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A Double Exponential Function Fitting Algorithm for Optimize Parameter of μH Curve

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Abstract. Saturable magnetic circuit is a common phenomenon in power system. It can lead to waveform distortion, coefficient of self inductance decrease and measurement error increase. So establishing a mathematical model for saturable magnetic circuit and revealing the mathematical relationships in saturable phenomenon. It is helpful to reliable and safe operation of power system. This paper base on double expontential function fitting algorithm and simplex algorithm to establish the function relationship between relative permeability and magnetic field intensity. Applying for the model,we can obtain the waveform of magnetic flux in transformer core and transformer voltage waveform. The research has certain significance in the abstract and foreground in the application for the study of saturable phenomenon.

Introduction

BH curve is the key to studying saturable phenomenon. Generally speaking,the BH curve can be determined in laboratory. Therefore there is no simple formula for this kind of curve. But if you look at the mathematics of the problem, BH curve can be gotten according to the polynomial fitting, cubic spline interpolation and so on. The data of curve fitting would be in error. Because calculation of secondary voltage transformers and magnetic flux of iron core have many procedures, calculation error has the trend of becoming bigger. Therefore, in this paper a new method of fitting $\mu_r H$ (μ_r: relative permeability) curve is proposed.

Applying for the model, we can reduce the amount of calculation and lower the calculation error.

Model Building

It is well known that experimental BH curve of silicon steel sheet,as shown in figure(1).

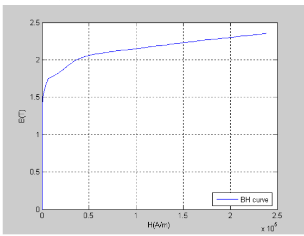

Fig. 1. BH curve of silicon steel sheet.

The relationship between relative permeability and magnetic field intensity, expressed by the simple equation(1). $\mu_r H$ curve shown in figiure(2).

$$\mu_r = \frac{B}{\mu_0 H} \tag{1}$$

In equation(1), the μ_0 is permeability of vacuum, μ_r is relative permeability, B is magnetic induction intensity,H is magnetic field strength.

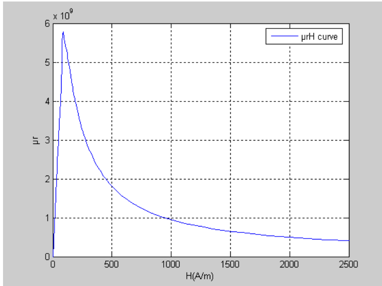

Fig. 2. $\mu_r H$ curve of silicon steel sheet.

Now, we utilized the curve-fitting to establish $\mu_r H$ fun-ction. $\mu_r H$ curve look like a impulse function. So double expontential function fitting algorithm can express $\mu_r H$ curve. The expression can be given as equation(2).

$$y = A(e^{-\alpha x} - e^{-\beta x}) \tag{2}$$

In equation(2). A, α , β is the fitting coefficient.

The basic ideas concerning curve fitting is that find the optimum solution of A, α , β , and make difference between the data of the curve fitting and the experimental data as small as possible. The error function can be given as equation(3).

$$E(A,\alpha,\beta) = [\mu_r - A(e^{-\alpha I_e} - e^{-\beta I_e})]^2 = \min \tag{3}$$

In ordor to find the optimum solution of A, α , β , we need solving the partial derivatives of E function. Then make partial derivatives of E function equal to zero,It can be shown as equation(4).

$$\begin{cases} \dfrac{\partial E(A,\alpha,\beta)}{\partial A} = 0 \\ \dfrac{\partial E(A,\alpha,\beta)}{\partial \alpha} = 0 \\ \dfrac{\partial E(A,\alpha,\beta)}{\partial \beta} = 0 \end{cases} \tag{4}$$

The simplex method is used to solve the system of algebraic equation(4). Since our prices are closely calculated, $A = 2.3584^{10}$, $\alpha = 0.0059429$, $\beta = 0.010769$. $\mu_r H$ curve as shown in figure(3).

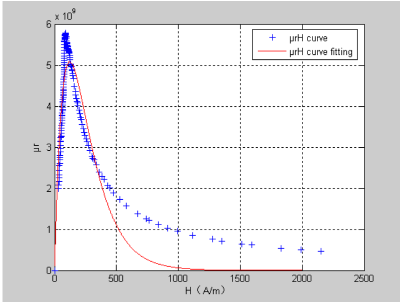

Fig. 3. $\mu_r H$ curve fitting.

From the $\mu_r H$ curve (figure 3), the fitting data accords with the experiment data basically. Fitting function can be shown as equation(5).

$$\mu_r = 2.3584^{10}(e^{-0.006H} - e^{-0.011H}) \tag{5}$$

The function relation between exciting current and magnetic field strength in transformer can be shown as equation(6).

$$H = \frac{NI_e}{l} \tag{6}$$

In equation(6). I_e is exciting current, N is turns,l is loop length.

Eq.(6) substituted in Eq(5), The function relation between relative permeability and exciting current can be express as equation(7).

$$\mu_r = 2.3584^{10}(e^{-0.006\frac{NI_e}{l}} - e^{-0.011\frac{NI_e}{l}}) \tag{7}$$

Model Application

Using the model(7), the magnetic flux and induced electromotive force in transformer core can be calculated. Model of power transformer as shown in the figure(4). Coil(1) is primary winding. The parameters as shown in the Table Ⅰ.

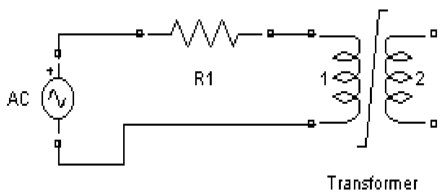

Fig. 4. Model of power transformer.

Table 1. Transformer Parameter

The capacity / frequency of transformer : 150MVA/ 50Hz					
Loss resistance / remanence flux of iron core:1.0805e+006ohm/ 0T					
Loop length / sectional area of iron core: 2m/ 1 m^2					
	Coil resistance R1	Coil leakage inductance L1	Nominal voltage peak	Nominal current peak	Turns of coil
Coil(1)	1.1111 ohm	0.11789H	500kV	300A	500
Coil(2)	1.1111 ohm	0.11789H	230kV	500A	300

According to Faraday law of electromagnetic induction, Induced electromotive force at primary winding can be expressed as equation(8).

$$e = \mu_r \mu_0 N (\frac{dH \cdot S}{dt}) \quad (8)$$

Suppose exciting current equals rated current. Using the model(7), the iron core magnetic flux-time function picture as shown in the figure(5).

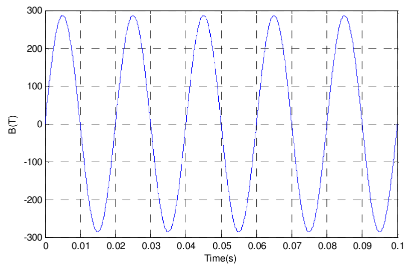

Fig. 5. Iron core magnetic flux-time function picture.

When iron core is not saturated,the magnetic flux-time function is a sine function. So using the model(8), the induced electromotive force at secondary winding is a sine wave as shown in the figure(6).

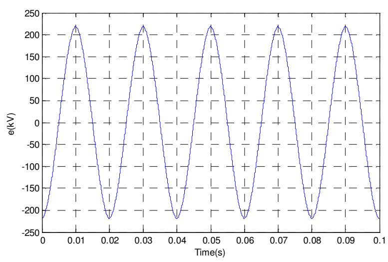

Fig. 6. Induced electromotive force -time function picture.

Suppose exciting current is greater than rated current. Using the model(7), the iron core magnetic flux-time function picture as shown in the figure(7).

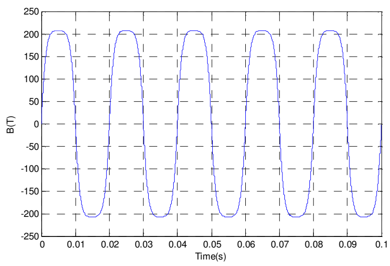

Fig. 7. Iron core magnetic flux-time function picture.

Because of core saturation, magnetic induction intensity in the iron core is a flat wave. Using the model(8), the induction electromotive force at secondary winding is a peaked wave. It shown in figure(8).

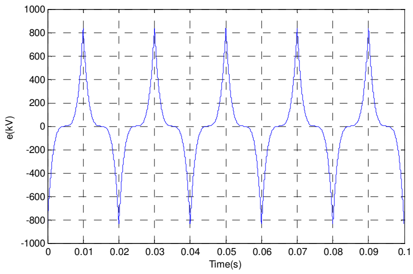

Fig. 8. Iron core induction electromotive force -time function picture.

Conclusion

Detailed calculations shows that it the result of the model(7) is in accordance with the theoretical analysis. So the model is feasible and available. These research and practices are useful references to us.

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