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MRAS-Super Twisting sliding Mode Observer for Speed Sensorless Vector Control of Induction Motor drive

***Abstract**. This article proposes a high-order super-twisting sliding mode observer associated to MRAS method applied to an induction motor fed by a power voltage source without speed sensor. Based on the vector control principle, high-order super-twisting sliding mode observer in speed loop and flux loop are designed respectively. The super-twisting sliding mode observer is utilised to improve the speed estimation and robustness of motor control systems. Meanwhile, high-order sliding modes are adopted to eliminate the chattering phenomenon at variable state observation. We also present the mechanism of adaptive super-twisting speed and rotor flux observers with the only assumption that from stator voltages and currents are measurable. The objective is to improve the sensorless speed control, the rotor flux control under load torque disturbances, inversion of rotor speed and zero speed operation. The simulation results prove clearly a good robustness against load torque disturbances, the estimated fluxes and the rotor speed converge to their real values. Our study is close to reality; all the simulations are based on real models simulated within the Matlab SymPower System environment in continuous time. To analyze our approach, a prototype is modeled, simulated and can be realized in an experimental test setup.*

***Streszczenie.** W artykule zaproponowano obserwator super-skrętnego poślizgu wysokiego rzędu, powiązany z metodą MRAS, zastosowany do silnika indukcyjnego zasilanego ze źródła napięcia bez czujnika prędkości. W oparciu o zasadę sterowania wektorowego zaprojektowano odpowiednio obserwator przesuwu super-skrętnego wysokiego rzędu w pętli prędkości i pętli strumienia. Obserwator trybu przesuwu super-skręcającego jest wykorzystywany do poprawy szacowania prędkości i odporności systemów sterowania silnikiem. Przedstawiamy również mechanizm adaptacyjnych obserwatorów super-skręcania i strumienia wirnika z jedynym założeniem, że z poziomu stojana mierzalne są napięcia i prądy. Celem jest poprawa bezczujnikowej kontroli prędkości, sterowania strumieniem wirnika pod wpływem zakłóceń momentu obciążenia, inwersji prędkości wirnika i pracy przy zerowej prędkości. Wyniki symulacji wyraźnie dowodzą dobrej odporności na zakłócenia momentu obciążenia, oszacowane strumienie i prędkość wirnika są zbieżne z ich rzeczywistymi wartościami. Nasze badanie jest bliskie rzeczywistości; wszystkie symulacje oparte są na rzeczywistych modelach symulowanych w środowisku Matlab SymPower System w czasie ciągłym. Aby przeanalizować nasze podejście, modeluje się prototyp, przeprowadza symulację i może zostać zrealizowany w eksperymentalnej konfiguracji testowej. (**Super-skrętny obserwator ślizgowy MRAS do wektorowego sterowania silnikiem indukcyjnym**)*

Keywords: Induction motor drives, Super Twisting Sliding Mode-MRAS Observer, speed estimation, Sensorless, Vector Control.
Słowa kluczowe: Napędy silników indukcyjnych, MRAS-Obserwator trybu przesuwnego Super Twisting, sterowanie wektorowe.

Introduction

The Induction Motor (IM) plays an important role in industrial applications, due to their reliability, low maintenance, robustness and low cost [1]. The model of IM is nonlinear, multi-variable and greatly coupled have a fairly complex control. The progress in non-linear control and the considerable technological advances, both in the field of power electronics and in microelectronics, made possible the implementation of high performance control of induction motor, making it a must in the areas of variable speed and fast torque control. This motor is a serious candidate for non-linear control [1, 2].

Several methods have been proposed to estimate speed and flux of induction motor such as: Luenberger observer and Kalman filter, high gain and adaptive observers, neural networks and signal injection, and sliding mode observer etc [3]. Compared with the other methods, sliding mode techniques has attractive advantage of robustness to disturbances and insensitive to parameter variation when the sliding mode is reached. However, the chattering behavior, that is inherent in standard sliding mode techniques, is often an obstacle for practical applications if neglected. Higher order sliding mode is one of the solutions which does not compromise robustness and avoids filtering estimation considered by other methods.

An improved rotor flux based model reference adaptive system (MRAS) scheme with a parallel rotor speed and stator resistance estimation algorithm is considered. Both the differences in instantaneous phase and amplitudes are used for speed estimation and stator resistance identification. In addition, the mismatch of rotor resistance introduces errors to the estimated speed in wide speed range operation [4]. The rotor resistance is more difficult to be identified online since the parallel estimation of speed and rotor resistance is possible only if rotor flux varies, which is not the case in steady state. Since the rotor inductance can be treated as a constant, the rotor time constant identification is equivalent to the identification. So far numerous online parameter estimation techniques have been proposed on the basis of existing speed estimation schemes, which are able to improve dynamic characteristics and noise immunity, as well as insensitivity to parameter variations. In this scheme, both rotor speed and rotor time constant can be estimated by a sliding function based on a second-order system. Extended kalman filters (EKF) based estimation scheme has significantly increased the accuracy of the estimation of the estimation of the stator and rotor resistances However, they have no specific tuning criteria. Sliding mode observers are recognized for their robustness against parameter variations, yet they suffer from chattering behavior at the same. By using auxiliary sliding mode surface chattering behavior can be reduced [5, 6].

The rest of the paper is organized as follows: physical modelling of induction motor and the control vector strategy of the study system with their equations model are shown in section 2. The modeling of the AC-DC inverter is set in section 3. In section 4, the standard MRAS observer system configuration is defined and described. Section 5 described the proposed sensorless vector control strategy of induction motor super twisting sliding mode based MRAS observer. The simulations results of the studied are presented in section 6. Finally, conclusions are drawn in section 7.

Dynamic Model of Induction Motor and Vector Control Strategy

The induction motor mathematical model in d-q coordinates established in a rotor flux oriented reference frame can be written as [7]:

(1) $$\begin{cases} v_{sd} = R_s i_{sd} + \dfrac{d\psi_{sd}}{dt} - \omega_e \psi_{sq} \\ v_{sq} = R_s i_{sq} + \dfrac{d\psi_{sq}}{dt} + \omega_e \psi_{sd} \\ 0 = R_r i_{rd} + \dfrac{d\psi_{rd}}{dt} - \omega_{sl} \psi_{rq} \\ 0 = R_r i_{rq} + \dfrac{d\psi_{rq}}{dt} + \omega_{sl} \psi_{rd} \end{cases}$$

where the stator and rotor flux linkages are given by:

(2) $$\begin{cases} \psi_{sd} = L_s i_{sd} + L_m i_{rd} \\ \psi_{sq} = L_s i_{sq} + L_m i_{rq} \\ \psi_{rd} = L_r i_{rd} + L_m i_{sd} \\ \psi_{rq} = L_r i_{rq} + L_m i_{sq} \end{cases}$$

The electromagnetic torque and the rotor speed are given by:

(3) $$T_{em} = \frac{3}{2} p_p \frac{L_m}{JL_r} (\psi_{rd} i_{sq} - \psi_{rq} i_{sd})$$

(4) $$\frac{d\omega_r}{dt} = \frac{p_p}{J} T_{em} - \frac{f}{J} \omega_r - \frac{p_p}{J} T_l$$

Under the rotor flux orientation conditions the rotor flux is aligned on the d-axis of the d-q rotor flux oriented frame and the rotor flux equations can be written as [8, 9]:

(5) $$\psi_{rd} = 0$$

(6) $$\psi_{rq} = L_m i_{sd}$$

The slip frequency can be calculated from the reference values of the stator current components represented in the rotor flux oriented reference frame as follow [10]:

(7) $$\omega_{sl} = \omega_e - \omega_r = \frac{1}{T_r} \frac{i_{sq}^*}{i_{sd}^*}$$

and the electromagnetic torque equation can be written as:

(8) $$T_{em} = \frac{3}{2} p_p \frac{L_m}{L_r} \psi_r i_{sq} = K_t i_{sq}$$

where K_t is the torque constant.

Model Reference Adaptive System (MRAS)

The classical rotor flux MRAS speed observer structure consists of a reference model, an adaptive model, and an adaptation scheme which generates the estimated speed. A lot of different MRAS-type estimators have been developed, based on simulators (mathematical models) of different state variables of the induction motor: MRASF — based on the simulators of the rotor flux vector, MRASEMF — based on the simulators of the electromotive force, MRASRP — based on the simulators of the reactive power... in this paperThe reference model, expressed as a voltage model (VM), represents the stator equation. It generates the reference value of the rotor flux components in the stationary reference frame from the stator voltage and monitored current components. The reference rotor flux components obtained from the reference model are given by [13, 14]:

(9) $$\begin{cases} \dfrac{d\psi_{rd}}{dt} = \dfrac{L_r}{L_m}\left(v_{sd} - R_s i_{sd} - \sigma L_s \dfrac{di_{sd}}{dt} \right) \\ \dfrac{d\psi_{rq}}{dt} = \dfrac{L_m}{L_r}\left(v_{sq} - R_s i_{sq} - \sigma L_s \dfrac{di_{sq}}{dt} \right) \end{cases}$$

The adaptive model, usually represented by the current model (CM), describes the rotor equation where the rotor flux components are expressed in terms of stator current components and the rotor speed. The rotor flux components obtained from the adaptive model are given by:

(10) $$\begin{cases} T_r \dfrac{d\hat{\psi}_{rd}}{dt} = L_m i_{sd} - \hat{\psi}_{rd} - \hat{\omega}_r T_r \hat{\psi}_{rq} \\ T_r \dfrac{d\hat{\psi}_{rq}}{dt} = L_m i_{sq} - \hat{\psi}_{rq} + \hat{\omega}_r T_r \hat{\psi}_{rd} \end{cases}$$

The MRAS-based schemes described in the previous section contain a reference model and an adaptive model. However, greater accuracy and robustness can be achieved if the mathematical model is partially replaced super twisting sliding mode observer.

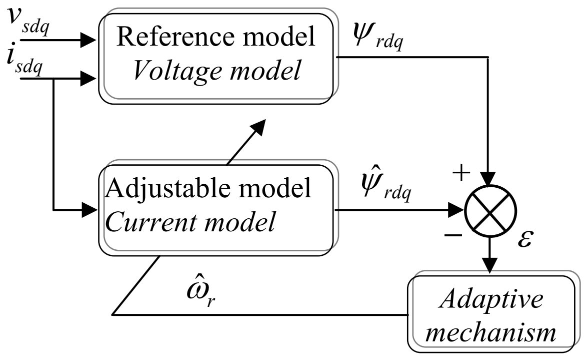

Fig. 1. Rotor speed estimation based on MRAS structure

A standard rotor flux MRAS observer is indicated in Fig 1. It is made up of an adjustable model, reference model and adaptive mechanism.

To obtain a stable nonlinear feedback system, a speed control signal PI regulator is used in the adaptation mechanism to generate the estimated speed. The speed control signal and the estimated speed expressions can be expressed by the following equation:

(11) $$\varepsilon_{\omega} = \psi_{rq} \hat{\psi}_{rd} - \psi_{rd} \hat{\psi}_{rq}$$

and:

(12) $$\hat{\omega} = \left\{ K_p + \frac{K_i}{s} \right\} \varepsilon_{\omega}$$

Where: k_p and k_i are proportional and integral constants

Super twisting sliding mode observer

The structure of the super twisting sliding mode observer does not require knowledge speed and motor parameters, unlike other observers [15]. This advantage allows the super twisting sliding mode observer to provide a good estimate of the rotor flux and the stator currents even under variation of these quantities. In addition, the use of super twisting sliding mode methods for the design of the observer ensures respectively robustness with respect to various disturbances, and good dynamic performance over the entire speed range.

The equations of the induction motor in a reference connected to the stator (α β) are given by the following equation:

(13)

$$\begin{cases} pi_{s\alpha} = -\left(k_1k_2 + R_sk_3\right)i_{s\alpha} + k_2\left(\dfrac{\psi_{r\alpha}}{T_r} + \omega_r\psi_{r\beta}\right) + k_3v_{s\alpha} \\ pi_{s\beta} = -\left(k_1k_2 + R_sk_3\right)i_{s\beta} + k_2\left(\dfrac{\psi_{r\beta}}{T_r} - \omega_r\psi_{r\alpha}\right) + k_3v_{s\beta} \\ p\psi_{s\alpha} = k_1i_{s\alpha} - \dfrac{\psi_{r\alpha}}{T_r} - \omega_r\psi_{r\beta} \\ p\psi_{s\beta} = k_1i_{s\beta} - \dfrac{\psi_{r\beta}}{T_r} + \omega_r\psi_{r\alpha} \end{cases}$$

where:

$$k_1 = \frac{L_m}{T_r},\ k_2 = \frac{L_m}{\sigma L_sL_r},\ k_3 = \frac{1}{\sigma L_s},\ \sigma = 1 - \frac{L_m^2}{L_sL_r}$$

The stability of the STSM observer has been proven by the Lyapunov method. We can write the STSM observer equation in the following simplest form:

(14)

$$\begin{cases} p\hat{x}_1 = f\left(\hat{x}_2\right) + \lambda\sqrt{\left|x_1 - \hat{x}_1\right|}.sign\left(x_1 - \hat{x}_1\right) + \rho_1 \\ p\hat{x}_2 = \delta\ sign\left(x_1 - \hat{x}_1\right) + \rho_2 \end{cases}$$

where: x_i denotes the state variables, λ and δ are switching gains, ρ_1 and ρ_2 represents the perturbation terms. According to [1], it is well known that the STSM is robustly stable to perturbations globally bounded by:

$$\rho_1 = 0,\ \left|\rho_2\right| < L$$

For any positive constant *L* when the gains are appropriately selected.

The system (17) can be rewritten as:

$$\begin{cases} pi_{s\alpha} = -R_sk_3i_{s\alpha} - k_2p\psi_{r\alpha} + k_3v_{s\alpha} \\ pi_{s\beta} = -R_sk_3i_{s\beta} - k_2p\psi_{r\beta} + k_3v_{s\beta} \\ p\psi_{s\alpha} = k_1i_{s\alpha} - \dfrac{\psi_{r\alpha}}{T_r} - \omega_r\psi_{r\beta} \\ p\psi_{s\beta} = k_1i_{s\beta} - \dfrac{\psi_{r\beta}}{T_r} + \omega_r\psi_{r\alpha} \end{cases} \quad (15)$$

We set the following change of variable:

$$\begin{cases} x_1 = i_{s\alpha} \\ x_2 = i_{s\beta} \\ x_3 = -p\psi_{r\alpha} \\ x_4 = -p\psi_{r\beta} \end{cases}, \quad (16)$$

We replace (13) in (16), that gives:

$$\begin{cases} px_1 = -R_sk_3x_1 - k_2x_3 + k_3v_{s\alpha} \\ px_2 = -R_sk_3x_2 - k_2x_4 + k_3v_{s\beta} \end{cases} \quad (17)$$

By applying the STSM to the induction motor model (13), a current observer can be constructed as [16]:

(18)

$$\begin{cases} p\hat{x}_1 = -R_sk_3\hat{x}_1 + k_2\hat{x}_3 + k_3v_{s\alpha} + \lambda_1\sqrt{\left|e_1\right|}\ sign\left(e_1\right) \\ p\hat{x}_2 = -R_sk_3\hat{x}_3 + k_2\hat{x}_4 + k_3v_{s\beta} + \lambda_2\sqrt{\left|e_2\right|}\ sign\left(e_2\right) \\ p\hat{x}_3 = \lambda_3\ sign\left(e_1\right) \\ p\hat{x}_4 = \lambda_4\ sign\left(e_2\right) \end{cases}$$

where:

$\hat{x}_1$, $\hat{x}_2$, $\hat{x}_3$ and $\hat{x}_4$ are the observations,

λ_1, λ_2, λ_3 and λ_4 are respectively the gains of the primary and auxiliary sliding mode surfaces,

The sign () represents the sign function,

k_2 and k_3 are treated as constants in the observer.

The errors are defined as:

$$\begin{cases} e_1 = x_1 - \hat{x}_1 \\ e_2 = x_2 - \hat{x}_2 \end{cases} \quad (19)$$

According to (15), there exists a simple relationship between the observations $\hat{x}_3$ and $\hat{x}_4$ and the derivatives of rotor flux:

$$p\hat{\psi}_r^x = \begin{bmatrix} -p\hat{\psi}_{r\alpha}^x \\ -p\hat{\psi}_{r\beta}^x \end{bmatrix} = \begin{bmatrix} -\hat{x}_3 \\ -\hat{x}_4 \end{bmatrix} \quad (20)$$

where: $p\hat{\psi}_r^x$ represents the estimated results with the physical significance of derivative of rotor flux.

Speed estimation scheme

Since we obtain the derivatives of rotor flux components, i.e., from the proposed observer, an adaptive mechanism of speed based on these observations is required. The current model of IM can be written as [17]:

$$p\psi_r^x = k_1i_s + \begin{bmatrix} -\dfrac{1}{T_r} & -\omega_r \\ \omega_r & -\dfrac{1}{T_r} \end{bmatrix} p\psi_r \quad (21)$$

In (21), there is the presence of the rotor speed variable. Regarding k_1 and T_r as constants, the observer equation can be constructed as:

$$p\hat{\psi}_r^x = k_1\hat{i}_s + \begin{bmatrix} -\dfrac{1}{T_r} & -\hat{\omega}_r \\ \hat{\omega}_r & -\dfrac{1}{T_r} \end{bmatrix} p\hat{\psi}_r \quad (22)$$

where:

$$i_s = \begin{bmatrix} i_{s\alpha} \\ i_{s\beta} \end{bmatrix},\ \hat{i}_s = \begin{bmatrix} \hat{x}_1 \\ \hat{x}_2 \end{bmatrix},\ \psi_r^i = \begin{bmatrix} \psi_{r\alpha}^i \\ \psi_{r\beta}^i \end{bmatrix},\ \hat{\psi}_r^i = \begin{bmatrix} \hat{\psi}_{r\alpha}^i \\ \hat{\psi}_{r\beta}^i \end{bmatrix}$$

Symbols ψ_r^i and $\hat{\psi}_r^i$ are respectively the actual and estimated rotor flux vectors calculated by the current model. By subtracting (21) from (22), we get:

$$pe_\psi^i = Ae_\psi^i - \Delta\omega_rJ\hat{\psi}_r^i \quad (23)$$

$$A=\begin{bmatrix}-\frac{1}{T_r} & -\omega_r \\ \omega_r & -\frac{1}{T_r}\end{bmatrix},\ J=\begin{bmatrix}0 & -1 \\ 1 & 0\end{bmatrix}$$

Differentiating (23) and simplifying the terms of differential errors, we obtain:

(24) $$p\left(pe_{\psi}^{i}\right)=Ape_{\psi}^{i}-\Delta\omega_r Jp\hat{\psi}_r^{i}$$

(25) $$e_{\psi}^{i}=\begin{bmatrix}e_{\psi\alpha}^{i} \\ e_{\psi\beta}^{i}\end{bmatrix}=\begin{bmatrix}\psi_{r\alpha}^{i}-\hat{\psi}_{r\alpha}^{i} \\ \psi_{r\beta}^{i}-\hat{\psi}_{r\beta}^{i}\end{bmatrix}$$

The stability of the above system has been discussed in [18]. For speed estimation, the output of the reference model is regarded as equal to the actual rotor flux vector, and hence:

(26) $$pe_{\psi}^{i}=\begin{bmatrix}p\psi_{r\alpha}^{i}-p\hat{\psi}_{r\alpha}^{i} \\ p\psi_{r\beta}^{i}-p\hat{\psi}_{r\beta}^{i}\end{bmatrix}=\begin{bmatrix}p\hat{\psi}_{r\alpha}^{x}-p\hat{\psi}_{r\alpha}^{i} \\ p\psi_{r\beta}^{x}-p\hat{\psi}_{r\beta}^{i}\end{bmatrix}$$

Finally, the estimate of the motor rotor speed can be determined by equation (12).

Since the MRAS method is based on the voltage model and flux linkage, the precision influences the accuracy of the speed estimation, which generally involves parameters related to the stator resistance. where:

$$e_{\omega}=\left(pe_{\psi}^{i}\right)^{T}Jp\hat{\psi}_r^{x}$$
$$=\left[p\hat{\psi}_{r\alpha}^{x}-p\hat{\psi}_{r\alpha}^{i}\quad p\hat{\psi}_{r\beta}^{x}-p\hat{\psi}_{r\beta}^{i}\right]\begin{bmatrix}0 & -1 \\ 1 & 0\end{bmatrix}\begin{bmatrix}p\hat{\psi}_{r\alpha}^{i} \\ p\hat{\psi}_{r\beta}^{i}\end{bmatrix}$$
$$=-p\hat{\psi}_{r\alpha}^{x}p\psi_{r\beta}^{i}+p\hat{\psi}_{r\beta}^{i}p\hat{\psi}_{r\alpha}^{i}$$

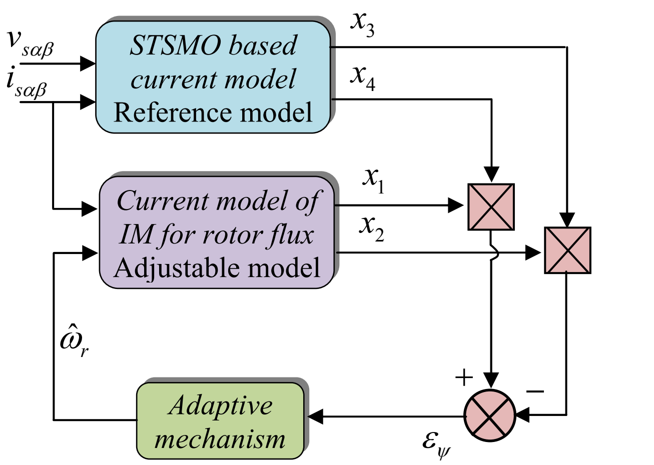

Fig. 3. Classical Model reference adaptive scheme for speed estimation

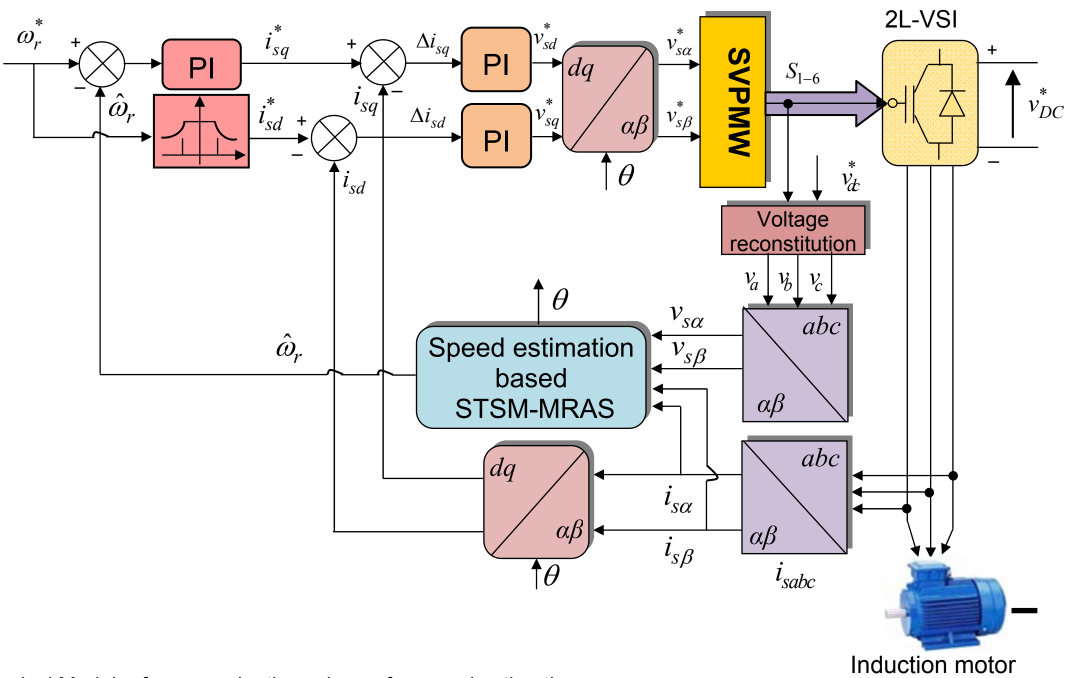

Fig. 4. Classical Model reference adaptive scheme for speed estimation

This influence could be further deteriorated by the changes in resistance during the motor operation. Meanwhile, the pure integrator contained in the voltage model leads to the accumulation of error and zero drift. This will result in a seriously-affected speed estimation precision for the low-speed operating scenario [19].

The overall block diagram of the rotor speed estimation scheme based on STSM-MRAS is illustrated in Fig. 3.

The super twisting sliding-mode with MRAS observer based vector control system of an induction motor is shown in Fig.4. To reduce the harmonic content in inverter output we are proposing SVPWM based two level Voltage source inverter circuit (2L-VSI). In this method, a revolving reference vector is used to provide the reference voltage [20].

The observer is used to estimate the speed and the rotor flux with its inputs including only the stator currents and the voltages measurment of the motor.

Simulation Results and Discussions

Simulations, using MATLAB software package, have been carried out to verify the effectiveness of the proposed scheme. The application of proposed reconstruction technique and estimation of feedback signals is illustrated by a computer simulation. Flux reference is set to its rated value and the DC link voltage is 500 V.

Some simulation results were provided to demonstrate the effectiveness of the proposed observer technique.

Initially, between t = 0 s and t = 0.9 s, the target speed is changed from 0 rad/s to 150 rad/s at 1.5 sec with no load applied. Fig.5 shows the simulation result of a speed at free acceleration using the estimation of speed. Additionally, the real speed is measured and compared. It can be seen that there is a very good accordance between real and estimated speed without any steady state error in this period.

At t = 0.9 second, the load was applied and omitted. Fig. 5. and its zoom shows the speed-sensorless control performance. The estimated speed coincides exactly with the real speed even the load torque application instant. As a result shown, with this variation, the proposed speed-sensorless control algorithm has good performances in this phase. To test the performance of the sensorless drive at very low speed and zero speed without load. Between t = 1.5 s and t = 1.8 seconds, the drive is subjected to speed step down from positive speed to negative speed passing through region zero. The speed control performance is shown in Fig. 5.

We can see that the speed follow perfectly the speed reference. However, it is important to note that the control system demonstrates a good performance even under those variations. We note that performance does not degrade as it approaches the zero speed regions and there is no chattering and oscillation in this phase.

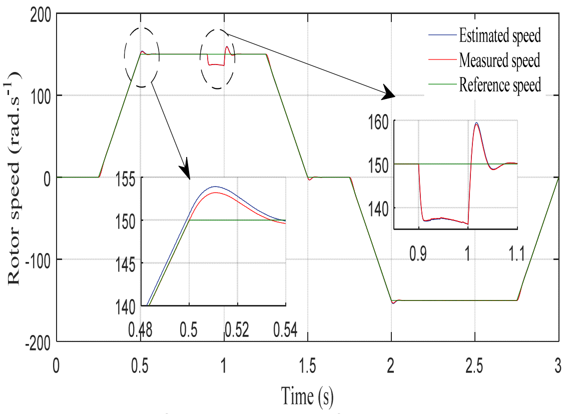

Fig. 5. Response of the system at free acceleration test. The reference, actual and estimated speed.

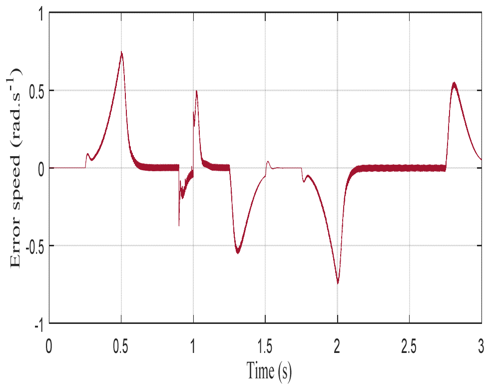

Fig. 6. Speed estimation error between measured speed and estimated speed

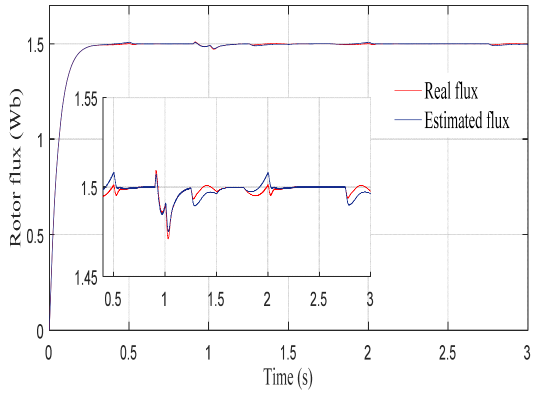

Fig. 7. Estimated and real rotor flux during step change of reference speed

From t=1.8 s at t=3 s, the reference speed is set to zero ras/s then the set point is changed to -150 rad/s at t=2 sec without any load. It is clear that the speed response exhibits good performances at both dynamics regimes. The result clearly shows that the estimated speed follows the actual speed and the error is not significant (see Fig 6).

Fig. 6 shows the error between real and estimated speeds. This figure indicates that the estimated value also tracks its true value very closely in both the forward and reverse directions.

Fig. 7 depicts the trajectories of the rotor flux, Fig. 8 and 9 display the estimated and measured stator currents evolution. It should be noted that the amplitude of the flux ripple is slightly higher. As shown above MRAS observer based super twisting sliding mode work properly and proves the robustness of the proposed speed observer. We can see the insensibility of the control algorithm at free acceleration test.

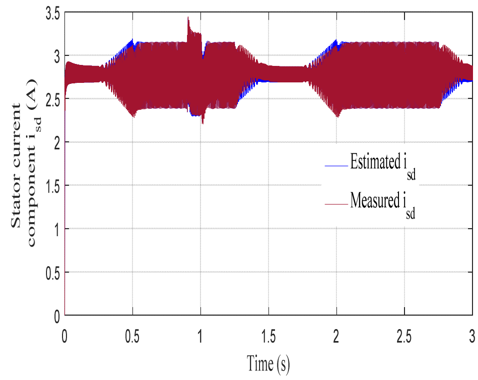

Fig. 8. Estimated stator currents evolution during step change of reference speed

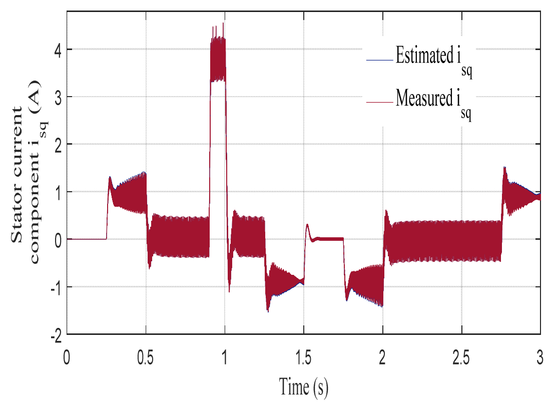

Fig. 9. Estimated stator currents evolution during step change of reference speed

From inspection of Fig. 6, 7, 8 and 9 it is possible to verify the excellent behavior of the proposed algorithm. In fact, the error on the estimation both of the stator currents and of the rotor flux are always very small (<5%, by referring to the actual values).

The real and estimated stator currents and the estimated rotor flux, when the motor is running at high speed with load applied, are given by Fig. 7, 8 and 9.

These figures show that the real and the estimated stator currents, the estimates rotor flux are in close agreement. As the value of rotor flux changed the value of stator current is also changed.

The real and reference current are shown in Fig. 8 and 9. We can see that that the measured currents converge to the reference one quickly, which validates the effectiveness of the system.

These results made the drive remain stable and this condition can be maintained indefinitely.

Excellent tracking performance was obtained no study state error and no overshoot and control performance of the drive is acceptable for load disturbance. The gotten results show the effectiveness of the proposed control scheme.

Conclusion

A super twisting sliding mode based MRAS observer for speed-sensorless induction motor drives has been presented. The purpose of the proposed observer is to estimate all the necessary values for vector control with robustness and efficiency. Its performance and behaviour has been analyzed and tested using Matlab/Simulink. Finally, simulation results confirm the robustness of the proposed STSM-MRAS observer to the load torque variation, reversal speed and low speed operation and its convergence without using a PI controller. The obtain results have shown the advantages of the proposed observer over a conventional method that uses a PI controller.

The main features are the following:

- The instantaneous speed is estimated by STSM-MRAS observer introduce a high order sliding mode technique.
- To obtain a high-dynamic current sensorless control, a current to voltage feed forward decoupling and a dynamic correction are applied.

Moreover, an accurate dynamic limitation of the real rotor flux and current is obtained.

- Extensive simulation results using an asynchronous motor drive prove high-dynamic performances and robustness of the proposed control.
- These proposed approaches can be implemented easily with DSP or Dspace platform.

APPENDIX

Table 1 The induction motor parameter

Components	Rating values
Stator resistance	Rs=11.8 Ω
Rotor resistance	Rr=11.3085 Ω
Stator/rotor inductance	Ls=Lr=0.5568 H
Mutual inductance	Lm=0.6585 H
Moment of inertia	J=0.0020 Kg.m^2
Viscous friction	f=3.1165e-004 N.m/rad/sec
Number of pole pairs	p_p=2
Rated Power	P= 1 kW
Rated speed	ω_r= 150 rad.s^{-1}

Nomenclature

v_{sd}, v_{sq}	The d, q components of the stator voltage [V]
i_{sd}, i_{sq}	The d, q components of the stator current [A]
ψ_{rd} , ψ_{rq}	The rotor flux d-q components in the rotor flux oriented reference frame [Wb]
T_r	The rotor time constant
R_s , R_r	The stator and rotor winding resistances
L_s , L_r , L_m	The stator, rotor and mutual inductances
ω_e , ω_r , ω_{sl}	The synchronous, rotor and slip speed in electrical [rad/s]
v_{dc}	DC bus voltage [V]
v^*_{dc}	Reference DC bus voltage [V]
i_{dc}	DC bus current [A]
C	DC link capacitor [mF]
p_p	The number of pole pairs in a motor
T_{em}	The electromagnetic torque [Nm]
T_l	The load torque [Nm]
J	The motor inertia [Kg.m^2]
f	Viscous friction coefficient [N.m/rad/sec]
σ	The leakage coefficient.
ε_ψ	The error between the measured and estimated flux component
AC	Alternating Current
CM	Current model
DC	Direct Current
DSP	Digital Signal Processor
EKF	Extended Kalman filter
IM	Induction motor
MRAS	Model reference adaptive system
PI	Proportional Intergal
STSM	Super twisting sliding mode
VM	Voltage model
2L-VSI	Two level voltage source inverter

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