Simulation of Sensor less Speed Control of Induction Motor Using Reduced Order Flux Observer

Miss. Vishakha S Zade[1] Dr.Ms.S. P. Muley[2] Prof.R.D.Jawale[3]
[1]M.Tech. Student [2]HOD [3]Professor
[1]Industrial Drives And Control [2,3] Department Of Electrical Engineering
[1,2,3]Priyadarsahni College Of Engineering nagpur, Maharashtra. India

Abstract—This paper describes a Model Reference Adaptive System (MRAS) for speed control of the Induction Motor drive (IM) without a speed sensor. In this scheme reduced-order Flux Observer is used instead of the Full-order Flux Observer, a reduced order flux observer is used for estimate the IM rotor speed, and these are used as feedback signals for the Field Oriented Control (FOC), which is a widely used control method for Induction Motor drive (IM). In comparison with the full order observer, the proposed method consumes less computation time and illustrated better speed performance. Simulation results shows that the proposed scheme can estimate the motor speed under various adaptive PI gains and estimated speed can replace to measured speed in sensorless induction motor drive.

Keywords: Induction motor drive, model reference adaptive system estimation sensor less control scheme.

I. INTRODUCTION

In recent years sensorless induction motor drives have been widely used due to their attractive features such as reliability, flexibility, robustness and poor cost. One of the most well-known methods used for control of induction motor drives are the Field Oriented Control (FOC) developed by Blaschke . FOC of induction motor drives is known to have a good dynamic performance with comparable to that of the Direct Torque Control (DTC) techniques developed by Takahashi . FOC technique has been used popularly for sensorless control of induction motor drives. However, when a very high accuracy is desired, the performance of speed estimation is not good particularly at low speeds. The main reason of the speed estimation error is imprecise of flux observer and the off-set of the stator current sensor. The method based on model reference adaptive system (MRAS) is one of the major approaches for rotor speed estimation. a rotational transducer such as a Tachogenerator, an encoder, was often mounted on the IM shaft. Various sensorless field oriented control (FOC)methods for induction motor drives have been proposed [5]-[7].an adaptive full-order flux observers (AFFO) is used. Adaptive full-order flux observers (AFFO) for estimating the speed of an IM were developed using Popov's and Lyapunov's stability criteria [9], [10]. Although computationally efficient, an AFFO with a nonzero gain matrix may become unstable The proportionality constant in the adaptive algorithm has to be adapted for different speeds. If the gain matrix of the AFFO is set to zero, no adaptation is required. However, large speed errors may appear under heavy loads, and steady-state speed disturbances may occur at light loads [10]. An adaptive pseudoreduced-order flux observer (APFO) for sensorless FOC was proposed in [10] using the Lyapunov method. By the application of APFO, the performance of the estimator was improved as compared to the AFFO. However, its superior performance was demonstrated only at medium and high-speed levels..

In a MRAS system, rotor flux-linkage components, Ψdr^s, Ψqr^s of the induction machine (which are obtained by using measured quantities, e .g. stator voltages and currents) are estimated in a reference model and are then compared with, Ψdr^s, Ψqr^s estimated by using an adaptive model [3]. Then effort is made to reduce this error to zero using adaptive mechanism (fig:2).

In this paper, a robust and accurate observer for estimating the speed of induction motors at both high speeds and low speeds, is developed, MRAS to determine the motor speed and thereby establishes vector controlled of motor as well as overall speed control. This paper presents the theory, modeling, simulation results of the proposed model reference adaptive system-based reduced-order flux observer for induction motor drives. Reduced-order flux observer for sensorless FOC is proposed of an IM. The Reduced order flux observer consumes less computational time and has a better speed response than the Full order flux observer over a wide speed range.

II. MODELING OF INDUCTION MOTOR

Modeling of induction motor is done in stationary reference frame [4] the most commonly used transformation is the polyphase to orthogonal two phase (or two-axis) transformation. For the n-phase to two-phase case, it can be expressed in the form of Clark transformation and park transformation respectively.

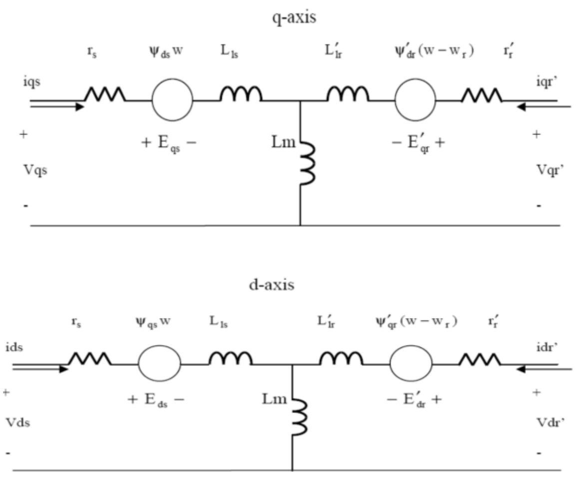

Fig. 1: Equivalent circuit representation of an induction machine in the arbitrary reference frame.

III. SPEED ESTIMATION

A. Model Reference Adaptive Systems:

Model Reference Adaptive System (MRAS) is one of the most popular adaptive control method used in motor control applications for tracking and observing system parameters and states. There exist a number of different model reference adaptive control techniques such as parallel model, series model, direct model and indirect model etc. MRAS used in this paper parallel model MRAS that compares both the outputs of a reference model and adaptive model, and processes the error between these two according to the appropriate adaptive laws that do not deteriorate the stability requirements of the applied system. A generalized parallel MRAS scheme is shown in Fig.2

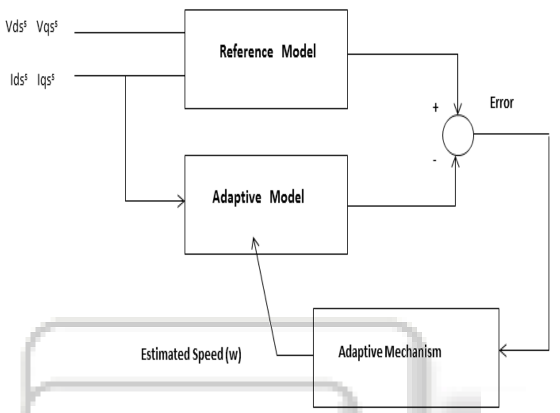

Fig. 2: generalized model reference adaptive system

B. Reference model

Stator voltage equation for Vds^s in d^s – q^s equivalent circuit can be written as:

$$V_{ds}^s = R_s i_{ds}^s + L_{ls}\frac{d}{dt}(i_{ds}^s) + \frac{d}{dt}(\Psi_{dm}^s) \quad (1)$$

$$V_{qs}^s = R_s i_{qs}^s + L_{ls}\frac{d}{dt}(i_{qs}^s) + \frac{d}{dt}(\Psi_{qm}^s) \quad (2)$$

Where, Vds^s, Vqs^s is d^s – q^s axis stator voltage respectively,ids^s,iqs^s is d^s –q^s axis stator current respectively, Rs, Rr is stator, rotor resistance respectively, Lls, Llr is stator, rotor leakage inductance respectively and Ψdm^s ,Ψqm^s is d^s –q^s axis flux linkage respectively.

We have,

$$\psi dm^s = \psi ds^s - Llsids^s = Lm(ids^s + idr^s) \quad (3)$$

$$\psi qm^s = \psi qs^s - Llsiqs^s = Lm(iqs^s + iqr^s) \quad (4)$$

$$\psi dr^s = Lm\, ids^s + Lridr^s \quad (5)$$

$$\psi qr^s = Lm\, iqs^s + Lriqr^s \quad (6)$$

Eliminating idr^s and iqr^s from equation no (5) & (6) with the help of equation no (3) & (4) respectively gives the following.

$$\psi dr^s = Lr/Lm\, \psi dm^s - Llrids^s \quad (7)$$

$$\psi qr^s = Lr/Lm\, \psi qm^s - Llriqs^s \quad (8)$$

C. Adaptive model.

Rotor circuit equation of d^s - q^s equivalent circuits From fig 1 can be given as.

$$\frac{d\psi dr^s}{dt} + Rr\, idr^s + \omega r \psi qr^s = 0 \quad (9)$$

$$\frac{d\psi qr^s}{dt} + Rriqr^s - \omega r \psi dr^s = 0 \quad (10)$$

Adding term (LmRr/Lr)ids^s& (LmRr/Lr)iqs^s , respectively, on both sides of the above equations

We get,

$$\frac{d\psi dr^s}{dt} + Rr/Lr\,(Lm\, ids^s + Lridr^s) - \omega r \psi qr^s = Lm\ Rr/Lr\ ids \text{--------------------} \quad (11)$$

$$\frac{d\psi qr^s}{dt} + Rr/Lr\,(Lm\, iqs^s + Lriqr^s) - \omega r \psi dr^s = Lm\ Rr/Lriqs^s \text{-----------------------------} \quad (12)$$

IV. FLUX OBSERVER

A. Full order flux observer

Full order flux observer model can be derive [2] from the d^s - q^{s}equivalant circuit shown in fig. 1

$$\frac{d}{dt}(X) = AX + BVs$$

Where

$$X = [ids^s iqs^s \psi dr^s \psi qr^2]^T$$

$$Vs = [Vds^s Vqs^s\ 0\ \ 0\,]^T$$

$$A = \begin{bmatrix} -\frac{(Lm^2Rr + Lr^2Rs)}{\sigma\, LsLr^2} & 0 & \frac{Lm\,Rr}{\sigma LsLr^2} & \frac{Lm\omega r}{\sigma LsLr} \\ 0 & -\frac{(Lm^2Rr + Lr^2Rs)}{\sigma\, LsLr^2} & -\frac{Lm\omega r}{\sigma LsLr} & \frac{Lm\,Rr}{\sigma LsLr^2} \\ LmRr/Lr & 0 & -Rr/Lr & -\omega r \\ 0 & LmRr/Lr & \omega r & Rr/Lr \end{bmatrix}$$

$$B = \begin{bmatrix} \frac{1}{eLs} & 0 \\ 0 & \frac{1}{eLs} \\ 0 & 0 \\ 0 & 0 \end{bmatrix}$$

B. Reduced order flux observer

The reduced-order model of presentinterest is the one wherein the electric transients are neglected only in the stator voltageequations.[12]

$$\frac{d}{dt}(X) = AX + BVs$$

Where

$$X = [ids^s iqs^s \psi dr^s \psi qr^2]^T$$

$$Vs = [Vds^s Vqs^s\ 0\ \ 0\,]^T$$

$$A = \begin{bmatrix} -\frac{Rs}{\sigma Ls} + \frac{(1-\sigma)}{\sigma Tr} & 0 & \frac{Lm}{\sigma LsLrTr} & \frac{Lm\omega r}{\sigma LsLr} \\ 0 & -\frac{Rs}{\sigma Ls} + \frac{(1-\sigma)}{\sigma Tr} & -\frac{Lm\omega r}{\sigma LsLr} & \frac{Lm}{\sigma LsLrTr} \\ Lm/Tr & 0 & -1/Tr & -\omega r \\ 0 & Lm/Tr & \omega r & 1/Tr \end{bmatrix}$$

$$B = \begin{bmatrix} \frac{1}{eLs} & 0 \\ 0 & \frac{1}{eLs} \\ 0 & 0 \\ 0 & 0 \end{bmatrix}$$

For augmented the dynamic of this observer during the transitory phase of rotor speed, we estimate the speed by large PI regulator; we added a supplementary term proportional of error. Then

$$\hat{\omega}_r = K_p\left(e_{isd}\,\hat{\emptyset}_{rq} - e_{isq}\hat{\emptyset}_{rd}\right) + K_i\int_0^t\left(e_{isd}\,\hat{\emptyset}_{rq} - e_{isq}\hat{\emptyset}_{rd}\right)dt \quad \text{-------- (13)}$$

Where Kpand Ki are adaptive gains for speed estimator.

V. SIMULATION AND RESULT

The basic configuration of speed estimation of sensorless induction motor drive is shown in figure (3).this Configuration will be used for both simulations. All reference or command preset values are subscripted with a " * " in the diagram.IM speed will be estimated by (13) and will be compared with the reference speed in order to create the error speed.

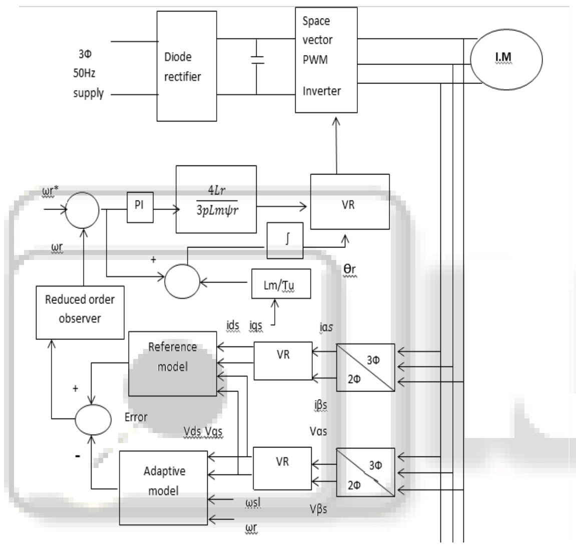

Fig.3: Block diagram of senser less induction motor drive.

The proposed reduced order flux observer for induction motor states estimations has been developed and applied in the direct field oriented control of induction motor and compared with full order flux observer.

The simulation of sensorless speed control of induction motor is done by using MATLAB/SIMULINK. The results are as follows,

CASE-1: Simulation result of induction motor in high speed region

A. *Full order flux observer*

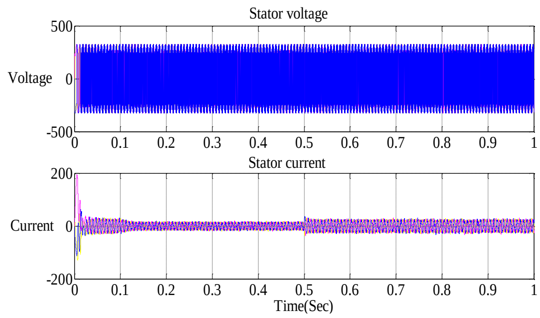

Fig.4: Induction motor input stator voltage and stator current

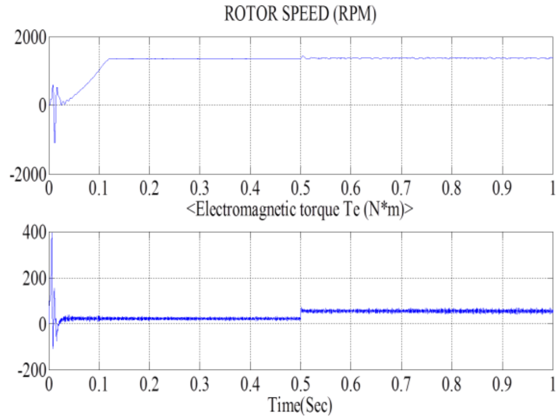

Fig.5:Speed response of induction motor drive

Reference speed (RPM)	1400	
Load	1/3rd	Full
Full order flux observer speed (RPM)	1375	1368
Reduced order flux observer speed(RPM)	1400	1410
Settling time of speed(sec) in full order observer	0.2	0.58
Settling time of speed(sec)in reduced order observer	0.14	0.54

Table. 2: comparison in high speed region

B. *Reduced order flux observer*

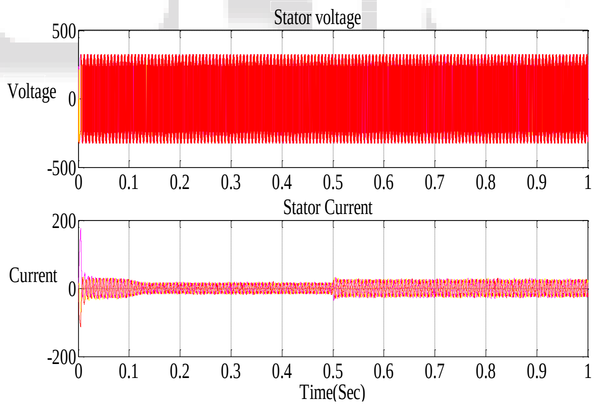

Fig. 6: Induction motor input stator voltage and stator current

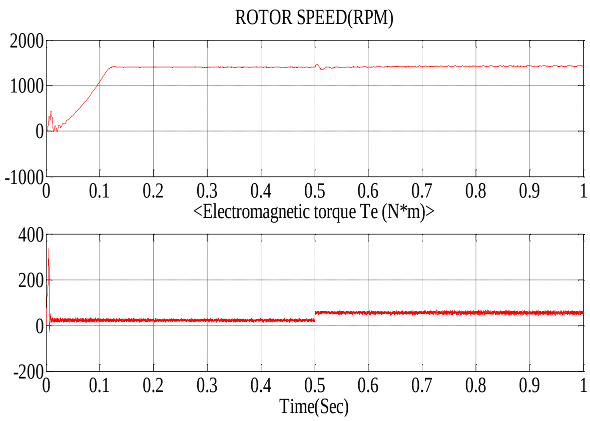

Fig.7: Speed response of induction motor drive

From above case-1 described the simulation result of induction motor with full order flux observer and reduced order flux observer and their comparison. when in the high speed region, reference speed is 1400 RPM where the stator voltage is 283 volt (Phase to ground) before 0.5 sec 1/3rd load is applied so that stator current is 9 amp at 1/3rd load and 16 amp at full load as shown in fig:4 and fig:6 . Fig:5 and Fig: 7 indicate full order flux observer speed 1375 RPM at 1/3rd load and 1368RPM Full load and reduced order flux observer give speed 1410RPM at 1/3rd load and 1400 RPM at full load .This result shown that reduced order flux observer give better response of speed also there settling time is more faster than full order flux observer which given in table no:2

Case-2 Simulation result of induction motor in Low speed region.

A. Full order flux observer

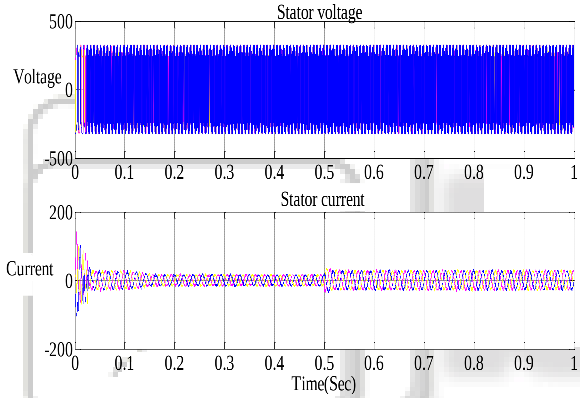

Fig. 8: Induction motor input stator voltage and stator current

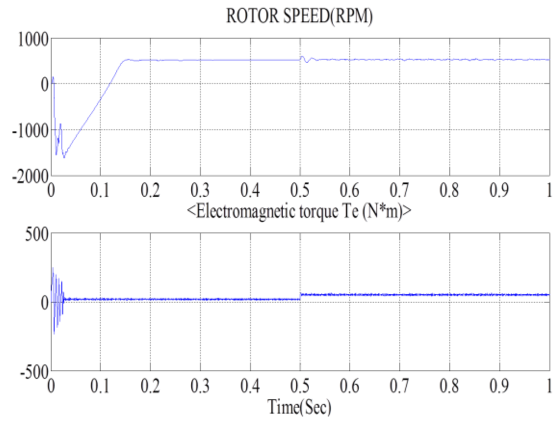

Fig. 9: Speed response of induction motor drive

Reference speed (RPM)	600	
Load	1/3rd	Full
Full order flux observer speed (RPM)	530	520
Reduced order flux observer speed(RPM)	590	570
Settling time of speed(sec) in full order observer	0.16	0.56
Settling time of speed(sec)in reduced order observer	0.08	0.54

Table. 3: Comparison in low speed region

B. Reduced order flux observer

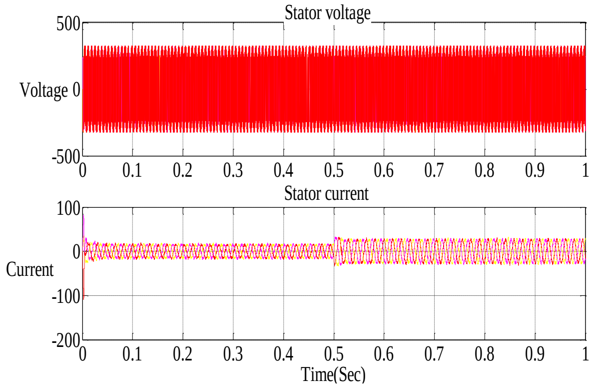

Fig. 10: Induction motor input stator voltage and stator current

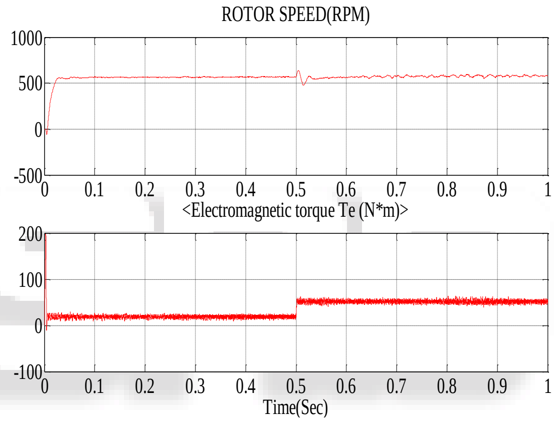

Fig. 11: Speed response of induction motor drive

The observer will be stable over the entire speed region from high speed to low speed. The proposed methodology sensorless drive is capable of operating at low speed region accurately. when in the low speed region, reference speed is 600 RPM where the stator voltage is 283 volt (Phase to ground) before 0.5 sec load is applied so that stator current is 12 amp at 1/3rd load and 22 amp at full load as shown in fig:8 and fig:10. Fig: 9 and Fig:11 indicate full order flux observer speed 530 RPM at 1/3rd load and 520 RPM Full load and reduced order flux observer give speed 590 RPM at 1/3rd load and 570 RPM at full load . In low speed region also reduced order flux observer give better response than full order flux observer table 3 shows the settling time response.

Motor	10h.p(7.5 kw)	Stator resistance	1.0ohm
Phase	3	Rotor resistance	0.77 0hm
Pole	4	Stator/rotor reactance	1.0ohm
Base /rated voltage	415 volt	Moment of inertia	0.1384kg-m

Base/ rated current	2.2 A	Frequency	50hz
Torque(N-M)	49N-M		

Table. 1: parameter of induction motor

VI. CONCLUSIONS

This paper has presented a new method for estimating IM speed based on model reference adaptive system. The proposed method has been applied to a direct field-oriented induction motor drive without a speed sensor. The observer will be stable over the entire speed region. Variations on the speed estimation can be eliminated by the proposed adaptive scheme. The validity of the reduced order flux observer based estimation method has been verified by simulation on an IM drive. The estimation error of speed is very small and the speed response is adequate for variable speed drives. Simulation results of proposed scheme show that estimation & response of the reduced order method is much faster than the methods which are based on previous full order flux observe also at low speed region reduced order flux observer work better than full order flux observer.

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