Study on Primary Harmonic Eliminator for Ferromagnetic Resonance in the Neutral Non-effective Grounding System

Cong Zhao¹, Suya Li¹, Songyuan Li¹, Nan Li¹, Bowen Guo¹ and Wei Yan¹
¹State Grid Tianjin Electric Power Research Institute, Tianjin 300384, China

zcgery@163.com

Abstract. The ferromagnetic resonance overvoltage and overcurrent can often appear in the neutral non-effective grounding system, which is caused by the electromagnetic voltage transformer saturation under a certain condition. At present, two different types of primary harmonic eliminators are mainly used to solve the ferromagnetic resonance, which are voltage-sensitive resistor type and thermal resistor type. In this paper, the simulation model based on ATP-EMTP program is established and the results of different harmonic eliminators are compared. The results prove that the primary harmonic eliminator of thermal resistor type can more effectively suppress the ferromagnetic resonance.

1. Introduction
In the neutral non-effective grounding system, it frequently occurs electromagnetic voltage transformer (TV) damage and high voltage fuse blowing, especially in the modern urban power grid with cables widely used. The reason is that there is a coupling capacitance between cables and ground, the more cables and the longer distance, the higher capacitance. Meanwhile, the TV is a nonlinear inductor component, which can be easily saturated as a result of some large disturbance or operation [1]. If the capacitance of cable matches the inductance of TV, ferromagnetic resonance will be induced, causing huge losses to the power grid [2]. Therefore, effective measures must be taken to prevent ferromagnetic resonance.

In recent years, several suppression measures for ferromagnetic resonance have been proposed. Such as using TV with uneasily saturated [3], installing arc suppression coil on the neutral point of main transformer [4], installing linear resistor [5], zero sequence TV [6] or primary harmonic eliminator on the primary neutral point of three-phase TV [7], and installing damping resistor on the secondary open-delta winding of three-phase TV [8], etc. According to operation experience, the most widely used is installing primary harmonic eliminator, including voltage-sensitive resistor type [9] and thermal resistor type [10]. However, the working principles and application effects of the two types of primary harmonic eliminators are different. There is not enough comprehensive and systematic study on how to select the two types of primary harmonic eliminators.

To solve this problem, the simulation model is established based on ATP-EMTP program. This paper makes comprehensive study on the advantages and disadvantages of the two types of primary harmonic eliminators. The simulation results prove that the primary harmonic eliminator of thermal resistor type can more effectively suppress the ferromagnetic resonance.
2. The establishment of simulation model

2.1. Simulation model of substation
The paper takes a 110kV substation for example and establishes simulation model, in which ferromagnetic resonance occurs. The simulation model contains a 110kV transformer, 10kV bus, 10kV three-phase TV, 10kV lines, primary harmonic eliminator and so on, which is shown in figure 1. The single-phase grounding capacitance of the 10kV lines is about 3.17μF.

![Simulation model of a 110kV substation.](image1)

Figure 1. Simulation model of a 110kV substation.

2.2. Simulation model of three-phase TV
In figure 1, TV-A, TV-B, and TV-C are the simulation models of TV, whose type is UNE10. Their excitation characteristic can be obtained with a $U$-$I$ curve by field testing, and can also be converted to a $\varphi$-$i$ curve as used in ATP-EMTP. The $U$-$I$ curve and the $\varphi$-$i$ curve are respectively shown in figure 2 and figure 3.

![U-I curve of TV.](image2) ![\varphi-i curve of TV.](image3)

Figure 2. $U$-$I$ curve of TV.  Figure 3. $\varphi$-$i$ curve of TV.

2.3. Simulation model of primary harmonic eliminator
This paper establishes the simulation model for the two types of primary harmonic eliminators, including voltage-sensitive resistor type and thermal resistor type.
2.3.1. Simulation model of voltage-sensitive resistor type harmonic eliminator. The voltage-sensitive resistor type harmonic eliminator is made of silicon carbide, and its resistance will decrease with voltage increasing, as shown in figure 4. When the ferromagnetic resonance occurs, its resistance will change from a high resistance state to a low resistance state.

![Figure 4. U-I curve of voltage-sensitive resistor type.](image1)

![Figure 5. R-T curve of thermal resistor type.](image2)

2.3.2. Simulation model of thermal resistor type harmonic eliminator. The thermal resistor type harmonic eliminator is made of semiconductor material, and its resistance is positively correlated with temperature, as shown in figure 5. When the ferromagnetic resonance occurs, its resistance will change from a low resistance state to a high resistance state.

3. Simulation analysis of ferromagnetic resonance
In order to study the advantages and disadvantages of the two types of primary harmonic eliminators, the paper compares the simulation waveforms of the three schemes to suppress ferromagnetic resonance, including TV grounded directly without harmonic eliminator, TV grounded with voltage-sensitive resistor type harmonic eliminator and TV grounded with thermal resistor type harmonic eliminator. The paper simulates a single-phase grounding fault in 10kV lines at 0.035s and sets the circuit breaker to open at 0.08s with the ferromagnetic resonance occurrence. The simulation results are shown in below.

3.1. Simulation analysis of no harmonic eliminator
As shown in figure 6, if the TV is grounded directly without harmonic eliminator, the typical ferromagnetic resonance will occur with a low frequency oscillation of 5Hz. The amplitude of TV voltage is 19.584kV, close to 2.0 p.u.. The amplitude of TV current is 1.437A, larger than the rated current of high voltage fuse, which is 0.5A. The amplitude of transformer neutral point voltage is 9.838kV, approximate to the transformer neutral point voltage of the single-phase grounding fault, which is 1.0 p.u.. The amplitude of TV neutral point current is 3.329A.

![Figure 6. Simulation results.](image3)
3.2. Simulation analysis of voltage-sensitive resistor type harmonic eliminator

As shown in figure 7, if the TV is grounded with voltage-sensitive resistor type harmonic eliminator, the ferromagnetic resonance will be suppressed. The amplitude of TV voltage is 19.632kV, close to 2.0 p.u.. The amplitude of TV current declines to 0.995A, but still larger than the rated current of high voltage fuse, which is 0.5A. The amplitude of transformer neutral point voltage is 9.838kV, approximate to the transformer neutral point voltage of the single-phase grounding fault, which is 1.0 p.u.. The amplitude of TV neutral point current is 2.159A. The amplitude of harmonic eliminator voltage is 3.793kV, at a low level.

Figure 6. Simulation waveforms of no harmonic eliminator.

Figure 7. Simulation waveforms of voltage-sensitive resistor type harmonic eliminator.
3.3. Simulation analysis of thermal resistor type harmonic eliminator

As shown in figure 8, if the TV is grounded with thermal resistor type harmonic eliminator, the ferromagnetic resonance will be suppressed. The amplitude of TV voltage is 19.639kV, close to 2.0 p.u.. The amplitude of TV current declines to 0.300A, smaller than the rated current of high voltage fuse, which is 0.5A. The amplitude of transformer neutral point voltage is 9.838kV, approximate to the transformer neutral point voltage of the single-phase grounding fault, which is 1.0 p.u.. The amplitude of TV neutral point current is 0.357A. The amplitude of harmonic eliminator voltage is 11.444kV, at a high level.

![Simulation waveforms of thermal resistor type harmonic eliminator.](image)

3.4. Comparison of three schemes

According to the simulation results, it proves that ferromagnetic resonance can easily occur in the neutral non-effective grounding system with cables. It can cause a low frequency oscillation to destroy the TV and high voltage fuse. Comparing between the three schemes, both of the TV voltage and transformer neutral point voltage are similar, respectively 2.0 p.u. and 1.0 p.u.. However, the TV current and TV neutral point current of three schemes are quite different, and the scheme of thermal resistor type harmonic eliminator realizes more effective suppression for the ferromagnetic resonance, which is shown in table 1. Moreover, as the thermal resistor type harmonic eliminator presents a high resistance state under ferromagnetic resonance, it will tolerate more voltage. Therefore, the insulation level of the TV neutral point needs to select higher standard.
Table 1. Simulation results of three schemes

| Scheme                                | Amplitude of TV-A Current (A) | Amplitude of TV-B Current (A) | Amplitude of TV-C Current (A) | Amplitude of TV Neutral Point Current (A) |
|---------------------------------------|-------------------------------|-------------------------------|-------------------------------|------------------------------------------|
| No harmonic eliminator                | 1.437                         | 1.264                         | 1.052                         | 3.329                                    |
| Voltage-sensitive resistor type harmonic eliminator | 0.995                         | 0.882                         | 0.736                         | 2.159                                    |
| Thermal resistor type harmonic eliminator | 0.300                         | 0.270                         | 0.235                         | 0.357                                    |

4. Conclusion
In the neutral non-effective grounding system with cables, the thermal resistor type harmonic eliminator has good effect to suppress ferromagnetic resonance, by reducing the amplitude of TV current and avoiding TV burning. However, the thermal resistor type harmonic eliminator also has some following disadvantages: slower elimination, higher insulation level and more investment costs. Therefore, the configuration should be selected according to the actual situation.

5. References
[1] Andrei R G, Halley B R 1989 Voltage transformer ferroresonance from an energy transfer standpoint IEEE Trans. Power Delivery 4 1773-78
[2] Xu Zhilong, Huang Jianhua and Wang Dazhong 2001 The digital simulation and study of TV ferroresonance over-voltage in 10 kV power network Electric Power Auto. Equip. 21 27-29
[3] Li Yunge, Shi Wei and Qin Rui and Yang Jilin 2003 A systematical method for suppressing ferroresonance at neutral-grounded substations IEEE Trans. Power Delivery 18 1009-14
[4] Zhou Hao, Yu Yuhong, Zhang Liting, Zhang Yuanlong and Lou Qimin 2005 Comparative study on ferro-resonance elimination measures in 10kV power distribution system by simulation method Power System Technol. 29 24-34
[5] Du Zhiye, Ruan Jiangjun and Wang Weigang 2004 Research of ferroresonance simulation using MATLAB/SIMULINK High Voltage Engin. 30 30-32.
[6] Wang Liang, Shi We, Sha Yuzhou, Hui Zhaopeng, Jia Jianhua, Guan Qingbo and An Zuoping 2005 Study on ferroresonance in the distribution system with 4TV method Gaodianya Jishu 31 15-17
[7] Li Yunge, Shi Wei and Qin Rui and Yang Jilin 2003 A systematical method for suppressing ferroresonance at neutral-grounded substations IEEE Trans. Power Delivery 18 1009-14
[8] Yang Binwen, Li Wensheng 2010 Causes of PT ferroresonance and countermeasures Electric Power Auto. Equip. 30 134-36
[9] Liang Zhirui, Dong Wei, Liu Wexuan, Huang Jiazhen and Wu Qunxiong 2012 Simulation analysis on ferroresonance of potential transformer High Voltage Apparatus 48 18-23
[10] Wu Xutao, Ai Shaogui, Fan Yiping, Yan Nanzheng and Song Shijun 2008 The study and application of the primary current limiting harmonic excluder for the type of the thermal resistor Ningxia Electric Power 6 35-37

Acknowledgments
Great thanks to the funding of State Grid Corporation of China Standard Compilation Project (KJ20-2-10): Guide for Condition Based Maintenance Strategy of Inductive Voltage Transformer.