Simulation Analysis of Ferro resonance of Generator-Transformer Group Shock Tripping

Dewen Zhang¹, *, Xinyu Wei², Peiyong Yu³, Yubo Shen¹, Haifeng Ma⁴

¹State Grid Heilongjiang Electric Power Co., Ltd. Electric Power Research Institute, Harbin, Heilongjiang, China
²State Grid Daxinganling Power Supply Company, Daxinganling, Heilongjiang, China
³State Grid Heilongjiang electric power company maintenance company, Harbin, Heilongjiang, China
⁴State Grid Hegang Power Supply Company, Hegang, Heilongjiang, China

*Corresponding author e-mail: zhangdewen@hperi.hl.sgcc.com.cn

Abstract. As a common self-excited oscillation in power systems, ferromagnetic resonance has a great threat to the insulation of electrical equipment due to overvoltage and overcurrent. The magnetizing inductance of electromagnetic voltage transformers has nonlinear characteristics, which tend to saturate the excitation and cause circuit resonance and generate resonance overvoltage. The ferromagnetic resonance overvoltage caused by the saturation of the transformer has greatly affected the safe and stable operation of the power grid. Therefore, it is very necessary to analyze, calculate and simulate the ferromagnetic resonance overvoltage, and to study the measures to eliminate resonance. Through theoretical calculation and simulation analysis of a hydroelectric power plant generator-transformer group reverse transmission impulse tripping fault, the cause of its ferromagnetic resonance was analysed, and relevant operation and maintenance suggestions were put forward to provide a basis for further research.

1. Introduction

Ferromagnetic resonance is a continuous and high amplitude resonance overvoltage phenomenon caused by the saturation of ferromagnetic inductors such as transformers and voltage transformers [1-4]. At present, although some achievements have been made in theoretical analysis of ferromagnetic resonance and measures to eliminate resonance overvoltage at home and abroad, the complexity of ferromagnetic resonance circuit, the randomness and diversity of resonance process led to the elimination of ferromagnetic resonance the vibration overvoltage measures have their application scope, and the harmonic elimination measures cannot be used blindly. Otherwise, not only the harmonic elimination effect is not good, but also the resonance intensity of the line may be increased, which will pose a threat to the insulation level of the system and affect the safe and stable operation of the system [5-9]. Therefore, it is of great significance to explore the generation mechanism of ferro resonance overvoltage, comprehensively analyze the effect of harmonic suppression measures of resonance, and compare with each other, and explore more effective harmonic elimination measures based on the existing research.
results, which is of great significance to improve the reliability of power supply and maintain the safe and stable operation of the system, and has great theoretical and application value [10-14].

Before the new transformer is put into operation, the impact closing test should be carried out to check whether the insulation strength of the transformer can withstand the impact of full voltage or switching overvoltage. In case of system failure or disturbance, the system operating parameters will change, which may trigger the generation of resonance [15-20]. Most of the inductors that excite ferromagnetic resonance are iron core elements with saturated nonlinear characteristics. The inductance value changes with the change of excitation current. When certain matching conditions are met, ferromagnetic resonance will occur in the system, leading to serious overvoltage accidents [21-24]. Ferromagnetic resonance overvoltage will cause the primary high voltage fuse of voltage transformer to fuse, even lead to insulation breakdown damage or voltage transformer overheating burning [25-27]. In the power grid, there is often a ferromagnetic resonance overvoltage caused by electromagnetic voltage transformer. In case of no-load bus closing, conductor grounding short-circuits, strong wind, lightning, etc., if appropriate measures are not taken, resonance may be excited, resulting in over-voltage, resulting in burning of voltage transformer and explosion of lightning arrester, and then power failure accident or damage of power system equipment [28-31]. This paper analyzes and simulates the impact trip fault of No.1 generator transformer unit in a hydropower plant, analyzes the causes of ferromagnetic resonance and the countermeasures, so as to provide the basis for further research.

2. Fault overview

After opening the 0241-knife switch at the outlet of #1 unit in a hydropower plant, the 0201 a knife switch at 220 kV side of No. 1 main transformer is closed. The 220kV side 0201 switch of No.1 main transformer is used to impact close the No.1 main transformer for 4 times with an interval of 5-10 minutes. After each impact closing, the appearance inspection of the equipment put into operation is normal. After the fourth impact closing, the 0201 switch at 220 kV side of No.1 main transformer is opened. The primary system diagram of unit 1 is shown in Figure 1.

![Figure 1. Primary system diagram of unit 1](image-url)
In a hydropower plant, the soft connection between No.1 generator and generator outlet bus was disconnected, and 0241 knife switch of unit was closed. 0201 switch on 220kV side of No.1 main transformer was used to make the fifth impact on No.1 main transformer. During the impact process, the fundamental wave zero sequence stator grounding protection of a and B sets of generator transformer unit protection (Xuji wfb-800a) tripped 0201 switch at the outlet.

On June 22, a hydropower plant cut off the excitation transformer of No.1 unit, and used 0201 switch to make the sixth impact on No.1 main transformer. During the impact process, the generator transformer unit a set of protection fundamental wave zero sequence stator grounding protection action tripped the 0201 switch. The current waveform recorded by a set of protection device of generator transformer unit in the sixth impact is shown in Fig. 2.

![Current waveform record](image)

(a) Current waveform of high voltage side and generator terminal

(b) Zero sequence current waveform

**Figure 2.** Current waveform recorded by a set of protection device (action) of generator transformer unit in the sixth impact

### 3. Analysis of impulse trip fault

Through investigation, no fault was found in the high-voltage side and low-voltage side of No.1 main transformer, which was caused by frequency division resonance of low-voltage system and saturation of voltage transformer at generator terminal.

The magnetic resonance transformer may lead to over voltage in the process of switching on the magnetic core transformer. Some parameters of the system are estimated as follows:
The actual test value of the capacitance to ground at the low voltage side of the main transformer is 0.02432μF, and the measured value of the solid insulated tubular bus at the low voltage side of the main transformer is 8.47 * 2 = 16.94nF = 0.01694μF. when the rated secondary excitation voltage at the inflection point of the voltage transformer is 61.84V, the excitation current is 0.3966A, and the transformation ratio of the voltage transformer is 138, and the excitation current converted to the primary side is as follows:

\[ I_L = \frac{0.3966}{138} = 0.002874 \, \text{A} \]  

(1)

The excitation reactance of the transformer is (2yh, 3yh two groups of transformers are in parallel):

\[ X_m = \frac{13800 / 0.002874}{2} = 2400835 \, \Omega \]  

(2)

The ground capacitance reactance of solid insulated tubular bus and transformer at low voltage side of main transformer is as follows:

\[ C_0 = 0.008107 + 2 \times 0.00847 = 0.02504 \, \mu F \]  

(3)

\[ X_{C0} = \frac{1}{\omega C_0} = \frac{10^6}{314} \times 0.02504 = 127185 \, \Omega \]  

(4)

\[ \frac{X_{C0}}{X_m} = \frac{127185}{2400835} = 0.053 \]  

(5)

![Figure 3. Resonance region of harmonics (Peterson resonance Partition Curve)](image)

It can be seen from Fig. 3 that the resonance region is closely related to \( \frac{X_{C0}}{X_m} \). When \( \frac{X_{C0}}{X_m} \) is about 0.01 to 0.08, 1/2 frequency division resonance will occur; when \( \frac{X_{C0}}{X_m} \) is about 0.08 to 0.8, fundamental resonance may occur; when \( \frac{X_{C0}}{X_m} \) is about 0.8 to 3, the nature of resonance is high-frequency resonance. Therefore, the possibility of 1/2 frequency division resonance in the process of reverse charging is judged.

If the newly replaced solid insulated tubular bus at low voltage side of main transformer is not included, the capacitance per phase to ground of low voltage side of main transformer is taken as 0.008107 μF, the excitation current is 0.3966A when the rated secondary excitation voltage at the inflection point of voltage transformer is 61.84V, and the transformation ratio of voltage transformer is 138, and the excitation current converted to primary side is:

\[ I_L = \frac{0.3966}{138} = 0.002874 \, \text{A} \]  

(6)

The excitation reactance of the transformer is (2yh, 3yh two groups of transformers are in parallel):
5

The ground capacitance reactance of solid insulated tubular bus bar and transformer group at low voltage side of main transformer is as follows:

\[ X_m = 13800 / 0.002874 / 2 = 2400835 \Omega \]  

(7)

It is still possible to have fundamental resonance.

4. Analysis of simulation results

4.1. Fault simulation playback

The output bus voltage of generator transformer unit recorded by fault recorder of generator transformer unit during the sixth impulse is simulated. Through harmonic analysis, it is found that the voltage recorded contains a large 25 Hz harmonic component. The simulation results are consistent with the calculation results of primary equipment parameters. It can be concluded that frequency division resonance occurs in the low voltage side system of main transformer during the sixth impulse.

4.2. Simulation of ferro resonance

According to the excitation characteristic curve of generator outlet voltage transformer and the measured parameters of generator outlet bus, the system simulation model is built in PSCAD, and the transformer impulse simulation model is shown in Fig. 4. The change trend of the secondary voltage waveform of the voltage transformer and the sixth on-site shock recording file is basically the same, and the opening triangle voltage is about 180V when closing 500ms, which is consistent with the fault message of the protection device. The shock simulation waveform is shown in Fig. 5.

\[ X_{c0} = 1 / \omega C_0 = 10^6 / 314 \times 0.008107 = 392835 \Omega \]  

(9)

\[ X_{c0} / X_m = 392835 / 2400835 = 0.164 \]  

(10)

It is still possible to have fundamental resonance.

Figure 4. Simulation model of transformer impulse
5. Conclusion
The main reason for this trip was that the zero-sequence overvoltage trip was caused by the ferromagnetic resonance caused by the matching of the inductance and capacitance of the low-voltage side system during the transformer impact. Since the pipe mother replaced at the outlet of the No. 1 generator has a larger capacitance to ground, it changes the inductance and capacitance parameters of the primary system. It is easy to produce voltage 1/2 frequency division resonance during the voltage sudden impact. Therefore, a certain factory is recommended Unit 1 does not use the slave system to perform reverse charging operation on the main transformer. It is better to use the zero-voltage boost method for voltage verification.

References
[1] MOSES P S, Masoum M A S, Toliyat H A. Impacts of hysteresis and magnetic couplings on the stability domain of ferromagnetic resonance in asymmetric three-phase three-leg transformers [J]. IEEE Transactions on Energy Conversion, 2011, 26 (2): 581 - 592.
[2] Arturo Corea-Araujo J, Antonio Barrado-Rodrigo J, Gonzalez-Molina F, et al. Ferromagnetic resonance analysis on power transformers interconnected to self-excited induction generators [J]. Electric Power Components and Systems, 2016, 44 (4): 359 - 368.
[3] Figueroa A I, Baker A A, Collins-McIntyre L J, et al. Spin pumping through a topological insulator probed by x-ray detected ferromagnetic resonance [J]. Journal of Magnetism and Magnetic Materials, 2016, 400: 178 - 183.
[4] Val Escudero M, Dudurych I, Redfern MA. Characterization of ferroresonant modes in HV substation with CB grading capacitors [J]. Electric Power Systems Research, 2007, 77 (11): 1506 - 1513.
[5] Mokryani G, Haghifam M R, Esmaeipoor J. Identification of ferroresonance based on wavelet transform and artificial neutral network [J]. European Transactions On Electrical Power, 2009, 19 (3): 474 - 486.