Sensor Less Speed Control of Three Phase Induction Motor by using MRAC

G. Balasubbarayudu[1],
Student (M.Tech),
Department of Electrical and Electronics Engineering,
St.Johns College of Engineering and Technology,
Yemmiganur, Kurnool, Andra Pradesh, India.

S. Rehana Begum[2]
Assistant Professor,
Department of Electrical and Electronics Engineering
and Technology, Yemmiganur,
Kurnool, Andra Pradesh, India

***Abstract*—a new model reference adaptive controller (MRAC) for the speed estimation of the vector controlled induction motor drive is presented in this paper. the sensor less speed control of induction motor is formulated by developing a new model reference adaptive system using steady–state values of X=($\dot{\vec{v}}^*$x $\vec{i}$ where *v*= supply voltage and *i*= supply current vector in synchronously rotating reference frame)which is a fictitious quantity. This is no need of physical significance. This formulation not only simply and more reliable but also made the sensor less drive stable in all four quadrants of operation. Speed estimation processing techniques are does not involve the stator and rotor flux. Modification of the vector controller drive can estimate the stator resistance in all the four quadrants of operation, if speed signal is available. The proposed MRAC-based speed sensor less vector control drive as well as the stator resistance estimation technique has been simulated in MATLAB/SIMULINK.**

***Index Terms*—induction motor (IM), model reference adaptive controller (MRAC), sensor less control, stator resistance, vector control.**

NOMENCLATURE

v_{sd}, v_{sq}	d and q- components of stator voltage vector.
$v_{s\alpha}, v_{s\beta}$	α and β-components of stator voltage vector.
i_{sd}, i_{sq}	d and q- components of stator current vector.
i_{sd}, i_{sq}	Reference value of d and q-components of stator Current vector.
$i_{s\alpha}, i_{s\beta}$	α and β-components of stator current vector.
$i_{s\beta}^{\cap}$	estimated value of $i_{s\beta}$
$V_{r\beta}$	β-components of rotor voltage vector.
$i_{r\alpha} i_{r\beta}$	α and β-components of rotor current vector.
$\Psi_{r\alpha}, \Psi_{r\beta}$	α and β-components of rotor flux vector.
L_r	Self inductance at the rotor side.
L_m	Magnetizing inductance.

I. INTRODUCTION

Vector-controlled induction motor drives are more extensively used in industry due to their cost effectiveness, ruggedness and, highly dynamic performance and easily implementation by using simple analog or digital signal processing techniques. Field-based-controlled or vector controlled drives are high performance of application. HOWEVER, the implementation of the vector controlled Schemes are requires the knowledge of the rotor speed, stator poles and other machine parameters. Speed encoders or tacho-generators, which are used to sense the rotor actual speed and reliable operation of the drive system. Various algorithms for speed and parameter estimations are available in literature [1]-[35].the stability of the sensor less speed control algorithm needs to be maintained in all the four quadrants of operation including low speeds (zero speed) for the satisfactory performance of the drive. On other way, the vector control algorithm, estimating speed, vector control algorithm, machine parameters are available in literature [5]-[8],[23],[27],[33],[35].

The speed estimation techniques are mainly classified into two types namely model-based method and signal addition-based methods are very attractive. In this area, the use of First order Low pass filter is popularly used due to its robustness and the need of reduced number of PI controllers [9],[30].

Elimination of the speed sensor makes the drive mechanically more robust. However, the influence of noise characteristics, the absence of criteria for tuning, and the computational burden of this clean observation is the major limitation for the wide acceptability.[10]-[13],[31],[35],[36].these method requires the flux and dependent machine parameters also as reported in [31],model-based methods are not stable in all the operating range of the drive. In this modify, a classical adaptive control based on model reference adaptive controller (MRAC) depends on special report. Flux [14],[16].[17]back EMF [19],reactive power[18]-[20] based model reference adaptive controller are proposed in literature. Flux based MRAC [14] stable in all the four quadrants. Proportional controller plus Integrator is replaced by low pass filter (LPF), as reported in [15].the low pass filter introduces gain and phase angle error in the flux estimation below cutoff frequency of the filter. A neural network-adaptive based integrator for the Flux estimation is reported as [16]back EMF based MRAC [19]also suffer from the failing performance at low speed due to the presence of derivative operator .A reactive power-based MRAC [18]-[20] overcomes all such problems but at the cost of loosing satiability in the regenerative mode of operation. The instability problem of the reactive power based-MRAC is presented in [18].

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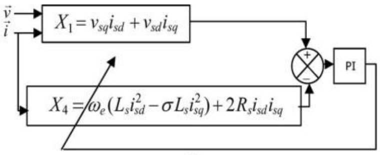
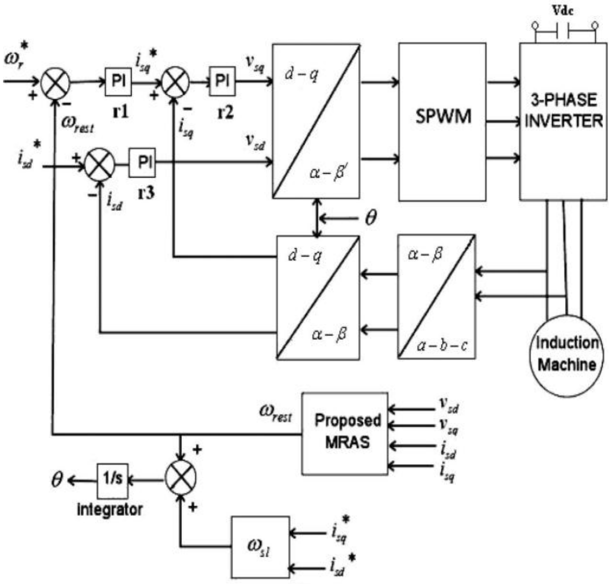
In this paper represents the stability problems related to the regenerating mode of operation is solved by considering a new quantity. The quantity is defined by the outer product of $v^{\rightarrow *}$and $i^{\rightarrow}$(i.e., $v^{\rightarrow *} x\ i^{\rightarrow}$).



(a)



(b)

Fig.(a) prposed MRAC(X-mrac)structure for estimate speed

Fig.(b) Block diagramm of vector control drive with the proposed MRAC-based speed estimation technique

The steady state values of $v^{\rightarrow *} x\ i^{\rightarrow}$ is used in the reference model and steady state Flux-based value of the same is considered for the adjustable model. The structure of such MRAC for speed estimation is shown in fig 1(a). the MRAC is the adding of X_1 and X_4 .The selection of $v^{\rightarrow *}$x $i^{\rightarrow}$ is a major success in the sense that the proposed system is now stable in all the four quadrant modes of operation. The estimation speed includes the low speed or zero speed and does not require flux orientation. These make the drive easy for implementation.

The paper is implemented in six sections. The following sections I and II deals with the basic idea of the proposed MRAC. Section III deals with the stability of the dynamic machine system. Simulation results are presented in section IV respectively. Section V deals with an MRAC that can accurately estimate the stator resistance for a standard indirect vector controlled system. The speed signal is available on the speed encoder. Section VI concludes the work.

I.SYSTEM MODELING

1. Proposed MRAC

The block diagram of the proposed MRAC based speed estimation is shows Fig.1(a). The outer product of $v^{\rightarrow *}$ and $i^{\rightarrow}$(i.e., $v^{\rightarrow *}$x $i^{\rightarrow}$) is selected as the functional candidate of the MRAC. Note that $v^{\rightarrow *}$x $i^{\rightarrow}$ is neither reactive power nor active power. The quantity is denoted as"X". The instantaneous value of the X (i.e.,x_1) is used in the reference model. On the other hand the steady state value of X under Flux –based condition (i.e.,x_4) is considered for the adjustable model. The error of the instantaneous value and steady state value (i.e.,$\epsilon=x_1-x_4$)is fed to the variation mechanism, which yields the estimated rotor speed(i.e.,w_{rest}). The X-based MRAC (X-MRAC) for speed estimation is shown in Fig.1(a). The schematic diagram of the complete vector control drive with the proposed X-MRAC shows the Fig.1(b) .

The X-MRAC can also be used for stator resistance estimation, if speed signal is available from speed encoder. This is discussed in section V at the end of this paper.

2. Formulation of the X-MRAC

The induction motor stator voltages in the synchronously rotating reference frame may be expressed as

$$v_{sq} = R_s i_{sq} + w_e L_s i_{sd} + \rho\sigma L_s i_{sq} + \frac{Lm}{Lr}(w_e \psi_{rd}) \qquad (1)$$

$$v_{sd} = R_s i_{sd} - w_e \sigma L_s i_{sq} + \rho\sigma L_s i_{sd} + \frac{Lm}{Lr}(w_e \psi_{rd} + \rho\psi_{rd}) \qquad (2)$$

Instanteous value of X(i.e.$^{\rightarrow *}$x $i^{\rightarrow}$)is defined as

$$X_1 = v_{sd} i_{sq} + v_{sq} i_{sd} \qquad (3)$$

Substituting the values of $v_{sq}$and $v_{sd}$from(1)and (2)in (3),the instantaneous value of X becomes

$$X_2 = \left[R_s i_{sq} + w_e L_s i_{sd} + \rho\sigma L_s i_{sq} + \frac{Lm}{Lr}(w_e \psi_{rd} + \rho\psi_{rd})\right] i_{sd} + \left[R_s i_{sq} - w_e \sigma L_s i_{sd} + \rho\sigma L_s i_{sd} + \rho\sigma L_s i_{sq} - \frac{Lm}{Lr}(w_e \psi_{rd} + \rho\psi_{rd})\right] i_{sq} \qquad (4)$$

At steady state value of X is

$$X_3 = \left[R_{s i_{sq}} w_e \sigma L_s i_{sd} + \rho\sigma L_s i_{sq} + \frac{Lm}{Lr}(w_e \psi_{rd} + \rho\psi_{rq})\right] i_{sd} + \left[R_s i_{sq} - w_e \sigma L_s i_{sd} + \rho\sigma L_s i_{sq} - \frac{Lm}{Lr}(w_e \psi_{rd} + \rho\psi_{rd})\right] i_{sq} \qquad (5)$$

The rotor flux-oriented drive, substituting ψ_{rd}=$L_m i_{sd}$, and ψ_{rq}=0,the simplified expression of X becomes

$$X_4 = w_e[L_s i_{sd}^2 - \sigma L_s i_{sq}^2] + 2R_s i_{sd} i_{sq} \qquad (6)$$

The expression of X_1 is independent of rotor speed. Hence, it is selected for the reference model.X_2,X_3 or X_4 may be chosen as the adjustable model as they are dependent an they are dependent on the rotor speed(w_r).However,X_4 is selected in the adjustable model, as this quantity does not involve flux estimation and any derivative operations.

II.PROPOSED SPEED ESTIMATION ALGORITHM

The speed is estimated using the concept of MRAC. Where reference and adjustable model reference controller compute a certain system variable. The system variable is computed by the reference model does not depend on the quality to be estimated, whereas the adjustable model depends directly estimated quantity. Active and reactive powers, here a fabricated quantity is, termed as X (X=$v_s^{\rightarrow *}$x $i_s^{\rightarrow}$) is considered as the functional candidate. The same value of X in adjustable model (x_a) is computed with the help of reference values of voltages and currents. The actual values of

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d- and q-axis currents are obtained by transforming two-phase currents (i_{α} and i_{β}) with the help of vector rotor.

$$X_r = v_{sq}^* i_{sd}^* + v_{sd}^* i_{sq}^* \quad (7)$$

$$X_a = v_{sq}^* i_{sd} + v_{sd}^* i_{sq} \quad (8)$$

$$\rho mr = \int wedt \quad (9)$$

III.STABILITY ANALYSIS

The vector controlled induction machine drive with the proposed speed of the algorithms has been found to be stable in all the four quadrants of operation. The steady has been performed in a realistic manner by considering all the PI controller values, required in a vector controlled drive and liner zing the machine equitation around stable operating points. The investigation is carried out around a nominal speed, and the dynamics for the mechanical equations for the mechanical equation for a perturbation of Δw_r is neglected as the mechanical time constant is much larger than the electrical time constant.

A. Basic equations

The state-space representation of the machine using stator currents and rotor flux (in the synchronously rotating reference frame) as the state variables is given by(7) and(8). This can be represented in state space domain as

$$\dot{x} = Ax + Bu \quad (10)$$

$$y = cx \quad (11)$$

Linear zing the state space equations around a stable operating point x_0,we get

$$\dot{\Delta x} = A\Delta x + \Delta A x0 + B\Delta u \quad (12)$$

$$\begin{bmatrix} \Delta isd \\ \Delta isq \end{bmatrix} = \Delta y = c\Delta x \quad (13)$$

Where

$$X_0=[i_{sd0} \quad i_{sq0} \quad \psi_{rd0} \quad \psi_{rq0}]^T \quad (14)$$

A. Stability of speed Estimation Algorithm

The block diagram of speed estimation using X-MRAC is shown in Fig.1(a).theΔ A matrix can be defined by

$$\Delta u = \begin{matrix} \Delta vsd \\ \Delta vsq \\ 0 \\ 0 \end{matrix} \quad (15)$$

Where,$a_3=(1/\sigma L_s)(\frac{Lm}{Lr})$.$\Delta v_{sd}$ and Δv_{sq} are obtained by linear zing the vector control equations, namely

$$V_{sd}=r_3(i_{sd}^* - i_{sd}) \quad (16)$$

$$v_{sq}=r_2\{r_1(w_r)-i_{sd}\} \quad (17)$$

Where,$r_1=(k_{p1}+(k_{i1/s})$=transfer function of the speed PI controller,$r_2=(k_{p2}+(k_{i2}/s))$ transfer function of the q-axis controller and $r_3=(k_{p3}+(k_{i3}/s))$ transfer function of the d-axis controller indicated.

$$\Delta vsd = -r3\Delta isd \quad (18)$$

$$\Delta vsq = -r2\{r1\Delta wr + \Delta isq\} \quad (19)$$

From(13),(15),(19)get the expression of $\Delta i_{sd}/\Delta w_r$ and $\Delta i_{sq}/\Delta w_r$.the X-MRAC error ϵ is given by

ϵ=X_1-X_4

$$\epsilon = v_{sq} i_{sd} + v_{sd} i_{sq} - w_e[L_s i_{sd}^2 - \sigma L_s i_{sq}^2] - 2R_s i_{sd} i_{sq} \quad (20)$$

Now, the variables are perturbed as: w_r^=w_{r0}+Δ w_r,i_{sd}=i_{sd0}+Δi_{sd0},i_{sq}=i_{sq0}+Δi_{sq},w_{sl}= w_{sl0}+Δ $w_{sl}$and ϵ= ϵ_0+$\Delta\epsilon$.

Considering the perturbed signals,Δ ϵ can be ex-pressed as

$$\Delta \epsilon=K_2\Delta i_{sd}+k_3\Delta i_{sq}+k_4\Delta w_{sl}+k_5\Delta w_r \quad (21)$$

TABLE I: Induction machine rating and parameters

Symbol	Meaning	Value
-	Rated shaft power	1.3Kw
-	Line to line voltage	400v
-	Stator phase current	4.4A
-	Rated speed	1430rpm
P	Pole pair	2
L_s	Stator self inductance	0.6848H
L_r	Rotor self-inductance	0.6848H
L_m	Magnetizing inductance	0.6705H
R_s	Stator resistance	5.71Ω
R_r	Rotor resistance	4.0859 Ω
J	Machine inertia	0.011kg-m^2
B	Viscous coefficient	0.0015

IV SIMULATION RESULTS

1. step change of rotor speed and zero-speed operation

The response of the induction motor for a step change in reference speed and zero speed operation can be in seen Fig.4. A step change in speed of 5 rad/sec is applied every 4s, and the actual speed is found to track the reference speed satisfactorily in Fig.2 (a). The estimated speed is available in Fig.2 (b), which shows that the same is very close to the actual rotor speed. Flux orientation is well maintained, is represented in Fig.2(c)

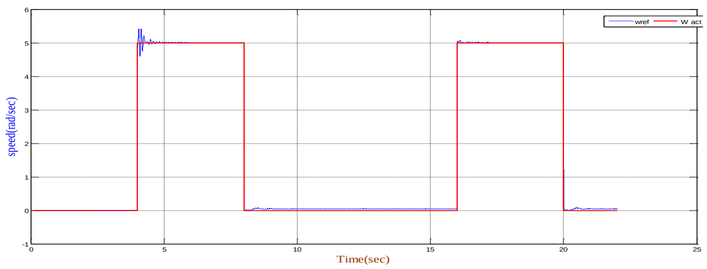

Fig.2 (a)Reference speed and actual speed[rad/sec]versus time[s]

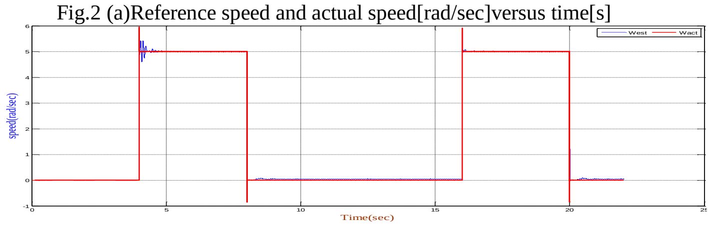

Fig .2 (b)Actual speed and estimated speed [rad/sec] versus time[s]

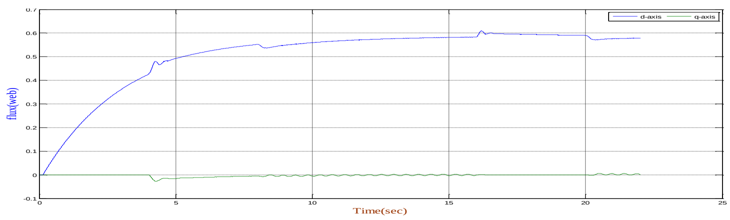

Fig.2 (c) d-axis and q-axis rotor flux[wb] versus time[s]

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2.Ramp response

The tracking performance of the algorithm at low speeds(zero speed) is tested by apllying a traingular wave input as in Fig.3 (a).The estimated speed is following the actual speed which in turn is matching with the reference speed,as shown in Fig.3 (b).the flux orientation is not disturbed as observed in Fig.3 (c).the results have also confirmed stable operation in forword and reverse motoring modes

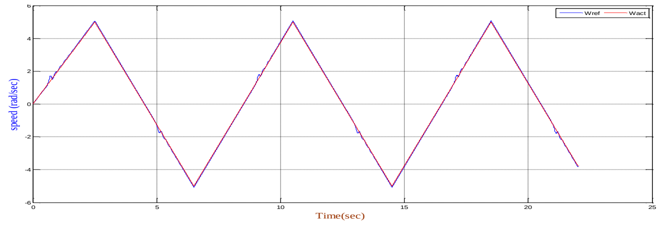

Fig.3 (a) Reference speed and actual speed[rad/sec]versus time[s]

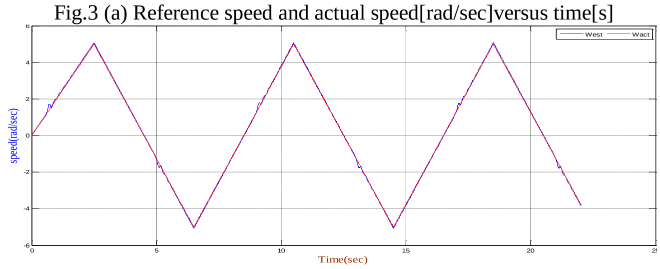

Fig.3 (b) Actual speed and estimated speed [rad/sec] versus time[s]

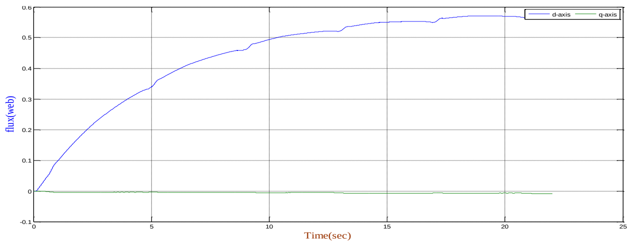

Fig.3 (c) d-axis and q-axis rotor flux[wb] versus time[s]

3. Low speed operation

The performance of the algorithm at a low speed of 1 rad/sec is shown in Fig.4.the estimated and actual speed are shown in Fig.4.(a) and actual and reference speed are shown in Fig.4.(b).the flux orientation is maitained ,which can be seen from shown in Fig.4.(c)

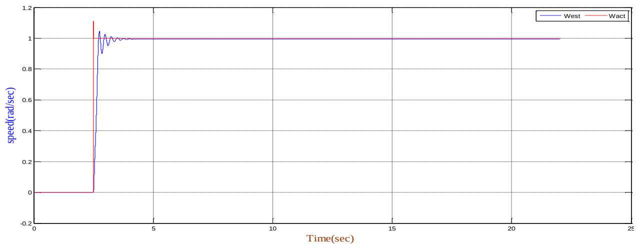

Fig.3 (a) Actual speed and estimated speed [rad/sec] versus time[s]

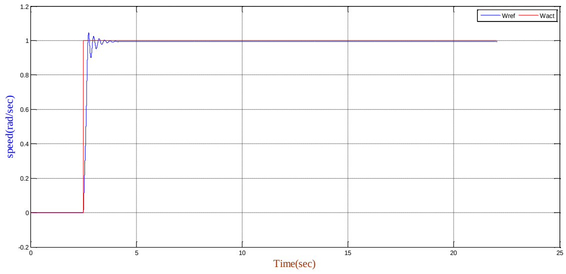

Fig.4 (b) Reference speed and actual speed[rad/sec]versus time[s]

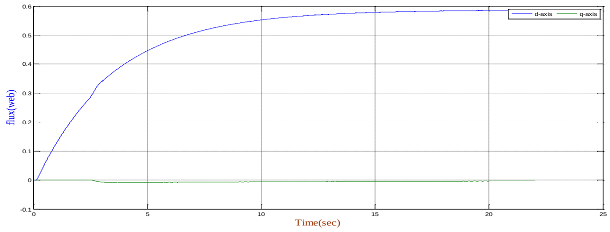

Fig.4 (c) d-axis and q-axis rotor flux[wb] versus time[s]

4. *Regenerating mode operation*

A).*second quadrant opearation*: The performance of the proposed speed estimator can be better seen from Fig.5 which shows the transition of the estimator from motoring to regenerating mode and back.the actual and reference speed are shown in Fig.5 (a) and the estimated and actual speed are shown in Fig.5 (b). the flux orientation is maitained ,which can be seen from shown in Fig.5 (c).the load torque is represented as shown in Fig.5 (d).

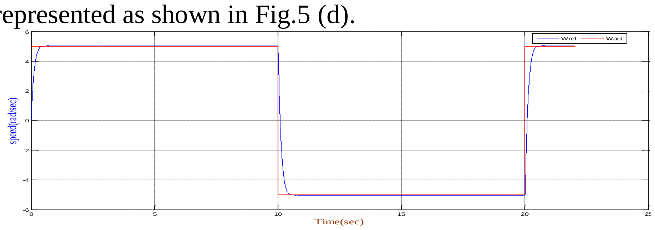

Fig.5 (a) Reference speed and actual speed[rad/sec]versus time[s]

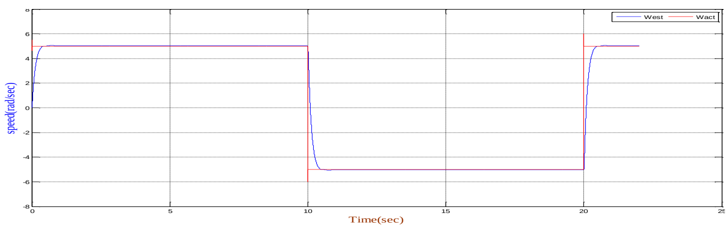

Fig.5 (b) Actual speed and estimated speed [rad/sec] versus time[s]

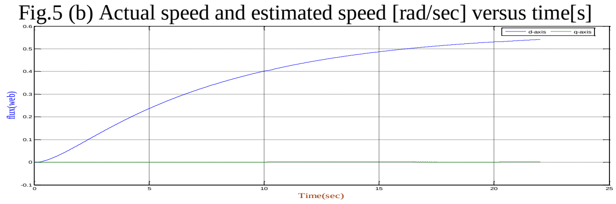

Fig.5 (c) d-axis and q-axis rotor flux[wb] versus time[s]

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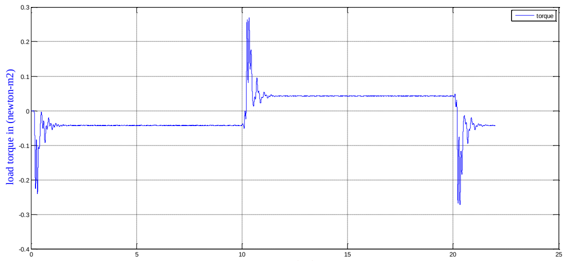

Fig.5 (d)Machine torque and load torque [Nm]versus time[sec]

B) Fourth quadrant operation :

The performance of the proposed speed estimator in the fourth quadrant can be seen from Fig.6. Which shows the transition of the machine from motoring to regenerating mode and back. the actual and reference speed are shown in Fig. 6(a).and the estimated and actual speed are shown in Fig. 6(b). the flux orientation is maitained ,which can be seen from shown in Fig. 6(c).the load torque is represented as shown in Fig.6(d)

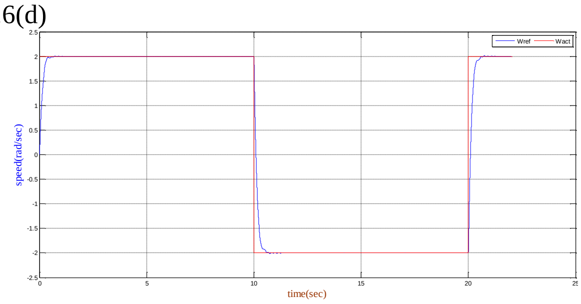

Fig.6(a) Reference speed and actual speed[rad/sec]versus time[s]

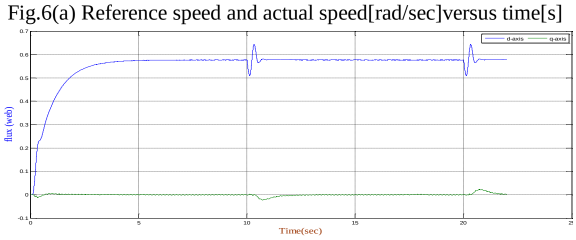

Fig.6(c) d-axis and q-axis rotor flux[wb] versus time[s]

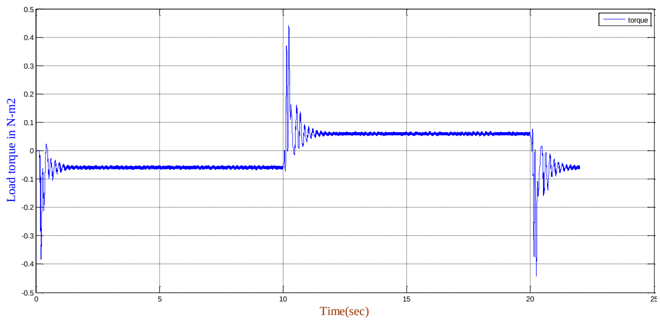

Fig.6 (d)Machine torque and load torque [Nm]versus time[sec]

5.Step change of rotor speed and zero speed operation

The response of the induction motor for step change and zero speed operation are shown in Fig.7.A step change speed of 5 rad/sec is applied every 4s from 0 rad/sec and the actual speed is found to track the performance speed satisfactorily. the actual and reference speed are shown in Fig.7(a).and the estimated and actual speed are shown in Fig.7(b). the flux orientation is maitained ,which can be seen from shown in Fig.7(c).

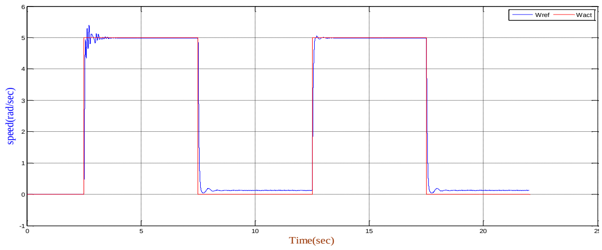

Fig.7(a) Reference speed and actual speed[rad/sec]versus time[s]

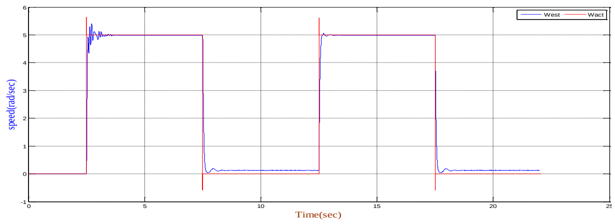

Fig.7(b) Actual speed and estimated speed [rad/sec] versus time[s]

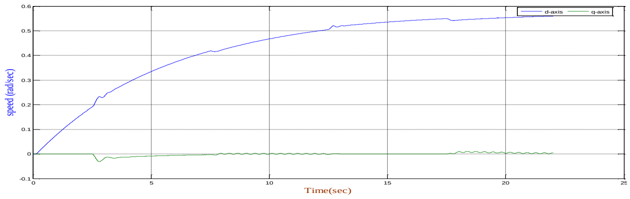

Fig.7(c) d-axis and q-axis rotor flux[wb] versus time[s]

6.Regenerative mode operation:

The performance of the regenerative mode is located in the second quadrant modes of operation .The torque generated by the induction machine shown in fig.8.A reference speed of -5rad/sec is applied to the machine the actual and reference speed are shown in Fig.8(a). the estimated and actual speed are shown in Fig.8(b). the flux orientation is maitained , the machine and load torque is represented as shown in Fig.8(d).which shows that the proposed MRACcan estimate the rotor speed satisfactorily even in the regenerative mode of operation.

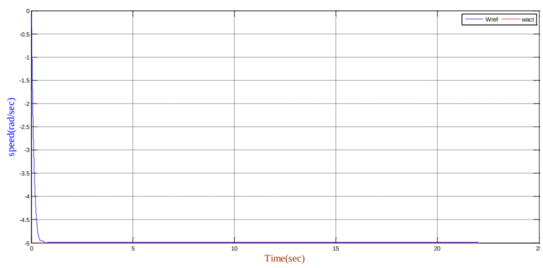

Fig.8(a) Reference speed and actual speed[rad/sec]versus time[s]

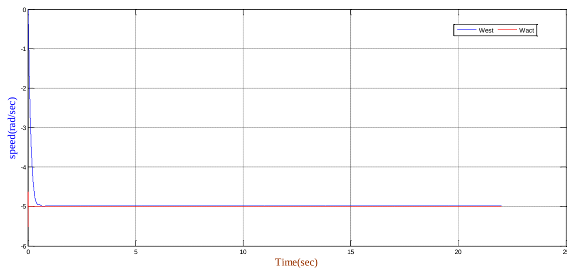

Fig.8(b) Actual speed and estimated speed [rad/sec] versus time[s]

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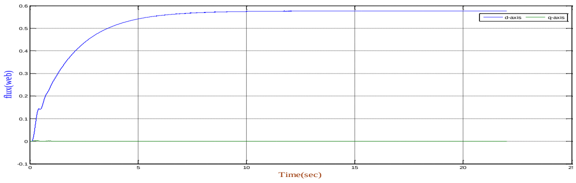


Fig.8(c) d-axis and q-axis rotor flux[wb] versus time[s]

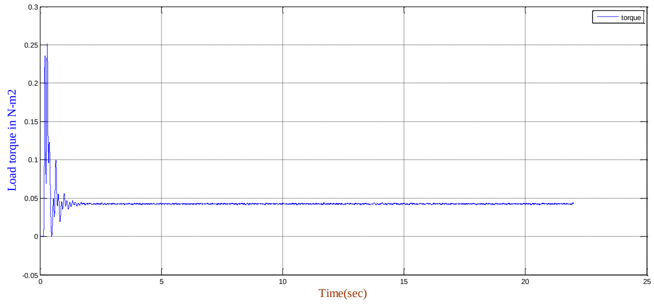


Fig.8(d)Machine torque and load torque [Nm]versus time[sec]

Response to ramp command in speed:

The performance of algorithm for a ramp command in speed reference is shown in fig.9. A reference speed of -5rad/sec is applied to the machine the actual and reference speed are shown in Fig.9(a).and the estimated and actual speed are shown in Fig.9(b). the flux orientation is maitained is shown in Fig.9(c).

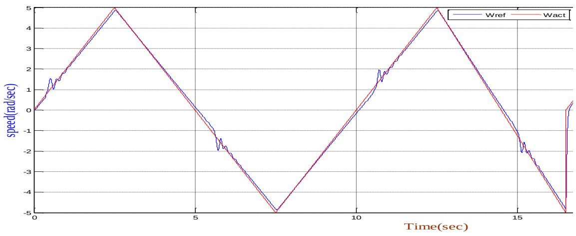


Fig 5.2.8.(a) Reference speed and actual speed[rad/sec]versus time[s]

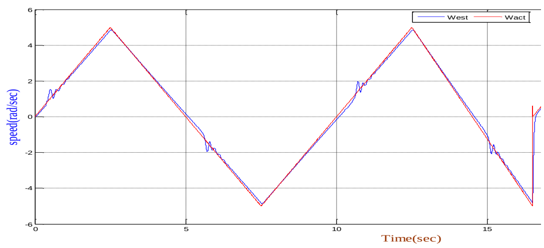


Fig.9 (b) Actual speed and estimated speed [rad/sec] versus time[s]

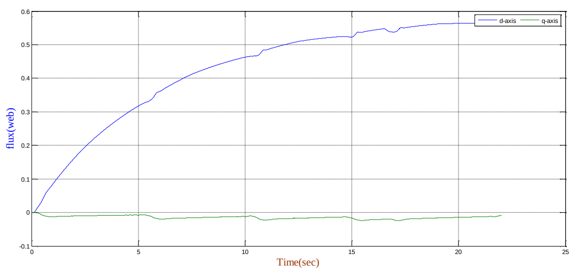


Fig.9 (c) d-axis and q-axis rotor flux[wb] versus time[s]

8.Low speed operation:

the simulation results corresponding to the operation of the proposed controller at 1 rad/sec reference can be seen from fig.10 the actual and reference speed are shown in Fig.10(a).and the estimated and actual speed are shown in Fig10(b). the flux orientation is maitained is shown in Fig.10(c).

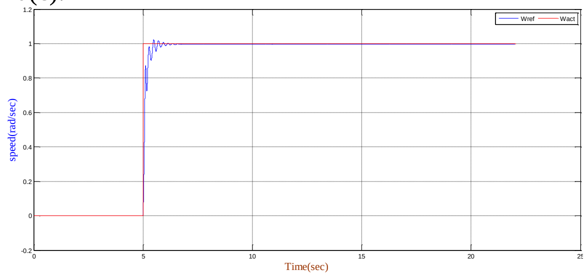


Fig.10(a) Reference speed and actual speed[rad/sec]versus time[s]

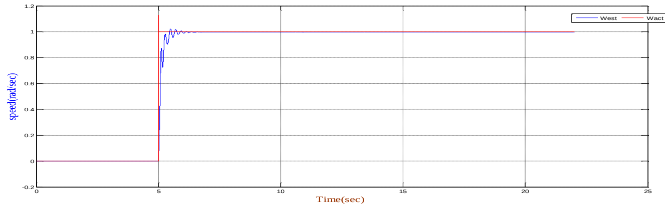


Fig.10(b) Actual speed and estimated speed [rad/sec] versus time[s]

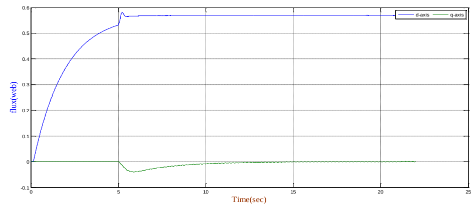
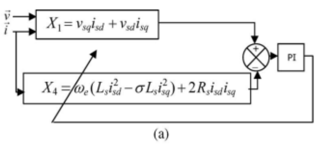


Fig.10(c) d-axis and q-axis rotor flux[wb] versus time[s]

V STATOR RESISTANCE ESTIMATION

A.stator resistance Estimation

The proposed controller requires an estimate of Rs to compute X_4 in the adjustable model.This dependency may be Fig.9.(a) Actual speed and Estimated speed[rad/sec]versus Time[s].(c)d-axis nad q-axis rotor flux[Wb] versus time[s].Fig.11.X-MRAC-based stator resistance estimation.



Exploited to from an algorithm to estimate Rs in case the speed signal is available from the speed encoder or tacho-generator.the corresponding the controller is shown in fig.11.

B. Simulation Result

The performance of the Rs-estimator (Fig. 10) under the step change of stator resistance is shown in Fig. 10. It can be seen that the estimated stator resistance is following the actual stator resistance satisfactorily

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VI. CONCLUSION

A new MRAC-based speed estimation technique is presented in this paper. In the proposed system, a fictitious quantity (called as $X = \vec{v}^{*} x \vec{i}$) is used as the functional candidate to form the MRAC. Such selection has resulted in several merits over the existing approaches. The proposed controller is stable in all the four quadrant modes of operation. Computation of flux is no longer required. Absence of pure integration in the controller has resulted in excellent performance at zero or low speeds. Selection of instantaneous and steady-state (with flux orientation) value of X in the reference and adjustable models, respectively, reduced the computational burden significantly. In case the speed signal is available from the encoder, the proposed MRAC may be slightly modified to estimate Rs. This is discussed in brief at the end of this paper. A correct estimation of Rs provides indirectly the rise in stator temperature of the machine, which is extremely important for condition monitor- ing of the drive. The usefulness of the proposed algorithms has been con- firmed through stability study (small signal analysis in state space domain), simulation (in MATLAB/SIMULINK).Note that the implementation of the proposed method requires no extra hardware, which makes it suitable for retreat applications.

APPENDIX CONTROLLER GAINS

Proportional gain of the speed controller	0.05
Integral gain of the speed controller	0.5
Proportional gain of the MRAC adaption mechanism	1
Integral gain of the MRAC adaption mechanism	9

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G.Balasubbarayudu was born in 1990.studying M.Tech(power electronics and electrical drives) in st.Johns college of engineering and technology from JNTUA. he received B.Tech degree in electrical and electronics engineering from anurag college of engineering from JNTU Hyderabad.


S.Rehana Begum was born in 1989.she received M.Tech(control system) degree in electrical and electronics engineering from JNTUA anatapur.she received B.Tech from sri sai institute of technology and science of JNTUA.presently she is working as Assistant professor in st.Johns college of engineering and technology.

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