学 位 論 文 内 容 の 要 旨

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学 位 論 文 題 名

Analysis of high-frequency electromagnetic devices based on equivalent circuit and homogenization method

（等価回路と均質化法による高周波電磁デバイスの解析）

For the reduction of device size, the driving frequency of power electronics circuits has been increased. The impedance of magnetic devices such as inductors and wireless power transfer (WPT) working at high frequency would be frequency dependent owing to the eddy current effect and displacement current effect. Although the devices can be analyzed using Finite Element Method (FEM), it needs large computing cost at high frequencies because they must be discretized into elements much smaller than skin depth. It is more prominent in the time domain simulation.

Therefore, alternative methods are required to accelerate the calculations, and the equivalent circuit is one choice. Recently Cauer circuit, partial element equivalent circuit (PEEC) and homogenized method are usually applied to solve problems shown below.

(1) When the working frequency is high, due to the proximity effect and skin effect the resistance of the device will increase and the inductance will decrease, it is time-consuming if we use FEM to do the simulation especially in time domain with complex input and applied in power system.

(2) For the winding in motor, because of the high-frequency harmonic in input Pulse-Width Modulation (PWM) wave, magnet in the rotor and the saturation of core, the copper loss of windings is of large consumption to calculate.

(3) Due to the stray capacitance, a high frequency inductor or coils in WPT has self-resonant points. When the inductor works at frequency larger than the first self-resonant frequency, it becomes capacitive, and the resistance and reactance increase sharply around the resonant point. Such analysis can hardly be performed only using quasi-magnetostatic FEM unless the Darwin approximation is introduced.

In this paper, based on the conventional FEM, homogenization method and other algorithms, the equivalent circuits are built to accelerate the simulation process of magnetic devices working at high frequency considering the eddy current and displacement current effect.

In Chapter 2, the basic construction of Cauer circuit and the AVM to calculate the parameters of Cauer circuit are introduced. The method to get the input impedance for building Cauer circuit, containing formula calculation and FEM calculation are shown. The Cauer circuit is used to represent the WPT and inductor. The nonlinearity and displacement of WPT are considered in the Cauer circuit. The result in frequency domain and time domain are shown in this chapter.

In Chapter 3, the basic theory of homogenization method is introduced and compared with Dowell's method. The impedance is calculated using homogenized method and Cauer circuit is built on the impedance. The results of Cauer circuit containing nonlinearity in time and frequency domain are

shown. To consider windings influenced by external magnetic field, another type of Cauer circuit is built based on the complex permeability. The copper loss of windings considering the external influence is calculated using the homogenized Cauer circuit.

In Chapter 4, the PEEC method is introduced to represent the magnetic devices and describe how to calculate the parameters of the PEEC using complex mutual inductance. The model is applied to analyze the inductor and wireless power transfer. The resonant point and the power factor are simulated using the equivalent circuit. The result in time domain simulation will also be shown in the chapter.

In Chapter 5, the conclusion and future works are discussed.