Study on Ferroresonance Elimination in 10kV Power Distribution System With 4TV Method

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Abstract. Distribution networks can emerge long-time over-voltage due to ferroresonance caused by the electromagnetic voltage transformer saturation under a certain condition, seriously impacting the secure operation of power system. Some distribution networks used 4TV method to restrain ferroresonance and achieved good effects. However, this method performed ineffective in other distribution networks. To solve this problem, the simulation model was established based on ATP-EMTP program. This paper made comprehensive research on the advantages and disadvantages of 4TV method and drew a comparison between connecting ways of 4TV method. It is proved out for electric power department to apply the results from above-mentioned research in practice to improve the power supply reliability of power distribution system.

Introduction

In the neutral ungrounded power distribution system, some disturbance make electromagnetic energy release from the excitation inductance of electromagnetic voltage transformer(TV) in a short period of time, which leads to TV saturation. This ferroresonance phenomenon possibly fuses TV high voltage fuse and TV, seriously impacting the secure operation of power system. Modern smart grid requires grid discovers and eliminate potential accidents in time and take measures to reduce loss. Therefore, it is significant to study the mechanism of ferroresonance and its suppression measures.

Common suppression measures of ferroresonance in distribution power networks[1-11] include: reducing number of TV sets in parallel, connecting single-phase TV to the neutral point of three-phase TV high voltage side(4TV method), connecting nonlinear resistance to the neutral point of three-phase TV high voltage side, connecting a damping resistance or subharmonic ferroresonance eliminator to broken delta winding of TV, connecting an arc extinguishing winding to the neural point of power system, installing neutral point grounding three –phase capacitor on bus bar, etc. Some distribution networks used 4TV (the basic principle of anti-resonance TV) to restrain ferroresonance and achieved good effects. However, this method performed ineffective in other distribution networks. There is not enough comprehensive and systematic study on 4TV method. Operators also encountered some confusion in practice. To solve this problem, the simulation model was established based on ATP-EMTP program. This paper made comprehensive research on the advantages and disadvantages of 4TV method and drew a comparison between connecting ways of 4TV method. It is proved out for electric power department to apply the results from above-mentioned research in practice to improve the power supply reliability of power distribution system.

The Establishment of Simulation Model

Substation Simulation Model. This paper takes the 10kV distribution system in a substation for example and establishes simulation model. This substation has 13 outlets in 10kV side. Bus bar and ends of outlets are all connected to TV, which is shown in fig. 1.

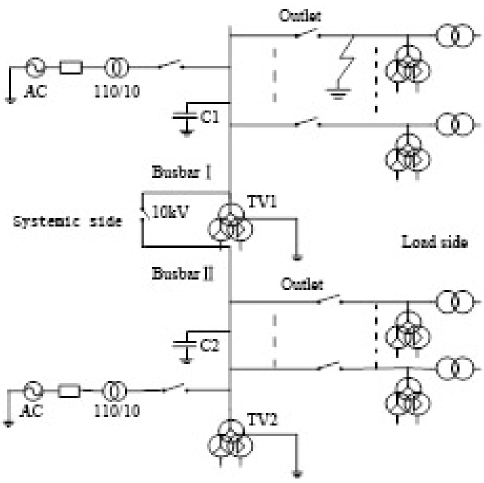
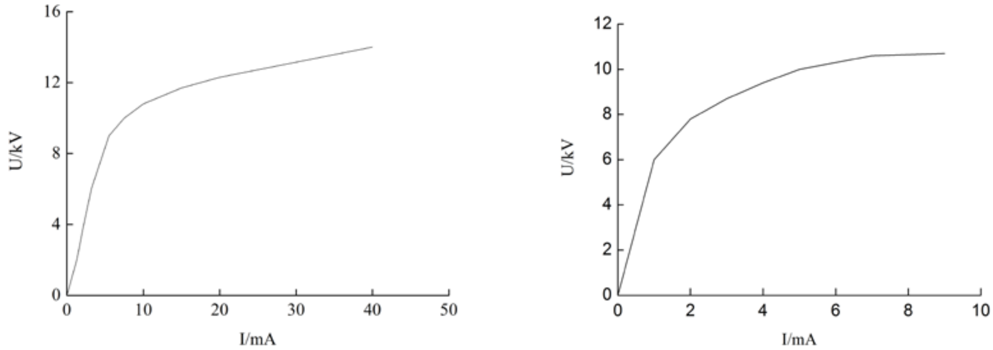


Fig. 1 Wiring diagram of a 10kV power network

In fig. 1, C1 and C2 are transmission line grounding capacitance. TV1 and TV2 indicate busbar voltage transformers whose type is JDZX11-10 C. Their excitation characteristic is shown in fig. 2 (a). The TV neutral points are grounded directly for effective insulation monitoring. There are 13 TVs at load side whose type is JDZJ-10. Their excitation characteristic is shown in fig. 2 (b). In fact, the method of grounding is likely to change at load side.



(a)JDZX11-10C (b)JDZJ-10

Fig. 2 Exciting characteristic curve of TV

If one main transformer cannot run, the other one will supply power to load side through bus bar. Under this extreme condition, the ferroresonance is much more serious. Disappearance of single-phase grounding fault is one of the most common factors to excite resonance in power distribution network. Therefore, a grounding point is set in the middle of a line. At 0.04 s, the single-phase grounding fault appears, after 0.1 s, when the current flows through the ground become zero, the fault disappears, and ferroresonance comes into being.

Waveform of Resonance. If TVs at systemic side are grounded and TVs at load side are ungrounded directly, subharmonic ferroresonance will appear instantly when the single-phase grounding fault disappears, as shown in fig. 3.Subharmonic ferroresonance makes three-phase voltage rise at the same time. The amplitude of overvoltage rises to 2.6 p.u., accompanied by a low frequency oscillation. Because there is damping in network, the amplitude of subharmonic ferroresonance suffers from attenuation by itself, but the overvoltage still lasts for quite a long time. The excitation current of TV at systemic side rise sharply, whose amplitude rises to 0.66 A. Such a high current may cause TV burned. The voltage of broken delta winding of TV at system side rises to 135 V, and the resonance frequency is approximately 1/4 ~ 1/5.

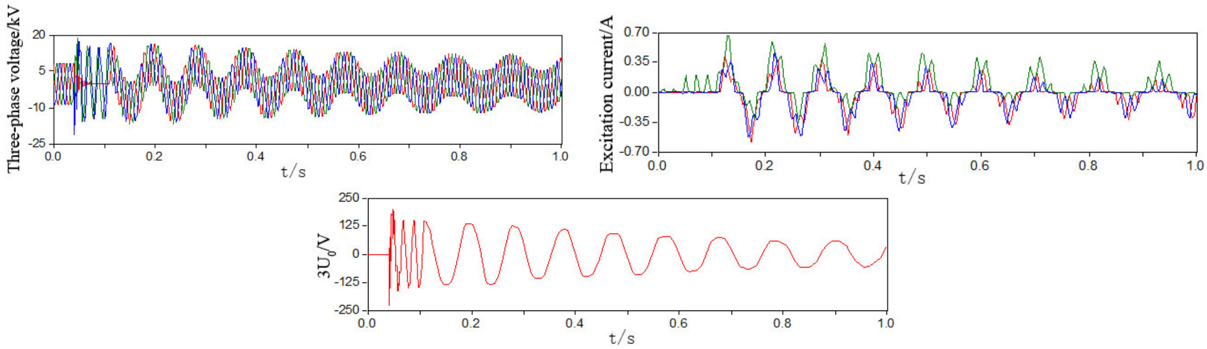


Fig. 3 Subharmonic ferroresonance waveform for TV ungrounded directly on load side

If TVs in system are all grounded directly, fundamental resonance will appear instantly when the single-phase grounding fault disappears, as shown in fig. 4. The amplitude of overvoltage rises to 3.6 p.u., accompanied by a low frequency oscillation. The excitation current of TV at systemic side rises sharply, whose amplitude rises to 0.32 A. The voltage of broken delta winding of TV at system side rises to 350 V, which is far more than the output of broken delta winding in single-phase grounding fault. The waveform of $3U_0$ also shows that fundamental resonance has intermittency. In fig. 4, $3U_0$ is very low within 0.4 ~ 0.46 s, which means that the system operates normally. After that, resonance appears again.

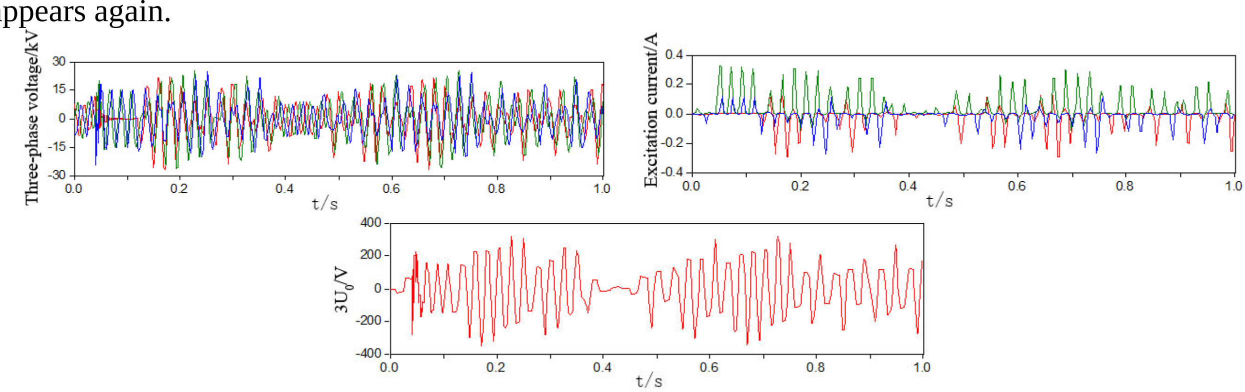


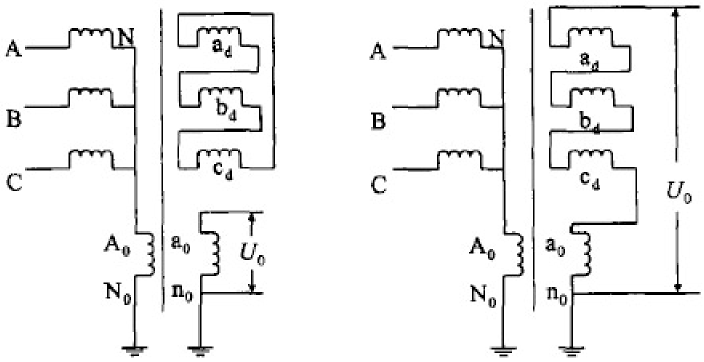
Fig. 4 Harmonic ferroresonance waveform for TV grounded directly on load side

Simulation Analysis of 4TV Method

Overview. When a single-phase TV is connected to the neutral point of three-phase TV, system voltage mainly is positive sequence component. In this way, the output of zero sequence voltage is low so that the single-phase TV has no bad influence on the system. When resonance appears, zero sequence voltage is mainly applied in the single-phase TV, in that three-phase TV still bear phase voltage. Therefore, the core is unlikely to saturate which avoids ferroresonance. Thus, when the voltage-dividing function is more obvious, the inhibition effect of 4TV method will be better. At present, there are two ways to apply 4TV to network[6]:

1) Closing the delta winding of TV, as shown in fig. 5(a). This way is simple to operate. It can restrain harmonic and improve the accuracy of secondary side measurement. The zero sequence voltage is measured by 4^{th} single-phase TV. However, overcurrent is likely to appear in the delta winding, which leads to overheat and breakdown.

2) Putting the broken delta winding and the secondary winding of single-phase TV in series. The zero sequence voltage is measured by the opening, as shown in fig. 5(b). This method is equivalent to the open circuit which avoids the overcurrent, but the action voltage of zero sequence voltage relay must be reset, and the voltage waveform of the secondary suffers from distortion, which affects measurement accuracy.



(a) (b)

Fig. 5 Two modes of connections using the 4TV method

TVs are Ungrounded on Load Side. When the former 4TV method is used on systemic side and TVs on load side are ungrounded, the three-phase voltage, excitation current, current in closed delta winding and zero sequence voltage are shown in fig. 6.

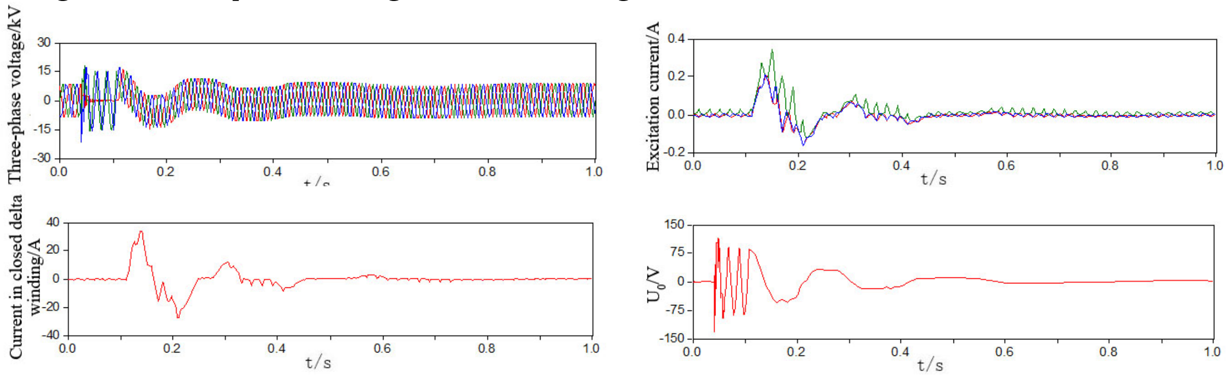


Fig. 6 Waveform for TV ungrounded directly on load side using 4TV method

Fig. 6 shows that, under the condition of TVs ungrounded on load side, it is effective to connect single-phase TV to the neutral point of three-phase to eliminate resonant overvoltage. However, it takes around 0.3 s to work which is a bit long. Large transient current will flow through the primary side of TV, whose amplitude rises to 0.35 A. There is also large zero sequence current flowing through closed delta wingding, which is up to 34 A. It may cause thermal breakdown and damage the equipment. Zero sequence voltage is measured precisely during normal operation and single-phase grounding fault so that it does not affect the relay protection.

When the latter 4TV method is used on systemic side and TVs on load side are ungrounded, the three-phase voltage, excitation current and zero sequence voltage are shown in fig. 7.

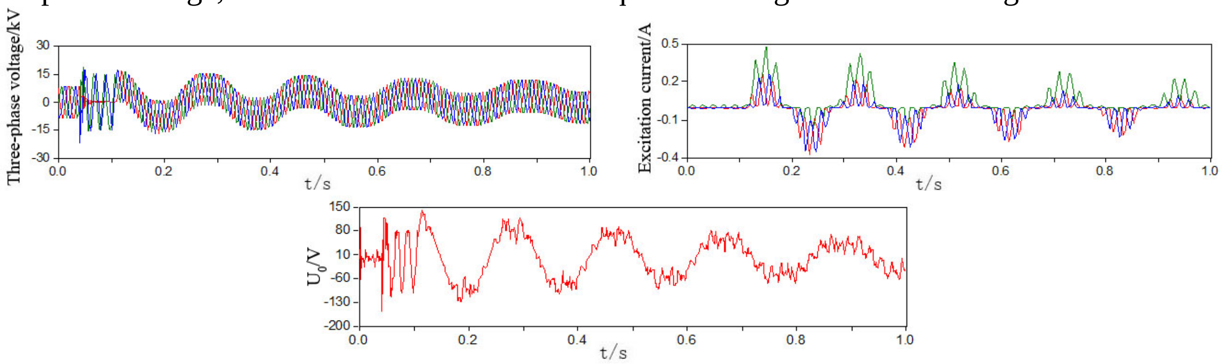


Fig. 7 Waveform for TV ungrounded directly on load side using 4TV method

Compared with fig. 3, it is concluded that the latter 4TV method can suppress ferroresonance, but the effect is poor. The reason is that when the former connection is adopted, the zero sequence voltage is almost all applied to the single-phase TV, fully avoiding the saturation of three-phase TV. But When the latter connection is adopted, the zero sequence voltage is applied to both three-phase TV and single-phase TV. The voltage-dividing ratio depends on excitation impedance in linear segment. If four TV have similar excitation characteristics, the voltage-dividing ratio will be about 1:3. On the one hand, the presence of zero sequence voltage in three-phase TV may make TV saturate, causing resonance. On the other hand, when the zero sequence voltage is so high, the single-phase TV may enter the saturation zone and reduce impedance, so that its function of dividing voltage may not work. Thus the ferroresonance becomes more serious, and form a vicious circle. Fig. 7 also shows that, if the latter method is used, zero sequence voltage is measured correctly during single-phase grounding fault. However, when the system works normally, there is still a small zero sequence voltage to be measured, which may influence the relay protection.

In general, the latter connection way can effectively inhibit circulation within the closed delta winding, but the harmonic elimination effect is poorer. From the angle of zero sequence voltage measurement, the former connection way is more effective.

Summary

1) 4TV method has good effect to restrain ferroresonance overvoltage, and can effectively reduce the current in primary side of TV, avoiding TV burning. It does not affect the measurement of zero sequence voltage and the action of relay protection device.

2) 4TV method has the following disadvantages: slower elimination(usually 0.3 ~ 0.4 s); do not have the overall importance(it can only prevent resonance of itself); the investment is too high to transform all the TVs in system.

3) 4TV method has two modes of connection: closed delta winding and broken delta winding. The simulation results show that the former connection mode can effectively restrain resonance, but is easy to form overcurrent in closed delta winding which may cause thermal breakdown. The latter connection mode can effectively inhibit overcurrent, but its elimination effect is poor.

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