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Sensorless Speed Control of Induction Motor Driven Electric Vehicle Using Model Reference Adaptive Controller

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Abstract

This paper proposes a new sensorless speed control technique for induction motor (IM) driven electric vehicle (EV) using a model reference adaptive controller (MRAC) with a basic energy optimization technique known as golden section method. The proposed MRAC for the vector controlled IM drive utilizes instantaneous and steady state values of a fictitious resistance (R) in the reference and adaptive models respectively. The proposed scheme is immune to the variation in stator resistance (R_s). Moreover, the unique formation of the MRAC with the instantaneous and steady-state reactive power completely eliminates the requirement of any flux estimation in the process of speed estimation. Thus, the method is insensitive to integrator-related problems like drift and saturation enabling the estimation at or around zero speed quite accurately. The proposed drive's performance with the R-MRAC is validated for various speed ranges and patterns in Matlab/Simulink. Sensitivity of various motor parameters and stability studies are carried out using eigenvalues loci plots by first order eigenvalue sensitivity analysis.

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Keywords: Drives; electric vehicles; estimation; induction motor; MRAC; optimization; sensorless; speed; stability

1. Introduction

Electric Vehicles (EVs) are the future of automobile technology in context of depleting oil reserves. In coming years, EVs will have the potential to solve the problems associated with environment, energy resources, and people health [1]. However, to prove its dominance in the coming era, EVs should be more energy efficient over the wide

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Nomenclature

$i_{ds}, i_{qs}, i_{dr}, i_{qr}$	: d and q-axis components of stator and rotor current (A)
$\psi_{ds}, \psi_{qs}, \psi_{dr}, \psi_{qr}$	: d and q-axis components of stator and rotor flux (Wb)
L_s, L_r, L_m, L_{ls}	: stator, rotor, mutual and stator leakage inductances (H)
R_s, R_r	: stator and rotor resistance (Ω)
$\omega_e, \omega_r, \omega_{sl}$	: synchronous speed, rotor speed, and slip speed (rad/s)
$\sigma = 1 - L_m^2/(L_r L_s)$	: total leakage factor
τ_r	: rotor circuit time constant (s)
^, *	: estimated, reference quantities
P	: time-derivative operator
ε	: error signal

speed and torque ranges. This can be achieved by a suitable choice of electric motor [2], [3]. However, induction motor (IM) drives are more rugged, compact, cheap and reliable in comparison to the other motors (e.g., DC motors or synchronous motors) of same capacity used for EV applications [4]. Vector Control or field oriented control (FOC) plays a critical role in extracting the drive's high performance due to its simplicity and fast dynamic response [5], [6]. However, for implementation of FOC, knowledge of either the flux or speed is necessary. In this regard, digital shaft position encoders and shaft mounted tachogenerator are usually employed to detect the rotor speed [6]. The flux and speed sensors lead to the increased size of drive system with additional involvement in cost for the sensors. In addition, these degrade the mechanical robustness reducing the system reliability. The emergence of sensorless vector control [7] has reduced the cost and size of drive system with the reduction of the hardware complexity, increased reliability, better noise immunity and less maintenance requirements.

In years, many improved speed estimation techniques such as sliding-mode observers, [7], extended Kalman filters [8], speed adaptive flux observer (Leunberger observer) [9] and model reference adaptive controller (MRAC) [10], [11] are reported in the literature. A brief review of different MRAC is available in [12]. Among all the strategies, MRAC based techniques have been proven to be as one of the best methods being proposed by the researchers due to its simple formulation, less computational complexity thereby ease in implementation [13].

Minimization of loss in the induction motor is directly related to the choice of the flux level. But extreme minimization causes a high copper loss [5]. For constant speed operation, if torque is variable then flux have to vary, to improve the drive efficiency. A number of energy optimization strategies such as simple state control [14], search control [15] and loss model based control [16] for IM drive are found in the literature. The on-line power search optimization controllers called search controllers (SCs) mainly works on the principle of optimization of a significant parameter (e.g., DC link power or DC-link current or stator current or drive losses) by trial and error method [17], [18]. Unlike other control strategies, the method does not depend upon the motor or converter parameters. However, the method suffers from the torque ripples and slow convergence rate. Nevertheless, the problem may be overcome using second order low-pass filter [19].

In the present work, golden section algorithm is used to minimize the drive loss. This also has a close relation to the Fibonacci search method [19]. However, the golden section technique has the edge over the Fibonacci search algorithm as the later needs to know *a priori* the number of evaluations in the minimum searching process, which is totally eliminated in former [20]. To achieve a minimal machine core loss, the golden section technique searches the optimal value of rotor flux reference using very fast convergence algorithm.

In addition, a new fictitious d- and q-axis resistance error based MRAC (R-MRAC) is proposed for the estimation