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Robust Sensorless Control of Induction Motor Drives using Model Reference Adaptive Strategy

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Abstract - **Sensorless speed control of Induction Motor drive has, become an advanced technology for control of speed over a wide speed range with improved stability. The elimination of the rotor speed sensor, without detoriation in the performance, is a recent trend in control of high performance drives. The drawbacks of conventional Model Reference Adaptive Control are parameter sensitivity, low speed instabilities and the stator resistance is the single most critical parameter for the fore mentioned disadvantages. Model Reference Adaptive Strategy (MRAS) based on rotor flux with observer has been proposed which overcomes the above said drawbacks. By this method a robust scheme is designed with reduced calculation effort and accurate speed estimation even at low speeds, because the sensorless flux observer is insensitive to motor parameter deviation. A closed loop estimation system with robustness against motor parameter variation is used for the control approach and the deviation between the estimated speed and the actual speed has been reduced. The proposed MRAS based speed estimator has been simulated for various load conditions using MATLAB/Simulink. The results prove that the proposed MRAS can be applied for retrofit applications.**

Keywords — Induction Motor, Model Reference Adaptive Strategy (MRAS), Observer, PI Controller, Sensorless Control

I. INTRODUCTION

Sensorless AC drives has been preferred in industries due to its multifaceted advantages like reduced hardware requirements, economical as it eliminates sensor and its cable, better noise immunity and also leads to improved reliability and robustness and also requires less maintenance. An encoder is expensive and increases the complexity for measurement of speed and it is less reliable in explosive or corrosive environments. With a sensor both sides of the shaft can be accessed and the shaft extension increases the drives cost.

There are various sensorless techniques for drives which are used for the estimation of the slip, rotor speed, rotor angle and flux in high performance drives. They are open loop estimators using monitored stator voltages and currents, estimators using the spatial saturation stator phase third harmonic voltage, estimators using saliency, Model Reference Adaptive Systems, Observers like Kalman and Luenberger and estimators using Artificial Intelligence. Some of the limitations for sensorless control is the DC offset components in the stator current and voltage acquisition channels at very low speeds. Hence voltage distortions caused by the PWM inverter become significant at lower speeds. It is a common feature of many of the sensorless techniques that they depend on machine parameters that they may depend on the temperature, saturation levels, frequency etc. To compensate for the parameter variations, various parameter adaptation techniques have also been proposed in the literature. In an ideal sensorless drive, speed and its control should be highly accurate and should be capable of operating at all operating points from zero speed to highest speed and also must be independent of parameter variation and saturation effects.

The use of PI controllers in industry based control applications is vast because of the advantages like its wide range of control and its satisfactory performance. That is the reason, in all MRAS based observer and control applications PI controllers are used. Though PI controllers are widely used it may not be able to provide good performance due to motor parameter variations and non-linearity in the inverter. Gain scheduling is often used to improve the controller performance. However the restrictions of its wide usability are due to the effect of noise characteristic and the absence of criteria for tuning.

Although several schemes are available for sensorless operation, MRAS is popular because of its less complexity.

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The design and the experimental validation of a new Linear Multivariable Generalized Predictive Control for speed and rotor flux of Induction Motor is given in [1]. This control approach has been designed in the d–q rotating reference frame, and the Indirect Vector Control has been employed. The challenges that are faced for achieving stability and good damping of a Sensorless Induction Motor drive compared to that of the sensored drive are discussed in [2]. Also reduced order observer and full order observer have been discussed, and it is found that these parameters are sensitive to stator resistance. New MRAC (Model Reference Adaptive Control) method, which calculates the instantaneous and steady state value of X which is product of voltage and current in synchronously rotating frame is proposed in [3]. The speed sensorless control is formulated by developing a new Model Reference Adaptive System (MRAS) using the outer product of Stator Voltage (V_S) and Stator Current (I_S) as the functional candidate and the current estimation also does not depend on stator resistance and hence the complete system can perform very well at low speed [4]. It discusses about the drawbacks of second order observer system for speed computation [5]. A novel MRAS speed and stator resistance estimators based on current estimation to overcome the drawbacks and improved stability is proposed in [6]. Speed sensorless direct torque control of induction motor using Artificial Intelligence is discussed in [7]. The next approach used for low speed sensorless operation is the signal injection technique. Carrier injection methods for sensorless control are sophisticated and the design must match the properties of the motor[8].Another observer based on Leunberger observer is used for rotor flux and speed estimation [9]. The Leunberger observer for the PMSM back emf in the stationary αβ frame is described [10]. The use of instantaneous reactive power and instantaneous active power provides a simplification of the speed estimation process [11]. Sensorless operation of vector controlled three phase drive is frequently described in literature whereas a limited number of publications are present in literature for multiphase AC machines [12].

II. Mathematical Modelling of Induction Motor Drives

Squirrel Cage Induction Motors called as the workhorse of industries has been widely used in many industrial applications. Here space vector representation of induction motor and its mathematical modeling has been discussed. A three-phase AC machine may be described using the space vector method as was shown by Kovacs and Racz [13]. A per-phase equivalent circuit of an induction motor is shown in Fig. 1. It consists of stator side resistance and leakage inductance, mutual inductance, rotor side resistance, inductance, and induced voltage.

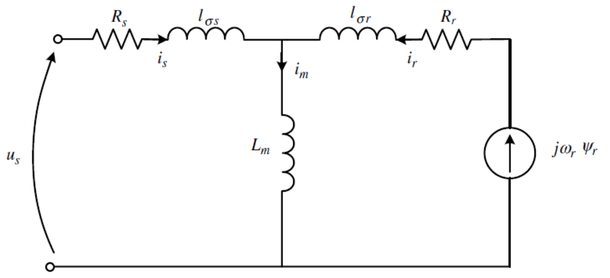

Fig.1 Per Phase Equivalent Circuit of Induction Motor

The induction motor in arbitrary reference frame K can be presented in per unit rotating angular speed ω_k as[14].

$$u_{sk} = R_{sk} i_{sk} + \frac{d\psi_{sk}}{dt} + j\omega_k \psi_{sk}. \quad (1)$$

$$u_{rk} = R_{rk} i_{rk} + \frac{d\psi_{rk}}{dt} + j(\omega_k - \omega_r)\psi_{sk} \quad (2)$$

$$\psi_{sk} = L_s i_{sk} + L_m i_{rk} \quad (3)$$

$$\psi_{rk} = L_r i_{rk} + L_m i_{sk} \quad (4)$$

$$\frac{d\omega_r}{dt} = \frac{1}{T_M}[I_m(\psi_{sk} * i_{sk}) - t_l] \quad (5)$$

where T_M is the mechanical time constant; where u_s,u_r,i_s, i_r ,ψ_s, ψ_r are voltage, current, and flux(stator and rotor) vectors; R_s,R_r are stator and rotor resistances; ω_r rotor angular speed; ω_a is angular speed of reference frame; J is the moment of inertia; and t_l is load torque. The current relations are

$$i_s = \frac{1}{L_s}\psi_s - \frac{L_m}{L_s} i_r. \quad (6)$$

$$i_r = \frac{1}{L_r}\psi_r - \frac{L_m}{L_r} i_s. \quad (7)$$

The Induction Motor (IM) model presented per unit in the rotating frame with arbitrary speed is given by [13][14][15].

$$\frac{di_{sx}}{d\tau} = \frac{R_s L_r^2 + R_r L_m^2}{L_r \omega_\sigma} i_{sx} + \frac{R_r L_m}{L_r \omega_\sigma}\psi_{rx} + \omega_k i_{sy} + \omega_r \frac{L_m}{\omega_\sigma}\psi_{ry} + \frac{L_r}{\omega_\sigma} u_{sx} \quad (8)$$

$$\frac{di_{sy}}{d\tau} = \frac{R_s L_r^2 + R_r L_m^2}{L_r \omega_\sigma} i_{sy} + \frac{R_r L_m}{L_r \omega_\sigma}\psi_{ry} - \omega_k i_{sx} - \omega_r \frac{L_m}{\omega_\sigma}\psi_{rx} + \frac{L_r}{\omega_\sigma} u_{sy} \quad (9)$$

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$$\frac{d\psi_{rx}}{d\tau} = -\frac{R_r}{L_r}\psi_{rx} + \omega_r\psi_{ry} + \frac{R_r L_m}{L_r} i_{sx} \qquad (10)$$

$$\frac{d\psi_{ry}}{d\tau} = -\frac{R_r}{L_r}\psi_{ry} + \omega_r\psi_{rx} + \frac{R_r L_m}{L_r} i_{sy}. \qquad (11)$$

$$\frac{d\omega_r}{d\tau} = \frac{L_m}{JL_r}(\psi_{rx} i_{sy} - \psi_{ry} i_{sx}) - \frac{1}{J} t_0 \qquad (12)$$

Here t_0 is load torque. The mathematical model of IM as differential equations of state variables presented in αβ stationary reference frame and ω_k=0 is [10]

$$\frac{di_{s\alpha}}{d\tau} = a_1 i_{s\alpha} + a_2\psi_{r\alpha} + \omega_r a_3\psi_{r\beta} + a_4 u_{s\alpha}. \qquad (13)$$

$$\frac{di_{s\beta}}{d\tau} = a_1 i_{s\beta} + a_2\psi_{r\beta} - \omega_r a_3\psi_{r\alpha} + a_4 u_{s\beta}. \qquad (14)$$

$$\frac{d\psi_{r\alpha}}{d\tau} = a_5\psi_{r\alpha} + (-\omega_r)\psi_{r\beta} + a_6 i_{s\alpha} \qquad (15)$$

$$\frac{d\psi_{r\beta}}{d\tau} = a_5\psi_{r\beta} + (-\omega_a)\psi_{r\alpha} + a_6 i_{s\beta} \qquad (16)$$

$$\frac{d\omega_r}{d\tau} = \frac{L_m}{JL_r}(\psi_{r\alpha} i_{s\beta} - \psi_{r\beta} i_{s\alpha}) - \frac{1}{J} t_0. \qquad (17)$$

$$a_1 = -\frac{R_s L_r^{\,2} + R_r L_m^{\,2}}{L_r \omega} \qquad (18)$$

$$a_2 = \frac{R_r L_m}{L_r \omega}. \qquad (19)$$

$$a_3 = \frac{L_m}{\omega} \qquad (20)$$

$$a_4 = \frac{L_r}{\omega} \qquad (21)$$

$$a_4 = \frac{L_r}{\omega} \qquad (22)$$

$$a_5 = -\frac{R_r}{L_r} \qquad (23)$$

$$a_6 = R_r \frac{L_m}{L_r} \qquad (24)$$

Eqn.8 to Eqn.24 represents the mathematical equations of per unit model of Induction Motor.

III. Conventional Rotor Flux MRAS Speed Estimation Technique

Three are many schemes that are available for sensorless control of a vector controlled Induction Motor drive. Among them, Model Reference Adaptive System has gained importance because of its simplicity and also its ability to estimate low values of speeds. The conventional rotor flux based Model Reference approach takes advantage of using two independent machine models for estimating the same state variable i.e., rotor flux. The reference model does not have the speed to be estimated and the other block which is has the speed to be estimated is considered as the adaptive model. The estimation error between the output of the reference and adjustable block is used to generate a proper mechanism for adapting the speed. From the block diagram it could be seen that the outputs of the reference model and the adjustable model are the two estimates of the rotor flux vectors.

In this scheme, the outputs of the reference model and the adjustable model are denoted in Fig.2. by $\psi_r(1)$ and $\psi_r(2)$ are two estimates of the rotor flux vectors.[16] The difference between the two estimated vectors is used to feed a PI controller and the output of the controller is used to tune the adjustable model. The tuning signal actuates the rotor speed, which in turn makes the error signal zero. The adaptation mechanism of MRAs is a simple gain or a PI controller.

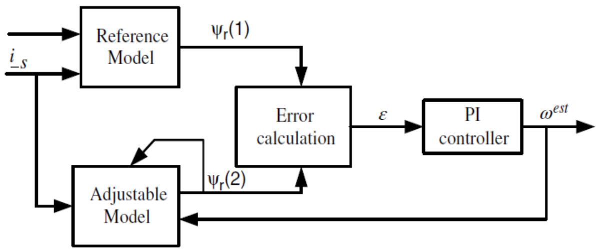

Fig.2 Block Diagram of MRAS

It is possible to estimate the rotor speed by using two estimators ie, a reference model based estimator and an adaptive model based one, which independently estimate the rotor flux linkage components and by using the difference between these flux linkage estimates to drive the speed of the adaptive model to that of the actual speed. The PI controller tunes the rotor speed to be estimated when the error between the two rotor flux linkage space vectors is not zero. In other words, when the rotor speed to be estimated is changed in the adjustable model in such a way that the difference between the output of reference model and the output of the adjustable model becomes zero, then the estimated speed is equal to the rotor speed. The error signal actuates the rotor speed identification algorithm which makes this error converge to zero. The algorithm is chosen to give quick and stable response.

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$$\omega_r^{est} = k_p \varepsilon + k_i \int \varepsilon dt \quad (25)$$

Where the input of the PI controller is

$$\varepsilon = \psi_{\beta r}{}^{(1)} \psi_{\alpha r}{}^{(2)} - \psi_{\alpha r}{}^{(1)} \psi_{\beta r}{}^{(2)} \quad (26)$$

K_p and Ki are the gains of the PI controller.

Some of the common problems of speed estimation using conventional MRAS are parameter insensitivity, drift due to integrator and overlapping loop problems in the control loop and the speed estimation loop may overlap and influence each other. The proposed observer is robust and non sensitive to motor parameters, which gives better results, even for very low frequencies.

IV PROPOSED SENSORLESS VECTOR CONTROL

The drawbacks of the conventional MRAS and the modeling of induction motor drives has been discussed. A scheme that uses MRAS has been proposed which overcomes the drawbacks of the conventional MRAS. The proposed scheme combines MRAS with observer to estimate the rotor speed. The proposed scheme has been simulated in Matlab/Simulink

Sensorless Vector control of an induction motor drive essentially means vector control without any speed sensor. An incremental shaft-mounted speed encoder(usually an optical type) is required for closed loop or position control in both vector and scalar-controlled drives. A speed signal is also required in indirect vector control in the whole speed range, and in direct vector control for the low-speed range, including the zero-speed start-up operation. A speed encoder is undesirable in a drive because it adds cost and reliability problems, besides the need for a shaft extension and mounting arrangement. It is possible to estimate the speed signal from machine terminals voltages and currents with the help of a Digital Signal Processor. However, the estimation is normally complex and heavily dependent on machine parameters. Although sensorless vector-controlled drives are commercially available at this time, the parameter variation problem particularly near zero speed imposes a challenge in the accuracy of speed estimation. In the vector control scheme the rotor speed can be computed from a difference between the synchronous speed and the slip speed given by the equation.

$$\hat{\omega} = \frac{\psi_{s\alpha}\psi_{s\beta(k)} - \psi_{s\beta}\psi_{s\alpha}}{\psi_s^{\ 2}} - \hat{\omega}_{2r} \quad (27)$$

where

$$\omega_{si} = \frac{R_r(\psi_{s\alpha} i_{s\beta} - \psi_{s\beta} i_{s\alpha})}{\psi_s^{\ 2}} \quad (28)$$

By using the open loop models or using closed loop observer systems the stator flux components (or rotor flux in the rotor flux oriented system) can be computed. These observers can be used for speed computation as well as the flux components.

A. Closed loop observer for speed estimation

The Sensorless flux observer is used for the estimation of stator and rotor fluxes. The observer can also be used for other variable estimations. The adaptive system is connected with inputs (fluxes) obtained from the Sensorless observer, which is used as the reference model. The reference model isused for adjusting the speed in an adaptive model. By this method a robust scheme is possible to be designed, because the sensorless flux observer is insensitive to motor parameter deviation.

At low speeds the accuracy of the open loop models decreases. The performance of open loop models depends on the methods the machine parameters can be identified. The machine parameters have the largest influence on system operation at low speeds. Thus robustness against machine parameter deviation is necessary and can be significantly improved by using closed loop observers.[19]. The observer is based on the combination of rotor flux, stator flux, stator currents relationships and voltage model of Induction motor.

$$\tau_s' \frac{d\psi_s}{d\tau} + \psi_s = k_r \psi_r + u_s \quad (29)$$

Low pass filters are used in order to prevent problems of voltage drift and to offset errors, instead of pure integrators. The limitation of the estimated stator flux is tuned to the stator flux nominal value. In additionto it, the extra compensation part is as shown in [17]. The rotor observer equations [18] are

$$\frac{d\hat{\psi}_{s\alpha}}{d\tau} = \frac{-\psi_{s\alpha} + k_r \hat{\psi}_{r\alpha} + \hat{u}_{s\alpha}}{\tau_s'} - k_{ab}(i_1 - \hat{i}_1) \quad (30)$$

where k is observer gain. The estimated value of the $\hat{i}_s$ current appearing in Eqn.31 is

$$\hat{\psi}_r = \frac{1}{k_r}(\hat{\psi}_s - \sigma L_s i_s) \quad (31)$$

$$\hat{i}_s = \frac{\hat{\psi}_s - k_r \hat{\psi}_r}{\sigma L_s} \quad (32)$$

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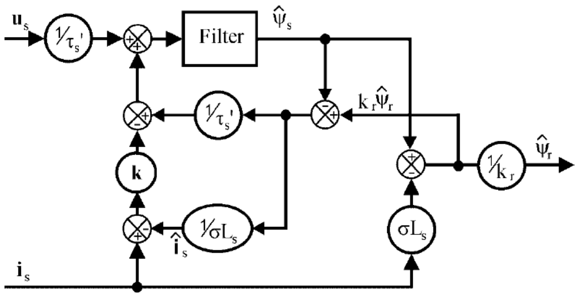

Fig. 3 Structure of the proposed observer

The observed stator flux components and the measured stator current components, are received by the rotor flux calculator which is further processed both in the stationary α-β axis frame. High precision input signals are required, which is achieved by using the error signal obtained from the difference between the estimated and the measured stator current vectors. From the estimated stator flux and rotor flux., the stator current is calculated. By providing the current error $(i_s - \hat{i}_s)$ as a negative feedback signal in the stator flux observer system the existing error may further be eliminated. The stator current is multiplied by a gain to increase its robustness and also to improve stability. It also helps to eliminate additional disturbances related to DC drift and measurement and numerical errors. The tuning of the matrix gain is a significant task for wide range of operating speeds and varying load conditions. Here the proposed observer works properly even for low values of motor voltages and small supply frequency. Another parameter that is required for transforming the stationary to rotating reference frame and vice versa for a vector controller is the rotor flux vector angle. The flux position calculator gives the rotor flux speed $\omega_{\psi r}$

The rotor flux speed $\omega_{\psi r}$, which is obtained from the rotor flux by differentiating its angle. The flux magnitude and angle position of rotor flux are

$$|\hat{\psi}_r| = \sqrt{\hat{\psi}_{r\alpha}^{\ 2} + \hat{\psi}_{r\beta}^{\ 2}} \qquad (33)$$

$$\hat{\rho}_{\psi r} = arctg\frac{\hat{\psi}_{r\beta}}{\hat{\psi}_{r\alpha}} \qquad (34)$$

The objective of the drive is to control the speed, so rotor speed is essential to perform closed loop control. In the proposed estimation method, the motor mechanical speed signal is obtained by subtracting the slip from the rotor flux speed.

$$\hat{\omega}_r = \hat{\omega}_{\psi r} - \hat{\omega}_2 \qquad (35)$$

where the rotor flux pulsation is

$$\hat{\omega}_{\psi r} = \frac{d\hat{\rho}_{\psi r}}{d\tau} \qquad (36)$$

and rotor slip pulsation is obtained from

$$\hat{\omega}_2 = \frac{(\hat{\psi}_{r\alpha}\hat{i}_{s\beta} - \hat{\psi}_{r\beta}\hat{i}_{s\alpha})}{|\hat{\psi}_r|^2} \qquad (37)$$

The rotor flux magnitude, position, and mechanical speed estimation structure is presented in Fig.4. The proposed observer does not contain any information on rotor speed, hence does not require knowledge of its shaft position. Therefore speed computation is performed which does not affect the precision of the proposed observer. Speed computation is performed as a separate block which does not affect the precision of the observer and hence eliminates any additional error associated with computing or even measuring signals. By this method it is possible to estimate the speed around zero speed with sufficient robustness against parameter variation.

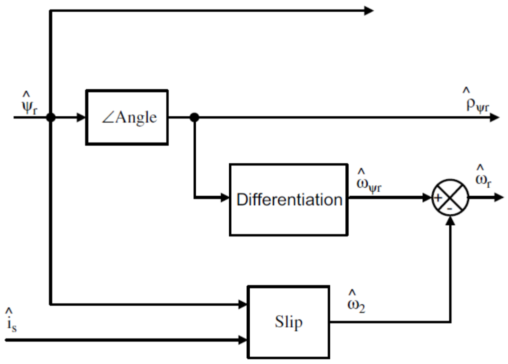

Fig.4 Speed Estimation Scheme

IV. SIMULATION RESULTS

The proposed scheme combines MRAS with observer to estimate the rotor speed and overcomes the drawback of the conventional MRAS. The proposed scheme has been simulated in Matlab/Simulink. The sensorless flux observer is used for the estimation of stator and rotor fluxes. The observer can also be used for other variable estimations. The adaptive system is connected with inputs (fluxes) obtained from the sensorless observer, which is used as the reference model. The reference model is used for adjusting the speed in an adaptive model. By this method a robust scheme is possible to be designed, because the sensorless flux observer is insensitive to motor parameter deviation. The simulation has been done for various load conditions. The simulation results contains the reference speed, measured speed, estimated speed, difference between measured speed and estimated speed, stator current components and rotor flux hodograph. The various load conditions are as given below.

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(i) The load torque is maintained constant with 0.25 p.u. (per unit) and reference speed=0.6p.u..
(ii) The load torque is not applied (i.e. only friction torque is present) and reference speed=0.2 p.u.
(iii) The load torque=0.2 p.u. and reverse operation at low-speed reference (+0.2p.u. to -0.2 p.u.).
(iv) The load torque = 0 p.u. and with braking operation.

A. Case 1

In the case the load torque is maintained constant with 0.26 p.u. and reference speed=0.6p.u. The simulation results of measured speed, estimated speed stator current components and rotor flux trajectory are as shown from Fig.5 to Fig.8, respectively. The results shows that the reference speed is tracked by the estimator and matches exactly even though it had initial variations. The alpha and beta components of the phase currents are plotted and could be observed that they have a phase shift of 90^0. The flux trajectory traces a circular path.

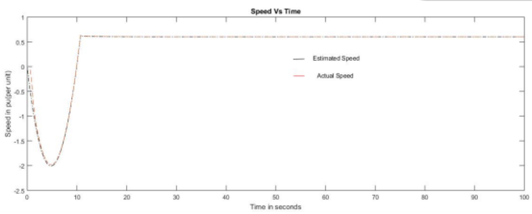

Fig.5 Actual Speed and Estimated Speed in p.u. for Case I

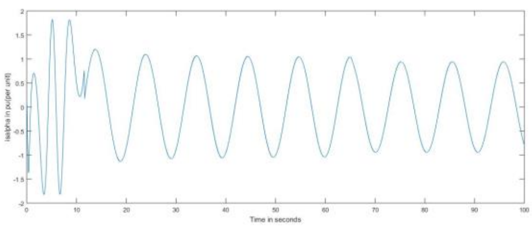

Fig.6 Stator Current ($I_{s\alpha}$) in p.u.for Case I

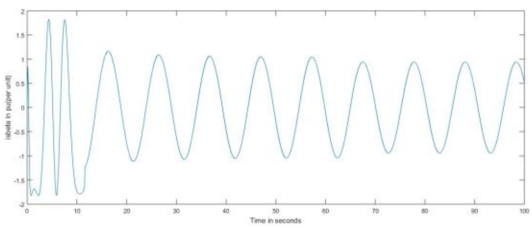

Fig.7 Stator Current ($I_{s\beta}$) in p.u.for Case I

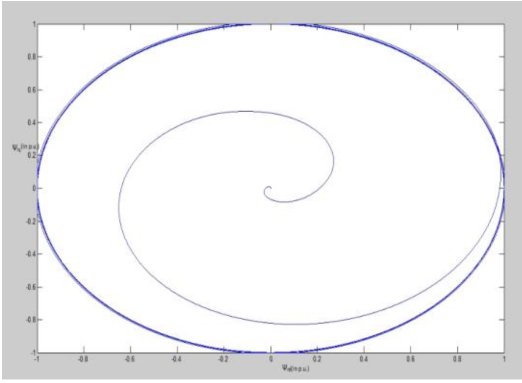

Fig. 8 Rotor Flux Trajectory for Case I

B. Case II

In the case the load torque not applied and reference speed=0.2p.u. The simulation results of measured speed, estimated speed, stator current components are as shown in Fig.9 to Fig.11, respectively. The rotor flux is found similar to case I following a circular trajectory. In Fig.9, it is observed that the motor accelerates and settles down at 0.2 pu and the estimated speed also tracks the same. The frequency of the stator current has decreased when compared to case I and the same the alpha and beta components are orthogonal. In this case also the flux follows a circular trajectory.

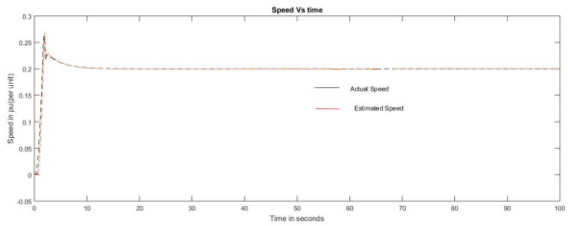

Fig.9 Actual Speed and Estimated Speed in p.u. for Case II

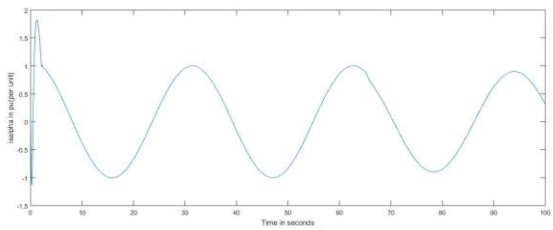

Fig.10 Stator Current ($I_{s\alpha}$) in p.u.for Case II

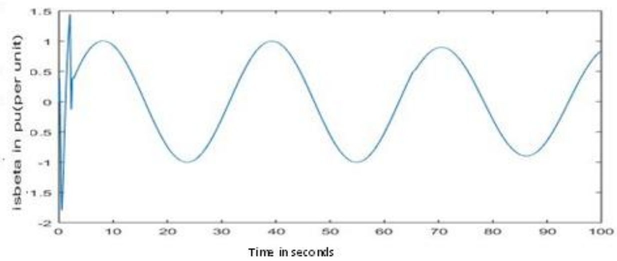

Fig.11 Stator current ($I_{s\beta}$) in p.u.for Case II

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C. *Case III*

In this case, load torque=0.2 p.u. and reverse operation at low-speed reference(-0.2 p.u. to +0.2 p.u.). The simulation results of measured speed, estimated speed stator current components are as shown in Fig.12 to Fig. 14, respectively. A load torque of 0.2 pu is applied is applied at 40seconds due to which a disturbance is observed. The current waveform reverses exactly at the same instant when a change in direction of speed is applied from negative to positive.

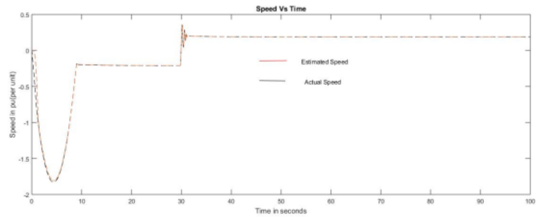

Fig.12 Actual Speed and Estimated Speed in p.u. for Case III

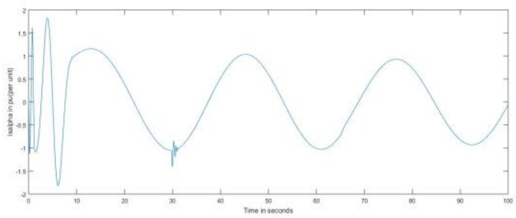

Fig.13 Stator Current ($I_{s\alpha}$) in p.u.for Case III

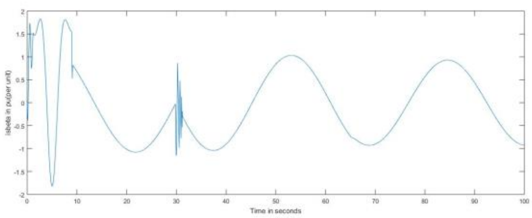

Fig.14 Stator Current ($I_{s\beta}$) in p.u.for Case III

D. *Case IV*

In this case, load torque = 0p.u. and with braking operation. The simulation results of measured speed, estimated speed stator current components and rotor flux trajectory are as shown in Fig. 15 to Fig. 17, respectively. It can be observed in all cases that the α and β components of stator currents are at a phase shift of 90^0 and the flux trajectory for all the cases are circular. Once the reference speed is made zero it was tracked by the estimator at the same instant.

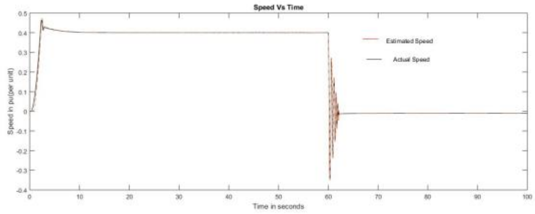

Fig.15 Actual Speed and Estimated Speed in p.u. for Case IV

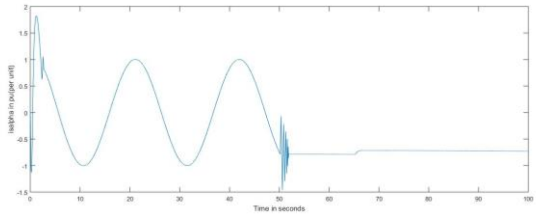

Fig.16 Stator Current ($I_{s\alpha}$) in p.u.for Case IV

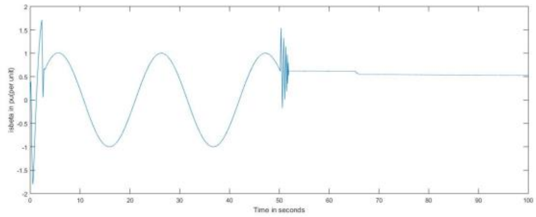

Fig. 17 Stator Current ($I_{s\beta}$) in p.u.for Case IV

From the above simulation following can be inferred. The Proposed MRAS estimates the speed in the standard load test conditions. Also the Proposed MRAS estimate very low speed (0.2 p.u.) even under breaking conditions. Under Braking condition the braking time i.e., the time at which the speed attains to zero is 2.5 s. The Proposed MRAS follows circular trajectory of flux under all standard load test conditions. Also the stator currents (in αβ co-ordinates) are as expected. From the above it can be concluded that the proposed MRAS can be applied for retrofit applications.

V. Conclusion

Model Reference Adaptive Strategy based on rotor flux has been proposed for speed and flux estimation by proposing a closed loop observer or speed estimation, and it proves to be a robust scheme as the sensorless flux observer is insensitive to motor parameter variation. The proposed closed loop estimation used for the control approach and the estimated speed(sensorless) exactly tracks the actual speed. The proposed rotor flux based MRAS has been simulated and analysed extensively in MATLAB/Simulink. The simulation has been analyzed thoroughly and it is concluded that the proposed MRAS estimates the speed in all the standard test conditions even at low speeds and braking conditions which was a drawback in many sensorless speed control methods. Hence the proposed MRAS is suitable for retrofit applications.

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The ratings of the induction motor used for simulations are as shown in Table 1

Table 1 Induction Motor Specifications

Sl. No	Parameter	Value (in SI units)	Value (in per unit)
1	Power, P(kW)	1.5	1
2	Line voltage, VL(V)	415	1
3	Frequency, f(Hz)	50	1
4	Stator resistance, $R_s(\Omega)$	5.0	0.0433
5	Rotor resistance, $R_r(\Omega)$	4.8661	0.0421
6	Stator inductance, L_s(H)	0.4088	1.2004
7	Rotor inductance, L_r(H)	0.4088	1.2004
8	Mutual inductance, L_m(H)	0.4411	1.11257
9	Pole pairs, P_p	2	1
10	Moment of inertia, J_L(kg-m^2)	0.02	0.283
11	Rated speed, N(rpm)	1500	1
12	Frictional coefficient, B_L(Nm/rad/s)	0	0

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