Available online at: http://www.ijmtst.com/vol6issue03.html

International Journal for Modern Trends in Science and Technology
ISSN: 2455-3778 :: Volume: 06, Issue No: 03, March 2020

Simulation of Sensorless Speed Control of Induction Motor using Model Reference Adaptive Technique with Fuzzy Inference System

K Narendra Babu[1] | N Sai Ajay Kumar[2] | A Mahesh Kumar[2] | Kalidindi Sai[2]

[1]Assistant Professor, Department of Electrical and Electronics Engineering, Godavari Institute of Engineering and Technology (A), Rajahmundry, Andhra Pradesh, India.
[2]UG Students, Department of Electrical and Electronics Engineering, Godavari Institute of Engineering and Technology (A), Rajahmundry, Andhra Pradesh, India.

To Cite this Article
K Narendra Babu, N Sai Ajay Kumar, A Mahesh Kumar and Kalidindi Sai, "Simulation of Sensorless Speed Control of Induction Motor using Model Reference Adaptive Technique with Fuzzy Inference System", *International Journal for Modern Trends in Science and Technology*, Vol. 06, Issue 03, March 2020, pp.:34-41.
Article Info
Received on 05-February-2020, Revised on 16-February-2020, Accepted on 28-February-2020, Published on 03-March-2020.

ABSTRACT

In the course of recent decades innovative advances in power gadgets and an expanding interest for superior modern hardware has added to fast improvements in computerized engine control. The point of this paper is to plan a fuzzy logic controller to control the speed induction motor drive working without a speed or position sensor yet having a unique exhibition tantamount to a sensored vector drive. This paper displays the control of an enlistment engine through sensorless vector control utilizing pid and fluffy pid controller. The hypothetical premise of every calculation is clarified in detail and its exhibition is tried with reproductions actualized in MATLAB/SIMULINK..

KEYWORDS: *Sensorless induction motor, fuzzy PID controller, Model Reference Adaptive System (MRAS)*

I. Introduction

Induction Motor (IM) can be considered as the 'workhorse' of the business as a result of its extraordinary highlights, for example, minimal effort, high unwavering quality, low idleness, straightforwardness and toughness. Indeed, even today IMs particularly the squirrel confine type, are broadly utilized for single speed applications instead of variable speed applications because of the unpredictability of controlling calculation and higher creation cost of IM variable speed drives. In any case, there is an extraordinary enthusiasm on factor speed activity of IM inside the exploration network predominantly in light of the fact that IMs can be considered as a significant modern heap of a force framework. Then again the IMs expend a lot of power created. Most of IMs are worked at consistent speed, dictated by the shaft pair number and the stator supply recurrence. The two names for a similar sort of engine, enlistment engine and offbeat engine, portray the two attributes wherein this kind of engine varies from DC engines and synchronous engines. Acceptance alludes to the way that the field in the rotor is actuated by the stator flows, and nonconcurrent alludes to the way that the rotor speed isn't equivalent to the stator recurrence. No sliding contacts and changeless magnets are expected to make an IM work, which makes it exceptionally basic and modest to fabricate. As engines, they tough and require next to no support. Be that as it may, their velocities are not as effectively controlled similarly as with DC engines. They draw enormous beginning flows, and work with a poor slacking factor when delicately stacked.

II. MODELLING OF INDUCTION MOTOR

Thecontrol and speed sensorless estimation of IM drives is a vast subject. Traditionally, the IM has been used with constant frequency sources and normally the squirrel-cage machine is utilized in many industrial applications,A typical construction of a squirrel cage IM is illustrated in Figure 1. Its main advantages are the mechanical and electrical simplicity and ruggedness, the lack of rotating contacts (brushes) and its capability to produce torque over the entire speed range.

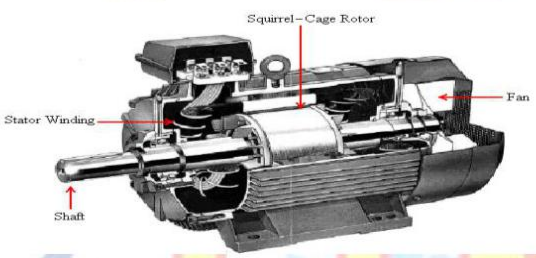

Fig .1: A cut-away view of a squirrel cage IM

Before going to dissect any engine or generator it is particularly essential to acquire the machine as far as its identical numerical conditions. Conventional per stage comparable circuit has been broadly utilized in relentless state investigation and structure of acceptance engine, however it isn't acknowledged to foresee the dynamic execution of the engine. The elements think about the immediate impacts of shifting voltage/flows, stator recurrence, and torque unsettling influence. The dynamic model of the acceptance engine is determined by utilizing a two-stage engine in direct and quadrature tomahawks. This methodology is alluring a direct result of the reasonable effortlessness acquired with two arrangements of windings, one on the stator and the other in the rotor. The comparability between the three stage and two stage machine models is gotten from basic perception, and this methodology is reasonable for extending it to show a n-stage machine by methods for a two stage machine.

A. Reference Frames

The necessary change in voltages, flows, or motion linkages is determined in a summed up way. The reference outlines are picked to be subjective and specific cases, for example, stationary, rotor and synchronous reference outlines are straightforward occurrences of the general case. R.H. Park, during the 1920s, proposed another hypothesis of electrical machine examination to speak to the machine in d – q model. He changed the stator factors to a synchronously pivoting reference outline fixed in the rotor, which is called Park's change. He demonstrated that all the time differing inductances that happen because of an electric circuit in relative movement and electric circuits with fluctuating attractive reluctances could be killed. The voltages v_{ds}^s and v_{qs}^s can be resolved into as-bs-cs components and can be represented in matrix from as,

$$\begin{bmatrix} V_{as} \\ V_{bs} \\ V_{cs} \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta & 1 \\ \cos(\theta-120^0) & \sin(\theta-120^0) & 1 \\ \cos(\theta+120^0) & \sin(\theta+120^0) & 1 \end{bmatrix} \begin{bmatrix} V_{qs}^s \\ V_{ds}^s \\ V_{os}^s \end{bmatrix} \quad 2.1$$

Here v_{os}^s is zero-sequence component, convenient to set $\theta = 0$ so that q_s axis is aligned with as-axis. Therefore ignoring zero-sequence component, it can be simplified as-

$$V_{qs}^s = \frac{2}{3}v_{as} - \frac{1}{3}v_{bs} - \frac{1}{3}v_{cs} = v_{as} \quad 2.2$$

$$V_{ds}^s = -\frac{1}{\sqrt{3}}v_{bs} + \frac{1}{\sqrt{3}}v_{cs} \quad 2.3$$

Equations 2.2consistively called as *Clark Transformation.*

Figure 1shows the synchronously rotating d_e-q_e axes, which rotate at synchronous speed w_e with respect to the d_s-q_s axes and the angle $\theta_y = \omega_e * t$. The two-phase d_s-q_s windings are transformed into the hypothetical windings mounted on the d_e-q_e axes. The voltages on the d_s-q_s axes can be transformed (or resolved) into the d_e-q_e frame as follows:

From the above figure the terminal voltages are as follows, $V_{qs} = R_q i_{qs} + p\,(L_{qq} i_{qs}) + p\,(L_{qd} i_{ds}) + p\,(L_{q\alpha} i_\alpha) + p\,(L_{q\beta} i_\beta)$

$V_{ds} = p\,(L_{dq} i_{qs}) + R_d i_{ds} + p\,(L_{dd} i_{ds}) + p\,(L_{d\alpha} i_\alpha) + p\,(L_{d\beta} i_\beta)$

2.4 $V_\alpha = p\,(L_{\alpha q} i_{qs}) + p\,(L_{\alpha d} i_{ds}) + R_\alpha i_\alpha + p\,(L_{\alpha\alpha} i_\alpha) + p\,(L_{\alpha\beta} i_\beta)$

$V_\beta = p\,(L_{\beta q} i_{qs}) + p\,(L_{\beta d} i_{ds}) + p\,(L_{\beta\alpha} i_\alpha) + R_\beta i_\beta + p\,(L_{\beta\beta} i_\beta)$

Where *p* is the differential operator *d/dt*, and v_{qs}, $v_{ds}$are the terminal voltages of the stator *q* axis and *d* axis. V_α, V_β are the voltages of rotor α and β windings, respectively. i_{qs} and i_{ds} are the stator *q* axis and *d* axis currents. Whereas i_α and i_β are the rotor α and β winding currents, respectively and L_{qq}, L_{dd}, $L_{\alpha\alpha}$ and $L_{\beta\beta}$ are the stator q and d axis winding and rotor α and β winding self-inductances, respectively.

The following are the assumptions made in order to simplify the equation

i. Uniform air-gap
ii. Balanced rotor and stator windings with sinusoidally distributed mmfs
iii. Inductance in rotor position is sinusoidal and
iv. Saturation and parameter changes are neglected

The rotor equations in above equation 2.10 are refereed to stator side as in the case of transformer equivalent circuit. From this, the physical isolation between stator and rotor d-q axis is eliminated.

Dynamic equations of the induction motor in any reference frame can be represented by using flux linkages as variables. This involves the reduction of a number of variables in the dynamic equations. Even when the voltages and currents are discontinuous the flux linkages are continuous. The stator and rotor flux linkages in the stator reference frame are defined as

$$\left.\begin{aligned} \psi_{qs} &= L_s i_{qs} + L_m i_{qr} \\ \psi_{ds} &= L_s i_{ds} + L_m i_{dr} \\ \psi_{qr} &= L_r i_{qr} + L_m i_{qs} \\ \psi_{dr} &= L_r i_{dr} + L_m i_{ds} \end{aligned}\right\} \quad 2.5$$

$$\left.\begin{aligned} \psi_{qm} &= L_m (i_{qs} + i_{qr}) \\ \psi_{dm} &= L_m (i_{ds} + i_{dr}) \end{aligned}\right\} \quad 2.6$$

$$\psi_{ds} = \int (v_{ds} - R_s i_{ds}) dt \quad 2.7$$

$$\psi_{qs} = \int (v_{qs} - R_s i_{qs}) dt \quad 2.8$$

$$\left.\psi_{dr} = \frac{-L_r \omega_r \psi_{qr} + L_m i_{ds} R_r}{R_r + sL_r}\right\} \quad 2.9$$

$$\psi_{qr} = \frac{L_r \omega_r \psi_{dr} + L_m R_r i_{qs}}{R_r + sL_r}$$

$$\left.\begin{aligned} i'_{ds} &= \frac{v_{ds}}{R_s + sL_s} - \left[\frac{\psi_{dr} . sL_m}{L_r .(R_s + sL_s)}\right] \\ i'_{qs} &= \frac{v_{qs}}{R_s + sL_s} - \left[\frac{\psi_{qr} . sL_m}{L_r .(R_s + sL_s)}\right] \end{aligned}\right| 2.10$$

The electromagnetic torque of the induction motor in stator reference frame is given by

$$T_e = \frac{3}{2}\frac{p}{2} L_m (i_{qs} i_{dr} - i_{ds} i_{qr}) \quad 2.11$$

$$\text{or } T_e = \frac{3}{2}\frac{p}{2}\frac{L_m}{L_r}(i_{qs}\psi_{dr} - i_{ds}\lambda_{qr}) \quad 2.12$$

III. PRINCIPLE OF VECTOR CONTROL

The fundamentals of vector control can be explained with the help of figure 2, where the machine model is represented in a synchronously rotating reference frame.

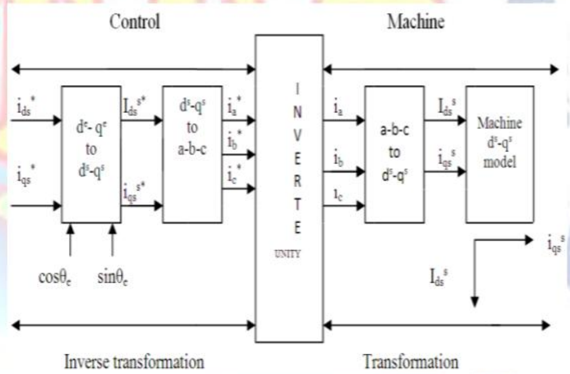

Fig 2: Basic block diagram of vector control

3.1 INVERTER

Processing of the torque status output and the flux status output is handled by the optimal switching logic. The function of the optimal switching logic is to select the appropriate stator voltage vector that will satisfy both the torque status output and the flux status output.

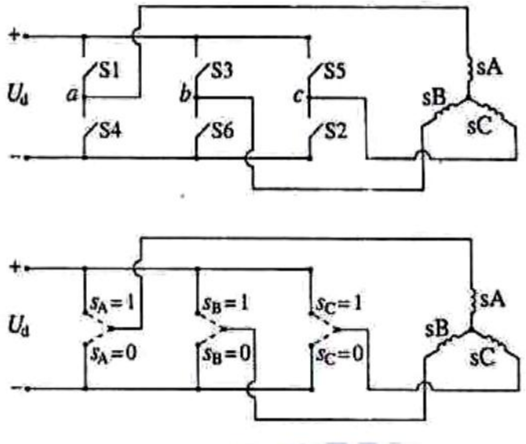

Fig 3: Schematic diagram of voltage source

inverter 3.2 BASIC THEORY

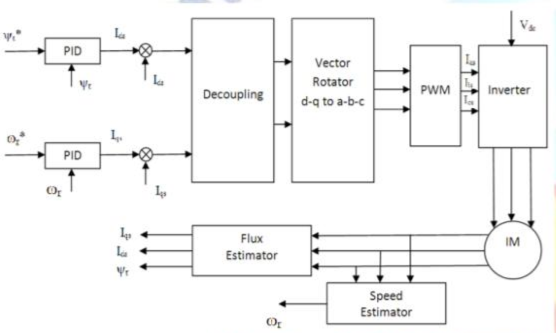

Fig 4: Block Diagram of Sensorless Control of Induction Motor

IV. MODEL REFERENCING ADAPTIVE SYSTEM (MRAS)

Tamai [5] has proposed one speed estimation technique based on the Model Reference Adaptive System (MRAS) in 1987. Two years later, Schauder [6] presented an alternative MRAS scheme which is less complex and more effective. The MRAS approach uses two models. The model that does not involve the quantity to be estimated (the rotor speed, ωr) is considered as the reference model. The model that has the quantity to be estimated involved is considered as the adaptive model (or adjustable model).

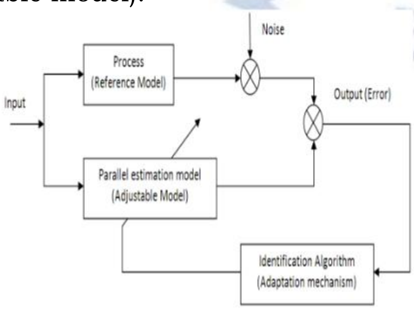

Fig 5: basic identification structures and their correspondence with MRAS

4.1 FUZZY CONTROLLER DESIGN

The main use of fuzzy control system is based on empirical rules is more effective. Fuzzy systems are easily upgraded by adding new rules or new features to improve performance. Fuzzy control can be used to improve existing traditional control systems by adding a layer of intelligence to the current control method [7]. The fuzzy logic controller consists of Fuzzy Inference System Editor. The output of the controller is crisp value. This Graphical User Interface consists of FIS Editor, Membership function Editor, Rule Editor, Rule Viewer and Surface Viewer.

4.2 MAMDANI-TYPE INFERENCE METHOD

Mamdani's fuzzy inference method is the most regularly observed fluffy philosophy. Mamdani's technique was among the primary control frameworks assembled utilizing fluffy set hypothesis. Mamdani-type deduction, as we have characterized it for the Fuzzy Logic Toolbox, expects the yield enrollment capacities to be fluffy sets. After the total procedure, there is a fluffy set for each yield variable that requirements defuzzification. It's conceivable, and by and large considerably more proficient, to utilize a solitary spike as the yield enrollment works as opposed to a disseminated fluffy set. This is now and then known as a singleton yield enrollment capacity, and it very well may be thought of as a pre-defuzzified fluffy set. It upgrades the productivity of the defuzzification procedure since it enormously improves the calculation required by the more broad Mamdani strategy, which finds the centroid of a two-dimensional capacity. The stream continues up from the contributions to the lower left, at that point over each line, or rule, and afterward down the standard yields to complete in the lower right. This is an exceptionally smaller method for indicating everything simultaneously, from etymological variable fuzzification completely through defuzzification of the total yield.

Fuzzy logic controllers normally outflank different controllers in unpredictable, nonlinear, or indistinct frameworks for which a decent pragmatic information exists. Fluffy rationale controllers depend on fluffy sets, i.e., classes of articles in which the progress from participation to non enrollment is smooth as opposed to unexpected. Accordingly, limits of fluffy sets can be dubious and uncertain, making them valuable for estimation frameworks.

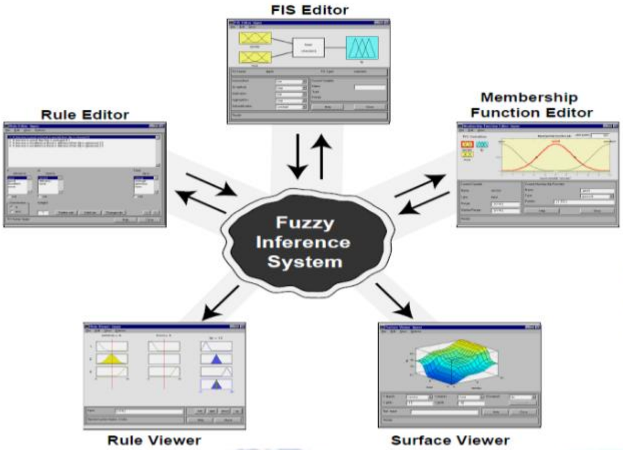

Fig.6: Fuzzy Inference System

There are five primary GUI tools for building, editing [3, 7], and observing fuzzy inference systems in the Fuzzy Logic Toolbox: the Fuzzy Inference System or FIS Editor, the Membership Function Editor, the Rule Editor, the Rule Viewer, the Surface Viewer.The FIS Editor handles the high-level issues for the system: The Fuzzy Logic Toolbox doesn't limit the number of inputs. However, the number of inputs may be limited by the available memory of the machine. If the number of inputs is too large, or the number of membership functions is too big, then it may also be difficult to analyze the FIS using the other GUI tools.

4.3 MEMBERSHIP FUNCTIONS

A membership function(MF) is a curve that defines how each point in the input space is mapped to a membership value (or degree of membership) between 0 and 1. The input space is sometimes referred to as the universe of discourse, a fancy name for a simple concept.The Fuzzy Logic Toolbox includes 11 built-in membership function types.

The simplest membership functions are formed using straight lines. Of these, the simplest is the Triangularmembership function, and it has the function name trimf. It's nothing more than a collection of three points forming a triangle. The Trapezoidalmembership function, trapmf, has a flat top and really is just a truncated triangle curve. These straight line membership functions have the advantage of simplicity.

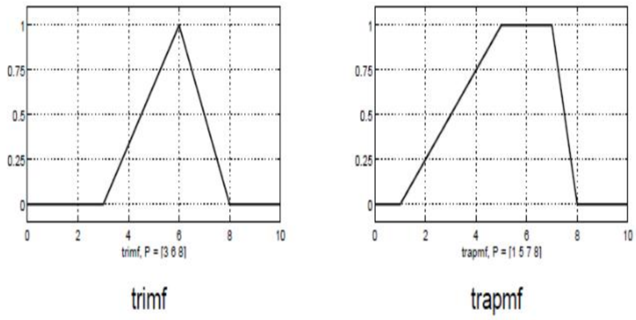

Fig.7: Triangular and Trapezoidal

4.4FUZZY LOGIC CONTROLLER WITH RULE VIEWER

The Fuzzy Logic Toolbox library contains the Fuzzy Logic Controller and Fuzzy Logic Controller with Rule Viewer blocks. It also includes a Membership Functions sublibrary that contains Simulink blocks for the built-in membership functions.

V. VECTOR CONTROL OF INDUCTION MOTOR

The Vector Control or Field orientation control of induction motor is simulated on MATLAB®/SIMULINK - platform to study the various aspects of the controller. The actual system can be modeled with a high degree of accuracy in this package.. This chapter discusses the realization of vector control of induction motor using Simulink blocks.

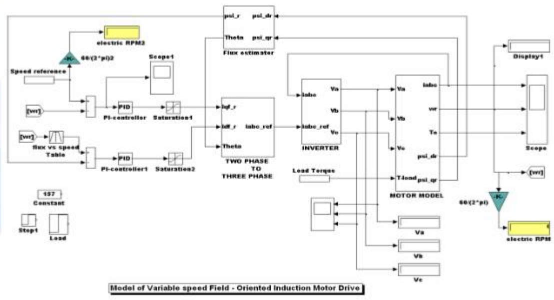

Fig 8: Simulink Model of Vector Controlled Induction motor

5.1 INDUCTION MOTOR MODEL

The motor is modeled in stator reference frame. The dynamic equations are given using these equations we can develop the induction motor model in stator reference frame. Fig 9 shows the simulink block diagram for motor model. Inputs to this block are direct and quadrature axes voltages and load torque. The outputs are direct and quadrate axis rotor fluxes, direct and quadrature axes stator currents, electrical torque developed and rotor speed.

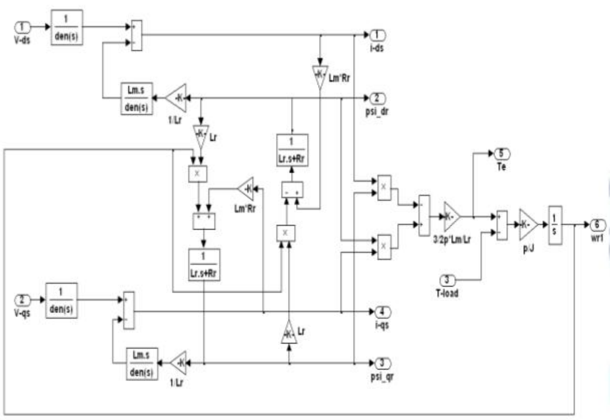

Fig.9: Simulink block diagram for induction motor model

5.2 INVERTER

The function of the optimal switching logic is to select the appropriate stator voltage vector that will satisfy both the torque status output and the flux status output. Processing of the torque status output and the flux status output is handled by the optimal switching logic.

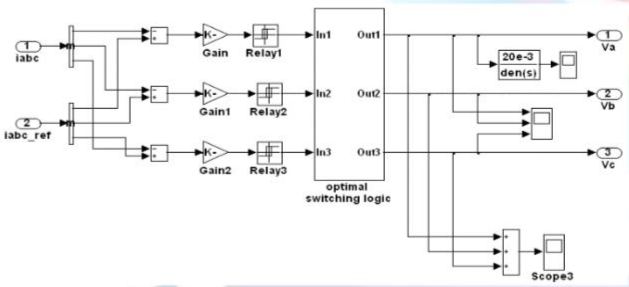

Fig 10: Voltage Source Inverter

5.3 SENSORLESS CONTROL OF INDUCTION MOTOR

The Sensorless control of induction motor using Model Reference Adaptive System (MRAS) is simulated on MATLAB/SIMULINK - platform to study the various aspects of the controller.. Here we are going to discuss the realization of Sensorless control of induction motor using MRAS for simulink blocks.. Main subsystems are the 3-phase to 2-phase transformation, 2-phase to 3-phase transformation, induction motor model, Model Reference Adaptive System (MRAS) and optimal switching logic & inverter.

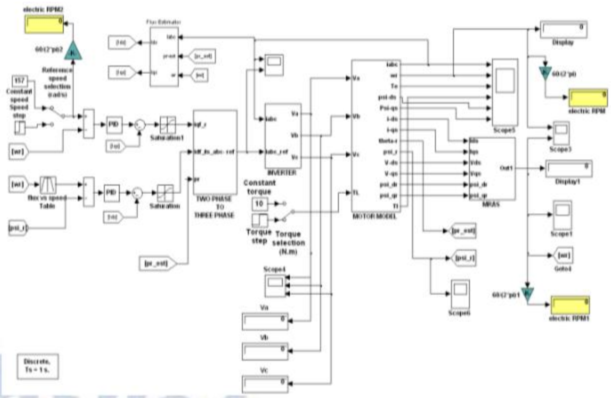

Fig 11: Simulink root block diagram of Sensorless control of induction motor using MRAS

5.4 MODEL REFERNCE ADAPTIVE SYSTEM (MRAS)

Figure15shows the simulink block diagram Model Referencing Adaptive System (MRAS). Which is consists Two blocks one is called Reference Model and other is Adaptive Model. The voltage model's stator-side equations, are defined as a Reference Model and the simulink block diagram of Reference Model is shown in Fig 11. The Adaptive Model receives the machine stator voltage and current signals and calculates the rotor flux vector signals, as indicated by equations, which is shown in Fig 12. By using suitable adaptive mechanism the speed ω_r, can be estimated and taken as feedback.

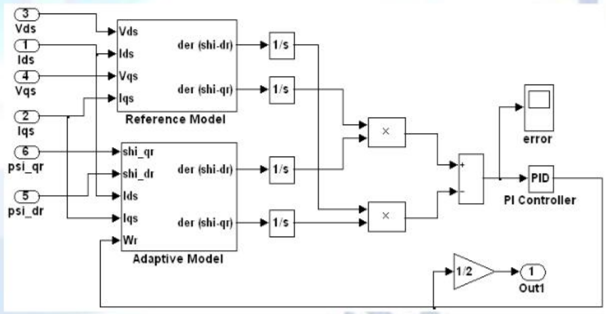

Fig 12:Simulink block diagram for Model Referencing Adaptive System with pi

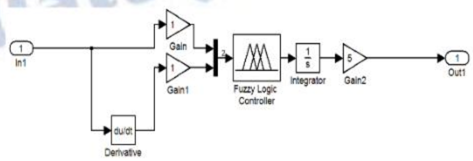

Fig 13:Simulink block diagram for fuzzy logic controller

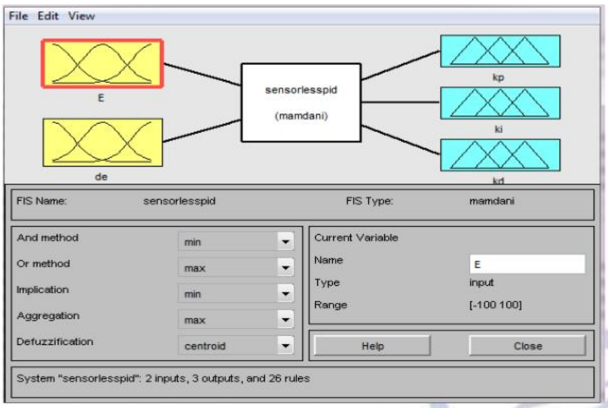

Fig 14:Simulink block diagram for fuzzy pid editor

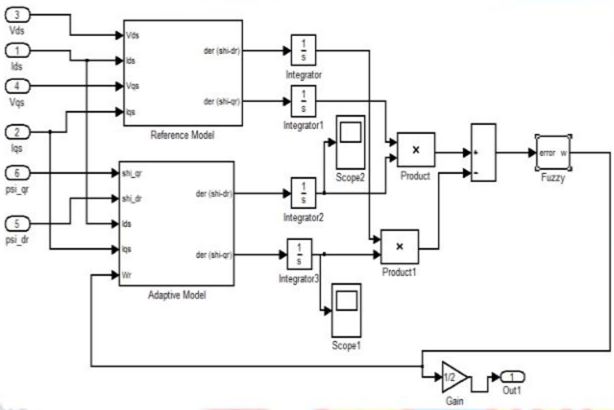

Fig 15:Simulink block diagram for Model Referencing AdaptiveSystem with fuzzy

VI. SIMULATION RESULTS

The simulation of Vector Control of Induction Motor is done by using MATLAB®/SIMULINK. The results for different cases are given below. Reference speed = 100 rad/sec

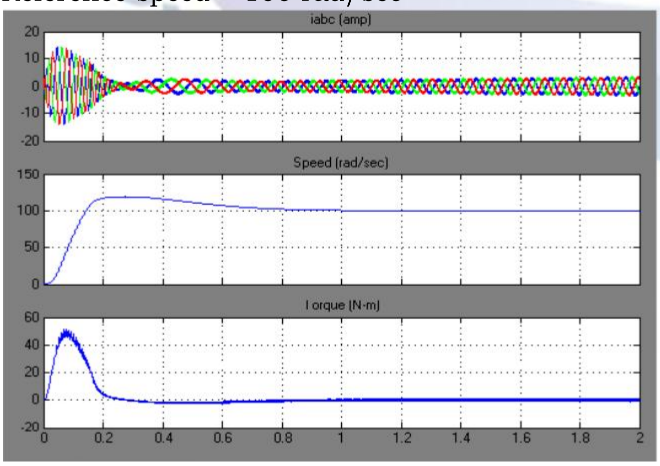

Fig 16: 3-ϕ currents, Speed, and Torque for no-load reference speed of 100 rad/sec with pid controller

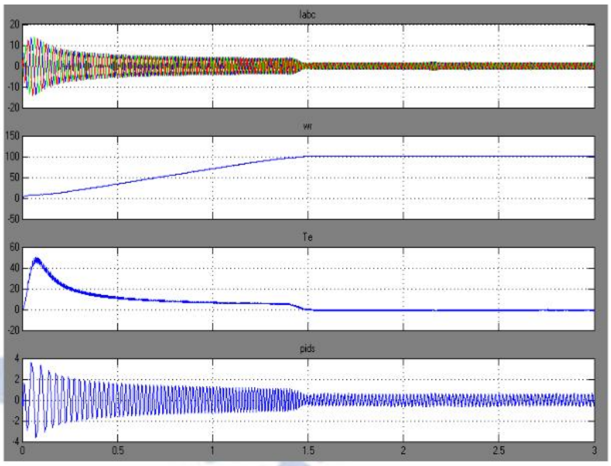

Fig 17: 3-ϕ currents, Speed, and Torque for no-load reference speed of 100 rad/sec with fuzzy pid controller

VII. CONCLUSION

In this paper, Sensorless control of enlistment engine utilizing Model Reference Adaptive System (MRAS) procedure has been proposed. Sensorless control gives the advantages of Vector control without utilizing any pole encoder. In this paper the guideline of vector control and Sensorless control of acceptance engine is given extravagantly. The scientific model of the drive framework has been created and results have been recreated. Recreation aftereffects of Vector Control and Sensorless Control of acceptance engine utilizing MRAS strategy utilizing pid and fluffy pid controller were completed by utilizing Matlab/Simulink and from the examination of the reproduction results, the transient and consistent state execution of the drive have been introduced and investigated.From the simulation results, it can be observed that, in steady state there are ripples intorque wave and also the starting current is high.

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