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Maximum Torque per Ampere Operation of Brushless Doubly Fed Induction Machines

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Abstract. In this paper, an analytical method for increasing the steady state torque per ampere capability for BDFMs, using equivalent circuit is presented. In this approach, uni-current proposition proposed to define a unique current value for optimization, and find the current angel corresponding to maximum torque. The accuracy of the proposition is verified by simulation. The effect of pole pair number selection of power and control windings on maximum torque is explained by dividing torque expression into synchronous and asynchronous terms. Finally, the optimal current values and optimal torque are achieved. Based on the optimal value of torque, or MTPA index, analytical optimization of machine design is suggested, which can be performed by manipulation of components of the MTPA index.

Key words

Brushless doubly fed machine (BDFM), maximum torque per ampere (MTPA), equivalent circuit model, synchronous frame dq model, uni-current proposition.

1. Introduction

BDFM has two uncoupled windings with different pole numbers on the stator. One winding is called power winding ($2p_1$ poles), while the other is control winding ($2p_2$ poles). The power winding is connected directly to the grid and the control winding is supplied by a bidirectional converter.

Because of the energy cost, electrical machines should operate at maximum efficiency. For the most machine designs, there are two important efficiency indices, maximum efficiency (or minimum loss) and maximum torque per ampere (MTPA).

Maximum machine efficiency occurs, when it has minimum losses at a given torque and speed. A lot of research is done on operation of the induction motor drives at the minimum power loss point [1]-[4]. The copper and core losses are the majority of the total electrical losses in a machine. It is possible to find a compromise between copper and core losses, such that the total loss is minimized.

In converter fed machines, efficient use of the power converter is important, because of the cost of the power converter. At low speeds, this optimization generally requires operating the machine at maximum torque per ampere to achieve high torque output for fast acceleration of the connected load [5]. A maximum torque per Ampere scheme was proposed by [6] to minimize the stator current and converter rating in certain speeds. Other works are done for maximum torque per ampere capability of IPMSMs [7] and induction motor drives [5], [6].

It was found that neither "minimum loss" nor "maximum torque per ampere" produced optimum machine efficiency, and the optimum efficiency occurred between the two indices [8], [9].

Minimizing the loss is not completely appropriate for a BDFM, since the stator currents are not minimized. As a result, the converter rating and its losses are not minimized. Furthermore, Core loss in a BDFM is not offered yet, so it is impossible to formulate all loss components and analyze them, numerically. Therefore, in this approach, we will neglect core losses, and will try to maximize the torque in fixed current amplitude.

Since shaft speed is not arbitrary in machine operation, stator current minimization should be considered independent of speed regulation [9]. Hence the optimization should be performed at the machine's most frequent operating point. In this paper the torque per ampere optimization performed through maximization of torque by the stator current angle. After that, torque-speed relationship is analyzed for optimal machine operation over different speed ranges. Also, the effect of selecting pole pair numbers of power and control windings on torque is explored. The main achievements of the optimization are found in the final part, where optimal torque value is used for machine design optimization purpose.

2. BDFM Models

There are some different models for BDFM including coupled-circuit, synchronous frame d-q-0 model, equivalent circuit and core model. The d-q-0 model is derived from the reduced order coupled-circuit model, and through transformation of this model into symmetrical components, the equivalent circuit model (Fig. 1) is obtained [10]. The core model is simplified version of equivalent circuit model [11].
For ease of analysis, synchronous reference frame d-q model [12] is used, which introduces constant system states in steady state operation of the machine.