Nonlinear Magnetic Modeling of EI Core Inductor by PLECS Simulation

Zhuning Wang, Seung-Ki Sul
Department of Electrical and Computer Engineering, Seoul National University

ABSTRACT

EI core inductor in power electronic circuit simulation is usually assumed as linear by using matrix model. However, nonlinear magnetic characteristics such as B-H characteristic are also important for the accurate simulation of the circuit behavior. To model nonlinear magnetic characteristics of EI core inductor with only DC bias table, this paper presents a method in PLECS simulation tool which is a commercially available simulation tool for power electronics circuit analysis. Comparing with ideal matrix model, the simplification and accuracy are improved by this modeling method. Also, compared to analysis by FEM, it is much simpler, faster and easier to simulate with power electronics circuit. Validation of the proposed model was verified by simulation and experiment results.

1. Introduction

Magnetic core are used widely in power electronic systems and devices, such as transformers, electric motors and filters in medium/high power converter systems[1]. In order to precisely predict and perform power electric system and circuit in simulation, the accurate modelling of magnetic component is important.

Some researches are focused on EI core model construction and design[2]-[4] as well as this paper. In ideal matrix model in simulation, each self and mutual inductance value of EI core is fixed with one constant value, which makes simulation performance lack of nonlinear magnetic characteristics. However, the simulation modeling method in this paper is to validate accurate nonlinear magnetic feathers of EI core inductor in PLECS simulation, which is a simulation tool, and to achieve a non-complicated but efficient nonlinear magnetic modeling purpose.

2. Nonlinear Magnetic Modeling of EI Core Inductor

2.1 EI Core Inductor Magnetic Equivalent Circuit Model

Magnetic core can be modeled as a magnetic equivalent circuit with magnetomotive force (MMF), flux and magnetic reluctance, which can be looked upon as analogous to an electric circuit[5]. Therefore, EI core can also be modelled as the magnetic equivalent circuit as shown in Fig.1. Each limb can be seen as a reluctance, and left and right limb reluctances are symmetric and larger than center limb because of containing longer magnetic path of core. When current flows through windings on each limb, magnetomotive force shall produce flux against limb reluctance.

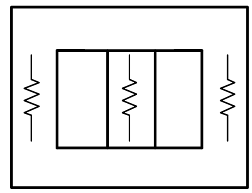


Figure 1. Magnetic equivalent circuit of EI core

2.2 Parameter Extraction and Calculation

According to PLECS library of magnetic domain, parameters including winding turn number, flux leakage path permeance, static and dynamic permeance of self and mutual flux path should be extracted to make nonlinear magnetic model of EI core inductor.

From DC bias table provided by EI core inductor data sheet, left, right and center limb dynamic inductances can be extracted as following equations.

$$L_{dyn} = \frac{d\lambda}{di} \quad (1)$$

$$\Phi = \frac{\lambda}{N} \quad (2)$$

$$\mathrm{F} = \mathrm{N} * \mathrm{I}. \quad (3)$$

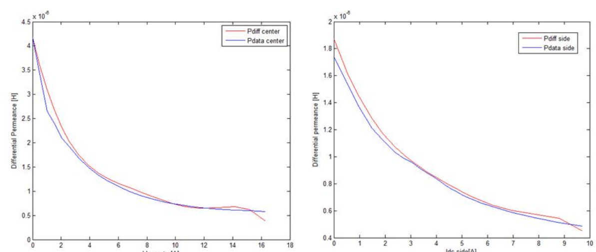
From equation (1)-(3), where L_{dyn} is dynamic inductance, λ is flux linkage, Φ is flux, N is winding turn number, F is magnetomotive force, and I is current flows through windings, flux linkage can be integrated by dynamic inductance, and flux and magnetomotive force can be calculated.

Next, from equation (4) and (5), static and dynamic permeance could be calculated,

$$\mathrm{P}_{std} = \frac{\Phi}{F}. \quad (4)$$

$$P_{diff} = \frac{d\Phi}{dF}. \quad (5)$$

where P_{std} is static permeance, P_{diff} is dynamic permeance, Φ is flux and F is magnetomotive force. Fig.2 (a) and (b) show the comparison of experimental and simulation results in plotting dynamic permeance table of center and side limb.



(a) (b)

Figure 2. Dynamic permeance table. (a) Center limb. (b) Side limb.

Mutual flux is also modeled by means of nonlinear calculation. Self flux is produced by limb winding MMF against limb reluctance itself, and mutual flux is the flux produced by MMF against other limb reluctances. After self flux and dynamic permeance calculation above, self flux would be divided to become mutual flux of the other two limbs. The magnitude of mutual flux is decided by the dynamic permeance value at that moment. Total flux of one limb is the summation of self and mutual flux.

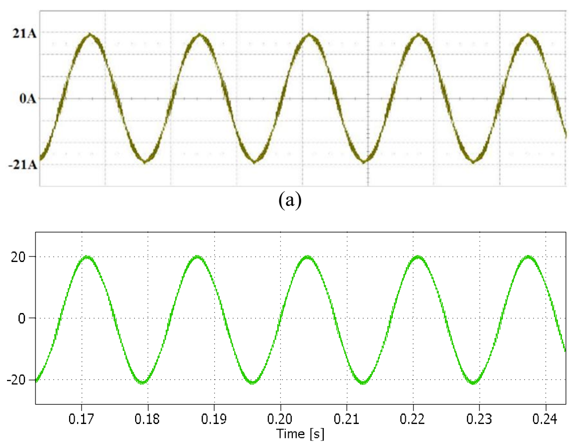
2.3 Comparison of Experimental and Simulation Result

To verify the validity and accuracy of nonlinear magnetic model by extracted parameters in 2.2, experimental and simulation results are compared with system parameters in Table 1.

The whole experiment and simulation system is based on 200V DC link voltage and 5kHz switching frequency PWM converter connected to three phase AC grid, whose voltage is 110Vrms line to line voltage.

Table 1. Parameters of experiment and simulation system

Quantity	Values
AC grid voltage; line to line voltage	110 Vrms
DC link voltage	200 V
Fundamental frequency	60 Hz
PWM switching frequency	5 kHz
Winding turn number	14 turns
Leakage inductance, measured	10 uH



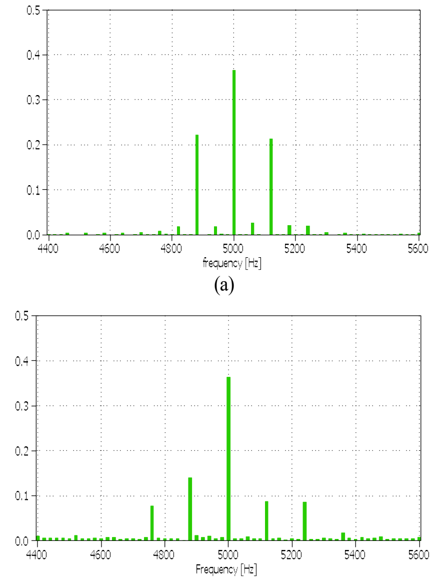
(b)

Figure 3. A phase current. (a) Experiment result. (b) Simulation result.

A phase current from experiment and simulation are shown in Fig.3 (a) and (b). And corresponding FFT plots from 4400Hz to 5600Hz are shown in Fig.4 (a) and (b).

From current waveform plot and FFT plot, A phase current magnitude at fundamental frequency are 20.05A in experiment and 20.28A in the simulation. Furthermore, at 5kHz switching frequency, sideband harmonics are 0.366A in experiment and 0.375A in simulation. Inductance can be calculated together with voltage value at 5kHz, which is 67.41V and 64.45V in experiment and simulation respectively. Thus, inductance at switching frequency can be calculated, resulting in 5.9mH and 5.5mH in experiment and simulation, respectively.

Nonlinear validation can be shown by inductance value between different frequencies. Because of nonlinear magnetic characteristics such as B-H characteristic, different magnitude of winding current would lead to different inductance of core. This is the nonlinear performance where simple matrix core model cannot achieve. At 4.88kHz, from FFT plots inductance are calculated to have 4.1mH and 3.8mH in experiment and simulation respectively.



(b)

Figure 4. A phase current FFT. (a) Experiment result. (b) Simulation result.

3. Conclusion

A novel method of modelling of a nonlinear magnetic inductor made by EI core for the simulation based on PLECS has been proposed in this paper. By the proposed modeling method, and with consideration of winding turn numbers, leakage inductance, self and mutual flux, static and dynamic permeance, nonlinear features like B-H characteristic have been fully incorporated in the model. Model accuracy in simulation has been validated by comparison with real experiment result at the same operating condition. The error bound of simulation and experiment is within 10 percent.

References

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