Fault Location of Transformer Excitation Short Circuit Based on Asymmetry

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Abstract: Based on electromagnetic coupling mechanism of transformer, changing characteristics of key excitation parameters are studied in this paper. Moreover, asymmetric characteristic model based on excitation parameters is established first, and then characteristics of excitation parameters are identified with principle of time-domain difference. Besides it, identification equation of excitation parameters for three-phase transformer is derived as well. What's more, under different DC disturbances and inter-turn short-circuit conditions with different voltage levels, electromagnetic characteristics of transformer are simulated and analyzed with the help of electromagnetic coupling method. Then, excitation current is used to characterize different abnormal states of transformer to so that fault location can be analyzed. Finally, simulation analysis results verify validity of identification characteristics of excitation parameter and accuracy of fault location analysis in excitation characteristics.

1 Introduction

Power transformer is one of the key equipment in power system, whose operating condition not only affects transformer's own safety but also affects stability and reliability of entire power system. At present, offline technology such as DGA is mainly used to determine transformer faults, which however cannot fully consider actual operation of transformer, and cannot find faults in time so that a lot of unnecessary maintenance will be brought. Therefore, it is necessary to study electromagnetic parameters protection of transformer and diagnose state of transformer in real time. In addition, key electromagnetic parameters of transformer which can be calculated through electrical information measured at port mainly include excitation inductance, dynamic inductance, leakage inductance, and excitation current, all of which can represent electromagnetic change of transformer when it is abnormal or faulty. Excitation current of high voltage transformer under DC bias is calculated to obtain no-load excitation current waveform, which is related calculation for no-load transformer and ignores load effect on excitation current [1-3].

2 Characteristics of Excitation Current Based on Electromagnetic Coupling

2.1 Dynamic Inductance Calculation

Assuming that winding current at a certain time is known, energy balance finite element method based on vector magnetic potential A is used to calculate dynamic inductance matrix LD, and magnetic field model is as follows.

$$\vartriangle\times\frac{1}{\lambda}\Delta A=j=f\left(i\right) \tag{1}$$

In formula (1), λ refers to magnetic permeability; J is current density vector, and f (i) represents distribution of winding excitation current i.

Galerkin weighted residual form of magnetic field model is as follows.

$$-\int_V m_n\Delta\left(\frac{1}{\lambda}\times A\right)dV=\int_V m_n JdV \tag{2}$$

In formula (2), (m_n） is weight function sequence which is the same as basis function, *m* refers to

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general term number of weight function sequence, and J is normal component of boundary surface unit. In addition, weighted residual equations are dispersed into algebraic equations to calculate vector magnetic potential of each node so that other field quantities can be further solved.

Based on principle of energy balance, L_D is calculated. When winding current increases by $\delta_{ij}(0\le\delta\le1)$, energy change of field circuit is correlated with state parameters.

$$\begin{cases} \delta W_1 = \dfrac{L_{Djk}\delta_{ij}\delta_{ik}}{2}, \qquad j,k=1,2 \\ \delta W_2 = \dfrac{\int \delta B \cdot \delta H dV}{2} \end{cases} \tag{3}$$

According to principle of energy balance, magnetic field-circuit coupling energy is equal, then dynamic inductance can be calculated [4].

2.2 Characterization of Excitation Current Based on Time-domain Differential Circuit

Dynamic inductance can be used to further calculate current, and winding circuit equation at the next moment is as follows.

$$\begin{cases} u_{a1} = i_{a1}r_1 + L_{a1}\dfrac{di_{a1}}{dt} + M_a\dfrac{di_{a2}}{dt} \\ u_{b1} = i_{b1}r_1 + L_{b1}\dfrac{di_{b1}}{dt} + M_b\dfrac{di_{b2}}{dt} \\ \vdots \end{cases} \tag{4}$$

In formula (4), i_{a1} and i_{b1} are winding current at Y-side, ia2 refers to winding current at Δ-side, and u_{a1} is winding voltage at Y-side. Besides it, u represents winding voltage at Δ-side, L_{a1} is self-inductance, Ma is mutual inductance, and r indicates winding resistance.

fourth-order Runge-Kuttamethod, RK4 is used to solve circuit model, and coil current i_k at t_k is used to calculate i_{k+1} at t_{k+1}.

$$i_{k+1} = i_k + \frac{h}{6}(s_1 + 2s_2 + 2s_3 + s_4) \tag{5}$$

In formula (5) h is step size, and s_1~s_4 are slope column vectors of segment calculation within step size. Y / Δ wiring three-phase transformer model is shown in Figure 1.

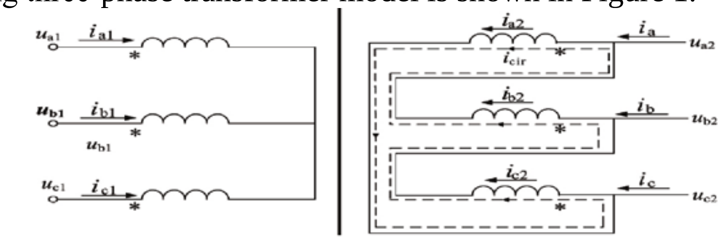

Fig.1Three-phase transformer model with Y/Δ connection

In Figure 1, i_a, i_b and i_c are three-phase current, and i_{cir} is circulation at Δ- side. Since primary resistance, leakage inductance, and excitation resistance in transformer are much smaller than excitation inductance, it can be ignored to obtain transformer circuit equation [5-6].

$$\begin{cases} U_{a1} - L_{ea}\dfrac{d(i_{a1}+i_{a2}+i_{cn})}{dt} = 0 \\ U_{b1} - L_{eb}\dfrac{d(i_{b1}+i_{b2}+i_{cn})}{dt} = 0 \\ U_{c1} - L_{ec}\dfrac{d(i_{c1}+i_{c2}+i_{cn})}{dt} = 0 \end{cases} \tag{6}$$

In Equation (6), L_{ea}, L_{eb} and L_{ec} are excitation inductances of each phase. Circulating current i_{cn} is eliminated, and three-phase current at Δ side is subjected to Δ → Y conversion.

$$\begin{cases} i_{ea} = \left[i_{a1} - i_{b1} + \dfrac{1}{3(i_a + i_c - 2i_b)} \right] \\ i_{eb} = \left[i_{b1} - i_{c1} + \dfrac{1}{3(i_b + i_a - 2i_c)} \right] \\ i_{ec} = \left[i_{c1} - i_{a1} + \dfrac{1}{3(i_c + i_b - 2i_a)} \right] \end{cases} \tag{7}$$

In Equation (7), L_{ea}, L_{eb} and L_{ec} are excitation inductances of each phase.

3 Simulation

Three single-phase transformers are connected to form 220V three-phase group transformer which is modeled and simulated in YN / d mode, where core silicon steel sheet model is DW360-50360. Moreover, transformer magnetic field model, ratio of whose size to actual size is 1: 1, is built with ANSYS to obtain dynamic inductance based on energy balance finite element method so that inductance parameter of circuit equation can be modified as well. Then, fourth-order Runge-Kutta program is written to calculate circuit model which will be fed into magnetic field model as next moment of excitation. Therefore, circuit is coupled with magnetic field through cyclic iteration, and excitation current is solved based on excitation parameter identification method during electromagnetic coupling iteration [7].

Under abnormal state of DC disturbance, working mode of transformer is full load operation, and primary side is connected to DC voltage source. What's more, generated DC current is $I_{DC,}$ and $I_{DC}=\alpha_{I0.}$ α refers to DC component coefficient, which indicates level of DC disturbance. Besides it, secondary side is connected to Δ connection resistance load. Then, transformer operating modes are respectively simulated when α is 0, 0.5 and 0.75, and simulation results of primary current i_1 and exciting current i_e are shown in Figure 2.

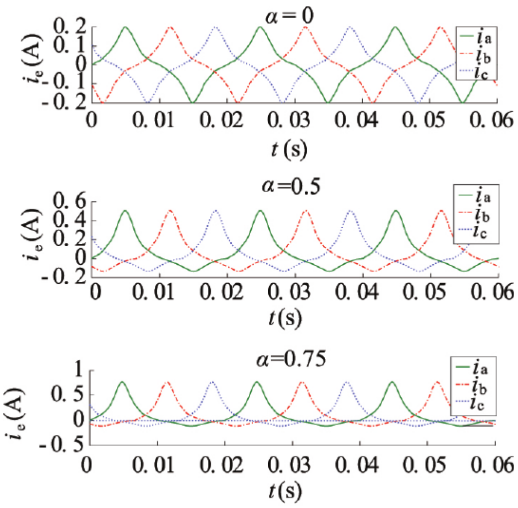

Fig.2 Simulation results of ieand i1in full load operation

It can be seen from Figure 2 that i_e is sharp wave, and as DC disturbance increases, saturation of excitation deepens. Besides it, distortion of i_e increases as well. Due to large amplitude of i_1, even if DC disturbance is deepened and i_e is seriously distorted, change of i_1 is not obvious. Simulation results of excitation current are basically measured, which not only verifies correctness of identification method in excitation short circuit fault location, but also shows excitation current identification can effectively reflect saturation state of transformer.

4 Conclusion

In terms of excitation characteristics of Y / Δ wiring transformer under abnormal conditions, relationship between excitation current and excitation state is studied, and conclusions are as follows.

(1)Electromagnetic coupling model of transformer is established to simulate and analyze electromagnetic characteristics of transformer in AC-DC hybrid mode and the inter-turn short circuit state so that changes of excitation current parameters under different abnormal conditions can be studied. By comparing simulation results and experimental data, correctness of model established in this paper is verified.

(2)Based on excitation current identification, saturation state of transformer under DC bias is characterized to perform harmonic analysis on excitation current, and it can be seen from results that saturation of transformer is deepened under DC disturbance, which corresponds to distortion of excitation current and harmonic content increased.

(3)Although in abnormal state of inter-turn short circuit, excitation current of fault phase does not distort, and transformer excitation is unsaturated, its amplitude is much larger than that of non-fault phase. When voltage level is 50V, which is low, it has increased significantly.

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