., when the L and C parameters of the power grid are properly matched, the resonant overvoltage is easily generated. The type may be fundamental resonance, high frequency resonance or frequency division resonance. In the three-phase circuit, the frequency division resonance is mainly a 1/2 frequency resonance [1]. The 66kV neutral point ungrounded system bus voltage transformer causes the system to be single-phase grounded instantaneously due to the short-circuit fault of the shunt reactor. When the ground fault disappears, the 66kV system 1/2 frequency-divided resonance is excited, due to the high amplitude and duration of the zero-sequence voltage. Long, eventually leading to two-phase electromagnetic voltage transformer explosion accident.

2. Resonance

2.1 Ferromagnetic resonance

In the grid of 66kV and below neutral point insulation, due to the unfavorable combination of ground capacitance and electromagnetic voltage transformer excitation inductance, the system voltage is greatly disturbed such as lightning strike, single-phase ground fault disappearing process and switching operation. The resulting ferromagnetic resonance phenomenon [2]. In the neutral point ungrounded system, in order to monitor the grounding insulation, the Y-wired electromagnetic voltage transformer is often connected to the bus bar. As shown in Figure 1, U_0 is the power supply potential and C is the grounding Capacitor of equipment such as lines, L is the voltage transformer's magnetizing inductance, and R_0 is the neutral point series harmonic elimination resistor [3].

  DOI: 10.25236/iwmecs.2019.095

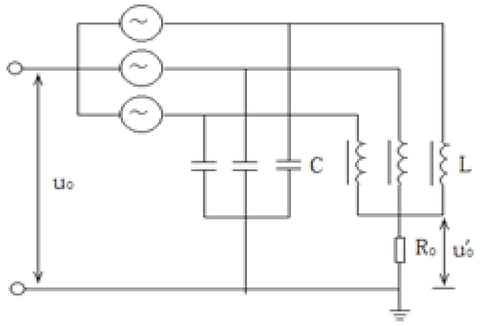

Fig.1 Equivalent circuit of ferromagnetic resonance caused by electromagnetic voltage transformer

In the normal operating state, the voltage transformer has strong inductance, and its value range is above mega-level and symmetrical. The C value depends on the length of the line. The longer the line is, the smaller the capacitive reactance is. That is, the relative capacitance is about 0.004μF for a 1km line, so its capacitive reactance is less than 1MΩ, so the whole network is still capacitive and basic. Symmetrical, the displacement voltage of the grid neutral point is very small, close to the ground potential. However, the magnetizing inductance of the voltage transformer varies with the magnitude of the current passing through, and its U-I characteristics are shown in Figure 2.

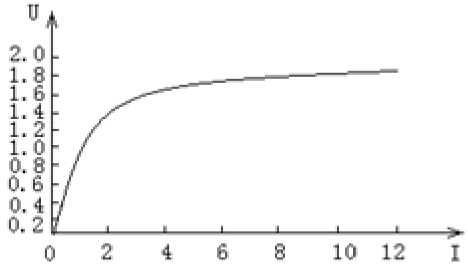

Fig.2 The voltage transformer U-I curve

As can be seen from Figure 2, the initial segment of the curve is close to a straight line and its inductance remains constant accordingly. When the excitation current is too large, the core is saturated, and the L value is greatly reduced. During normal operation, the iron core works in a straight line range. When some fluctuations occur in the system, such as the huge inrush current of the voltage transformer suddenly closing, and the single-phase arc grounding of the line instantaneously, the voltage transformers are saturated to three degrees, and even The symmetry of the power grid is destroyed, and the high-displacement voltage appears at the neutral point of the power grid, causing power frequency resonance or excitation frequency-dividing resonance [1].

The resonance that occurs when the ratio X_{C0}/X_m is small is a frequency division resonance. Capacitance and inductance require a longer time for energy exchange during oscillation, and the oscillation frequency is lower, which is characterized by a lower overvoltage multiple, generally not exceeding 2.5 times the phase voltage; the indication value of the three-phase voltmeter is simultaneously increased and periodically Swing, the line voltage is normal; the over current is very large, generally can reach dozens of times or even hundreds of times of the excitation current, which often leads to the fuse of the voltage transformer fuse, and even burns the transformer when it is serious [4].

2.2 Conditions for resonance

In a power grid where the neutral point is not grounded, in general, the ferromagnetic resonance of the power grid needs to satisfy the following three conditions [1].

(1) The ratio X_{C0}/X_m of the network-to-ground capacitance X_{C0} to the excitation inductance X_m of the voltage transformer should fall within the resonance curve area of Figure 3.

(2) The power supply voltage should be kept within a certain range.

(3) There must be certain conditions for activation.

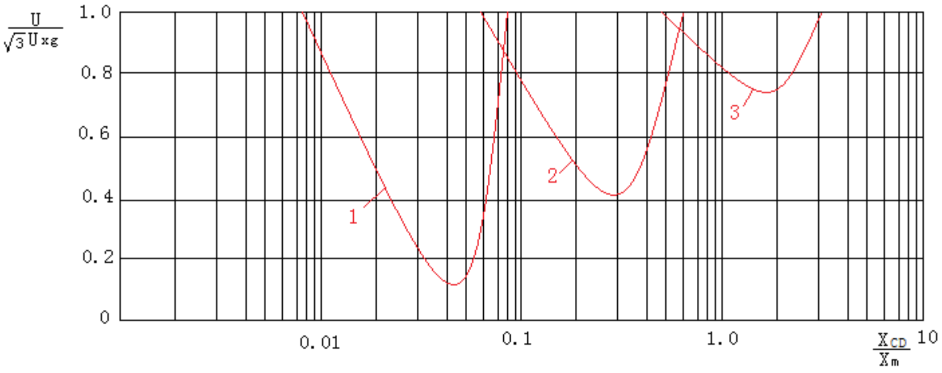

Fig.3 Resonant region with different parameters

3. Accident overview

3.1 Accidents

At 18:28 on February 3, 2011, the 66kV No. 2 reactor of No. 1 main transformer of a 220kV substation was protected by over current, and the circuit breaker tripped. Subsequently, the operator found that the background voltage of the 66kV I segment of the background machine was abnormal. According to the requirements, the operating personnel docked the equipment in the 66kV I section bus line for infrared temperature measurement, no abnormalities, and 66kV measurement and control screen, 66kV I section mother voltage transformer secondary side air switch, etc., no abnormalities. At 20:59, the operator found the 66kV I segment of the mother-phase C-phase voltage transformer injection at the scene, and then the B-inductor also began to inject oil. For safety, the branch personnel immediately evacuated from the scene. At 21 o'clock, the 66kV I segment mother B and C phase voltage transformers exploded and ignited one after another. The 220kV No. 1 main transformer differential protection action and the three-side switch tripped. From the discovery of an abnormality to the switch trip for about 150 minutes.

3.2 Inspection situation

After the accident, the site was inspected and found that there was a very obvious discharge black mark between the third and fourth envelopes of phase C of the 66kV No. 2 reactor. As shown in Figure 4, the outer insulation of the B phase reactor body was damaged by external insulation. , 66kV I segment mother B phase, C phase voltage transformer explosion, only the base remains, as shown in Figure 5, phase A has obvious arc ablation marks, 66kV voltage transformer spacing around the circuit breaker, current transformer porcelain The umbrella skirt, the pillar insulator umbrella skirt and the 66kV bus bar tensile insulator umbrella skirt have various degrees of damage. The damaged device around the voltage transformer is shown in Figure 6.

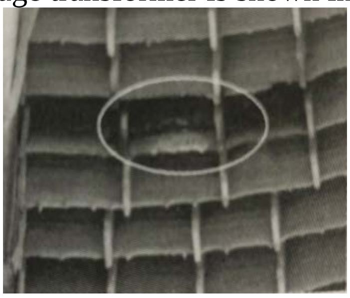

Fig.4 No. 2 reactor C phase fault condition

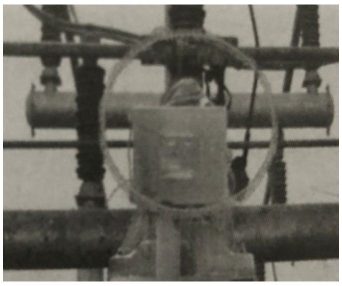

Fig.5 Damage of the 66kV voltage transformer

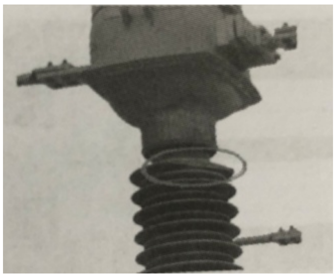

Figure 6 Current transformer damage

4. Analysis of the cause of the accident

The wiring diagram of the 66kV side system of the 220kV No. 1 main transformer is shown in Figure 7.

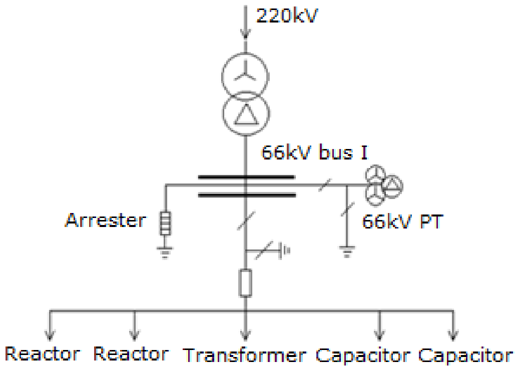

Fig.7 Wiring diagram of the 66 kV side system of 220kV No. 1 main transformer

It can be seen from Figure 7 that the 66kV voltage transformer is installed on the bus bar between the main secondary casing of No.1 main transformer and the main secondary switch No.1, and the two-phase voltage transformer of B and C is grounded due to the explosion. The short circuit fault is within the differential protection range of the transformer, and the relay protection action is correct. The recording of the 66kV system at the beginning of the fault is shown in Figure 8.

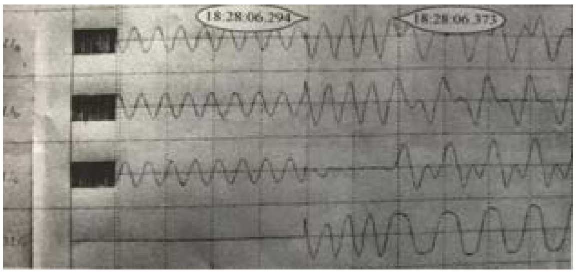

Fig.8 Waveform at the beginning of the 66kV fault

It can be seen from Figure 8 that at 18:28:6.294, the phase C of the 66kV system has a single-phase ground fault, and at 18:28, 6.373 seconds, the single phase connection disappears and the duration is about 80ms. In the moment when the ground fault disappears, the system resonance is induced. From the case of $3U_0$ recording, the zero-sequence voltage oscillation period is close to 40ms, and the frequency is about 25Hz, which is a typical 1/2-frequency resonance. The frequency division resonance process continues until 20:58:55.272, as shown in Figure 9.

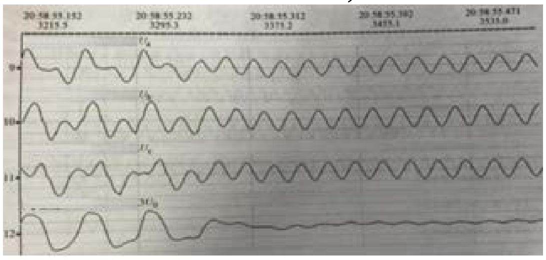

Fig.9 1/2 frequency resonance process end waveform

In this process, the maximum effective values of the relative ground voltages of the 66kV system A, B, and C are 71.98kV, 74.60kV, and 74.78kV, respectively, with the C phase being the largest and the A phase being the smallest. Due to the superposition, the three relative ground voltages The waveform distortion is severe, the period is approximately 40ms, and the maximum effective value of the zero sequence voltage is 45.04kV.

After 20:58:55.272, the frequency-divided vibration phenomenon disappears, and the relative voltage waveforms of A, B, and C return to normal. The effective values are about 33.0kV, 38.9kV, and 35.4kV, respectively, with phase A being the smallest and phase C being the second. The B phase is the largest. At the same time, the neutral point has a power frequency voltage of about 3.5kV. After about 5S, that is, at 20:59:4.436, the amplitude of the zero voltage at the neutral point starts with time. Increase and gradually increase, as shown in Figure 10.

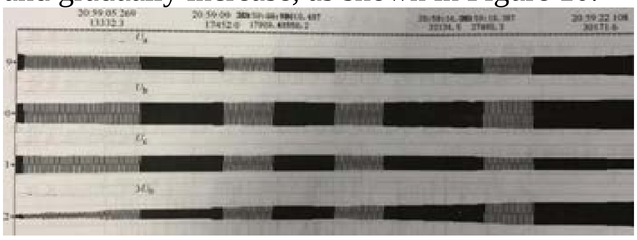

Fig.10 Three-phase and zero-sequence voltage waveform of the 1/2-frequency resonance process

Figure 10 shows that the voltages of the A and B phase voltages and the zero-sequence voltage of the neutral point increase gradually with time, and the amplitude of the B phase is the largest (the maximum effective value is about 64.2 kV), and the amplitude of the C phase voltage. When the ratio increases and decreases, the effective value is reduced to about 14.1kV, and the neutral point zero-sequence voltage RMS value rises to 31.5kV. This process indicates that the insulation condition of the C-phase voltage transformer has begun to deteriorate seriously. At 20:59:33.390, the phase B voltage also begins to drop, indicating that the insulation condition of the phase voltage transformer begins to deteriorate. 21:00:7.316, the voltage of the B and C phase voltage transformers drops to almost zero at the same time, indicating that the main insulation of the two mutual inductors has been safely broken down. The fault recording in Figure 11 shows that the two phases are almost simultaneously Grounding, causing two-phase grounding short-circuit fault, after about 58ms, the main transformer differential protection action, the main transformer switch tripped, the fault is removed.

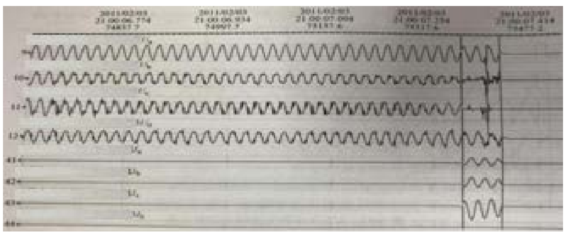

Fig.11 Voltage transformer pre-accident waveform

Compared with the above conditions, the single-ground capacitance of the current 66kV system resonance is mainly composed of the main secondary side capacitance to ground C_{30} of the 220kV main transformer, the C_{kx} of the bus bar to ground of the 66kV, and the C_{CT} of the main secondary current transformer to the ground. The equivalent circuit is shown in Figure 12.

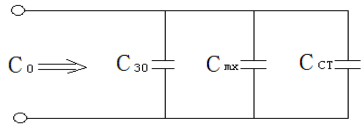

Fig.12 The single relative capacitance equivalent circuit

In the calculation, usually half of C30 is converted to the neutral point side of the transformer, and the other half is converted to the outgoing side of the transformer. Since the 66kV bus is shorter, its capacitance C_{mx} to ground is 500pF. Therefore, the total relative capacitance C_0 is the sum of $C_{30}/2$， C_{mx} and C_{CT}. The excitation characteristic curve of the faulty 66kV voltage transformer is shown in Figure 13.

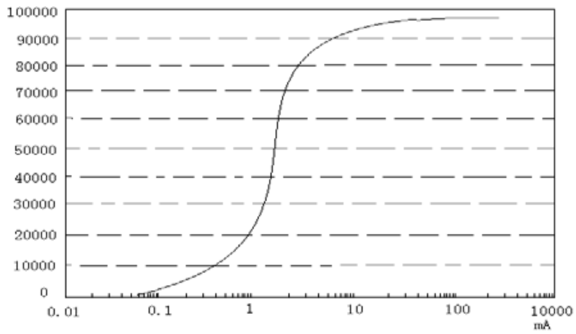

Fig.13 Voltage transformer excitation characteristics

As can be seen from Fig. 13, the excitation current of the voltage transformer at a voltage of 66 kV is about 5 mA, and the excitation inductance at this time is X_m = 66 × 10 3/5 × 10-3 = 13.2 (MΩ), thereby obtaining X_{c0}/X_m is 0.034.

Referring to Figure 3, 0.034 just falls within the 1-segment region of the curve, that is, the 1/2-divided resonance region satisfies the ferromagnetic resonance condition (1), that is, the network-to-ground capacitance X_{C0} and the voltage transformer The ratio X_{C0}/X_m of the excitation inductance X_m should fall within the resonance curve region of Fig. 3; at this time, the system has corresponding voltage maintenance, which satisfies the condition 2, that is, the power supply voltage should be kept within a certain range; The excitation that disappears instantaneously after the ground fault occurs in the system meets the condition 3, that is, there must be certain excitation conditions. During resonance, the voltage amplitude applied to the three phases of A, B and C is relatively high, and the maximum effective value is above 1.9 times the phase voltage. The voltage transformer is designed according to 1.9 times rated voltage 8h, and the voltage mutual inductance flows. The excitation current of the winding is sharply increased, and the core is severely saturated. Under the action of 150 min for a long time, the generated heat is accumulated in a large amount, and the insulation of the transformer deteriorates from good to deteriorated to severe breakdown to discharge breakdown in a short time, due to the rapid oil. Decomposition, the pressure inside the transformer increases, and eventually leads to an explosion accident. In this process, the energy that maintains the system's resonant oscillations and resistive component losses is provided by the commercial frequency power supply, which is transformed by the nonlinear factors of the inductance.

5. Countermeasures

In order to avoid the ferromagnetic resonance accident of the same type of voltage transformer again, the following two effective measures are scientifically proposed.

(1) Adjusting the relevant parameters of the system that originally participated in the resonance,

aiming to fundamentally eliminate the occurrence of system resonance.

1) Select electronic voltage transformers. Electronic (or photoelectric) voltage transformers have developed rapidly in recent years and are used in intelligent substations. Since there is no core or coil like an ordinary electromagnetic voltage transformer, resonance is hard to occur.

2) Capacitive voltage transformers are used. Capacitive voltage transformers are capacitive loads and are widely used in systems with voltage ratings of 220kV and above. They have also been used in 66kV systems in recent years. Because it does not have the conditions for generating resonance with the zero-sequence parameters of the system, it can be considered in some cases where ferromagnetic resonance is easy to occur.

3) Electromagnetic voltage transformer with better excitation characteristics. Electromagnetic voltage transformers with good excitation characteristics are not easy to saturate due to the iron core, and can effectively prevent the occurrence of resonance to some extent. For example, an electromagnetic voltage transformer using a release core has an excitation characteristic curve even at a very high voltage. They are all linear, so it is difficult to intersect with the zero-sequence capacitance characteristic curve of the system, and the purpose of avoiding resonance can be achieved. Even if single-frequency resonance occurs, the resonance is destroyed as long as the parameters are slightly changed (such as a simple operation such as switching a line).

(2) Suppress the generated resonance until it is eliminated, and restore the power grid to normal operation. The main methods are as follows:

1) Connect the damping resistor at both ends of the open delta of the voltage transformer.

2) Connect a damping resistor between the high voltage neutral point of the voltage transformer and ground.

3) A special harmonic elimination device is connected at both ends of the open triangle of the voltage transformer, and an alarm is issued after the harmonic elimination is unsuccessful.

6. Conclusion

66kV neutral point ungrounded system bus voltage transformer explosion accident is mostly caused by 1/2 frequency resonance, its voltage amplitude is high and its duration is long. In order to prevent the occurrence of ferromagnetic frequency resonance, an electronic voltage transformer, a capacitive voltage transformer or an electromagnetic voltage transformer having better excitation characteristics may be used. Since the operation time of the electronic voltage transformer in the system is still short, the operation experience has yet to be accumulated, so in the selection, attention should be paid to its safety, stability and reliability. Capacitive voltage transformers are relatively complex in structure, and their probability of failure is relatively high. Secondly, there is a risk of resonance, and accuracy is greatly affected by system parameters. It should be fully considered in application. It is also possible to suppress the resonance by means of a harmonic elimination device.

References

[1] Ling Zishu. High Voltage Transformer Technology Manual. Beijing: China Electric Power Press, 2005.

[2] Wang Shige, Zhang Junyang. Transformer Fault and Typical Case Analysis. Beijing: China Electric Power Press, 2013.

[3] Xiao Yaorong, Gao Zumian. The Principle and Design Basis of Transformer. Shenyang: Liaoning Science and Technology Press, 2003.

[4] Wang Ruzhen, Huang Weishu, Liu Zhaohui. Structural Design and Operation and Maintenance of Synthetic Thin Film Insulated Current Transformer. Beijing: China Electric Power Press, 2010.