Performance Analysis of Indirect Vector Controlled Induction Motor Drive Using PI & Fuzzy Logic Controllers

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ABSTRACT

This paper proposes an effective control strategy for Indirect vector control of Induction motor using Fuzzy Inference System (FIS). The steady-state & dynamic performance of the induction motor drive can be considerably improved with the proposed strategy. The Fuzzy Inference System (FIS) built with two inputs (error & change in error) & one output (command signal). This scheme doesn't require algorithms for estimation of rotor resistance when drive gets heated up which is the case with conventional PI control. The drive performance proves to be equally good even when the rotor resistance deviates from the actual value due to motor heating. The performance of the drive at different load torques & reference speeds with FIS controller against the conventional PI controller shows the effectiveness of the proposed scheme. The entire simulation study is performed using MATLAB/Simulink software using basic building blocks.

Keywords:

Fuzzy Inference System, PI controller, Fuzzy logic controller, Indirect Vector Control of Induction Motor

1. INTRODUCTION

Induction motors are being widely used in the industries due to their ruggedness & simplicity. Due to the advent of power electronics in late 1970's it made possible to control the induction motor speed & torque more precisely as per the load requirement without compromising the drive efficiency. However the design engineers still face challenges due to non-linearity & complex mathematical model of the induction motor. For high performance applications the motor speed should closely follow the reference disregarding load disturbances & machine parameter variations. Traditionally the speed control of induction motor is achieved using fixed PID gains. But the fixed gain controllers are very sensitive to parameter variations, load disturbances etc. Thus, the controller parameters have to be continuously adapted [main]. The development exact mathematical model of induction motor solves the problem of having fixed gain controllers to some extent. However it is often difficult to develop an accurate mathematical model due to non-linearity, unknown load variation and unavoidable parameter variations due to temperature variations and system disturbance. The stated problems can be overcome using, Fuzzy logic controller (FLC) for motor control purpose. The advantage of FLC compared to conventional PI controller is the designer is relieved from need of having plant mathematical model. FLC is based on linguistic rules within IFTHEN general structure, which is the basic of the human logic [3].

In this paper the performance analysis of conventional PI & Fuzzy logic controllers applied to control speed of Induction motor using Indirect vector control is presented. The performance of the drive system with these controllers is extensively studied & results show that ANFIS controllers perform superior compared to other controllers.

2. INDIRECT VECTOR CONTROL

The indirect vector control method is essentially same as the direct vector control except the unit vector is generated in an indirect manner using the measured speed ω_r and slip speed ω_{sl}. The following dynamic equations are taken into consideration to implement indirect vector control strategy [1].

$$\theta e = \int \omega_e \, dt \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$\frac{d\,\Psi_{dr}}{dt} + \frac{R_r}{L_r}\,\Psi_{dr} - \frac{L_m}{L_r}\,R_r\,i_{ds} - \omega_{sl}\,\Psi_{qr} \ \ldots (2)$$

$$\frac{d\,\Psi_{qr}}{dt} + \frac{R_r}{L_r}\,\Psi_{qr} - \frac{L_m}{L_r}\,R_r\,i_{qs} - \omega_{sl}\,\Psi_{dr} \ \ldots (3)$$

For decoupling control $\Psi_{qr} = 0$, So the total flux Ψ_r directs on the d^e axis.

Now from equations (1) and (2) we get,

$$\frac{L_r}{R_r}\frac{d\,\Psi_r}{dt} + \Psi_r = L_m\,i_{ds} \ \ldots\ldots\ldots\ldots\ldots (4)$$

Slip frequency can be calculated as

$$\omega_{sl} = \frac{L_m}{\Psi_r}\frac{R_r}{L_r}\,i_{qs} \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

For constant rotor flux Ψ_r and $\frac{d\Psi_r}{dt} = 0$ substituting in equation (4) yields the rotor flux set as

$$\widehat{\Psi}_r = L_m\,i_{ds} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

The electromechanical torque developed is given by

$$T_e = \frac{3}{2}\,\frac{P}{2}\frac{L_m}{L_r}\,\widehat{\Psi}_r\,i_{qs} \ \ldots\ldots\ldots\ldots\ldots (7)$$

From equations (6) & (7) reference current i_s* is generated as shown in the 'Vector control' subsystem block in Figure.1. On the other hand Torque reference T_e* is calculated with respect to the machine operating conditions(whether motoring or generating) using the 'flux controller' subsystem shown in Figure.1.

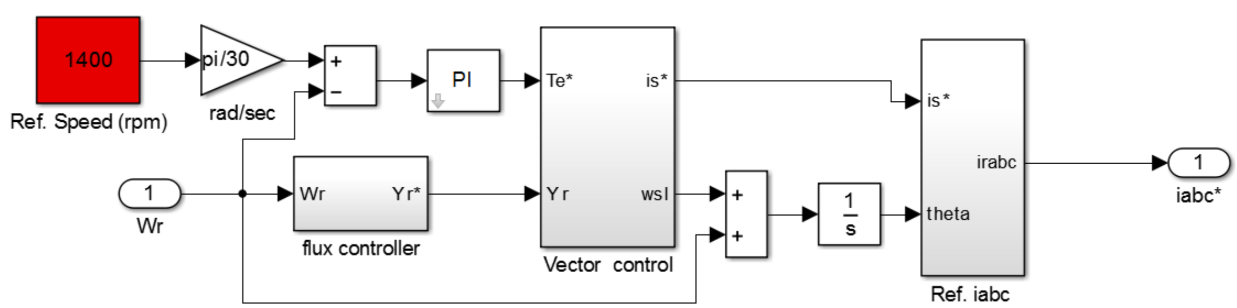

Figure.1 Simulink implementation of indirect vector control using PI Controller

The main principle of indirect vector control lies in the fact, how the rotor position is calculated. In case of direct torque control rotor position is evaluated using Hall Effect sensors embedded in stator winding. In case of indirect vector control the rotor position is evaluated by calculating the slip speed ω_{sl}, adding it to the current rotor speed ω_r & taking the integral of the synchronous speed ω_e calculated. The Simulink blocks shown in the Figure.1 also illustrates the calculation of rotor position θ_e.

The complete Simulink model of indirect vector control using PI controller is shown in Figure.2.

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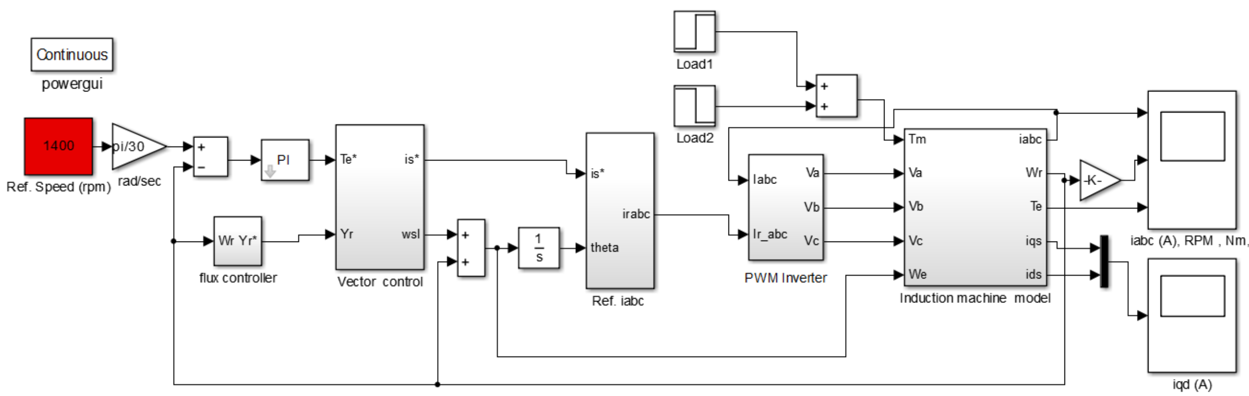

Figure.2 Simulink implementation of indirect vector control using PI Controller

The reference current i_s* generated is decomposed into 3-Φ currents with respect to the rotor position θ_e calculated as shown in 'Ref i_{abc}' subsystem in Figure.2. The 'PWM inverter' subsystem generates 3-Φ voltages so as to control motor speed & torque with respect to reference speed & load torque.

3. Simulation Results with PI

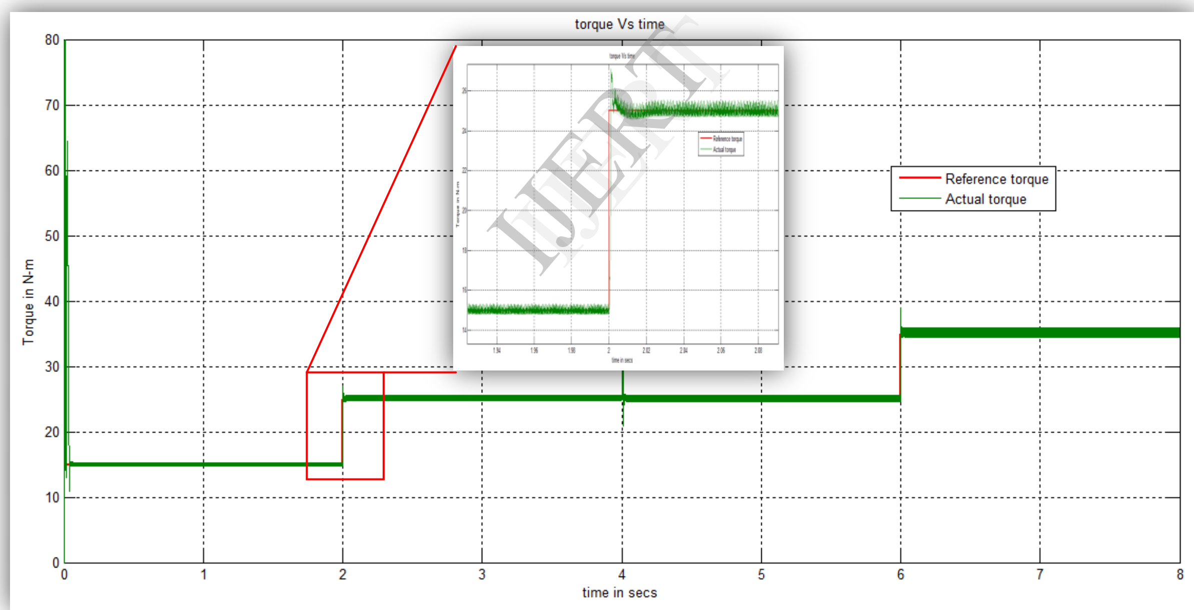

Figure.3 Torque developed for different load torques using PI Controller

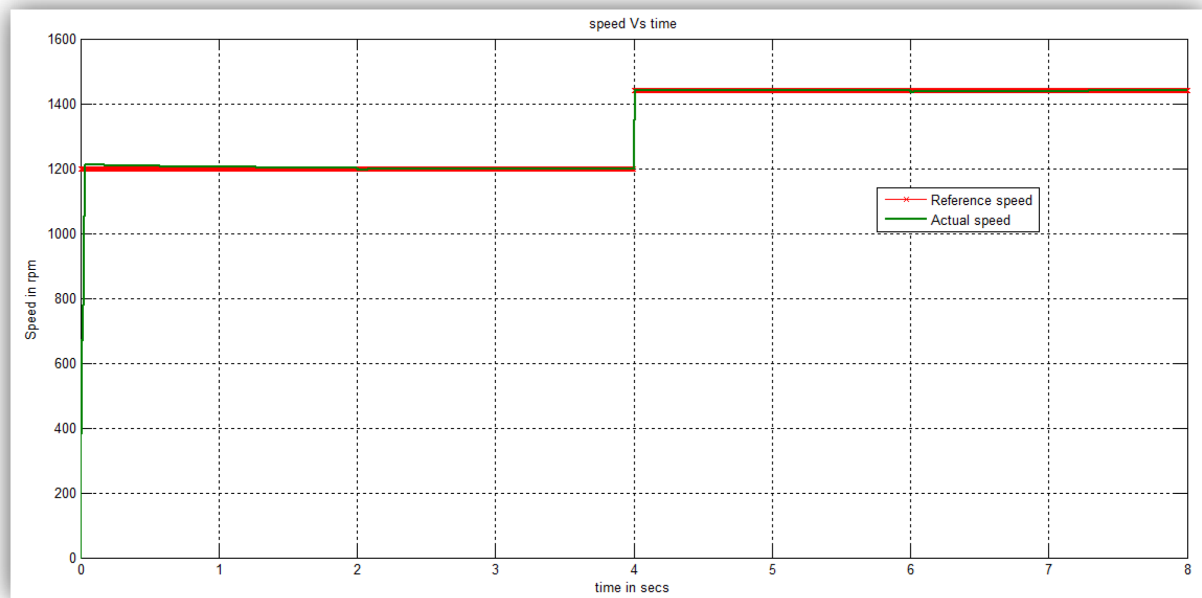

Figure.4 Reference & actual speed signals with PI controller

Test Scenario: The reference speed is set to 1200 rpm for t = 0 to 4secs 1440 rpm for t = 4 to 8secs. Load torque set to 15 N-m for t= 0 to 2secs, 25 N-m for t = 2 to 6secs and 35 N-m for t = 6 to 8secs

The plots for Torque in Figure.3 & Speed in Figure.4 prove the response of the drive is effective with very less steady state error. This kind of drive behavior is important where the machine speed has to stay constant irrespective of the load torque (or external disturbance) & control of speed as specified by the user. The electromagnetic torque developed by the induction motor with respect to the reference is almost instantaneous as shown in the plot.

4. Simulations Results with FLC

The same test scenario is implemented by replacing the PI controller with Fuzzy logic controller. FLC is designed using the MATLAB Fuzzy logic toolbox. The FLC controller has two inputs error & change in error & produces output.

About 49 rules are created with respect to the membership functions created for error & change in error. Sugeno type fuzzy inference system is selected to process the error & change in error and produces crisp output. Figure.5 shows the plot between error, change in error & Fuzzy controller output.

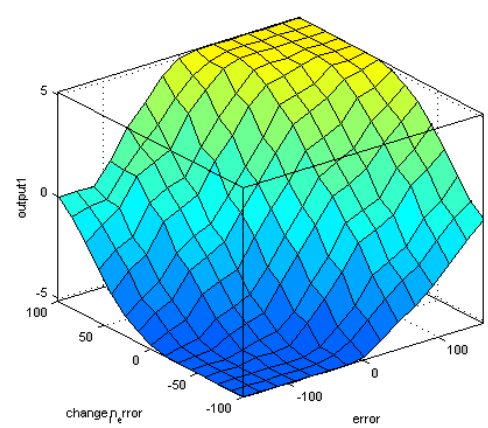

Figure.5 Plot between error, change in error & Fuzzy controller output

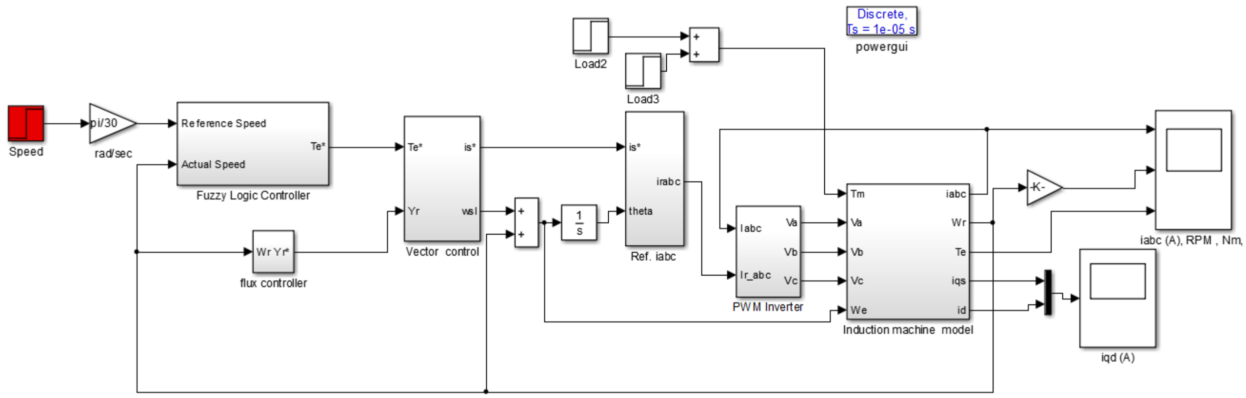

Figure.6 Complete Simulink model of Fuzzy logic Controller based Indirect Vector Control of Induction Motor

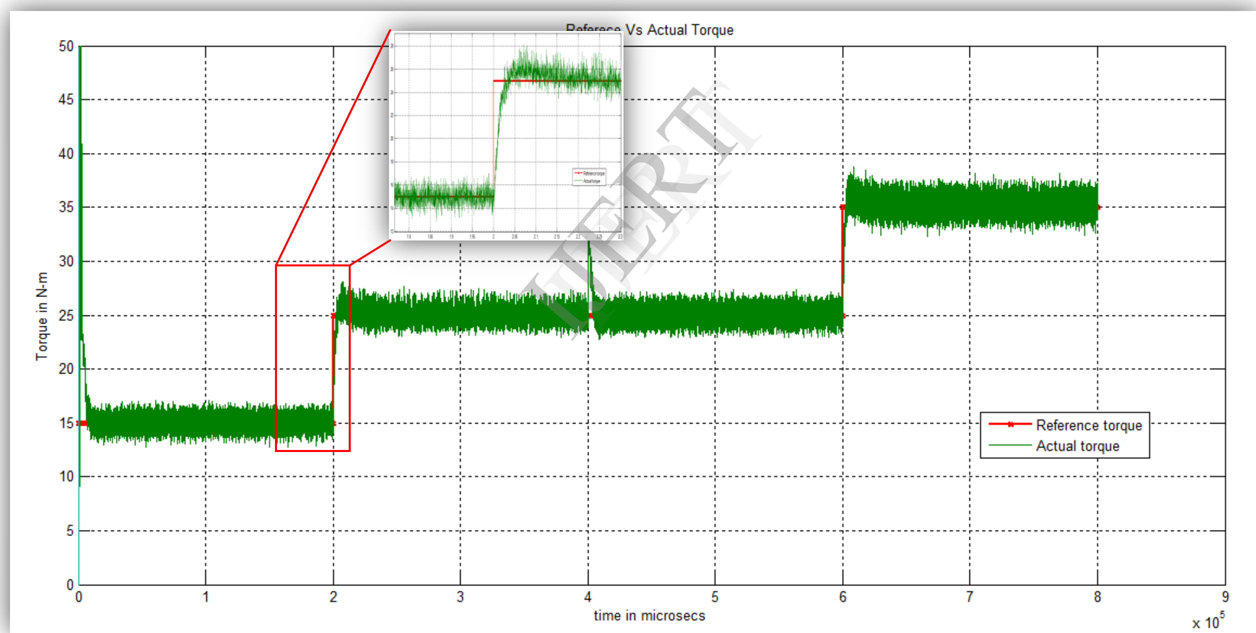

Figure.7 Reference & actual torques signals with fuzzy logic controller

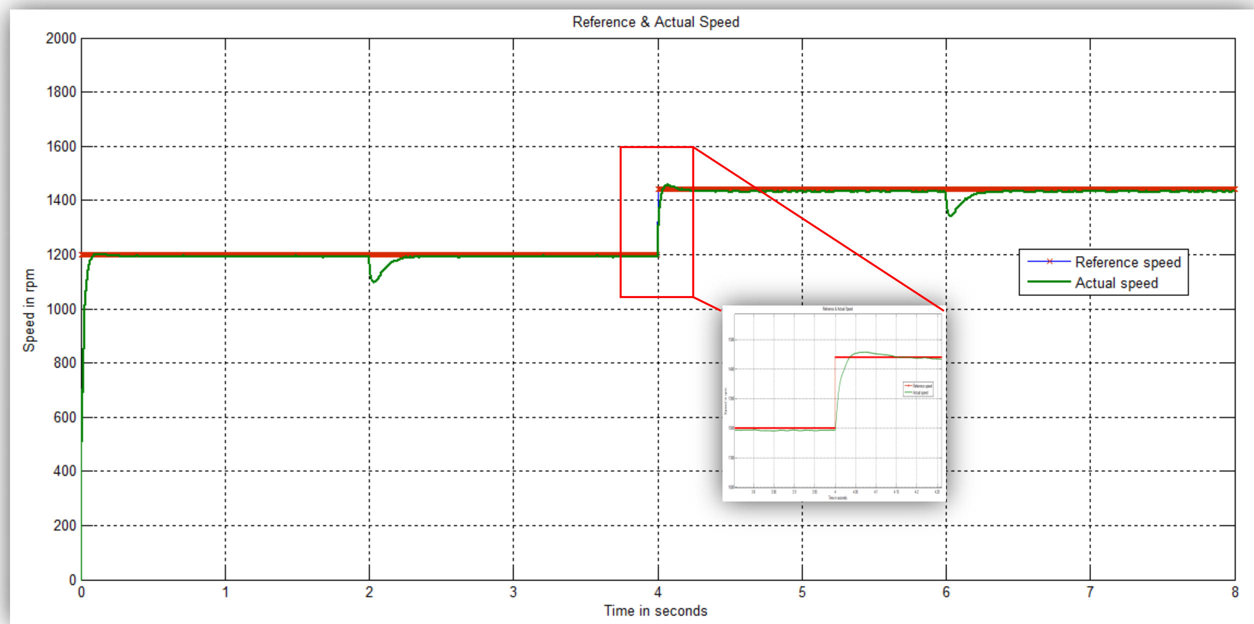

Figure 8 Reference & actual speeds with fuzzy logic controller

6. PI Controller response to Parameter Variation

Indirect vector control of induction motor performance with conventional PI controller showed desirable response under change in reference speed & load torques. The controller response is quite good under varying loads, however PI controllers are very sensitive to system parameter variations, and any change in machine parameters results in unsatisfactory control over speed & electromagnetic torque generated as shown in plots. The gains have to be re-adjusted to obtain better control over speed & torque.

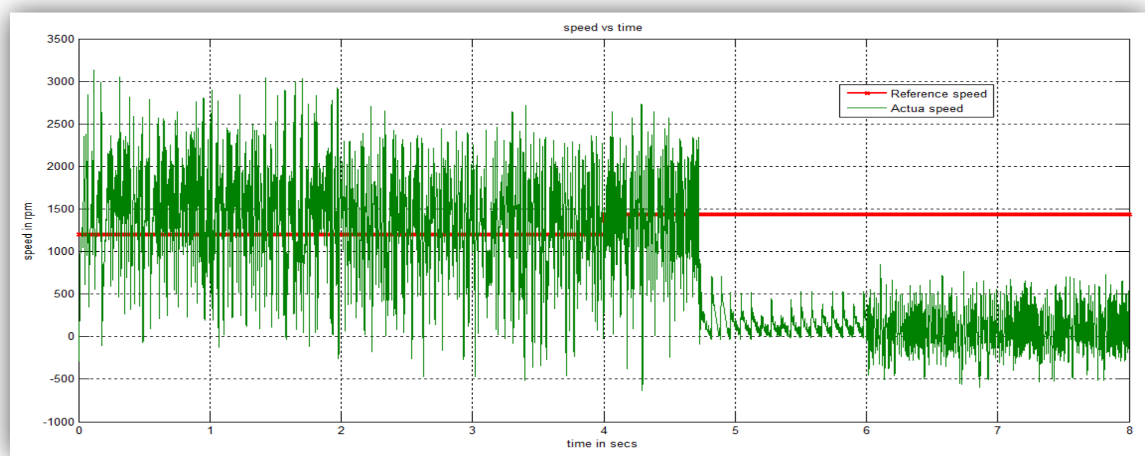

Figure.9 Speed response using PI controller with change in machine resistance

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7. Fuzzy Logic Controller response to Parameter Variation

On the other hand Fuzzy logic controller also gave quite good performance over speed & load torque changes & performs well under dynamics. Fuzzy logic controller out-performs PI controller when machine parameters change, for instance, when induction motor is loaded, the rotor resistance of the motor increases due to heating. This increase in rotor resistance results in uncontrolled system with PI controller. Fuzzy logic controller is very little affected with this change & gives equally good performance with respect to normal working conditions.

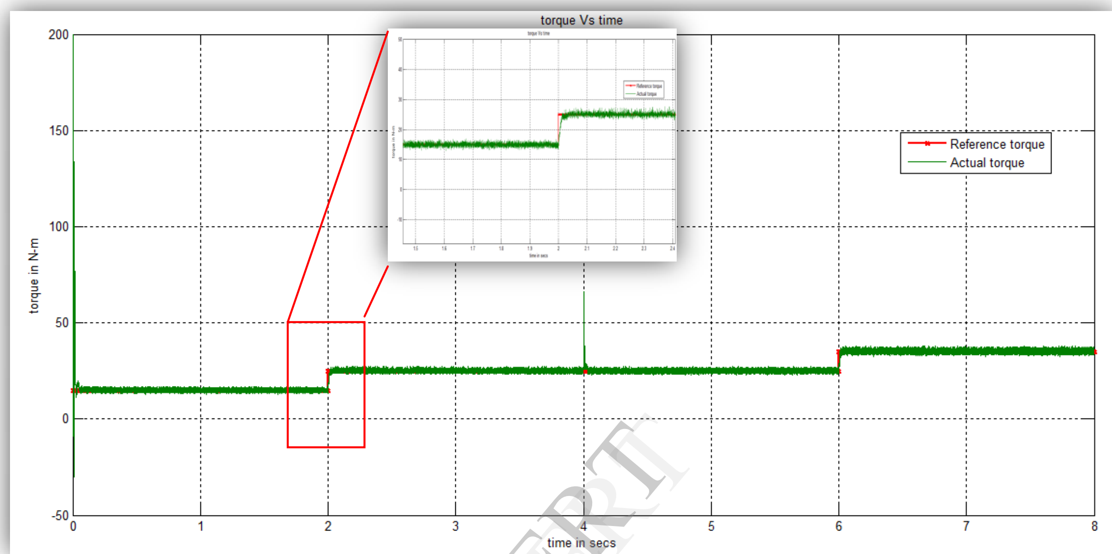

Figure 10 Torque response using Fuzzy logic controller with change in machine resistance

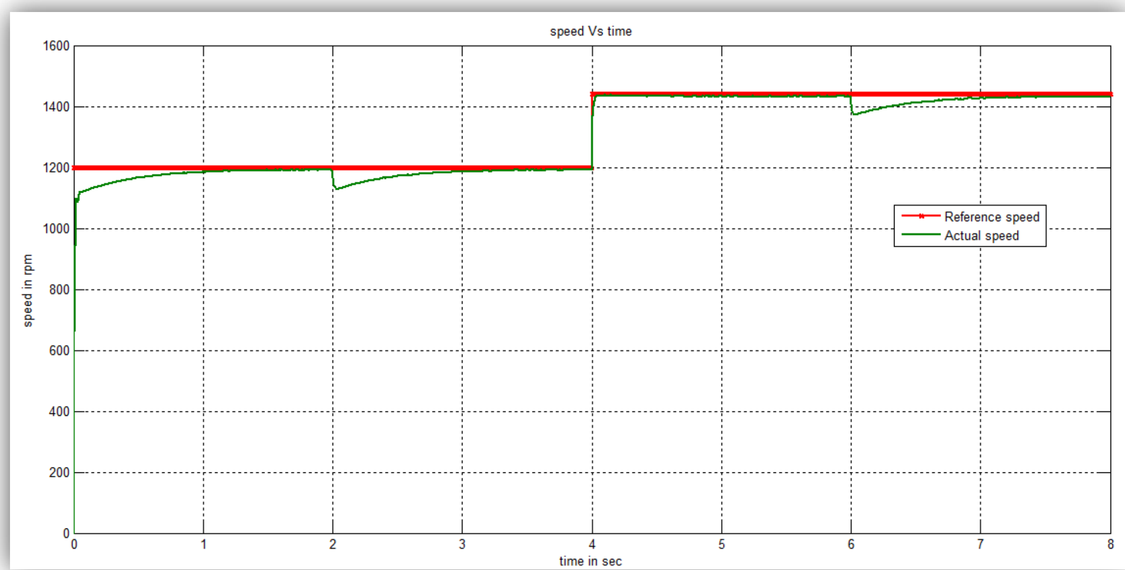

Figure.11 Speed response using Fuzzy logic controller with change in machine resistance

8. Conclusion

Indirect Vector control of induction motor using conventional PI controller & Fuzzy logic controller is implemented using MATLAB/Simulink model. The induction machine model is created with the help of d-q analysis.

This paper proposed an effective control strategy for Indirect vector control of Induction motor using Fuzzy Inference System (FIS). The steady-state & dynamic performance of the induction motor drive can be considerably improved with the proposed strategy. The Fuzzy Inference System (FIS) is built with two inputs (error & change in error) & one output (command signal). This scheme doesn't require algorithms for estimation of rotor resistance when drive gets heated up which is the case with conventional PI control. The drive performance proves to be equally good even when the rotor resistance deviates from the actual value due to motor heating. The performance of the drive at different load torques & reference speeds with FIS controller against the conventional PI controller shows the effectiveness of the proposed scheme. The entire simulation study is performed using MATLAB/Simulink software using basic blocks.

The machine performance under parameter variation (in this case stator & rotor resistances due to heating of motor) using conventional PI controller & Fuzzy logic controller is shown with the help of plots. Performance of the machine under parameter variation is equally good with Fuzzy logic controller which failed to achieve the same performance with conventional PI controller. Fuzzy logic controller proved to be more effective & less sensitive to parameter variation.

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