Ferroresonance Analysis of 500kV GIS Substation during Commissioning Process

Dewen Zhang¹, a, Xiaoxu Hu², b, Hongda Zhang¹, c, Hao Yu¹, d, Yubo Shen¹, e

¹State Grid Heilongjiang Electric Power Co., Ltd. Electric Power Research Institute
²State Grid Heilongjiang Electric Power Overhaul Co., Ltd. Co., Electric Power Overhaul

dewen1984@163.com, sunny0227@163.com, hongda1983@163.com,
yuhao@126.com, yubo21@126.com

Abstract. Ferroresonance is an important factor affecting the security and stability operation of Gas Insulated Switchgear (GIS) substation. The nonlinearity of excitation characteristic of inductance elements with iron cores is the fundamental cause for exciting ferroresonance. A 500kV GIS substation is taken into account in this paper, a variety of operating conditions which may excite ferroresonance during the commissioning process are analyzed by a numerical simulation method. The comparison with actual commissioning results shows that ferroresonance will be excited by opening circuit breakers to switch off no-load buses during the commissioning process. For single-phase electromagnetic potential transformer (PT), ferroresonance can be effectively suppressed by connecting damping resistance in parallel with residual winding temporarily.

1. Introduction
The power system contains a series of inductance and capacitance components, which constitute an extremely complex oscillation circuit [1]. Oscillation phenomenon will not occur under normal operation conditions. However, in the event of system failures or circuit breaker operation disturbances, the inductance elements with iron cores (such as no-load transformer, potential transformer (PT), etc.) and the capacitance elements constitute the resonance circuit in the power grid. Due to the saturation phenomenon of inductance elements with iron cores, nonlinear variations will be presented by the inductance parameters of circuit. Ferroresonance will be generated when the circuit containing nonlinear inductance elements meets certain resonance conditions [2]. Ferroresonance is a periodic or quasi-periodic oscillation status, which is characterized by a sharp increase in the voltage amplitude of one or several harmonics, resulting in the resonance overvoltage and overcurrent with a long duration and a high resonance frequency. Therefore, it is extremely harmful to the insulation of electrical equipment [3]. Ferroresonance overvoltage is a common internal overvoltage that occurs in all voltage-level systems. In September 2008, during the commissioning process of Longtoushi 500kV GIS hydropower station, a one-third fractional frequency ferroresonance was induced by induced by the operation of circuit breakers, which caused the overcurrent and posed a serious threat to the safety of the equipment.
2. Ferroresonance analysis of GIS substation

In this paper, the ferroresonance problem occurred in the commissioning process of the 500kV GIS substation of a power plant is studied and analyzed. The electrical wiring diagram of the substation is shown in Fig. 1. Three-second bus connection with two incoming lines and two outgoing lines is employed to the substation. Before the substation of the power plant is put into operation, the incoming line has exited operation and outgoing line transmits power, so as to detect whether the overall status of the substation could be put into normal operation.

![Electrical wiring diagram of 500kV GIS substation](image)

**Fig. 1** Electrical wiring diagram of 500kV GIS substation

Before the 500kV GIS substation is put into operation, the action of each circuit breaker and disconnecting switch during the commissioning process is shown in Fig. 1 [4]. The commissioning power supply comes from the outgoing line of the system, and the two main transforms exit operations. The equivalent power supply model with internal impedance is adopted by the outgoing power supply. The peak power frequency voltage of the power supply is 449.07kV, and the short-circuit capacity on the power supply side is 5300MVA. The internal resistance value of each phase is equal to 15.2+j11.42Ω through calculation.

During the commissioning process, main transforms 1 and 2 exit operation, and outgoing lines 1 and 2 transmit power. Circuit breaker CB11 is in hot standby status. When circuit breaker CB11 is switched off, the ferroresonance is occurred at the position of VTM1, and the voltage waveform is shown in Fig. 2. As can be seen from Fig. 2, one-third fractional frequency ferroresonance is induced by the opening operation of circuit breaker during the commissioning process.

![Ferroresonance waveform of 500kV GIS substation](image)

**Fig. 2** Ferroresonance waveform of 500kV GIS substation
EMTP software is utilized to implement simulation calculation and analysis of ferroresonance occurred in the system under the above operating conditions [5-6]. The simulation calculation is considered strictly. The A phase of circuit breaker CB11 is switched off at the moment of positive peak voltage, and the other two phases are switched off successively according to the opening time difference of 3ms. The voltage and current waveforms of the primary winding of VTM1 are shown in Fig. 3 and Fig. 4, respectively.

![Fig. 3 Voltage waveform of primary winding of VTM1](image1)

![Fig. 4 Current waveform of primary winding of VTM1](image2)

As can be seen from Fig. 3 and Fig. 4, after the circuit breaker is switched off, the fractional frequency oscillation voltage is occurred at VTM1. The peak overvoltage is 599.1kV, which accompanied by the fractional frequency oscillation overcurrent with a high amplitude of 98.0mA. The amplitude-frequency characteristic diagram can be obtained by performing the frequency spectrum analysis on the voltage waveform in Fig. 3, which is shown in Fig. 5. As can be seen from Fig. 5, the resonance frequency is about 16.7Hz, which is one-third fractional frequency resonance. The effective value of the rated current of the primary winding of the PT is 0.6mA, and the effective value of the maximum power frequency current allowed in 1s is less than or equal to 200mA. This kind of low-frequency current oscillation with long duration and high amplitude will pose a great threat to the PT.
The simulation results show that one-third fractional frequency ferroresonance will be excited by opening circuit breakers to switch off no-load bus during the commissioning process of system. Meanwhile, the amplitude of the overvoltage (1.33p.u.) is not high. All the above are consistent with the actual commissioning results.

3. Ferroresonance Suppression
Nonlinear ferromagnetic characteristics are the fundamental cause of ferroresonance generation. However, the amplitude of overvoltage is limited by the saturation effect of ferromagnetic elements. Furthermore, the circuit loss also makes the resonance overvoltage subject to damping and limitation. When the circuit resistance is greater than a certain value, strong ferroresonance overvoltage will not be excited. It is to explain why the ferroresonance overvoltage in the power system is usually induced when the transformer is at the status of no or light load [7].

Due to the structural characteristics of 500kV GIS, the potential transformers (PTs) used in GIS are mostly single-phase electromagnetic PTs. Traditional ferroresonance suppression measures (such as opening operation of triangular winding connected to damping device) are not applicable [8-9]. In this paper, for ferroresonance generated during the commissioning process of GIS, the measure of short-time parallel damping resistance on the residual winding of each phase of PT is adopted to suppress ferroresonance.

Different parallel damping resistor values of residual winding of PT have different damping effects, which have different requirements for capacity and power of damping resistors. In the simulation model, the values of damping resistances are 1Ω, 3Ω, and 5Ω respectively. When the damping resistance value is 5Ω, the simulation results are as shown in Fig. 6 and Fig. 7, and the simulation data is as shown in Tab. 1. As can be seen from the simulation results, the smaller the damping resistance value is, the more obvious the damping effect is.
The calculation and analysis show that the smaller the value of damping resistance, the smaller the amplitude and duration of primary overcurrent of PT during the oscillation process. However, with the decrease of damping resistance value, the absorbing power and absorbing energy of damping resistance both increase. Therefore, the high power ageing resistance carbon resistance can be temporarily connected in parallel with the residual winding of each phase during the commissioning process.

According to the simulation results, when the circuit breaker opens to switch off no-load bus during commissioning process, a 5Ω damping resistor is immediately connected in parallel with the residual winding of each phase of PT for a short time, as shown in Fig. 8. The damping resistor is composed of five 1Ω carbon resistors connected in series. The specific heat is about 2.0J/cm³·℃, and the energy
density is about 600J/cm$^3$. While the temperature rise does not exceed the threshold of 360℃, the short-time MW-level high power pulse can be withstand for many times. Meanwhile, the energy absorbed in the low-frequency resonance meets the actual requirement.

The ferroresonance is quickly eliminated suppressed after the damping resistance is connected in parallel with the residual winding of each phase of PT, the waveform is as shown in Fig. 9.

4. Conclusion
Through the simulation calculation and analysis on the working condition of ferroresonance excitation in the commissioning operation of a 500kV GIS substation of a power plant, and comparing with the actual commissioning results, the following conclusions are concluded as follows.

The nonlinearity of exciting winding of PT in GIS is the main cause of ferroresonance generation. When the system is subjected to large disturbances, the iron core of PT is reflected as saturated status. The ferroresonance will be excited, thereby resulting in overvoltage and overcurrent. The low-frequency ferroresonance is easily induced by opening circuit breakers to switch off no-load buses during the commissioning process.

For the single-phase electromagnetic PT used in 500kV GIS, the low-frequency ferroresonance can be effectively suppressed by connecting the damping resistance in parallel with the residual winding of PT temporarily.

The smaller the value of parallel damping resistance, the smaller the amplitude and duration of overvoltage and overcurrent during the oscillation process. Meanwhile, with the decrease of damping resistance value, the absorbing power and absorbing energy of damping resistance increase.
References

[1] Wang Xiaoyun, The Simulation in Research on Ferroresonance in Grounded Neutral Point [D]. North China Electric Power University, Beijing, 2002.

[2] Zhang Ling, Hao Chunjuan. Ferroresonance Over-Voltage on Power Transformer and Its Prevention[J]. Electric Power Automation Equipment, 2000, 20(3): 29-31.

[3] Du Guangping, Yu Huining, Jiang Yingmei, et al. Analysis of the Prevention and Treatment of Ferroresonance[J]. Heilongjiang Electric Power, 2010, 32(1): 64-66.

[4] Lei Juan, Guo Jie, Gao Yuan, et al. Approach to Simulation Model of Ferroresonance[J]. Insulators and Surge Arresters, 2007, 218(6): 33-37.

[5] Zhang Mingxin, Wang Dachuan. Measures Preventing from Iron Core Magnetic Resonance Caused by Iron Core Saturation of Potential Transformer[J]. Heilongjiang Electric Power, 2007, 29(3): 201-202.

[6] Du Zhiye, Ruan Jiangjun, Wang Weigang. Improvements on Simulation Model of Ferroresonance[J]. Relay, 2004, 32(8): 26-29.

[7] Zhang Bo, Lu Tiechen, Du Xiaolei. Nonlinear Dynamic Analysis of Ferroresonance in Neutral-grounded Power System[J]. High Voltage Engineering, 2007, 33(1): 31-35.

[8] He Yaofeng, Shang Jianhua, Feng Xiaodong, et al. Analysis of Syntonic Overvoltage in Neutral Indirectly Grounded System[J]. Relay, 2006, 34(23): 66-69.

[9] Li Shunfu. Analysis of Iron-core Saturation Resonance Over-voltage on Voltage Mutual Inductor and Its Precautionary Measures[J]. Qinghai Electric Power, 2003, 4: 20-24.