Establishment of Transformer Turn-to-turn Fault Model Based on Relay Protection Management System

Tu Yong, Su Shenghao, Chen Qingfang，
Tang Luqing，Yang Shuang，Chen Dinghui
Liangshan electric power company
State grid
Sichuan, China

Xiangli Deng, Li Qingbo, Nan Meng
School of Electric Engineering
Shanghai University of Electric Power
Shanghai, China
Email: xiangli_deng@163.com.

***Abstract*--This paper describes a method to establish turn-to-turn fault model of transformer based on fault analysis expert system. This method can be an advanced application function to be merged into protective relay management system. This paper also establishes differential equations of multi-winding transformer. The turn-to-turn fault winding can be divided to two parts: normal winding and fault winding. The Lest Square Method (LSM) can be used to estimate the self-inductance and mutual inductance values. Then, the fault winding leakage factor can be estimated and the leakage factor curve can be obtained. According to the curve, the turn-to-turn fault model of transformer can be established. Using EMTP simulation tool, the turn-to-turn fault of transformer can be simulated. The dynamic simulation test validates the proposed method in this paper.**

Keywords--fault analysis expert system;lest square method;protective relay management system; transformer model establishment; turn-to-turn fault;

I. INTRODUCTION

With the development of computer networks and communications technologies and the construction of the smart grid in the world, a wide range of various data collection and sharing of Power Systems have been an inevitable trend. Relay protection and fault information system consist of the primary equipment run-time information, Power Systems fault recorder information of the primary equipment and information systems of relay protection. These have become an indispensable part of modern Power Systems information[1-3].With building a mathematical model of the primary equipment based on the fault recording data in real time and operational parameters, there will be great convenience for the analysis of grid accident.

The traditional method for primary equipment modeling in Power Systems is offline. It gets the rated parameters of primary equipment or the system operation parameters, then uses Real Time Digital Simulators in dynamic simulation laboratory (or physical dynamic systems) or Electro-Magnetic Transient Program for modeling. But there are two main disadvantages:

the mathematical model can not respond, the system state at the time of failure.

the mathematical model can not be used for online replay and analysis.

Therefore, we can achieve accident replaying and failure analysis by using not only recorded fault data in relay protection and fault information system but also the precise establishment of mathematical models in real time, all of these can solve the problems in traditional modeling for primary equipment in Power Systems.

Transformers, the nonlinear elements of Power Systems, whose mathematical mode in turn-to-turn fault is one of the most difficult problem in primary equipment modeling. With the establishment of transformer model in turn-to-turn fault by using fault recording data of relay, we not only can

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make further research in the traditional transformer protection algorithm in other to improve and enhance the algorithm, but also can work over transformer's turn-to-turn fault' playback in real time, accurate analysis and location of the accident .

EMTP, electromagnetic transient program, is widely used in primary equipment modeling of Power Systems[4].Reference [5] summarizes the modeling method of transformer, and uses methods to establish models in complex ways. The parameters which are needed by these models are difficult to obtain. Reference [6] uses the transformer core size data and calculates winding leakage inductance of the windings to build transformer model with EMTP, however,the structural parameters of transformer is difficult to obtain.Reference [7] uses optimization technique to determine leakage inductance ,which is taken as the independent variable in the technique, but this method can not create the turn-to-turn fault model for any turns of transformer winding.

To solve the above problems, the paper proposes an accurate online model establishment method for transformer turn-to-turn fault with recorded fault data in relay protection and fault information system. With EMTP transformer model, the method use transformer port current and voltage wave data to estimate leakage inductance coupling coefficient of transformer short-circuit winding using least-squares fitting technique, determines the short-circuit winding leakage inductance, then use EMTP software to establish the model of transformer turn-to-turn fault. This method can be used as an advanced functionality which is inserted into fault analysis expert system, with many advanced application features such as protective action analysis, replaying of fault, protection setting verification.

II. THE TRANSFORMER MODEL

A. The transformer model establishment

If the transformer is made up of three single-phase transformer sets, it can be described by linear differential equation which is showed as equation (1):

$$[u]_9 = [R]_{9\times9}[i]_9 + \frac{d}{dt}[L]_{9\times9}[i]_9 \qquad (1)$$

In the equations (1), because of no magnetic linkage between three single-phase transformers, $[R]_{9\times9}$,$[L]_{9\times9}$ can be expressed as block matrices, which is shown :

$$[R]_{9\times9} = \begin{bmatrix} [R_1]_{3\times3} & & 0 \\ & [R_2]_{3\times3} & \\ 0 & & [R_3]_{3\times3} \end{bmatrix} \quad [L]_{9\times9} = \begin{bmatrix} [L_1]_{3\times3} & & 0 \\ & [L_2]_{3\times3} & \\ 0 & & [L_3]_{3\times3} \end{bmatrix}$$

$[R_i]_{3\times3}$ and $[L_i]_{3\times3}$ $(1 \le i \le 3)$ are diagonal block matrices.Because of no magnetic connection between single phase transformers, some block matrices in $[L]_{9\times9}$ are all zeros.

B. Autotransformer turn-to-turn fault models in common windings

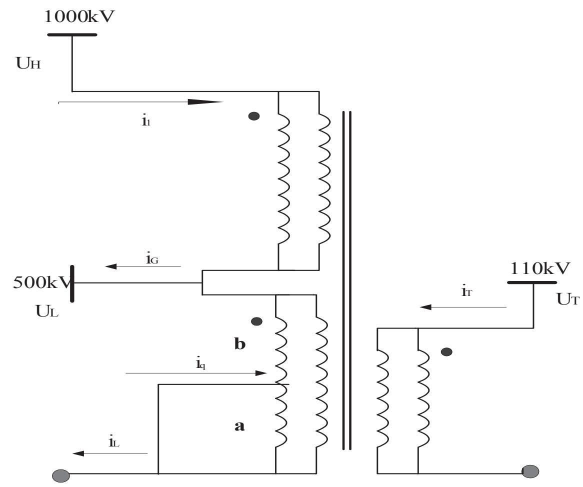

Fig. 1 Autotransformer turn-to-turn fault

As shown in Fig. 1, the series winding can be divided into short circuit winding a and non-short-circuit winding b..

C. Short-circuit winding leakage inductance coupling coefficient calculation based on least square fitting

Since it is difficult to get the dimensions of the transformer windings and iron core, short-circuit winding leakage inductance coupling coefficient σ_{ab} is difficult to access directly. With the recorded fault data based on fault information platform, we can utilize least square fitting to calculate the short-circuit winding inductance and mutual inductance parameters, and then short-circuit winding parameters are used to determine the short-circuit winding leakage inductance coupling coefficient σ_{ab}.

The paper assumes that the transformer model parameters[R],[L]will not change with transformer operation manners, considers the transformer model as a model constituted by the inductance and resistance. The parameter matrices of turn-to-turn short circuit in a transformer$[R]_{10\times10}$,$[L]_{10\times10}$of different differential equations are thus determined As shown in Fig. 1, common winding was divided into two windings a and b , so it needs to determine the parameter matrices.Transformer modeling via differential equations (1) is described.

Due to the transformer low voltage side for delta connection, the winding flows through the loop even without load at low voltage side;high and medium voltage side is Y-connection and neutral ground, so the current of high-voltage side is zero-sequence current.Assuming turn-to-turn fault is set in the common winding of high-voltage side A phase (can also be set to the other side) as well as B and C phases are sound phase, loop current i_Δ in triangle winding can be calculated by B .As shown in Fig. 1, if the no-load voltage is applied to the medium voltage side, high voltage side and low voltage side is on open-circuit, the differential equation of triangle winding in B phase is as follows:

$$R_3 i_\Delta + L_3 \frac{di_\Delta}{dt} + (M_{13} + M_{23}) \frac{di_{1B}}{dt} = u_{TB} \tag{2}$$

So, the least-square fitting values of $L_a + M_{ab}$、M_{3a}、M_{4a} show as equation (3) like this:

$$\begin{cases} L_a + M_{ab} = (A_{k\times1}^T A_{k\times1})^{-1} A_{k\times1}^T U1_{k\times1} \\ M_{4a} = (B_{k\times1}^T B_{k\times1})^{-1} B_{k\times1}^T U2_{k\times1} \\ M_{1a} = (C_{k\times1}^T C_{k\times1})^{-1} C_{k\times1}^T U3_{k\times1} \end{cases} \tag{3}$$

$A_{k\times1}$、$B_{k\times1}$、$C_{k\times1}$ are matrices which must be discreted in the derivation of equations,there are k sample matrices of recorded fault data in left side of the equation. To the right, for equations with k sample matrices of recorded fault data are $U1_{k\times1}$、$U2_{k\times1}$、$U3_{k\times1}$.Therefore, we calculate the loop current in triangle winding firstly, then use equations of least-squares fitting (3)to get self inductance and mutual inductance parameters of short-circuit winding,finally through the following formulas (4) can calculate the short-circuit winding leakage inductance coupling coefficient σ_{ab}.

$$\sigma_{ab} = 1 - \frac{M_{ab}^{\;2}}{L_a L_b} \tag{4}$$

D. Advanced features in turn-to-turn fault modeling realized on platform of EMS/protective relay management system

Due to protective relay management system in power network can provide real-time fault information to improve dispatching automation and intelligent level.

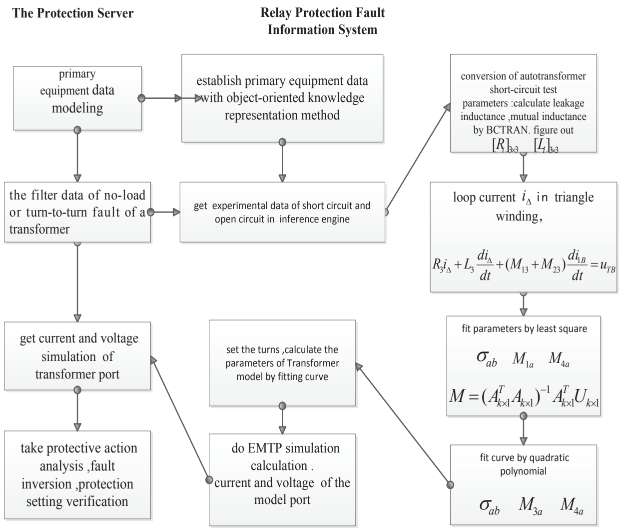

Fig. 2 The fault analysis system with turn-to-turn fault modeling application function

Protective action analysis,fault inversion and protection setting verification only with more accurate mathematical model of primary equipment, especially primary equipment fault models (such as models of turn-to-turn short-circuit in transformers), can achieve quantitative analysis. EMTP is matured analysis software of electromagnetic transient analysis in Power Systems analysis. With integrating EMTP models with fault analysis expert system and using

EMTP matured model, it will have a strong function of faults analysis .

As shown in Fig. 2,the protection salve (protective relay management system) provide a large number of data samples for modeling of turn-to-turn short circuit in transformers. Fault analysis expert system add each server's primary equipment parameters to equipment knowledge base with object-oriented knowledge representation method. Inference engine completes classification of phase transformer fault recording data, then we could use the method of turn-to-turn short circuit in a transformer to establish transformer fault model, complete protective action analysis of protection device-level and realize fault inversion.

III. DYNAMIC SIMULATION EXPERIMENT AND ANALYSIS

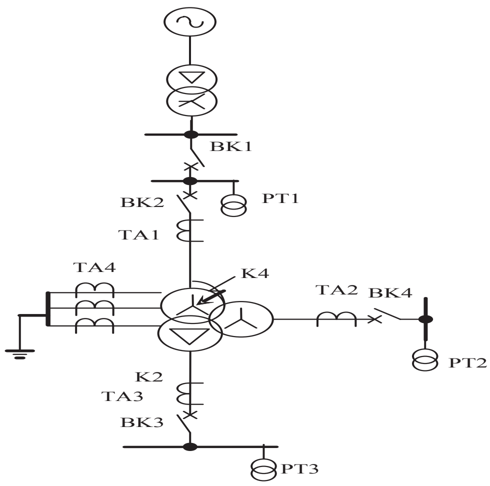

Fig. 3 Dynamic testing diagram of transformer paper modeling

In order to verify the validity of the algorithm, the author took dynamic imitation in the Huazhong University dynamic simulation laboratory. Dynamic testing diagram of transformer paper modeling as shown in Fig. 3. Transformer in the system is three single phase transformer sets with Y0/Y0/d11 wiring, the rated capacity (single phase) for 2.5/2.5/0.83 kVA, the rated voltage (single phase) for1000/:500/:110,short circuit impedance (%) for U =14.8,U=67.2,U=52.3,setting transformer turn-to-turn fault on C phase in common winding.Fault data was taken from the DF3630 of large power transformer protection devices of Dongfang electronic limited liability company. In the actual protective relay management system, transformer nominal parameter will be transmitted to the control center through the protection servers, fault analysis expert system will add these parameters to knowledge base of the device, collate and correlate. The author repeated tests to simulate the fault to get the transformer recorded fault data .

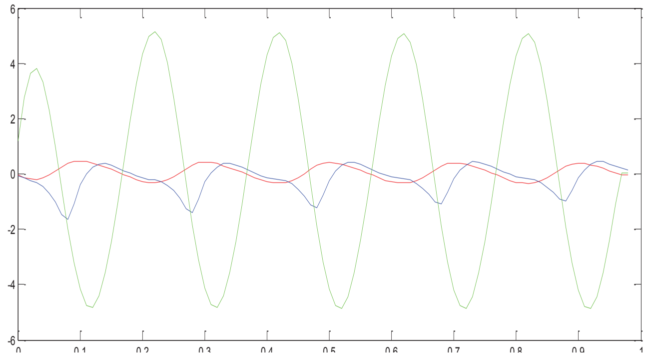

Fig. 4 Three phase current waveforms of 3% of common winding taking place turn-to-turn fault during energizing

In order to verify the validity of this model, the author compared EMTP simulation model with dynamic simulation in short circuit output current.

Turn-to-turn fault in EMTP simulation model is set to 14% the common winding ground.As known,the short circuit leakage inductance σ_{ab} is 0.11, then other parameters of the transformer model is figured out. As Fig. 5 shows, it is a comparison between simulation value and dynamic testing value,they have a little error which is verified the validity of the curve.

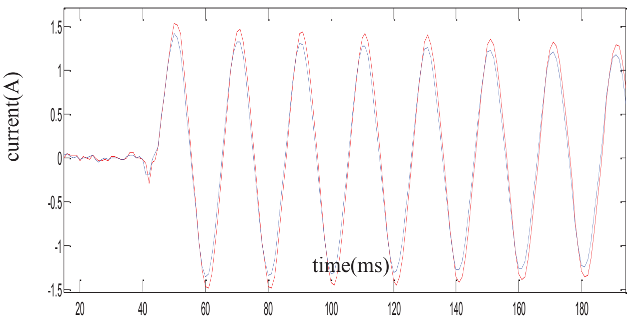

Fig. 5 Comparison between simulation value and dynamic testing value with 14% of turn-to-turn fault

IV. CONCLUSION

The paper describes a method to establish real-time mathematical turn-to-turn fault model of transformer by least square fitting of samples of recorder information in relay protection and fault information system.This method could establish transformer turn-to-turn fault model without windings and iron core data of the transformer.

The parameter matrices of the transformer are calculated by BCTRN during normal state.With the recording data of transformer’s turn-to-turn fault in fault analysis expert system,we can get the curve by least square fitting of short circuit leakage inductance in transformer’s turn-to-turn fault,transformer’s turn-turn fault can be emulated according to the curve and EMTP .

This method can be used as an advanced feature integrate with relay protection fault information system ,in other to enhance the level of automation and intelligent in dispatching system.

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