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MODELLING OF A MODEL REFERENCE ADAPTIVE SYSTEM FOR VECTOR CONTROL OF INDUCTION MOTOR

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Abstract: - ***In this project, a novel rotor speed estimation method using model reference adaptive system (MRAS) is proposed to improve the performance of a sensor less vector control in the very low and zero speed regions. In the classical MRAS method, the rotor flux of the adaptive model is compared with that of the reference model. The rotor speed is estimated from the fluxes difference of the two models using adequate adaptive mechanism. However, the performance of this technique at low speed remains uncertain and the MRAS loses its efficiency, but in the new MRAS method, two differences are used at the same time. The first is between rotor fluxes and the second between electromagnetic torques. The adaptive mechanism used in this new structure contains two parallel loops having Proportional-integral controller and low-pass filter. The first and the second loops are used to adjust the rotor flux and electromagnetic torque. To ensure good performance, a robust vector control using sliding mode control is proposed. Matlab Simulation is carried out for checking the effectiveness of the proposed speed estimation method at low and zero speed regions, and good robustness with respect to parameter variations, measurement errors, and noise is obtained.***

Keywords:- MRAS, Induction Motot, Vector Control, Speed & Torque Control, etc.

1. INTRODUCTION

Three phase Induction motors are the most common motors used in industrial motion control systems. Low-cost, simple and rugged design and low maintenance are the main advantages of induction motors. Due to that, these motors are often called the workhorse of the motion industry. Squirrel cage is the widely type of induction motors used in industry. Generally, most of the industrial applications which contain induction motor need to vary their speed. However, induction motors can only run at their rated speed when they are connected directly to the main power supply. This is the reason why variable speed drives are needed to vary the rotor speed of an induction motor. The most popular algorithm for the control of a three-phase induction motor is the V/f control approach. Open-loop control is sometimes used in motor speed control system. However, open–loop AC motor speed control requires a precise speed profile to operate the motor from stand still to full speed. Speed error may arise due to load changes or external disturbances. To overcome these shortages, closed-loop control is frequently utilized in AC motor speed control system. Designing a robust controller will ensure the system to remains stable and keeps its required speed even the loads are applied or external disturbances occur.

In speed sensor less vector control of induction motor (IM), speed estimation determines the performance of the system. Therefore, a PI parameters adjustment method of speed observer based on model reference adaptive system (MRAS) is proposed. Aiming at the problem of integral saturation and dc offset in voltage model flux observer (VM) using pure integrator, the method of high-pass filter with compensation is adopted. The transfer function of speed observer is deduced based on modern control theory. The stability of speed observer is analyzed and the PI parameters are designed according to the stability conditions, which avoids the complexity of empirical method and pole placement method, and has strong portability.

Induction motor (IM), with its simple structure low cost and high control accuracy, occupies an important position in the field of motion control. Compared with the traditional vector control system with speed sensor, the sensor-less vector control system does not need encoder and other speed sensors, which reduces the complexity of hardware and maintenance cost, and is suitable for use in severe working conditions. In order to estimate the speed and obtain better dynamic performance, model reference adaptive system (MRAS) was used to estimate the speed in recent decades, many great scholars have adopted model reference adaptive system (MRAS) to estimate speed, There are many methods, such as MRAS based reactive power, MRAS based back EMF, etc. The control technique based on MRAS was firstly proposed by H.P.Whitaker, a professor at the Massachusetts institute of technology of United States in the 1950s, to challenge the unmanned aircraft problem. Colin Schauder came up with an idea that the voltage model without rotor speed information can be regarded as reference model, while the current model, which contains speed information, can be taken as adjustable model, and rotor speed is usually identified by selecting PI adaptive rules.

2. PROPOSED WORK

Fig. 1 is the structure of vector control system for three-phase asynchronous motor in the basis of rotor flux orientation. Where ASR stands for the speed regulator while ATR and AΨR represent the torque controller and the flux regulator, respectively.

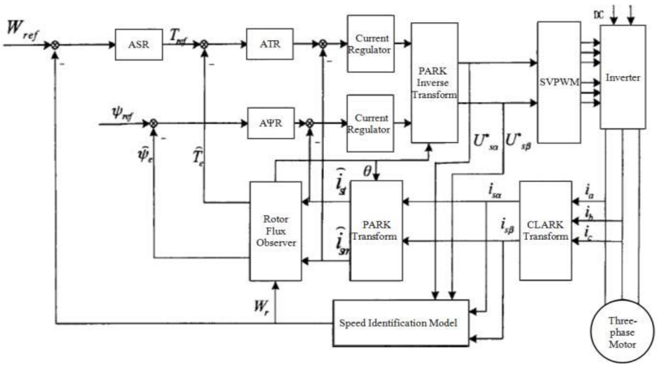

Fig. 1: The structure of vector control system for asynchronous motor

The fundamental principle of vector control implement is, by measuring the parameter of asynchronous motor stator current vector, controlling magnetizing current and torque current separately in the basis of field orientation theory, so as to achieve the purpose of asynchronous motor torque control. Vector control follows the tenets of generating equal magneto motive force, converting three-phase stationary coordinate system to two-phase stationary coordinate system and then to two-phase rotating coordinate system, which completely decouples the stator current excitation component and torque component. After the asynchronous motor is equivalent to DC motor, the control method of DC motor can be applied to control asynchronous motor.

Usually, the traditional asynchronous motors install speed encoder to detect velocity, and feedback velocity signal. But measuring velocity by speed sensor leads to quantities of trouble, such as the bigger volume and the difficulty in sensor maintenance. In addition, the installation of speed sensor increases the manufacturing cost and reduces the reliability of the system. The speed sensor less vector control strategy requires no hardware testing, which gets rid of all sorts of trouble brought by speed sensor. Therefore, asynchronous motor vector control without speed sensor has a better prospect in engineering application.

I.M. In recent decades, many great scholars have adopted model reference adaptive system (MRAS) to estimate speed, There are many methods, such as MRAS based reactive power, MRAS based back EMF, etc. Usually MRAS takes the voltage model flux observer (VM) as reference model, and takes the current model flux observer (CM) containing speed information as adjustable model, the errors generated by the two models are sent to the adaptive mechanism for speed identification. Facts have proved that it is difficulty to adjust the PI parameters of the adaptive mechanism. In the research study it is proves that PI controller is replaced by fuzzy-PI controller, which avoids the trouble of adjusting PI parameters but cannot avoid multifarious of experience method and still needs a lot of precise data to create fuzzy control rule table. On the basis of MRAS, uses pole placement to configure PI parameters, which is a classical method, but it needs too much calculation. The process of speed identification needs to consider the influence of disturbance. In this project the mathematical model will be set up and the vector controller will be designed founded on the control object, the small three-phase asynchronous motor. Furthermore, the speed identification method based on MRAS is discussed in detail. When designing the adaptive mechanism of MRAS, a first-order low-pass filter instead of a pure integrator is applied to the voltage reference model, which eliminates the impact upon speed identification caused by zero drift and integral initial values when the motor is operating at low speed. After that, the stability of the system is proved by using Popov super stability theorem. Results from the simulation of asynchronous motor vector control without speed sensor verified the accuracy of the identified speed of MRAS.

3. VECTOR CONTROL OF I.M

Vector control or field oriented control has invented by Blaschke to emulate DC motor characteristics in an induction motor. In general, an electrical motor can be thought of as controlled torque source. The torque is produce in the motor by the interaction between the magnetic field of the stator field and the current in the rotor. The stator field should maintain at a certain level, sufficiently high to produce a high torque, but not too high to result in excessive saturation of the magnetic circuit of the motor. By fixed stator field, the torque is proportional to the rotor current. The construction of a separately excited DC motor ensures that the stator field is always orthogonal to the rotor field. Being orthogonal, there is no interaction between these two fields. Therefore, independent control of the rotor current and stator field is feasible where the current in the stator determine the system field, while the current in the rotor can be used as a direct mean of torque control.

In squirrel-cage induction motor, the rotor current is not fed directly by an externally source but it result from induced e.m.f in the rotor winding. In other words, the stator current is the source of magnetic field in the stator and rotor current. Therefore, the control of induction motor is not simple as DC motor due to the interaction between the stator field and rotor field whose orientation is not always held at 90° but it is varying depending on the operation conditions. We can obtain DC motor like performance in an induction motor by holding orthogonal orientation between the stator and rotor fields to achieve independently control of flux and torque. Such a scheme is called vector control or field oriented control.

Vector Control for I.M

From the inception of Vector Control (VC) method, IM has started replacing DC motors in various commercial and industrial applications. VC technique introduces decoupling between torque and flux control, enabling the IM to operate as a separately excited dc motor. The presence of speed sensor in Vector Controlled Induction Motor Drive (VCIMD) contributes towards the increase in cost. The drawbacks incorporated by use of mechanical speed sensor in closed loop control may be overcome by estimating the speed using electrical measured parameters (such as voltage and current).

Basic Principle of Vector Control

Blaschke projected a scheme, which denotes the control of induction motor like a separately excited dc motor, called “Field Oriented Control” (Vector Control). In an AC machine, both the phase angle and the magnitude of the current must be well-ordered. This is the reason for the term “Vector Control”. In this scheme, the induction motor is examined from a synchronously rotating reference frame where all the fundamental AC variables appear to be DC quantities. The torque and flux components of currents are recognized and controlled autonomously to attain good dynamic response. Vector control suggests that an AC motor is forced to behave dynamically as a D.C. machine by the use of feedback control. Field-oriented control (indirect FOC) of induction machine achieves decoupled torque and flux dynamics. This is achieved by orthogonal projection of the stator current into a torque-producing component and flux-producing component. This technique is performed by two basic methods:

- Direct vector control
- Indirect vector control

With direct field orientation, the prompt value of the flux is required and gained by direct measurement using flux sensors or flux estimators, whereas indirect field orientation is centered on the inverse flux model dynamics; and there are three possible execution based on the stator, rotor, or air gap flux orientation.
The rotor flux indirect vector control technique is the most extensively used due to its minimalism. Indirect FOC methods are pretty good but suffer from one major drawback. They are subtle to parameter variations such as rotor time constant and improper flux measurement or estimation at low speeds. This approach needs more calculations than other standard control schemes but has the following advantages:

- Full motor torque capability at low speed
- Better dynamic behavior
- Higher efficiency for each operation point in a wide speed range
- Decoupled control of torque and flux
- Short term overload capability
- Four quadrant operation

Among various techniques of rotor speed estimation, MRAS has come out to be one of the better techniques proposed by researchers mainly due to its simplicity in control. The method first appeared in literature taking Rotor Flux (RF) as the functional candidate. In recent half of the decade, various modifications in the technique adopted in MRAS have been executed. Rotor flux based MRAS seriously suffers from drawbacks due to pure integration (for flux estimation) and speed estimation at low speed operation (stator resistance changes during machine operation). An alternative for the problem of pure integration is by selecting Back E.m.f (BE) as an alternate functional candidate for computation, having known the value of stator resistance with a suitable accuracy.

In comparing the speed estimation methodology using RF and BE MRAS structures, apart from the advantages that the BE MRAS technique introduced, it also made researchers conscious towards difficulties like differentiation of stator currents. An option of improvement has been pointed out in RF MRAS technique when operated at low speeds, by making use of parallel processing of two differences, namely, RF and electromagnetic torque, respectively, towards the feedback input to the ADM. The effect of variation of stator resistance is also an important aspect in BE MRAS methodology.

Control Topology

The control architecture of MRAS comprises a Reference Model (RM) and an Adjustable Model (AM) respectively. RM and AM are used to generate an error signal, which drives an adaptive mechanism to make the error converge towards zero through a closed loop control. The output signal of the adaptive mechanism (ADM) is the estimated rotor speed, and the structure of ADM is obtained from Popov’s hyper stability criteria. Here a simple Proportional-Integral (PI) controller logic is used to realize the structure of ADM.
For estimation of a desired quantity, the basic condition is that the RM should be independent of the quantity which is coming from ADM whereas AM should be dependent on it. Estimated rotor speed is given as follows-

$$\omega_r = (K_{pmras} + K_{imras}/_S)(\psi_{\beta r}\hat{\psi}_{\alpha r} - \psi_{\alpha r}\hat{\psi}_{\beta r}) \qquad (1)$$

$$\omega_r = (K_{pmras} + K_{imras}/_S)(e_{m\beta}\hat{e}_{m\alpha} - e_{m\alpha}\hat{e}_{m\beta}) \qquad (2)$$

Where Kpmras and Kimras are the parameters of PI control logic used to realize the ADM.

Rotor Flux based MRAS

The basis of Rotor flux (RF) based MRAS is that rotor flux may be estimated either using the voltage model or the current model of an induction motor. The structure of reference model (RM) and adjustable model (AM) may be realized as follows:

Reference Model

$$\psi_{\alpha r} = \frac{L_r}{L_m}\left[\int (v_{\alpha s} - R_s i_{\alpha s})dt - \sigma L_s i_{\alpha s}\right] \quad (3)$$

$$\psi_{\beta r} = \frac{L_r}{L_m}\left[\int (v_{\beta s} - R_s i_{\beta s})dt - \sigma L_s i_{\beta s}\right] \quad (4)$$

Adjustable Model

$$\psi_{\alpha r} = \int \left(-\frac{1}{T_r}\psi_{\alpha r} - \omega_r \psi_{\beta r} + \frac{L_m}{T_r} i_{\alpha s}\right) \quad (5)$$

$$\psi_{\beta r} = \int \left(-\frac{1}{T_r}\psi_{\beta r} + \omega_r \psi_{\alpha r} + \frac{L_m}{T_r} i_{\beta s}\right) \quad (6)$$

The RM provides a reference value for rotor flux while the AM provides the estimated value of rotor flux. Error generated from these two models, is fed to the ADM for speed estimation. At steady state, error converges towards zero equating the estimated and actual speeds respectively

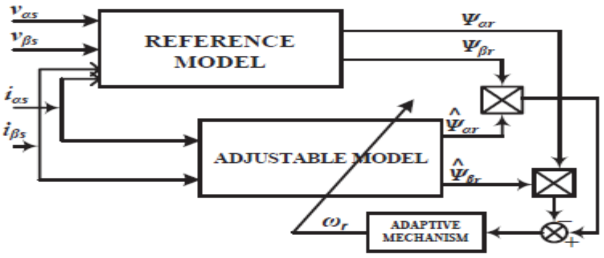

Fig 2- Basic Block Diagram of Rotor Flux based MRAS Speed Estimator

B. Back E.m.f based MRAS

Back-E.m.f (BE) can be an alternative functional candidate to drive the adaptation mechanism. Computation of rotor flux through the process of integration, introduces problems such as, initial condition and drift. The RM and AM in back e.m.f based MRAS control scheme may be defined as follows:

Reference Model

$$e_{m\alpha} = v_{\alpha s} - \left(R_s i_{\alpha s} + \sigma L_s \frac{di_{\alpha s}}{dt}\right) \quad (7)$$

$$e_{m\beta} = v_{\beta s} - \left(R_s i_{\beta s} + \sigma L_s \frac{di_{\beta s}}{dt}\right) \quad (8)$$

Adjustable Model

$$\hat{e}_{m\alpha} = \frac{L_m}{L_r T_r}\left(L_m i_{\alpha s} - \psi_{\alpha r} - \omega_r T_r \psi_{\beta r}\right) \quad (9)$$

$$\hat{e}_{m\beta} = \frac{L_m}{L_r T_r}\left(L_m i_{\beta s} - \psi_{\beta r} + \omega_r T_r \psi_{\alpha r}\right) \quad (10)$$

To realize the RM of BE based MRAS, extraction of the fundamental component of input voltage applied to the induction machine is important otherwise computation of back-e.m.f will contain higher order harmonics, which in turn would affect the quality of the estimated speed.

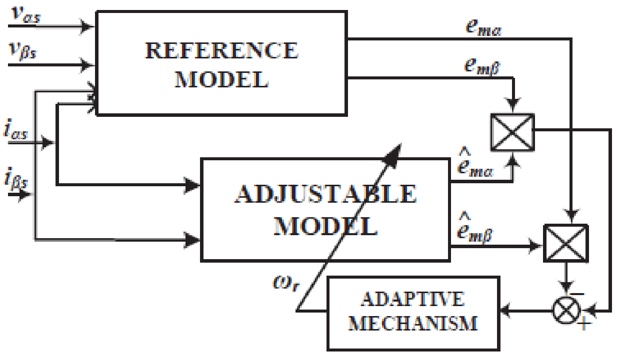

Fig 3-Basic Block Diagram of Back-E.m.f based MRAS Speed Estimator

4. METHODOLOGY

Mathematical transformations are devices which make complex framework easy to study and easy to focus. In electrical machines analysis, a three phase variables to two phase variables transformation is applied to produce less complex expressions that provide more understanding into the cooperation of the distinctive parameters. In this chapter, the various transformations studied in the past have been presented.

General change of variables in transformations

Consider a symmetrical three phase induction machine with stationary three axes at 2π/3 angle apart as shown in Fig. 4.1. The real three phase supply system can be represented by these three axes. Whereas, the two axes are representing two fictitious phases perpendicular to one other. The change of three phase variables to two phase variables can be possible in such a way that the two phase variables are either in a stationary reference frame or in synchronously rotating reference frame. Transformation into a synchronously pivoted rotating reference frame is more common and it can be possible with the transformation of the three phase variables into two phase variables and after that transform these to synchronously moving reference frame.

Transformation into a stationary reference frame
It is considered that the three phase axes and the two phase axes are in a stationary reference frame. Our aim is to transform the three phase (abc) variables to two phase (αβ0) variables. The relationship between three phase variables and two phase variables in stationary reference frame is given below and the transformation from three phase stationary reference frame to two phase stationary reference frame can be understood from Fig. 4.

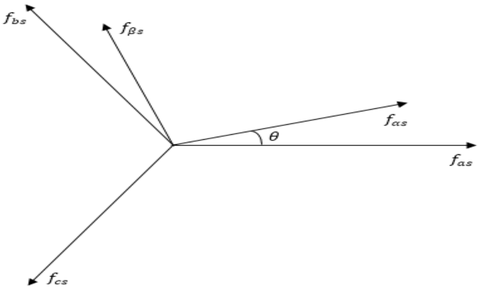

Fig. 4 Three-axes and two-axes in stationary reference frame

In the above diagram, Fig. 4, the voltage, current, or flux linkage can be denoted by f. The subscript s represents the variable associated with stationary reference frame. The angle, θ is the displacement of the two phase α-β winding, from the three phase, a-b-c winding. $f\alpha s$ and $f\beta s$ variables are perpendicular to each other. fas, fbs and fcs may be considered as three phase variables in the stationary reference frame each displaced by 2п/3 electrical degrees.

Transformation of the three phase variables in stationary reference frame to an arbitrary reference frame can be expressed in matrix form as:

$$\begin{bmatrix} f_{\alpha s} \\ f_{\beta s} \\ f_{0s} \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos\theta & \cos\left(\theta-\frac{2\pi}{3}\right) & \cos\left(\theta+\frac{2\pi}{3}\right) \\ \sin\theta & \sin\left(\theta-\frac{2\pi}{3}\right) & \sin\left(\theta+\frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}\begin{bmatrix} f_{as} \\ f_{ab} \\ f_{ac} \end{bmatrix}$$

….. (4.1)

The corresponding inverse of Equation (4.1), is

$$\begin{bmatrix} f_{as} \\ f_{ab} \\ f_{ac} \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta & 1 \\ \cos\left(\theta-\frac{2\pi}{3}\right) & \sin\left(\theta-\frac{2\pi}{3}\right) & 1 \\ \cos\left(\theta+\frac{2\pi}{3}\right) & \sin\left(\theta+\frac{2\pi}{3}\right) & 1 \end{bmatrix}\begin{bmatrix} f_{\alpha s} \\ f_{\beta s} \\ f_{0s} \end{bmatrix}$$

…….. (4.2)

It is convenient to set θ=0, so that the α-axis is aligned with the a-axis. Therefore the Equation (4.1) will be written as

$$\begin{bmatrix} f_{\alpha s} \\ f_{\beta s} \\ f_{0s} \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & -\frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}\begin{bmatrix} f_{as} \\ f_{ab} \\ f_{ac} \end{bmatrix}$$

…….. (4.3)

And Equation (4.2) will be simplified to

$$\begin{bmatrix} f_{as} \\ f_{ab} \\ f_{ac} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 1 \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} & 1 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} & 1 \end{bmatrix}\begin{bmatrix} f_{\alpha s} \\ f_{\beta s} \\ f_{0s} \end{bmatrix}$$

…….. (4.4)

Equations (4.3) and (4.4) shows that the magnitude of the phase quantities, voltages and currents, in the three phase stationary reference frame (a-b-c) variables and two phase stationary reference frame (d-q) variables remain the same. In this transformation, it is considered that the number of turns in each phase of the three phase winding and the two phase winding are same.

5. MODELLING & SIMULATION

Matlab Simulation of Conventional Vector Controlling I.M Speed Control

A Simulink model of speed sensorless vector control for three phase induction motor has been developed in MATLAB, Simulink. The Matlab Model includes vector control topology for Induction Motor speed control. The simulation model of the proposed system is shown in fig 5 below.

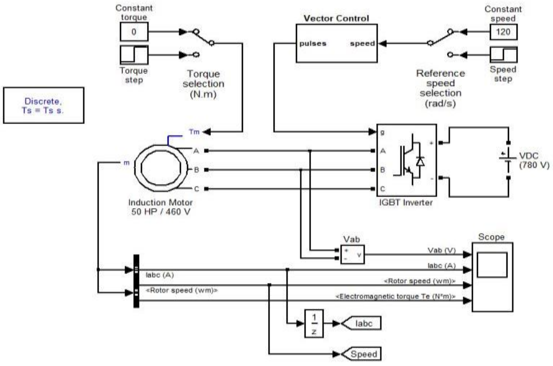

Fig 5- Matlab Simulation of Conventional Vector Control system for I.M

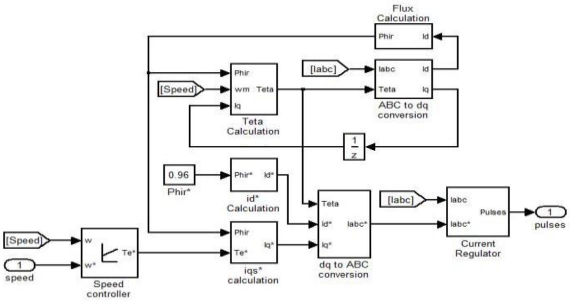

Fig 6- Vector Controlling Subsystem

As shown in fig 6 the vector controlling subsystem includes the ABC to dq0 transformation and dq0 to ABC transformation for direct and Quadrature axis parameters calculation. The reference speed and measured speed from the motor is given to compare and calculate the torque deviation in Induction Motor. The above controlling system provides conventional vector control topology for motor speed control and the simulation results are shown in the below section.

Simulation Results of Conventional Vector Control for I.M Speed Control

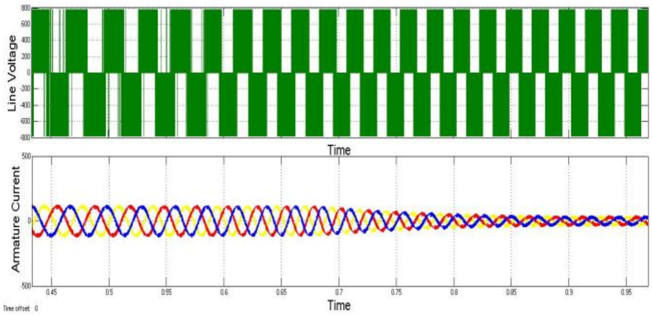

Fig 7- Simulation Results of Line Voltage and Armature Current

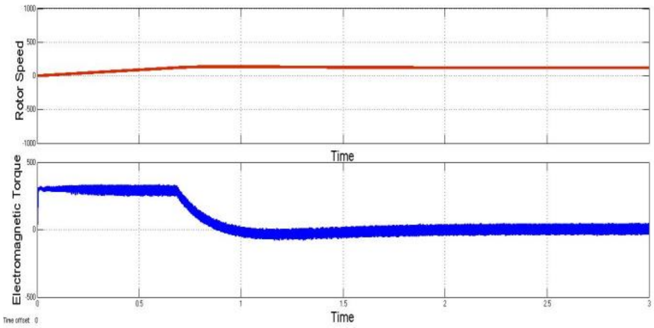

Fig 8- Simulation results of I.M speed and Electromagnetic Torque Variation

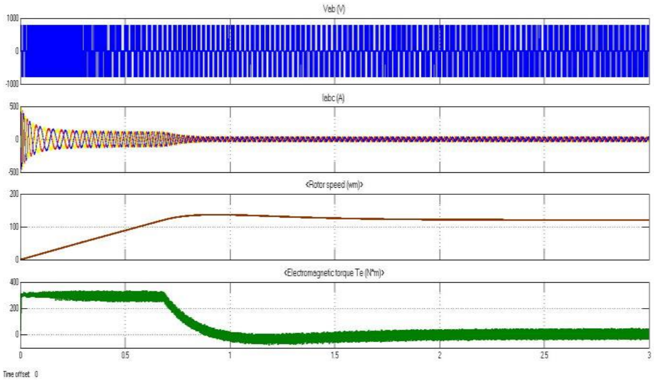

Fig 9- Simulation Results of Induction Motor All Parameters

Model Reference Adaptive System Control for I.M

- In the proposed system we have the develop simulation of induction motor torque speed control using SVPWM and inverter topology.
- In the propose system abc to dq0 transformation and vector control topology has been utilize for the triggering pulse control.

Using the field oriented control topology and SVPWM we can derive triggering pulse of 3 level inverter.

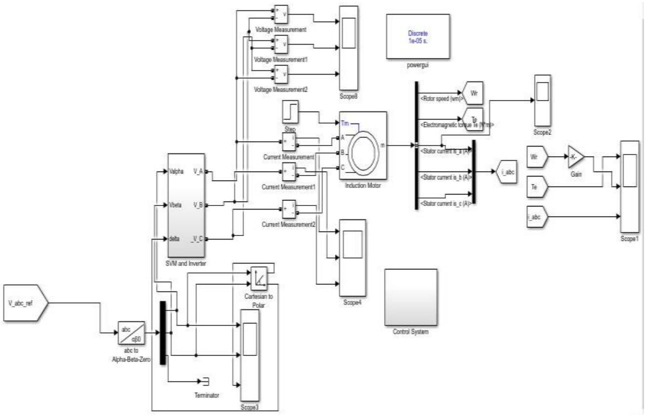

Figure 10 Diagram of induction motor connected with SVPWM

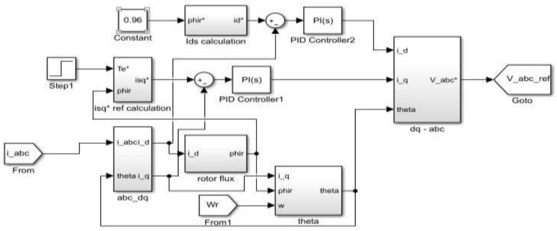

Figure-11 MRAS Control System for Motor Speed and Torque Control

The propose control system provide torque speed characteristics control protection in the system .the voltage references for the inverter pulses for the controlling block and given to the SVPWM block.

Simulation Results of Proposed System

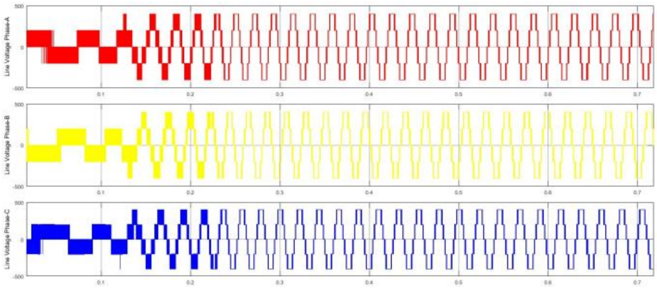

Figure 12 Simulation Results of Line Voltages of Each Phase

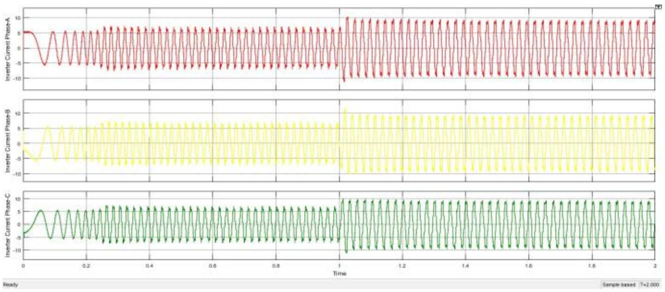

Figure 13 Simulation Results of Line Current of Each Phase

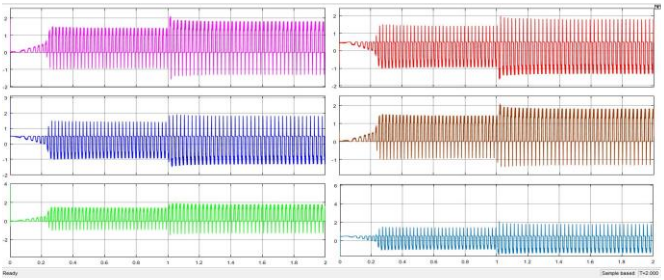

Figure 14 Simulation Results of Each Vector Controlling

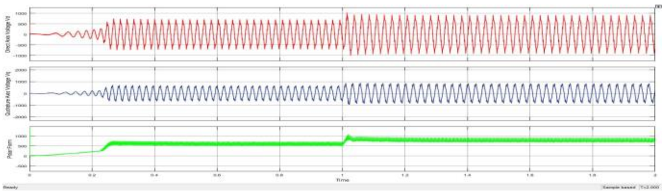

Figure 15- Simulation Results of direct and quadrature axis and polar signal

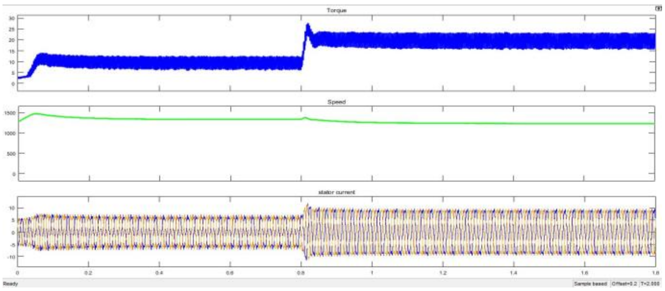

Figure 16 Simulation Results of All Controlled parameters of Induction Motor

6. CONCLUSION

The objective of this project was to develop a speed sensor less drive for three phase induction motor based on a rotor flux observer. In this project, a novel rotor speed estimation method using model reference adaptive system (MRAS) is proposed to improve the performance of a sensor less vector control in the very low and zero speed regions. In the classical MRAS method, the rotor flux of the adaptive model is compared with that of the reference model. In this project we have referred direct torque control method and field oriented control techniques. We have referred SVPWM control, pi control, part transformation and VSI fed inverter control. From the simulation results we can conclude that Propose control topology helps for indirect FOC and DTC control in induction motor. The simulation has been successfully carried out using MATLAB Simulink tools and torque speed control has been achieved in this project.

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