Optimal Efficiency Control Strategy for Interior Permanent Magnet Synchronous Motor Drives

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Abstract-- **In this paper, the problem of efficiency optimization in vector controlled interior permanent magnet synchronous motor drives is investigated. A loss model controller is introduced that determines the optimal *d*-axis component of the stator current that minimizes power losses. For the implementation of the suggested controller, the knowledge of the loss model is not required, since an experimental procedure is followed to determine its parameters. Furthermore, it is shown that the loss model of the interior permanent magnet motor can be used as a basis for deriving loss minimization conditions for surface permanent magnet synchronous motors and synchronous reluctance motors as well. Experimental results of an interior permanent magnet motor are presented to validate the effectiveness of the proposed method and demonstrate the operational improvements.**

Index Terms-- **Permanent magnet motors, losses, optimization methods, optimal control, variable speed drives.**

NOMENCLATURE

R_s	Stator resistance.
L_{md} , L_{mq}	*d*- and *q*-axis magnetizing inductances.
L_{ls}	Stator leakage inductance.
ω_e	Supply frequency.
ω_r	Motor speed.
V_s	Stator voltage.
V_m	Air-gap voltage.
Φ_m	Air-gap magnetic flux.
I_s	Stator current.
I_d, I_q	*d*- and *q*-axis components of stator current.
I_m	Magnetizing current.
I_{md}, I_{mq}	*d*-and *q*-axis components of magnetizing current.
I'_f	Equivalent excitation current of the permanent magnet.
T_e	Electromagnetic torque.
P_l	Total power losses.
P_{Cu}	Copper losses.
P_{Fe}	Iron losses.
P_{str}	Stray losses.
P_m	Mechanical losses.
c_{Fe}	Iron loss coefficient.
c_{str}	Stray loss coefficient.
c_m	Mechanical loss coefficient.

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I. INTRODUCTION

PERMANENT Magnet (PM) synchronous motor adjustable speed drives offer significant advantages over induction motor drives in a wide variety of industrial applications (i.e. high power density, high efficiency, improved dynamic performance and reliability) [1]. Since vector control in PM synchronous motors provides fast dynamic response with a less complex and non-parameter dependent controller, PM motor drives can be an attractive alternative choice [2].

Improvement of PM motor efficiency is a most important priority, especially in cases where drives are powered by a battery source. Therefore, significant efforts are taken to improve their efficiency. Since there are a great variety of PM motor configurations, the efforts are mainly focused on the search for the optimum rotor structure [3]-[7]. However, efficiency can also be improved by intervening in the motor operation principle with automatic control techniques.

Several control methods have been proposed in order to reduce the loss of PM motor drives and improve their performance. The copper loss can be minimized by the maximum torque-per-ampere current control [8]. In surface PM motor drives, maximum torque-per-ampere current ratio is attained by keeping the *d*-axis component of the stator current equal to zero (I_d = 0) [9], [10]. Since the "I_d =0 control" prevents the demagnetization of the PM, it is often employed in interior PM motor drives. However, the I_d current, that provides maximum torque-per-ampere current ratio in interior PM motor drives, is a function of the I_q current and opposes the excitation field of the PM [8]-[11].

Several attempts to minimize both copper and iron losses have been recently presented [12]-[14]. However, the proposed loss minimization conditions are complex and can only be implemented using off-line made look-up tables. Therefore, a number of costly and time-consuming measurements are required. A control method, described in [15], improves efficiency of PM motors and is implemented using a voltage source inverter. The efficiency improvement is attained with appropriate control of stator voltage in order to keep power factor equal to unity. However, although the real to apparent power ratio (kW/kVA) of the PM motor is maximized, power losses are not minimized. An adaptive search controller for interior PM motors was developed in [16]. Finally, an approach that specifies the optimal *d*-axis current for minimizing interior PM motor losses was presented in [17].