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Model Reference Adaptive Control for DC Motor and Induction Motor Drive

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Abstract

A new general scheme for robust model reference adaptive controller (MRAC) is proposed for single variable nonlinear plants and can be applied without any modifications to single variable nonlinear plants, bothtime-invariant and time varying in nature. The proposed robust MRAC is based on the estimation of the difference between the linear time-invariant model plant parameters and actual plant parameters that show nonlinearity and time varyingness. The approach used in this work is an extension of the approach commonly used to develop MRAC for a lineartime-invariant plants. The boundedness of the signals and stability of theplant with the proposed robust MRAC in use are achieved by using Lyapunov's direct method. Simulation results are used to demonstrate the effectiveness of the proposed MRAC

***Keywords-** DC motor, mrac, fuzzy, induction motro*

Introduction

In automation literature more plants need newer and modern control strategies to obtain the technical demands and desired performances. Some plants have time varying or unknown parameters, other are partially known or are altered by disturbance. A solution for these problems is to adapt the parameters of the initial controller and to obtain a so-called adaptive controller. In this paper is presented the implementation of the two adaptive control strategies (model reference adaptive control MRAC and fuzzy model reference learning control FMRLC) and the comparison of their performances. In MRAC, as in FMRLC, the technical demands and the desired input-output behavior of the closed loop system is given via the corresponding dynamics of the reference model. Therefore, the basic task is to design such a control, which will ensure the minimal error between the reference model and the plant outputs (adaptation error) despite the uncertainties or variations in the plant parameters and working conditions.

The design of controllers, using conventional techniques, for plants with non-linear dynamics and modeling uncertainties can be often quite difficult. The first approach is the design of the model reference adaptive control MRAC using the stability theory of Lyapunov. This theory assures that the adaptation error 0 is asymptotically stable. Of course, fuzzy control is a practical alternative for a variety of challenging control applications, since it provides a convenient method for constructing non-linear controllers via the use of heuristic information. However, some of the problems encountered in practical control problems, such as model uncertainties or the difficulty to choose some of the fuzzy controller parameters, demand a way to automatically tune the fuzzy controller so that it can adapt to different operating conditions

Based on fuzzy logic controller we then focus on the design of the second adaptive controller named fuzzy model reference learning controller FMRLC. The term “learning” is used as opposed to “adaptive” to distinguish the two control structures. In particular, the

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distinction is drawn since the FMRLC, which is a direct model reference adaptive controller too, will tune and to some extent will remember the values it had tuned in the past, while the conventional adaptive approach (MRAC) will continue to tune the controller parameters. In the end the performances of the two proposed control algorithms are evaluated in a local adaptive control structure for a flexible-link gear drive. Robot control is a complex process, which needs knowledge from different domains. The control of the robot can be done in the free workspace or in the constrained workspace. Flexiblelink gear drive with high reduction ratio provides a linearization of the robot system dynamics. Further, this gear drive offers the possibility to use the decoupling control method or the local compensation of the non-linear interactions between different motion axes.

DC MOTOR

A common actuator in control systems is the DC motor. It directly provides rotary motion and, coupled with wheels or drums and cables, can provide transitional motion. A Dc motor is a good example of an electromechanical system, which contains both mechanical and electrical components interconnected to provide a composite function. It is a common actuator in a variety of engineering systems, including mechatronics and robotics. The Dc motor directly provides rotary motion. The electric circuit of the armature and the free-body diagram of the rotor are shown in fig 4.1.

The DC motor circuit is as shown below:

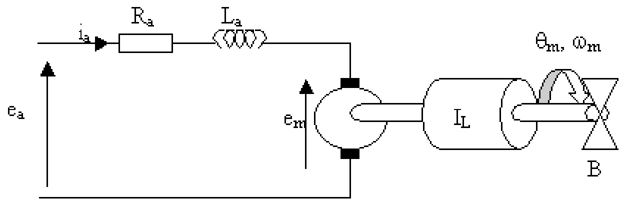


fig 1 Schematic diagram of DC motor

The parameters shown are:

e_a = Armature voltage.
i_a = Armature current.
R_a = Armature resistance.
L_a = Armature inductance.
e_m = back emf.
I_L = Load moment of inertia.
θ_m = Angular position of motor shaft.
ω_m = Angular velocity of motor shaft.
B = Frictional (speed dependant) load.

The modeling equations are obtained by using electrical circuit laws (KVL, KCL etc) and basic mechanics (Newton's laws). The armature is driven by the circuit shown in fig and the motor torque T is related to the armature current i(t) by a constant factor K, while the rotor and shaft are assumed to be rigid. Hence by summing up the torques on the rotor's free body diagram, an expression for the current i(t) in terms of the motor angular speed and acceleration is obtained as follows:

$$J\frac{d^2\theta}{dt^2} + B\frac{d\theta}{dt} = T = Ki \qquad \text{------------ } \mathbf{2.1}$$

$$i = J\left(\frac{d^2\theta}{dt^2} + B\frac{d\theta}{dt}\right) \qquad \text{------------ } \mathbf{2.2}$$

The back emf is related to the angular speed such that:

$$L\frac{di}{Dt} - Ri = v - k\theta \qquad \text{------------ } \mathbf{2.3}$$

Where v (t) is the supply voltage.

DC MOTOR BLOCK DIAGRAM:

With the advent of the control systems, any system can be represented in the form of a block diagram in which each block represents the specific components of the system and the connectivity between each block for proper functioning is obtained by using the lines. The DC motor can also be represented in the form of block diagram as shown below in fig 2.1.1

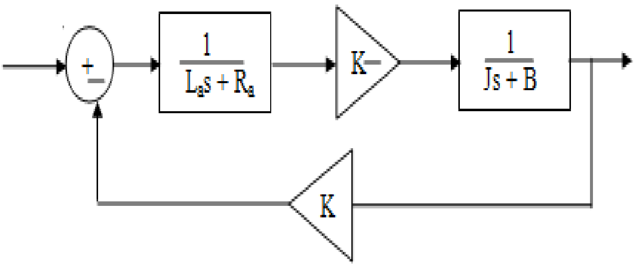


fig 2.Block diagram of a DC motor

The various blocks in the above block diagram represent the various parts of the DC motor such as the armature circuit, field circuit and the friction. The transfer function of the DC motor taking the armature excitation as the input and the angular position of the shaft is taken as the output is derived in the next section.

The kinematics of the serial robot has a special construction. The forces and the moments of the different arms of the serial robot are interacting. A solution for resolving the non-linear interactions is the parallel robots. If this physical solution is not possible, an alternative is obtained with the combination between gear drive and adaptive controller.

The modern adaptive controller assures the robustness of the global system even in presence of the model uncertainties or payload variations. We suppose that each flexible-link of the robot is gear driven by a dc motor. So, our plant used in digital simulation is in fact a dc motor. The dynamic equations of the dc motor with independent excitation are

$$\begin{cases} u(t) = R \cdot i(t) + L \cdot di(t)/dt + k_e \cdot \Omega_{dc}(t) \\ k_m \cdot i(t) = J \cdot d\Omega_{dc}(t)/dt + B \cdot \Omega_{dc}(t) + C_r(t) \\ \Omega_{dc}(t) = d\theta_{dc}(t)/dt, \theta(t) = \mu \cdot \theta_{dc}(t) \end{cases}$$

Where the plant parameters are voltage *u*, current *i*, circuit resistance *R (1.025Ω)*, circuit inductance *L (0.1H)*, electromotive voltage *keΩ (ke=0.5247V·min/rot)*, motor torque *kmi (km=6.1V·min/rot)*, inertia *J (8kg·m2)*, viscous frictional coefficient *B (1.5Nms/rad)*, load torque *Cr*, rotational speed *Ωdc*, reduction ratio *μ (0.01)*, motor angle *θdc*, gear angle *θ*.

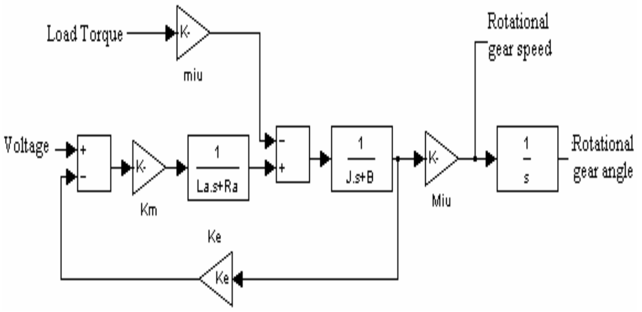


fig 3 Simulink plant model.

Dynamic equations of induction machine

Generally, an IM can be described uniquely in arbitrary rotating frame, stationary reference frame or synchronously rotating frame. For transient studies of adjustable speed drives, it is usually more convenient to simulate an IM and its converter on a stationary reference frame. Moreover, calculations with stationary reference frame are less complex due to zero frame speed. For small signal stability analysis about some operating condition, a synchronously rotating frame which yields steady values of steady-state voltages and currents under balanced conditions is used.

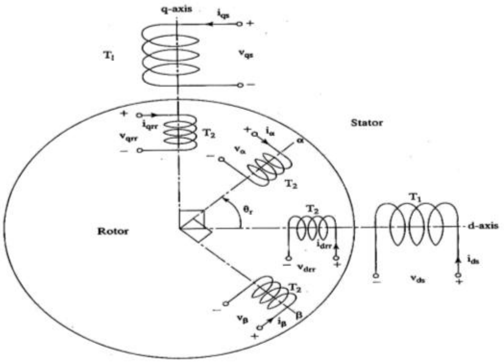


Fig 4 Two-phase equivalent diagram of induction motor

The two-phase equivalent diagram of three-phase induction motor with stator and rotor windings referred to d – q axes is shown in Fig 2.2(a). The windings are spaced by 90^o electrical and rotor winding α, is at an angle θ_r from the stator d-axis. It is assumed that the d axis is leading the q axis in clockwise direction of rotation of the rotor. If the clockwise phase sequence is dq, the rotating magnetic field will be revolving at the angular speed of the supply frequency but counter to the phase sequence of the stator supply. Therefore the rotor is pulled in the direction of the rotating magnetic field i.e. counter clockwise, in this case. The currents and voltages of the stator and rotor windings are marked in figure 2.2(a). The number of turns per phase in the stator and rotor respectively are T_1 and T_2. A pair of poles is assumed for this figure. But it is applicable with slight modification for any number of pairs of poles if it is drawn in terms of electrical degrees. Note that θ_r is the electrical rotor position at any instant, obtained by multiplying the mechanical rotor position by pair of poles. The terminal voltages of the stator and rotor windings can be expressed as the sum of the voltage drops in resistances, and rate of change of flux linkages, which are the products of currents and inductances.

CONTROLLERS

A control system is an interconnection of components forming a system configuration that will provide a desired response. The basis for analysis of a system is provided by linear system theory, which assumes a cause effect relationship for the components of a system. The input-output relationship represents the cause-and-effect relationship of the process, which in turn represents the processing of the input signal to provide an output signal variable, often with power amplification.

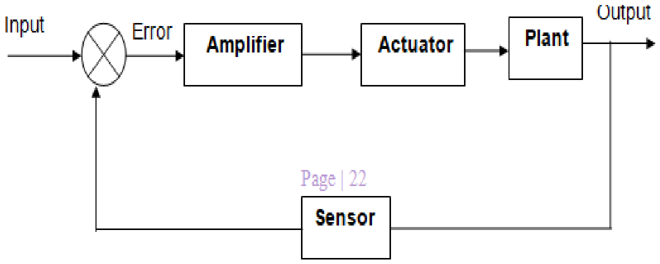


fig.5 Block Diagram of a basic control system

Fuzzy Model Reference Learning Control (FMRLC)

A "learning system" possesses the capability to improve its performance over time by interacting with its environment. A learning control system is designed so that its "learning controller" has the ability to improve the performance of the closed-loop system by generating command inputs to the plant and utilizing feedback information from the plant.

In this section we introduce the "fuzzy model reference learning controller" (FMRLC), which is a (direct) model reference adaptive controller. The term "learning" is used as opposed to "adaptive" to distinguish it from the approach to the conventional model reference adaptive controller for linear systems with unknown plant parameters. In particular, the distinction is drawn since the FMRLC will tune and to some extent remember the values that it had tuned in the past, while the conventional approaches for linear systems simply continue to tune the controller parameters. Hence, for some applications when a properly designed FMRLC returns to a familiar operating condition, it will already know how to control for that condition. Many past conventional adaptive control techniques for linear systems would have to retune each time a new operating condition is encountered.

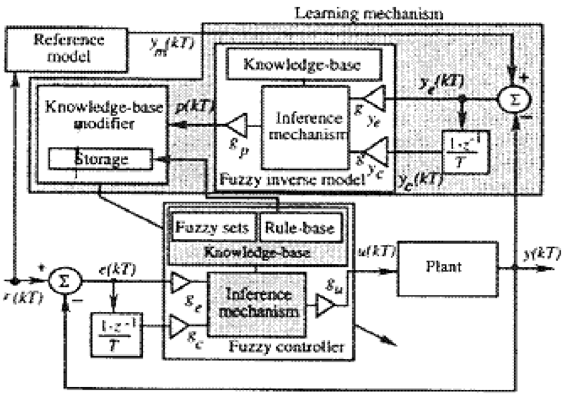


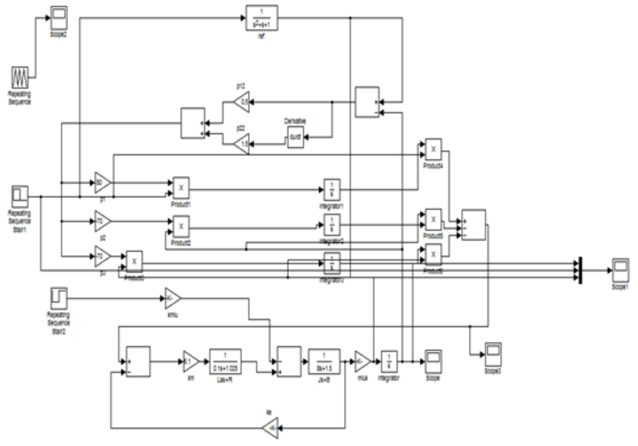
Figure 6 Fuzzy model reference learning controller

The functional block diagram for the FMRLC is shown in Figure 3.3. It has four main parts: the plant, the fuzzy controller to be tuned, the reference model, and the learning mechanism (an adaptation mechanism). We use discrete time signals since it is easier to explain the operation of the FMRLC for discrete time systems. The FMRLC uses the learning mechanism to observe numerical data from a fuzzy control system (i.e., r(kT) and y(kT) where T is the sampling period). Using this numerical data, it characterizes the fuzzy control system's current performance and automatically synthesizes or adjusts the fuzzy controller so that some given performance objectives are met.

These performance objectives (closed-loop specifications) are characterized via the reference model shown in Figure 3.3. In a manner analogous to conventional MRAC where conventional controllers are adjusted, the learning mechanism seeks to adjust the fuzzy controller so that the closed-loop system (the map from r(kT) to y(kT)) acts like the given reference model (the map from r(kT) to ym(kT)). Basically, the fuzzy control system loop (the lower part of Figure 3.3) operates to make y(kT) track r(kT) by manipulating u(kT), while the upper-level adaptation control loop (the upper part of Figure 3.3) seeks to make the output of the plant y(kT) track the output of the reference model $y_m(kT)$ by manipulating the fuzzy controller parameters.

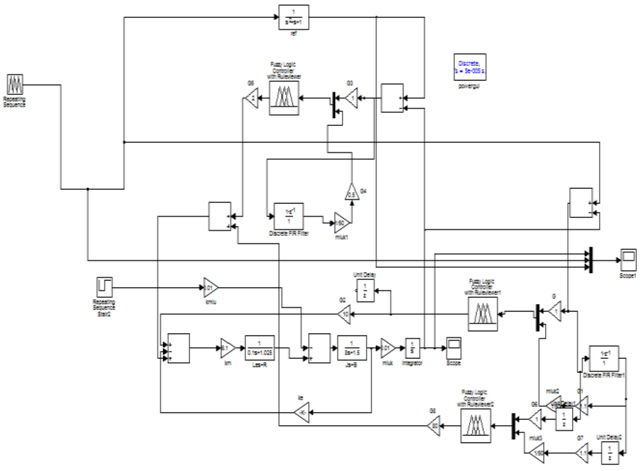
SIMULATION BLOCK DIAGRAMS

The following is the block diagram of model reference adaptive control (MRAC) applied to a plant which is DC motor. A square and triangular inputs are given to the process and the response is compared.



Simulation block for MRAC

The following is the block diagram of fuzzy model reference learning control (FMRLC) applied to a plant which is DC motor. A square and triangular inputs are given to the process and the response is compared.



Simulation block for FMRLC

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. It provides a user interactive platform and a wide variety of numerical algorithms. This chapter discusses the realization of vector control of induction motor using Simulink blocks.

Fig. 5.1 shows the Vector controlled Induction Motor block simulink diagram for simulation. This system consisting of Induction Motor Model, Three Phase to Two phase transformation block, Two phase to Three phase block, Flux estimator block and Inverter block.

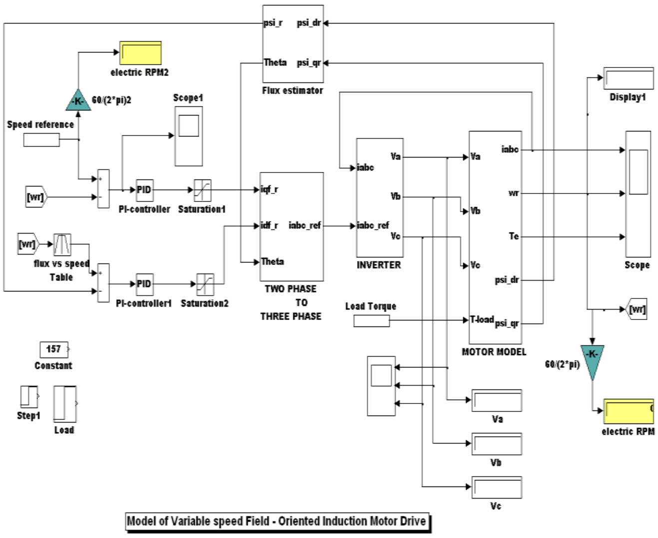


Fig 5.1 Simulink Model of Vector Controlled Induction motor

Induction Motor Model:

The motor is modeled in stator reference frame. The dynamic equations are given by (2.21) to (2.29). By using these equations we can develop the induction motor model in stator reference frame. Fig 5.2 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.

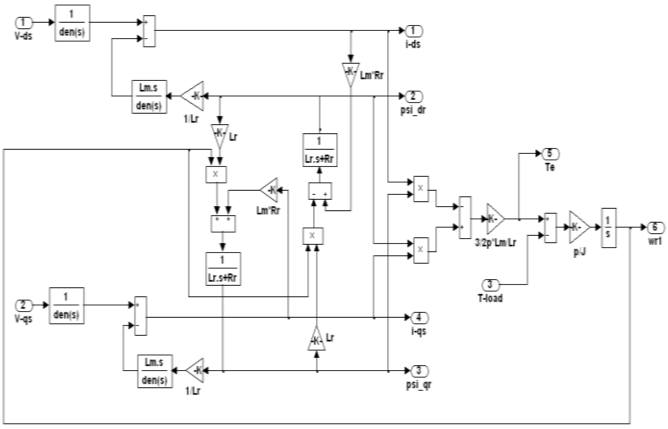


Fig.5.3: Simulink block diagram for induction motor model

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. The actual system can be modeled with a high degree of accuracy in this package. It provides a user interactive platform and a wide variety of numerical algorithms. Here we are going to discuss the realization of Sensorless control of induction motor using MRAS for simulink blocks. Fig. 5.9 shows the root-block simulink diagram for simulation. 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.

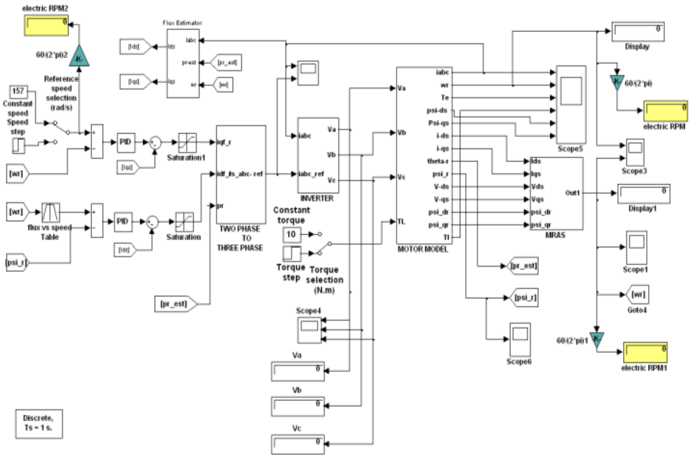


Fig 5.9 Simulink root block diagram of Sensorless control of induction motor using MRAS

Model Refernce Adaptive System (MRAS)

Fig 5.11 shows 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, (4.7) & (4.8) are defined as a Reference Model and the simulink block diagram of Reference Model is shown in Fig5.12. The Adaptive Model receives the machine stator voltage and current signals and calculates the rotor flux vector signals, as indicated by equations, (4.15) and (4.16) which is shown in Fig 5.13. By using suitable adaptive mechanism the speed ω_r, can be estimated and taken as feedback.

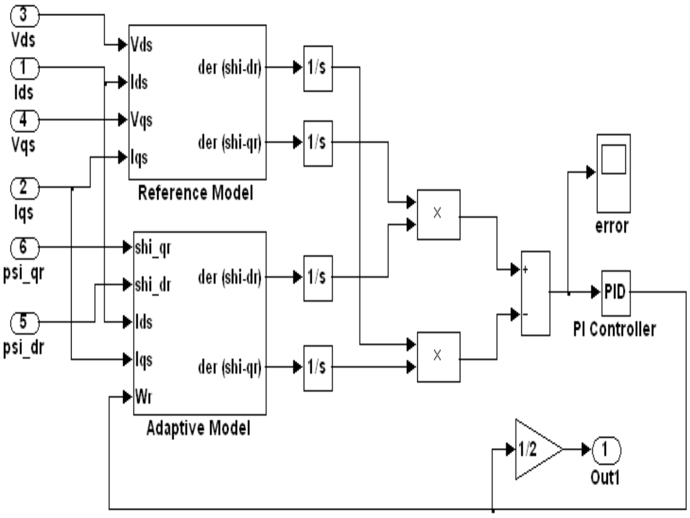
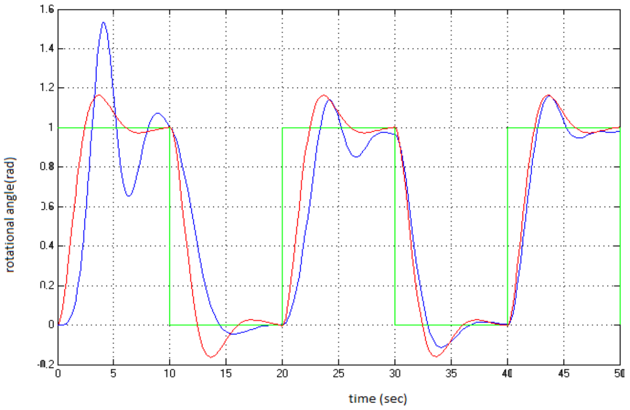


Fig 5.11 Simulink block diagram for Model Referencing Adaptive System

Simulation results:



ROTATIONAL ANGLE FOR SQUARE WAVE INPUT using MRAC

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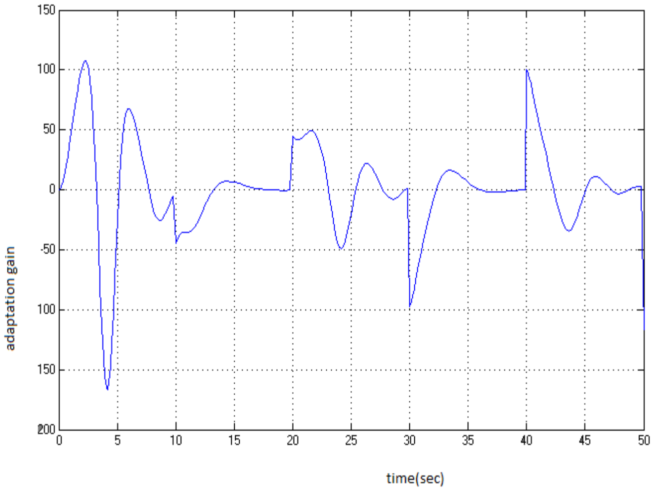
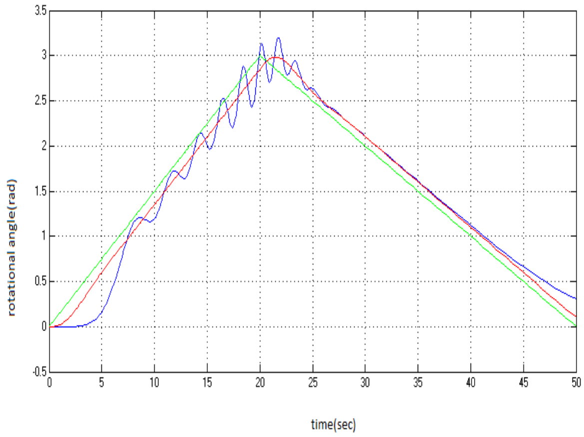
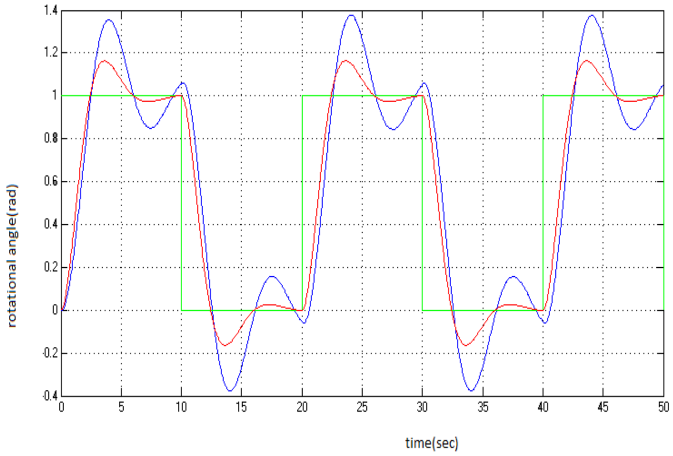


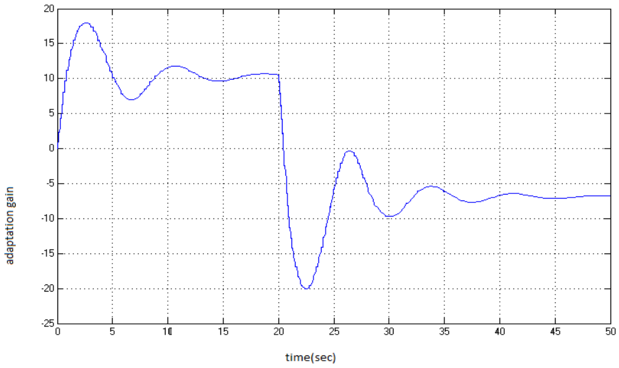
ADAPTIVE GAIN FOR SQUARE WAVE INPUT USIN MRAC



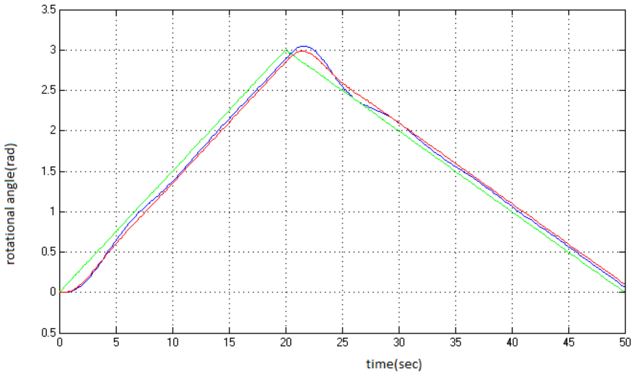
ROTATIONAL ANGLE TRIANGULAR WAVE INPUT USING MRAC



ROTATIONAL ANGLE FOR SQUARE WAVE INPUT USING FMRLC



ADAPTIVE GAIN FOR SQUARE WAVE INPUT USING FMRLC



ROTATIONAL ANGLE TRIANGULAR WAVE INPUT USING FMRLC

Case-1: No-Load Condition

Reference speed = 100 rad/sec and on no-load

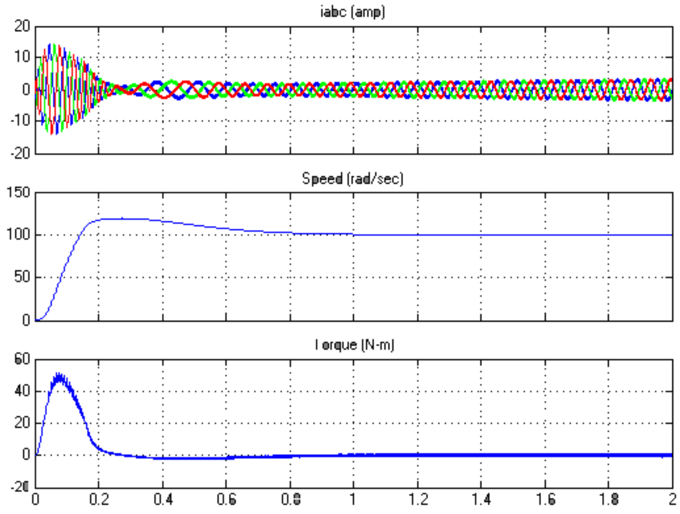


Fig 6.1: 3-ϕ currents, Speed, and Torque for no-load reference speed of 100 rad/sec

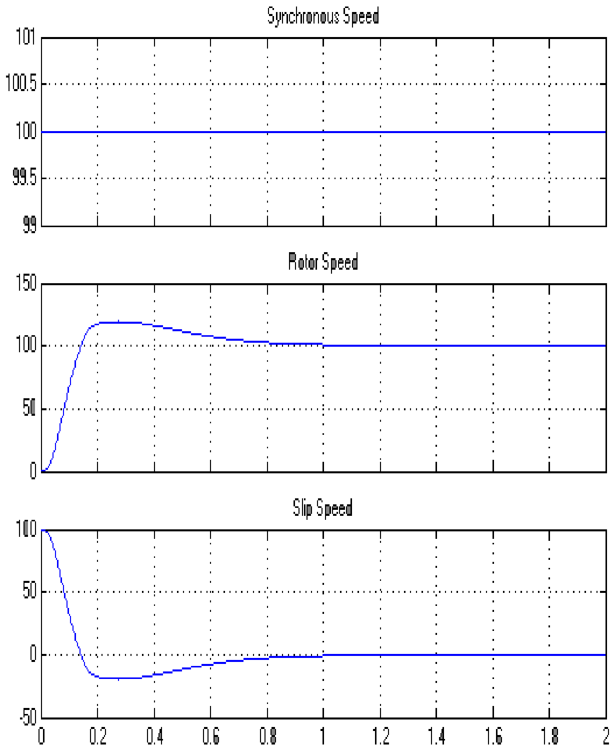


Fig 6.2: Reference speed, Rotor Speed, Slip Speed Respectively

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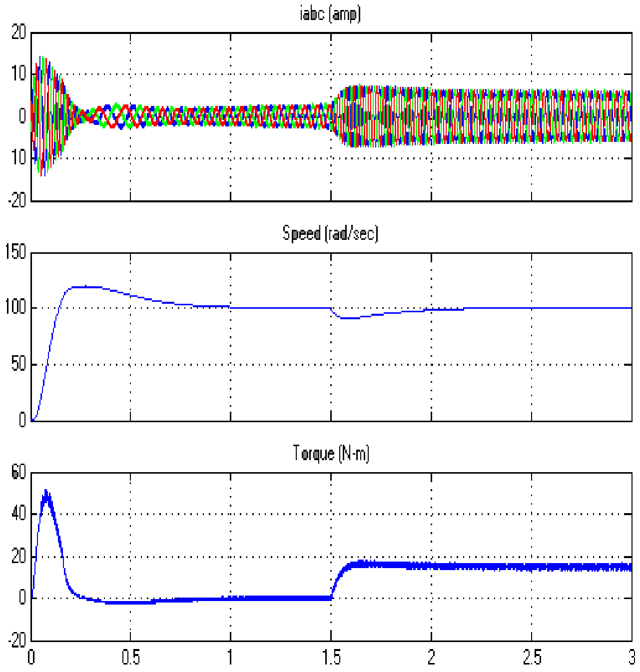

Fig 6.5: 3-ϕ currents, Speed, and Torque for no-load reference speed of 100 rad/sec

CONCLUSION

This paper studied the implementation of two adaptive control techniques as applied to a time varying plant. The MRAC scheme applies to systems with known dynamic structure, linear or non-linear, but with unknown constants or slowly varying parameters. The adaptive controller designed for our plant is inherently non-linear. The MRAC system can handle large variations of the plant parameters with slow varying dynamic response. Otherwise, the stability of the closed-loop system and the convergence of the adaptation error are assured by the Lyapunov theory of stability.

The direct fuzzy controller allowed the use of heuristics (which model the human control of the process) via the use of the rule table. Since we generally know the way to control a flexible-link gear drive, the heuristics we chose in the design of the fuzzy controller proved very useful. The FMRLC took the controller design a step further by supplying an inductive update method, which produced an adaptive fuzzy controller. Having analyzed the response of both control schemes it is obvious the FMRLC seems to perform better.

MRAC technique is applied for both dc motor and induction machine. The input variations and speed variations are exactly traced my MRAC.

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