The simulation of ferroresonance measures of PT based on the nonlinear resistance

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Abstract. Earth capacitance of system line can be matched with inductance parameters of electromagnetic voltage transformer (PT), thereby leading to ferromagnetic resonance in the power system under the condition of instantaneous single-phase grounding and other fault types. Application scope limitations and deficiencies of the existing harmonic elimination measures are analyzed and compared on the basis of analyzing formation mechanism of PT ferromagnetic resonance. Resonance-eliminating measures of PT neutral point through nonlinear resistance grounding is proposed, in addition simulation analysis verification is conducted. Simulation verifies that the resonance-eliminating measures have excellent inhibition effect on fundamental resonance, frequency division resonance and high-frequency resonance. A solution is proposed aiming at the problem of high voltage on PT low voltage side due to PT neutral point through nonlinear resistor, namely three harmonic filter is added on PT center. Simulation analysis is conducted, and simulation result verifies the feasibility of the measures.

Introduction

In actual operation, there are few measures for eliminating and suppressing PT ferromagnetic resonance, but these measures have their own application scope limitations, and the harmonic elimination is ineffective. Resonance-eliminating measures mentioned in literature [2、4、5、7] have own application scope limitation and ineffective resonance-eliminating effect factors: (1) Neutral point series single-phase PT resonance-eliminating measure cannot ensure resonance-eliminating effect of other PT in the system generally; (2) Resonance-eliminating measures of PT neutral point through arc suppression coil grounding have ineffective suppression effect on harmonic under the condition of weak capacitive current; (3) Resonance-eliminating mode of installing neutral grounding three-phase star capacitor bank on bus is adopted, PT damage or high-voltage fuse breaking can be caused due to improper value of Xc0/Xm. (4) If PT resonance-eliminating measures with good volt-ampere characteristics are adopted, PT volt-ampere characteristics also can be worsened due to increase of paralleled PTs.

Formation Mechanism and Characteristics of ferromagnetic Resonance

Since ferromagnetic resonance is only related with system zero-sequence circuit, and it has no relation with wire intra-phase capacitors and capacitor banks for improving power factor, system PT ferromagnetic resonance circuit can be simplified as shown in Figure 1[4].

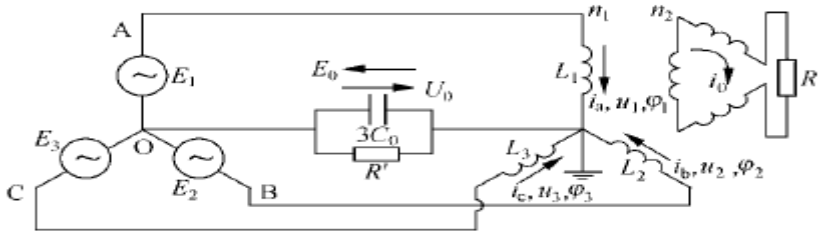


Fig.1 Ferro-magnetic resonance circuit with PT

According to Figure 1, PT loss resistance is ignored, the follows can be obtained according to Kirchhoff's first law under the condition that opening triangle is opened.

$$E_0 = \frac{\frac{E_1}{\omega L_1} + \frac{E_2}{\omega L_2} + \frac{E_3}{\omega L_3}}{3\omega C_0 - \left(\frac{1}{\omega L_1} + \frac{1}{\omega L_2} + \frac{1}{\omega L_3}\right)} \qquad (1)$$

When the following conditions occur in the system: The system suffers from lightning, single-phase ground fault suddenly disappears, etc., the system three phase is not balanced any longer, neutral displacement voltage E_0 is not zero, thereby resulting in continuously increased line current, and gradual magnetic saturation of PT iron core, and parameter match between capacitance and inductance, and stimulating the ferromagnetic resonance.

Establishment of Simulation Circuit Model

In the paper, simulink and powerlib modules in MATLAB are utilized for simulation analysis on PT ferromagnetic resonance[3]. The simulation circuit is shown in Figure 2[1]. Instantaneous single-phase ground fault is adopted for stimulating the system to produce ferromagnetic resonance, and instantaneous single-phase ground fault is realized by opening and closing switch Breaker.

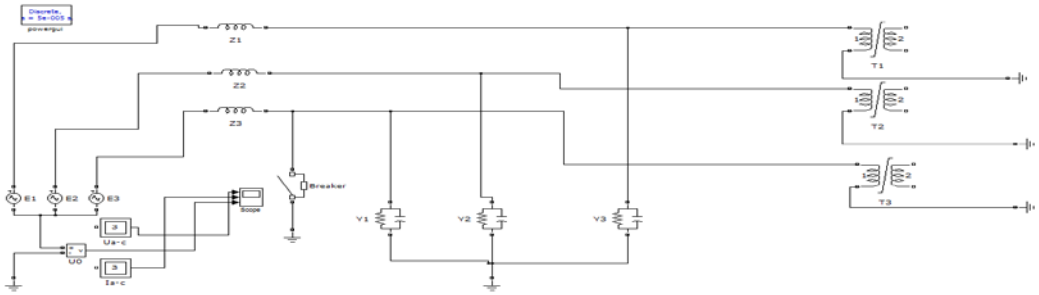


Fig.2 the simulation circuit of ferromagnetic resonance in 10kV system

In Figure 2, E1 to E3 refer to system three-phase power supply, Z1 to Z3 denote equivalent line impedance of the system, Y1 to Y3 respectively refer to ground capacitance and insulation resistance of system equivalent line, specific parameters are obtained based on actual line parameters after conversion. T1, T2 and T3 are three-phase windings of PT. System single-phase ground fault is stimulated by opening and closing switch Breaker, and 0.05Ω is adopted as switch grounding impedance.

Simulation Analysis of Resonance Elimination by PT Neutral Point through Nonlinear Resistance Grounding

Equivalent circuit during PT ferromagnetic resonance (Figure 1) shows that the resistance value of nonlinear resistance is sharply decreased due to increase of voltage added on both ends thereof under the condition of ignoring PT loss resistance and connecting nonlinear resistance on PT neutral point, thereby quickly reducing ground voltage of system neutral point. Resonance elimination idea of connecting nonlinear resistance in PT neutral point, proposed in the paper, is based on the above introduction. In the paper, four broken lines with different slopes are adopted for simulating current voltage characteristics of the applied nonlinear resistors.

In the paper, LXQ (D) 11-10 type resonance eliminator, the non-linear resistor, is adopted for simulation analysis. Table 1 shows current voltage characteristic data of LXQ (D) 11-10 type harmonic eliminator. Figure 3 shows current voltage characteristic curve of piecewise linearization.

Tab.1 the volt-ampere characteristic of harmonic elimination

U (A)	603	810	1036	1265	1535	1942	2040	2610
I (mA)	1	5	10	17	28	49	59	100
U (A)	2945	3245	3645	4015	4365	4505	5005	5435
I (mA)	125	155	194	233	276	285	343	399

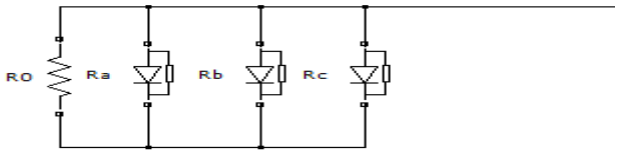


Fig.3 the volt-ampere characteristics of resistance with multistage broken line

R0, Ra, Rb and Rc represent slopes of all resistance value current voltage characteristic curves in the equivalent circuits, equivalent resistances of the system under various states are represented by R1, R2, R3 and R4, and the calculation results are shown as follows:

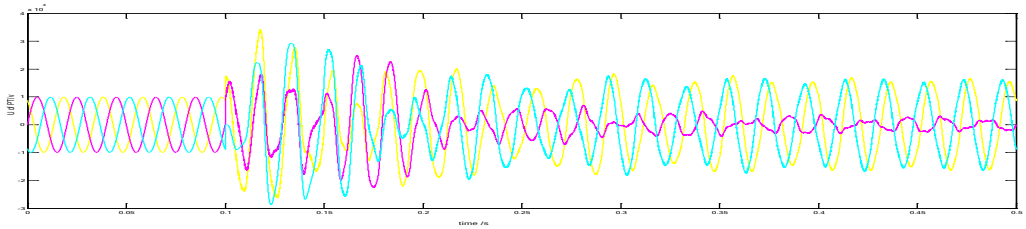
$|U| \le U1$时， $R1 = th\alpha 1 = 0.5M\Omega, R0 = R1 = 0.5M\Omega$

$|U| \succ U1$时， $R2 = th\alpha 2 = 0.03M\Omega, Ra = 0.03195M\Omega$

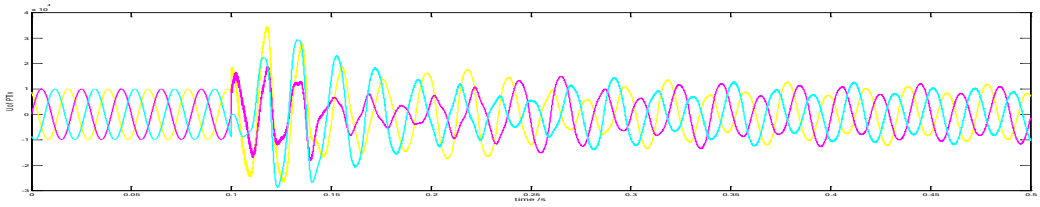
$|U| \succ U2$时， $R3 = th\alpha 3 = 0.013M\Omega, Rb = 0.0229M\Omega$

$|U| \succ U3$时， $R3 = th\alpha 3 = 0.009M\Omega, Rc = 0.02933M\Omega$

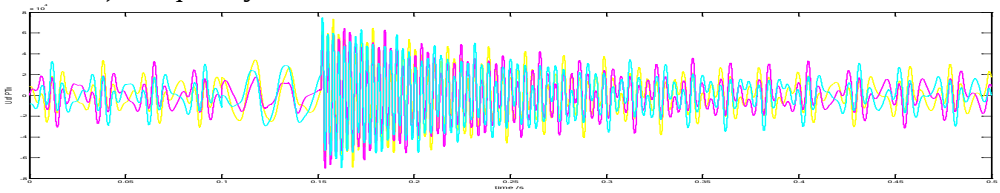
Figure 4 shows that after non-linear resistors are connected in PT neutral point, over-voltage of ferromagnetic resonance (including fundamental resonance, frequency division resonance and high-frequency resonance) is reduced to normal level, over-current is also reduced to normal level, thereby effectively suppressing and eliminating ferromagnetic resonance, and maintaining voltage stability of the center point. In summary, it is not difficult to draw the following conclusions: After nonlinear resistor is connected in series into PT neutral point, PT ferromagnetic resonance (including fundamental resonance, frequency division resonance and high-frequency resonance) is well suppressed, thereby avoiding PT damage.



a) Fundamental resonance after nonlinear resistor is added



b) Frequency division resonance after nonlinear resistor is added



c) High-frequency resonance after nonlinear resistor is added

Fig.4 the voltage waveform of PT's Primary side after the condition of nonlinear resistance on the excitation conditions

Addition of Three Harmonic Filter in PT Neutral Point

After nonlinear resistors are connected into PT neutral point, PT ferromagnetic resonance can be basically eliminated and suppressed. However, voltage in PT low-voltage side is high during dozens of periods after disappearance of single-phase ground fault under the condition of shorter system line, and it can be up to about 200V. Voltage relay (general setting value of 150 ~ 300V) can be actuated, thereby resulting in misjudgment of working personnel. In the paper, solution of adding three harmonic filter on PT center point is proposed aiming at the above problems. After nonlinear resistance is installed on PT neutral point, over-voltage of ferromagnetic resonance (including fundamental resonance, frequency division resonance and high-frequency resonance) is suppressed to reach requirements of system safe operation. After three harmonic filter is added, Figure 5 shows that the voltage is greatly reduced and maintained at about 100V, thus ensuring reliable operation of relay.

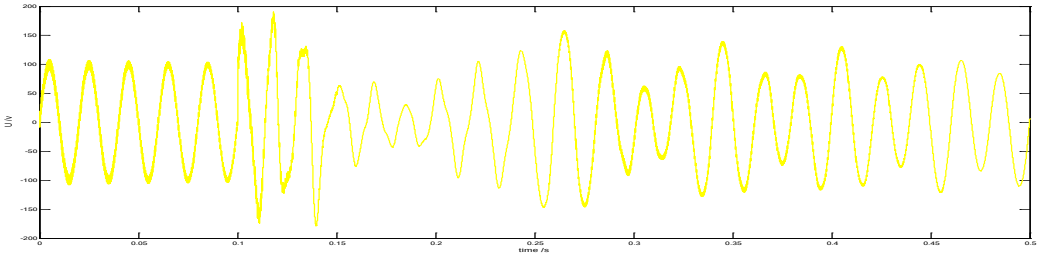


Fig5. Change condition of PT secondary side voltage of the system during elimination of single-phase grounding fault (voltage wave form after addition of nonlinear resistance and three harmonic filter in turn.)

Conclusion

The method is different from advantages of general resonance eliminating measure proposed in foreword, the former theoretical analysis can prove that the resonance eliminating effect of ferromagnetic resonance, proposed in the paper, is very prominent. The point is also verified through stimulation. In addition, the measure of adding three harmonic filter in PT neutral point is proposed aiming at the condition in the paper, and effectiveness of the measure is proved through stimulation, and the information is not considered in current study. Only one simulation software is adopted for simulation verification in the paper due to time constraints and my limited energy, thereby leading to single means. Meanwhile, the non-linear resistors adopted in the paper are not analyzed and compared for making clear the best model. The above two points will be studied by me in the future.

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