Research on Ferroresonance of Electromagnetic Voltage Transformer in 550kV HGIS

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***Abstract*—For a 550kV HGIS electromagnetic voltage transformer(PT), ferromagnetic resonance occured after the disconnector was opened. In this paper, firstly, considering the ferromagnetic resonance condition, the fault disintegration, fault recording, and operating overvoltage datas were analyzed to analyze the causes of ferromagnetic resonance.Then a HGIS simulation model was built by EMTP-ATP to calculate very fast transient voltage which was caused by opening operation of disconnector. According to the results, the VFTO amplitude at the PT is not large, but the wave front steepness reaches 2837kV/μs, which is harmful to the inter-turn insulation of the PT primary winding. It may cause partial inter-turn short circuit and then induce core saturation. Finally, the preventive measures of ferromagnetic resonance are proposed.**

Keywords-disconnector; very fast transient overvoltage; electromagnetic voltage transformer; front steepness; ferromagnetic resonance; EMTP-ATP

I. INTRODUCTION

In recent years, with the rapid development of power grids, HGIS (GIS) has been widely adopted by many substations and power plants because of its safety, stability, high integration and small footprint [1-3]. Voltage transformers are an important part of HGIS (GIS), and basically use electromagnetic structure, as voltage, energy measurement and relay protection [4-6].

The electromagnetic voltage transformer (PT) has a high excitation impedance on the high voltage side before the core is saturated. Under the overvoltage or inter-turn short circuit, the iron core will be extremely saturated, so that the high-side excitation resistance drops sharply, and the wire is grounded. Special three-phase or single-phase resonant circuits are formed between the stray capacitance of capacitors or other devices, and can excite ferromagnetic resonance overvoltages of various harmonics [7-13]. In actual operation, due to the poor quality of the core material and the incomplete production process, the inflection point voltage of the PT excitation characteristic is too low, or operation overvoltage shock causes the PT core to saturate and then ferromagnetic resonance occurs. The problem of primary winding heating and burning occurs [14-15].

This paper analyzes the faults of PT in HGIS, and finds the cause of PT faults through disintegration inspection, fault recording analysis and simulation. After eliminating various possibilities, the impact of very fast transient overvoltage (VFTO) caused by the disconnector opening operation on PT ferromagnetic resonance is proposed.

II. EQUIPMENT CONDITION

The series reactor circuit adopts HGIS equipment. The main electrical wiringEquivalent circuit is shown in Figure 1. DS1 and DS2 are outlet isolation switches; DS3 is series anti-bypass isolation switch. An electromagnetic voltage transformer (PT) is arranged on the side of the DS1 near the busbar, and MOA1 and MOA2 are arresters.The dotted line in the figure is the 500kV circuit breaker spacing, both of which are AIS structures, and CB1 and CB2 are circuit breakers.

When the CB1 and CB2 switches were placed in the hot standby state and DS1 was opened, ferromagnetic resonance occurred in A-phase PT and the voltage rose to 180 kV. The fault recording chart is shown in Figure 2.

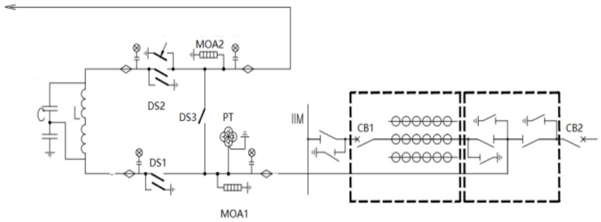


Figure 1. Equivalent circuit.

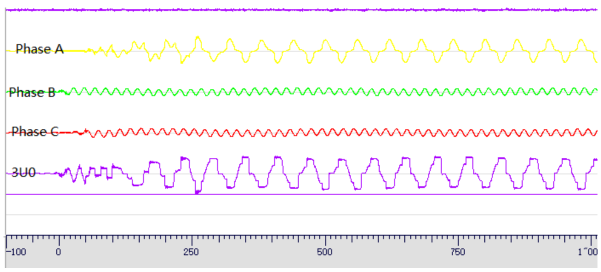


Figure 2. Fault recording chart.

After disintegration, it was found that there was no trace of discharge in the A-phase PT, and no discharge or overheating trace on the secondary windingl. The direct resistance of the secondary winding was normal. There was a large area of short-circuit ablation in the primary winding, and the direct resistance was reduced by 79%.

As shown in Figure 3, it was judged that the A-phase PT had been ferromagnetic resonance.

Figure 3. Internal ablation winding of A-phase PT.

III. Ferromagnetic Resonance Condition

A. Excitation Characteristic Curve

We selected the same batch of PT for laboratory primary winding pressurization to obtain the PT excitation characteristic curve, as shown in Figure 4. The inflection point of the PT excitation characteristic curve was not less than 1.5Un, which met the operational requirements.

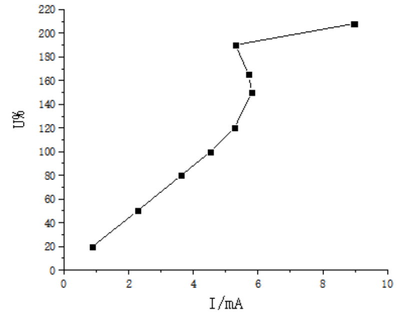


Figure 4. Overall excitation characteristics of PT.

We removed the primary winding and pressurized the secondary winding to obtain the core excitation characteristic curve, as shown in Figure 2. It can be considered that the faulty PT core met the process requirements.

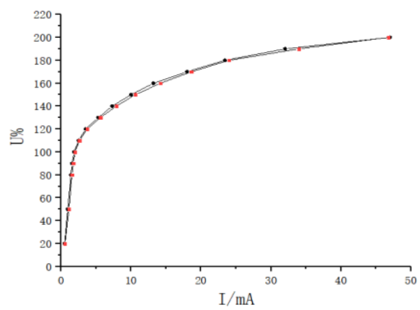


Figure 5. Comparison of core excitation characteristics.

B. Frequency Division Resonance Condition

The PETERSON HA resonance region diagram given by typical PT excitation characteristics is shown in Figure 6, where XC0 is the equivalent capacitive reactance to ground. Xm is the excitation inductance of the PT winding under the action of the rated phase voltage. Ex is the ferromagnetic resonance excitation. Voltage; Ux is the PT working phase voltage. Curve 1 envelope region is frequency division resonance. Curve 2 envelope region is fundamental frequency resonance. Curve 3 envelope region is high frequency resonance.

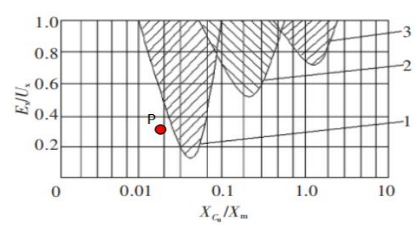


Figure 6. PETERSON H A resonance region diagram.

According to the PETERSON HA resonance region diagram，when XC0/Xm=0.01~0.07, the frequency-dividing resonance is easy to occur, and the ferromagnetic resonance excitation voltage is relatively low at this time. When

XC0/Xm =0.07~0.55, the fundamental frequency resonance is easy to occur. When XC0/Xm = 0.55~2.8, high frequency resonance is easy to occur.The actual parameters of the HGIS loop can be calculated as follows:

$$0.01 < \frac{X_{C_0}}{X_m} \approx 0.0123 < 0.07$$

In this mode of operation, the HGIS loop parameter is located at point P of the PETERSON HA resonance region and falls outside the frequency division resonance region. If the PT is affected by an accidental transient process, the core is saturated, and XC0/Xm increases to enter the frequency division resonance region.

IV. Analysis of Operational Overvoltage

Since CB1 and CB2 did not have closing resistors, Operating overvoltage will generate during the closing operation. The measured overvoltage multiple was shown in Figure. 7. The maximum voltage multiple reached 1.86p.u., which satisfied the lightning arrester action value.

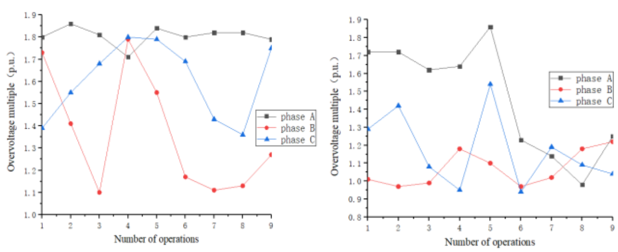


Figure 7. Overvoltage multiple of circuit breaker closing operation.

The maximum value of the overvoltage of the circuit breaker closing operation is less than the impact tolerance value of the pressure change type test operation, and the arrester operates correctly. Therefore, the PT can be considered to withstand the influence of operation overvoltag during the circuit breaker closing progress.

V. Analysis of very Fast Transient Overvoltage

Since the disconnector has no arc extinguishing device and the moving contact speed is slow, it is easy to generate a very fast transient overvoltage (VFTO) in the HGIS during the opening process of the disconnector. The steep wave rise time is ns. The typical waveform of VFTO generated by the isolation switch opening operation in HGIS is shown in Figure. 8. The VFTO amplitude is the highest in the final stage.

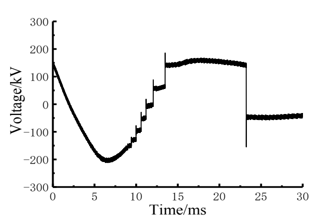


Figure 8. Typical VFTO waveform during the opening operation of disconnector.

During the opening operation of the disconnector, when the breaking voltage was greater than the breaking voltage of the fracture, a single breakdown occurredin the fracture.The breakdown voltage of the fracture increased with the increase of the gap of the contact movement until the fracture breakdown condition was satisfied. This process was a insulation recovery stage.

In order to analyze the overvoltage condition of the insulation recovery stage after the breakdown of the opening operation, the opening operation simulation diagram of DS1 was established according to the HGIS loop parameters.

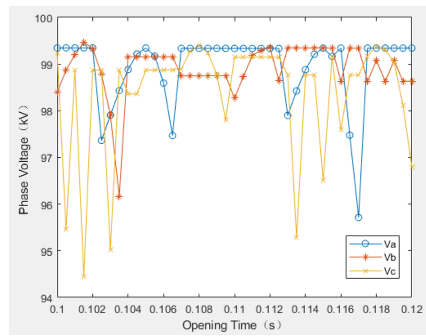


Figure 9. Phase voltage of PT （RMS）.

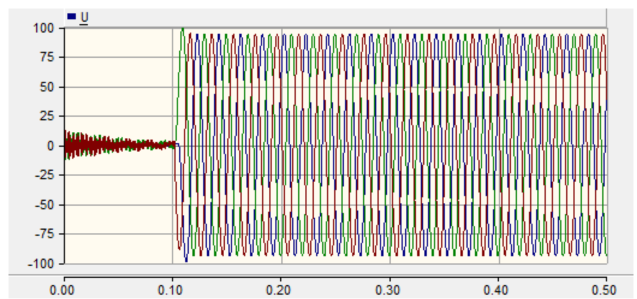


Figure 10. Typical voltage waveform during opening operation of DS1.

Under different opening phase angles of one power frequency cycle, the DS1 opening operation is 40 times. The phase voltage of the PT is shown in Figure.9, and the amplitude is about 100kV. A typical voltage waveform is shown in Figure.10. It can be seen there is no excessive operation overvoltage during the insulation recovery stage of the fracture in DS1 opening operation .

We need to consider the influence of VFTO on the pressure change, and simulate VFTO of the final single-breakdown stage . The simulation model is shown in Figure 11. The voltage peak of the isolated switch power supply side is 1.0p.u. (1.0p.u.=420kV), the residual voltage of the load side busbar is approximately 0, and the calculation time is 10 μs.

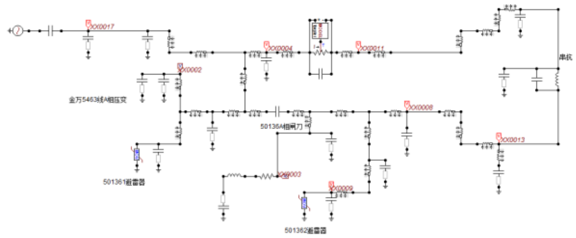
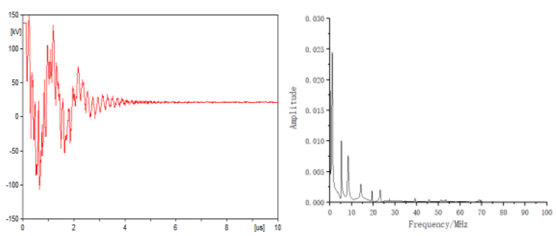


Figure 11 Typical VFTO waveform during the opening operation of disconnector.

Figure 12 shows the single-discharge VFTO waveform and spectrum generated by the A-phase voltage change on the power supply side near the opening of the blade when the DS1 is opened. It is found that the VFTO waveform contains a very rich frequency component, and the frequency is up to about 70 MHz. Mainly depends on the HGIS loop structure and parameters. The background fault recording screen cannot record the transient process waveform due to the low sampling rate.



（a）Voltage waveform （b）Spectrum

Figure 12. VFTO at the entrance of PT.

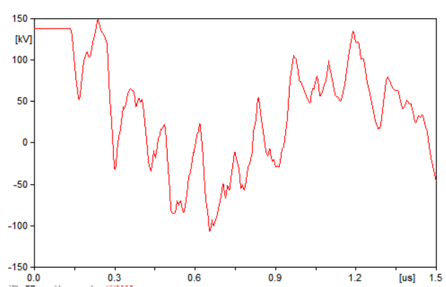


Figure 13. Expanded waveform of VFTO.

It can be seen from Fig. 13 that when CB1 and CB2 were in the hot standby state, the VFTO amplitude generated by repeated breakdown of the fracture was not high during the opening operation of DS1. But the wave front steepness was relatively large, reaching 2837kV/μs, which exceeded the product type test report. The first-order lightning impulse full-wave wavefront steepness was 1397kV/μs, which was very likely to cause uneven distribution of transient voltage in the primary winding. In this process, the partiall insulation weak point of the primary winding of the voltage change was damaged, and partial inter-turn short circuit is formed. The fault gradually expanded, which easily caused the core to be saturated .And then L0 was decreased. When U_X was unchanged, X_{C0}/X_m kept increasing, and point P moved right into the frequency division resonance region. After the DS1 was opened, ferromagnetic resonance occurred by voltage division between equivalent capacitance of the ground and and voltage excitation of the circuit breaker.

VI. Conclusion

The VFTO occurred during the opening operation of the disconnector, and the electromagnetic voltage transformer structurewas weak tolerant to the Very Fast Transient Steep Wave .The wave front was too steep, which was easy to damage the primary winding insulation.

After the primary winding being partially short-circuited, the iron core was extremely saturated, which will result in ferromagnetic resonance. The primary winding would be burnt due to the overload of the ferromagnetic resonance wire.

It is recommended to optimize the relevant operation mode and sequence to avoid the opening operation of the HGIS disconnector to generate VFTO after the voltage division between equivalent capacitance of the ground and the capacitor of the fracture.

HGIS (GIS) compression should be designed with a better structure to meet the safe operation of the grid.

References

[1] ZHOU Hao，YU Yu-hong，ZHANG Li-ting，et al. Comparative study on ferroresonance elimination measures in 10 kVpower distribution system by system by simulation method[J]. Power System Technology，2005(22)：28-38.

[2] WANG Hai-tang,DOU Chun-xia，WANG Ning，et al.Research on PT ferroreonance elimination measures based onATP-EMTP[J]. Transformer，2008，45(3)：24-28.

[3] GE Dong.Study and simulation calculation of overvoltage and overcurrent caused by saturated electromagnetic voltage transformers in power distribution networks [D].Wuhan:Wuhan University，2004

[4] Povhd, Schmitth, Volckero, et al. Modelling and Analysis Guidelines for Very Fast Transients[J]. PD, 1996, 11(4):2028-2035.

[5] HORAK J.A review of ferroresonance [C].57th Annual Conference for Protective Relay Engineers. USA: IEEE,2004:l-29

[6] Zhou Lixia,Yin Zhongdong,Zheng Li.Research on Principle of PT Resonance in Distribution Power System and Its Suppression[J]. Transactions of China Electrotechnical Society,2007,5(22):153-158.

[7] Wang Wei,Ji Shengchang,Cao Tao,et al.Theoretial Analysis and Experimental Verification of Fundamental Frequency Ferroresonance[J].PowerSystemTechnology,2009,17(33):226-230.

[8] Janssens N, Van Craenenbroeek D. Direct calculation of the stability domains of threephase ferroresonance in isolated neutral networks with grounded neutral voltage transformers [J]. IEEE Transactions on Power Delivery, 1996,11 (3):1546-1553.

[9] LIU Jijun. PT ferromagnetic resonance overv-oltage andcauses suppression measures [J]. Electrical Switch, 2011(1) : 4-6.

[10] ZHAO Cuiyu， GUAN Yibin. Analysis and prevention forvoltage transformer and switch capacitor erromagnetic resonance[J]. Automation of Power Systems， 2002，26(2):72-74.

[11] Li Zhibing, Li Xiaoang, Chen Weijiang, et al . Impedance Characteristics of High-frequence Arc in Short SF_6 Gap[J]. High Voltage Engineering, 2013, 39(06) : 1411-1418.

[12] MEI Chenglin，ZHANG Chaoshu. Voltage transformer ferroresonance analysis[J]. Power System Technology，2008，32(2):311-313.

[13] WANG Kun， ZHANG Guohong， WANG Shixu. Ferromagnetic resonance over-voltage power system generation mechanism [C]//Chinese Society of Electrical Engineering of the Tenth Conference of Youth.Jilin：Chinese Society of Electrical Engineering ，2008：1-3

[14] Dai Xianbin. Analysis of electromagnetic voltage transformer ferromagnetic resonance and harmonic elimination method[J]. Electric Switch， 2011(1):4-5.

[15] YANG Hua'an. Ferromagnetic resonance overv-oltage analysis and prevention[J]. Jiangxi Electric Power，2009，33(4):27-28