A novel adaptive control method for induction motor based on Backstepping approach using dSpace DS 1104 control board

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A B S T R A C T

This paper presents a new adaptive Backstepping technique to handle the induction motor (IM) rotor resistance tracking problem. The proposed solution leads to improve the robustness of the control system. Given the presence of static error when estimating the rotor resistance with classical methods, and the sensitivity to the load torque variation at low speed, a new Backstepping observer enhanced with an integral action of the tracking errors is presented, which can be established in two steps. The first one consists to estimate the rotor flux using a Backstepping observer. The second step, defines the adaptation mechanism of the rotor resistance based on the estimated rotor-flux. The asymptotic stability of the observer is proven by Lyapunov theory. To validate the proposed solution, a simulation and experimental benchmarking of a 3 kW induction motor are presented and analyzed. The obtained results show the effectiveness of the proposed solution compared to the model reference adaptive system (MRAS) rotor resistance observer presented in other recent works.

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1. Introduction

The induction motors are the most used electrical machines in several industrial applications, due to their ruggedness, low price and low maintenance cost. The induction motor can be operated directly from the mains, but variable speed and often better energy efficiency are achieved by means of an inverter controlled using a digital signal processor [1–3]. In recent years, several methods that use inverters for the variable speed control of induction motor have been proposed [4–14]. The performance of these control strategies depend heavily on the knowledge of the real motor parameters. Unfortunately, those parameters may change widely with the temperature, the current amplitude and the inverter frequency. In particular, the rotor resistance is the most critical changing parameter. In the literature, several control methods have been proposed to circumvent the problem of the rotor resistance variation which is principally due to ohmic heating [15,16]. Indeed, a mismatch of this parameter affects significantly the open loop slip estimator and degrades the performance of the speed control, even though the motor is not loaded [17,18]. To solve this problem, many researchers have proposed various control law based on adaptive identification of the rotor resistance \( R_r \), in order to improve the performances of electric drive systems towards the parametric variations [13,17,19–23]. The most popular rotor resistance observer is that based on model reference adaptive system (MRAS), which consists in comparing the output of both estimators and the error between them is injected in an adaptation mechanism which can generate the estimated value of the rotor resistance [24–28]. The
work presented in [17], shows that the fuzzy estimator of the rotor resistance doesn’t guarantee a good estimation when the reference speed undergoes a sudden change. In [22], the authors present the MRAS-sliding mode observer and specify that the main drawback of this solution is the appearance of the chattering phenomenon, due to the high switching frequency control signals. The solution based on Luenberger observer presented in [23], shows that the estimation error of the rotor resistance converges approximately to 10\% of the nominal value, and doesn’t guarantee a high performance of speed control.

The solution presented in [26], which is based on the reactive-power reference model and motor torque, shows that the estimation algorithm of the rotor resistance is very sensitive to the load torque variation. Soliman [29] has also found that the induction motor drives can suffer from instability problems especially at low speed operation, if the estimation error of the rotor resistance is greater than or equal to 10\%.

The most interesting approach to this issue has been proposed by Chen [30] using Time Division Approach. However, their solution is very sensitive to parametric variations mainly at low speed, and the load torque exhibits oscillations due to the unbalanced current metering scaling. Even though the rotor resistance observer has been improved in recent years, most improvements don’t guarantee a high performance control which take into account the minimization of response time with a lowest estimation error and the load torque variation. Nonetheless, it is possible to further improve rotor resistance observer by the Backstepping technique using the integral of tracking errors to overcome the drawbacks of the solutions cited above, and guarantee the stability of the drive system even at low speed. The idea is inspired from the work presented in [13], and extended in [14] to the rotor speed observer. The stability of proposed observer is proven by Lyapunov Stability Theory. Simulation and experimental results are presented to demonstrate the main characteristics of the proposed observer, and it’s compared with the MRAS-rotor resistance observer and other works.

The main contributions of the proposed control scheme can be summarized as follows:

1. The propositions of a rotor resistance estimator based on a new rotor flux observer without increasing the order of the observer compared the work presented in [13];
2. Guarantee an accurate estimation of the rotor resistance 10 times less than other recent works with a minimal response time;
3. Improve the robustness of the observer facing to load torque variation even at low speed;
4. A simulation benchmarking study was carried on;
5. A real time experimental comparative study using dSpace DS 1104 board of the IRFOC of an IM is performed.

This paper is organized as follows: in Section 2, the mathematical model of the induction motor is presented. In the next Section, we briefly review the Indirect Rotor Flux-Oriented Control of induction motor. The procedure design proposed to estimate the rotor resistance based on Backstepping technique using the integral of tracking errors is described in Section 4. Experimental and simulation results are presented in Section 5, and compared with classical MRAS observer and other recent works. Finally, in Section 6 some comments and conclusion are given.
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