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TRANSIENT VOLTAGE OF NEUTRAL POINT IN THE THREE PHASE TRANSFORMERS

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Abstract- Neutral point displacement of a power transformer is mostly posed in the unbalanced load and line impedances. However, the neutral point may have a non-zero voltage even when the primary and secondary sides of a Y-Y non-grounded transformer are connected to a balanced three phase voltage and load respectively. This can be significant during switching transient period and its value is being effectively influenced by the magnetic characteristics of the transformer core. In this paper the comprehensive model of a transformer is simulated using the Preisach model of hysteresis. In this simulation the hysteresis model of the core is coupled with the electrical equations of the terminal circuits. A transient load switching problem is studied and the neutral point displacement of the secondary side is investigated while the primary of a laboratory built Y-Y transformer is grounded. This study is imperative regarding the protection and safety issues.

Keywords: Displacement of Neutral Point, Preisach Model, Transformer, Transient.

I. INTRODUCTION

Many studyings have been achieved about displacement the zero point in three-phase transformers with star connection which cause harmful effects to the earth equipments [1-2]. All of these scrutinizes have been done in the unbalanced voltages or unsymmetrical loads, so, for getting rid of the created problems, the solutions for begetting the balanced and symmetric current of each phase is being posed.

In this paper we take the transient voltage of the neutral point into consideration in the balanced loads and voltages. Therefore, we need a model which is capable enough to express the electric and magnetic behaviors of transformers. Because of the complexity of the magnetic and hysteresis behavior of a transformer core, no model which can show the electric and magnetic behavior of transformers has been presented. Firstly, we model the magnetic behavior of the iron core by means of the non-linear and multi-value model of Preisach and then by mixing the electrical equations and the proposed algorithm, we reach a complete and comprehensive model for transformers. It's marvelous that in this proposed model some considerations have been used that by them we can minimize complexity of the Preisach model [3].

In this paper we prove that exactly like the transient phenomena such as the inrush current in the neutral point, transient voltages occur which produce extra currents that can be harmful for the transformers and earth equipments.

II. SIMULATION OF THE PREISACH MODEL

While ferromagnetic material is exposed to a periodic symmetric field with a specified peak value, the magnetization and the steady-state flux density of each point of the material can be calculated by one-dimensional Preisach model. In fact, the number of broken lines shown in Figure 1 at the boundary of S^+ and S^-, illustrates the number of local extremum of magnetic field, since last absolute extremum until present time. Knowing the vertices of the broken lines up to the time t, the value of M and then B can be determined for the time $t+\Delta t$ by a computer simulation. The program examines whether the value of $H(t+\Delta t)$ is more or less than $H(t)$ and then calculates the values of M and B using equations (1) to (3). After these calculations, new vertices of cursives in the border of S^+ and S^- for the time $t+\Delta t$ can be determined.

$$M_s = \frac{1}{2}\iint_{S(t)} p(a,b)dadb \quad (1)$$

$$M(t) = -M_s + 2\iint_{S^+(t)} p(a,b)dadb \quad (2)$$

$$B(t) = \mu_0\{H(t) + M(t)\} \quad (3)$$

where $p(a,b)$ is named the density function.

A. Density Function

The steel lamination employed as a core for the transformer of the present paper is LOSIL-630. Four descriptive parameters of two-variable density function of the material have been already determined precisely using the experimental results by reference [4]. Parameters of the multi-equation function are given in this reference.

General form of the density function is:

$$2p(a,b)=\frac{m_{ss}}{\pi\sigma_1\sigma_2}\exp\left(-\frac{(a+b)^2}{4\sigma_1^{\ 2}}-\frac{(a-b-2u_c)^2}{4\sigma_2^{\ 2}}\right)$$

where four parameters σ_1, σ_2, u_c and m_{ss} are different for various materials and areas of the Preisach triangle. As mentioned earlier, these variables are determined using the experimental $B-H$ and iron loss per kilogram characteristics of the material given by manufacturers and the best curve fitting approach. For more details see references [4-5].

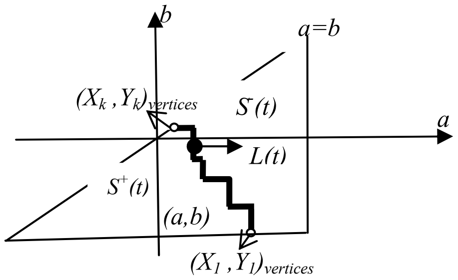

Figure 1. Preisach triangle

B. Initial Conditions

Firstly specifying the initial values of H and B is necessary. In fact, absolute minimum and the broken lines of the Preisach triangle or the vertices are needed for simulating a transformer. If the initial values of H and B are zero, to determine properly the vertices of the Preisach triangle, the symmetric characteristic of the density function with respect to the line $a=-b$ line is used to determine the vertices. It is essential to choose too many vertices of Preisach triangle as far as possible near to the line $a=-b$ to achieve zero conditions for magnetic core. In a real experiment to achieve the zero condition for a magnetic core ($H\cong 0, B\cong 0$), i.e. omitting the residual flux density of the core, we should apply a slowly vanishing sinusoidal voltage to eliminate the magnetic field of the core. Figure 2, will completely show the movement on the loops and reaching to the zero point. To reach the zero residual condition it is essential to apply sinusoidal voltage with low frequency vanishing amplitude (e.g. 5 Hz). In fact, each extremum of H plot produces a breakage at the boundary of S^+ and S^- in Preisach plane. Therefore all vertices of Preisach plane (Figure 3) are related to returning points of hysteresis loops in the second and fourth quadrant (Figure 2).

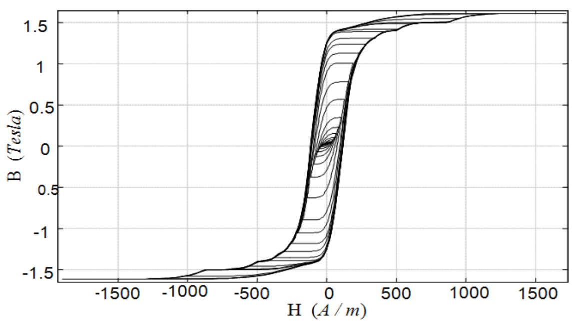

Figure 2. *B-H* curve while core is becoming close to point of *H*=0 & *B*=0, by applying vanishing magnetic field

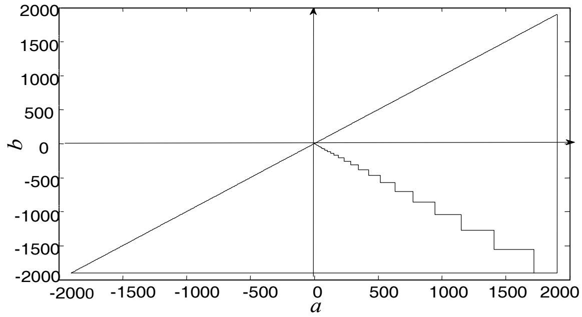

Figure. 3. Triangle Preisach after applying a vanishing magnetic field (Each breakage is associated with an extermum)

III. MODELING THE UNDER STUDY SYSTEM

The studied system, as shown in Figure 4, is a three-phase network in which a balanced three-phase source feed a symmetric load by means of a transmission line and a three-phase transformer with YgY connection.

We can write the system equations as:

$$V_{AS}(t)=R_{Line1}i_A+L_{Line1}\frac{di_A}{dt}+N_1A\frac{dB_A}{dt} \quad (4)$$

$$V_{BS}(t)=R_{Line1}i_B+L_{Line1}\frac{di_B}{dt}+N_1A\frac{dB_B}{dt} \quad (5)$$

$$V_{CS}(t)=R_{Line1}i_C+L_{Line1}\frac{di_C}{dt}+N_1A\frac{dB_C}{dt} \quad (6)$$

$$Vn(t)+V_{an}(t)=(R_{Line2}+R_{Load})i_a+(L_{Line2}+L_{Load})\frac{di_a}{dt} \quad (7)$$

$$Vn(t)+V_{bn}(t)=(R_{Line2}+R_{Load})i_b+(L_{Line2}+L_{Load})\frac{di_b}{dt} \quad (8)$$

$$Vn(t)+V_{cn}(t)=(R_{Line2}+R_{Load})i_c+(L_{Line2}+L_{Load})\frac{di_c}{dt} \quad (9)$$

$$V_{an}(t)=N_2A\frac{dB_A}{dt} \quad (10)$$

$$V_{bn}(t)=N_2A\frac{dB_B}{dt} \quad (11)$$

$$V_{cn}(t)=N_2A\frac{dB_C}{dt} \quad (12)$$

$$-N_1i_A+H_Al_A+N_2i_a-H_Bl_B+N_1i_B-N_2i_b=0 \quad (13)$$

$$-N_1i_B+H_Bl_B+N_2i_b-H_Cl_C+N_1i_C-N_2i_c=0 \quad (14)$$

$$B_A+B_B+B_C=0 \quad (15)$$

$$B_A=\text{Preisach}(H_A) \quad (16)$$

$$B_B=\text{Preisach}(H_B) \quad (17)$$

$$B_C=\text{Preisach}(H_C) \quad (18)$$

In order to solve the equations 4 to 18, according to the Rang-Koutah method, rewrite them in this way:

$$\left(\frac{V_{AS}(t+\Delta t)+V_{AS}(t)}{2}\right)\Delta t=R_{Line1}\left(\frac{i_A(t+\Delta t)+i_A(t)}{2}\right)\Delta t$$
$$+L_{Line1}(i_A(t+\Delta t)-i_A(t))+N_1A(B_A(t+\Delta t)-B_A(t)) \quad (19)$$

$$\left(\frac{V_{BS}(t+\Delta t)+V_{BS}(t)}{2}\right)\Delta t=R_{Line1}\left(\frac{i_B(t+\Delta t)+i_B(t)}{2}\right)\Delta t$$
$$+L_{Line1}(i_B(t+\Delta t)-i_B(t))+N_1A(B_B(t+\Delta t)-B_B(t)) \quad (20)$$

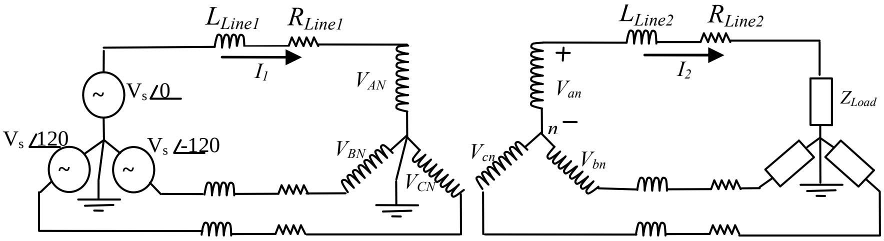

Figure 4. The under study system

$$(\frac{V_{CS}(t+\Delta t)+V_{CS}(t)}{2})\Delta t = R_{Line1}(\frac{i_C(t+\Delta t)+i_C(t)}{2})\Delta t + L_{Line1}(i_C(t+\Delta t)-i_C(t)) + N_1 A(B_C(t+\Delta t)-B_C(t)) \quad (21)$$

$$(\frac{V_n(t+\Delta t)+V_n(t)}{2})\Delta t + (\frac{V_{an}(t+\Delta t)+V_{an}(t)}{2})\Delta t = (R_{Line2}+R_{Load})(\frac{i_a(t+\Delta t)+i_a(t)}{2})\Delta t + (L_{Line2}+L_{Load})(i_a(t+\Delta t)-i_a(t)) \quad (22)$$

$$(\frac{V_n(t+\Delta t)+V_n(t)}{2})\Delta t + (\frac{V_{bn}(t+\Delta t)+V_{bn}(t)}{2})\Delta t = (R_{Line2}+R_{Load})(\frac{i_b(t+\Delta t)+i_b(t)}{2})\Delta t + (L_{Line2}+L_{Load})(i_b(t+\Delta t)-i_b(t)) \quad (23)$$

$$(\frac{V_n(t+\Delta t)+V_n(t)}{2})\Delta t + (\frac{V_{cn}(t+\Delta t)+V_{cn}(t)}{2})\Delta t = (R_{Line2}+R_{Load})(\frac{i_c(t+\Delta t)+i_c(t)}{2})\Delta t + (L_{Line2}+L_{Load})(i_c(t+\Delta t)-i_c(t)) \quad (24)$$

$$(\frac{V_{an}(t+\Delta t)+V_{an}(t)}{2})\Delta t = N_2 A(B_A(t+\Delta t)-B_A(t)) \quad (25)$$

$$(\frac{V_{bn}(t+\Delta t)+V_{bn}(t)}{2})\Delta t = N_2 A(B_B(t+\Delta t)-B_B(t)) \quad (26)$$

$$(\frac{V_{cn}(t+\Delta t)+V_{cn}(t)}{2})\Delta t = N_2 A(B_C(t+\Delta t)-B_C(t)) \quad (27)$$

$$-N_1 i_A(t+\Delta t) + H_A(t+\Delta t) l_A + N_2 i_a(t+\Delta t) - H_B(t+\Delta t) l_B + N_1 i_B(t+\Delta t) - N_2 i_b(t+\Delta t) = 0 \quad (28)$$

$$-N_1 i_B(t+\Delta t) + H_B(t+\Delta t) l_B + N_2 i_b(t+\Delta t) - H_C(t+\Delta t) l_C + N_1 i_C(t+\Delta t) - N_2 i_c(t+\Delta t) = 0 \quad (29)$$

$$B_A(t+\Delta t) + B_B(t+\Delta t) + B_C(t+\Delta t) = 0 \quad (30)$$

$$B_A(t+\Delta t) = \text{Preisach}(H_A(t+\Delta t)) \quad (31)$$

$$B_B(t+\Delta t) = \text{Preisach}(H_B(t+\Delta t)) \quad (32)$$

$$B_C(t+\Delta t) = \text{Preisach}(H_C(t+\Delta t)) \quad (33)$$

For solving the above equations, choose the special time steps and find the other variables which are really difficult and may face the instability of numerical method. So, for dissolving this problem, we choose proper steps for H and then find other variables such as time steps. This method is shown in the algorithm of Figure 5.

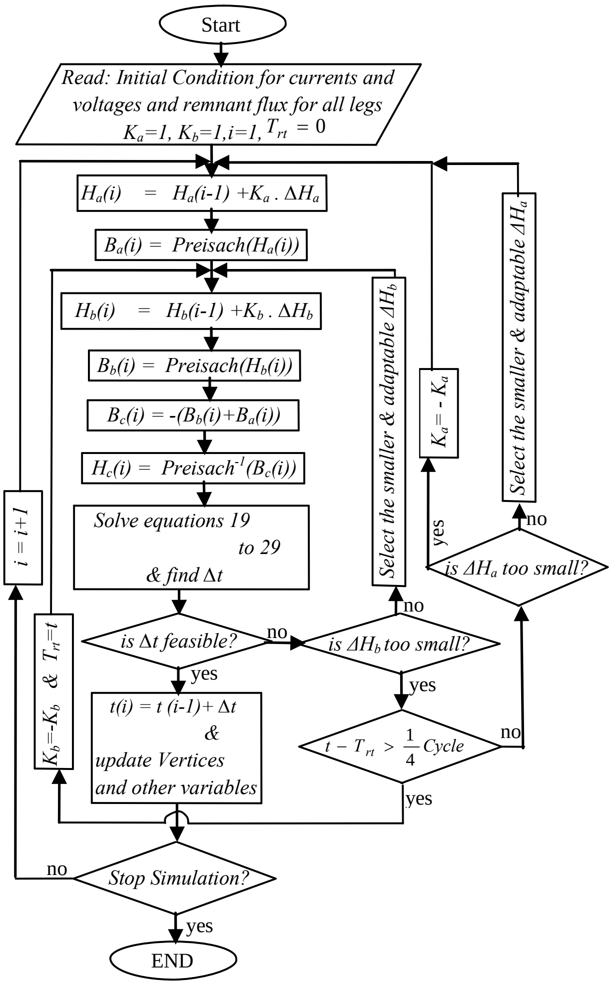

Figure 5. Simulation Algorithm

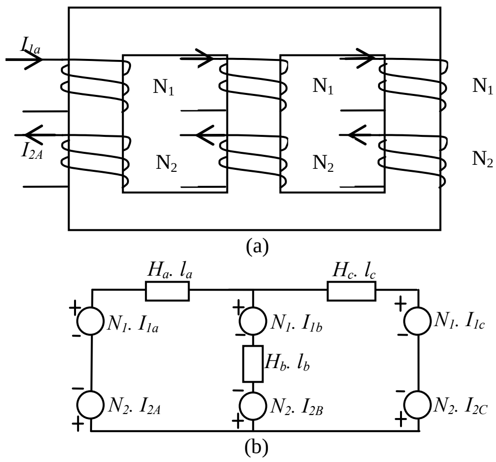

Figure 6. (a) the three phase transformer with three legs core (b) the equivalent circuit based on duality

IV. SIMULATION RESULTS

We simulate the network which was introduced previously, by applying a balanced three-phase voltage and symmetric load with different initial conditions. For instance, for the state that occurring the inrush current in phase A and remnant flux is zero, yields Figures 7 to 12. These figures refer to transient waveforms of currents, voltages, magnetic field intensity and magnetic flux density. As it illustrated in Figure 12 by being in the transient conditions of other variables of network, the neutral point has a transient voltage.

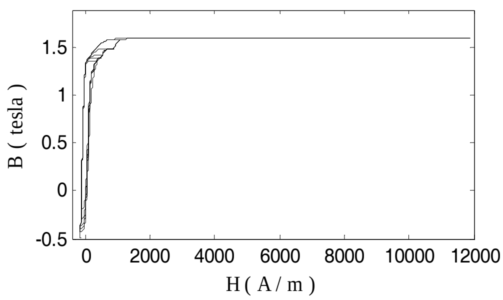

Figure 7. Transient *B-H* curve in leg which phase A windings are twisted around it

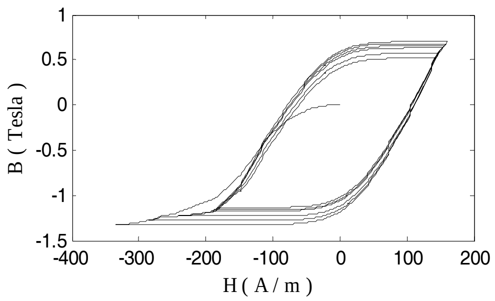

Figure 8. Transient *B-H* curve in leg which phase B windings are twisted around it

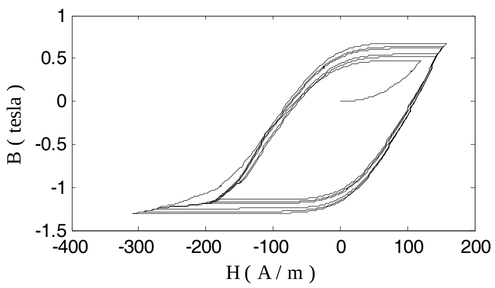

Figure 9. Transient *B-H* curve in leg which phase C windings are twisted around it

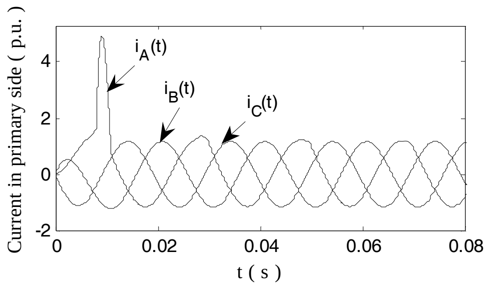

Figure 10. Transient current of primary in the all phases

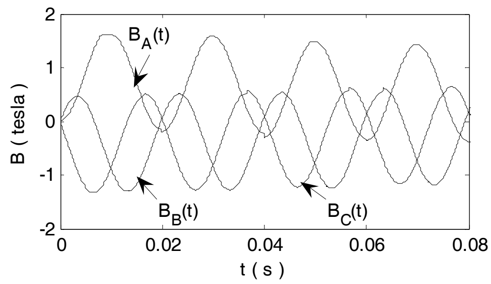

Figure 11. Transient flux density in all legs of the core

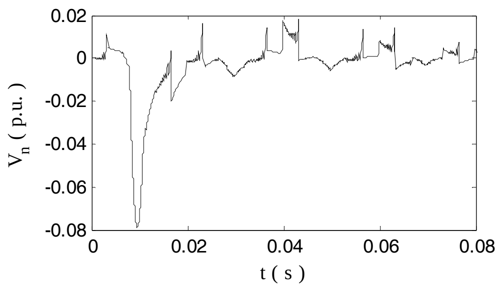

Figure 12. Transient voltage of the neutral point

V. CONCLUSIONS

According to the simulation results, exactly like the transient condition of the other variables of network and proportional with the inrush current intensity, the neutral point in transformers with star connection has a transient voltage. Even if we connect this point to ground by creating extra current, it harms the earth equipments. This scrutiny is done just by a complete and comprehensive model which consist electric equations and magnetic characteristics of the transformers. In this paper, we combine the electric and magnetic equations based on Preisach model and Ampere law. According to simulation results, the voltage magnitude of the neutral point at the time of exceeding the inrush current increases, so, the considerations are performed for reduction of the inrush current are helpful to the decrease in this transient voltage.

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BIOGRAPHIES

Ahmad Darabi received the B.Sc. degree in electrical engineering from Tehran University, Tehran, Iran in 1989 and the MSc degree in the same field from Ferdowsi University of Mashhad, Mashhad, Iran, in 1992. He obtained the Ph.D. degree with the electrical machine group, Queen's University, Belfast, UK, in 2002. He is now an associated professor and has been with Faculty of Electrical and Robotic Engineering, Shahrood University of Technology, Iran from 1993. His research activities are mostly on design, modeling and manufacturing of miniature electrical machines and generating sets.

Mohsen Khosravi was born in Shahrood, Iran in May 1983. He received the B.Sc. degree in electrical engineering in 2006 and the M.Sc degree in the same field in 2009 from Shahrood University of Technology, Sharood, Iran. He is now a Ph.D. student in electrical engineering, Shahrood University of Technology. His research interests include hysteresis modeling, design and modeling of transformer and intelligent system designing.