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Hysteresis loss in Brushless Doubly Fed Induction Machines

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Abstract. Brushless doubly fed machine (BDFM) is a potential for future wind energy generation, due to its lower maintenance costs and higher reliability than conventional doubly fed systems. While efficiency and design optimization of the machine has become critical issues recently, no analytical core loss model is investigated in the literature. Furthermore, core loss modeling is different from conventional induction machines, because of double frequency excitation of the machine. In this paper, a dynamical system is used for modeling of hysteretic behavior of iron core, and hysteresis losses of BDFM are analyzed and modeled mathematically. The flux waveforms of BDFM are assumed pure double sine, as in wound rotor BDFM lower harmonic values than nested loop design exist.

Key words

Brushless doubly fed machine (BDFM), core losses, hysteresis loop, dynamical systems, curve fitting.

1. Introduction

In standard frequencies (50 or 60 Hz), core losses are around 20-25 percent of losses in electrical machines [1]. In BDFM, the amount of core loss is increased due to poor magnetic design [2]. Since this machine has two supply frequencies (power and control windings), definition of operating point is fairly different with single fed machines, so there are more different parameters for designing the machine. Until now, there is no contribution on mathematical calculation of losses in BDFM to be used in optimization of machine design or operating point, except the simulation of the machine by Ferreira et al [3], using 2D finite element method. In the simulation, the nonlinearity and saturation effects of iron core are taken into account. To calculate core losses, hysteresis and eddy current losses are considered, but hysteresis loss is calculated using classic models of conventional singly fed machines, where single sinusoidal supply exists. However, this is not compatible with flux distribution of a BDFM.

Core losses are generally divided into hysteresis, classic eddy, and excess eddy current losses. For each of them, there are certain dynamic and mathematic relations. In this paper, hysteresis loss of a BDFM is investigated. To do this, core flux is assumed 2D, to simplify flux calculation.

2. Hysteresis Losses

There are three main ideas for modeling the hysteresis systems. First method is fundamental analysis based on physical principles of the system, resulting in a large dynamic system [4], [5]. Although the method is the most accurate model, modeling comprehensive internal mechanisms of the system is mandatory, so it is complicated. Even, if the accurate model of the system is obtained, it should be simplified for computer simulations.

The second approach utilizes static models extracted from interpolation of experimental data. This method is generally used for sinusoidal supply systems and is widely used in electrical engineering systems. The main goal of these methods is to calculate energy losses in hysteretic systems. In fact, these models cannot simulate the hysteresis loops, and only contribute an estimate for the surface of the hysteresis loop. The waveforms studied in these models, are quasi-sine waves with little distortion from fundamental harmonic, separating the hysteresis loop into major and minor loops. These methods are based on estimation of surface of major and minor loops, as a function of waveform peak values. The most familiar nonlinear model is found in [6], introducing area of the hysteresis loop as an algebraic function of the peak flux density. The exponent is a constant number, which varies by the material. There are more accurate exponential models, which have the term of peak of flux density in their exponents [7]. In some of these models, exponent is a linear function of magnetic flux density [8], and in some others, quadratic function is preferred [9]. These models are mainly applied to single sinusoidally excited cores and the constants are calculated by curve fitting approach.

The third approach combines the two ideas to obtain a macroscopic view of hysteresis dynamics. This mathematical modeling approach can be verified by analogy of experimental and theoretical properties of the system. Since the hysteresis phenomenon is nonlinear, the model should be nonlinear either. If the model was linear, the accuracy of the model could be evaluated by a single experiment, according to Representation Theorem [10]. For experimental evaluation of the nonlinear model, infinite experiments are required, and the system cannot be evaluated by a single experiment anymore [11]. So, the model is evaluated qualitatively, by means of assessment of the main characteristics of the real system and the model. Then the model parameters and functions can be determined by experimental data. According to