Research on suppression measures of ferromagnetic resonance based on ATP-EMTP

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Abstract: Aiming at the electromagnetic transformer of a 35kV substation in a certain area, a simulation model of ferromagnetic resonance based on ATP-EMTP software was established. Several methods of suppressing ferromagnetic resonance overvoltage were analyzed, and it was found that the harmonic elimination device could not completely suppress the occurrence of ferromagnetic resonance, and improvements are proposed based on this.

1. Introduction

Ferromagnetic resonance is a common overvoltage in power systems, which seriously affects the safe and stable operation of the distribution network. The essence of ferromagnetic resonance is that the transient energy generated during single-phase grounding causes a large amount of charge to accumulate in the capacitor to ground. On capacitive equipment, after the ground fault disappears, there is no effective way to release the electric current from the capacitor to the ground, so that it flows through the excitation branch of the voltage transformer and generates an inrush current, which makes the excitation inductance drop and matches the capacitance to ground. Overvoltage is generated. There are two requirements for the generation of ferromagnetic resonance: (1) the voltage transformer has non-linear excitation characteristics; (2) the excitation inductance of the transformer must be greater than the capacitive reactance. In terms of the suppression of ferromagnetic resonance, scholars at home and abroad have done a lot of research and proposed various effective suppression measures, mainly (1) changing system parameters; (2) consuming resonance energy. [1][2][3]

2. The establishment of a ferromagnetic resonance simulation model

Ferromagnetic resonance often occurs in distribution networks where the neutral point is not grounded. The principle wiring diagram is shown in the following figure. The most common excitation method is a single-phase ground fault because the neutral point of the distribution network is not grounded. After a single-phase ground fault occurs, the voltage of the faulted phase drops to 0, and the voltage of the non-faulted phase becomes √3 times. After the ground fault disappears, there is no effective way to discharge the charge charged to the capacitor, and a large current will flow through the PT iron core, which saturates the iron core, reduces the inductance, and matches the capacitance to ground to form a ferromagnetic resonance overvoltage. [4][5][6]
This article uses a JDZX-35 type voltage transformer with a rated voltage of $35 / \sqrt{3} / 0.1 / \sqrt{3} / 0.1 / \sqrt{3} / 0.1 / 0.1 / 0.1 / 3$ (KV). The inductance and reactance of the transformer high-voltage winding. RM and LM are the resistance and reactance of the field winding. Since there is no direct module in ATP-EMTP to simulate the non-linear characteristics of the field winding of the transformer, it needs to be added manually. In the state, one end of the ATP-EMTP module is not allowed to be completely open, so a small capacitor can be connected during the simulation. Excitation characteristics are shown in Table 1.[7][8]

| i/mA  | 0.283 | 0.655 | 0.977 | 1.337 | 1.650 | 1.998 | 3.899 | 8.445 | 14.02 |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| φ/Wb  | 18.34 | 36.5  | 55.9  | 74.85 | 92.04 | 115.46| 139.62| 169.43| 173.45|

3. The neutral point of the primary side of the PT is grounded via a non-linear resistor

Based on the above simulation model, the system was set to have a single-phase ground fault at 0.065s, the ground fault disappeared at 0.25s, and the simulation duration was 2s. The method of suppressing non-linear resistance ferromagnetic resonance is to hope that the resistance is approximately zero when the power grid is operating normally, and the resistance is approximately infinite when a ferromagnetic resonance fault occurs, so that the neutral point of the PT is equivalent to an ungrounded state. The non-linear resistor commonly used in engineering is zinc oxide varistor, and the expression of volt-ampere characteristic is $U = k \times i^a$, $k$ should be adjusted according to different system parameters. In this paper, $k = 110 \times 10^4$ KV / A, $a = 0.56$. 

Figure 3 ABC three-phase voltage waveform diagram of PT neutral point without adding anti-resonance resistor
It can be seen from Figure 3 that after the single-phase ground fault disappeared, the system experienced a ferromagnetic resonance fault and existed in the system for a long time. The three-phase voltage value increased at the same time, and the amplitude reached about 58KV. It can be seen that after adding a non-linear resistor to the primary side of the PT, the ferromagnetic resonance is suppressed, and the suppression period is about 0.2s.

According to the above simulation results, it can be obtained that adding a non-linear resistor at the neutral point of the PT primary side can suppress ferromagnetic resonance, but the suppression period is longer, and the thermal capacity of the non-linear resistor has higher requirements. In practical engineering applications, if a non-linear zinc oxide varistor is installed on the primary side of the PT, the PT may still be burned out, and general engineering requirements $R > 0.6L_x$.

4. PT delta winding connected to damping resistor

In the normal operation of the power grid, the triangular winding of the PT needs to sense the zero sequence voltage of the system. Ferromagnetic resonance mainly occurs in the zero sequence loop. Therefore, when ferromagnetic resonance occurs, the triangular winding is connected to the damping electricity lease, and the resistance will flow Zero crossing sequence current. Under normal circumstances, the smaller the resistance value, the more energy is consumed, and the more obvious the effect of eliminating resonance. According to H.A. Peterson's conclusion, $R < X_l / n^2$, $X_l$ is the excitation inductance of the PT at the rated voltage, and $n$ is the ratio of the high voltage winding to the open delta winding. In the 35KV substation of this paper, the converted $R < 16.3 \Omega$.

![Figure 5 R = 16Ω Three-phase voltage waveform](image-url)
Through the above simulation analysis, comparing Fig. 5 and Fig. 7, it can be obtained that the smaller the damping resistance of the open delta winding, the better the harmonic elimination effect, and the shorter the time taken to eliminate resonance, the more obvious the harmonic elimination effect; compare Fig. 6 and Fig. 8. It can be obtained that the smaller the damping resistance connected to the triangular winding, the larger the zero-sequence current flowing through the triangular winding. When the damping resistance is $R = 16\Omega$, the current flowing after the system is stable is about 1.5A. When the damping resistance is $R = 5\Omega$, the current flowing is about 9A. Therefore, the damping resistor connected in the opening triangle cannot be too small. If the resistance is too small, a large circulating current will burn the PT. In actual applications, the voltage transformer may be burned because the damping resistance is too small or the input time is not accurate.

5. **PT high-voltage side is grounded via single-phase PT (4PT method)**

The principle of 4PT is to connect a single-phase PT in series with the neutral point of the high-voltage winding of the PT, which is called zero-sequence PT. This method can improve the zero-sequence characteristics of PT, which is equivalent to the superposition of the zero-sequence characteristics of three-phase PT and the volt-ampere characteristics of single-phase PT, which changes the excitation parameters of the system and reduces the saturation area of the transformer to a
certain extent Avoidance of resonance. Adopting this wiring method has no effect on the normal operation of the system. When the system undergoes ferromagnetic resonance, most of the zero-sequence voltage drops on the zero-sequence PT.

6. Conclusion
The simulation analysis of three ferromagnetic resonance suppression methods can be obtained by adding non-linear resistance to the PT primary side, PT open delta winding plus damping resistance, and PT high-voltage side through single-phase PT grounding. These methods can effectively suppress iron. The occurrence of magnetic resonance cannot be completely suppressed.

(1) PT primary side plus non-linear resistor grounding has higher requirements on the thermal capacity of non-linear resistors. Each substation should determine the capacity of non-linear resistors according to the actual situation;

(2) The PT open delta winding with damping resistor is the simplest method of suppression, but this method cannot completely avoid the occurrence of ferromagnetic resonance. The smaller the theoretical resistance, the better the suppression effect, and the greater the circulating current in the delta winding, the more likely it will burn out. In addition to this, the voltage transformer must also accurately control the moment of input of the damping resistor;

(3) Grounding the PT high-voltage side through a single-phase PT can only effectively reduce the area of ferromagnetic resonance, and cannot completely avoid saturation of the iron core. Once
resonance occurs, the harm is greater, the input cost is greater, and the wiring is more complicated.

In summary, because the parameters of each substation are different, the most effective measures should be taken for the suppression of ferromagnetic resonance according to the specific situation.

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