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Review Article

SIMULATION AND CONTROL OF INDUCTION MOTOR DRIVE USING ADVANCED SOFT COMPUTING TECHNIQUES

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ABSTRACT

Induction motor drives have certain advantages such as less cost, ruggedness, and required low maintenance. Field oriented control provides a good solution for industrial applications. Normally to implement a vector control operation, we generally require number of position sensors such as speed, voltage, and current sensors. But if we use, the position sensors then the cost and size will be increased. Hence, to overcome this, we need to use a limited number of sensors. Reducing the number of sensors will increase the reliability of the system. Hence, if we eliminate the number of sensors, we need to estimate the required quantity. The estimation can be done using different strategies like model based and signal based out of this model-based estimation the best method to estimate the speed using model reference adaptive system.

Keywords: Induction motor, Vector control, Model reference adaptive system.

INTRODUCTION

There are different model reference adaptive system (MRAS) methods available such as flux-based MRAS and reactive power based MRAS. [1-4] flux-based MRAS has certain disadvantages like consisting of a pure integrator and the effect of stator resistance [2]. The back electromotive force based MRAS does have problem of pure integrator but it has disadvantage of derivative terms [2]. If we go for a reactive power based MRAS, it has advantages like the absence of pure integrator and it also does not have effect of stator resistance, but the problem with this kind of MRAS is that it is unstable in regenerative mode of operation [3]. A vector controlled induction motor offers an exact control of induction motor over a scalar control because a scalar control although provides good steady state response but it possesses very poor performance during dynamic situation [3]. To achieve field oriented control the entire flux should be aligned on the direct axis [1]. To convert the three phase machine variables into two phase variables, we have to perform Clarks transformation [4]. Different reference frames are discussed [4]. The machine modeling equations are considered in synchronous reference frame where all the variables appear as DC quantities [3-6].

MODELING OF AN INDUCTION MOTOR

Fig. 1 shows block diagram of various steps in modeling the induction machine.

Dynamic model state – space equations

Let's define the flux linkage variables as follows:

$$F_{qs}=w_b\Psi_{qs} \quad (1)$$

$$F_{qr}=w_b\Psi_{qr} \quad (2)$$

$$F_{ds}=w_b\Psi_{ds} \quad (3)$$

$$F_{dr}=w_b\Psi_{dr} \quad (4)$$

Where, w_b=Base frequency of machine.

$$V_{qs} = R_s i_{qs} + \frac{1}{w_b}\frac{d(F_{qs})}{dt} + \frac{w_e}{w_b}F_{ds} \quad (5)$$

$$V_{ds} = R_s i_{ds} + \frac{1}{w_b}\frac{d(F_{ds})}{dt} + \frac{w_e}{w_b}F_{qs} \quad (6)$$

$$0 = R_r i_{qr} + \frac{1}{w_b}\frac{d(F_{qr})}{dt} + \frac{w_e - w_r}{w_b}F_{dr} \quad (7)$$

$$0 = R_r i_{dr} + \frac{1}{w_b}\frac{d(F_{dr})}{dt} - \frac{w_e - w_r}{w_b}F_{qr} \quad (8)$$

It is assumed that $V_{qr}=V_{dr}=0$.

Multiplying the equations by w_b on both sides, the flux linkage expressions will be:

$$F_{qs}=w_b\Psi_{qs}=X_{ls}i_{qs}+X_m(i_{qs}+i_{qr}) \quad (9)$$

$$F_{qr}=w_b\Psi_{qr}=X_{lr}i_{qr}+X_m(i_{qs}+i_{qr}) \quad (10)$$

$$F_{qm}=w_b\Psi_{qm}=X_m(i_{qs}+i_{qr}) \quad (11)$$

$$F_{ds}=w_b\Psi_{ds}=X_{ls}i_{ds}+X_m(i_{ds}+i_{dr}) \quad (12)$$

$$F_{dr}=w_b\Psi_{dr}=X_{lr}i_{dr}+X_m(i_{ds}+i_{dr}) \quad (13)$$

$$F_{dm}=w_b\Psi_{dm}=X_m(i_{ds}+i_{dr}) \quad (14)$$

Where, $X_{ls}=w_bL_{ls}$, $X_{lr}=w_bL_{lr}$ and $X_m=w_bL_m$ or

$$F_{qs}=X_{ls}i_{qs}+F_{qm} \quad (15)$$

$$F_{qr}=X_{lr}i_{qr}+F_{qm} \quad (16)$$

$$F_{ds}=X_{ls}i_{ds}+F_{dm} \quad (17)$$

$$F_{dr}=X_{ls}i_{dr}+F_{dm} \quad (18)$$

From Equations (15-18), the currents can be expressed in terms of flux linkages as:

$$i_{qs} = \frac{F_{qs} - F_{qm}}{X_{ls}} \quad (19)$$

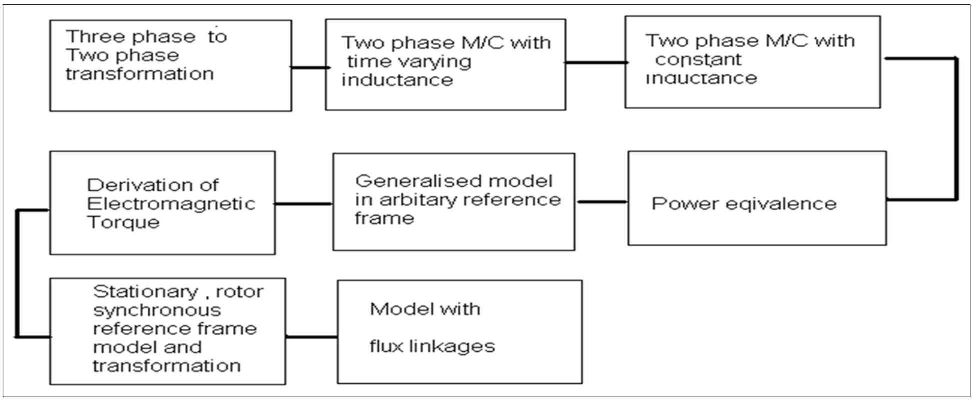


Fig. 1: Steps involved in modeling of induction machine

$$i_{qr} = \frac{F_{qr} - F_{qm}}{X_{lr}} \quad (20)$$

$$i_{ds} = \frac{F_{ds} - F_{qm}}{X_{ls}} \quad (21)$$

$$i_{dr} = \frac{F_{dr} - F_{qm}}{X_{lr}} \quad (22)$$

$$F_{qm} = X_m \left[\frac{F_{qs} - F_{qm}}{X_{ls}} + \frac{F_{qr} - F_{qm}}{X_{lr}} \right] \quad (23)$$

$$F_{qm} = F_{qs}\frac{X_{ml}}{X_{ls}} + F_{qr}\frac{X_{ml}}{X_{lr}} \quad (24)$$

Where, $X_{ml} = \dfrac{1}{\frac{1}{X_m} + \frac{1}{X_{ls}} + \frac{1}{X_{lr}}}$ (25)

And for F_{dm} as:

$$F_{qm} = F_{qs}\frac{X_{ml}}{X_{ls}} + F_{qr}\frac{X_{ml}}{X_{lr}} \quad (26)$$

$$V_{qs} = \frac{R_s}{X_{ls}}(F_{qs} - F_{qm}) + \frac{1}{w_b}\frac{d(F_{qs})}{dt} + \frac{w_e}{w_b}F_{ds} \quad (27)$$

$$V_{ds} = \frac{R_s}{X_{ls}}(F_{ds} - F_{dm}) + \frac{1}{w_b}\frac{d(F_{ds})}{dt} - \frac{w_e}{w_b}F_{ds} \quad (28)$$

$$0 = \frac{R_r}{X_{lr}}(F_{qr} - F_{qm}) + \frac{1}{w_b}\frac{d(F_{qr})}{dt} + \frac{w_e - w_r}{w_b}F_{dr} \quad (29)$$

$$0 = \frac{R_r}{X_{lr}}(F_{dr} - F_{dm}) + \frac{1}{w_b}\frac{d(F_{dr})}{dt} + \frac{w_e - w_r}{w_b}F_{qr} \quad (30)$$

It can be expressed in state-space form as:

$$\frac{d(F_{qs})}{dt} = w_b\left[V_{qs} - \frac{w_e}{w_b}F_{ds} - \frac{R_s}{X_{ls}}(F_{qs} - F_{qm})\right] \quad (31)$$

$$\frac{d(F_{ds})}{dt} = w_b\left[V_{ds} - \frac{w_e}{w_b}F_{qs} - \frac{R_s}{X_{ls}}(F_{ds} - F_{qm})\right] \quad (32)$$

$$\frac{d(F_{qr})}{dt} = -w_b\left[\frac{w_e}{w_b}F_{dr} + \frac{R_r}{X_{lr}}(F_{qr} - F_{qm})\right] \quad (33)$$

$$\frac{d(F_{qs})}{dt} = -w_b\left[\frac{w_e}{w_b}F_{qr} + \frac{R_r}{X_{lr}}(F_{dr} - F_{dm})\right] \quad (34)$$

(or)

$$F_{qs} = \int\left\{w_b\left[V_{qs} - \frac{w_e}{w_b}F_{ds} - \frac{R_s}{X_{ls}}(F_{qs} - F_{qm})\right]\right\} \quad (35)$$

$$F_{ds} = \int\left\{w_b\left[V_{ds} - \frac{w_e}{w_b}F_{qs} - \frac{R_s}{X_{ls}}(F_{ds} - F_{dm})\right]\right\} \quad (36)$$

$$F_{qr} = \int\left\{w_b\left[\frac{w_e}{w_b}F_{dr} + \frac{R_r}{X_{lr}}(F_{qr} - F_{qr})\right]\right\} \quad (37)$$

$$F_{dr} = \int\left\{w_b\left[\frac{w_e}{w_b}F_{qr} + \frac{R_r}{X_{lr}}(F_{lr} - F_{dm})\right]\right\} \quad (38)$$

Finally, from Equation (6),

T_e=(3/2)(p/2)(1/w_b)($F_{ds}i_{qs}$–$F_{qs}i_{ds}$) (39)

Equations (35-39) describe the complete model in state-space form where F_{qs}, F_{qr}, F_{ds}, F_{dr} are the state variables.

$$T_e = T_L + J\frac{dw_m}{dt} + Bw_m$$

(or)

$$w_m = \frac{1}{J}\int(T_e - T_1)$$

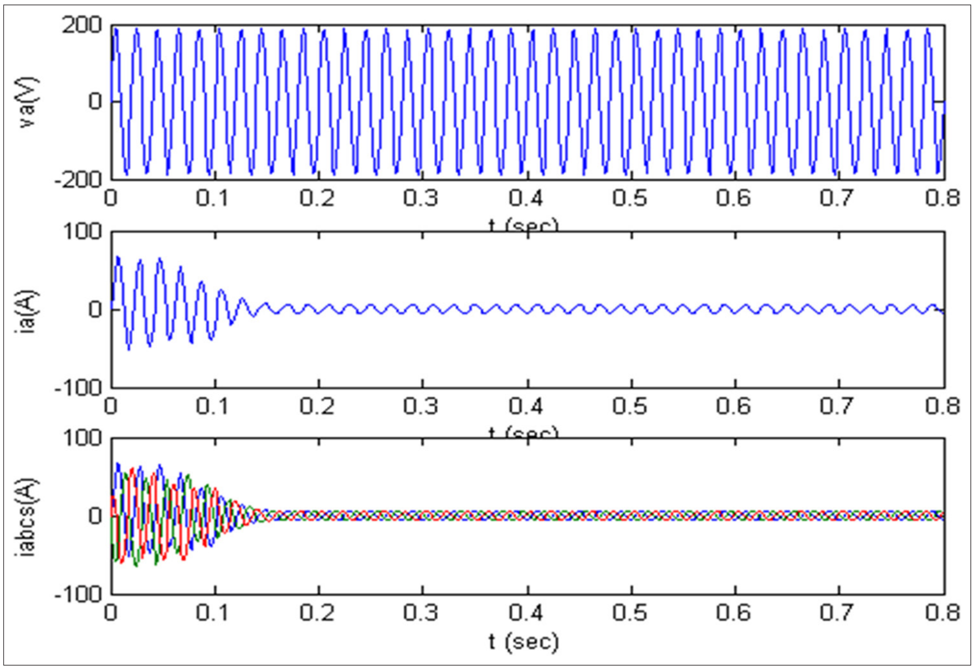
Simulation results

Free acceleration characteristics of an induction motor are given maintaining the load torque as zero (Graphs 1-3).

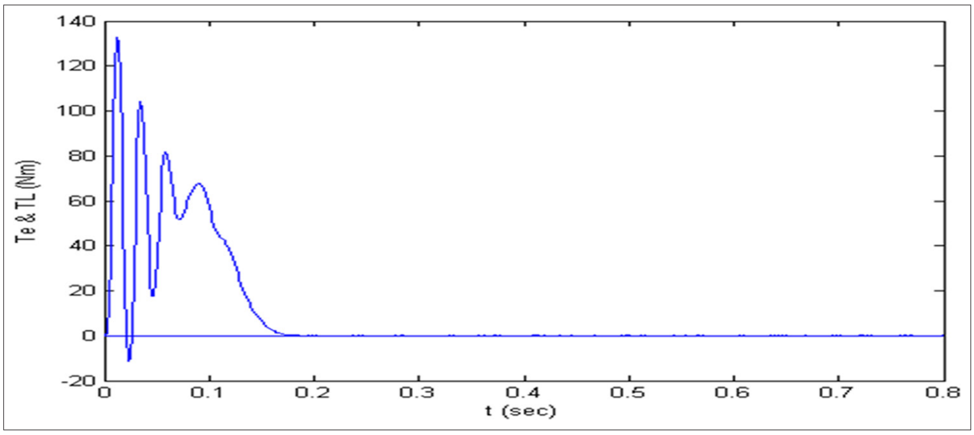
SENSORLESS VECTOR CONTROL

Closed loop observers

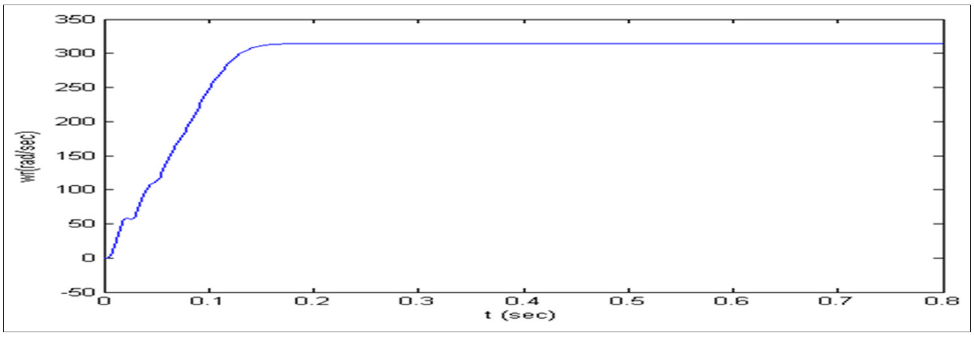
Among all the closed loop observers a MRAS attracts more attention. In this MRAS observer, the output is generated from comparison between two estimators.



Graph 1: No-load response of stationary frame induction motor model



Graph 2: Torque response in direct AC startup with T_L=0



Graph 3: Speed response in direct AC startup with T_L=0

Adaptive control

Adaptive control can be explained in many ways the best way to explain is "a system which adapts itself accordingly with the changes in the system."

MRAS

It consists of reference model and adaptable model as shown in Fig. 2. The speed adaption mechanism will adjust its output based on the outputs of reference and adaptive models.

MRAS based on rotor flux estimation (Fig. 3)

By using the stator voltage equations in stationary reference frame, the reference model equations can be expressed as:

Reference model equations:

$$\dot{\psi}_{dr} = \frac{L_r}{L_m}\upsilon_{ds} - \frac{L_r}{L_m}\left(R_s + \sigma L_s \frac{d}{dt}\right) i_{ds}$$

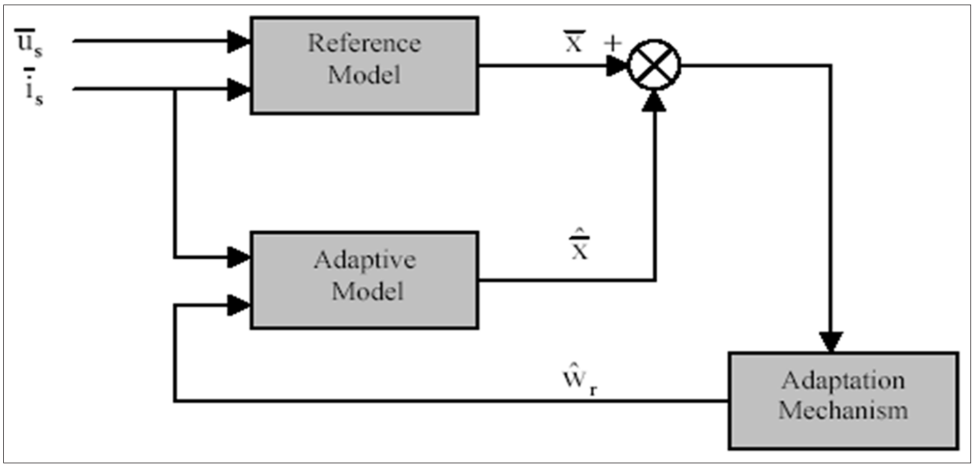


Fig. 2: Model reference adaptive system

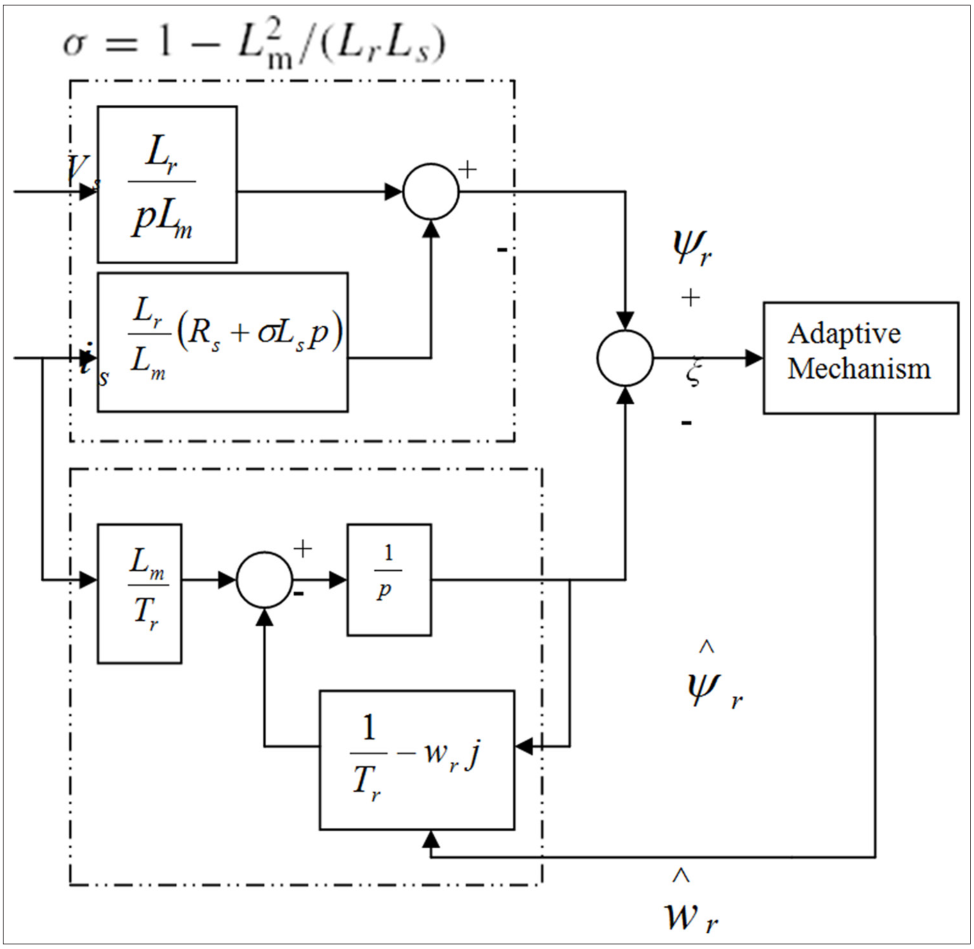


Fig. 3: Model reference adaptive system based on rotor flux estimation

$$\dot{\psi}_{qr} = \frac{L_r}{L_m}\upsilon_{qs} - \frac{L_r}{L_m}\left(R_s + \sigma L_s \frac{d}{dt}\right)i_{qs} \quad (40)$$

Where, Ψ is flux linkage,
L_r, L_m are inductances,
R_s is resistance and,
σ is the leakage coefficient of the motor.

$$\hat{\psi}^s_{dr} = \int\left(\frac{L_m}{T_r}i_{ds} - w_r\hat{\psi}^s_{qr} - \frac{1}{T_r}\hat{\psi}^s_{dr}\right)$$

$$\hat{\psi}^s_{qr} = \int\left(\frac{L_m}{T_r}i_{qs} - w_r\hat{\psi}^s_{dr} - \frac{1}{T_r}\hat{\psi}^s_{qr}\right) \quad (41)$$

Where, w_r is rotor electrical speed and $T_r = L_r/R_r$ is rotor time constant.

Fig. 4 shows the block diagram sensorless vector control.

Simulink implementation of MRAS

V_{ds}, V_{qs}, i_{ds}, i_{qs} inputs are derived from the IM, and their stationary values are calculated in the stationary reference frame.

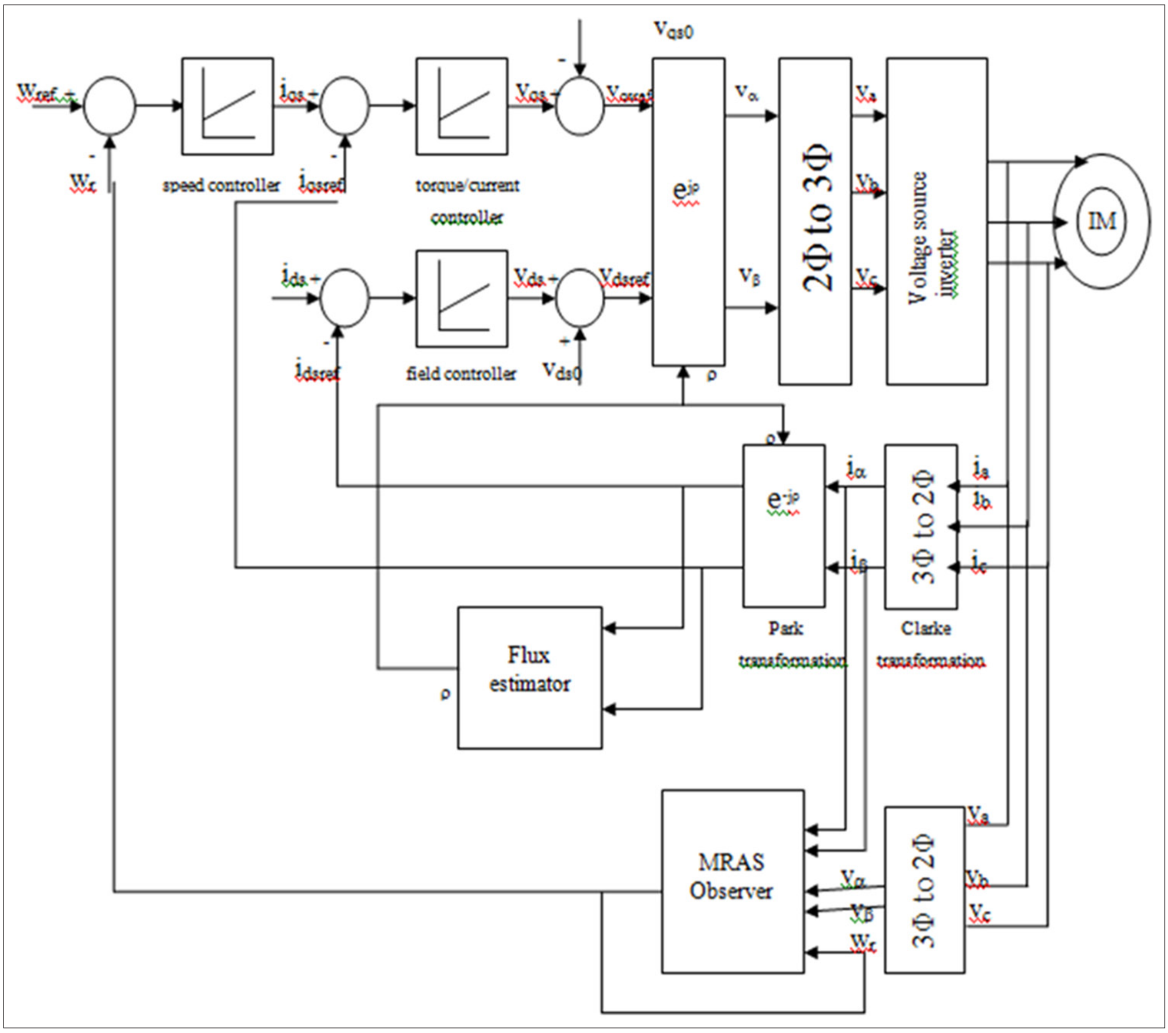


Fig. 4: Block diagram for sensor-less vector control

Using V_{ds}^{s}, V_{qs}^{s}, i_{ds}^{s}, i_{qs}^{s} values ψ_{dr}^{s}, ψ_{qr}^{s} are calculated from reference model equations.

$$\dot{\psi}_{dr} = \frac{L_r}{L_m}\upsilon_{ds} - \frac{L_r}{L_m}\left(R_s + \sigma L_s \frac{d}{dt}\right)i_{ds}$$

$$\dot{\psi}_{qr} = \frac{L_r}{L_m}\upsilon_{qs} - \frac{L_r}{L_m}\left(R_s + \sigma L_s \frac{d}{dt}\right)i_{qs}$$

Similarly by using i_{ds}, i_{qs} and $\hat{\psi}_{dr}^{s}$, $\hat{\psi}_{qr}^{s}$ values $\hat{\psi}_{dr}^{s}$, $\hat{\psi}_{qr}^{s}$ are calculated from the equations, these are the actual estimated values.

$$\hat{\psi}_{dr}^{s} = \int\left(\frac{L_m}{T_r}i_{ds} - w_r\hat{\psi}_{qr}^{s} - \frac{1}{T_r}\hat{\psi}_{dr}^{s}\right)$$

$$\hat{\psi}_{qr}^{s} = \int\left(\frac{L_m}{T_r}i_{ds} + w_r\hat{\psi}_{dr}^{s} - \frac{1}{T_r}\hat{\psi}_{qr}^{s}\right)$$

Using these values, the error can be calculated as:

i.e., $\xi = X - Y = \hat{\psi}_{dr}^{s}\,\hat{\psi}_{qr}^{s} - \hat{\psi}_{qr}^{s}\,\hat{\psi}_{dr}^{s}$

Equation for speed estimation.

Simulation of proposed system (Figs. 5 and 6)
The simulation study is carried out using fuzzy-MRAS based induction motor drive control system in sensorless estimation mode. The Fig. 5 and 6 depict the simulation diagrams of the proposed system

Simulation results
Case A: Ramp response (Graphs 4 and 5).

Case B: Regenerating mode of operation (Graphs 6 and 7).

Case C: Performance under low speed (5 rad/s) (Graphs 8 and 9).

Case D: Linear increase in speed (Graphs 10 and 11).

Fuzzy logic controllers (Figs. 7 and 8)
Simulation results of MRAS observer with fuzzy controller
Case A: Regenerative mode of operation (Graphs 12 and 13).

Case B: Regenerative mode of operation (Graph 14).

Case C: Response under low speed (Graphs 15).

Case D: Linear increase in speed (Graphs 16).

CONCLUSION AND FUTURE SCOPE

This work presented a speed sensorless vector controlled induction motor drive which provides same dynamic and satisfactory performance as that of a vector controlled Induction motor drive using a sensor. The dynamic performance of the proposed system is

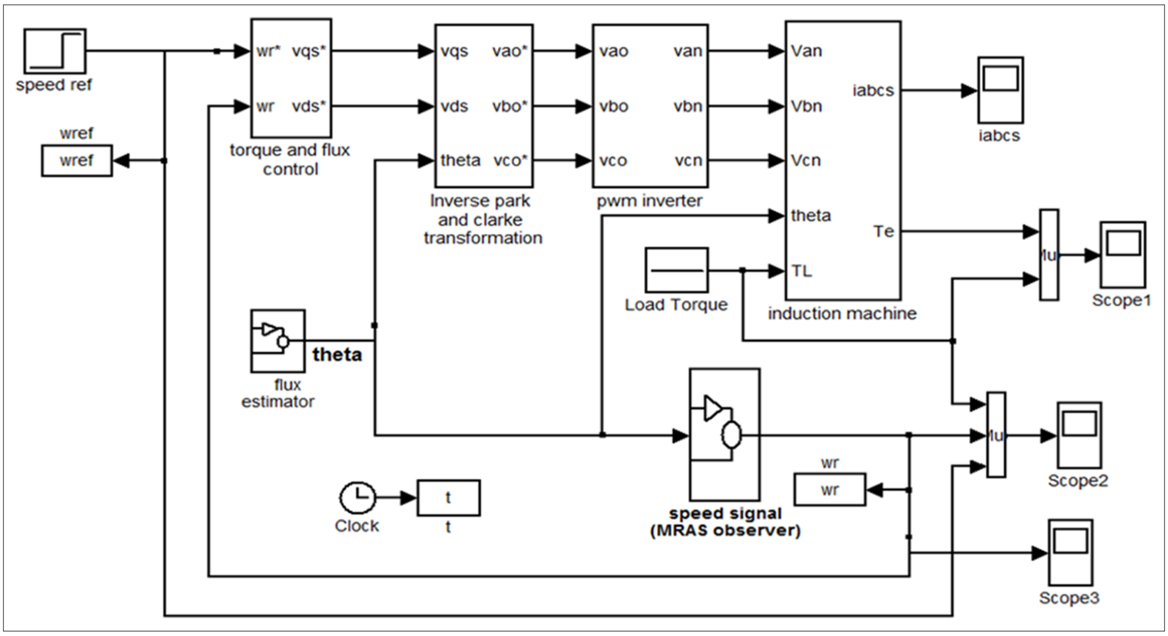


Fig. 5: Simulink model of sensorless vector controlled induction motor drive

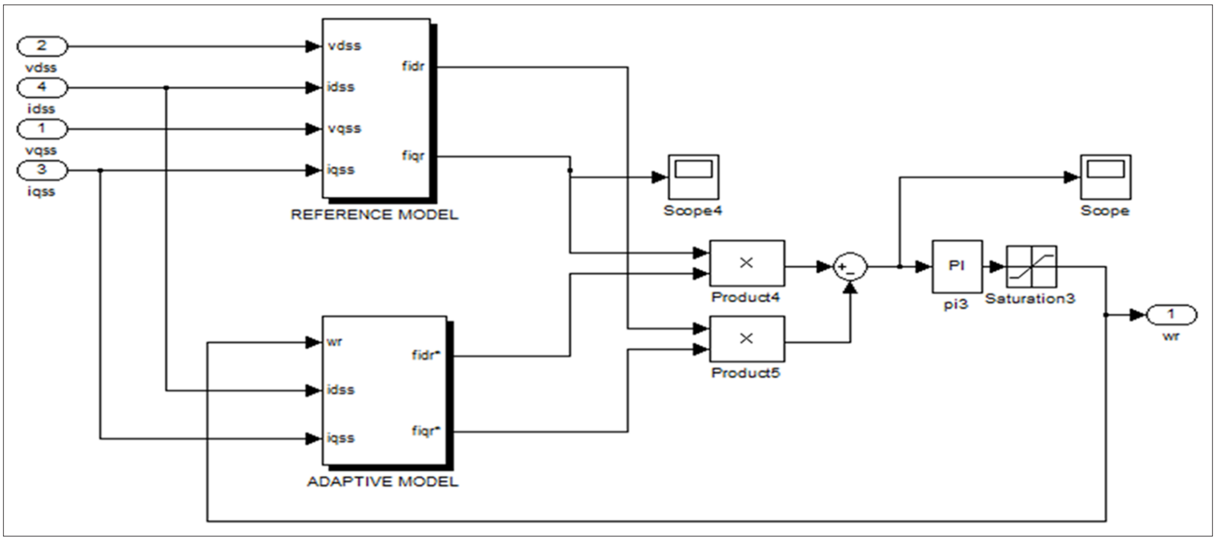
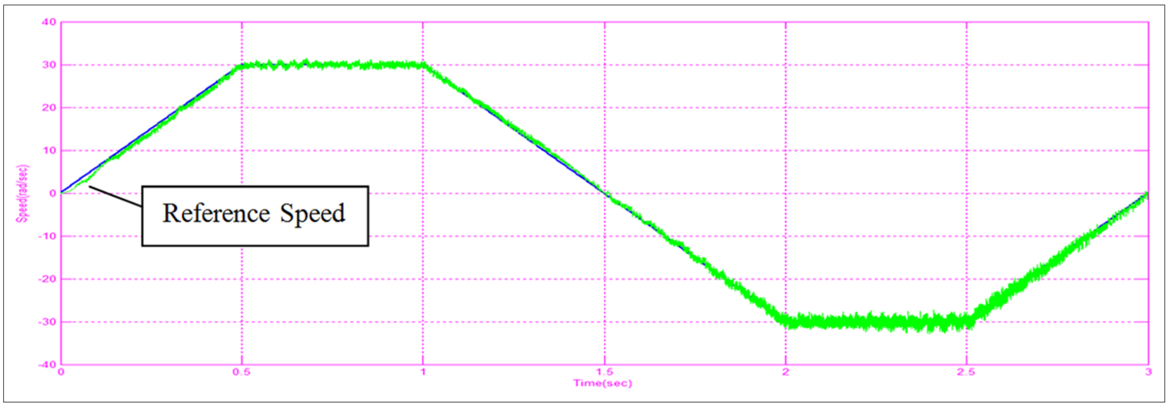
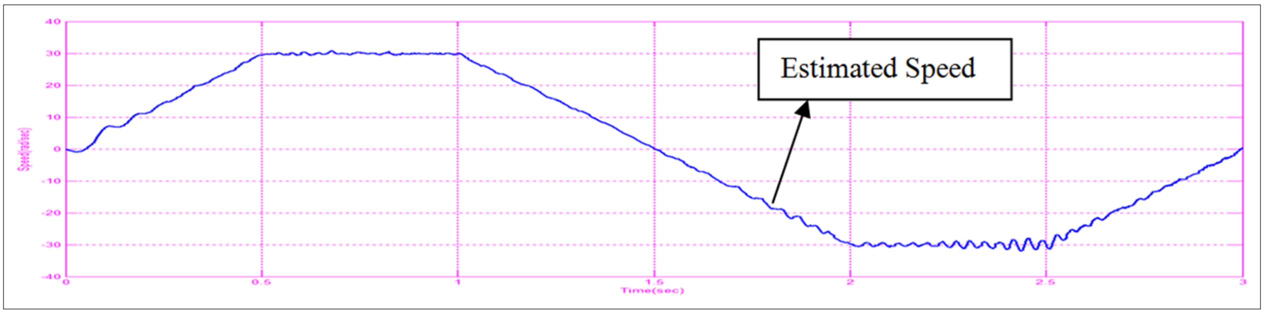


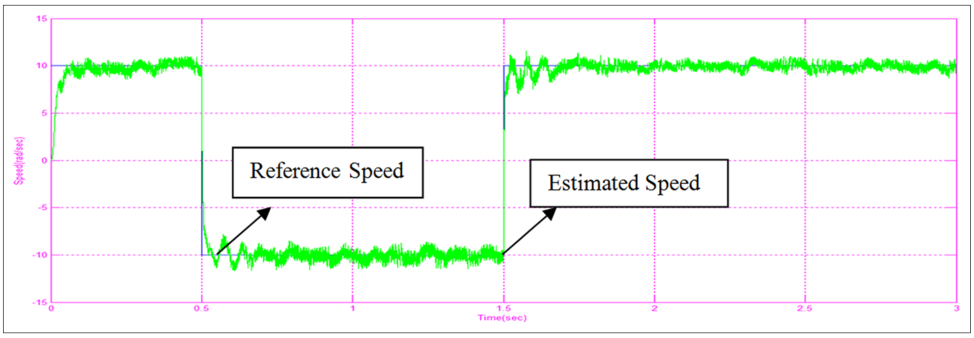
Fig. 6: Simulink model of model reference adaptive system observer



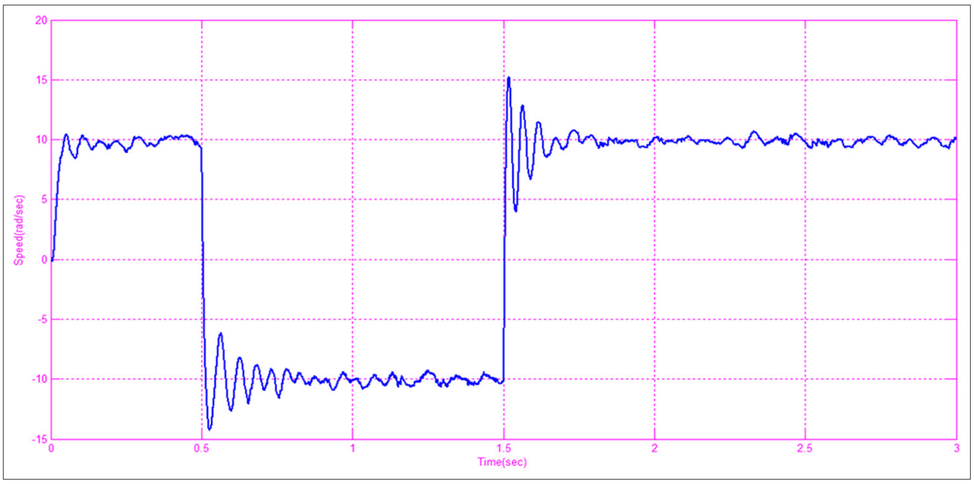
Graph 4: Reference and estimated speeds with ramp response



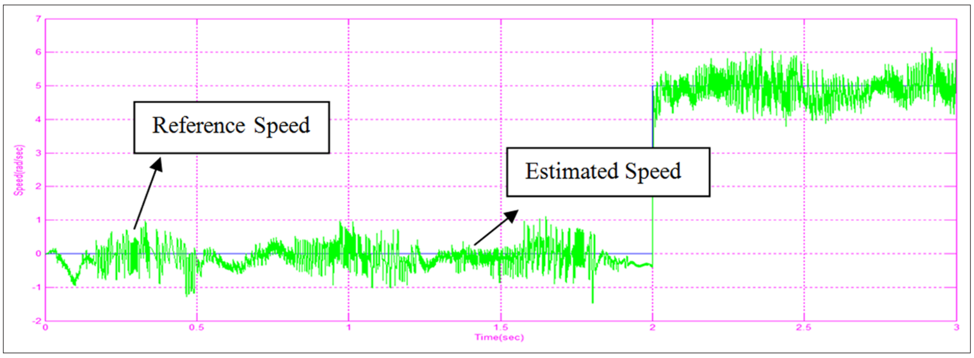
Graph 5: Estimated speed with ramp response



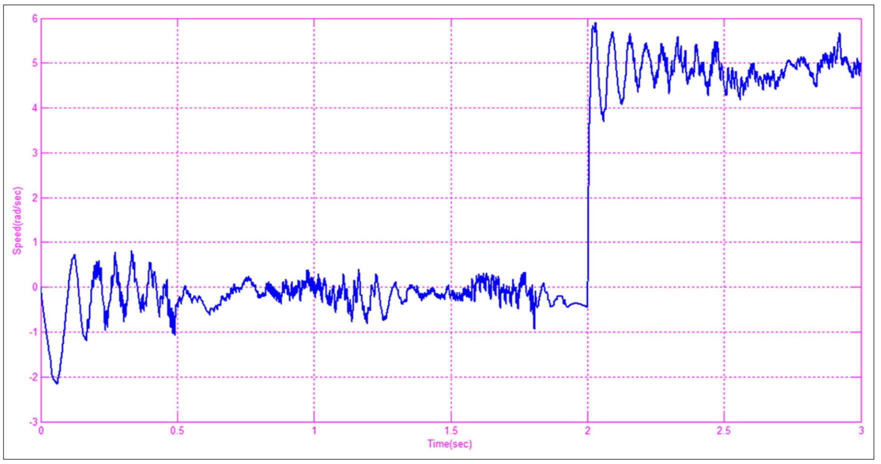
Graph 6: Reference and estimated speeds in regenerative modes of operation



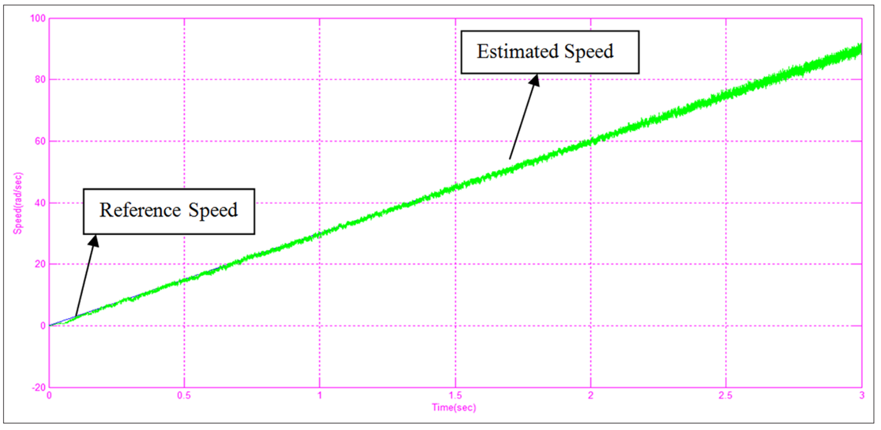
Graph 7: Estimated speed in regenerative modes of operation



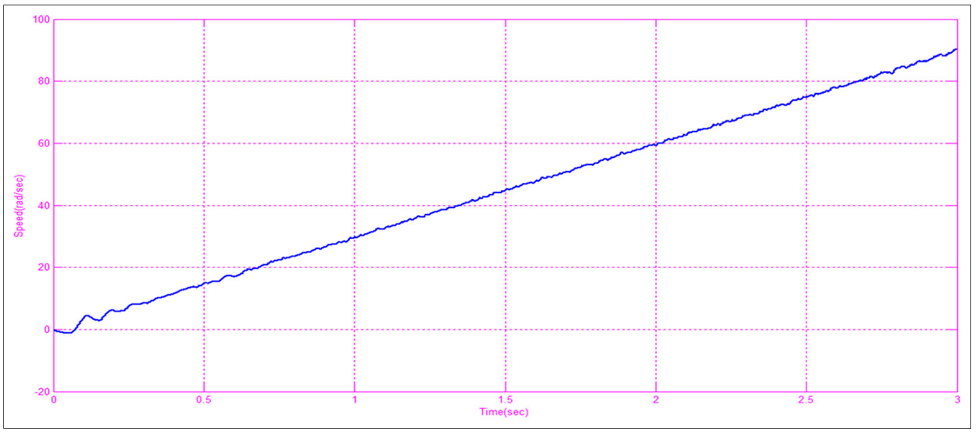
Graph 8: Reference and estimated speeds under low speed range



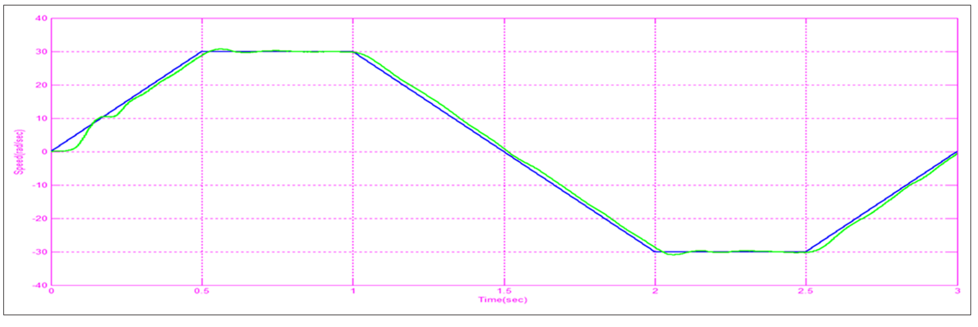
Graph 9: Estimated speed under low speed range



Graph 10: Reference and estimated speeds with linear raise



Graph 11: Estimated speed with linear raise



Graph 12: Reference and estimated speeds with ramp response using fuzzy-MRAS

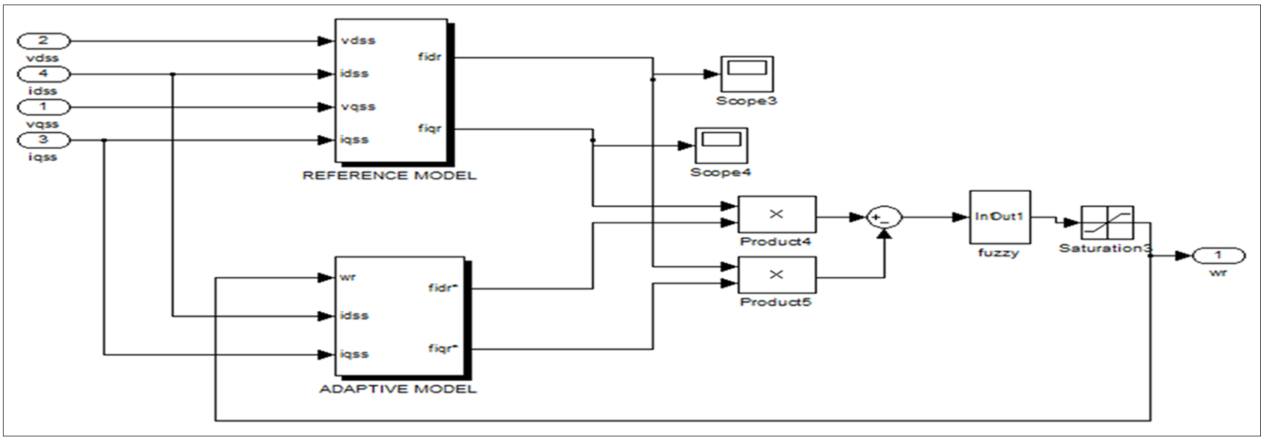


Fig. 7: Simulink block diagram of model reference adaptive system observer with fuzzy controller

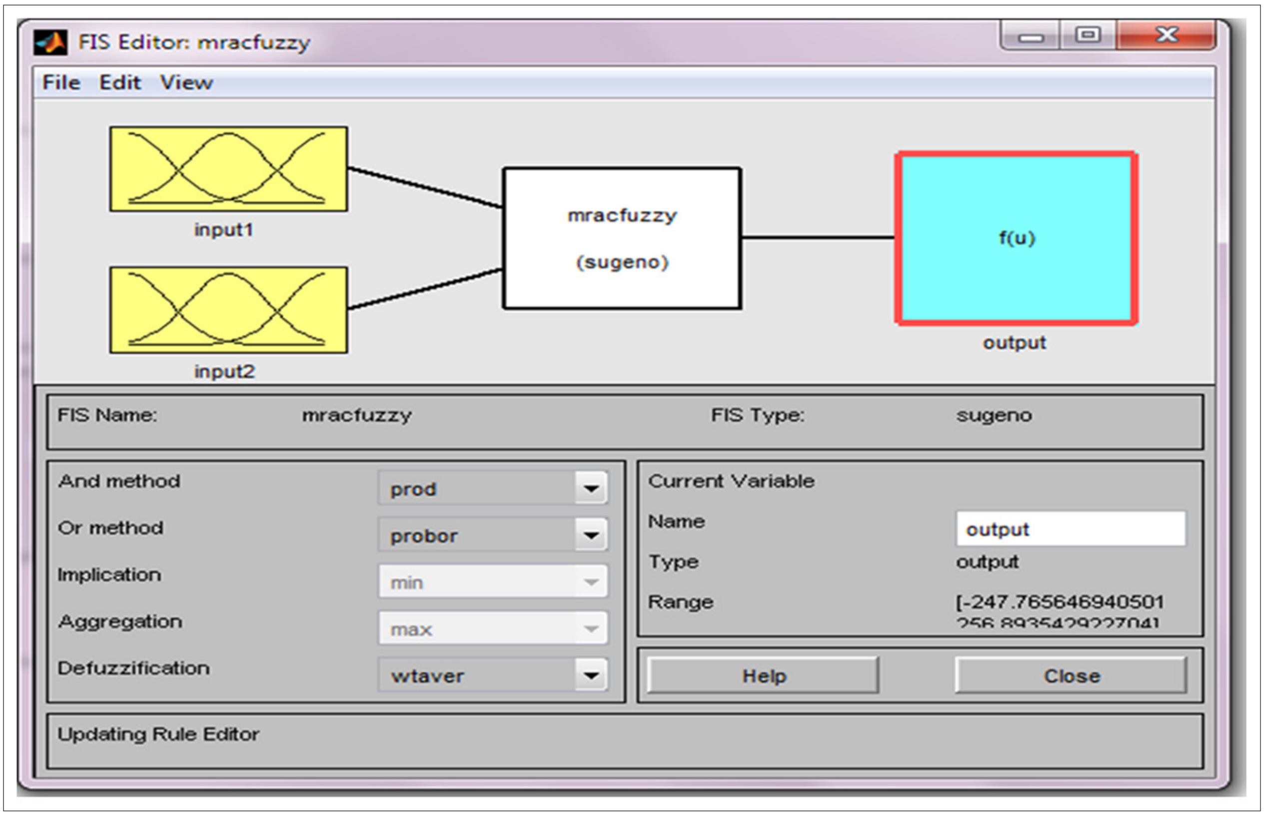
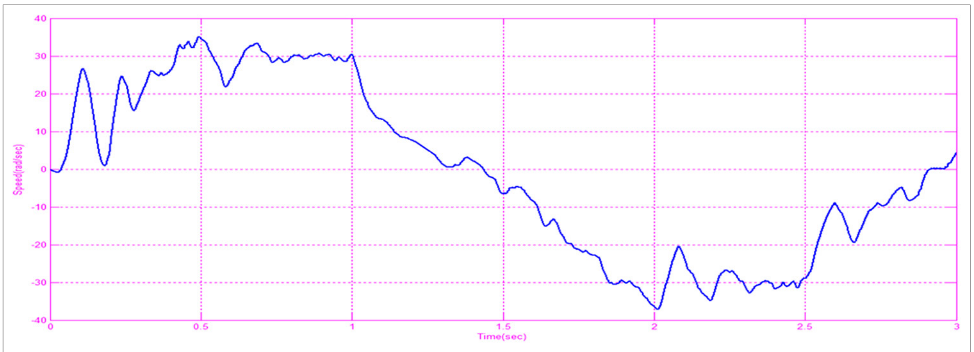
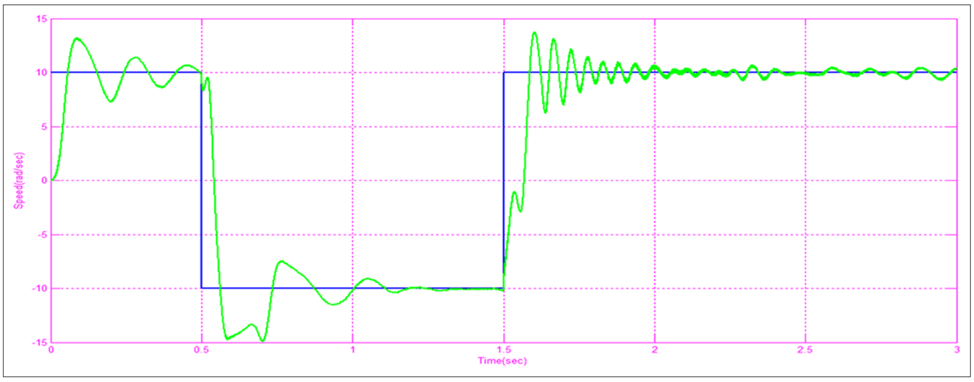


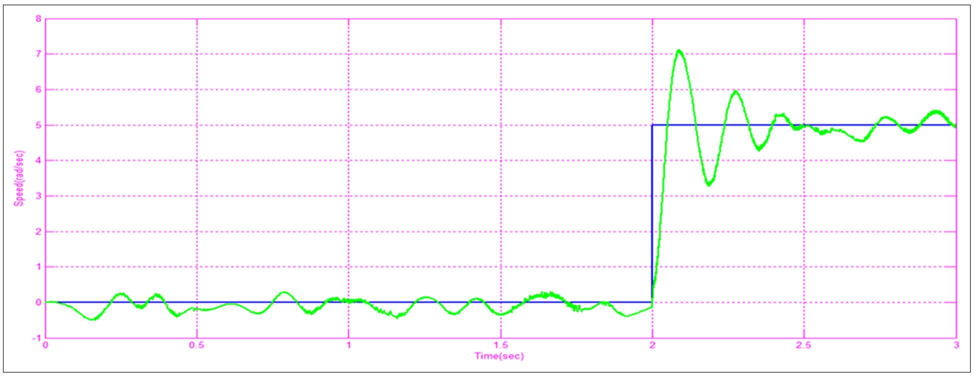
Fig. 8: Editor view of fuzzy controller in MATLAB/Simulink



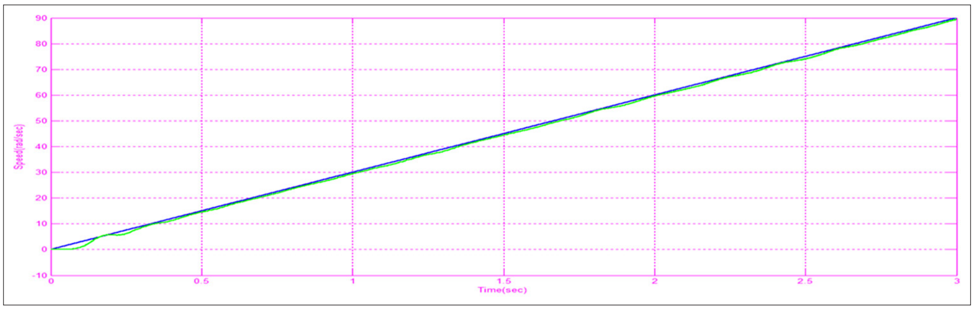
Graph 13: Estimated speed using Fuzzy-MRAS controller for ramp response



Graph 14: Reference and estimated speeds for regenerative mode of operation using Fuzzy-MRAS



Graph 15: Reference and estimated speeds for low speeds using Fuzzy-MRAS



Graph 16: In case of linear increase in speed using Fuzzy-MRAS

tested under many cases. This work also presented a fuzzy controller based MRAS which will give better results than a PI controller based MRAS.

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