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Speed Sensorless Vector Controlled Inverter Fed Induction Motor Drive Using Fuzzy Logic Controller

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Abstract*: A Fuzzy logic controller based Model Reference Adaptive System (MRAS) is proposed in this paper to estimate the speed of an Induction Motor. In order to Implement Field oriented Control of an Induction Motor it require sensors like current sensor, voltage sensor and Speed sensor, use of such sensors will add additional cost. In the proposed paper efforts are made to eliminate the speed sensor. The proposed work is implemented in MATLAB/simulink and results are displayed in this paper.*

Index Terms: *Speed estimation, Field oriented control, Induction motor (IM), Model Reference Adaptive System (MRAS), Fuzzy logic controller.*

I. Introduction

Induction motor drives have certain advantages like less cost, ruggedness and required low maintenance. Field oriented control provides good solution for industrial applications. [1] Normally in order to implement a vector control operation we generally require number of position sensors like speed, voltage, current sensors. But if we use the position sensors then the cost and size will be increased. So, to overcome this we need to use limited number of sensors [2]. Reducing the number of sensors will increase the reliability of the system. So, if we eliminate the number of sensors we need to estimate the required quantity. The estimation can be done by using different strategies like model based and signal based out of this model based estimation the best method to estimate the speed by using Model Reference Adaptive System (MRAS). [3] An induction motor can be looked as a transformer with a moving secondary where the coupling coefficient between the stator and rotor phase's changes continuously with a change of rotor position θr. The steady state model neglects all electrical transients during load changes and stator frequency variations. So we need to build a dynamic model which takes into account of all transients. This model can be described by differential equations with time varying mutual inductances, but this kind of motor is very hard to build. The dynamic model of IM can be developed by using a two phase machine models in direct and quadrature axes. A three phase machine can be represented by two phase machine as shown in Fig 3.1 where ds-qs are stator direct and quadrature axis, and dr-qr axes are correspond to rotor direct and quadrature axis.There are different MRAS methods available like flux based MRAS, reactive power based MRAS etc. [4]

The back emf 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 absence of pure integrator and it also doesn't 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 a exact control of induction motor over a scalar control, because a scalar control although provides good steady state response but it posses very poor performance during dynamic situation [3] . In order 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 modelling equations are considered in synchronous reference frame where all the variables appear as DC quantities. [3]

II. MODELING OF INDUCTION MOTOR

An induction motor can be looked as a transformer with a moving secondary where the coupling coefficient between the stator and rotor phase's changes continuously with a change of rotor position θr. The steady state model neglects all electrical transients during load changes and stator frequency variations. So we need to build a dynamic model which takes into account of all transients. This model can be described by differential equations with time varying mutual inductances, but this kind of motor is very hard to build. The dynamic model of IM can be developed by using a two phase machine models in direct and quadrature axes. A three phase machine can be represented by two phase machine as shown in Fig 1.1 where ds-qs are stator direct and quadrature axis, and dr-qraxes are correspond to rotor directand quadrature axis.

But the problem of time varying inductances will remain the same. So, in order to eliminate these we need to refer all these stator and rotor variables to a common reference frame(arbitrary reference frame). Such a model can be obtained by means of space vector phasor theory.

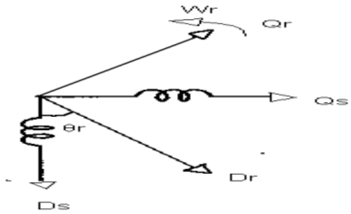

Fig 1.1 Two Phase equivalent of a machine

two-axis theory of electrical machines. Both methods are actually close and two-axis theory and will be explained here. The power must be equal in three phase and its equivalent two phase model [3]. Following figure shows block diagram of various steps in modelling the induction machine. Equations for dynamic modelling of Induction Machine are:

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

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

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

Torque Equation is given as:

$$T_e = (3/2)(p/2)(1/w_b)(F_{ds}i_{qs} - F_{qs}i_{ds}) \quad T_e = T_L + J\frac{dw_m}{dt} + BW_m \quad \text{(or)} \quad W_m = \frac{1}{J}\int(T_e - T_1)$$

III. Vector Control or Field oriented control

Among the various control methods of an IM a Scalar control method is very easy to implement but in an IM there is coupling effect so the control of IM through scalar control will be very sluggish so, in order to overcome this effect we are going for a vector control. Basically a vector control offers very clear-cut control over a scalar control.

There are two types of field oriented controls, they are :

i. Direct field oriented control

ii. Indirect field oriented control

In a direct field oriented control measurement of flux is done by using hall sensors of stator sense coils. These measured air gap flux linkage components are used in calculating rotor flux linkage space phasor position and also its magnitude. In Indirect vector control flux estimator is used to estimate the flux linkage space phasors position and magnitude. These kind of sensing will provide more flexible systems than a normal standard system with hall effect sensors.

A. VARIOUS BLOCKS IN SIMULINK

1. Speed controller

This generates q-axis reference current (isqref), by PI controller

$$i_{sqref} = \left(w_r^* - w_r\right)\left(k_p + \frac{k_i}{s}\right)$$

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2. TORQUE/CURRENT CONTROLLER

This generates the q-axis component of voltage vqs, which corresponds to the torque component, by PI controller. This controller is also known as q-controller.

$$v_{qs} = (i_{sqref} - i_{qs})\left(k_p + \frac{k_i}{s}\right)$$

3. FIELD CONTROLLER

This generates the d-axis component of voltage vds, which corresponds to the flux component, by PI controller. This controller is also known as d-controller

$$v_{ds} = (i_{sdref} - i_{ds})\left(k_p + \frac{k_i}{s}\right)$$

4. SLIP CALCULATOR

The slip speed between synchronous speed and rotor speed will be required to find out the flux linkage space phasor angular position ρ. This is calculated by following expression

$$w_{sl} = \frac{i_{qs}^{e}}{(\tau_r * i_{mr})}$$

This block also calculates the angular position by integrating the synchronous speed obtained by adding rotor speed and slip speed.

ρ = θ r + θsl = ∫ (ωsl +ωr)

IV. Sensor less Vector Control

Normally in order to achieve accurate control we generally use closed loop control. To achieve closed loop operation we require feedback signal, to get this signal we generally use sensors, but use of sensors not only increase the cost of the system but also the size of the system will increases. These sensors are very sensitive to damage. So, removing these sensors from the system will not only reduces the cost but also reduces the size of the system. So, we are choosing to control our motor without a sensor. But now the question is how can I get a feedback signal to control our motor. Instead of measuring it with sensors we can also get the information through estimation.

A. Model Reference adaptive system (mras). Basically it has two models one is reference model and the other one is adjustable model. The model which does not depends on which quantity it has to be measured is known as reference model and the model which depends on which quantity it has to be measured is known as adaptive model. The error generated from these two models is used as an input for the adaptive mechanism. In sensorless controls most of the times the quantity which defers the two models is rotor speed.

It consists of reference model and adaptable model as shown in the figure 5.1. The Speed adaption mechanism will adjust its output based upon the outputs of reference and adaptive models.

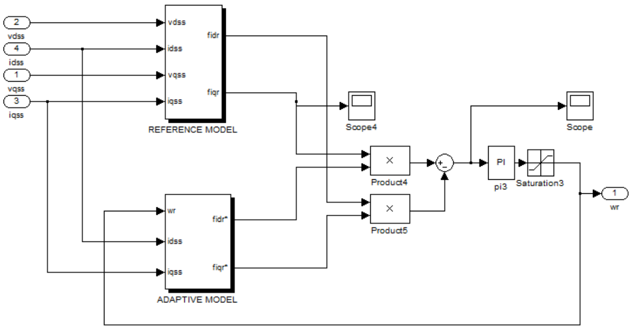

Fig 3.1 : Simulation model of MRAS

B. Simulation model of proposed system

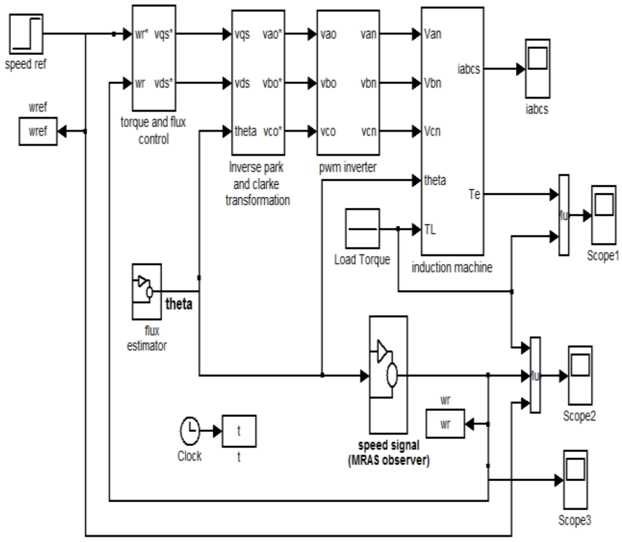

Fig 3.2 : Simulation model of proposed system

C. FUZZY LOGIC CONTROLLERS:

Boolean logic was developed based on the thinking of human. It states that the human takes decisions based on yes or no analysis, or simply '1' / '0'. By using this logic a traditional Expert system model was formulated. But in practical human decisions are not always based on yes or no analysis they are normally fuzzy in nature. By considering the above drawback a fuzzy logic was developed. If we consider a situation in normal Boolean logic the output will be logic 1 if it is true and if it is false the output will be logic 0. Unlike this a fuzzy offers more crystal clear output of a given situation, here the output will have degree of membership and output may be anywhere between 0 and 1. With all these advantages fuzzy logic controllers have been used in many applications like refrigerators, washing machines etc.

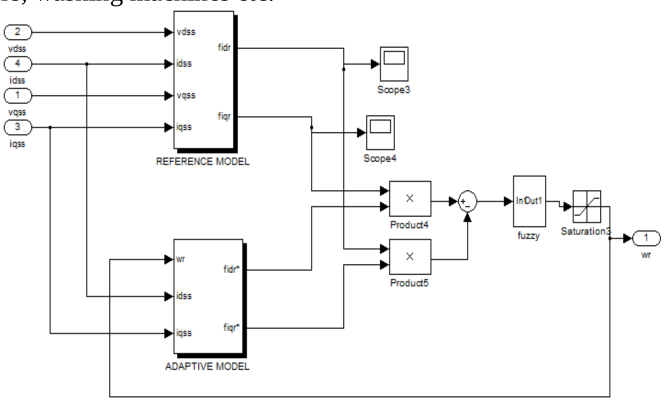

Fig 3.3 : Simulation model of MRAS with Fuzzy logic controller

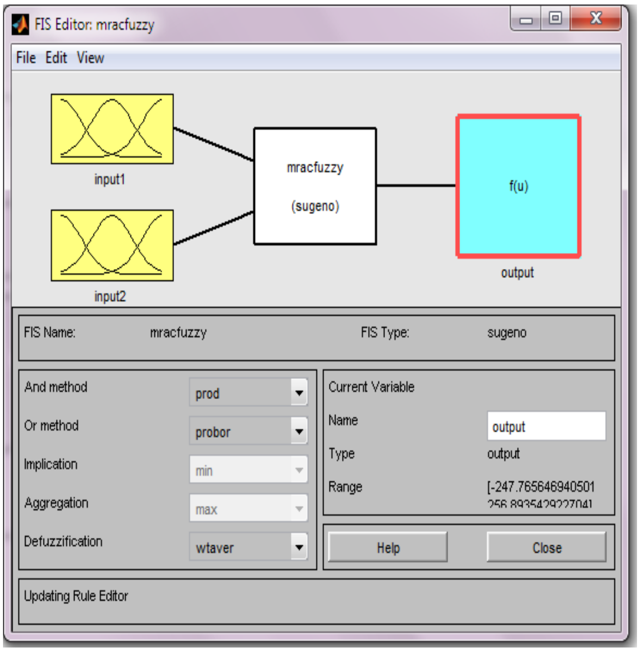

Fig 3.4 : Editor view of fuzzy controller in MATLAB/Simulink

V. SIMULATION RESULTS

The proposed MRAS-based speed sensor less vector-controlled IM drive is simulated in MATLAB/Simulink.This section first presents the simulation results showing the MRAS observer with normal PI-Controller. Thereafter, simulation results corresponding to MRAS observer with Fuzzy logic controller are shown.

Case (a): Ramp Response:

The ramp response of speed estimator is shown in Fig.4.1 & 4.3. In Fig.4.1 a Reference Speed is gradually changed from 0 to 30 rad/sec following a ramp signal. The reference and estimated speeds are shown in Fig.4.1 for a PI-controller based MRAS and in Fig.4.2 the actual speed of motor is shown. In Fig.4.3 A fuzzy controller based MRAS is shown. Note that the actual speed of the motor is measured directly by placing a sensor.

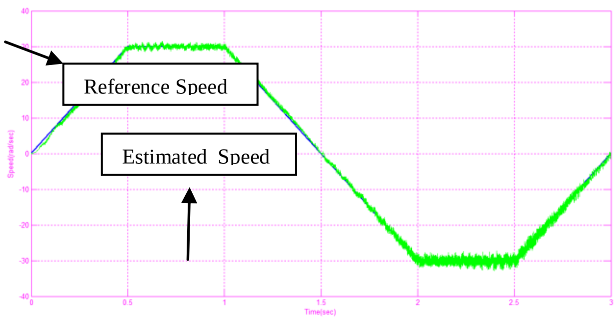

FIg 4.1: simulation results of reference and estimated speed

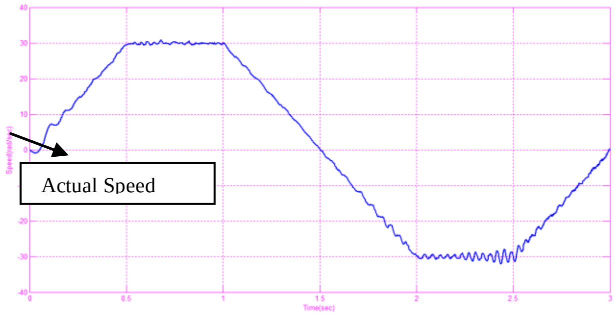

Fig 4.2 : simulation results of Actual speed

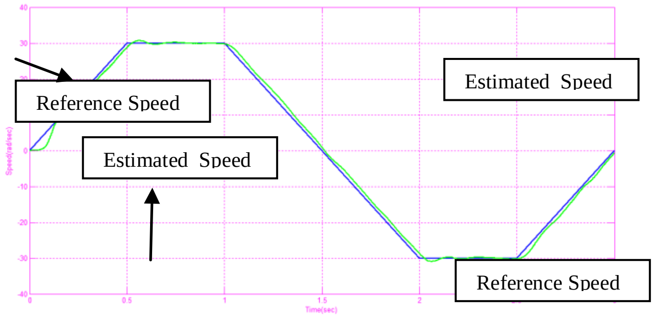

Fig 4.3: simulation results of reference and estimated speed

Case (B) : Regenerating mode of operation:

The performance of the speed estimator is studied under regenrative mode of operation and the results are shown in fig.4.4-4.6. The reference and estimated speeds are shown in Fig.4.4 for a PI-controller based MRAS and in Fig.4.5 the actual speed of motor is shown. In Fig.4.6 A fuzzy controller based MRAS is shown. Note that the actual speed of the motor is meassured directly by placing a sensor.

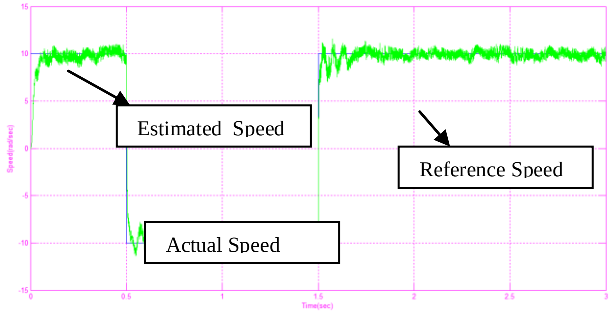

FIg 4.4: simulation results of reference and estimated speed

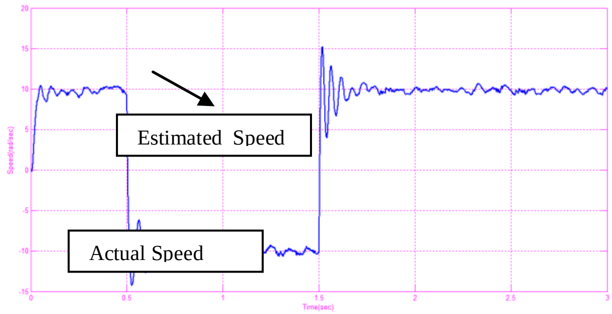

Fig 4.5 : simulation results of Actual speed

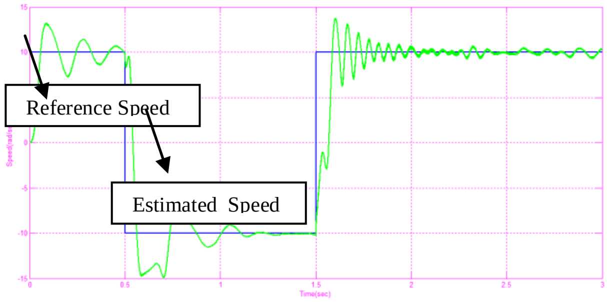

Fig 4.6: simulation results of reference and estimated speed

Case (c) : Response under low speed:

The performance of the speed estimator is studied under low speed conditions and the results are shown in fig.4.7 -4.9. The reference and estimated speeds are shown in Fig.4.7 for a PI-controller based MRAS and in Fig.4.8 the actual speed of motor is shown. In Fig.4.9 A fuzzy controller based MRAS is shown. Note that the actual speed of the motor is measured directly by placing a sensor.

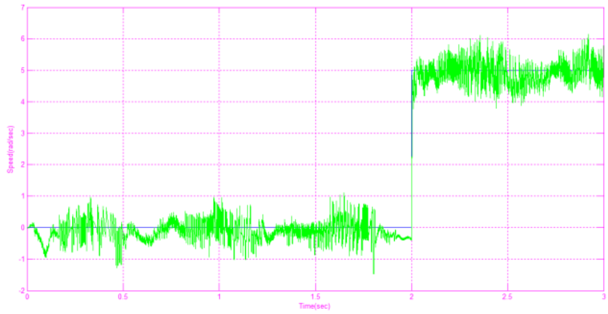

FIg 4.7: simulation results of reference and estimated speed

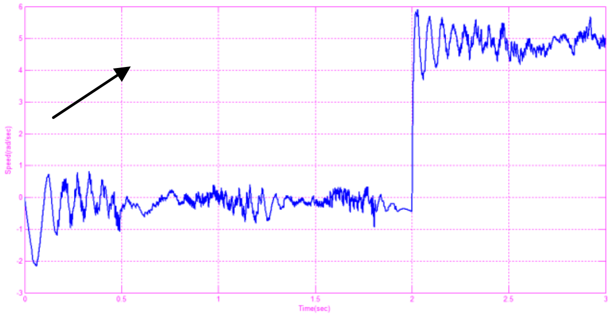

Fig 4.8 : simulation results of Actual speed

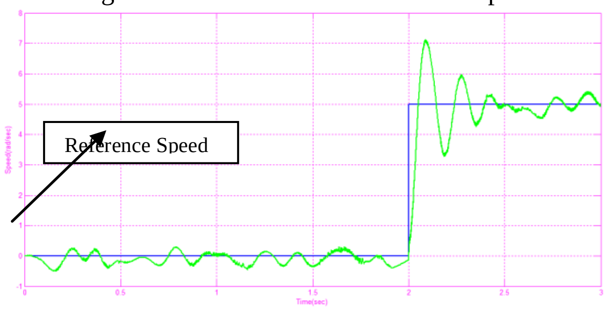

Fig 4.9: simulation results of reference and estimated speed

VI. CONCLUSION

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

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