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FIELD ORIENT CONTROLLED INDUCTION MOTOR DRIVE AT LOAD CONDITION

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ABSTRACT

This paper present a mathematical modeling of vector-controlled induction motor drive (VCIMD) system with speed sensor and without speed sensor has been carried out to investigate the performance of drive system at different load condtion. VCIMD has been implemented using both Fuzzy and pi controllers at loaded condtions. The dynamic response of VCIMD under various operating conditions such as starting, speed reversal, speed re-reversal and load perturbation is simulated and examined in MATLAB environment using Simulink and power system block set toolboxes.

Keywords: Induction Machine, Fuzzy Logic, Harmonics, Matlab, Vector Control, Dynamic Response.

I. INTRODUCTION

Controlled induction motor drives without mechanical speed sensors at the motor shaft are attraction of low cost and high reliability. To replace the sensor, the information on the rotor speed is extracted from measured stator voltages and currents at the motor terminals [1-5]. Vector controlled drives require estimating the magnitude and spatial Orientation of the fundamental magnetic flux waves in the stator or in the rotor. To reduce total hardware complexity and costs and to increase mechanical robustness, it is desirable to eliminate speed and position sensors in vector- controlled drives [7- 9]. In drives operating in hostile environments or in high-speed drives, speed sensors cannot be mounted. As real-time computation costs are continuously decreasing, speed estimation can be performed by using various software-based estimation techniques where stator voltages and/or currents are monitored on-line. Sometimes it is possible to use a scheme where the dc link voltage is monitored and this information is combined with information on the switching states of the inverter. It is also possible to use other types of solutions, e.g. the stator phase third harmonic methods which are based on direct stator flux estimation utilizing monitored stator voltages and currents yield unsatisfactory performance at the low speed region, since they use pure integration for the stator flux and they are sensitive to the offset voltage of the voltage sensors and the variation of the stator resistance [6].

The most significant limitation of speed and flux estimation methods that rely on back emf is lack of robustness at low to zero speed. Techniques which include the use of MRAC systems are all limited by the fact that the back emf becomes nearly zero at very low speeds and at low frequency the integration of the voltages is problematic. Incorporation of the mechanical system model including torque estimate feed forward into the MRAC significantly improves the speed estimation dynamics, including low speed transients. Incorporation of a closed-loop observer into the MRAC improves zero speed operation [10].

II. SPEED ESTIMATION

There are various possibilities to obtain open-loop flux and speed estimators. For this purpose it is possible to use monitored terminal voltages and currents, or monitored currents together with the monitored dc link voltage. If the latter strategy is used then knowledge on the switching states of the inverter can be employed to reconstruct the voltages. The most direct and simple way to determine the stator and rotor fluxes is to utilize monitored stator currents and monitored or reconstructed stator voltages. The stator flux linkages can then be obtained by integration [11-13].

The stator resistance is also required. The rotor fluxes can then be obtained using additional machine parameters, e.g. the stator transient inductance and the ratio of the magnetizing inductance to the inductance of the rotor. However, at low speed there are well-known problems, since the ohmic drop is large and even small measurement errors and an imprecise value of the stator resistance can lead to significant errors. Even at high speed it is important to have an accurate representation of the stator resistance. In a drive containing a speed sensor, the low speed problems are usually avoided by using a flux mode which relies on the rotor voltage equations, and utilizes the well-known slip relation [14-17].

This technique is sensitive to the rotor time constant and, at high speed to speed measurement errors. To avoid some of these problems, in a drive with a speed-sensor, it is possible to use a hybrid flux estimator. In this case at low speed the rotor-voltage equation-based flux model is used and for high-speed the stator voltage equation is utilized.

It is also possible to obtain real-time estimates of the speed by utilizing various flux linkages in the machine. This is based on the physical fact that the rotor speed is the difference between the speed of the flux vector considered and the slip speed. The flux vector speed can be obtained form the terminal voltages and currents, by using the components of the flux vector (which can be obtained by the techniques described above) [18]. The slip speed can be obtained by also using the torque producing current component. In a scheme where the slip frequency is also a function of the derivative of the torque producing current, the sensitivity to noise is an important factor. The techniques utilizing the flux linkages for speed determination have similar problems to those associated with the flux estimators described above. One important problem is parameter sensitivity, but this depends on the choice of the estimated flux [19].

In a laboratory implementation, low-pass filters are used to remove high frequency voltage components. Signal offset at integrator inputs must also be removed to prevent saturation. For this purpose, during calibration of the voltage and current sensors an average offset is obtained and this is subtracted from the measured value during operation. The integration step length has also an important effect on the performance of the estimator [20-22].

It should be noted that there are inherent errors in any implementation of the flux estimator and these errors will have a detrimental effect on the drive performance. However, if fuzzy controllers are used, an improvement in the overall drive performance can be expected due to the tolerance of these controller types to imprecision. An alternative approach is to reduce the Error in the flux estimator employing by extended observers which are inherently closed loop in nature.

To obtain the full-order state adaptive observer, first the model of the induction machine is considered in the stationary reference frame and then an error compensator term is added to this [23-24].

III. FULL ORDER ADAPTIVE STATE OBSERVER

An Estimator is a dynamic system whose state variables are estimates of some other system (e.g. electrical machine). There are basically two forms of the implementation of an estimator: open-loop and closed-loop, the distinction between two being whether or not a correction term, involving the estimation error, is used to adjust the response of the estimator. A closed loop estimator is referred to as an observer [2].

In this dissertation a full order adaptive state observer is implemented. It's a modified estimator which can be used to estimate the rotor flux linkages of an induction machine. And is then modified so it can also yield the speed estimate, and thus an adaptive speed estimator is derived from that estimator. To obtain a stable system, the adaptation mechanism is derived by using the state-error dynamic equations together with lyaponav's stability theorem. In an inverter-fed drive system, the observer uses the monitored stator currents together with the monitored stator voltages or reference stator voltages [12].

IV. STATE OBSERVER

A state observer estimates the state variables based on the measurements of the output and control variables. Consider the system defined by

$$\dot{x} = Ax + Bu \qquad\qquad y = Cx$$

$$\dot{\tilde{x}} = A\tilde{x} + Bu + G(y - C\tilde{x})$$

which represents the state observer. It can be seen that the observer has y and u as inputs and $\dot{\tilde{X}}$ as output. The last term on the right-hand side of this model equation, (4.3), is a correction term that involves the difference between the measured output y and the estimated output $C\tilde{X}$. Matrix G serves as a weighting matrix. The correction term monitors the state $\tilde{X}$. In the presence of discrepancies between the A and B matrices used in the model and those of the actual system, the addition of the correction term, will help to reduce the effects due to difference between the dynamic model and the actual system. Fig 1.1 shows the block diagram of the system and the full-order state observer.

The observer error equation

$$\dot{X} - \dot{\tilde{X}} = AX - A\tilde{X} - G(Cx - C\tilde{X}) = (A - GC)(x - \tilde{X})$$

Define the difference between x and $\tilde{X}$ as the error vector e, or

$$e = x - \tilde{X}$$

then equation becomes

$$\dot{e} = (A - GC)\ e$$

We see that the dynamic behavior of the error vector is determined by the eigenvalues of matrix $(A - GC)$. G is chosen in such a way that the dynamic behavior of the error vector is asymptotically stable and is adequately fast, and then the error vector will tend to zero (origin) with an adequate speed.

If the system is completely observable, then it can be proved that it is possible to choose matrix G such that $(A - GC)$ has arbitrarily desired eigen values. That is, the observer gain matrix G can be determined to yield the desired matrix $(A - GC)$.

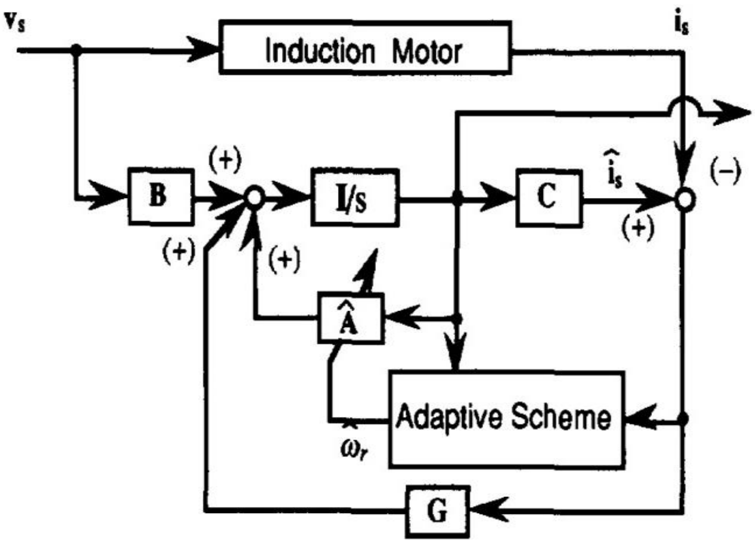

Fig 1: Full-order state Adaptive speed observer

V. OBSERVER MODEL

The dynamic model of induction motor can be written choosing as state variables currents and/or fluxes for the electrical equations, and the rotor speed for the mechanical equation.

Assuming the rotor speed to be measurable, ω_r can be considered as a time varying parameter so that the dynamic model can be rewritten as the following fourth order linear time varying system:

$$\dot{x} = A(w_r)x + Bu$$

where

$$x = \left(i_D, i_Q, \Phi_d, \Phi_q\right)^T \qquad u = \left(v_D, v_Q\right)^T$$

Where u is the space vector of stator voltages and the system matrices are $B = \begin{pmatrix} \frac{1}{\sigma L_S} & 0 & 0 & 0 \\ 0 & \frac{1}{\sigma L_S} & 0 & 0 \end{pmatrix}^T$

$$A(w_r) = \begin{pmatrix} a11 & a12 \\ a21 & a22 \end{pmatrix}$$

with

A_{11} = -(R_s + $L_m^{2*}R_r$/L_r^2) / (σ *L_s) * I

A_{12} = L_m / (σ *t_r*L_s*L_r) * I; (4.13)

A_{21} = L_m/t_r * I;

A_{22}= -1/t_r * I;

A_w = [Lm/(σ *L_s*L_r) * I; -I];

Where Lm and Lr are the magnetizing inductance and rotor self-Inductance respectively. Assuming that, among electrical state variables, only stator currents are measurable. Then coherent choice for the output variables is $y = (i_D, i_Q)^T$. The dynamic model can be so completed with the output equation

$$y = Cx$$

Where the matrix C is given by

$$C = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}$$

This dynamic model is used for the estimation of rotor speed of the induction motor. The observer can be writtenas $\frac{d\tilde{i}_s}{dt} = A_{11}\tilde{i}_s + A_{12}\tilde{\phi}_r + \frac{1}{\sigma L_S}v_S + G(\tilde{i}_s - i_S)$ Where the observer gain matrix G is calculated based on the pole placement technique. The selection of the observer pole is based on the compromise between the rapidity of error and the sensitivity to the disturbances and measurement noises.

VI. FUZZY LOGIC CONTROLLER

The main feature of fuzzy logic controllers (FLCs) is that linguistic, imprecise knowledge of human experts is used. However, the implementation of conventional fuzzy logic controllers suffers from the disadvantage that no formal procedures exist for the direct incorporation of the expert knowledge during the development of the controller. The structure of the fuzzy controller (number of rules, the rules themselves, number and shape of membership functions, etc) is achieved through a time consuming tuning process which is essentially manual in nature. The ability to automatically 'learn' characteristics and structure which may be obscure to the human observer is, however, inherent in neural networks. A fuzzy logic-type controller having the structure of a neural network offers the advantages of both - the ability of fuzzy logic to use expert human knowledge and the learning ability of the neural network - and overcomes their disadvantages - the lack of a formal learning procedure for the fuzzy controller fuzzy controller and the lack of a clear correlation with the physical problem when using neural networks.

The conventional controllers for vector controlled induction motor drive (VCIMD) suffer from the problem of stability, besides these controllers show either steady state error or sluggish response to the perturbation in reference setting or during load perturbation. The motor control issues are traditionally handled by fixed gain PI and Proportional-integral-derivative (PID) controllers. However, the fixed-gain controllers are very sensitive to parameter variations, load disturbances, etc. Thus, the controller parameters have to be continually adapted. However, it is often difficult to develop an accurate system mathematical model due to unknown load variation, temperature variations, unknown and unavoidable parameter variations due to saturation and system disturbances. In order to overcome the above problems, recently, the fuzzy-logic controller (FLC) is being used for motor control purpose.

VII. OBSERVER BASED SENSOR LESS VECTOR CONTROL OF INDUCTION MOTOR DRIVE

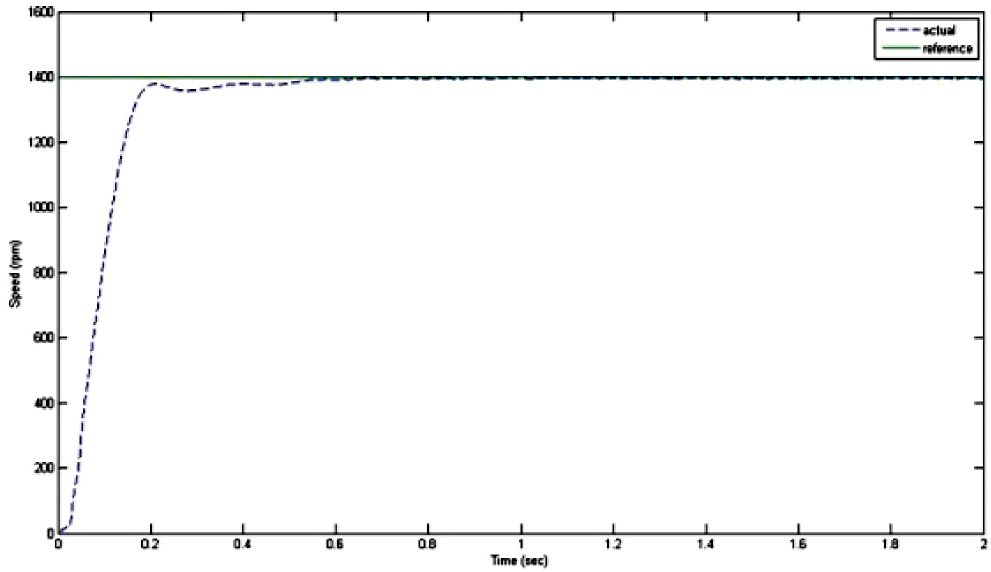

Fig 2: Speed response with PI controller

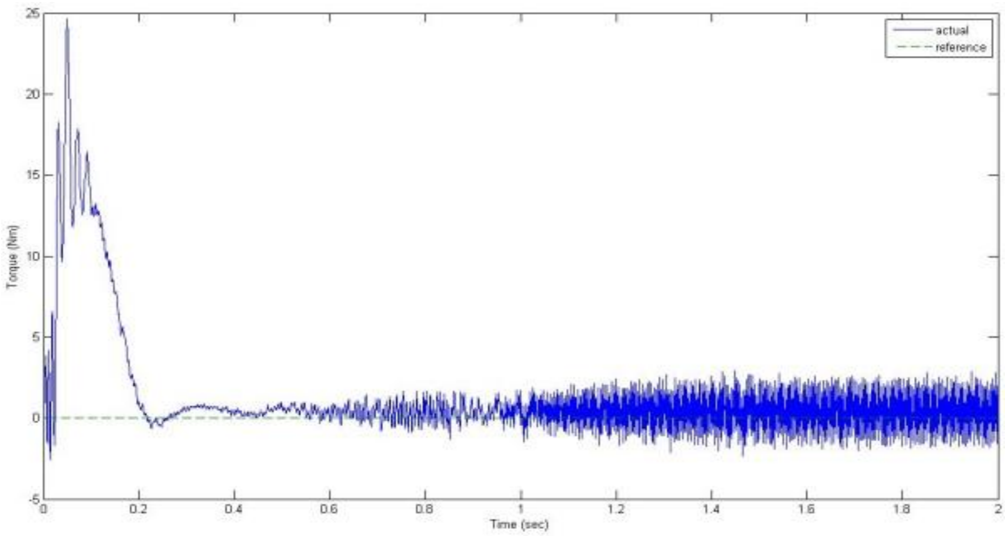

Fig 3: Torque response with PI controller

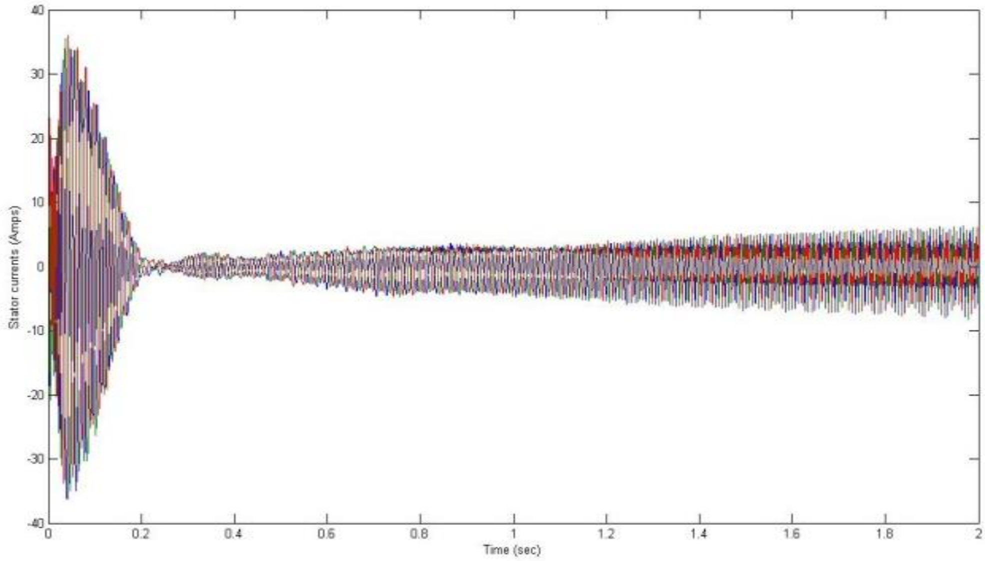

Fig 4: Stator currents response with PI Controller

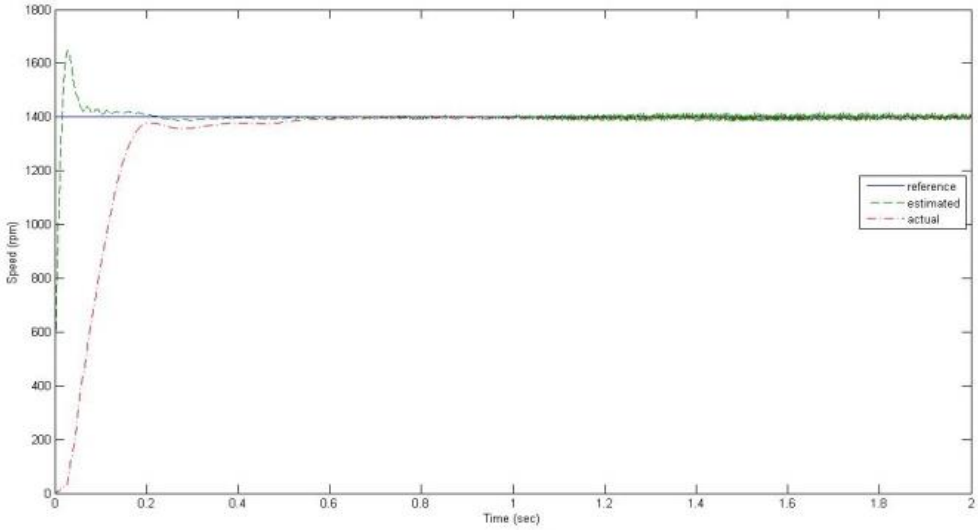

Fig 5: Speed comparison with PI Controller

The simulation results of the 5.4HP Vector controlled Induction motor drive are presented in the following figures for the operation of the drive for different speeds and loads by using Fuzzy logic controller. Fig.2 gives the speed response of the induction motor drive with starting speed set at 1400 rpm by using step source externally.by comparing the speed response using Fuzzy controller with speed response using PI controller,the speed reached the reference speed with in less time as compared to the later. And the peak overshoot occurred in case of drive using Fuzzy controller. The electromagnetic torque produced is shown in Fig 3. The drive is operated at no load . From the Fig.it is observed that the starting torque produced is more in this case and the ripples reduced because of using Fuzzy controller. Fig.4 shows the three phase winding currents and they are approximately sinusoidal and one can observe the variation of the frequency of the currents of the drive speed changes Fig 5. gives the response of speed comparision of induction motor drive consisting of actual speed,estimated speed, and reference speed. One can observe that both the estimated and actual speed follows the reference speed at 0.3sec.

Response under load condition:

For the analysis of torque response under load condition, a load torque of 10 Nm is applied at 1.2 sec and reference speed has changed from 1400rpm to 1000 rpm at 0.8 sec. The response of the system shows that under steady state condition developed torque follows the load torque, independent of speed command. If the speed reference changed to a new value, then also electromagnetic torque follows the load torque. Behavior of

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the motor under load condition is shown in the following figures. Fig.7 gives the comparison of actual speed and estimated speed under a load of 10 Nm applied on induction motor drive

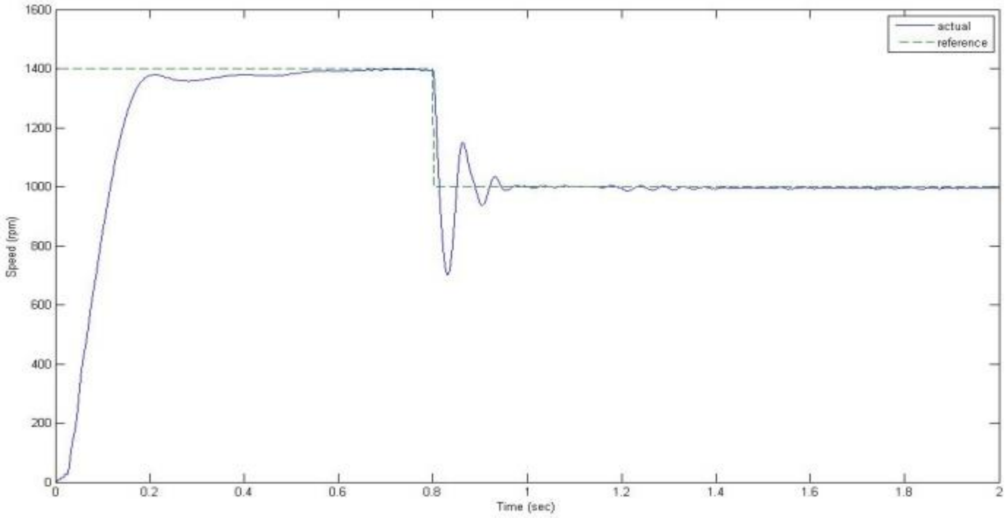

Fig 6: Speed response under load condition with Fuzzy controller

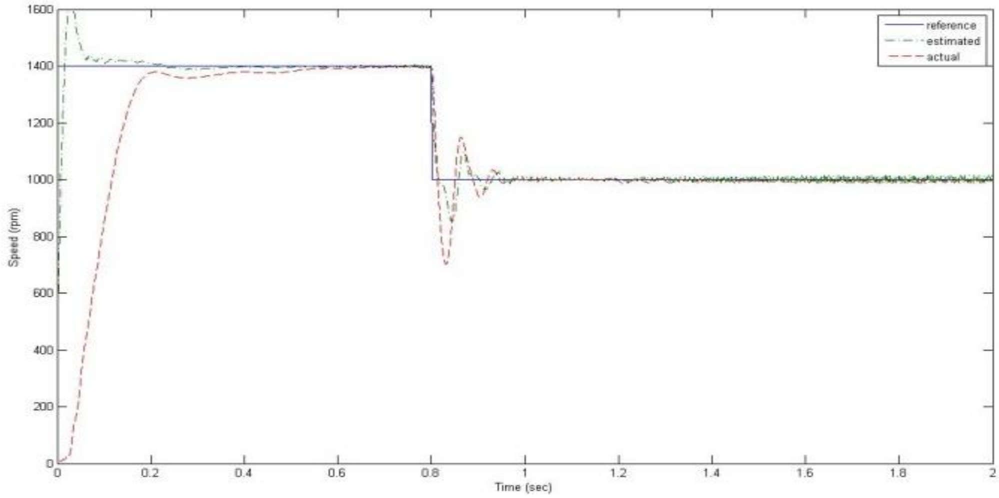

Fig 7: Speed comparison under load condition with Fuzzy controller

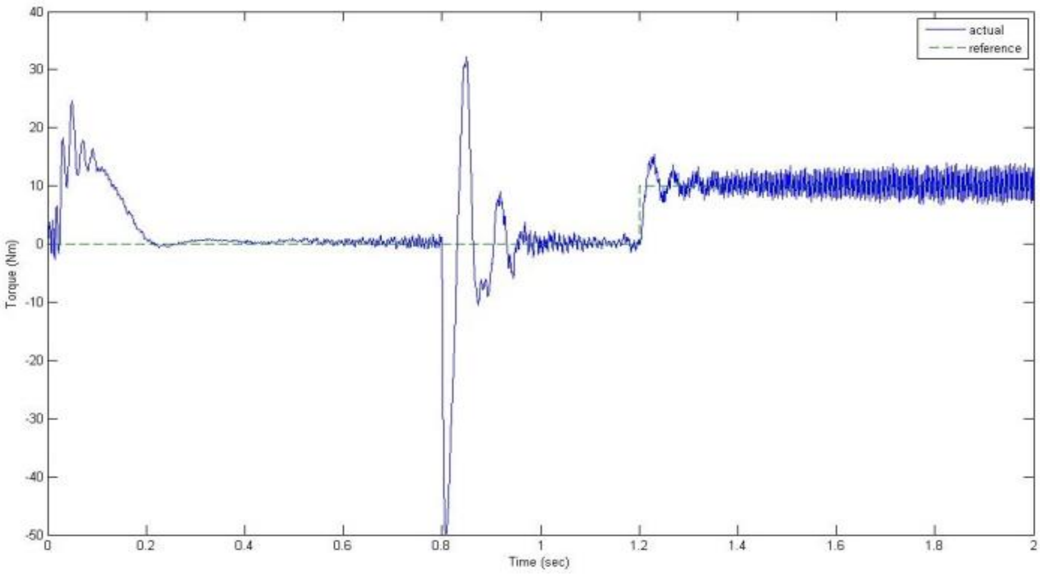

Fig 8: Torque response under load condition with Fuzzy controller

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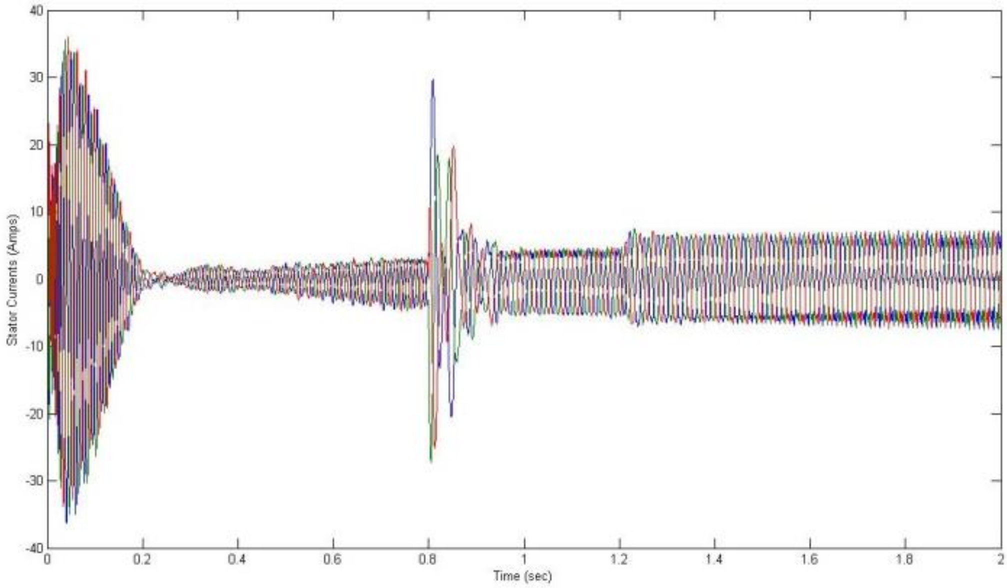

Fig 9: Stator currents response under load condition with Fuzzy controller

Response under Speed reversal operation

For simulation in reverse motoring operation, a step speed command of +1400 rpm to -600rpm is set as reference speed command. There is a step change in speed at 1.2sec. Load torque is set to zero. Speed response show in fig.10 shows that actual rotor speed closely follows the reference speed with minimum oscillations during positive reference speed i.e. during acceleration. But during deceleration the oscillations occurred. This response is obtained with PI controller .where as with Fuzzy controller the oscillation gets reduced and the actual rotor speed closely follows the reference speed with minimum oscillations under all conditions i.e. during acceleration, deceleration and steady state. Fig. 11 shows the comparison of actual speed and estimated speed.

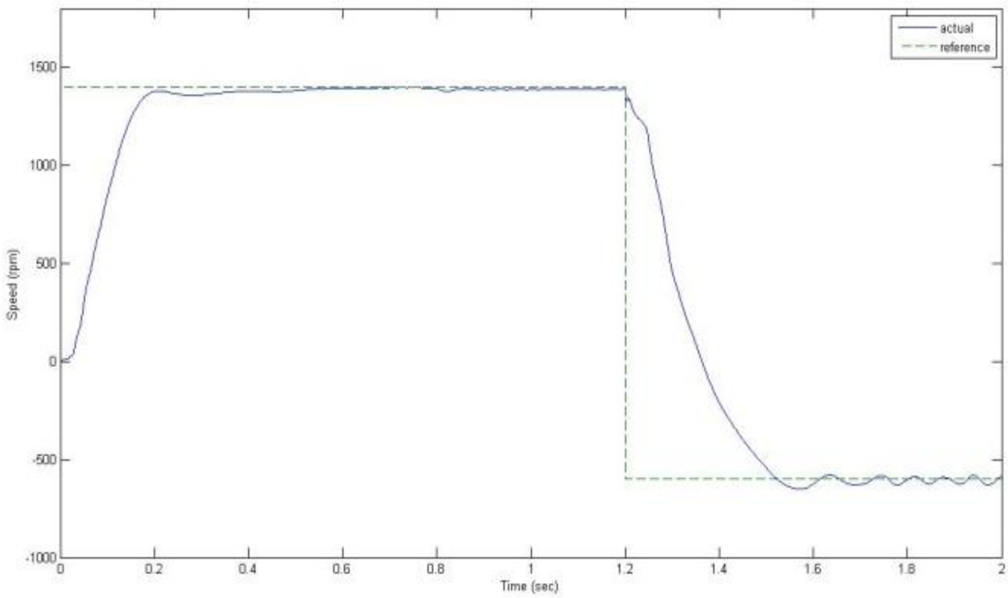

Fig 10: Speed reversal response with PI Controller

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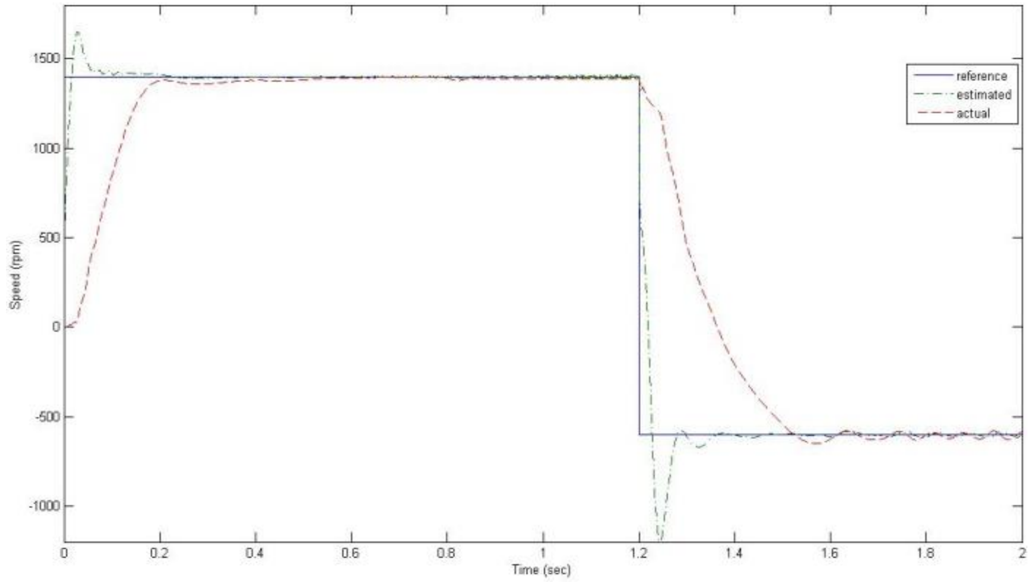

Fig 11: Speed comparison with PI Controller

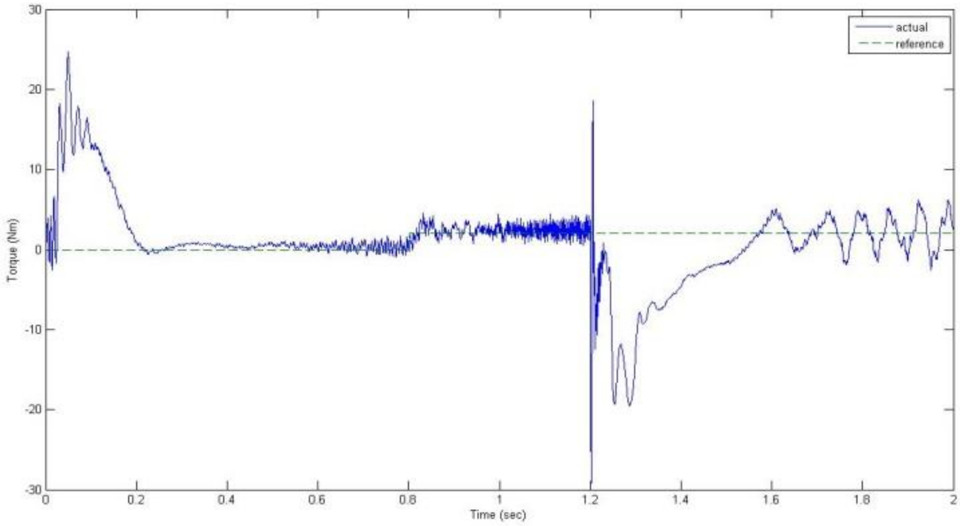

Fig 12: Torque response during Speed reversal with PI Controller

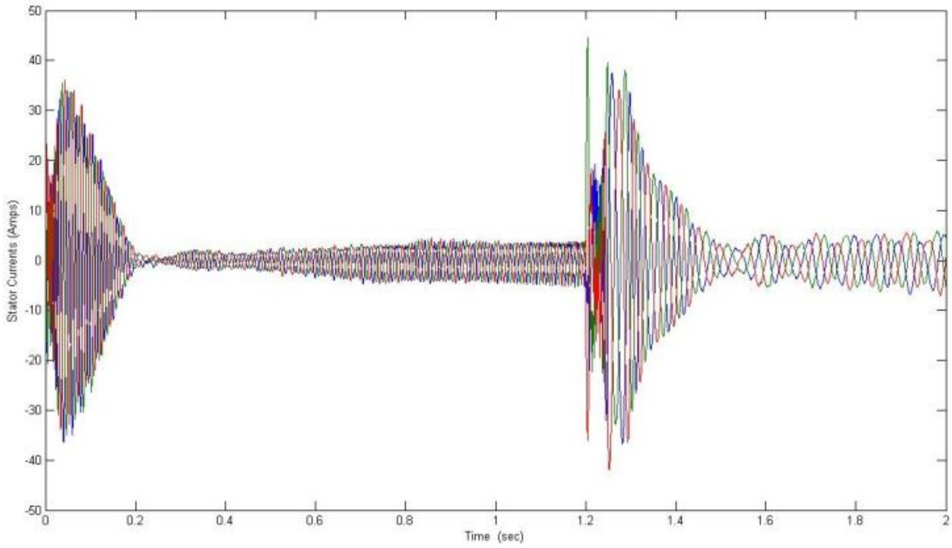

Fig 13: Stator currents response during speed reversal with PI Controller

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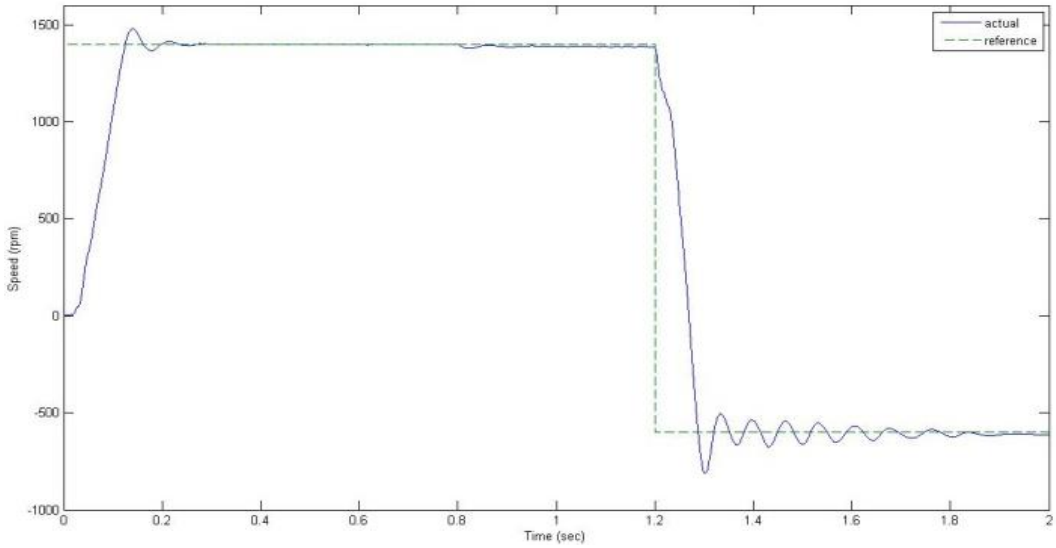

Fig 14: Speed reversal response with Fuzzy Controller

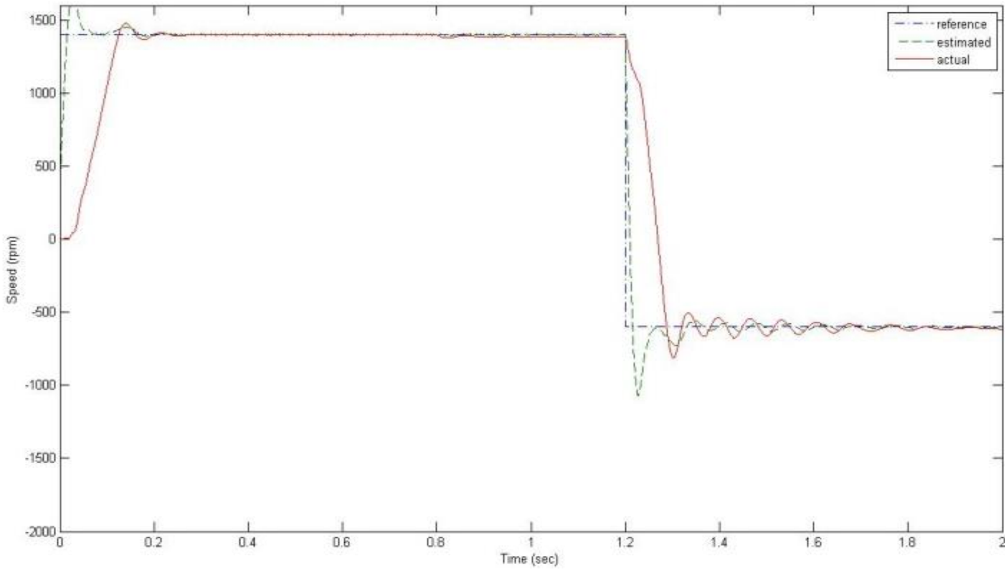

Fig 15: Speed comparison during reversal with Fuzzy Controller

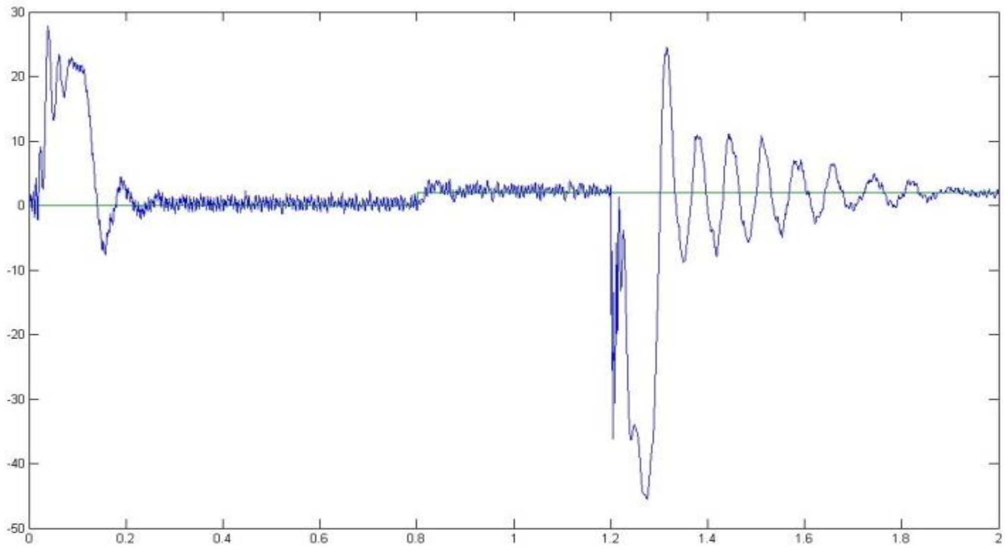

Fig 16: Torque response using Fuzzy controller

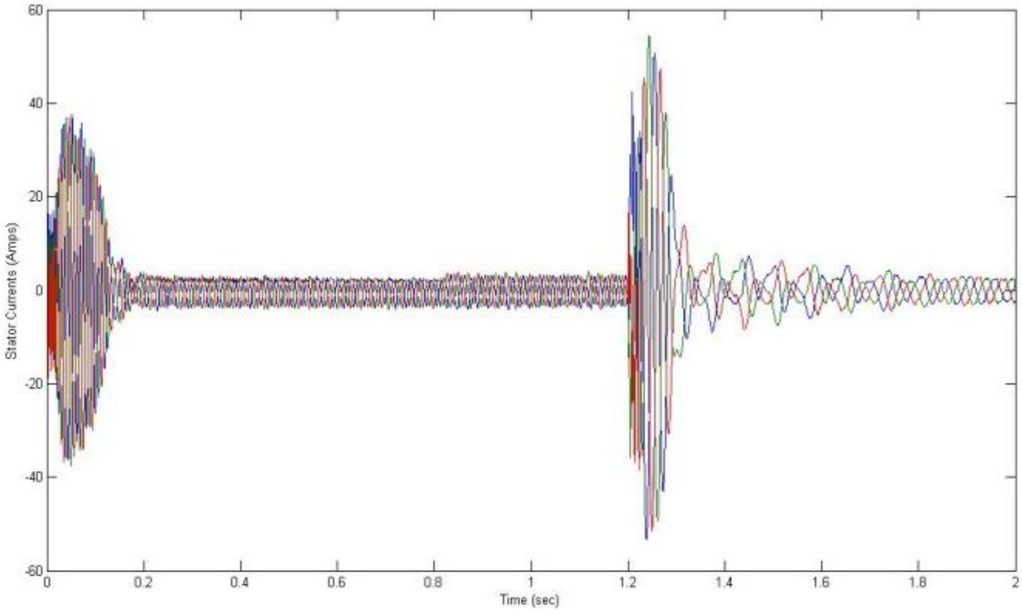

Fig 17: Stator currents response with Fuzzy Controller during speed reversal

VIII. CONCLUSION

In the present dissertation the performance analysis of an observer-based sensor less speed-controlled squirrel cage induction motor drive employing a controlled voltage source PWM inverter has been carried out. Through the simulation study performed by using the MATLAB/SIMULINK package, it is established that the field-oriented control structure in conjunction with a Fuzzy controller, provides a faster dynamic response in view of settling time and peak overshoot. Further, the speed response doesn't depend upon direct measurement of rotor speed but it is estimated by the observer and good performance is achieved. The variation of the magnitude and frequency of the stator current of the motor, in desired manner, results in quicker accelerating torque. If required, this may also lead to regenerative action, as well as change in the phase sequence. This happens in response to disturbances in the drive structure such as perturbations in one or more of the system variables like the load on the shaft, the reference speed setting. With the above improved dynamic response of the induction motor drive system, it well suited for a number of applications involving variable speed such as the process industries, machine tools, textiles industries, paper mills, lifts and traction.

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