Analysis of Pt Ferroresonance based on Excitation Characteristic and Self-Excitation Mechanism

Yu Zhang¹*, Shijun Xie¹, Nanxi Jiang¹, Zhirong Zhao¹, Donghui Luo¹, Naihui Wang² and Jian Li³

¹ State Grid Sichuan Electric Power Research Institute, Chengdu, China
¹ State Grid Leshan Electric Power Supply Company, Leshan, China
¹ State Grid Meishan Electric Power Supply Company, Meishan, China

*Corresponding author e-mail: zy863129@163.com

Abstract. PT ferroresonance occurred frequently in distribution network, which seriously threatened the safety of personnel and equipment of substation, and seriously affected the power supply reliability of distribution network. In order to reveal the real cause of PT ferro resonance, to propose the solutions. In order to solve the problem of PT resonance and provide theoretical basis for PT resonance prevention and control, this paper carried out the analysis of PT resonance mechanism, PT excitation characteristics and PT frequency division resonance self-mechanism.

1. Introduction

Distribution network is a neutral point ungrounded system. In the case of single-phase ground fault recovery, lightning intrusion, operating overvoltage, etc., PT is easy to saturate and resonant with the circuit capacitance. Over-current and over-voltage will cause equipment damage.

PT ferroresonance occurred frequently in distribution network [1-3], which seriously threatened the safety of personnel and equipment of substation, and seriously affected the power supply reliability of distribution network. In order to reveal the real cause of PT ferro resonance, to propose the solutions. In order to solve the problem of PT resonance and provide theoretical basis for PT resonance prevention and control, this paper carried out the analysis of PT resonance mechanism, PT excitation characteristics and PT frequency division resonance self-mechanism.

2. Analysis of PT resonance excitation mechanism

In neutral ungrounded system, the midpoint of the three-phase potential transformer is directly grounded and the excitation branch of the potential transformer is in parallel with grounding capacitance of the power grid for the need of ground protection. When the core of electromagnetic potential transformer is not saturated, the excitation impedance is large, and the total impedance of parallel branch is capacitive, the equivalent circuit of neutral ungrounded system is shown in Fig.1 when the iron core of potential transformer is not saturated, C0 is the equivalent parallel value of the line to earth capacitive reactance and excitation inductive reactance of electromagnetic potential transformer when the iron core is not saturated.
The excitation characteristic curve of iron core for 35kV potential transformer is shown in Fig.2. The flux linkage of potential transformer is the voltage integral at the end of potential transformer, so the working curve for flux linkage of voltage transformer in normal conditions, that is, at power frequency voltage, is shown in Fig.3, shows the working curve of flux linkage for potential transformer at the transient voltage[4-7].

Due to the excitation of switch closing transient voltage, in potential transformer's flux saturation area, because of the saturated of iron core, the excitation impedance of potential transformer is greatly reduced, and the total parallel impedance of excitation branch and capacitance of conductors to earth is inductive. We assume that when AC core of potential transformer is saturated, the equivalent circuit of neutral ungrounded system is shown in Fig.4, \( L_0 \) is the equivalent parallel value of the line capacitive reactance to ground and excitation inductive reactance of potential transformer when its iron core is saturated.
Figure 4. Equivalent circuit of the system

\[ E_A + E_B + E_C = 0 \]

Figure 5. Single phase equivalent circuit of the system

The simplified single-phase diagram of the circuit in fig.4 is shown in fig.5, because of \( E_A + E_B + E_C = 0 \), \( U_N \) can be acquired as shown in equation (1).

\[
U_N = \frac{E_B (\omega C_0 + \frac{1}{\omega L_0})}{\omega C_0 - \frac{2}{\omega L_0}}
\]  

(1)

When \( \frac{2}{\omega L_0} = \omega C_0 \), the resonance happens in circuit. The neutral voltage \( U_N \) excurs to \(-E_B\) widely. When \( U_N = -E_B \), the voltage of unsaturated phase B is 0, and the virtual grounding phenomenon represented by typical fundamental frequency resonance is formed, and the fundamental frequency resonance oscillogram of AC phase potential transformer recorded in substation is shown in Fig.6, it can be found that the B-phase voltage is grounded at 0, phase AC is line voltage.

Fig. 6 Resonance waveform of AC phase voltage transformer

With the analysis above, transient voltage excites core saturation of potential transformer, excitation inductance of potential transformer decreases, and the series resonance circuit is formed with system circuit, the power frequency supply voltage increases at the saturation phase of the potential transformer to maintain the saturation state of the core of the potential transformer and self-excitation of fundamental frequency resonance.

According to the spectrum analysis on the oscillogram recorded by resonant faults, there are a large number of subdivision harmonics, in the case that only power frequency power supply and no frequency division excitation source, subharmonic has be in the circuit and no attenuation, it is necessary to analyse how the frequency harmonics generates.
3. Analysis on the mechanism of PT self-retention of frequency division resonance

After ferro resonance occurs in the potential transformer, the frequency division component exists in the circuit stably. In the case that there is no obvious dividing excitation source in the circuit, how can this frequency component keep remained? This section will explore the problem in terms of the frequency stability principle from Control Theory based on excitation characteristics and spectral characteristics.

Firstly, in terms of energy, if there is no external excitation source, the electric and magnetic field energy which the RLC circuit stores will keep attenuating and go to 0 at last. In linear system, it can be regarded that all voltage and current of non-power frequency component have no stability of energy basis, it can at most be found in some transitions processes in the system for a limited time. However, the voltage and the current exist in nonlinear system because nonlinear element can play a role as a stable harmonic source under certain conditions.

For the convenience of discussion, we divided RLC series resonant circuit with the consideration of resistance shown in Fig.5 into linear part and nonlinear part. The structure diagram and input and output physical quantities of each part are shown as Fig.7.

![Fig. 7 Signal diagram of RLC series circuit](image)

All units are linear parts except \( i = f(\varphi) \). After exciting current passing through the resistance and capacitance links, it forms the voltage of both ends of the inductor superimposed with the power frequency excitation source, and main flux chain of the inductor is the result of voltage integral. When stable frequency resonance or high-frequency frequency resonance happens, energy consumption of non-power harmonics in linear part will be replenished by power frequency exciter, and the coupling relationship is an inevitable channel to maintain the stable existence of non-power frequency component. Then we take stable existence of 1/3 Frequency component as an example to explain how power frequency component exchanges energy with others, to make calculation simple, we assume that the flux contains only 1/3 frequency division component and power frequency component, then the expression of the flux linkage can be written as:

\[
\varphi = \varphi_{1/3} \sin\left(\frac{1}{3}wt\right) + \varphi_1 \sin(wt) \tag{2}
\]

The nonlinear excitation curve takes the following function:

\[
i = a \varphi + b \varphi^3 \tag{3}
\]

Substitute equation (2) into equation 3), the amplitude of 1/3 frequency division component \( i_{1/3} \) and fundamental wave component \( i_1 \) are calculated:

\[
i_{1/3} = a\varphi_{1/3} + \frac{3}{4}b\varphi_{1/3}^3 - \frac{3}{4}b\varphi_{1/3}^2\varphi_1 + \frac{3}{2}b\varphi_{1/3}\varphi_1^2 \tag{4}
\]

\[
i_1 = a\varphi_1 - \frac{1}{4}b\varphi_{1/3}^3 + \frac{3}{2}b\varphi_{1/3}^2\varphi_1 + \frac{3}{4}b\varphi_1^3 \tag{5}
\]
The effect of the fundamental frequency component of the flux on the 1/3 frequency component of the current:

$$\frac{\partial i_{1/3}}{\partial \phi_1} = -\frac{3}{4} b \phi_{1/3}^2 + 3b \phi_{1/3} \phi_1$$  \hspace{1cm} (6)

When $\phi_{1/3} < 4 \phi_1$, $\frac{\partial i_{1/3}}{\partial \phi_1} > 0$ that is the effect of the fundamental frequency component of the flux on the 1/3 frequency component of the current is when the amplitude of the 1/3 frequency component of the flux is less than 4 times of the fundamental frequency component, the 1/3 frequency component of the excitation current will increase as the fundamental frequency component of the flux increases and decrease as it decreases.

Because of the stable excitation of power frequency source, reduction of power frequency component of the excitation current will directly lead to the increase of the power frequency component in the flux, and then increases the 1/3 frequency component of the excitation current by the coupling of nonlinear excitation links, this is exactly primary cause that frequency component can remain unattenuated without excitation source.

4. Conclusion

By analyzing the resonance mechanism of PT fundamental frequency, the resonance loop of PT in ferroresonance is obtained, as well as the loop parameters that influence the resonance. By analyzing the frequency division resonance mechanism of PT, it is obtained that when PT is in frequency division resonance, the energy of frequency division resonance comes from the power supply and is caused by the nonlinear inductance of PT after saturation. The conclusion of this paper can provide theoretical basis for PT resonance suppression measures.

References

[1] Mork, B.A, Stuehm, et al. Application of nonlinear dynamics and chaos to ferroresonance in distribution systems[J]. Owr Dlvry Ranaon, 1994, (2):1009-1017.

[2] Bohmann L J, McDaniel J, Stanek E K. Lightning arrester failure and ferroresonance on a distribution system[J]. IEEE Transactions on Industry Applications, 1993, 29(6):1189-1195.

[3] Horak J. A review of ferroresonance[C]// Protective Relay Engineers, 2004 57th Annual Conference for.IEEE, 2004:1-29.

[4] Tanggawelu B, Mukerjee R N, Ariffin A E. Ferroresonance studies in Malaysian utility's distribution network[C]. Power Engineering Society General Meeting, 2003, IEEE, IEEE, 2003.

[5] Radmanesh H, Gharehpetian G B. Ferroresonance suppression in power transformers using chaos theory[J]. International Journal of Electrical Power & Energy Systems, 2013, 45(1):1-9.

[6] Mork, B.A, Stuehm D L. Application of nonlinear dynamics and chaos to ferroresonance in distribution systems[J]. Power Delivery IEEE Transactions on, 1994, 9(2):1009-1017.

[7] Chakravarthy S K, Nayar C V. Series ferroresonance in power systems[J]. International Journal of Electrical Power & Energy Systems, 1995, 17(4):267-274.