A Novel Speed Controller Based on Lagrange’s Interpolation for Closed-loop Control of a CSI-fed Induction Motor Drive

S. M. Tripathi [1] A. K. Srivastava [2] A. K. Pandey [3]

Abstract–This work aims to investigate the feasibility of a novel speed controller based on Lagrange’s interpolation (LI) for better performance of a self-commutated current source inverter-fed induction motor drive. The LI speed controller is based upon the look-up table prepared from a series of simulated patterns of ‘reference slip speed’ *vs.* ‘speed error’ of the classical PI speed controller. The performance of the drive employing this novel LI speed controller is evaluated analytically for a 1-hp induction motor and is compared to that with classical PI speed controller using MATLAB simulation.

Keywords–Closed-loop control, current source inverter, induction motor drive, Lagrange’s interpolation (LI), speed controller.

I. INTRODUCTION

Induction motors in high performance variable speed drive applications have a series of advantages. For such kind of application, the variable speed drive requires a good power processing system and a good controller. A good power processing system is characterized by its simplicity, ruggedness, and lower cost. The current source inverter (CSI) has all these features. In CSI-fed induction motor drive, the current source at the front end makes the system naturally capable of power regeneration [1]-[3].

Proportional plus integral (PI) controllers, which are conventionally employed for CSI-fed induction motor drives; suffer from some limitations as the design of these controllers depends on exact mathematical model with accurate parameters [4]. A model reference adaptive controller (MRAC) was reported to improve the behavior of CSI-fed induction motor drive. However, in wide range of speed control, the design of MRAC controller becomes rather complicated [4].

The design of intelligent controllers based on artificial intelligence (AI) does not need the exact mathematical model of the system. Therefore, artificial neural network (ANN) and fuzzy logic control (FLC) demand special attention for speed control of high performance induction motor drives [5]-[6]. The main design problem with FLC lies in the determination of consistent and complete rule set and shape of the membership functions. On the other hand, ANN alone is insufficient if the training data are not enough to take care of all the operating modes [6].

In the present paper, the closed-loop scheme of a self-commutated current source inverter-fed induction motor drive employing a novel Lagrange’s interpolation (LI) based speed controller is investigated for better performance.

II. LAGRANGE’S INTERPOLATION (LI) BASED SPEED CONTROLLER

The conventional CSI-fed induction motor drive system essentially consists of a three-phase AC source, a PWM rectifier, a DC link smoothening reactor, a current-controlled inverter, a three-phase squirrel cage induction motor, a three-phase capacitor bank, and two PI controllers – one in the outer speed feedback loop and the other in the inner current feedback loop. In the present work, the outer PI speed controller of the conventional CSI-fed induction motor drive system [7]-[8] has been replaced by a novel speed controller based on the Lagrange’s interpolation (LI) technique as shown in Figure 1.

The closed-form mathematical model of the CSI-fed induction motor drive system has been considered the same as developed in [8] excluding the speed controller in outer feedback loop. The control law for the LI based speed controller in outer feedback loop is developed in this section.

The LI based speed controller compares the reference speed and the actual rotor speed and processes the speed error to obtain the reference slip speed (ω_{sl}^{*}). The functional relationship between reference slip speed ω_{sl}^{*} and the speed error $\Delta\omega$ $(=\omega_{ref}-\omega_r)$ can be expressed as:

$$\omega_{sl}^{*}=\psi(\Delta\omega)\ ;\ \Delta\omega_0\le\Delta\omega\le\Delta\omega_n \tag{1}$$

Polynomial interpolation is based on the well known fact that any n^{th} order polynomial is uniquely determined by $(n+1)$ points with distinct argument values. Compliant with a famous theorem due to Weierstrass [9], the single-valued function $\psi(\Delta\omega)$ can be approximated by a polynomial $P_n(\Delta\omega)$ passing through the $(n+1)$ points $[\Delta\omega_i\,,\psi(\Delta\omega_i)]$; $i=0,1,2,\cdots\cdots n$ with very small error, *i.e.*

$$\psi(\Delta\omega)\cong P_n(\Delta\omega)=A_0+A_1\Delta\omega+A_2(\Delta\omega)^2+\cdots\cdots+A_n(\Delta\omega)^n \tag{2}$$

where A_i ’s are constants.

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[1] Department of Electrical Engg., Kamla Nehru Institute of Technology, Sultanpur (U.P.), India, E-mail: mani_excel@yahoo.co.in

[2] Department of Electrical & Electronics Engineering, Kamla Nehru Institute of Physical & Social Sciences, Sultanpur (U.P.), India, E-mail: aankit.srivastava32@gmail.com

[3] Department of Electrical Engineering, M. M. M. Engineering College, Gorakhpur (U.P.), India, E-mail: akp1234@gmail.com

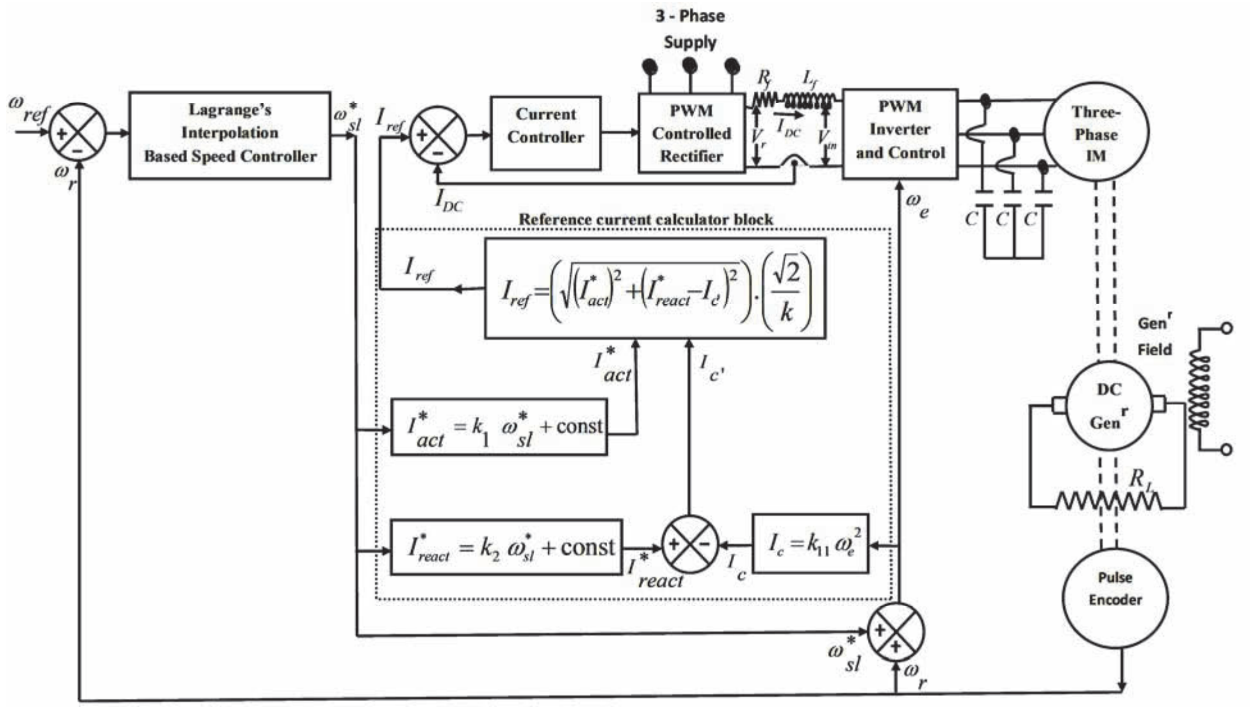

Fig. 1: Variable speed self-commutated current source inverter-fed induction motor drive with LI speed controller

On putting, $P_n(\Delta\omega_i)=\psi(\Delta\omega_i)$; $i=0,1,2,\cdots\cdots n$ in (2), and eliminating $A_0, A_1, A_2,\cdots\cdots A_n$ the following expression is obtained:

$$\begin{vmatrix} \psi(\Delta\omega) & 1 & \Delta\omega & (\Delta\omega)^2 & \cdots & (\Delta\omega)^n \\ \psi(\Delta\omega_0) & 1 & \Delta\omega_0 & (\Delta\omega_0)^2 & \cdots & (\Delta\omega_0)^n \\ \psi(\Delta\omega_1) & 1 & \Delta\omega_1 & (\Delta\omega_1)^2 & \cdots & (\Delta\omega_1)^n \\ \psi(\Delta\omega_2) & 1 & \Delta\omega_2 & (\Delta\omega_2)^2 & \cdots & (\Delta\omega_2)^n \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \psi(\Delta\omega_n) & 1 & \Delta\omega_n & (\Delta\omega_n)^2 & \cdots & (\Delta\omega_n)^n \end{vmatrix}=0 \qquad (3)$$

Expanding in terms of the elements of the first column, the required control law for Lagrange's interpolation based speed controller is obtained as follows:

$$\omega^*_{sl}=\psi(\Delta\omega)=\sum_{i=0}^{n}\left[\left\{\prod_{\substack{j=0\\ j\neq i}}^{n}\left(\frac{\Delta\omega-\Delta\omega_j}{\Delta\omega_i-\Delta\omega_j}\right)\right\}\psi(\Delta\omega_i)\right] \qquad (4)$$

Numerous patterns for 'reference slip speed' *vs.* 'speed error' with conventional PI speed controller, keeping parameters such as k_{p_s} and k_{i_s} to optimal values for a given loading condition, are obtained through a MATLAB program. A few of these patterns are selected to constitute a look-up table, which of course is the result of a few repeated trials. These look-up data sets are considered as $(n+1)$ points *viz.* $[\Delta\omega_i\ ,\psi(\Delta\omega_i)]$; $i=0,1,2,\cdots\cdots n$ in the control law (4) for Lagrange's interpolation based speed controller. Using (4) the value of reference slip speed ω^*_{sl} can be determined whenever speed error is $\Delta\omega$. This reference slip speed (ω^*_{sl}) is required to estimate the reference stator active current (I^*_{act}), reference stator reactive current (I^*_{react}) of the induction motor and the switching frequency of the inverter (ω_e) using the following equations:

$$I^*_{act}=k_1\ \omega^*_{sl}+\text{constant} \qquad (5)$$

$$I^*_{react}=k_2\ \omega^*_{sl}+\text{constant} \qquad (6)$$

$$\omega_e=\omega_r+\omega^*_{sl} \qquad (7)$$

Here, k_1 and k_2 are the slopes of the 'stator active current' *vs.* 'slip speed' and 'stator reactive current' *vs.* 'slip speed' characteristics respectively. These characteristics are obtained experimentally [7]. The reference DC link current is determined using the equations:

$$I_{ref}=\left(\sqrt{\left(I^*_{act}\right)^2+\left(I^*_{react}-I_{c'}\right)^2}\right)\cdot\left(\frac{\sqrt{2}}{k}\right) \qquad (8)$$

$$I_{c'}=I^*_{react}-I_c \qquad (9)$$

$$I_c=k_{11}\ \omega_e^{\ 2} \qquad (10)$$

$$k_{11}=\frac{I_{c\,(rated)}}{(\omega_{e\,(rated)})^2} \qquad (11)$$

III. SIMULATION RESULTS AND DISCUSSIONS

Simulations are factually focused on whether or not the performance of the drive with LI-PI (LI speed and PI current) controllers is better than that with PI-PI (PI speed and PI current) controllers. For the comparison in terms of the percentage overshoot, settling time and steady-state error, MATLAB simulations of the conventional CSI drive employing PI-PI controllers and the proposed CSI drive employing LI-PI controllers are performed for different step variations in reference speed each after an interval of 10 seconds as shown in Fig. 2. For a clear judgment, the responses of the drive are considered separately for each alteration in reference speed.

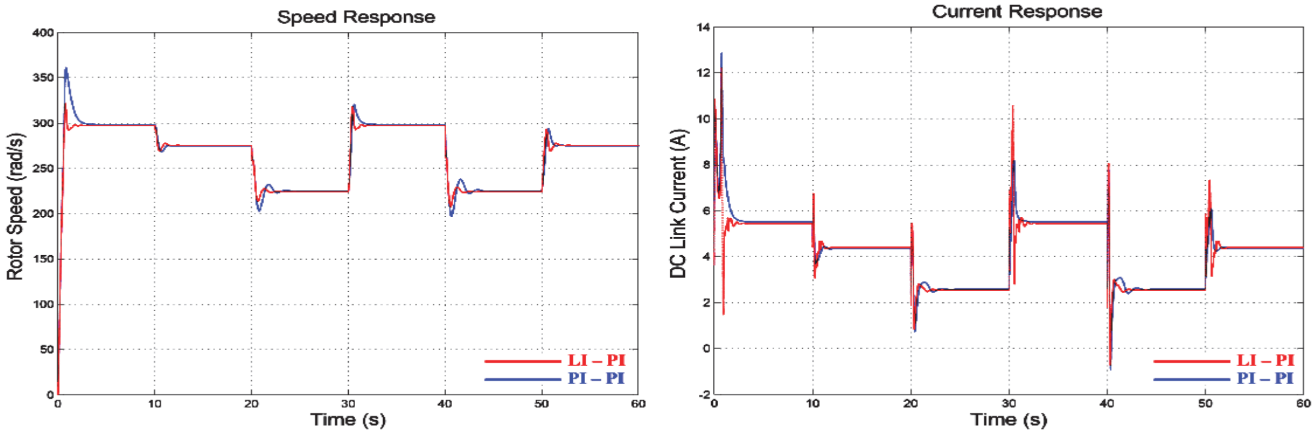

Fig. 2: Response of the drive for step changes in reference speed each after an interval of 10 seconds

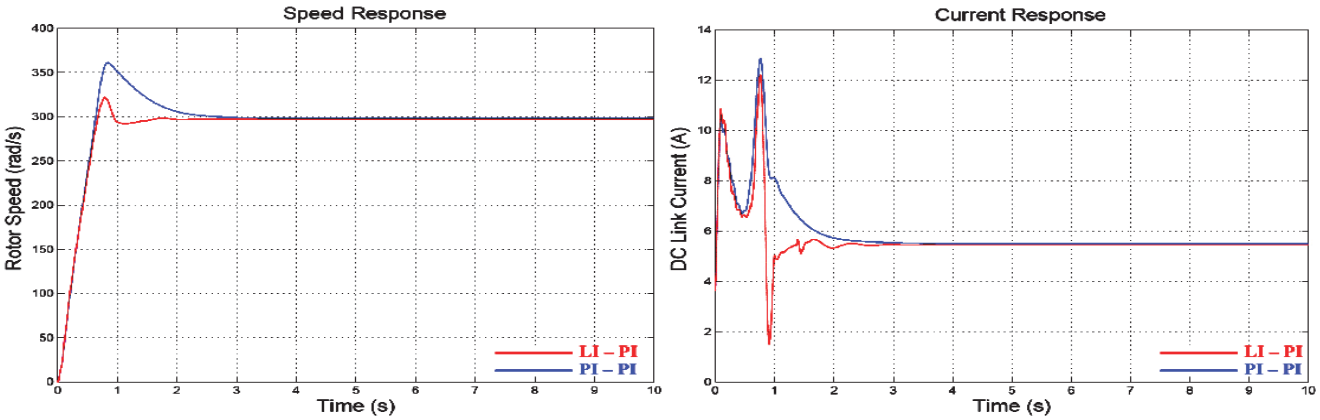

Fig.3: Response of the drive for step changes in reference speed from 0 rad/s to 298.29 rad/s

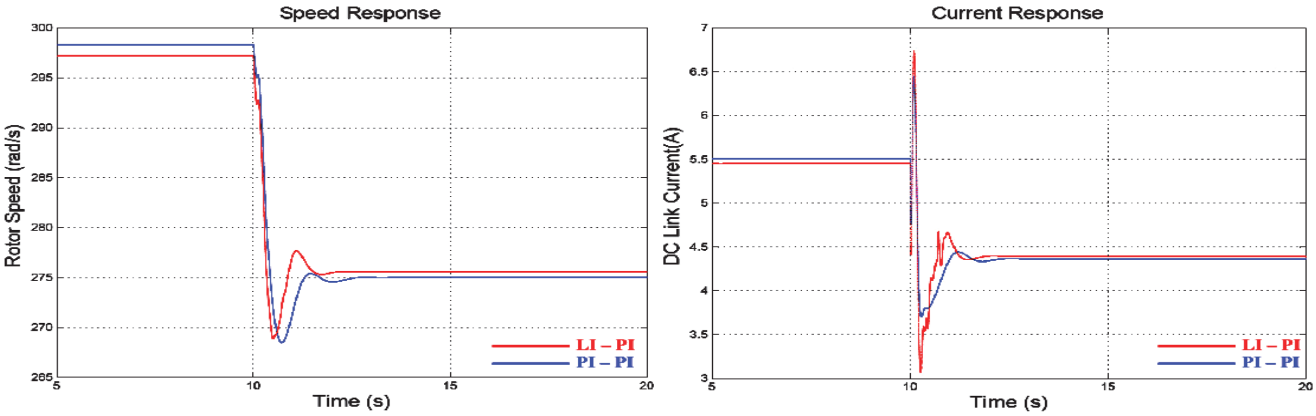

Fig.4: Response of the drive for step changes in reference speed from 298.29 rad/s to 275 rad/s

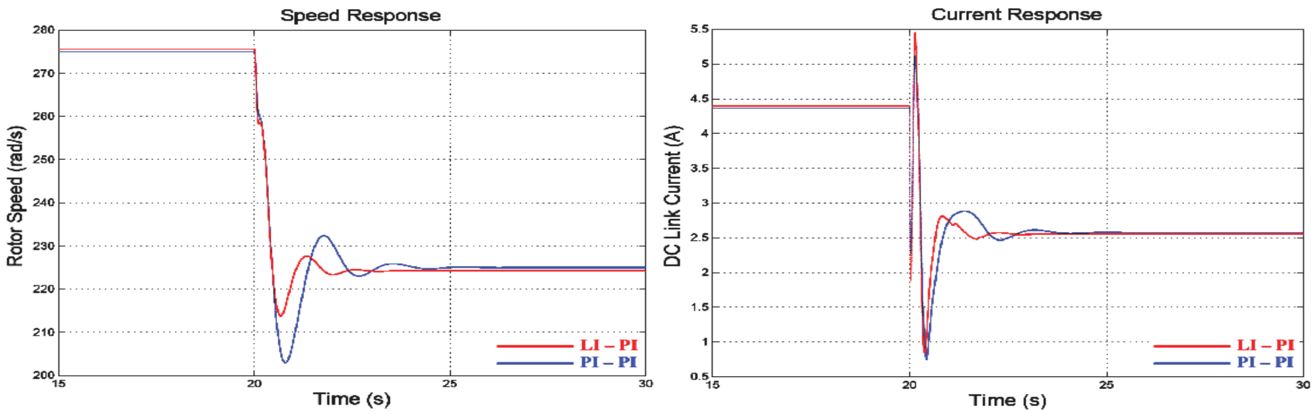

Fig. 5: Response of the drive for step changes in reference speed from 275 rad/s to 225 rad/s

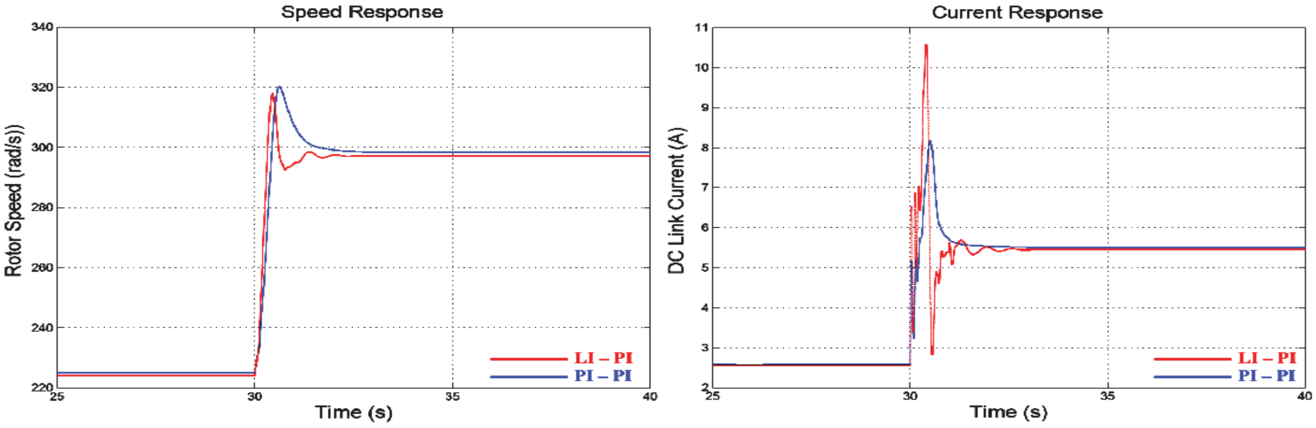

Fig. 6: Response of the drive for step changes in reference speed from 225 rad/s to 298.29 rad/s

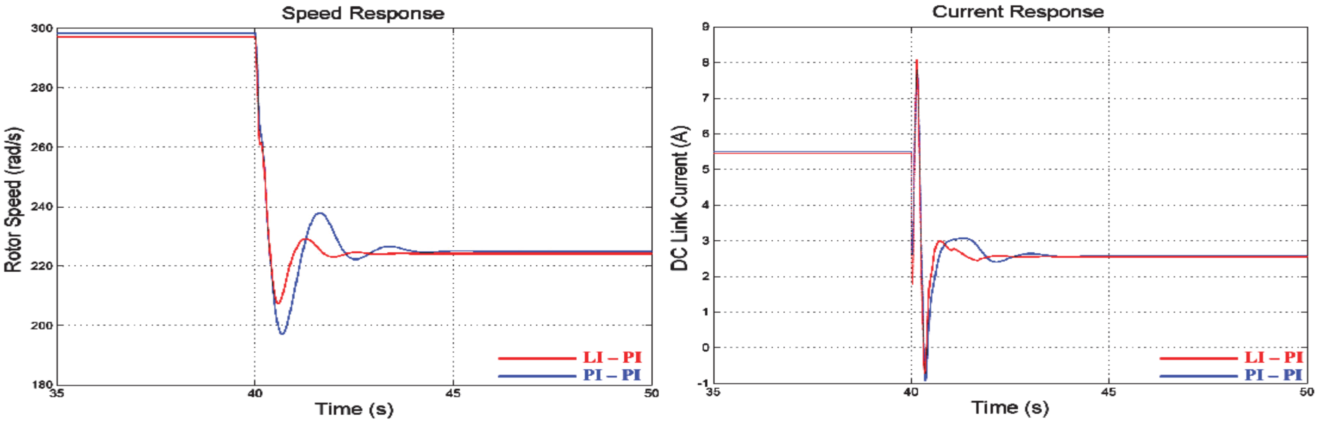

Fig. 7: Response of the drive for step changes in reference speed from 298.29 rad/s to 225 rad/s

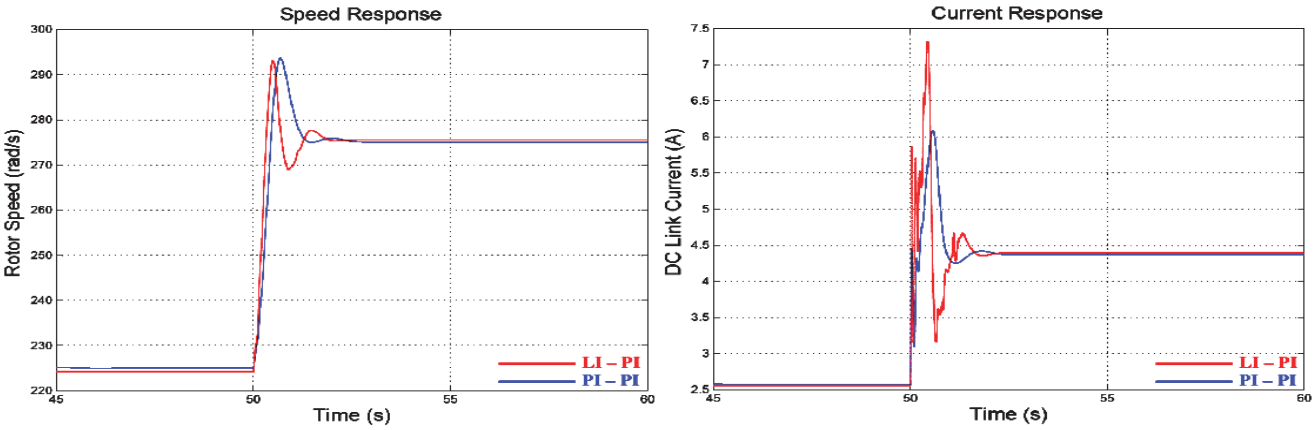

Fig.8: Response of the drive for step changes in reference speed from 225 rad/s to 275 rad/s

Figs: 3-8 show the speed and DC link current responses of the drive separately for step changes in reference speed from 0 rad/s to 298.29 rad/s (start-up), 298.29 rad/s to 275 rad/s (deceleration), 275 rad/s to 225 rad/s (deceleration), 225 rad/s to 298.29 rad/s (acceleration), 298.29 rad/s to 225 rad/s (deceleration), and 225 rad/s to 275 rad/s (acceleration) respectively.

The steady-state DC link current, percentage overshoot, drive settling time and steady-state error corresponding to different alterations in reference speed stated aforesaid, are summarized in Table-1. It has been found that the steady-state value of the DC link current is increased / decreased with increase / decrease in motor speed. The percentage overshoot and settling time of the drive with LI based speed controller is less than that with the conventional PI speed controller. It is also observed that the steady-state error in speed response of the drive with LI based speed controller is more than that with conventional PI speed controller. In fact, this is due to the error associated with the approximation of the function $\psi(\Delta\omega)$ by means of a polynomial $P_n(\Delta\omega)$. However, the percentage steady-state error is within the prescribed limit of 2%.

This way the speed and current response curves obtained through MATLAB simulation and facts in Table 1 show the success of proposed LI based speed controller.

Table 1: Performance of the drive for each alteration in reference speed

Sr.	Step-change in reference speed (rad/s)		Steady-state DC link current (A)		Speed overshoot (%)		Drive settling time (s)		Steady-state speed error (%)	
	From	**To**	**LI - PI**	**PI - PI**	**LI – PI**	**PI - PI**	**LI – PI**	**PI - PI**	**LI - PI**	**PI - PI**
1.	0	298.29	5.446	5.506	7.78	20.98	2.41	3.24	0.365	0.010
2.	298.29	275	4.391	4.365	2.23	2.36	2.20	2.75	0.204	0.014
3.	275	225	2.554	2.573	5.01	9.82	2.85	3.92	0.364	0.009
4.	225	298.29	5.446	5.506	6.56	7.27	2.53	2.75	0.365	0.010
5.	298.29	225	2.554	2.573	7.84	12.4	2.93	3.96	0.364	0.009
6.	225	275	4.391	4.365	6.59	6.76	2.10	2.49	0.204	0.014

IV. CONCLUSIONS

A novel speed controller based on Lagrange's interpolation has been introduced for CSI-fed induction motor drive and the control law for LI speed controller is established. The drive is simulated for both PI and LI speed controllers for different speed variations in the reference speed. The results for both controllers under each variation in reference speed are compared and analyzed. It is observed that the changes in the DC link currents, in accordance with any disturbances in the reference speed, are immediate with LI-PI controllers when compared with PI-PI controllers. Though, it is also seen that the steady state error in the speed response of the drive is more with LI speed controller than that with conventional PI speed controller, yet it is within prescribed limit and is, therefore, acceptable. Moreover, the CSI fed induction motor drive system using an LI speed controller has reduced speed overshoot and settling time compared to the system with a PI speed controller. This way, the simulation results have proved the feasibility and better performance of the proposed speed controller based on Lagrange's interpolation for closed-loop control of a self-commutated CSI-fed induction motor drive.

APPENDIX

Name plate ratings of induction motor

1 hp, three-phase, 400 V, 50 Hz, 4-pole, 1425 rpm, star

Induction motor parameters

$R_s = 3.520\,\Omega \quad R_r = 2.780\,\Omega \quad L_s = 0.165\text{ H}$

$L_r = 0.165\text{ H} \quad L_m = 0.150\text{ H} \quad J = 0.01289\text{ kg-m}^2$

Parameters of DC link and capacitor bank

$R_f = 0.250\,\Omega, \quad L_f = 0.040\text{ H}, \quad C = 150\,\mu\text{F}$

DC Generator specification

1 hp, 220 V, 4 A, 1500 rpm, shunt connected

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BIOGRAPHIES

Saurabh Mani Tripathi is presently working as Assistant Professor of Electrical Engineering at Kamla Nehru Institute of Technology, Sultanpur, (U.P.), India. He obtained his B.Tech. degree in Electrical & Electronics Engineering in 2006 and did his M.Tech. in Electrical Engineering in 2009 from U.P. Technical University, Lucknow. He has authored several books on 'Modern Control System' and 'Basic System Analysis'. His areas of current interest include electrical machines, control systems, power electronics and electric drives.

Ankit Kumar Srivastava is with the department of Electrical & Electronics Engineering at Kamla Nehru Institute of Physical & Social Sciences, Sultanpur, (U.P.) India. He received his B.Tech. degree in Electrical Engineering in 2008 from V.B.S. Purvanchal University, Jaunpur, (U.P.), India. He did his M.Tech. in Power Electronics and Drives in 2011 from Kamla Nehru Institute of Technology, Sultanpur, (U.P.), India. His interests are in the areas of power electronics and electric drives.

Ashok Kumar Pandey received his Ph.D. degree in Electrical Engineering from Indian Institute of Technology, Roorkee in 2003. He did his M.Tech. in Power Electronics, Electrical Machines and Drives from Indian Institute of Technology, Delhi in 1995. Currently, he is working as an Associate Professor with the Department of Electrical Engineering at M.M.M. Engineering College, Gorakhpur, (U.P.), India. His areas of interest include power electronics, electrical machines, and drive.