# SPEED SENSOR FAULT DETECTION AND DIAGNOSIS OF INDUCTION MOTOR USING FUZZY BASED FAULT TOLERANT ALGORITHM

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## ABSTRACT

This paper presents a three phase squirrel cage induction motor operates using indirect field control is used and speed sensor fault is diagnosis by fuzzy logic control. Induction motors are highly reliable, they are susceptible to many types of faults that can became catastrophic and cause production shutdowns, personal injuries, and waste of raw material. Induction motor faults can be detected in an initial stage in order to prevent the complete failure of the system and unexpected production costs. So,new fault tolerant algorithm is used to detect the faults and diagnosis the fault, with the help of current estimated and speed estimated blocks. Fault tolerant algorithm was used for diagnosis current and speed sensor faults.Here, IFOC techniques is used to control the switches of the inverter and system performance is analysed. Estimated current control block is used to diagnosis speed and current sensor which is estimated by logic based decision algorithm. In this paper modeling and simulation of three phase induction motor was deceloped using IFOC and fuzzy based new fault tolerant algorithm is also developed by using MATLAB/SIMULINK software.

## Keywords

Current estimation, speed estimation, fault detection algorithms, induction motor(IM)drive, fuzzy logic control,Indirect field oriented control.

## 1.INTRODUCTION

Reliability assessment of motor drives is important transportation applications. Safety is a major anxiety in such applications, and it is directly related to re-liability. Induction machines, due to their massive advantages like reliability and low cost, are widely used in industrial applications. However, several electrical and mechanical faults may occur during their life span. In industry, most failures disrupt a process and finally reduce or even stop the production.So inorder to prevent some monitoring techniques are needed to detect rotor fault and short winding fault,bearing fault and load fault etc. Thus, exclusive scheduled maintenance is performed in order to prevent sudden failure and avoid economic damage[1]

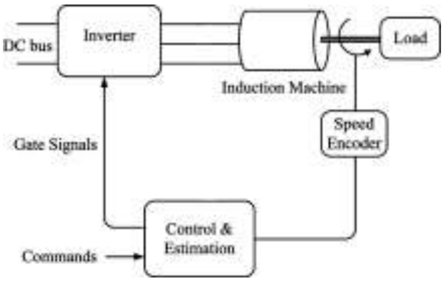

Fig. 1. Typical Induction Motor Drive

The computer simulation for these various modes of operation is conveniently obtained from the equations which describe the symmetrical induction machine in an arbitrary reference frame [2]. As in Fig. 1[3] shows entire block diagram of induction motor drive. To control the rotor which creates torque equation is called as rotor flux DQ model. while faults in supply voltages that is affected on stator voltage and not affected on rotor voltage. Because rotor voltages produced due to electromagnetic induction principle. So rotor flux DQ model is used. stator and synchronous reference frame is applicable for squirrel cage induction motor[2]. Because rotor part is short circuited in squirrel cage induction motor.The rotor reference frame is applicable for slip ring or wound rotor induction motor. Here synchronous reference frame is presented. Because when converting 3 phase to 2 phase which all parts considering DC quantity and control method is plain. The d-axis component is aligned with the rotor flux vector and regarded as the flux-producing current component. On the other hand, the q-axis current, which is perpendicular to the d-axis, is exclusively responsible for torque production.

The vector-control technique is now used for high-impact applications[4]. The source of failure may be due to the machine (such as stator inter turn faults, broken bar in the rotor, etc.), converters(i.e., failure of the switching devices). Indirect Field-oriented control or vector control of IM offers high recital (due to the decoupling of flux and torque) and has become an industry standard. In industry, most failures suspend a process and finally reduce or even stop the production. Thus, expensive scheduled maintenance is performed in order to prevent sudden failure and also avoid the economic damage.

The control reorganization is carried out by a fuzzy decision, which assures a smooth transition from the encoder-based (using sliding mode) to the sensorless controller (utilizing fuzzy control). All these approaches sacrifice field orientation when fault occurs and hence offer poor dynamic performance. The implementation is difficult and also such techniques cannot be used for complex applications inverter-fed induction motors are analyzed under indirect field oriented control. So here fault tolerant algotithm is developed to diagnosis the faults and fuzzy based fault algorithm is also compared to normal fault tolerant algorithm.

## 2. DYNAMIC MODEL OF INDUCTION MOTOR

The dynamic model model of squirrel cage induction motor[SEIM] in stationary reference frame in α-β reference frame variables [5].

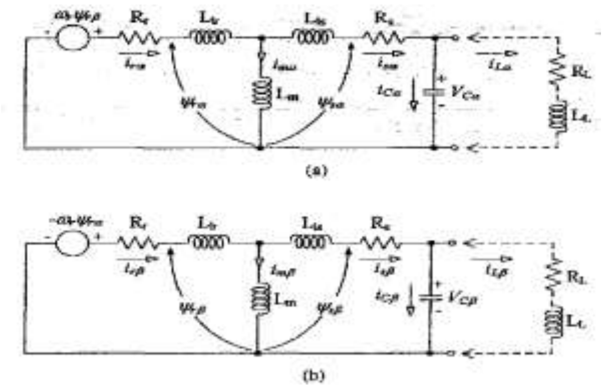

Fig. 2. Equivalent Circuit of SCIM (a) α axis (b) β axis

Components stator and rotor voltage of the induction motor can be expressed as follows.In order to analyse the system performance in dynamically, need to convert time domain to another form.so state variable form is introduced in this modeling and create the variable constants.

$$V_{s\alpha} = R_s i_{s\alpha} + L_s \frac{d}{dt} i_{s\alpha} + L_m \frac{d}{dt} i_{r\alpha} \tag{1}$$

$$V_{s\beta} = R_s i_{s\beta} + L_s \frac{d}{dt} i_{s\beta} + L_m \frac{d}{dt} i_{r\beta} \tag{2}$$

$$0 = R_r i_{r\alpha} + L_r \frac{d}{dt} i_{r\alpha} + L_m \frac{d}{dt} i_{s\alpha} + \omega_r \Psi_{r\beta} \tag{3}$$

$$0 = R_r i_{r\beta} + L_r \frac{d}{dt} i_{r\beta} + L_m \frac{d}{dt} i_{s\beta} - \omega_r \Psi_{r\alpha} \tag{4}$$

The components of rotor flux linkage in the stationary reference can be written as

$$\Psi_{r\alpha} = L_m i_{s\alpha} + L_r i_{r\alpha} + \Psi_{r\alpha 0} \tag{5}$$

$$\Psi_{r\beta} = L_m i_{s\beta} + L_r i_{r\beta} + \Psi_{r\beta 0} \tag{6}$$

Where $\Psi_{r\alpha 0}$ and $\Psi_{r\beta 0}$ are the residual rotor flux linkages in α-β axis, respectively.

Then, with an electrical rotor speed of $\omega_r$ ,the components of rotating voltage in the stationary reference frame are as the follows:

$$\omega_r \Psi_{r\alpha} = \omega_r L_m i_{s\alpha} + \omega_r L_r i_{s\alpha} + \omega_r \Psi_{r\alpha 0} \tag{7}$$

$$\omega_r \Psi_{r\beta} = \omega_r L_m i_{s\beta} + \omega_r L_r i_{s\beta} + \omega_r \Psi_{r\beta 0} \tag{8}$$

The expressions for capacitor voltages are,

$$V_{c\alpha} = \frac{1}{c} \int i_{C\alpha}\, dt + V_{c\alpha 0} \tag{9}$$

$$V_{c\beta} = \frac{1}{c} \int i_{C\beta}\, dt + V_{c\beta 0} \tag{10}$$

Using Fig. 2 equations (1)-(10), for the matrix equations of SCIM at no-load in the stationary reference frame are given by

$$\begin{bmatrix}0\\0\\0\\0\end{bmatrix}\begin{bmatrix} R_s+pL_s & 0 & pL_m & 0 \\ 0 & R_s+pL_s & 0 & pL_m \\ pL_m & \omega_r L_m & R_r+pL_r & \omega_r L_r \\ -\omega_r L_m & pL_m & -\omega_r L_r & R_r+pL_r \end{bmatrix}$$

$$\begin{bmatrix} i_{s\alpha} \\ i_{s\beta} \\ i_{r\alpha} \\ i_{r\beta} \end{bmatrix} + \begin{bmatrix} V_{c\alpha} \\ V_{c\beta} \\ \omega_r \Psi_{r\beta 0} \\ -\omega_r \Psi_{r\alpha 0} \end{bmatrix} \qquad (11)$$

From (11), can be written the state equations as follows:

$$AI_G + BI_G + V_G = 0 \qquad (12)$$

Where,

$$A = \begin{bmatrix} L_s & 0 & L_m & 0 \\ 0 & L_s & 0 & L_m \\ L_m & 0 & L_r & 0 \\ 0 & L_m & 0 & L_r \end{bmatrix},\ B = \begin{bmatrix} R_s & 0 & 0 & 0 \\ 0 & R_s & 0 & 0 \\ 0 & \omega_r L_m & R_r & \omega_r L_r \\ -\omega_r L_m & 0 & -\omega_r L_r & R_s \end{bmatrix}$$

$$I_G = \begin{bmatrix} i_{s\alpha} \\ i_{s\beta} \\ i_{r\alpha} \\ i_{r\beta} \end{bmatrix},\ V_G = \begin{bmatrix} V_{c\alpha} \\ V_{c\beta} \\ \omega_r \Psi_{r\beta 0} \\ -\omega_r \Psi_{r\alpha 0} \end{bmatrix}$$

## 3.INDIRECT FIELD ORIENTED CONTROL (IFOC) OF INDUCTION MOTOR

In Fig. 3 shows the block diagram of indirect field orientation control strategy with sensor in which speed regulation is possible using a control loop.

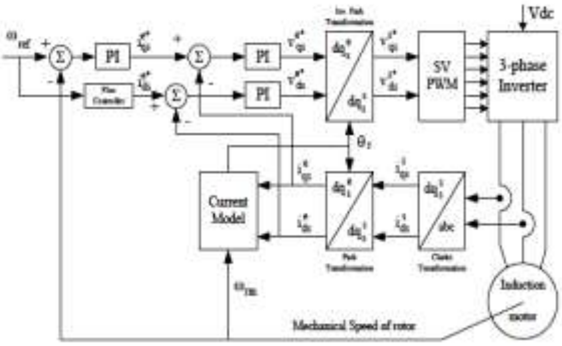

Fig. 3. Indirect Field-Oriented Control for Induction Motor Drives

There are two vector control methods, one is Direct Field Oriented control (DFOC) and another one, Indirect Field Oriented Control (IFOC), IFOC being more commonly used because in closed-loop mode such drives more easily operate throughout the speed range from zero speed to high-speed field-weakening in DFOC, flux magnitude and angle feedback signals are directly calculated using so-called voltage or current models. Fig.3. explains the fundamental principle of indirect vector control with the help of a phasor diagram. The $d^s$- $q^s$axes are fixed on the stator, but the $d^r$-$q^r$axes, which are fixed on the rotor, are moving at speed $\omega_r$. Synchronously rotating axes $d^e$- $q^e$are rotating ahead of the $d^r$-$q^r$axes by the positive slip angle $\theta_{sl}$ corresponding to slip frequency $\omega_{sl}$.

Since the rotor pole is directed on the $d^e$axis and $\omega_e = \omega_r + \omega_{sl}$ , one can write

$$q^e = \int \omega_e \, dt = \int (\omega_r + \omega_{sl})\, dt = \theta_r + \theta_{sl} \qquad (13)$$

The phasor diagram explain that for decoupling control, the stator flux component of current $i_{ds}^e$should be aligned on the $d^e$axis, and the torque component of current $i_{qs}^e$should be on the $q^e$axis, as shown.

$$v_{qs}^e = p\lambda_{qs}^e + \omega_e \lambda_{ds}^e + r_s i_{qs}^e$$

$$v_{qr}'^e = p\lambda_{qr}'^e + (\omega_e - \omega_r)\lambda_{dr}'^e + r_r' i_{qr}'^e \qquad (14)$$

If *d* –*q* axis is aligned with the rotor field, the q-component of the rotor field, $\lambda'^{e}_{qr}$, in the chosen reference frame would be zero.

$$T^{e}_{em} = \frac{3}{2}\frac{P}{2}\left(\lambda'^{e}_{qr} i'^{e}_{dr} - \lambda'^{e}_{dr} i'^{e}_{qr}\right) \qquad (15)$$

With $\lambda'^{e}_{qr}$zero, the equation of thedeveloped torque, eqn.(2.3), reduces to

$$T_{em} = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_r}\lambda'^{e}_{dr} i^{e}_{qs} \qquad (16)$$

which shows that if the rotor flux linkage $\lambda'^{e}_{qr}$is not disturbed, the torquecan be independently controlled by adjusting the stator q component current, $i^{e}_{qs}$.

For $\lambda'^{e}_{qr}$to remain unchanged at zero, its time derivative ($p\lambda'^{e}_{qr}$) mustbe zero.

$$\lambda'^{e*}_{dr} = \frac{r_r L_m}{r'_r + pL'_r} i^{e*}_{qs} \qquad (17)$$

When the field is properly oriented, $i'^{e}_{dr}$is zero, $\lambda'^{e*}_{dr} = L_m i^{e}_{ds}$thus, the slip speed of eqn can be written as

$$\omega^{e*}_{sl} = \omega_e - \omega_r = \frac{r'_r}{L'_r}\frac{i'^{e*}_{qs}}{i'^{e*}_{ds}} \qquad (18)$$

In IFOC, flux space angle feed forward and flux magnitude signals first measure stator currents and rotor speed for then deriving flux space angle proper by summing the rotor angle corresponding to the rotor speed and the calculated reference value of slip angle corresponding to the slip frequency. Indirect field orientation is based on sensing the rotor position that is very sensitive to motor parameters.[6]

## 4.FAULT DIAGNOSIS ALGORITHM

The new current control technique is based on the concept that the angular speed and the magnitude of the stator current can be controlled by two stator voltage components relative to the stator current**.**It is assumed that the system works with two current sensors and a speed sensor. These two current sensors may be put in any two phases. Note that the transformations from three-phase to two phase quantities required Following the standard procedure, first, it is assumed that the a-phase (of the three-phase system) and *α*-phase (of the two-phase system) are along the same axes.

$$\begin{bmatrix} i_{s\alpha} \\ i_{s\beta} \end{bmatrix} = \begin{bmatrix} \frac{3}{2} & 0 \\ \frac{\sqrt{3}}{2} & \sqrt{3} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \end{bmatrix} \qquad (19)$$

However, if the b-phase sensor is defective, the corresponding current of the *α*-phase will remain correct, while the current in the *β*-phasewill be wrong. Other hand, a unique feature is extracted if the *α*–*β* phase are rotated by 120˚.A logic-based detection mechanism in the *α*–*β* reference frame is proposed to make the drive fault tolerant against current sensor failures[7].

The error (E= $X_r$−$X_s$) is fed to the adaptation mechanism to generate the speed signal. This estimated value of the rotor speed will be used to make the drive fault tolerant against speed sensor failure a phase loss, the field orientation is lost, and hence, the q-axes flux can be checked to make a correct decision[8].

$$\begin{bmatrix} i'_{s\beta\_est} \\ i'_{s\alpha\_est} \end{bmatrix} = \begin{bmatrix} sin_{30^\circ - pms} & cos_{30^\circ - pms} \\ cos_{30^\circ - pms} & sin_{30^\circ - pms} \end{bmatrix} \begin{bmatrix} i^{*}_{sd} \\ i^{*}_{sq} \end{bmatrix} \qquad (20)$$

Therefore, depending on a fault either in b-phase or a-phase, the use of a proper transformation (either considering that *α*-phase is along a-phase or *α*-phase is along b-phase) will provide us the true estimate of the corresponding *α*-phase current. Fault detection can only be carried out if a correct estimate is available[9].

## 5.SIMULATION AND EXPERIMENTS

Some of the faults could damage the experimental setup and cannot be tested directly. Also, many commercial motor drives have built-in protection circuitry and algorithms that take action after a fault by shutting down or otherwise altering operation. It is not easy (or advisable) to override protection, but fault modes used here can also integrate protection in several aspects[10]. Even though the simulations here do not model or cover all physical dynamics, noise, vibration, power loss, and nonlinearities of material, they provide a useful tool that can save the cost of rebuilding a motor drive, or most other systems, after severe failure[11].

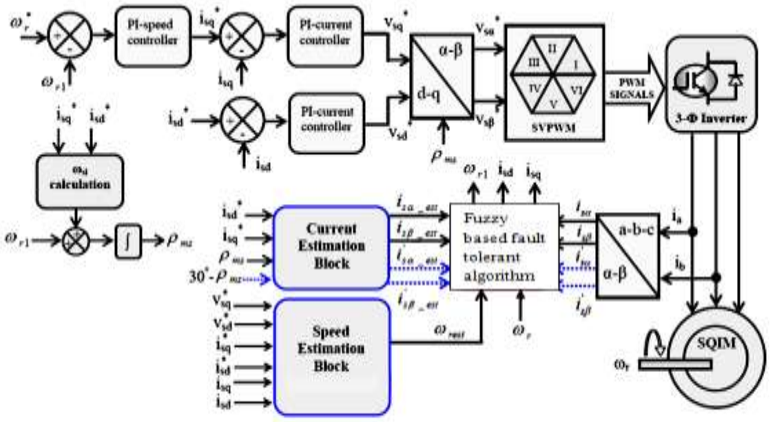

Fig. 4 Block Diagram of Fault-Tolerant Vector Controlled IM Drive

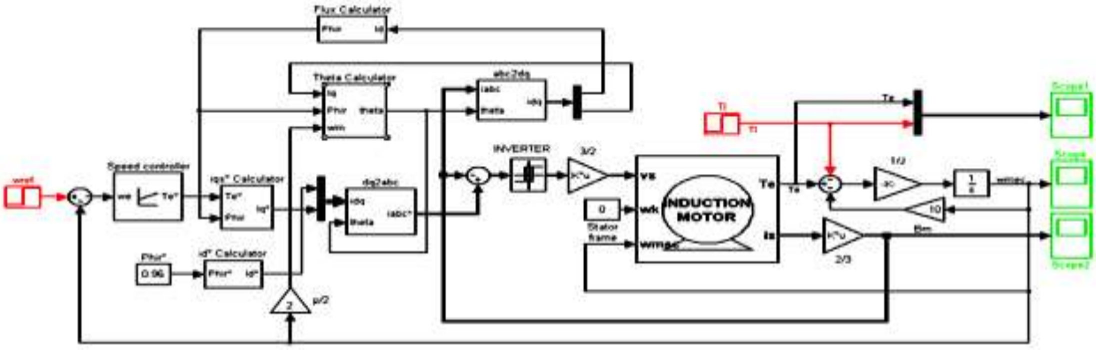

Fig. 5 Simulation Block Diagram of Closed loop IFOC

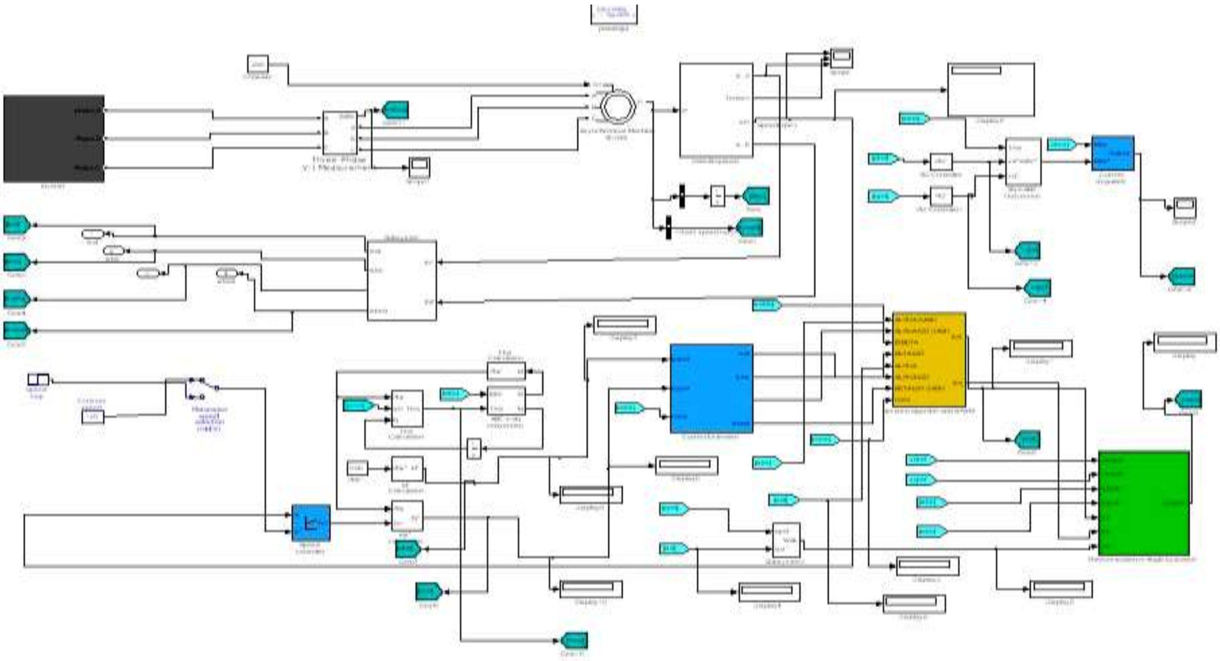

Fig. 6 Simulation Diagram of speed sensor fault diagnosis of three phase induction motor

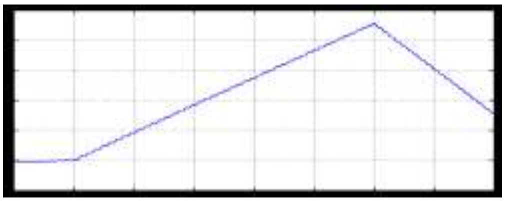

Fig. 7 Speed of Induction Motor Under Fault Condition

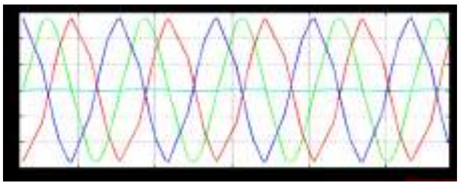

Fig. 8 Current Estimation of Induction Motor

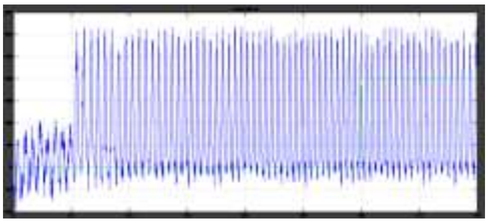

Fig.9 Torque of Induction Motor Under Fault Condition

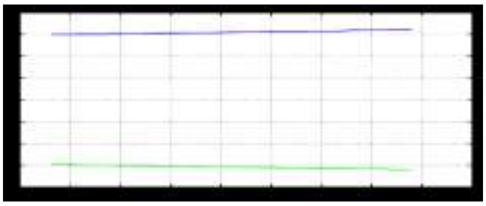

Fig.10 Fault Diagnosis Of D & Q Current

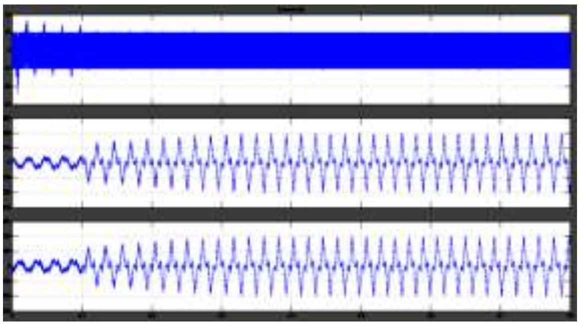

Fig. 11 stator Current of Induction Motor Under Fault Condition

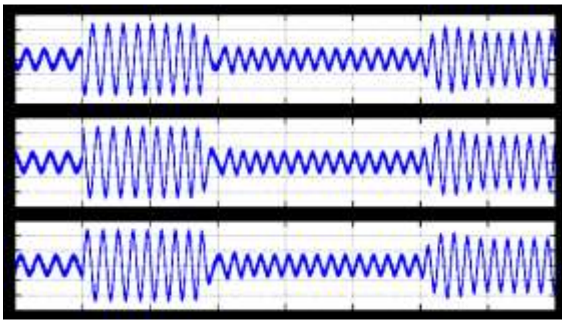

Fig. 12 Fault Diagnosis of Stator Current

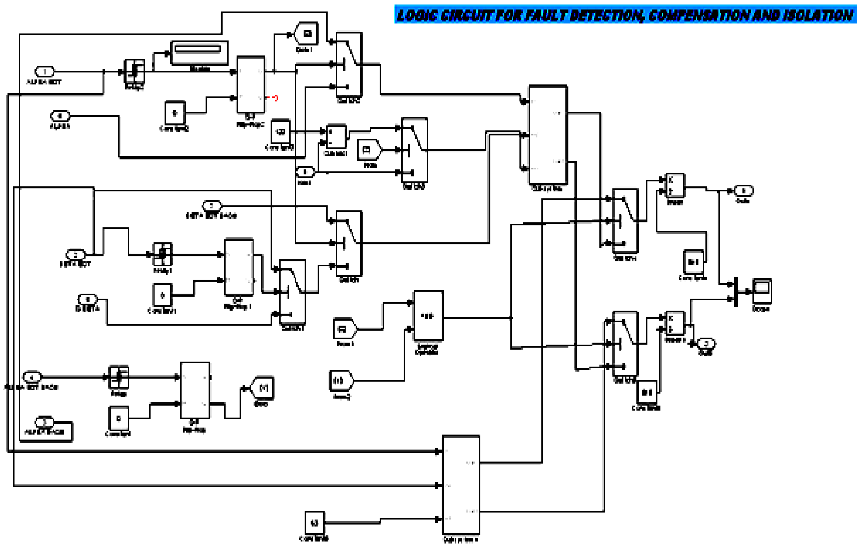

Fig. 13 Simulation Diagram for Current Sensor Fault Detection, Isolation, and Compensation

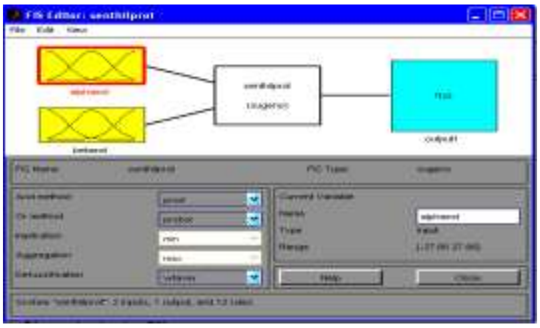

Fig.14 Fuzzy Input and Output Block for fault tolerant Algorithm

Fig 16. Fuzzy membership function editor for fault tolerant Algorithm

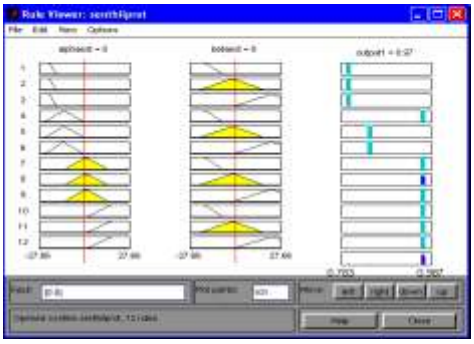

Fig 15. Fuzzy logic rule viewer for fault tolerant algorithm

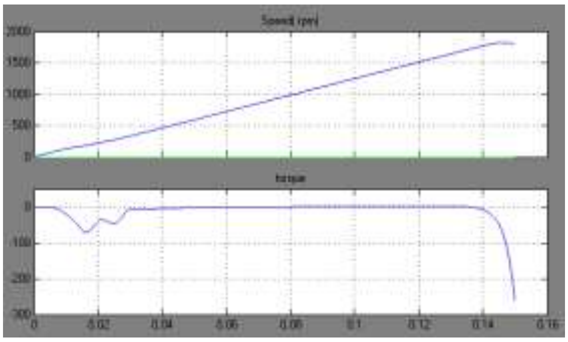

Fig 17. Simulation Results For Speed And Torque after Using Fuzzy Logic

## 6.CONCLUSION

This paper has presented a complete implementation of a fault-tolerant Indirect field oriented of controlled IM drive. This system is capable to detect a fault and reconfigure itself to switch to the correct algorithm. The controller keeps estimating different currents and speed and, in case of a fault, switches to the correct estimated value[12],[13]. By using SVPWM with vector rotator is introduced in simulation for deciding correct estimated value. This technique works perfectly even in case of multiple sensor failure. Such fault-tolerant controller will make the IM drive more rugged (mechanically) and reliable and will be very useful for applications like electric vehicles, where safety and reliability play a crucial role for drive selection. In this paper simulation of induction motor was created using IFOC and new fault tolerant algorithm with current and speed estimated values and fuzzy based fault tolerant algorithm also developed by using MATLAB/SIMULINK software.

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