

Analysis of 10kV Voltage Transformer Burning Accident

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Abstract: Firstly, the working principle of electromagnetic voltage transformer is introduced, which is used to connect with metering device, measuring instrument and relay protection device. Secondly, the concept of ferromagnetic resonance, the mechanism and the harm of ferromagnetic resonance, and the measures to prevent ferromagnetic resonance are introduced. And then the phenomenon and harm of frequency division resonance and high frequency resonance are introduced. It is proved by examples that the burning accident of Taidong 10kV voltage transformer is caused by frequency division resonance. The most direct and effective measure to avoid the burning accident of 10kV voltage transformer is to prevent the occurrence of resonance. In order to avoid resonance, the automatic protection of microcomputer harmonic elimination device should be inspected regularly, and the test area of primary harmonic elimination device should be inspected, maintained and dispatching center regularly. The protection automation must connect the 10kV system bus zero sequence voltage to the automatic monitoring system.

1. Introduction

The electromagnetic voltage transformer is a kind of special transformer, and its working principle is the same as transformer. The primary winding of electromagnetic voltage transformer is connected in parallel with high voltage network. The secondary winding is reduced to a standard low voltage at the turn ratio to the primary winding, usually 1100V/100/1.732V and 100/3V. The secondary winding is connected to the load such as metering, measuring instrument and relay protection device. The impedance of the secondary winding meter is very large, so the current of the secondary winding is very small and the current is basically constant. The capacity of the electromagnetic voltage transformer is very small (the maximum is 50VA), which is close to the no-load operation condition. Under normal operation, the secondary voltage is constant and proportional to the primary voltage^[1].

2. Ferromagnetic resonance

Ferromagnetic resonance in power system can be divided into two categories: one is in the power network with 66kV and below neutral point insulation, the other is on the no-load bus in 220kV (or 110kV) substations. The first one is as the unfavorable combination of ground capacitance reactance and excitation inductance of electromagnetic voltage transformer. There is a great disturbance of voltage in the system, such as being struck by lightning, the fault disappearance of single-phase to earth and switching operation etc.

The series resonance is generated in the process of the main switch or the bus-connected switch with the fracture-equalizing capacity of 220kV and 110kV is used for charging the empty bus with the electromagnetic type voltage transformer, or when the bus-connected switch with the electromagnetic voltage transformer is cut off (including the protection whole group transmission linkage), the operation transient process enables a phase, two-phase or three-phase excitation of a phase, two-phase or three-phase excitation to be generated in an electromagnetic type voltage transformer group connected to an empty bus. In a simple way, the resonance due to the inductive

coupling between the high-voltage circuit-breaker capacitor and the bus-voltage transformer, which is limited to the substation no-load bus range, and it is also called the substation empty-bus resonance.

3. The reason of ferromagnetic Resonance occurred in Neutral ungrounded system

In a neutral ungrounded system, in order to monitor the insulation to the ground, the bus is often connected with an electromagnetic voltage transformer connected with Y wiring. As shown in figure 1, U_0 is the power source potential, C is the earth capacitance of equipment, L is the excitation inductance of the voltage transformer, and R_0 is the series harmonic elimination resistance of the neutral point.

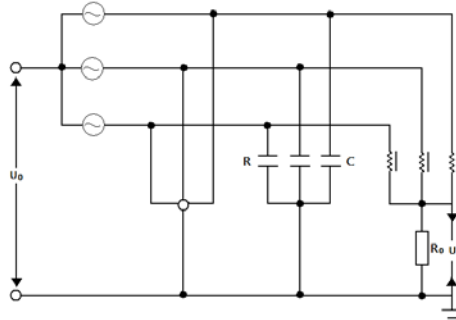


Fig. 1 Equivalent circuit of ferromagnetic resonance caused by electromagnetic voltage transformer

Under the normal operation condition, the excitation inductance of voltage transformer is very large, and its numerical range is above megabyte and each phase is symmetrical. The capacitance is determined by the length of line. The longer the line is, the smaller the capacitance reactance is. To one kilometer line, the capacitance of each phase is about $0.004\mu\text{F}$. Its capacitance reactance is less than $1\text{m}\Omega$, so the whole network is still capacitive and symmetrical to the ground. The displacement voltage of neutral point of power network is very small, which close to ground potential. However, the excitation inductance of the voltage transformer varies with the passing current, and its U-I characteristic is shown in Figure 2.

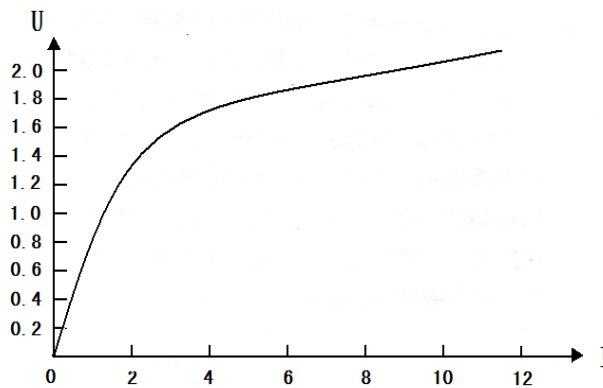


Fig. 2 U-I characteristic of voltage transformer

The initial section of the curve is close to the straight line, and its inductance keeps constant accordingly. When the magnetic current is too large, the core is saturated, then the value of the inductance is greatly reduced.

During normal operation, the iron core works in a linear range. When some fluctuations in the system occurred, such as the huge inrush current of the voltage transformer suddenly closing, the instantaneous single-phase arc grounding of the line, etc. The voltage transformer is saturated with different degrees of three-phase. Even if the symmetry of the power network is destroyed, the neutral point of the power network will have a higher displacement voltage, which will cause the power frequency resonance or the excitation frequency division resonance.

Among operation equipment, as the low insulation of equipment in the isolated neutral system. Generally speaking, single-phase grounding fault is the most common excitation mode of ferromagnetic resonance. There are three main factors that trigger ferroresonance.

(1) System impact caused by grounding, breakage and non-synchronous closing of circuit breakers.

(2) Turn off or on the empty bus or system disturbance excitation resonance

(3) In some special operation mode, the parameters of the system are matched, and the resonance condition is achieved.

4. The form and phenomenon of ferromagnetic resonance

The resonance of different frequencies in the power network is directly related to three parts. The first one is the distribution capacitive reactance X_{co} , which is the wire to ground. The second is the inductance X_m of the parallel operation of the voltage transformer. The last is the ratio of X_{co} to X_m . X_{co} depends on the specific situation. The capacitance X_{co} of overhead line is $350 \times 31/2/L$, $k\Omega/km$. The cable X_{co} is $10 \times 31/2/L$, $k\Omega/km$. The X_{co} of transformer coil to ground is generally $600 k\Omega$ to $1000 k\Omega$. L is the length of the line and the unit is km . X_m is the second side inductance of the voltage transformer $100V / I$ converted to the primary side inductance. I is the actual test current of the secondary side.

4.1 Frequency division resonance

The energy exchange time of capacitance and inductor is longer and the oscillation frequency is lower. The overvoltage multiple is lower, less than 2.5 times. The indicator value of the three-phase voltmeter increases at the same time and oscillates periodically and the line voltage is normal. The overcurrent is extremely large, which can reach tens or even hundreds times of the excitation current. It causes the fuse of the voltage transformer to fuse and even burn out the transformer when it is serious.

4.2 High frequency resonance

The resonance is high frequency resonance when the ratio of X_{co} to X_m is 0.55 to 2.8. The ground capacitance of the circuit is smaller and the energy exchange is faster when the high frequency resonance occurs. The indicator value of the three-phase voltmeter increases at the same time, the maximum value can reach 4 to 5 times of the phase voltage, the line voltage is basically normal, and the over-current is small at resonance. ^[1]

4.3 Fundamental resonance

When the ratio of X_{co} to X_m is close to 1, the resonant frequency is the same as that of power network. So it is called fundamental frequency resonance. The results are as follows: the indicating value in the three-phase voltmeter is two phase increase and one phase decreases, the overcurrent can reach 4.0 to 17.5 times of rated excitation current, and the overvoltage is generally less than 3.2 times phase voltage, accompanied by earthing signal indication, It is called illusory earth phenomenon. When the value of X_{co} divide X_m is less than 0.01 or more than 2.8, ferroresonance will not occur in the system. In different resonant regions, the external trigger voltage of resonance is different. The resonance voltage is the lowest in the frequency division resonance region, and the resonance can be triggered if the system fluctuates slightly under the normal rated voltage. The resonance voltage in the high frequency resonance region is the highest. Under different ratios in the same resonant region, the minimum external trigger voltage (critical value) of resonance is also different.

4.4 Influence of ferromagnetic Resonance on safe Operation of Power system

Through the above analysis, we can see that the single phase grounding or circuit breaker operation occurs, the voltage of the voltage transformer increases, which leads to the gradual magnetic saturation of the core of the voltage transformer. When it is close to $\omega L / \omega C$, the resonance

condition is met, which results in the resonance overvoltage, the main effects of which are as follows:

(1) In the neutral ungrounded system, the main feature of its operation mode is that after single-phase grounding, it is allowed to maintain a certain period of time, usually for 2 hours, without causing the user to be cut off. However, with the expansion of the medium and low-voltage power grid, the number of outgoing lines is increased, the line is longer, the cable line is gradually increased, and the current of the ground capacitance of the medium and low-voltage power grid is also greatly increased. Generally it is 3 to 5 times of the phase voltage or even higher, so that the insulation in the power grid is weak and the breakdown is caused, and the second-point grounding development can be easily caused under the action of over-voltage. The equipment is damaged and the power failure is caused, and the safety operation of the power grid is seriously threatened.

(2) When resonance occurs, the primary excitation current of the voltage transformer increases sharply, which makes the high voltage fuse broken. If the current does not reach the fuse breaking value but exceeds the rated current of the voltage transformer and runs under the condition of overcurrent for a long time it will inevitably cause the voltage transformer to burn.

4.5 Accident example

4.5.1 The course of accidents

At Taidong station the second-line overflow protection of the 10kV Taiqing line was tripped and the coincidence was successful at 19:16. The voltage of the 10kV line of the Taidong transformer started to decrease. At 20: 45 the voltage dropped to zero volt. At 20: 55, the voltage of the 10 kV Qingnian transformer started to decrease, and at 20.00, the voltage was reduced to zero volt. All of the voltage transformers in the first and second sections of the Taidong transformer are burned.



Fig. 3 Zero-phase Voltage Transformer in the second stage of Taidong Transformer substation



Fig. 4 Zero-phase Voltage Transformer in the first stage of Taidong Transformer substation

4.5.2 The cause of accidents

Before the 10kV voltage transformer is burned, the 10kV system is grounded and the Taiqing second line tripped, which results in the 10kV transformer burning. The phase voltage and the line voltage of the Taidong transformer substation have no obvious increase from the recorded in the automatic monitoring system (CC2000), and only 5% of the fluctuation is made. Then the voltage

drops to zero volt within 15 minutes. It is concluded that the grounding disappearance of Taidong transformer substation caused the frequency division resonance. The voltage fluctuation is not large, the primary excitation current of the voltage transformer is rapidly increased, and the transformer of Taidong transformer substation is completely burnt out. From the operation mode of the system, the frequency division harmonic of the Taidong transformer system will only affect the zero sequence voltage transformer of Qingnian road. It causes zero sequence voltage transformer to burn and has no effect on other three-phase voltage transformer.

5. Measures to prevent ferromagnetic resonance

5.1 Reducing the number of parallel stations of Voltage Transformer

In the same power network, the number of voltage transformers should be reduced as far as possible, especially the number of neutral grounding voltage transformers. The more the number of parallel voltage transformers, the easier it is to saturation the total excitation characteristics of the network and the easier resonance is to occur. The general resonance can be avoid when a set of voltage transformers are connected. But it is possible to produce resonance when two or more sets of voltage transformer.^[3]

5.2 Selection of Voltage Transformer with saturate difficult

Using the voltage transformer with good excitation characteristics, the voltage transformer used in 10kV system should select the excitation inductance larger than $1.5\text{M}\Omega$. The voltage transformer has good volt-ampere characteristic and the starting saturation voltage is above $1.9U_e$. General overvoltage will not enter the saturation region, so it is difficult to form parameter matching resonance, which reduces the probability of resonance.

5.3 Installation of arc-suppression coil at neutral point

When resonance occurs in the 10kV system, and the current value of single-phase grounding is large or close to 10A, the neutral point can be grounded through the arc-suppression coil. When the neutral point is grounded through the arc-suppression coil, the inductance of the arc-suppression coil is much smaller than that of the voltage transformer. The natural frequency of the circuit will be determined by $3L$ and C_0 (relative earth capacitance). So it is impossible that the ferromagnetic resonance caused by TV. Furthermore, the high current of the voltage transformer can be limited in operation, so that the fuse of the voltage transformer will not be destroyed.

5.4 Opening Triangle Winding with small Resistance

The practical experience shows that the small resistance can also effectively eliminate harmonics at both ends of the open triangle winding without affecting normal operation. It can also be used in conjunction with other harmonic elimination measures.

6. Conclusions

The most direct and effective measure to avoid the 10kV voltage transformer burning accident is to prevent the resonance. So during the transition period of 66kV substation transformation, it is strictly prohibited to transfer part of the line load through a 10kV line through the 10kV bus. The number of parallel voltage transformers should be minimized. From the phenomenon and analysis of the accident, this way leads to the decrease of the reactance in the system. Under the special conditions, the capacitance current increases obviously, and the ferromagnetic resonance is easily caused after the grounding fault of the system 10kV disappears. In order to strengthen the automatic protection of microcomputer harmonic elimination device, it is necessary to periodically check, maintain, dispatch and protect the 10kV system bus zero sequence voltage into the automatic monitoring system.

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