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Estimation of Rotor Velocity in Induction Motor Drive using Sliding Mode Observer

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ABSTRACT:.A sensorless control scheme is presented for induction motor with core loss and anon linear model is developed in well known (α, β) stationary reference frame, where the core is represented with a resistance in parallel with a magnetization inductance. An optimal rotor flux modulus is calculated by minimizing copper and core loss. This flux modulus is forced to be tracked by the induction motor along with a desired rotor velocity by means of sliding mode observer by using the super twisting algorithm. The rotor velocity is estimated by two methods. The first consist of a super twisting sliding mode observer for rotor fluxes with the purpose of retrieving the back-electromotive force components by means of the equivalent control method. The second method is based on a generalization of the phase – locked loop methodology. PI controller is used in both the technique. The robustness of the system is checked by varying the stator, rotor and core resistances.

KEYWORDS: Induction motors (IMs), phase-locked loops, sensorless control, sliding mode control

I.INTRODUCTION

Induction motors are widely used in industrial applications due to their, low service requirements, simple mechanical construction and lower costs with respect to DC motors, also widely used in the industry. On the other hand, IMs constitute a classical benchmark for high performance controllers, since they represent coupled multi input multi output nonlinear systems, resulting in a challenging control problem. Field- oriented control has been a classical control technique for IMs. Active research area includes adaptive input- output feedback linearization, adaptive control sliding mode artificial neural networks fuzzy control.

Sensorless control schemes have attracted the more attention of the researchers, not only for the cost and space reductions in the final setup. Sensorless control of IMs is active research area. The common appoarchof the observer design, is based on the classical sliding mode technique. It is well known that chattering phenomena may appear due to neglected dynamics and the implementation issues of the discontinuous control action in digital devices operating with constant sampling frequency.

Another approach is based on the phase-locked loop (PLL) technique, which allows obtaining precise position and velocity estimates . By usingSensorless control techniques based on PLL have demonstrated almost perfect speed regulation, commonly difficult to obtain by conventional closed loop control systems.

The literature is mainly concentrated on IM models that do not consider power core losses, which leads to the low performance of the controllers. On the contrary, IM models taking into account core losses allow determining the expression of the optimal rotor flux to be used as reference signal, so minimising power losses in the copper and core.
In this paper, IM model considering core losses is proposed. Asensorless controller for output tracking of the rotor velocity and flux modulus is designed. A twisting controller is designed to track a desired rotor velocity reference and the optimal referencesignal(for power loss reduction). After that, a super twisting(ST) sliding mode observer for stator current is designed and the rotor flux is calculated, using the equivalent control method. The controller performance is compared considering two different observer schemes for the rotor velocity estimation. The first is sliding mode super

twisting(ST) observer, and the second is based on a generalization of the well known PLL technique. Atlast, a simple Luenberger observer is designed, filtering the rotor velocity estimated . Twisting and ST techniques have been replacing the classical sliding mode control mainly for its chattering elimation property, and retaining all the other desirable properties. The advantage of the proposed procedure is that we do not make the hypothesis $\dot{\omega}=0$ in the observer design.

II.LITERATUE SURVEY

Once which was impossible is possible today. The modifications and improvement of the drawbacks of previous work has lead to many changes and advancement in the induction motors. The journals which are the base for this work are: a journal on 'sensorless control of induction motor drives' by J. Holtz, a journal on 'copper and core loss minimization for induction motor using high order sliding mode control' by J. Rivera, 'Robust nested sliding mode regulation with application to induction motors' by B. Castillo, S. Di Gennaro, A.G. loukianov and J.Rivera, A journal on ' A class of speed-sensorless sliding mode observer for high performance' byC. Lascu , I. Boldea and F. Blaabjerg.

III.MODELLING OF INDUCTION MOTOR AND ASSUMPTIONS

Assumption : Flux distribution is sinusoidal.

Mathematical modelling of Induction motor

The mathematical modelling equations of induction motor with core loss in stator reference frame α, β with the assumptions of equal mutual inductance and linearmagnetic circuit are

$$\dot{\omega} = \eta_0(\phi_\alpha i_\beta - \phi_\beta i_\alpha) - \frac{f_v}{J}\omega - \frac{1}{J}T_l$$

$$\dot{\phi}_\alpha = -\eta_4\phi_\alpha - p\omega\phi_\beta + \eta_4 L_m i_{m,\alpha}$$

$$\dot{\phi}_\beta = -\eta_4\phi_\beta + p\omega\phi_\alpha + \eta_4 L_m i_{m,\beta}$$

$$\frac{di_{m,\alpha}}{dt} = -(\eta_1 + \eta_2)i_{m,\alpha} + \frac{\eta_1}{L_m}\phi_\alpha + \eta_2 i_\alpha$$

$$\frac{di_{m,\beta}}{dt} = -(\eta_1 + \eta_2)i_{m,\beta} + \frac{\eta_1}{L_m}\phi_\beta + \eta_2 i_\beta$$

$$\frac{di_\alpha}{dt} = -(R_s\eta_3 + \eta_5)i_\alpha - \eta_1\eta_3\phi_\alpha + \eta_6 i_{m,\alpha} + \eta_3 v_\alpha$$

$$\frac{di_\beta}{dt} = -(R_s\eta_3 + \eta_5)i_\beta - \eta_1\eta_3\phi_\beta + \eta_6 i_{m,\beta} + \eta_3 v_\beta \quad (1)$$

where ω is rotor velocity, $v\alpha$, $v\beta$ are stator voltages, $i\alpha, i\beta$ are stator currents, im,α, im,β are magnetization currents,$\varphi\alpha$, $\varphi\beta$ are rotor fluxes, and $Tl$is the load torque, Rsisstator resistance, Lm is magnetizing inductance, p is number the pole pairs, J is rotor moment of inertia, and $fv$is viscous damping coefficient. Finally, $\eta0 = 3pLm/(2JLl,r)$,$\eta1 = Rc/Ll,r$, $\eta2 = Rc/Lm$, $\eta3 = 1/Ll,s$, $\eta4 = Rr/Ll,r$, $\eta5 =Rc/Ll,s$, $\eta6 = \eta5 + \eta1\eta3Lm$, with$Ll,s$, Ll,r, are stator androtor leakage inductances, $Lr= Ll,r+ Lm$, $Ls= Ll,s+ Lm$arerotor and stator inductances, Rr, $Rc$are rotor and coreresistances, respectively.

The model allows writing explicitly the expression of the optimal rotor flux vector.

$$\phi_{o,\alpha} = \gamma_1 i_{R_c,\alpha} - \gamma_2 i_\alpha + \gamma_3 i_{m,\alpha}$$
$$\phi_{o,\beta} = \gamma_1 i_{R_c,\beta} - \gamma_2 i_\beta + \gamma_3 i_{m,\beta} \qquad (2)$$

with$\gamma 1=RsLl,r/Rt$, $\gamma 2=RcLl,r/Rt$, $\gamma 3=(RsLr+ RrLm+RcLr)/Rt$, $Rt = Rs+ Rr+ Rc$, which minimizes the IMpower losses, and which therefore will be considered asreference for the flux modulus.

When the currents $iRc,\alpha= i\alpha +ir,\alpha - im,\alpha$, $iRc,\beta = i\beta + ir,\beta - im,\beta$ circulating through thecore are zero, with ir,α and ir,β the rotor current components,it can be easily shown that (1) reduces to the classical model ofIM, and one recovers the usual dynamics for the stator currents,in which ω appears.

IV.SENSORLESS CONTROL DESIGN FOR INDUCTION MOTOR

In this scheme, each node with message searches for possible path nodes to copy its message. Hence, possible path nodes of a node are considered. The rotor angular velocity and rotor flux modulus to track some desired reference.The control problem is to force the rotor angular velocity ω and the square of the rotor flux modulus $\phi 2m = \phi 2\alpha + \phi 2\beta$to track some desired references ωrefand $\phi 2m$,refrespectively, ensuring the rejection of the disturbance due to the load torque Tl.

$$Pr= \phi_\alpha i_{m,\alpha} + \phi_\beta i_{m,\beta} \qquad (3)$$

Rotor Flux Observer Design:

$$im,\alpha =1/Lm\varphi s,\alpha -Ll,s/Lmi\alpha \qquad (4)$$
$$im,\beta =1/Lm\varphi s,\beta -Ll,s/Lmi\beta \qquad (5)$$

Angular Velocity Observers

In this section, the rotor angular velocity will be estimated. Two observers will be designed and compared in both the simulation and in the real-time implementation: a sliding mode super-twisting (ST) observer and a phase-locked loop (PLL)- like observer.

1) **ST Observer**: The estimates of the rotor flux components obtained from (17), (16), (14) can be used to obtain an estimate of the rotor velocity. For, one first considers a further sliding mode observer for the rotor fluxes ˙

2) $\hat{}\varphi\alpha = -\eta 4 \hat{}\varphi\alpha +\eta 4Lmim,\alpha + \rho\alpha$, $\dot{}\hat{}\varphi\beta = -\eta 4 \hat{}\varphi\beta + \eta 4Lmim,\beta + \rho\beta$ (6)

3) , where $\hat{}\phi_\alpha$,$\hat{}\phi_\beta$ are these further rotor flux estimates, and ρ_α, ρ_β are injected inputs to the observer. To obtain $\hat{}\omega$, we compare these new velocity

$$\omega_{c,1} = \frac{\kappa_\alpha \phi_{c,\beta} - \kappa_\beta \phi_{c,\alpha}}{p(\phi^2_{c,\alpha} + \phi^2_{c,\beta})}. \qquad (7)$$

2) **PLL-Like Observer:** The angular velocity can also be estimated making use of a technique which generalize the classic PLL scheme, sketched in Fig. 2 [19]. This technique is based on the assumption of sinusoidal flux distribution, i.e.,

$\phi_\alpha = |\phi| \cos\theta_\phi$, $\phi_\beta = |\phi| \sin\theta_\phi$, with $|\phi| =\_\phi 2\alpha + \phi 2\beta$, (8)

$\theta_\phi$the rotor flux angle

the rotor velocity is given by

$$\omega_{c,2} = -\frac{1}{p}\hat{\omega}_\phi + \eta_4 L_m \frac{\phi_{c,\beta} i_{m,\alpha} - \phi_{c,\alpha} i_{m,\beta}}{p(\phi^2_{c,\alpha} + \phi^2_{c,\beta})}. \qquad (9)$$

V. RESULT AND DISCUSSION

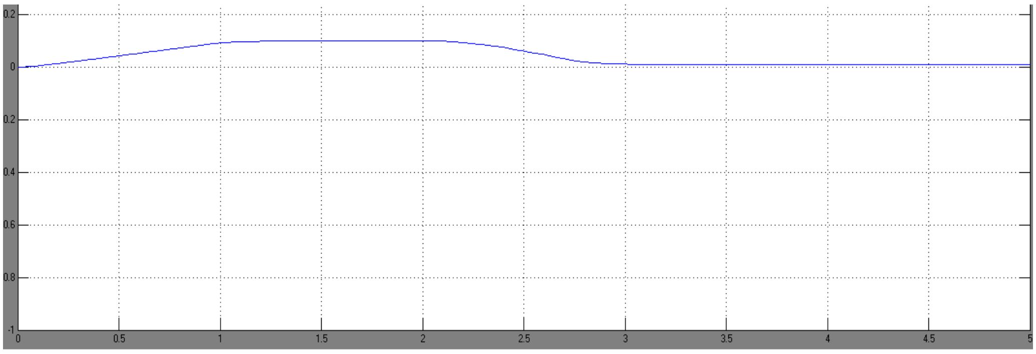
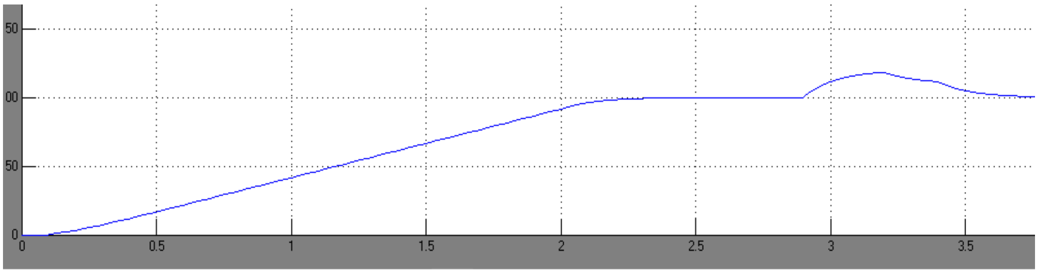


Fig.1 Flux waveform of ST Observer

The optimal flux automatically reaches an adequate value consistent with the load torque valueas shown in fig.1 and highlighted by the behaviour of transient due to the load torque decrement.



speed response of ST

Fig.2 Speed waveform of ST Observer

The rotor velocity is increasing signal in first 2 s from o to 100 rad/s and then maintained constant in fig.2.

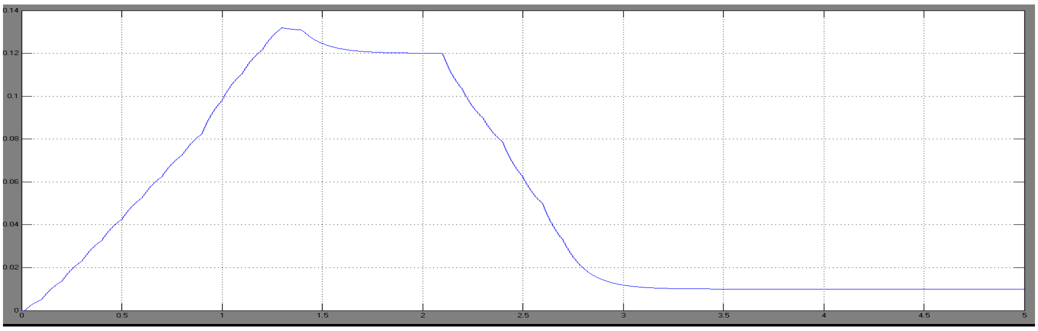


Fig.3 Flux waveform of PLLobserver

The optimal flux modulus decrease corresponds to the a decrease of the stator current and voltage. So avoiding an excess of current demand which could yield to higher power losses in fig.3.

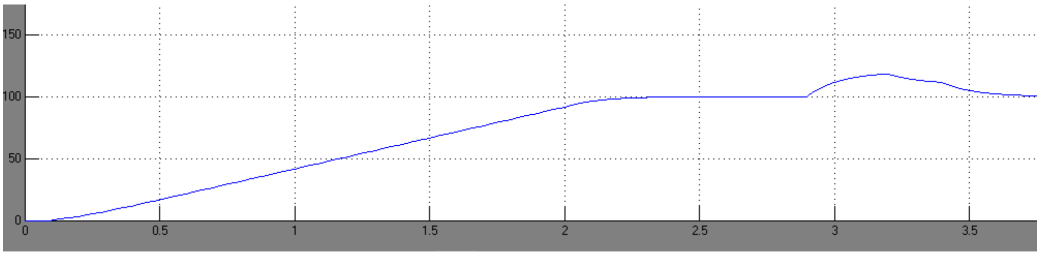


Fig.4 Speed waveform of PLL

The rotor velocity is increasing signal in first 2 s from o to 100 rad/s and then maintained constant in fig.4.

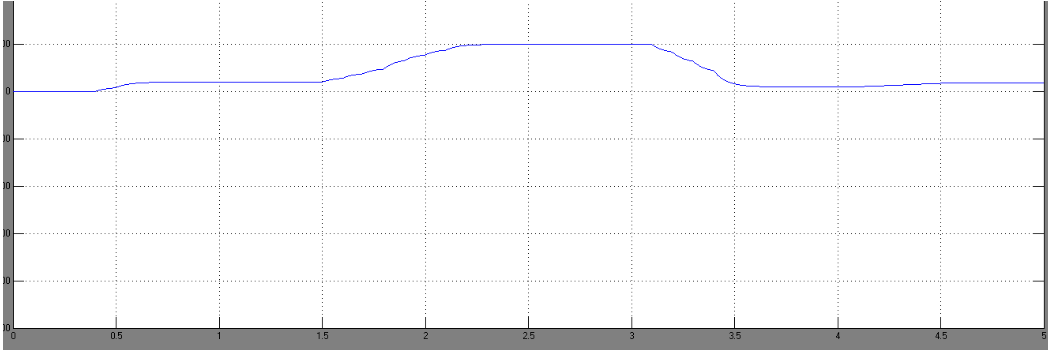


Fig.5 Rotor velocity when rotor resistance is varied

To test the robustness of the proposed control schemes the parameters are varied. The rotor resistance is varied by +50 % fig.5 shows the waveform.

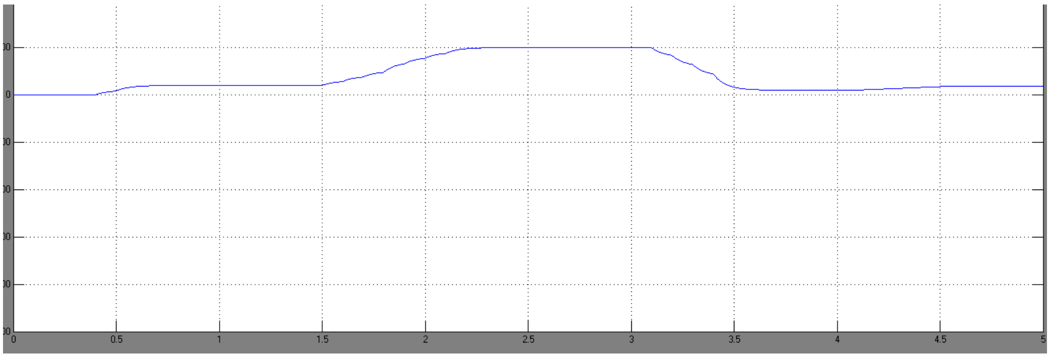


Fig.6 Rotor velocity when stator resistance is varied

To test the robustness of the proposed control schemes the parameters are varied. The stator resistance is varied by +50 % fig.6 shows the waveform.

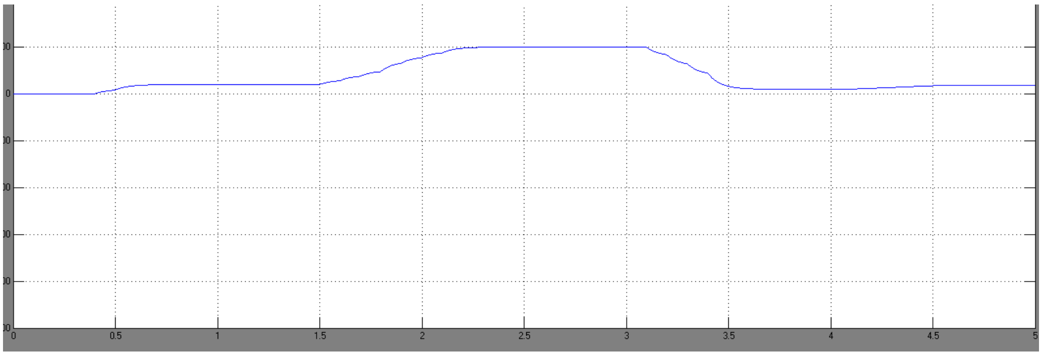


Fig.7 Rotor velocity when core resistance is varied

To test the robustness of the proposed control schemes the parameters are varied. The core resistance is varied by +50 % fig.7 shows the waveform

Table 1
Simulation precision error and chattering in the case of resistance variation

Rotor Velocity	**P_e**		**C_h**	
+50%	**ST(%)**	**PLL(%)**	**ST(%)**	**PLL(%)**
R_r	**0.5**	**0.45**	**0.1**	**≈0**
R_s	**≈0**	**≈0**	**0.15**	**≈0**
R_c	**2.7**	**2.7**	**0.04**	**≈0**

Flux Modulus	**P_e**		**C_h**	
+50%	**ST (%)**	**PLL (%)**	**ST (%)**	**PLL (%)**
R_r	**≈0**	**≈0**	**1.9**	**0.5**
R_s	**≈0**	**≈0**	**1.5**	**0.4**
R_c	**≈0**	**≈0**	**0.3**	**0.4**

VI. CONCLUSION

In this paper, two sensorless control schemes have been designed and testedfor IMs with core loss. Both schemes use a controller designed using sliding mode twisting algorithm, to track a desired rotor velocity signal and an optimal rotor flux modulus. The unmeasured variables are constructed by means of a ST sliding mode observer, which allows the determination of the rotor flux, and the rotor velocity is estimated by two types of observers : the first consists of a ST observer, and the second is based on a generalization of the PLL technique by using PI controller. In general, both control schemes yield satisfactory results, as verified by simulations results, making difficult to decide which sensorless control scheme performs better. Some interesting issues remain to be investigated, such as the digital implementation of these controllers.

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