A GENERALIZED MODEL RESEARCH FOR TRANSFOMER BASED ON MAGNATIC CIRCUIT

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ABSTRACT

*In this paper a new generalized transformer model is developed.,based on the magnetic circuit. The model can be used in the general and special transformer's simulation. The model is relative to the transformer structure and parameters of model can be gotten from the structure characteristic of transformer. The established process of the transformer model is given particularly. The simulating calculation of three-phase and three-leg transformer is made and the result is satisfaction. Thereby the application of the proposed model to a test system shows its correctness and validit***y.**

Keywords-- transformer ; magnetic circuit model ; simulation; structure parameter

INTRODUCTION

Transfromer is one of the most important equipment. The performance and normal run of the whole electric power system are affected by the transformer's magnetic characteristic. In the recent years, many researchers have been focusing on the transformer model and gotten some fruit. At present, there are two ways to the transformer model simulation research. One is that the electric parameter of transformer is calculated using transformer circuit model [1–9] . And the other is based upon magnetic model to calculate the parameter [10–12] . As brief the first simulation model is, it can be used easily, and many simulation software are based on it. However, it couldn't reflect the real magnetic transient process, and its physical conception is fuzzy, while the latter could research the fault of transformer based on the magnetic circuit. As the established models are too simple to describe the internal structure, this paper presents a transformer generalized model which is set up based on the transformer transient model in reference [1]. The model adequately considers the iron-core magnetic circuit flux, the eddy effect and the leak flux. Finally the correctness and validity of the model are proved by simulation. Generalized relation can't be found between the models. Generalized transient model is set up according to all kinds of transformers in this paper. This model considers general and special transformer synthetically. simultaneously many factors are involved, for instance, inner magnetic flux of iron-core, iron-yoke, leakage magnetic flux of coil and non-linear hysteresis loop of ferromagnet, etc. In this paper the simulating example is S9—100/10 three-phase and three-leg transformer in the condition of single power supply and symmetry load. Thereby the application of the proposed model to a test system shows its correctness and validity.

GENERALIZED MAGNATIC MODEL OF TRANSFOMER

The structure of generalised transfomers is shown in Fig.1.

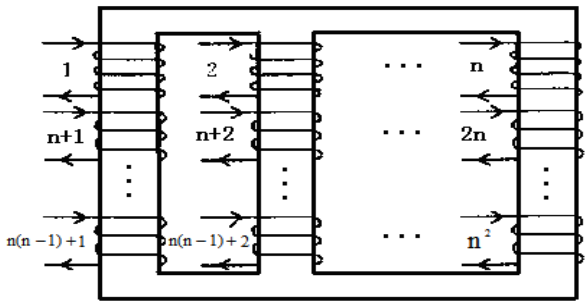

Fig1 the structure of generalized transformers

1.Magnetic Flux Linkage and Voltage Equations

The magnetic circuit of generalized transformers is shown in Fig.2. considering the leakage permeance .it the magnetic linkage and voltage equations are shown:

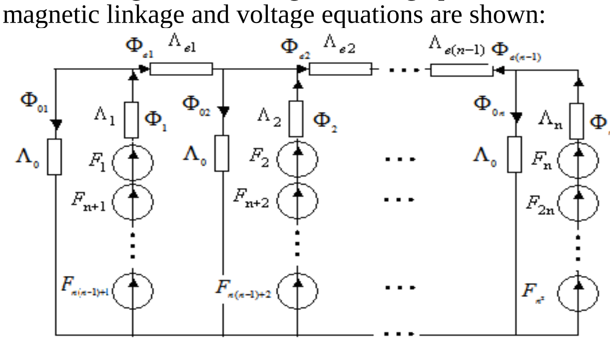

Fig2 the magnetic circuit of generalized transformers

$$\begin{aligned}\lambda_1 &= N_1^2(\Lambda_{11}i_1-\Lambda_{12}i_2-\cdots-\Lambda_{1n}i_n)\\&+N_1N_2(\Lambda_{11}i_{n+1}-\Lambda_{12}i_{n+2}-\cdots-\Lambda_{1n}i_{2n})\\&+\cdots+N_1N_n(\Lambda_{11}i_{n(n-1)+1}-\Lambda_{12}i_{n(n-1)+2}-\cdots-\Lambda_{1n}i_{n^2})\\&+N_1^2\Lambda_{K1L}i_1\end{aligned} \tag{1}$$

$$\begin{aligned}U_1=e_1=\frac{d}{dt}\lambda_1 &= N_1^2(\Lambda_{11}\frac{d}{dt}i_1-\Lambda_{12}\frac{d}{dt}i_2-\cdots-\Lambda_{1n}\frac{d}{dt}i_n)\\&+N_1N_2(\Lambda_{11}\frac{d}{dt}i_{n+1}-\Lambda_{12}\frac{d}{dt}i_{n+2}-\cdots-\Lambda_{1n}\frac{d}{dt}i_{2n})\\&+\cdots+N_1N_n(\Lambda_{11}\frac{d}{dt}i_{n(n-1)+1}-\Lambda_{12}\frac{d}{dt}i_{n(n-1)+2}-\cdots-\Lambda_{1n}\frac{d}{dt}i_{n^2})\\&+N_1^2\Lambda_{K1L}\frac{d}{dt}i_1\end{aligned} \tag{2}$$

Homoplastically the magnetic linkage and voltage equations of other windings could be set up. Considering resistance of the winding, the basic equation of generalized transformer transient model could be shown:

$$[U]=[R][i]+[\Lambda]\frac{d}{dt}[I][N]+[N][E]_{n\times n}[\Lambda_K]\frac{d}{dt}[i] \quad (3)$$

where

$$[U]=\left[U_1,U_2,\cdots U_n,-U_{n+1},-U_{n+2},\cdots -U_{n^2},\right]^T \quad (4)$$

$$[R]=diag\left[R_1,R_2,\cdots,R_{n^2},\right]$$

(5)

$$[i]=\left[i_1,i_2,\cdots,i_{n^2}\right]^T \quad (6)$$

$$[\Lambda]=\begin{bmatrix}\Lambda_{11} & -\Lambda_{12} & -\Lambda_{13} & \cdots & -\Lambda_{1n}\\ -\Lambda_{12} & \Lambda_{22} & -\Lambda_{23} & \cdots & -\Lambda_{2n}\\ -\Lambda_{13} & -\Lambda_{23} & \Lambda_{33} & \dots & -\Lambda_{3n}\\ \vdots & \vdots & \vdots & \cdots & \vdots\\ -\Lambda_{1n} & -\Lambda_{2n} & -\Lambda_{3n} & \cdots & \Lambda_{nn}\end{bmatrix} \quad (7)$$

$$[I]=\begin{bmatrix} i_1 & i_{n+1} & i_{2n+1} & \cdots & i_{n(n-1)+1}\\ i_2 & i_{n+2} & i_{2n+2} & \cdots & i_{n(n-1)+2}\\ i_3 & i_{n+3} & i_{2n+3} & \dots & i_{n(n-1)+3}\\ \vdots & \vdots & \vdots & \cdots & \vdots\\ i_n & i_{2n} & i_{3n} & \cdots & i_{n^2}\end{bmatrix} \quad (8)$$

$$[N]=\begin{bmatrix} N_1^2 & N_1N_2 & N_1N_3 & \cdots & N_1N_n\\ N_1N_2 & N_2^2 & N_2N_3 & \cdots & N_2N_n\\ N_1N_3 & N_2N_3 & N_3^2 & \dots & N_3N_n\\ \vdots & \vdots & \vdots & \cdots & \vdots\\ N_1N_n & N_2N_n & N_3N_n & \cdots & N_n^2\end{bmatrix} \quad (9)$$

$$[\Lambda_K]=diag\left[\Lambda_{K,1L} \quad \Lambda_{K,2L} \quad \cdots \quad \Lambda_{K,nL}\right] \quad (10)$$

2.Magnetic Circuit Equation

During the solved voltage equation, the calculation to magnetic conductance matrix is involved in magnetic permeability μ_i and magnetic force equation. Because of the magnetic hysteresis of the core, μ_i is mutative continuously in simulation. At present, three sect linearization of magnetization curve is used in multitude simulation soft., namely two saturation sects and one linearity sect. This method is too simple to reflect the hysteresis of ferromagne. hysteresis loop of ferromagnet is considered in the model simulation.The calculation method is compressed algorithm of dynamic hysteresis loop of ferromagnet in preference [13]. In that the relation of the magnetic flux and current of the core and yoke must be calculated. The equation is set up below based on magnetic circle relation in Fig.2.

$$[M][\Phi]=[F] \quad (11)$$

where

$$[\Phi]=[[\Phi_{in}] \quad [\Phi_e] \quad [\Phi_0]] \quad (12)$$

$$[M]=\begin{bmatrix}[M_1] & [M_2] & [M_3]\\ [M_4] & [M_5] & [M_6]\\ [M_7] & [M_8] & [M_9]\end{bmatrix} \quad (13)$$

$$[F]=\begin{bmatrix}[0]_{n\times 1}\\ [F_{cir}]\end{bmatrix} \quad (14)$$

thereinto

$$[\Phi_{in}]=[\Phi_1 \quad \Phi_2 \quad \cdots \quad \Phi_n]$$

$$[\Phi_e]=[\Phi_{e1} \quad \Phi_{e2} \quad \cdots \quad \Phi_{e(n-1)}]$$

$$[\Phi_0]=[\Phi_{01} \quad \Phi_{02} \quad \cdots \quad \Phi_{0n}]$$

$$[M_1]=[E]_{n\times n} \qquad [M_3]=[-E]_{n\times n}$$

$$[M_2]=\begin{bmatrix}-1 & 0 & 0 & 0 & \cdots & 0\\ 0 & 1 & -1 & 0 & \cdots & 0\\ 0 & 0 & 1 & -1 & \cdots & 0\\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots\\ 0 & 0 & 0 & \cdots & 1 & -1\\ 0 & 0 & 0 & \cdots & 0 & 1\end{bmatrix}_{n\times(n-1)}$$

$$[M_4]=diag\begin{bmatrix}\frac{1}{\Lambda_1} & \frac{1}{\Lambda_2} & \cdots & \frac{1}{\Lambda_n}\end{bmatrix}_{n\times n}$$

$$[M_5]=[0]_{n\times(n-1)} \qquad [M_6]=\frac{1}{\Lambda_0}[E]_{n\times n}$$

$$[M_7]=diag\begin{bmatrix}\frac{1}{\Lambda_2} & \frac{1}{\Lambda_3} & \cdots & \frac{1}{\Lambda_n}\end{bmatrix}_{(n-1)\times n}$$

$$[M_8]=diag\begin{bmatrix}\frac{1}{\Lambda_{e1}} & \frac{1}{\Lambda_{e2}} & \cdots & \frac{1}{\Lambda_{e(n-1)}}\end{bmatrix}_{(n-1)\times(n-1)}$$

$$[M_9]=\begin{bmatrix}0 & \frac{1}{\Lambda_0} & 0 & 0 & \cdots & 0\\ 0 & 0 & \frac{1}{\Lambda_0} & 0 & \cdots & 0\\ 0 & 0 & 0 & \frac{1}{\Lambda_0} & \cdots & 0\\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots\\ 0 & 0 & 0 & \cdots & \frac{1}{\Lambda_0} & 0\\ 0 & 0 & 0 & \cdots & \frac{1}{\Lambda_0} & 0\end{bmatrix}_{(n-1)\times n}$$

$$[F_{cir}]=\begin{bmatrix}F_1+F_{n+1}+F_{2n+1}+\cdots+F_{n\times(n-1)+1}\\ F_2+F_{n+2}+F_{2n+2}+\cdots+F_{n\times(n-1)+2}\\ \vdots\\ F_n+F_{2n}+F_{3n}+\cdots+F_{n^2}\end{bmatrix}_{n\times 1}$$

The equation (3)—(14) are the model of generalized transformer. The model can be used in general and special transformers' simulation, for example, single-phase and two winding transformer that two iron-cores and two layer wingdings are appointed . three-phase and three –leg, two-winding transformer that three iron-cores and two layer wingdings are appointed. three-phase and five –leg, two-winding transformer that five iron-cores and two layer wingdings are appointed and left and right iron-core turn are zero. When the model parameters are decided, dimensions of the involved matrix correspond to the change.

MODEL PARAMETERS MAKE CERTAIN

1. Resistance in Series

It is difficult to directly measure AC resistance wastage in series, so DC resistance is preferred to AC resistance. In fact, a difference of a equivalent mixed wastage resistance exists between AC resistance and DC resistance, but a equivalent mixed wastage resistance is very small, which is 5 percent of DC resistance, and can't influence computing precision. Usually, it is ignored. Thereby, DC resistance can replace AC resistance. DC resistance of transformer is always measured by adopting the short circuit testing. Wastage of the short circuit testing includes iron-core wastage of transformer and DC resistance of windings. But because testing voltage is small, iron-core wastage is very little too. Consequently, short circuit wastage is commonly looked upon DC resistance wastage. General DC resistance of transformer is measured through the method. Resistance in series of windings is done by distributing the general DC resistance pro rata.

2. Zero-sequence Permeance

there are two kinds of Calculating arithmetic of zero-sequence permeance. One is directly calculating arithmetic by the equation[3].,

$$\Lambda_0 = \frac{\pi\mu_0 (H + 6h_1)}{18(\ln(L+\pi R_1) - \ln(L+\pi r_1))} \quad (14)$$

In the equation(14), zero-sequence permeance of transformer is computed. For the zero sequence passageway of transformer zero sequence flux is too small, and to be ignored usually. So the model is simplified, dimensions are depreciated and calculating time is shortened.

Zero-sequence permeance is also computed by testing method, in which secondary winding is open and zero voltage is put on first-winding.

3.3 Leakage permeance

There are also two kinds of calculating arithmetic of zero-sequence permeance. One is leakage magnetic enery arithmetic[9] that is computed by leakage magnetic distributing.

Another is short-circuit testing method by which rated voltage is put on first-winding and secondary winding is short-circuit. And short circuit is measured. According to winding resistance, leakage reactance is gained. Moreover, leakage permeance can be gotten.

SIMULATION RESULT

In this paper the simulating model is S9—100/10 three-phase and three-leg transformer. The parameters are below. The pole length is Da=Db=Dc=42.6cm, yoke length De=Df=48.0cm, the core section area Sa=Sb=Sc=Se=Sf=113cm^2, the primary circles Nd=1375, the secondary circles Ng=55, the primary resistance 9.8430Ω, the secondary 0.0086Ω, the three phase loads Ra=Rb=Rc=1.590 Ω, the connection pattern Y/Y and electrical source is three phase symmetrical. Simulition result is shown in Fig.3.

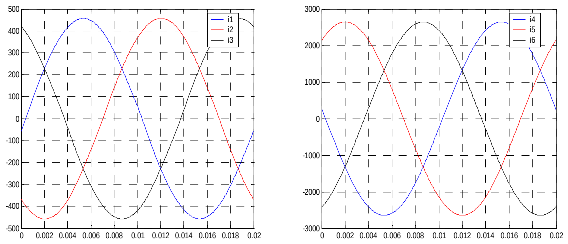

fig.3 each winding current

CONCLUSION

Bring forward a new generalized model of transformer based on magnetic circuit. This model considers general and special transformer synthetically. Simultaneously many factors are involved, for instance inner magnetic flux of iron-core, iron-yoke, leakage magnetic flux of coil and non-linear hysteresis loop of ferromagnet, etc. Transient currents of transformer windings are computed through solving the differential equation of changing coefficient. And the correctness and validity are validated by MATLAB simulation.

LIST OF SYMBOLS

Λ_i = each iron-core permeance $i = 1,2,\cdots,n$

Λ_{ei} =each iron-yoke permeance $i = 1,2,\cdots,n-1$

Λ_0 = each zero-sequence permeance of iron-core

$\Lambda_{K,iL}$ = each leakage permeance of coil

Λ_{ij} = each mutual-permeance and self-permeance of coil $i, j = 1,2,\cdots,n$

$[\Lambda]$=permeance matrix

$[\Lambda_K]$= leakage permeance compute matrix

$[E]$= identity matrix

F_i =magnetometive force of coil $i = 1,2,\cdots,n^2$

$[F]$=general magnetometive force matrix

$[F_{cir}]$=each core magnetometive force matrix

Φ_i =each inner magnetic flux of core $i = 1,2,\cdots,n$

$[\Phi_i]$=inner magnetic flux matrix of iron-core

Φ_{0i} = each zero-sequence magnetic flux of iron-core $i = 1,2,\cdots,n$

$[\Phi_0]$= zero-sequence magnetic flux matrix of iron-core

Φ_{ei} =each zero-sequence magnetic flux of iron-yoke $i=1,2,\cdots,n-1$

$[\Phi_e]$=inner magnetic flux matrix of iron-yoke

$[\Phi]$= magnetic flux matrix

N_i =turn number of each layer coil $i=1,2,\cdots,n$

i_j =each coil current

$[U]$=voltage matrix of coil

$[i]$=current matrix of coil

$[I]$=current compute matix of coil

$[R]$= resistance matrix of coil

$[M]$=magnetic resistance matrix

$[M_i]$ = magnetic resistance compute matrix $i=1,2,\cdots,9$

μ_i = permeability of core

λ_i =each magnetic linkage of coil $i=1,2,\cdots,n^2$

$[N]$=trun matrix

$[N_K]$=turn compute matrix of leakage reactance

$diag\ [\ ]$= diagonal matrix

μ_0 =air- permeability（constant）

H =coil height of transfomer

h_1 = distance of coil bottom and oil box bottom

L = center distance between core and core

R_1= center distance between inner surface of oil-box and core

r_1= center distance between exterior surface of coil and core

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BIOGRAPHIES

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