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Experimental Results of Sensorless Rotor Field Oriented Control Using MRAS

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***Abstract*—This work deals with design and implementation of sensorless rotor field oriented control using model reference adaptive system (MRAS) of induction motor (IM) drives. SVPWM, using an injected Zero-Sequence Signal (ZSS), is used for controlling the motor. Proportional Integral Controllers with antiwindup are designed. A 3Kw, 3-phase, 50Hz, 1420rpm, induction motor and a dSPACE DS1104 hardware/software are used to carry out the control application. The experimental results show the effectiveness and the limitation of the control method.**

Keywords—*Sensorless, Rotor Field Oriented Control, MRAS, Speed Observer, Induction Motor*

I. INTRODUCTION

The induction motor (IM) is the workhorse of industry due to its simple design, rugged construction and lower in cost and maintenance [1-3]. Thanks to the progress in power electronics, microelectronics and sophisticated control methods, the IM drives are replacing DC motor drives. Indirect field oriented control (IFOC) method is widely used for IM drives. In IFOC a speed sensor is required for good operation. The speed sensor increase the system cost, decrease the system reliability and require special attention to noise. In some applications, such as hostile environment, it's difficult to install a speed sensor in the motor shaft. Therefore the elimination of the speed sensor becomes a challenged topic [1-3]. Multiple sensorless IFOC methods have been proposed using software sensor instead of hardware speed sensor. Sensorless speed control based on Model Reference Adaptive System (MRAS) is one of the most popular techniques [1-7].

This work deals with design and implementation of sensorless rotor field oriented control using model reference adaptive system (MRAS) of induction motor (IM) drives. SVPWM [4-9], using an injected Zero-Sequence Signal (ZSS), is used for controlling the motor. Proportional Integral Controllers with antiwindup are designed. A 3Kw, 3-phase, 50Hz, 1420rpm, induction motor and a dSPACE DS1104 hardware/software are used to carry out the control application. The experimental results show the effectiveness and the limitation of the control method.

II. MATERIALS AND METHODS

The experimental testing ground (see Fig. 1.) contains:

- An experimental platform using a 3 kW three phase squirrel cage induction motor fed by a SEMIKRON IGBT PWM VSI. The load torque is controlled by a magnetic powder breaker (FP3),
- A personal computer with MATLAB/Sirnulink software to design/simulate induction machine control,
- A dSPACE DS1104 DSP-board [doc ds1104] and ControlDesk software [doc dspace] used for real time control of the induction motor drive,
- An interface board to adapt control signals to the IGBT drivers and to protect power modules using drivers' error signal
- An interface board for signal conditioning for current and voltage LEM transducers as well as a speed and torque sensors,

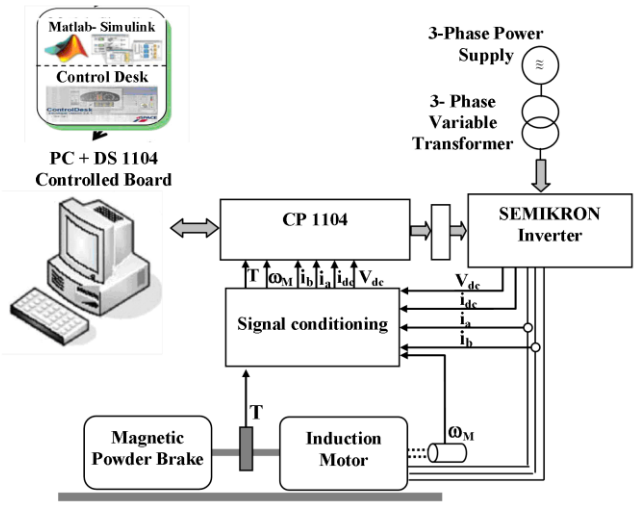

Fig. 1. Block diagram of the laboratory hardware apparatus.

Fig. 2 shows the structure of the sensorless Indirect Rotor Field Oriented (IRFO) Control system of induction motor with MRAS speed estimator.

Two phase currents are acquired by LEM LA25-P Hall sensors. The DC-link voltage V_{dc} is acquired by LEM LV25-P Hall sensors.

Prior to each operation, DC-offsets are measured and must be eliminated.

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The block ''duty_cycle'' generates the phase duty cycles using the hybrid modulator for generating the different injected Zero-Sequence Signal (ZSS) [8-13]. There is a large number of ZSS. For example the use of μ=0 and μ=1 results in DPWMMIN (Discontinus PWMMIN) and DPWMMAX respectively. The use of μ=0.5 results in the Space Vector PWM (SVPWM) which is, in term of harmonic distortion factor, superior to all other methods [13]. Detail of ''duty_cycle'' is shown in Fig. 3.

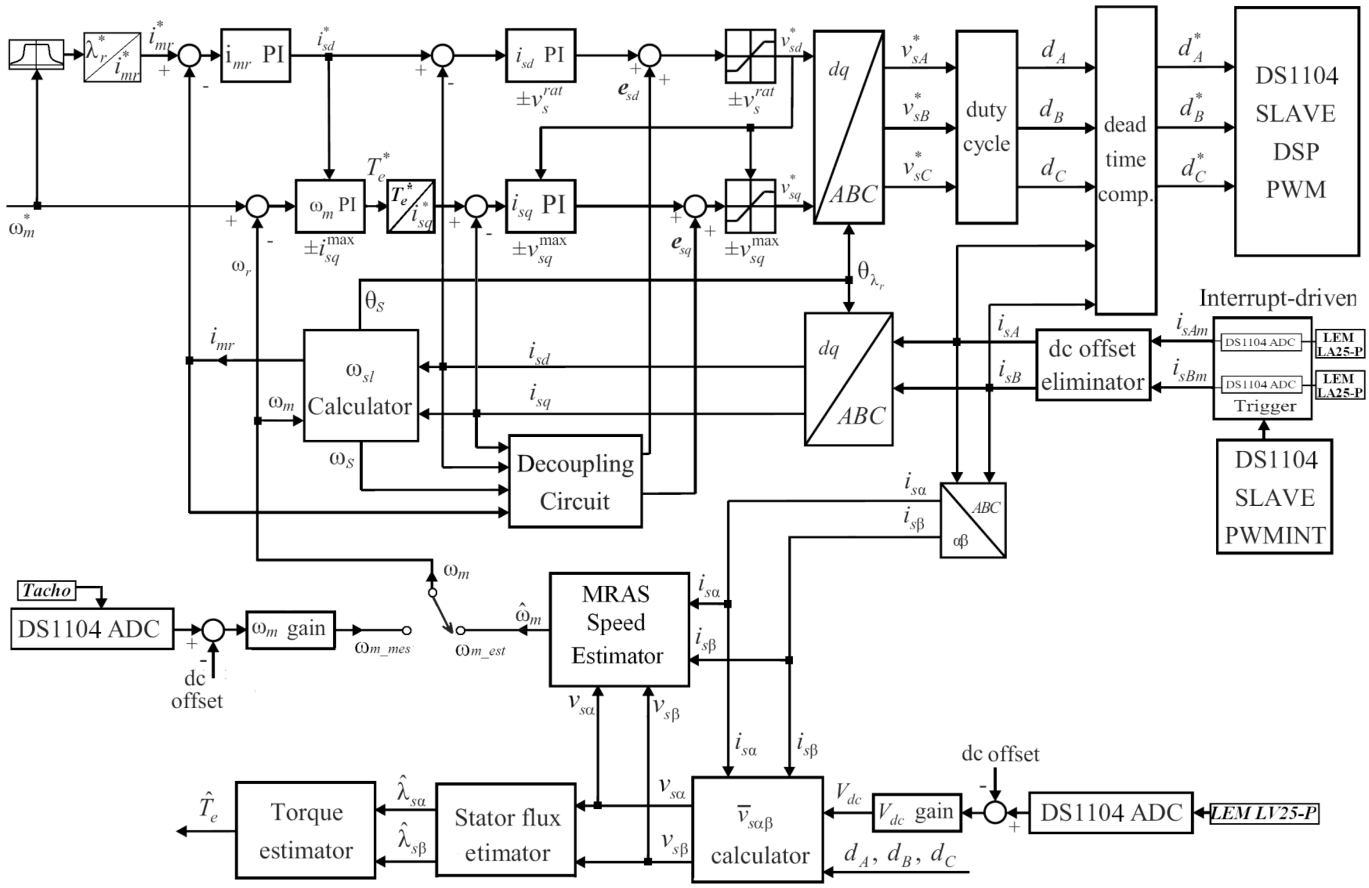

Fig. 2. IRFO control system block diagram with MRAS speed estimator.

The four PI with antiwindup controllers of Fig. 2 are designed using pole placement method [14].

The dead time compensation is implemented in the block ''dead time comp.'' The duty-cycles are adjusted as follows:

$$
\begin{aligned}
d_A^* &= d_A + \frac{T_d}{T_{pwm}} sign(i_A) \\
d_B^* &= d_B + \frac{T_d}{T_{pwm}} sign(i_B) \; . \\
d_C^* &= d_C + \frac{T_d}{T_{pwm}} sign(i_C)
\end{aligned}
\qquad (1)
$$

The block ''MRAS speed estimator'' uses the rotor-flux MRAS structure which is the best known and the widely referenced in literature [1-7]. MRAS is based on Popov's criterion for hyperstability [5], [15]. Detail of ''MRAS speed estimator'' is shown in Fig. 4. Two models are used:

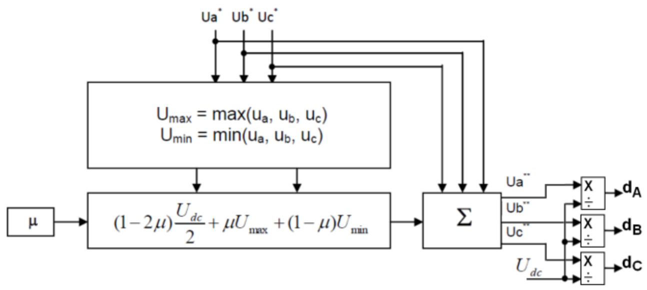

Fig. 3. Block diagram of the hybrid modulator generating PWM signals with injected Zero-Sequence Signal (ZSS).

1. the reference model (2) which is the voltage model:

$$
\begin{aligned}
p\hat{\lambda}_{\alpha rV} &= \frac{L_r}{L_m}(v_{\alpha s} - (R_s + \sigma L_s) i_{\alpha s}) \\
p\hat{\lambda}_{\beta rV} &= \frac{L_r}{L_m}(v_{\beta s} - (R_s + \sigma L_s) i_{\beta s})
\end{aligned}
\; . \qquad (2)
$$

2. the adjustable model (3) which is the current model:

$$\begin{aligned} p\hat{\lambda}_{\alpha rI} &= \frac{L_m}{T_r} i_{\alpha s} - \frac{1}{T_r}\hat{\lambda}_{\alpha rI} - \hat{\omega}_m \hat{\lambda}_{\beta rI} \\ p\hat{\lambda}_{\beta rI} &= \frac{L_m}{T_r} i_{\beta s} - \frac{1}{T_r}\hat{\lambda}_{\beta rI} + \hat{\omega}_m \hat{\lambda}_{\alpha rI} \end{aligned} \quad (3)$$

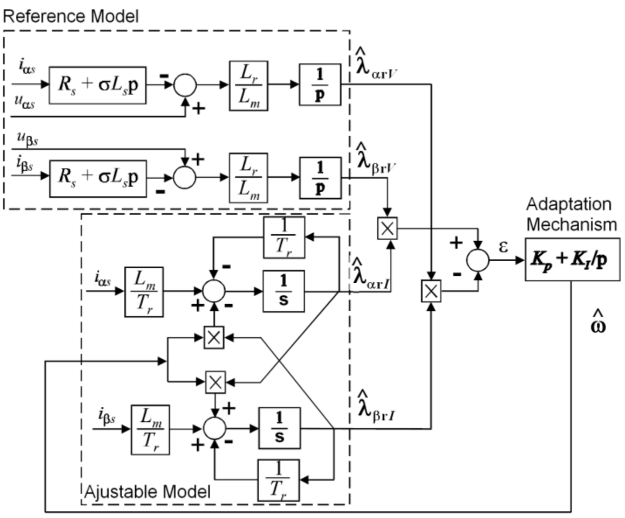

Fig. 4. Block diagram of MRAS speed estimation.

Symbol p stands for d/dt, R_s is the stator resistance, R_r is the rotor resistance, L_s is the stator inductance, L_m is the magnetizing inductance T_r is the rotor time constant, $\sigma=1-L_m^2/(L_sL_r)$ and L_r is the rotor inductance. Voltage, current and flux are denoted by v, i and λ, respectively and handled on the stator coordinate system (α,β).

The current model (adjustable model) involves the rotor speed whereas the voltage model (reference model) does not. The outputs of the two models are compared. The speed is estimated throw an adaptive mechanism:

$$\hat{\omega}_m = (K_P + \frac{K_I}{p})\varepsilon . \quad (4)$$

where:

$$\varepsilon = \hat{\lambda}_{\alpha rI}\hat{\lambda}_{\beta rV} - \hat{\lambda}_{\alpha rV}\hat{\lambda}_{\beta rI} . \quad (5)$$

In [7] K_P and K_I are expressed by:

$$\begin{cases} K_P = (2\xi\omega_c - 1/T_r)/|\lambda_r|^2 \\ K_I = \omega_c^2/|\lambda_r|^2 \end{cases} . \quad (6)$$

where: ξ and ω_c are the damping factor and the natural angular frequency, respectively.

In practice, the initial value and drift problems of the pure integrator, in the voltage model (reference model), are avoided by the use of a low pass filter instead of the pure integrator, which is equivalent to a voltage model and a high-pass filter (HPF). The same HPF is added to the current model as shown by figure 5 [7]. T is a time constant of HPF.

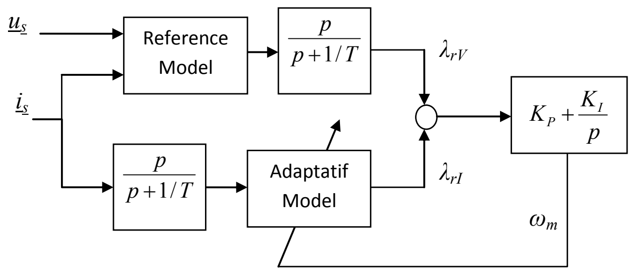

Fig. 5. Block diagram of the experimental MRAS speed estimator.

III. RESULTS

In Fig. 6, Fig. 7 and Fig. 8, screen dumps of experimental speed tracking of sensorless IRFO using MRAS.

Experimental results of reversal speed test with 4Nm load are shown in Fig. 9.

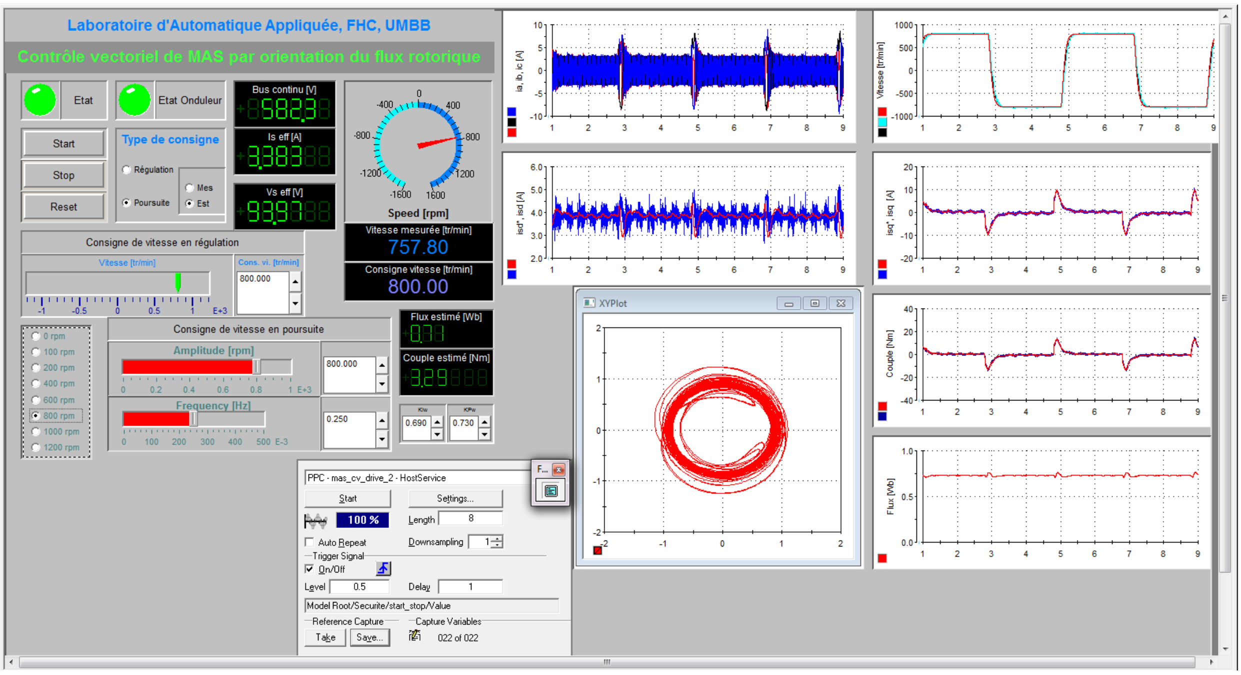

Fig. 6. The ControlDesk panel for sensorless IRFO using MRAS: tracking response ($\omega_m^* \in$[-800rpm 800rpm]).

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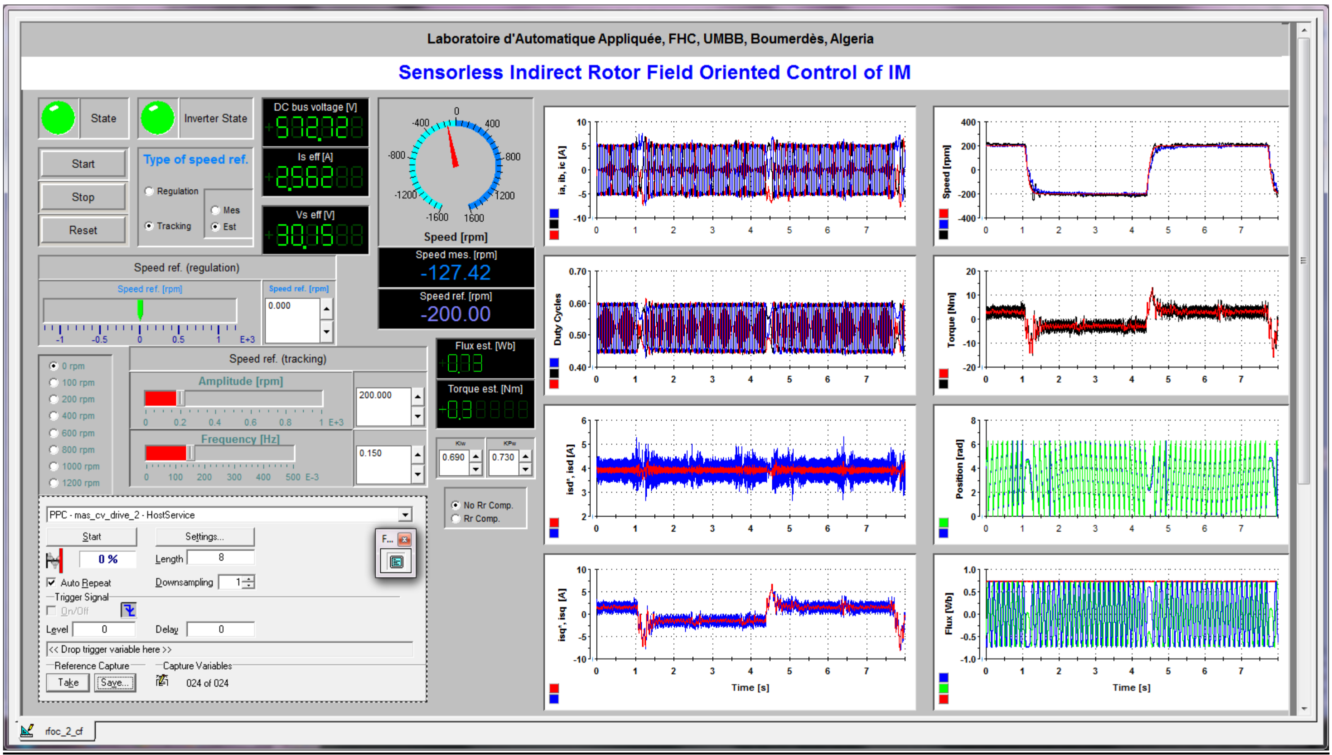

Fig. 7. The ControlDesk panel for sensorless IRFO using MRAS: tracking response ($\omega_m^* \in$[-200rpm 200rpm]).

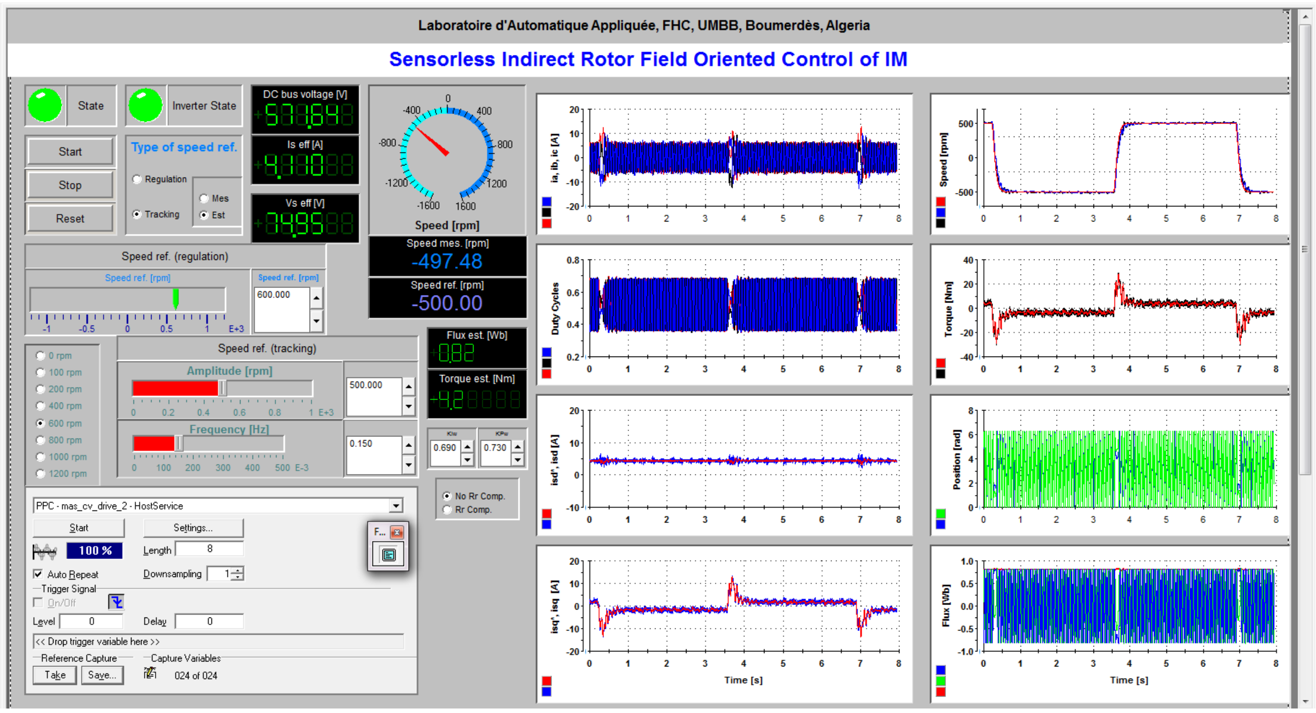

Fig. 8. The ControlDesk panel for sensorless IRFO using MRAS: tracking response ($\omega_m^* \in$[-500rpm 500rpm]).

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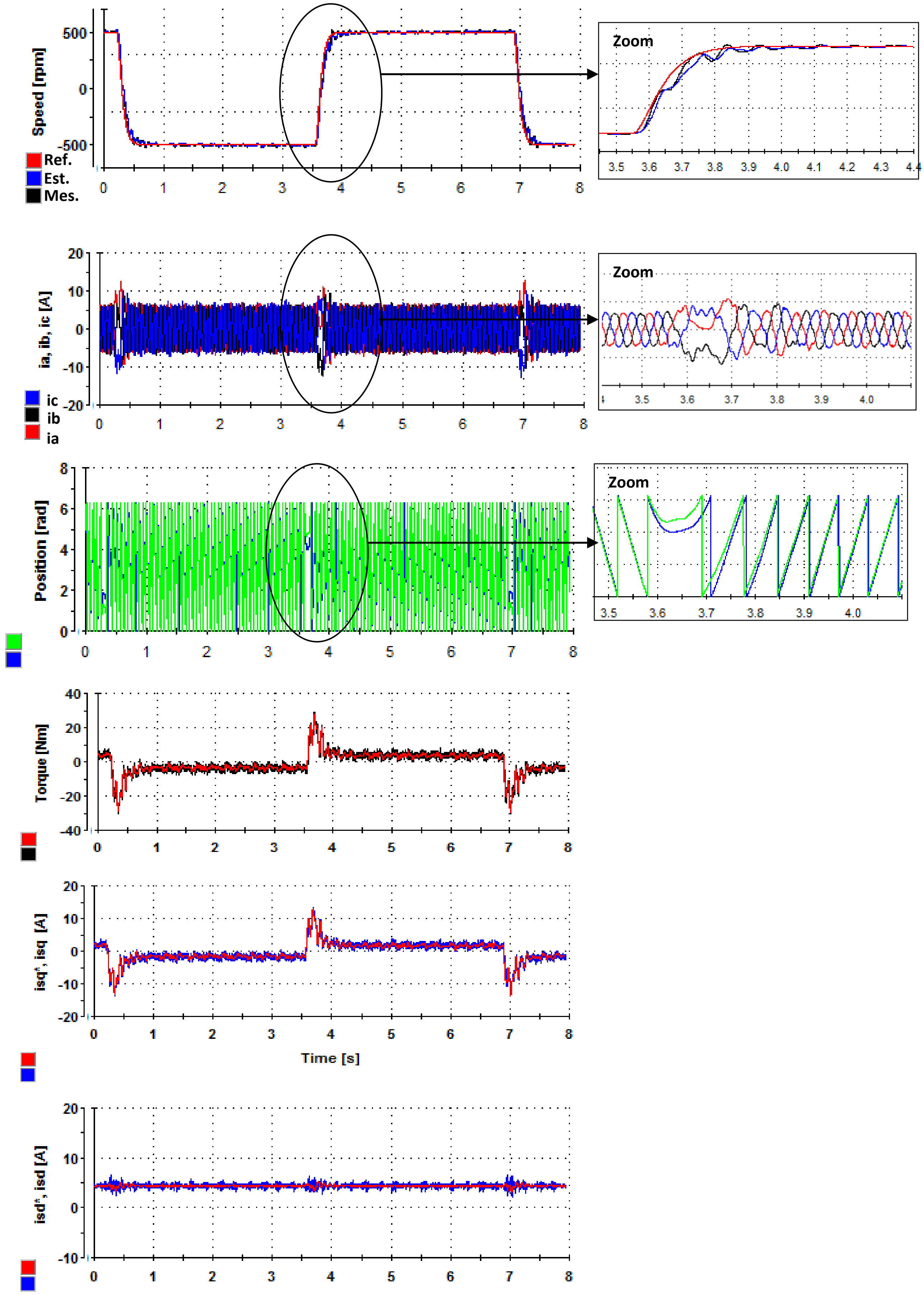

Fig. 9. Experimental results, reversal speed test with 4Nm load.

IV. CONCLUSIONS

In this paper a design and implementation of sensorless rotor field oriented control using model reference adaptive system (MRAS) of induction motor (IM) drives are described. SVPWM, using an injected Zero-Sequence Signal (ZSS), is used for controlling the motor. Proportional Integral Controllers with antiwindup are designed. A 3Kw, 3-phase, 50Hz, 1420rpm, induction motor and a dSPACE DS1104 hardware/software are used to carry out the control application. The experiments illustrate the successful the effectiveness of the control method in the high speed range. Poor performances were observed for low speed range.

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