COMPARATIVE ANALYSIS OF PI CONTROL AND MODEL REFERENCE ADAPTIVE CONTROL BASED VECTOR CONTROL STRATEGY FOR INDUCTION MOTOR DRIVE

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ABSTRACT
Variable-speed drives for induction motors require both wide operating range of speed and fast torque response, regardless of load variations. The field oriented control is the most successful in meeting the above requirements. Using the field-oriented control, a highly coupled, nonlinear, multivariable induction motor can be simply controlled through linear independent decoupled control of torque and flux, similar to separately excited dc motors. In this paper PI controller and Model Reference Adaptive Control scheme is used with MIT rule to control the speed and flux of field oriented controlled Induction motor. In MRAC systems, the stability and tracking error convergence are usually guaranteed regardless of the richness of the signals. Due to the property of MRAC, it changes the behavior of the process. So, under the transient periods, the system is said to be stable and the performance is much improved by the use of MRAC system as compared to conventional PI controller. The Speed and Stator flux errors are used to run the PI controller to generate required Current and voltage referred to stator side for controlling the speed and flux of Induction motor. In MRAC scheme the critically damped second order system is considered as the reference model and output error is used to define the control law under constant and varying load conditions. Simulation is done in MATLAB and SIMULINK and results are discussed in detail.

Keywords - **Field vector control, Model reference adaptive control, MIT rule, Sensorless control.**

1. Introduction
Major improvements in modern industrial processes over the past 50 years can be largely attributed to advances in variable speed motor drives. With the advancement in power electronic devices and the advent of DSP technology fast, reliable and cost effective control of induction motors is now possible. The area of AC motor control has continued to expand because induction motors are excellent candidates for use in Electric or Hybrid Electric Vehicles. Over the past two decades a great deal of work has been done into techniques such as Field Oriented Control, Direct Torque Control and Space Vector Pulse Width Modulation. This paper thoroughly investigated the aforementioned techniques and used them to develop a Field Oriented Control Scheme for use in any Electric applications. By providing decoupling of torque and flux control demands, the vector control can govern an induction motor drive similar to a separate excited direct current motor without sacrificing the quality of the dynamic performance.

The objective of a variable-speed control system for higher productivity is to track the reference speed as fast as possible. Therefore, under the constraints of input voltage and current, a control scheme which yields the maximum torque over the entire speed range can be usefully applicable to minimum-time speed control of induction motors.

Field oriented control method is widely used for advanced control of induction motor drives. However, the field oriented control of induction motor drives presents two main problems that have been providing quite a bit research interest in the last decade. The first one relies on the uncertainties in the machine models and load torque, and the second one is the precise computation of the motor speed without using speed sensors. The decoupling characteristics of the vector control are sensitive to machine parameters variations. Moreover, the machine load characteristics are not exactly known, and may vary during motor operations. Thus the dynamic characteristics of such systems are very complex and nonlinear. To overcome the above system uncertainties, the variable structure control strategy using adaptive control mode has been focused on many studies and research for the control of the AC servo drive system in the past decades.

In this paper, a sensorless vector control scheme consisting of an adaptive rotor speed estimation method based on MRAS is used in order to improve the performance of a sensorless vector controller in a low speed region. Using the sensorless [1- 3] variable structure control to govern the induction motor drive, the rotor speed becomes insensitive to variations in the motor parameters and load disturbances. Moreover, the proposed control scheme provides a good transient response and exponential convergence of the speed trajectory tracking in spite of parameter uncertainties and load torque disturbances.

This paper compares the control techniques on Induction motor with load Torque variation. The two different control techniques which are used in this paper to control Induction Motor are Conventional Control (PI controller) [4] and Adaptive Control (MRAC) [5]. The observed parameters are speed and flux signals of the Induction motor with different load conditions.

The conventional PID controllers with fixed gain are unable to cope up with the load varying problems. Though recently advanced fuzzy PID controllers [6-10] have been developed to deal with such problems for electrical and mechanical systems. Also the concept of neural network is applied to develop the PID controllers [11-12] to enhance the dynamic characteristics of controller. Still to obtain the complete adaptive nature, specific adaptive control techniques are needed. Adaptive control changes the control algorithm coefficients in real time to compensate for variations in environment or in the system itself. It also varies the system transfer function according to situation.

Out of many adaptive control schemes, this paper mainly deals with the model reference adaptive control approach based on MIT rule [13-14]. In MRAC [13-17], the output response is forced to track the response of a reference model irrespective of plant parameter variations. The controller parameters are adjusted to give a desired closed-loop performance.

2. Model reference adaptive control

This technique of adaptive control comes under the category of Non-dual adaptive control. A reference model describes desired system performance. The adaptive controller is then designed to force the system or plant to behave like the reference model. Model output is compared to the actual output, and the difference is used to adjust feedback controller parameters. MRAS has two loops: an inner loop or regulator loop that is an ordinary control loop consisting of the plant and regulator, and an outer or adaptation loop that adjusts the parameters of the regulator in such a way as to drive the error between the model output and plant output to zero.

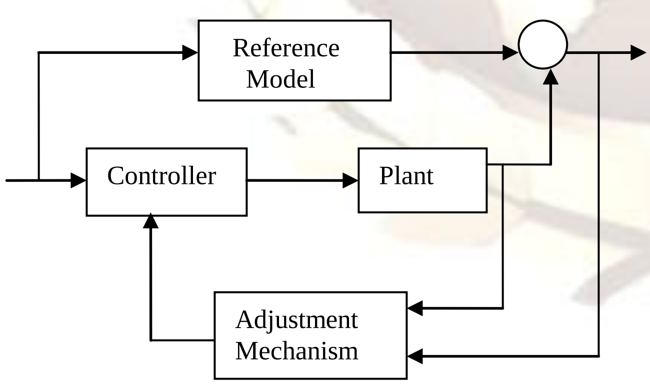

Figure1. Model Reference Adaptive Controller

2.1 Components of Model Reference Adaptive Controller

2.1.1 Reference Model

It is used to specify the ideal response of the adaptive control system to external command. It should reflect the performance specifications in control tasks. The ideal behavior specified by the reference model should be achievable for the adaptive control system. The critically damped second order system is taken as reference model in this paper.

2.1.2 Controller

It is usually parameterized by a number of adjustable parameters. In this paper two parameters θ_1 and θ_2 are used to define the controller law. Adaptive controller design normally requires linear parameterization in order to obtain adaptation mechanism with guaranteed stability and tracking convergence.

2.1.3 Adaptation Mechanism

It is used to adjust the parameters in the control law. Adaptation law searches for the parameters such that the response of the plant which should be same as the reference model. It is designed to guarantee the stability of the control system as well as convergence of tracking error to zero.

3. The MIT Rule

This rule is developed in Massachusetts Institute of technology and is used to apply the MRAC approach to any practical system. In this rule the cost function or loss function is defined as

$$F(\theta) = e^2 / 2 \qquad (1)$$

Where, e is the output error and is the difference of the output of the reference model and the actual model, while θ is the adjustable parameter known as control parameter.

In this rule the parameter θ is adjusted in such a way so that the loss function is minimized. For this it is reasonable to change the parameter in the direction of the negative gradient of *F*, that is,

$$d\theta/dt = -\gamma\, \partial F / \partial\theta \qquad (2)$$

$$= -\gamma\, e\, \partial e / \partial\theta \qquad (3)$$

The partial derivative term $\partial e / \partial\theta$, is called the sensitivity derivative of the system. This shows how the error is dependent on the adjustable parameter, θ. There are many alternatives to choose the loss function *F*, like it can be taken as mode of error also. Similarly, dθ/dt can also have different relations for different applications.

4. Mathematical Modeling of Induction Motor

The three phase induction motor is first converted into corresponding two phase Kron's model. The voltage equations of the three phase induction motor in synchronous reference frame are:

$$V_{qs}^{s} = R_s i_{qs}^{s} + d\Psi_{qs}^{s}/dt \qquad (4)$$

$$V_{ds}^{s} = R_s i_{ds}^{s} + d\Psi_{ds}^{s}/dt \qquad (5)$$

Where, Ψ_{qs} and Ψ_{ds} are q-axis and d-axis stator flux linkages, respectively. The aim of vector control is to implement control schemes which produce high-dynamic performance and are similar to those used to control DC machines. To achieve this, the reference frames may be aligned with the stator flux-linkage space vector, the rotor flux-linkage space vector or the magnetizing space vector. The most popular reference frame is the reference frame attached to the rotor flux linkage space vector with direct axis (*d*) and quadrature axis (*q*). After transformation into d-q coordinates the motor model follows:

These equations in d^e-q^e frame are,

$$Vqs = Rsiqs + d\Psi qs/dt + \omega e \Psi ds \quad (6)$$

$$Vds = Rsids + d\Psi ds/dt - \omega e \Psi qs \quad (7)$$

Where, all the variables are in rotating form. The last term in Equations V_{qs} and V_{ds} can be defined as speed emf due to rotation of the axes. ω_e and ω_r are the speed of the reference frame and the mechanical speed of the rotor in rad/sec. R_s and R_r are the stator and rotor resistances per phase of the motor respectively.

If $\omega_e = 0$, the equations are changed in to stationary form. Note that the flux linkage in the d^e and q^e axes induces emf in the q^e and d^e axes respectively, with Π/2 lead angle. If the rotor is not moving, i.e., $\omega_r = 0$, the rotor equations for a doubly-fed wound-rotor machine will be similar to above two equations.

$$Vdr = Rr\,idr + d\,\Psi dr/dt - \omega e^*\Psi qr \quad (8)$$

$$Vqr = Rr\,iqr + d\,\Psi qr/dt + \omega e^*\Psi dr \quad (9)$$

Here, all the variables and parameters are referred to the stator. Since the rotor moves at a speed $\omega_e - \omega_r$ relative to the synchronously rotating frame, therefore, in d^e - q^e frame, the rotor equations are modified as,

$$Vdr = Rs\,idr + d\,\Psi dr/dt - (\omega e - \omega r)\,\Psi qr \quad (10)$$

$$Vqr = Rr\,iqr + d\,\Psi qr/dt + (\omega e - \omega r)\,\Psi dr \quad (11)$$

The Electromagnetic Torque is given by

$$Te = 3P(\Psi dsiqs - \Psi qs\,ids)/2 \quad (12)$$

The torque balance equation is:

$$J^*d\omega r/dt = Te - TL - B\omega r \quad (13)$$

Where, in the equations (8), (9), (10), (11) all voltages and currents refer to the arbitrary reference frame.

J is the moment of inertia and B is the coefficient of viscous friction. T_e is the developed torque and T_L is the load torque.

$$T_e = 3PL_m(\Psi_{dr}\, i_{qs} - \Psi_{qr}\, i_{ds})/2L_r \quad (14)$$

5. 2R-2S Transformation

The two phase d^s-q^s windings are transformed in to the hypothetical windings mounted on the d^e-q^e axes. The voltages on the d^s-q^s axes can be converted in to the d^e-q^e frame as follows.

$$v_{qs} = v_{qs}^{s} * \cos\theta_e - v_{ds}^{s} \sin\theta_e \quad (15)$$

$$v_{ds} = v_{qs}^{s} * \sin\theta_e + v_{ds}^{s} \cos\theta_e \quad (16)$$

Resolving rotating parameters in to stationary parameters, in a stationary frame, the relations are,

$$v_{qs}^{s} = v_{qs} \cos\theta_e + v_{ds}\sin\theta_e \quad (17)$$

$$v_{ds}^{s} = -v_{qs} \sin\theta_e + v_{ds}\cos\theta_e \quad (18)$$

6. Load Torque Disturbance (T_L) Compensation

A sudden load or disturbance torque T_L can cause a droop in the speed in a speed-controlled drive system, which may not be desirable. The speed droop can be compensated with the help of a disturbance torque observer. The speed and torque are given by the following relation

$$Jd\omega_m/dt + B\omega_m = T_e - T_L \quad (19)$$

Where, B = viscous friction coefficient. Therefore, T_L can be estimated by the following equation:

$$T_L = T_e - (JS+B)\,\omega_m \quad (20)$$

The actual speed ω_m is measured with the measurement delay time T_d. The signal is processed through the inverse mechanical model (JS + B) and then subtracted from the effective torque T_e' to generate the estimated torque signal.

7. Vector Control of Induction Motor

Field angle is calculated by using terminal voltages and currents. The control parameters i_{ds} and i_{qs} which are dc values in synchronously rotating reference frame converted to stationary frame by using unit vectors generated from flux vector signals Ψ_{dr} and Ψ_{qr}. These flux signals are generated from the machine terminal voltages and currents with the help of the voltage model estimator. For precision control of flux control loop should be added. The torque component of current i_{qs} is generated from the speed control loop through $i_{qs.}$ The angular position of the d^e axis with respect to the d^s axis is θ_e.

$$\Psi_{dr}^{\ s} = \Psi_r \operatorname{Cos} \theta_e \quad (21)$$

$$\Psi_{qr}^{\ s} = \Psi_r \operatorname{Sin} \theta_e \quad (22)$$

$$\Psi_r = \sqrt{[(\Psi_{dr}^{\ s})^2 + (\Psi_{qr}^{\ s})^2]} \quad (23)$$

Ψ_r vector is represented by magnitude Ψ_r. This unit vector signal, when used for vector rotation, gives currents i_{ds} on d^e axis and i_{qs} on q^e axis. When $\Psi_{qr} = 0$ and $\Psi_{dr} = \Psi_r$, then the torque expression will be same as dc machine expression. In direct vector control, the generation of a unit vector signal is from feedback flux vector. In Induction motor the effective Time Constant under electrical transients is small (looking at the stator). So by manipulating stator MMF independent control can be achieved for Torque and Flux components of stator current. Induction motors can now be used for the applications requiring high dynamic performances like a separately excited DC motors. The torque T_e may responds instantly but the flux has first order delay (with time constant = L_r/R_r).

8. Induction Motor With PI Controller

In a PI controlled drive, the tuning of the proportional and integral gains of a simulated or experimental system can be done. In the past, several commercial auto tuned P-I-D controllers for general purpose and higher order linear controlled systems were available. In this thesis, simulation diagram of vector controlled drive system where the PI controller gains k_p and k_i are being tuned in the speed control loop. The expert controller contains the knowledge base for tuning the controller. It is assumed that initially, the PI parameters will be loaded such that the system will remain within the stability limit. The initial parameters can be derived from the knowledge of the plant parameters.

A square wave auxiliary test signal is injected as the speed command ω_r^* and the pattern of the error response e is retrieved. From the knowledge base, the controller can look in to the error response and determine how the k_p and k_i parameters are to be modified to get the correct tuning. For the second order drive system, reducing k_i will reduce the loop gain constant as well as reduce the cross over frequency.

Whereas reducing k_p will only decrease the cross over frequency with a constant gain. In this paper the vector controlled induction motor is attached with a PI controller for improving the steady state characteristics in term of speed and flux.

9. Induction Motor With Model Reference Adaptive Controller

A linear control system with invariant plant parameters can be designed easily with the classic design techniques. Ideally, a vector controlled ac drive can be considered as linear, like a dc drive system. However, in industrial applications, the electrical and mechanical parameters of the drive hardly remain constant besides there is a load torque disturbance effect. The effect of the parameter variation can be compensated to some extent by a high gain negative feedback loop. But, excessive gain may cause an under damping or instability problem in extreme cases. The problems discussed above require adaptation of the controller in real time, depending on the plant parameter variation and load torque disturbance, so that the system response is not affected. In this paper MIT rule is used for MRAC scheme. The second order critically damped system is used as a reference model and the output of induction motor in terms of speed and flux is compared with the output of reference model.
Similarly, the reference model is described by

$$d^2 y_m/dt^2 = -a_m\, dy_m/dt - b_m y_m + b_m r \quad (24)$$

Where, y_m is the output of reference model (second order critically damped system) and r is the reference input (unit step input).
Take a_m =8 and b_m=16
The transfer function can be written as

$$Y_m(s)/R(s) = 16/(s^2+8s+16) \quad (25)$$

Here the object is to compare the actual output (y) and the reference output (y_m) and by applying model reference adaptive control scheme to improve the overall output. Let the controller is described by the law

$$u(t) = \theta_1 r(t) - \theta_2 y(t) \quad (26)$$

The controller parameters are chosen as

$$\theta_1 = b_m / b \quad \text{and} \quad \theta_2 = (a_m - a) / b \quad (27)$$

The update rule for the controller parameters using MIT rule is described by

$$d\theta_1/dt = - \gamma\, e\, \partial e / \partial \theta_1$$
$$= - \gamma\, e\, [b\, r / (p + a_m)]$$
$$= - \alpha\, e\, [a_m r/(p+a_m)] \quad (28)$$

and $d\theta_2/dt = - \alpha\, e\, [a_m y/(p+a_m)]$ (29)
Where, $\alpha = \gamma\, b/a_m$ is the adaptation gain and error $e = y - y_m$.

10. Simulation Results

The model for vector control Induction motor with PI controller and MRAC using vector control scheme is simulated in MATLAB.

10.1 No Load Characteristics

(NO LOAD torque Vs. time without any disturbance)

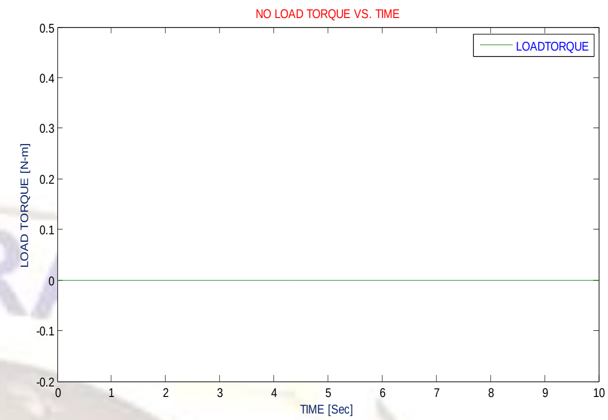

Figure2. No Load Torque Vs. Time

10.1.1 Without any controller

10.1.1.1 Rotor Speed characteristic

Scaling: X-axis: 1 Unit = 1 sec
Y-axis: 1 Unit = 150 rad/sec

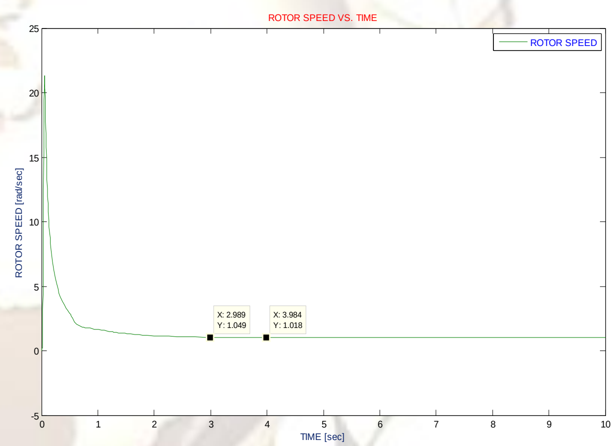

Figure3. Rotor Speed Vs. Time without any controller

10.1.1.2 Rotor Torque characteristic

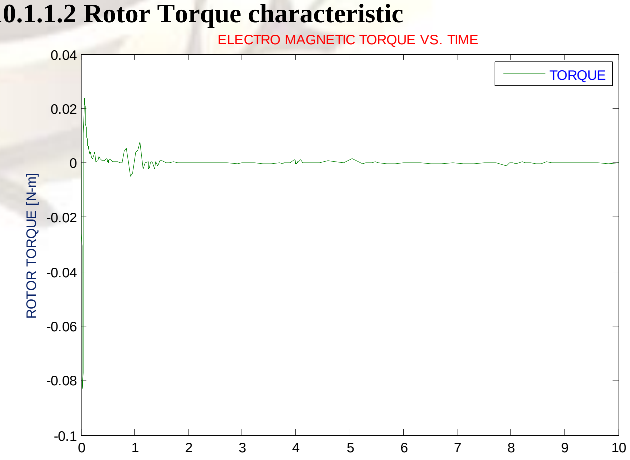

Figure4. Electro Magnetic Torque Vs. Time without any controller

10.1.1.3 Rotor Flux characteristic

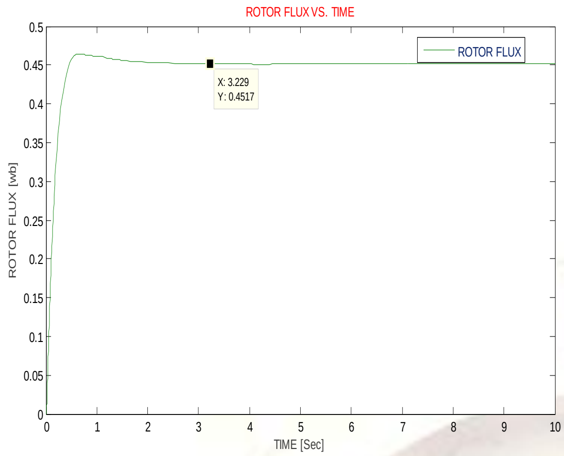

Figure5. Rotor Flux Vs. Time without any controller

10.1.2 With PI Controller

10.1.2.1 Rotor Speed characteristic

Scaling: X-axis: 1 Unit = 1 sec

Y-axis: 1 Unit = 150 rad/sec

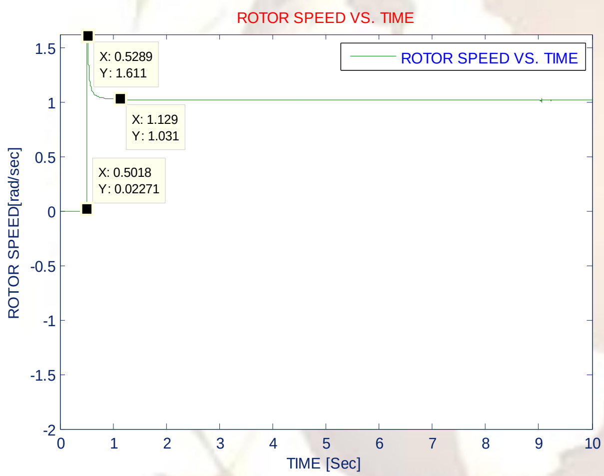

Figure6. No Load Rotor Speed (rad/sec) Vs. Time (Sec) with PI Controller

10.1.2.2 Rotor Torque characteristic

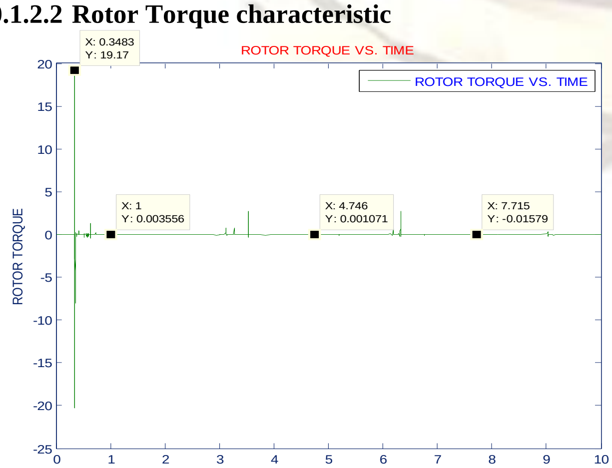

Figure7. Electromagnetic Torque Vs. Time with PI Controller

10.1.2.3 Rotor Flux characteristic

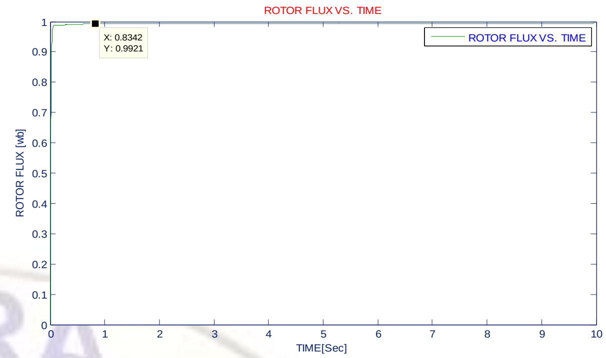

Figure8. Rotor Flux Vs. Time with PI Controller

10.1.2.4 d-axis and q-axis flux with reference to the stator side

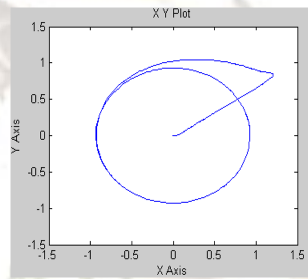

Figure9. d-axis flux with reference to stator side using PI controller

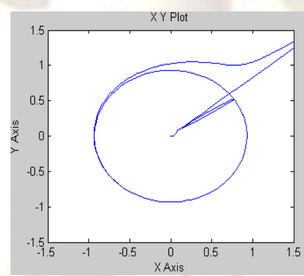

Figure10. q-axis flux with reference to stator side using PI controller

10.1.3 With MRAC

10.1.3.1Rotor Speed characteristic

Scaling: X-axis: 1 Unit = 1 sec

Y-axis: 1 Unit = 150 rad/sec

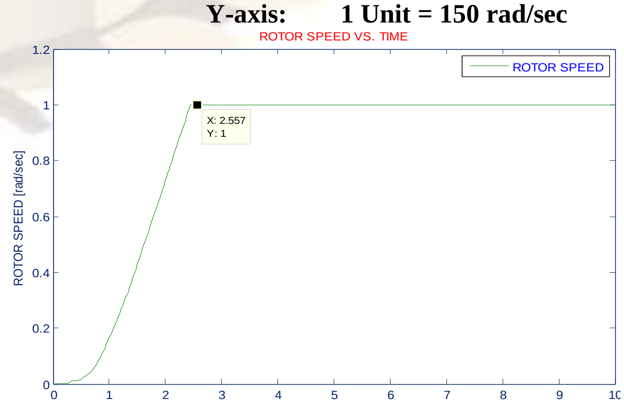

Figure11. Rotor Speed Vs. Time with MRAC

10.1.3.2 Rotor Torque characteristic

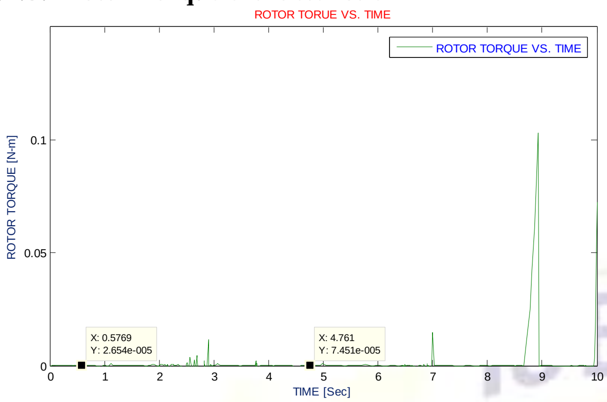

Figure12. Electro Magnetic Torque Vs. Time with MRAC

10.1.3.3 Rotor Flux characteristic

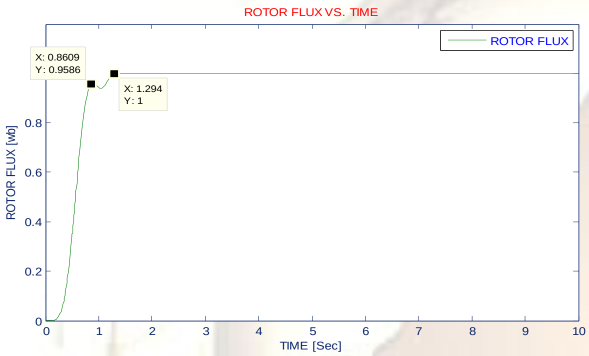

Figure13. Rotor Flux Vs. Time with MRAC

10.1.3.4 d-axis and q-axis flux with reference to the stator side

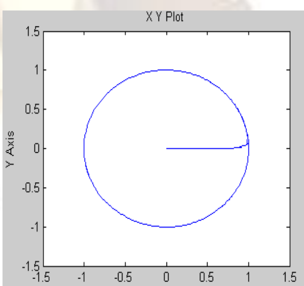

Figure14. d-axis flux with reference to stator side using MRAC

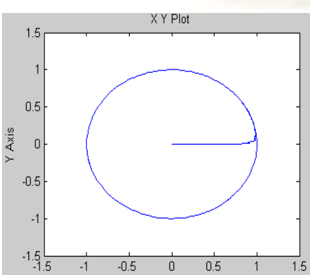

Figure15. q-axis flux with reference to stator side using MRAC

10.2 Constant Load Characteristics

[Characteristic (Load torque Vs. time) of Constant load (with constant disturbance)]

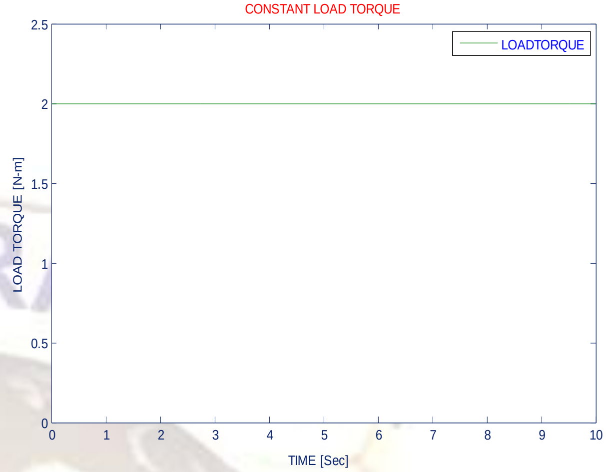

Figure16. Constant Load Torque Vs. Time

10.2.1 Without any controller

10.2.1.1 Rotor Speed characteristic

Scaling: X-axis: 1 Unit = 1 sec
Y-axis: 1 Unit = 150 rad/sec

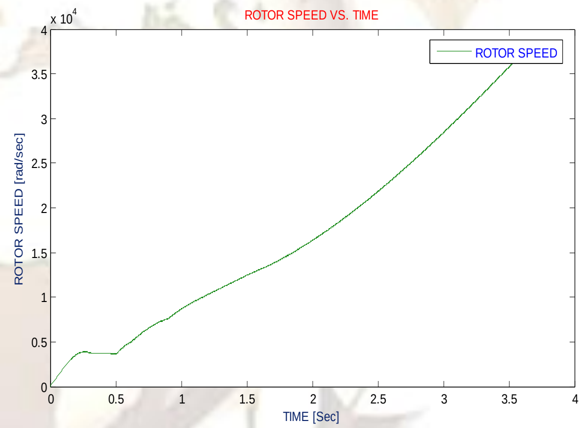

Figure17. Rotor Speed Vs. Time without any controller

10.2.1.2 Rotor Torque characteristic

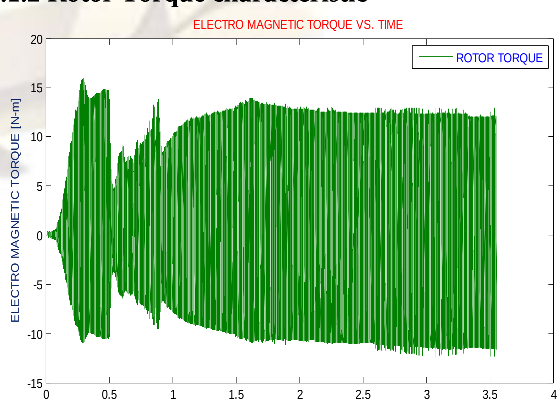

Figure18. Electro Magnetic Torque Vs. Time without any controller

10.2.1.3 Rotor Flux characteristic

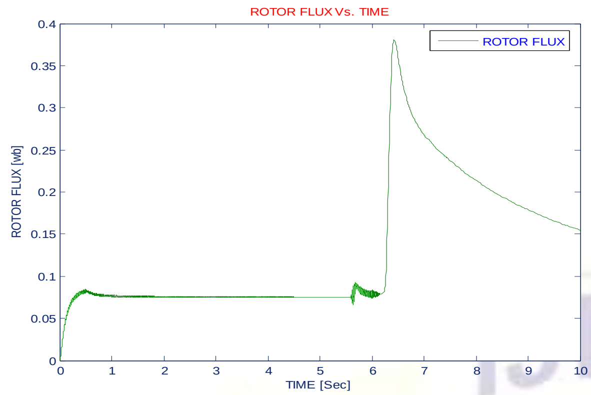

Figure19. Rotor Flux Vs. Time without any controller

10.2.2 With PI Controller

10.2.2.1 Rotor Speed characteristic

Scaling: X-axis: 1 Unit = 1 sec

Y-axis: 1 Unit = 150 rad/sec

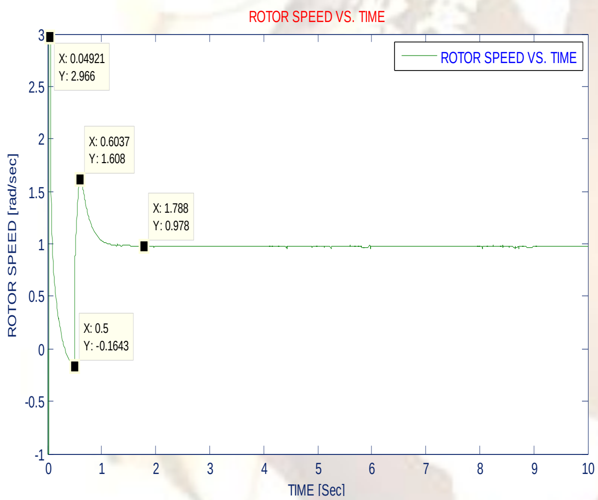

Figure20. Rotor Speed Vs. Time with PI controller

10.2.2.2 Rotor Torque characteristic

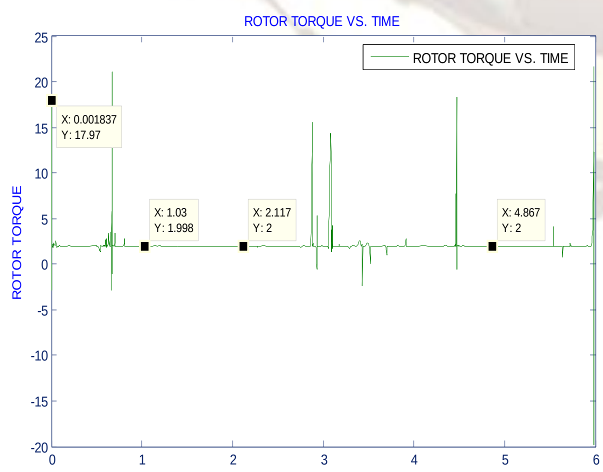

Figure21. Electromagnetic Torque Vs. Time with PI Controller

10.2.2.3 Rotor Flux characteristic

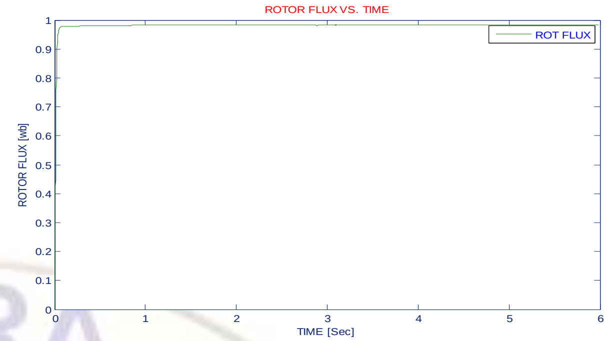

Figure22. Rotor Flux Vs. Time with PI Controller

10.2.2.4 d-axis and q-axis flux with reference to the stator side

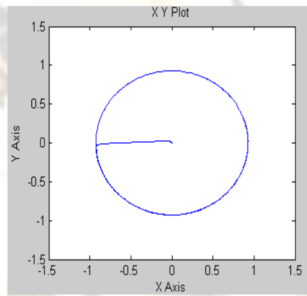

Figure23. d-axis flux with reference to stator side using PI controller

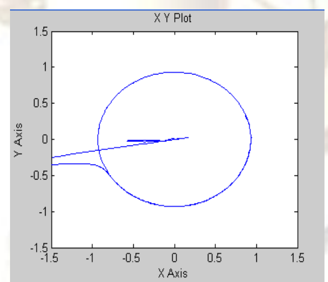

Figure24. q-axis flux with reference to stator side using PI controller

10.2.3 With MRAC

10.2.3.1Rotor Speed characteristic

Scaling: X-axis: 1 Unit = 1 sec

Y-axis: 1 Unit = 150 rad/sec

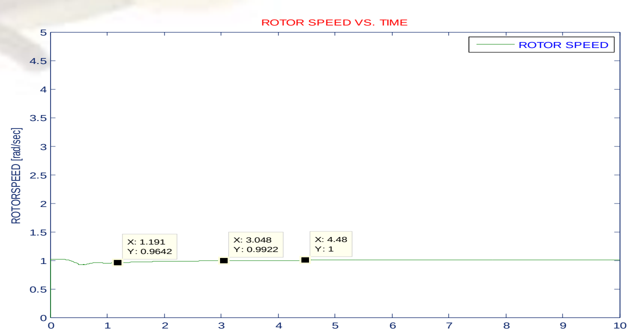

Figure25. Constant Load Rotor Speed Vs. Time with MRAC

10.2.3.2Rotor Torque characteristic

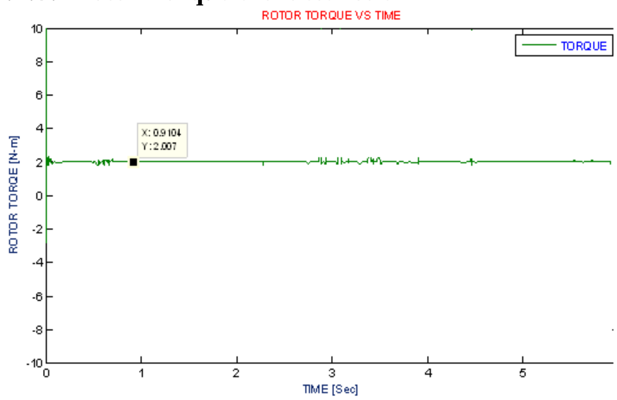

Figure26. Electro Magnetic Torque Vs. Time with MRAC

10.2.3.3Rotor Flux characteristic

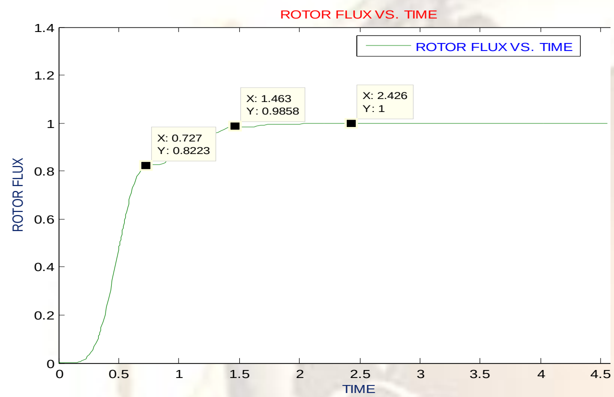

Figure27. Rotor Flux Vs. Time with MRAC

10.2.3.4d-axis and q-axis flux with reference to the stator side

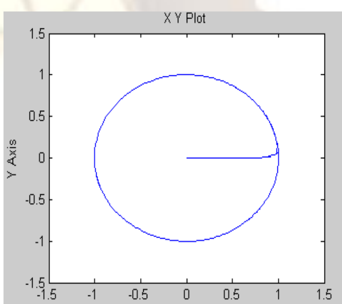

Figure28. d-axis flux with reference to stator side using MRAC

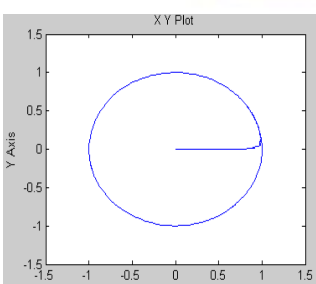

Figure29. q-axis flux with reference to stator side using MRAC

10.3Varying Load Characteristics
(Load torque Vs. time with Varying disturbance)

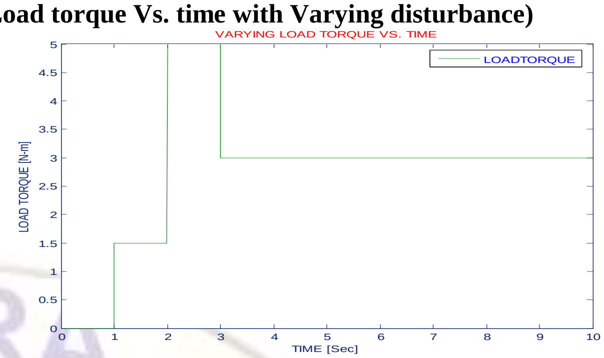

Figure30. Varying Load Torque Vs. Time

10.3.1 Without any Controller
10.3.1.1 Rotor Speed characteristic

Scaling: X-axis: 1 Unit = 1 sec

Y-axis: 1 Unit = 150 rad/sec

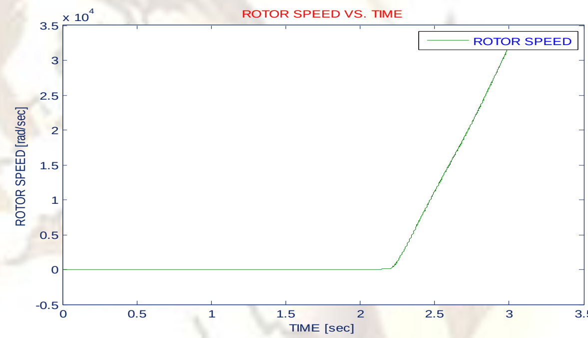

Figure31. Rotor Speed Vs. Time without any controller for varying load

10.3.1.2 Rotor Torque characteristic

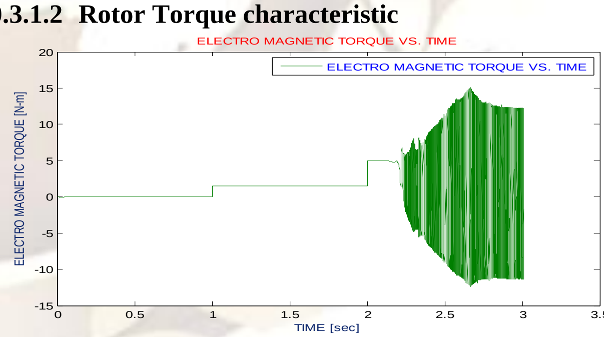

Figure32. Electro Magnetic Torque Vs. Time without any controller

10.3.1.3 Rotor Flux characteristic

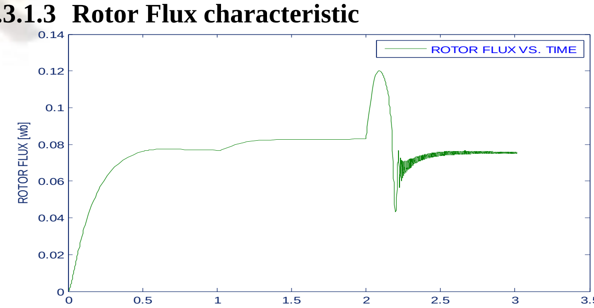

Figure33. Rotor Flux Vs. Time without any controller

10.3.2 With PI Controller:

10.3.2.1 Rotor Speed characteristic

Scaling: X-axis: 1 Unit = 1 sec
Y-axis: 1 Unit = 150 rad/sec

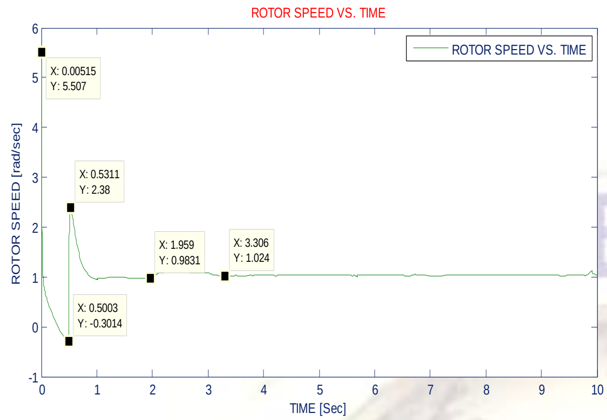

Figure34. Varying Load Rotor Speed Vs. Time with PI Controller

10.3.2.2 Rotor Torque characteristic

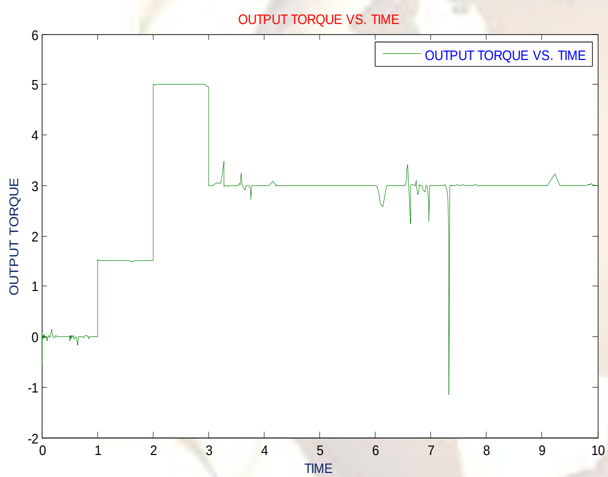

Figure35. Electro Magnetic Torque Vs. Time with PI controller

10.3.2.3 Rotor Flux characteristic

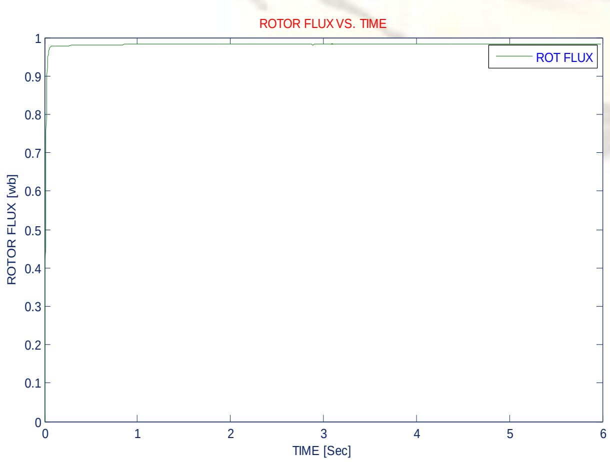

Figure36. Rotor Flux Vs. Time with PI controller

10.3.2.4 d-axis and q-axis flux with reference to the stator side

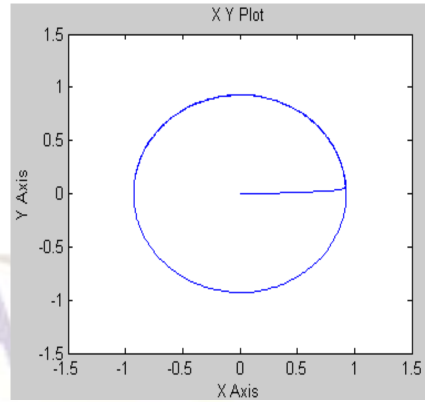

Figure37. d-axis flux with reference to stator side using PI controller

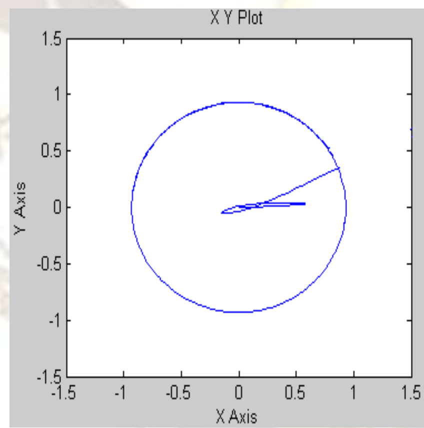

Figure38. q-axis flux with reference to stator side using PI controller

10.3.3 MRAC

10.3.3.1 Rotor Speed characteristic

Scaling: X-axis: 1 Unit = 1 sec
Y-axis: 1 Unit = 150 rad/sec

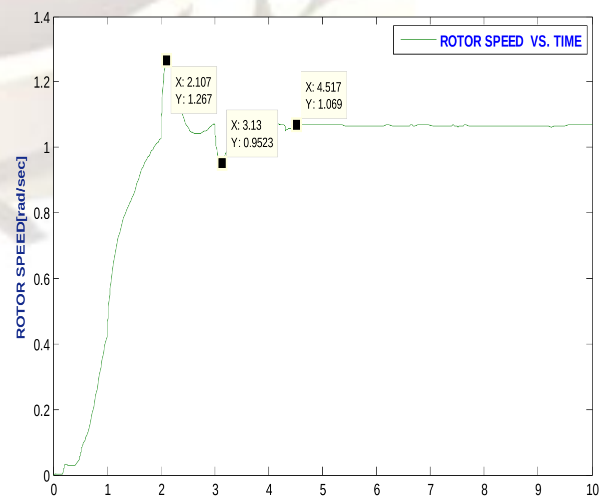

Figure39. Varying Load Rotor Speed Vs. Time with MRAC

10.3.3.2 Rotor Torque characteristic

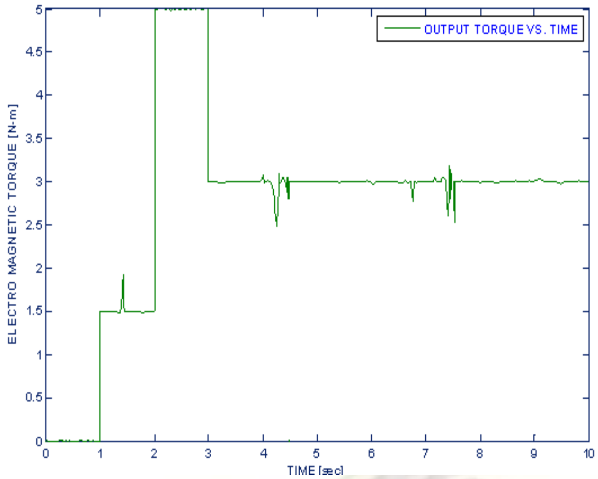

Figure40. Electro Magnetic Torque Vs. Time with MRAC

10.3.3.3 Rotor Flux characteristic

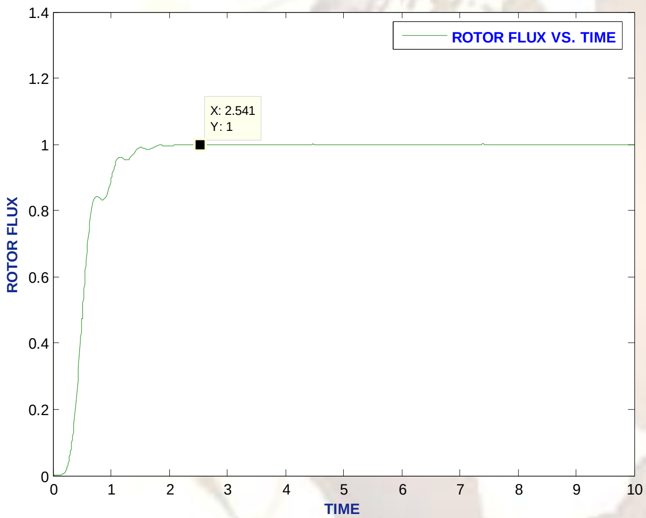

Figure41. Rotor Flux Vs. Time with MRAC

10.3.3.4 d-axis and q-axis flux with reference to the stator side

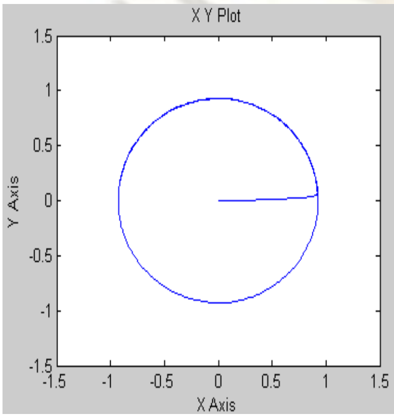

Figure42. d-axis flux with reference to stator side using MRAC

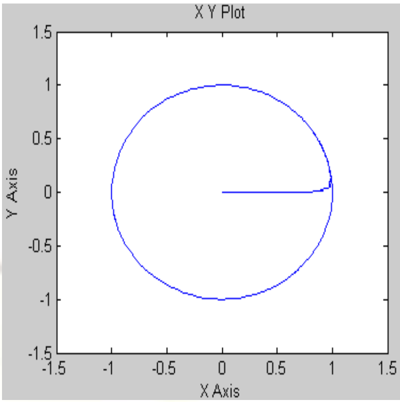

Figure43. q-axis flux with reference to stator side using MRAC

11. Conclusion

Comprehensive study on dynamic d-q model and vector control has been made. To study the dynamic performance of an induction motor, MATLAB SIMULINK toolbox is used. It is observed that during transients, the Induction motor without any controller becomes unstable. Its dynamic characteristics are improved with the application of PI controller and they are further modified with the application of model reference adaptive controller. Tables I and II give the comparison of Induction motor performance without any controller, with PI controller and with MRAC. This comparison is carried out for different loading conditions. Firstly the motor is at no load condition then it is loaded with constant load and finally it is loaded with variable load. Under these conditions the speed and flux of induction motor are calculated and their characteristics are shown in figures. The specifications which are taken for the comparison are maximum Overshoot, settling time, steady state value and steady state error. From the simulation results, it can be concluded that the MRAC is giving best results. It is most capable scheme for reducing the spikes, maximum overshoot, and Steady state error. But, the settling time is comparatively more than the PI controller in loaded conditions due to complexity in its nature.

TABLE I
Comparative Analysis of Induction Motor Performance for Speed as a Parameter

	WITHOUT ANY CONTROLLER			PI CONTROLLER			MRAC		
Description	*No Load*	*Constant Load*	*Variable Load*	*No Load*	*Constant Load*	*Variable Load*	*No Load*	*Constant Load*	*Variable Load*
% Max.OverShoot	20.5	Unstable	Unstable	0.611	1.966	4.507	0	0	0.267
Settling Time (Sec)	3.984	Unstable	Unstable	1.121	1.788	3.306	2.557	4.48	4.517
Steady State Speed	1.018	Unstable	Unstable	1.031	0.978	1.024	1.00	1.00	1.02
Steady State Error	-0.018	Unstable	Unstable	-0.031	0.022	-0.024	0	0	- 0.02

TABLE II
Comparative Analysis of Induction Motor Performance for Flux as a Parameter

	WITHOUT ANY CONTROLLER			PI CONTROLLER			MRAC		
Description	*No Load*	*Constant Load*	*Variable Load*	*No Load*	*Constant Load*	*Variable Load*	*No Load*	*Constant Load*	*Variable Load*
% Max.Overshoot	0	Unstable	Unstable	0	0	0	0	0	0
Settling Time (Sec)	3.229	Unstable	Unstable	0.8342	0.98	0.982	1.294	1.782	2.74
Steady State Flux	0.4517	Unstable	Unstable	0.9921	0.982	0.983	1.00	1.00	1.00
Steady State Error	0.5483	Unstable	Unstable	0.0097	0.018	0.017	0	0	0

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