

MRAS Based Speed Sensor-less Vector Controlled Induction Motor Using Modified Adaptive Mechanism

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Abstract: To improve operational stability of control system induction motor, a speed sensorless vector control system for induction motor based on DSP (TMS320F2808) was presented, fluxes estimation and speed observer based on PI adaptive method; model reference adaptive system (MRAS), a speed sensorless field-oriented control (FOC) system for induction motor was adopted. The speed estimation was based on the difference between two fluxes estimators; reference and adaptive model. The adaptive mechanism of the conventional estimator was replaced with a booster module driven by error signal from the two models. The proposed control algorithm, simulations, implementation data, diagrams and test results were given. It shows good performance for the sensorless vector control system in torque, speed and robustness. *Copyright © 2013 IFSA.*

Key words: Field oriented control (FOC), Sensor-less, Induction motor, Operational stability, Estimators.

1. Introduction

High-performance motor control is characterized by smooth rotation over the entire speed range of the motor, full torque control at low speed, fast accelerations and decelerations. To achieve these operational stability qualities, speed sensorless vector control techniques are used for induction motor. Several algorithms have been applied to solve stability problem associated with speed sensorless vector control induction machine at low speed. Low-Pass Filters (LPF) with very low cut-off frequency have been used to replace the pure integrator, but they introduce phase and gain errors due to their natural delay which causes problems in the frequency range below the filter cut-off frequency [1, 2], this

work introduced field oriented control (FOC) with a booster module as the adaptation mechanisms in placement of “gain constants and low-pass filter” of the back-EMF-based MRAS control algorithm for sensorless control of induction motor. This cuts down on tuning time while providing a good and fast response. The simulation and implementation result were shown in this paper that proved the cost effective and dynamic response of the algorithm.

2. Field Oriented Control Theory

With the advent of FOC by Balaschke has made control system more flexible. The basic idea of the vector control (FOC) is to provide an algorithm capable of decomposing a stator current into a

magnetic field-generating part (i_d) and a torque-generating part (i_q), both components can be controlled separately after decomposition. The structure of the motor controller become simple as that for a separately excited DC motor allowing accurate transient and steady state manipulation [3,4]. The proposed sensorless vector control scheme is illustrated by Fig. 1.

The machine equations in the stator reference frame, written in terms of space vectors, are:

$$\bar{V}_s = R_s \bar{I}_s + \frac{d\bar{\varphi}_s}{dt} \quad (1)$$

$$0 = R_r \bar{I}_r + \frac{d\bar{\varphi}_r}{dt} - j\omega_m \bar{\varphi}_r \quad (2)$$

$$\varphi_s = L_s \bar{I}_s + M \bar{I}_r \quad (3)$$

$$\varphi_r = L_r \bar{I}_r + M \bar{I}_s \quad (4)$$

$$\frac{d\Omega}{dt} = \frac{T - T_L}{J} \quad (5)$$

$$T = P \frac{M}{JL_r} (\varphi_{rd} i_{sq} - \varphi_{rq} i_{sd}) \quad (6)$$

These expressions signify the control strategy based on the orientation of the flux vector along d-axis which can be expressed by considering:

$$\varphi_r^{d,q} = (\varphi_{rd}^2, 0)^T$$

Equations (5) and (6) can be written in the rotor reference frame with respect to the axis components, leads to:

$$\frac{d\varphi_{rd}}{dt} + \frac{1}{\tau_r} \varphi_{rd} = \frac{M}{\tau_r} i_{sd} \quad (7)$$

$$T = P \frac{M}{JL_r} \varphi_{rd} i_{sq} \quad (8)$$

These equations represent the basic fundamental principle of FOC and are derived based on the decoupling control concept where the fluxes values and orthogonal spatial angles between them and MMF are achieved, in the current mode, the total rotor flux-linkage is aligned with the d-axis component [2, 3]. This explicitly illustrated in the Fig. 1.

The flux estimation is given as:

$$\frac{d\bar{\varphi}_s}{dt} = u_s - R_s \bar{i}_s + u_{off}, \quad (9)$$

where u_{off} is the unavoidable errors.

$$\bar{\varphi}_r = \frac{L_r}{M} (\bar{\varphi}_s - \sigma L_s \bar{i}_s) \quad (10)$$

The flux estimator was considered to be ideal, being the effects due to parameter variations at low speed.

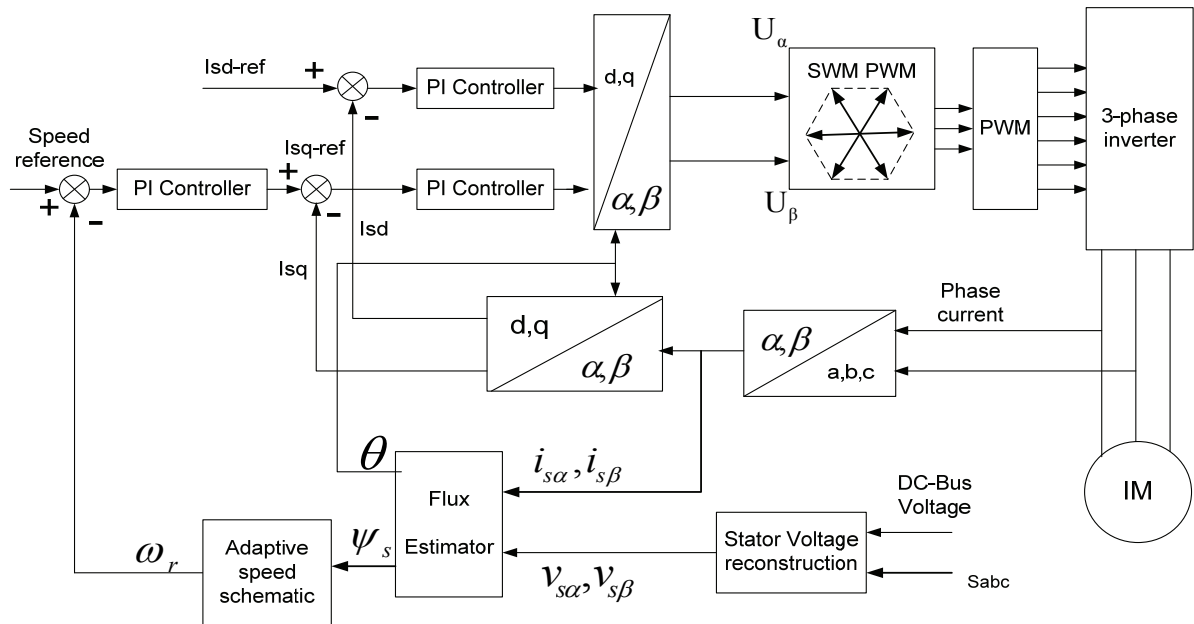


Fig. 1. Block Diagram of sensorless vector control IM drive.

3. Model Reference Adaptive System

Model Reference Adaptive Systems (MRAS) are used to estimate quantities using a reference model and an adaptive model. The difference between the outputs of the two models drives an adaptive mechanism (booster module) that provides the quantity that is to be estimated. Different approaches have been developed using MRAS, such as rotor flux-linkage estimation-based and back-EMF-based MRAS (reactive-power-based) [5, 6]. In this thesis we used the improved back-EMF-based MRAS and we proposed the module to replace the adaptation gain constants and low-pass filter in the adaptive mechanism to produced high dynamic response.

3.1. Rotor Flux-linkage Estimation-based

It uses state observer model with current error feedback and rotor current models for flux estimation. The reference model is given by:

$$\dot{\hat{\psi}}_{rd} = \frac{L_r}{L_m} \left(\int (\hat{u}_{sd} - R_s \hat{i}_{sd}) dt - \sigma L_s \hat{i}_{sd} \right) \quad (11)$$

$$\dot{\hat{\psi}}_{rq} = \frac{L_r}{L_m} \left(\int (\hat{u}_{sq} - R_s \hat{i}_{sq}) dt - \sigma L_s \hat{i}_{sq} \right) \quad (12)$$

The adjustable model is given by:

$$\dot{\bar{\psi}}_{rd} = \frac{1}{T_r} (L_m \hat{i}_{sd} - \bar{\psi}_{rd} - \omega_r T_r \bar{\psi}_{rq}) \quad (13)$$

$$\dot{\bar{\psi}}_{rq} = \frac{1}{T_r} (L_m \hat{i}_{sq} - \bar{\psi}_{rq} - \omega_r T_r \bar{\psi}_{rd}) \quad (14)$$

The rotor speed is obtained from the adaptation mechanism as follow:

$$\hat{\omega}_{re} = \left(k_p + \frac{k_i}{p} \right) (\bar{\psi}_{rq} \hat{\psi}_{rd} - \bar{\psi}_{rd} \hat{\psi}_{rq}) \quad (15)$$

3.2. Back-EMF-based MRAS (Reactive-Power-based)

The model expression is given as follows. The reference model is given by:

$$e_d = u_{sd} - R_s \hat{i}_{sd} - L'_s \hat{i}'_{sd} \quad (16)$$

$$e_d = u_{sq} - R_s \hat{i}_{sq} - L'_s \hat{i}'_{sq} \quad (17)$$

The adjustable model is given by:

$$e_d = \frac{L_m}{L_r} \frac{L_m \hat{i}_{sd} - \hat{\psi}_{rd} - \omega_r T_r \hat{\psi}_{rq}}{T_r} \quad (18)$$

$$e_d = \frac{L_m}{L_r} \frac{L_m \hat{i}_{sd} - \hat{\psi}_{rd} - \omega_r T_r \hat{\psi}_{rq}}{T_r} \quad (19)$$

The rotor speed is obtained from the estimator as follow:

$$\hat{\omega}_{re} = K_p (\hat{e}_{\beta s} \tilde{e}_{\alpha s} - \hat{e}_{\alpha s} \tilde{e}_{\beta s}) + K_i \int (\hat{e}_{\beta s} \tilde{e}_{\alpha s} - \hat{e}_{\alpha s} \tilde{e}_{\beta s}) dt, \quad (20)$$

where K_p and K_i are the proportional and integral gain constants respectively [3].

The use of booster module Fig. 3 eliminated the effect of tuning in the adaptive mechanism. The error between the reference and adaptive outputs, along with the reference speed (N_{ref}) is passed to drive the booster block. The initial condition of both signals was kept at zero. The rate limiter restricts the change of the signal passed to it by limiting the slope. The output of the rate limiter is calculated as follows:

$$O_{i/p}(i) = \nabla t \cdot \gamma + N(t-1), \quad (21)$$

$$O_{i/p}(i) = \nabla t \cdot \sigma + N(t-1) \quad (22)$$

$$O_{i/p}(i) = N(i) \quad (23)$$

The upper limit is called the rising slew parameter (δ) and the lower limit is the falling slew parameter (γ). N refers to the input to the rate limiter. The output is passed to a Zero Order Hold (ZOH) to generate continuous time input by holding each sample value constant over one sample period. The ZOH also acts as a hypothetical filter that gives a piece-wise signal as is demonstrated by equation (24)

$$O_{ZOH/p}(t) = \sum_{n=-\infty}^{\infty} N_{in}(n) \cdot \text{rect}\left(\frac{t-nT}{T} - \frac{1}{2}\right) \quad (24)$$

Finally, the estimated speed is calculated as:
Estimated Speed (ω_{est})

$$= \omega_{ref}(i) - \omega_{booster}(i) \quad (25)$$

$\omega_{booster}$ is the speed error detected in the booster module.

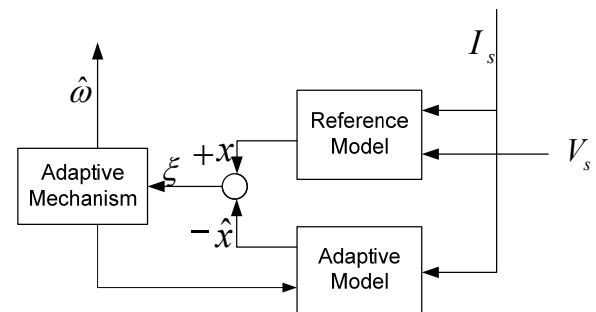


Fig. 2. Configuration of the conventional MRAS.

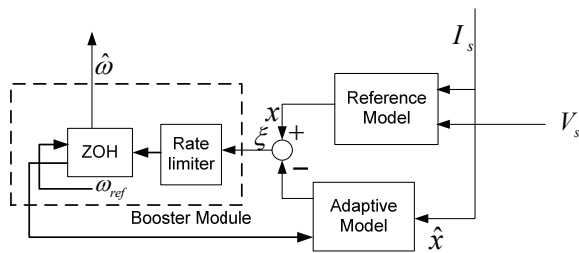


Fig. 3. Configuration of the Booster module MRAS.

4. Simulation Result and Analysis

Simulation was performed to verify the dynamic behavior and operational stability of the drives in responds to back-EMF based MRAS with substituted booster module for adaptive mechanism, using the MATLAB/Simulink. The induction motor used for the implementation of the proposed algorithm has the rated values $P_N = 2.2$ kW, $f_N = 50$ Hz, $V_N = 220$ V, $p=2$ pole pairs, and parameters $R_s=0.877$ Ω , $R_r=1.4752$ Ω , $L_s = L_r = 1.4752$ H, $L_m = 0.8428$ H, rated speed =1750 rpm. The measured results are shown in Fig (4-7), the adaptation gain constants (K_p and K_i) tuning difficulty were able to be avoided. This was achieved by passing output of the reference and adaptive model blocks to drive the booster module that minimized the estimated speed error to nearly zero, it acts as filter. Referring to equation (19), it can be seen that at every change in the reference speed, the values of proportional and integral gains (K_p/K_i) has to be continually changing and do not yield in convergence in the speed and fluxes. The adoption of the booster module in place of the gains yields very good performances as shown by the simulation result.

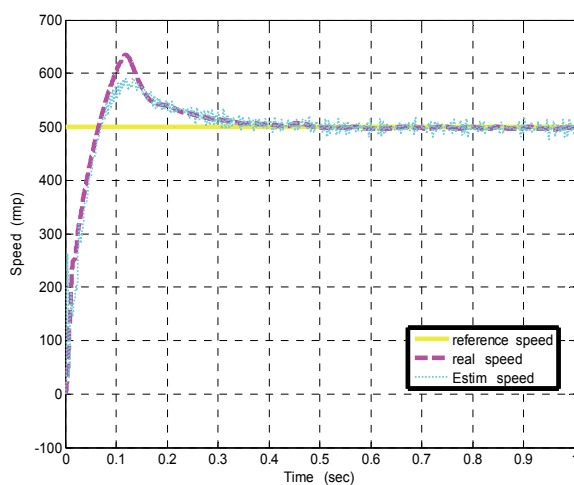


Fig. 4. Real, Estimated speed at reference speed of 500 rpm.

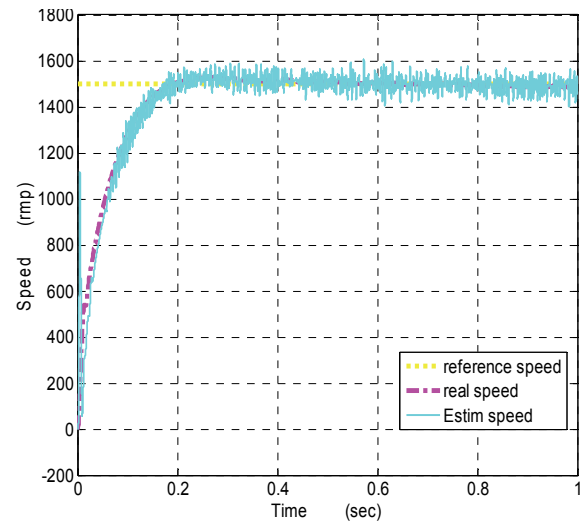


Fig. 5. Real, Estimated speed at reference speed of 1500 rpm.

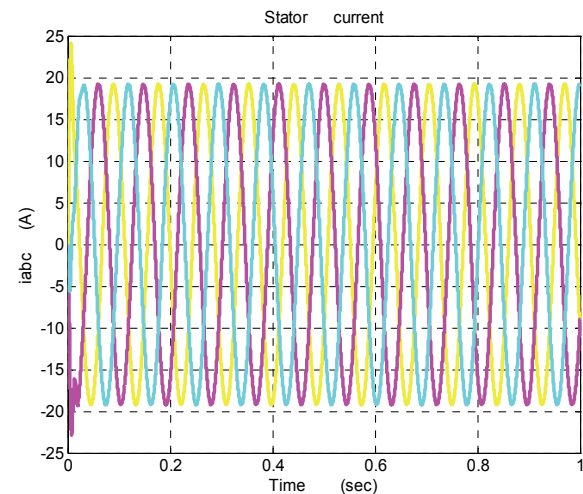


Fig. 6. Instantaneous three phase Stator currents.

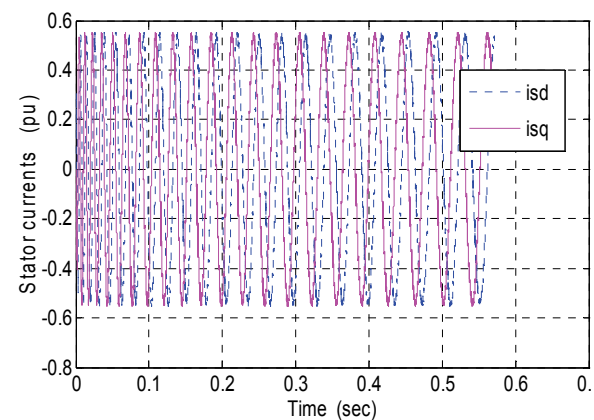


Fig. 7. Stator current in two coordinate axis (dq).

5. Experimentation Results

The proposed control schemes were implemented on a low cost Texas instruments' DSP (TMS320F2808) based PWM inverter system, to regulate the motor speed and current when running on load. The control intervals of the adaptive observation system are set at 100 μ s and the control

intervals of the speed control loop are set at 5 ms. In this paper' the integration of the observer was transferred to the "booster module" with the initial value setting to zero. The DSP performs the calculations required for the speed estimator and the flux observer, the sampling period is 10 μ s, and the test results are showed in the Fig. 8 and 9.

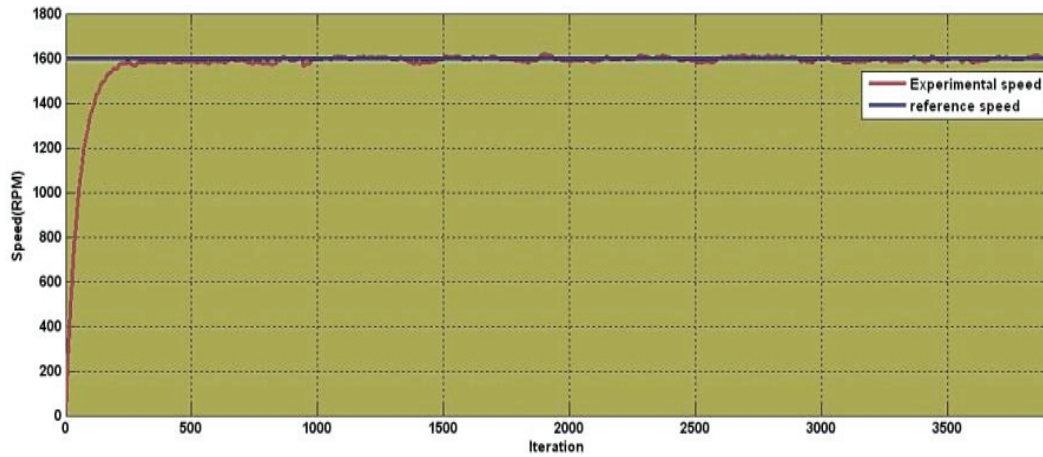


Fig. 8. Experimental and reference speed at 1600 rpm.

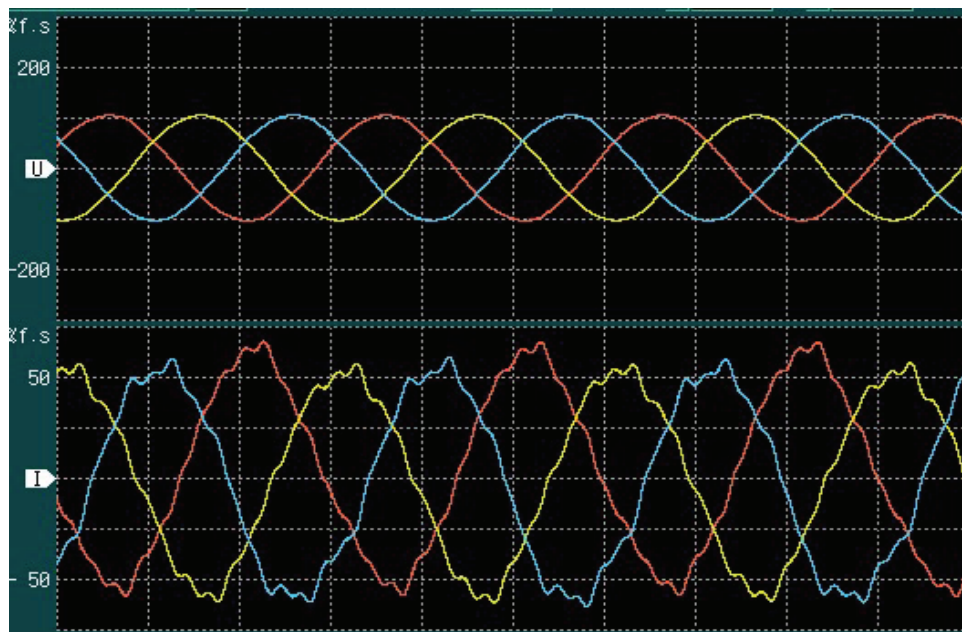


Fig. 9. Instantaneous three phase Stator Voltages (Volt) & currents (Ampere).

6. Conclusion

The concept of speed estimation based on Booster module MRAS, which uses the back-EMF-based MRAS (reactive-power-based), the estimator has performed very well in the wide range of speed references in the sensor-less vector control drives system. The estimator works in a stable way even for relatively big parameter variation and the stability points were detected. The drive system works well

for low speed reference with load torque, with limited error of about ± 45 rpm. The analysis confirmed very good dynamic responds and robustness of the Booster module for adaptive mechanism.

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