Australian Journal of Basic and Applied Sciences, 8(17) November 2014, Pages: 220-231

AENSI Journals

Australian Journal of Basic and Applied Sciences

ISSN:1991-8178

Journal home page: www.ajbasweb.com

Speed Controller design of Inverter fed Indirect Vector Controlled Induction Motor Drive Systems

[1]N. Mohanapriyaa, [2]Dr. K. Ayyar, [3]Dr. A. Nirmalkumar

[1]*Associate Professor, Department of EEE, Vivekanandha College of Engineering for Women, Namakkal-637 205, Tamilnadu, India*
[2]*Assistant Professor, Department of EEE, Vivekanandha Institute of Engineering and Technology for Women, Namakkal-637 205, Tamilnadu, India*
[3]*Professor, Department of EEE, Karpagam College of Engineering, Coimbatore-641032, Tamilnadu, India*

ARTICLE INFO

Article history:
Received 19 August 2014
Received in revised form
19 September 2014
Accepted 29 September 2014
Available online 8 November 2014

Keywords:
Model Order Reduction, Genetic Algorithm, PI controller, indirect vector control, Induction motor drives

ABSTRACT

Background: This paper presents a speed controller design of inverter fed indirect vector controlled induction motor drive with Model Order Reduction (MOR) technique. **Objective:** The designed controller parameters are tuned using Genetic Algorithm (GA) optimization approach. Conventionally traditional PI Controller is used in speed loop for indirect vector control system of induction motor drive; it gives low precision of the controller which affects the performance of the whole system. To overcome this problem, MOR with GA based PI controller is proposed. **Results:** The performance of this controller has been investigated with time domain specifications such as Overshoot, rise time and settling time using MATLAB-SIMULINK digital simulation software package. **Conclusion:** The simulated results show that the proposed controller is better than that of the conventional PI controller.

To Cite This Article: N. Mohanapriyaa, Dr.K. Ayyar and Dr.A.Nirmalkumar., Speed Controller design of Inverter fed Indirect Vector Controlled Induction Motor Drive Systems, ***Aust. J. Basic & Appl. Sci.,*** *8(17): 220-231, 2014*

INTRODUCTION

Nowadays, as a consequence of the important progress in power electronics and micro computing, the control of AC electric machines has seen considerable development and the possibility for industrial application (Hazzab, A., *et al*., 2005). The induction motor, known for its robustness, relatively low cost, reliability and efficiency, is the object of several research works. However the control of induction motor drive presents difficulties because of its high non-linearity and its coupled structure (Mansouri, A., *et al*., 2004). The technique known as vector control, first introduced by Blaschke and Hasse, has resulted in large change in the field of electrical drives. This is because, with this type of approach, the robust induction motor can be controlled for giving better performance. This control strategy can provide the same performance as obtained from a separately excited DC motor (Bousserhane, I.K., A. Hazzab, 2000; Meziane, S., *et al*., 2008).

Next, Induction motor is the most used drive in all the industrial speed control applications. In this regard design of speed controller forms a major part of the motor control system. But an induction motor is a higher order, multivariable, nonlinear, uncertain system which seems to be very difficult to control. In practice many nonlinear processes are approximated by reduced order models only, possibly linear which are clearly related to the underlying process characteristics. In this regard a new model order reduction technique which is cross multiplied of polynomials method (Ramesh, K., *et al*., 2004) used to obtain the equivalent reduced order model of the inverter fed indirect vector controlled induction motor drive. Several authors have proposed variety of model order reduction methods in time domain, frequency domain or combination of both the analysis. Some techniques like Routh array and Pade approximation are widely used in the reduction process of continuous systems and are available in the literature, such as the methods described in (Chandra, D., *et al*., 2004; Bhagat, S.K., *et al*., 2004). The routh array method will give the stable reduced order model but the closeness between the higher order model and reduced model is not assured. In case of Pade approximation, the reduced order is closely matched with the higher order model but sometimes it leads to an unstable reduced order model even if the higher order model is stable.

Now days, some mixed methods are proposed by several authors for the reduction of higher order systems like methods proposed by (Mittal, S.K., *et al*., 2009; Kranthi Kumar, D., *et al*., 2011). In the method proposed by (Mittal, S.K., *et al*., 2009), the time moments matching and markov parameters are employed to obtain the

Corresponding Author: N. Mohanapriyaa, Associate Professor, Department of EEE, Vivekanandha College of Engineering for Women, Namakkal-637 205, Tamilnadu, India.
Email: monapriyaa123@gmail.com, Ph: 9442333653

reduced order model. In the method proposed by (Kranthi Kumar, D., *et al*., 2011), Mihailov criterion and Cauer second form are employed to obtain the stable reduced model. But in both cases, the closeness between reduced order and higher order models is not fair. Recently, with the advancement in optimization techniques such as Genetic Algorithm, Particle Swarm Optimization, Differential Evolution etc., some model order reduction techniques are developed like the methods proposed by (Devender Kumar Saini, Rajendra Prasad, 2010; Sivanandam, S.N., S.N. Deepa, 2009). System model is necessary for tuning controller coefficients in an appropriate manner (e.g., percent overshoot, settling time).

PI controller is the most commonly used control algorithm in industrial drives. The main reason is its relatively simple structure which can be easily understood and implemented in practice and that many sophisticated control strategies such as model predictive control, are based on it. In spite of its widespread use there exists no generally accepted design method for the controller (Wang, Y.G., H.H. Shao, 2000). This linear regulator is depends only on two parameters, namely the proportional gain (k_p) and the integral gain (k_i). In this work, the initial values of controller coefficient are obtained from reduced order model of the system with the help of pole zero cancellation technique. The obtained controller coefficients are tuned till the design specifications are met with. The tuned controller is connected with the original system and the closed loop response is observed for stabilization process.

Several design techniques are used to obtain a perfect controller characteristic using artificial intelligent schemes and particle swarm technique (Nagaraj, B., *et al*., 2008). The designing includes new control schemes or betterment of existing controller by tuning them. One such popular existing conventional method of tuning is Ziegler Nichols (Z-N).This method is applied even when the transfer function of the system is unknown, but it is only an approximated tuning method which does not give optimized gain values. To overcome the drawbacks of Z-N method artificial intelligence techniques like Fuzzy Logic (FL), Neural Network (NN), and Genetic Algorithm (GA) were introduced either offline or online (Arunima Dey, *et al*., 2009). GA scheme gives improved responses under normal conditions for vector controlled induction motor drive (Krishnan, R., A.S. Bharadwaj, 1991).

The GA methods have been employed successfully to solve complex optimization problems. The use of GA methods in the determination of the different controller parameters is practical due to their fast convergence and reasonable accuracy. The parameters of the PI controller are determined by the minimization of an objective function. The goal of this work is to show that by the optimization of the parameters of the PI controller, a new class of optimization can be achieved. This can be seen by comparing the results of the Model Order Reduction (MOR) technique based PI controller using genetic algorithm tuned gains and the conventional Symmetric Optimum (SO) approximation method based PI controller. The modeling and simulation are done using MATLAB.

Statement of Problem:

Consider the n^{th} order linear dynamic SISO system described by the system transfer function,

$$G(s) = \frac{N(s)}{D(s)} = \frac{a_0 + a_1 s + a_2 s^2 + ... + a_{n-1} s^{n-1}}{b_0 + b_1 s + b_2 s^2 + ... + b_{n-1} s^{n-1} + b_n s^n} = \frac{\sum_{i=0}^{n-1} a_i s^i}{\sum_{i=0}^{n} b_i s^i} \quad (1)$$

where a_i $(0 \le i \le n-1)$ and b_i $(0 \le i \le n)$ are known as scalar constants. The corresponding r^{th} (r < n) order reduced model is synthesized as

$$G_r(s) = \frac{N_r(s)}{D_r(s)} = \frac{d_0 + d_1 s + d_2 s^2 + ... + d_{r-1} s^{r-1}}{e_0 + e_1 s + e_2 s^2 + ... + e_{r-1} s^{r-1} + e_r s^r} = \frac{\sum_{i=0}^{r-1} d_i s^i}{\sum_{i=0}^{r} e_i s^i} \quad (2)$$

where d_i $(0 \le i \le r-1)$ and e_i $(0 \le i \le r)$ are known as scalar constants. The objective is to realize reduced r^{th} order model R(s) in the form of Equation (2) from Equation (1) such that it retains the important features of the original system G(s) and approximates its step response as close as possible, while $N_r(s)$ and $D_r(s)$ are the numerator and denominator polynomial of reduced order model.

Description of the Method:

The Cross Multiplied of Polynomials Model order reduction method consists of the following steps.

Step-1:

The denominator and numerator polynomial s^0 constant terms in the reduced order model can be obtained by Pade approximation method. The transfer function of the control system is expressed as in Equation (1).This can be expanded into a power series about s=0 i.e.

$$G(s) = c_0 + c_1 s + c_2 s^2 + \cdots \tag{3}$$

where,

$$c_0 = \frac{a_0}{b_0} \tag{4}$$

and

$$c_i = \frac{1}{b_0}\left[a_i - \sum_{j=1}^{i} b_j c_{i-j}\right], \quad i > 0 \tag{5}$$

Then for $G_r(s)$ to be Pade approximation of $G(s)$, the following equations are obtained as per the method proposed by Aguirre (Aguirre, L.A., 1994).

$$\begin{aligned} d_0 &= e_0 \cdot c_0 \\ d_1 &= e_0 \cdot c_1 + e_1 \cdot c_0 \\ d_2 &= e_0 c_2 + e_1 c_1 + e_2 c_0 \\ &\vdots \\ 0 &= e_0 \cdot c_{2r-2} + e_1 \cdot c_{2r-1} + \cdots c_{r-1} \\ 0 &= e_0 \cdot c_{2r-1} + \cdots c_r \end{aligned} \tag{6}$$

From Equations (4) and (6),

$$c_0 = \frac{a_0}{b_0} = \frac{d_0}{e_0} \tag{7}$$

According to Equation (7), let

$$\left.\begin{aligned} a_0 &= d_0 \\ b_0 &= e_0 \end{aligned}\right\} \tag{8}$$

Step 2:

The remaining constants of the reduced order model can be obtained by cross multiplied of polynomials method proposed by (Ramesh, K., *et al*., 2004).The given higher order system transfer function of n^{th} order is equated and cross multiplied with r^{th} order general transfer function. This process yields (n+2) equations with (2r-1) unknown reduced order transfer function coefficients. This step is similar to the model order reduction method proposed in (Manigandan, T., *et al*., 2005), where the values of e_0 or d_0 are kept as equal to '1' irrespective of the system condition to obtain the values of unknown coefficients in the reduced order model transfer function. But in the present method, the values of e_0 and d_0 are obtained through Pade approximation method. This leads to better system approximation as compared to the model order reduction method proposed by (Manigandan, T., *et al*., 2005). Equating the higher order and lower order system as,

$$\frac{a_0 + a_1 s + a_2 s^2 + \ldots + a_{n-1} s^{n-1}}{b_0 + b_1 s + b_2 s^2 + \ldots + b_{n-1} s^{n-1} + b_n s^n} = \frac{d_0 + d_1 s + d_2 s^2 + \ldots + d_{r-1} s^{r-1}}{e_0 + e_1 s + e_2 s^2 + \ldots + e_{r-1} s^{r-1} + e_r s^r} \tag{9}$$

and cross multiplying them yields

$$\begin{aligned} &\left(a_0 + a_1 s + a_2 s^2 + \ldots + a_{n-1} s^{n-1}\right)\left(e_0 + e_1 s + e_2 s^2 + \ldots + e_{r-1} s^{r-1} + e_r s^r\right) \\ &\quad = \left(b_0 + b_1 s + b_2 s^2 + \ldots + b_{n-1} s^{n-1} + b_n s^n\right)\left(d_0 + d_1 s + d_2 s^2 + \ldots + d_{r-1} s^{r-1}\right) \end{aligned} \tag{10}$$

After cross multiplying the terms, the coefficients of same power of 's' on both sides of Equation (10) are equated and they are given by,

$$\begin{aligned} a_{n-1} \cdot e_r &= b_n \cdot d_{r-1} \\ a_{n-1} \cdot e_{r-1} + a_{n-2} \cdot e_r &= b_{n-1} \cdot d_{r-1} + b_n \cdot d_{r-2} \\ &\vdots \\ a_2 \cdot e_0 + a_1 \cdot e_1 + a_0 \cdot e_2 &= b_0 \cdot d_2 + b_1 \cdot d_1 + b_2 \cdot d_0 \\ a_1 \cdot e_0 + a_0 \cdot e_1 &= b_1 \cdot d_0 + b_0 \cdot d_1 \\ a_0 \cdot e_0 &= b_0 \cdot d_0 \end{aligned} \tag{11}$$

Australian Journal of Basic and Applied Sciences, 8(17) November 2014, Pages: 220-231

The (n+2) number equations in (11) are solved with the values of d_0, e_0 obtained by Equation (8). This leads to different equations for solving the remaining unknown parameters. Based on the optimal ISE value, the unknown values are selected and the reduced order model is obtained as,

$$G_r(s) = \frac{d_0 + d_1 s + d_2 s^2 + \ldots + d_{r-1} s^{r-1}}{e_0 + e_1 s + e_2 s^2 + \ldots + e_{r-1} s^{r-1} + e_r s^r} \tag{12}$$

If $r = 2$, then

$$G_2(s) = \frac{d_1 s + d_0}{e_2 s^2 + e_1 s + e_0} \tag{13}$$

If $r = 1$, then

$$G_1(s) = \frac{d_0}{e_1 s + e_0} \tag{14}$$

Indirect Vector Controlled Induction Motor (IVCIM) Drive System:

Vector (Field oriented) control is widely used in industry for high performance IM drives as the same performance as separately excited DC motor. Here knowledge of synchronous angular velocity is often necessary in phase transformation to achieve favourable decoupling control between motor torque and rotor flux, the same as one used for separately excited DC motor. This is done by one of the two types of vector control, i.e., direct or indirect vector control. Both the methods have been implemented in industrial drives demonstrating performances suitable for a wide range of technological applications. But IM controlled performance is still affected by uncertainty such as mechanical parameter variation, external disturbance, and unstructured uncertainty due to non-ideal field orientation in a transient state.

In this section the indirect vector control induction motor parameters are derived from the dynamic equations of the induction machine in the synchronously rotating reference frames. To simplify the derivation, a current source inverter is assumed. In that case, the stator phase currents serve as inputs. Hence the stator dynamics can be neglected. In turn this can lead to omitting the stator equations from further consideration.

If the rotor flux linkages used as variables then the rotor circuit equations of the induction machine become

$$R_r i_{qr}^e + p\lambda_{qr}^e + \omega_{sl}\lambda_{dr}^e = 0 \tag{15}$$

$$R_r i_{dr}^e + p\lambda_{dr}^e - \omega_{sl}\lambda_{qr}^e = 0 \tag{16}$$

$$\omega_{sl} = \omega_s - \omega_r \tag{17}$$

where

R_r = rotor resistance per phase
L_m = magnetizing inductance per phase
L_r = rotor inductance per phase referred to stator
i_{dr}^e = direct axis rotor current
i_{qr}^e = quadrature axis rotor current
P = differential operator d/dt.
ω_{sl} = slip speed in rad/sec,
ω_s = electrical stator frequency in rad/sec.
ω_r = electrical rotor speed in rad/sec
λ_{dr}^e = direct axis rotor flux linkages and
λ_{qr}^e = quadrature axis rotor flux linkages

The rotor flux linkage expressions can be given as

$$\lambda_{qr}^e = L_m i_{qs}^e + L_r i_{qr}^e \tag{18}$$

$$\lambda_{dr}^e = L_m i_{ds}^e + L_r i_{dr}^e \tag{19}$$

The resultant rotor flux linkage, λ_r, also known as the rotor flux-linkage phasor is assumed to be on the direct axis to reduce the number of variables in the equations by one. Moreover it corresponds with the reality that the rotor flux linkages are a single variable. Hence aligning the *d* axis with rotor flux phasor yields

$$\lambda_r = \lambda_{dr}^e \tag{20}$$

$$\lambda_{qr}^e = 0 \tag{21}$$

$$p\lambda_{qr}^e = 0 \tag{22}$$

Substituting equations (20) to (22) in (15) and (16) causes the new rotor equations

$$R_r i_{qr}^e + \omega_{sl}\lambda_r = 0 \tag{23}$$

$$R_r i_{dr}^e + p\lambda_r = 0 \tag{24}$$

The rotor currents in terms of the stator currents are derived from equations (18) and (19) as

$$i_{qr}^e = -\frac{L_m}{L_r} i_{qs}^e \tag{25}$$

$$i_{dr}^e = \frac{\lambda_r}{L_r} - \frac{L_m}{L_r} i_{ds}^e \tag{26}$$

Substituting for d and q axes rotor currents from equations (25) and (26) into equations (23) and (24), the following are obtained.

$$i_f = \frac{1}{L_m}\left[1 + T_r p\right]\lambda_r \tag{27}$$

$$\omega_{sl} = K_{it}\left[\frac{L_r}{T_r}\right]\left[\frac{T_e}{\lambda_1^{\,2}}\right] = K_{it} R_f \left[\frac{T_e}{\lambda_1^{\,2}}\right] = \frac{L_m}{T_r} \cdot \frac{i_T}{\lambda_r} \tag{28}$$

where

$$i_f = i_{ds}^e \tag{29}$$

$$i_T = i_{qs}^e \tag{30}$$

$$T_r = \frac{L_r}{R_r} \tag{31}$$

$$K_{it} = \frac{2}{3} \cdot \frac{2}{P} \tag{32}$$

The q and d axes currents are relabeled as torque current (i_T) and flux current (i_f) producing components of the stator current phasor respectively. T_r denotes the rotor time constant. The equation (27) resembles the field equation in a separately excited dc machine whose time constant is usually on the order of seconds. Likewise the induction motor rotor time constant is also on the order of a second is to be noted. Similarly by the same substitution of the rotor currents from equations (25) and (26) into the torque expression, the electromagnetic torque is derived as

$$T_e = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_r}\left(\lambda_{dr}^e i_{qs}^e - \lambda_{qr}^e i_{ds}^e\right) = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_r}\left(\lambda_{dr}^e i_{qs}^e\right) = K_{te}\lambda_r i_{qs}^e = K_{te}\lambda_r i_T \tag{33}$$

where the torque constant K_{te} is defined as

$$K_{te} = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_r} \tag{34}$$

The stator current phasor which is the phasor sum of the *d* and *q* axes stator currents in any frames; it is given by

$$i_s = \sqrt{\left(i_{qs}^e\right)^2 - \left(i_{ds}^e\right)^2} \tag{35}$$

and the dq axis to abc phase current relationship is obtained from

$$\begin{bmatrix} i_{qs}^e \\ i_{ds}^e \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos\theta_f & \cos\left(\theta_f - \frac{2\pi}{3}\right) & \cos\left(\theta_f + \frac{2\pi}{3}\right) \\ \sin\theta_f & \sin\left(\theta_f - \frac{2\pi}{3}\right) & \sin\left(\theta_f + \frac{2\pi}{3}\right) \end{bmatrix}\begin{bmatrix} i_{as} \\ i_{bs} \\ i_{cs} \end{bmatrix} \tag{36}$$

This is compactly expressed as

$$i_{qd} = [T][i_{abc}] \tag{37}$$

and

$$i_{qd} = \begin{bmatrix} i_{qs}^e & i_{ds}^e \end{bmatrix}^t \tag{38}$$

$$i_{abc} = \begin{bmatrix} i_{as} & i_{bs} & i_{cs} \end{bmatrix}^t \tag{39}$$

$$[T] = \frac{2}{3}\begin{bmatrix} \cos\theta_f & \cos\left(\theta_f - \frac{2\pi}{3}\right) & \cos\left(\theta_f + \frac{2\pi}{3}\right) \\ \sin\theta_f & \sin\left(\theta_f - \frac{2\pi}{3}\right) & \sin\left(\theta_f + \frac{2\pi}{3}\right) \end{bmatrix} \tag{40}$$

where i_{as}, i_{bs} and i_{cs} are the three phase stator currents.

It is known that the elements in the T matrix are cosinusoidal functions of electrical angle, θ_f. The electrical field angle in this case is that of the rotor flux-linkages phasor and is obtained as the sum of the rotor and slip angles.

$$\theta_f = \theta_r + \theta_{sl} \tag{41}$$

and the slip angle is obtained by integrating the slip speed and is given as

$$\theta_{sl} = \int \omega_{sl}\, dt \tag{42}$$

Further this mathematical model is used to design the speed controller for an indirect vector controlled induction motor drive .

Speed Controlled design using MOR with GA:

The block diagram of the inverter fed indirect vector controlled induction motor drive is shown in Fig. 1. The current open loop transfer function is from Fig. 1 is

$$G_i(s) = \frac{13.38s + 40.542}{8.58\times10^{-7}s^3 + 3.5171\times10^{-3}s^2 + 4.802s + 40.69} \tag{43}$$

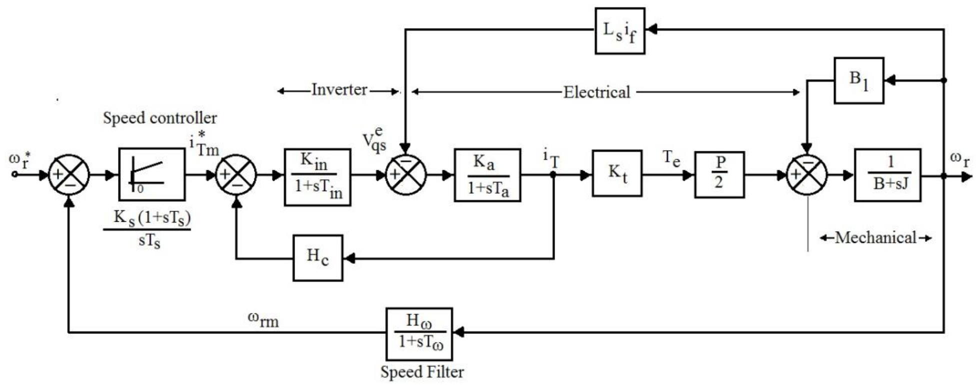

Fig. 1: Block diagram of the vector controlled induction motor.

This transfer function is a third order system and to reduce the order of the system for analytical design of speed controller, model order reduction technique serves. Using the proposed model order reduction technique, the reduced first order system is $G_{ri}(s)$ obtained from the reduced second order system which is suitable for use in the design of a speed loop. Hence the reduced second order system is

$$G_{ri}(s) = \frac{3801s + 11520}{s^2 + 1364s + 11560} \tag{44}$$

The step response, gain and phase plots of the exact and reduced second order current loop transfer functions is shown in Fig. 2, 3 and 4, respectively.

The step response can be analyzed with the help of time domain specifications such as overshoot, rise time and settling time which are given in Table 1. This reduced order current loop transfer function is substituted in the design of the speed controller as follows.

Table 1: Comparison of Step Response of Current Loop Transfer Function.

Strategy of Control	Rise time (t_r) in sec	Settling time (t_s) in sec	% Overshoot
Original higher order system	0.000398	0.461	180
Reduced order system	0.000441	0.464	175

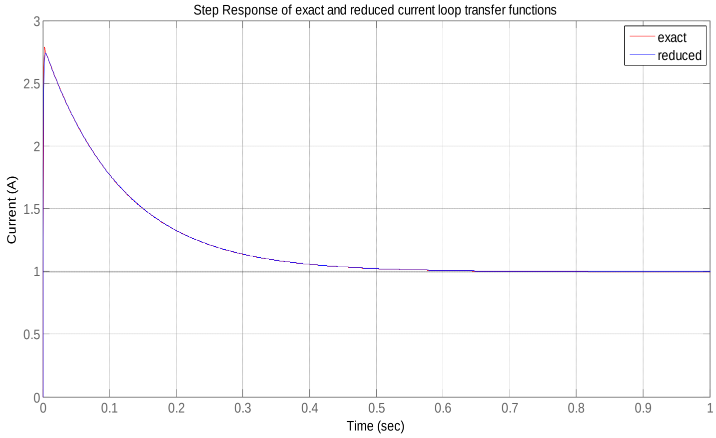

Fig. 2: Step response of exact and reduced current loop transfer functions.

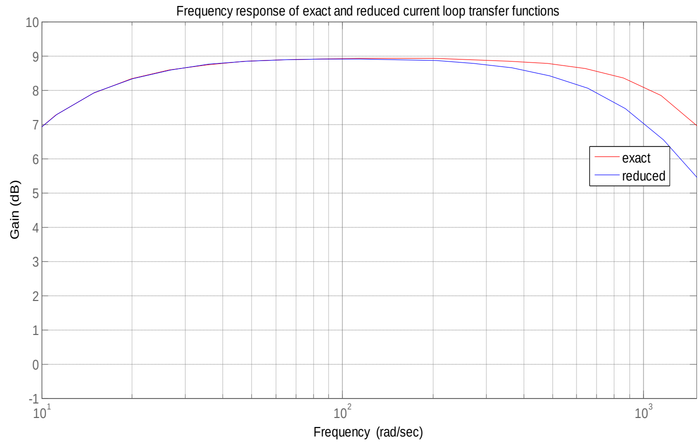

Fig. 3: Frequency response of exact and reduced current loop transfer functions.

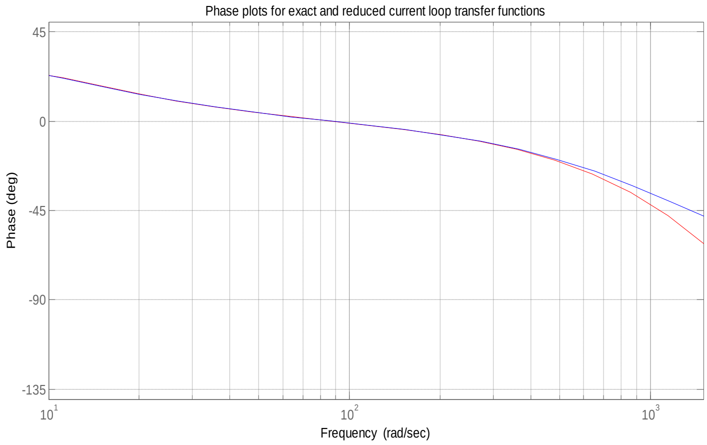

Fig. 4: Phase plots for exact and reduced current loop transfer functions.

The speed loop with the simplified current loop is shown in Fig. 5. The open loop speed transfer function with the reduced current loop is given by

$$G_{os}(s) = G_{ri}(s).G_m(s) = \frac{137700s + 417300}{0.33s^3 + 451.1s^2 + 5179s + 11560} \quad (45)$$

By using the Pole-Zero cancellation technique the initial values of K_p and K_i are obtained from the reduced second order current loop transfer function as:

$K_p = 1364$, $K_i = 11560$.

Australian Journal of Basic and Applied Sciences, 8(17) November 2014, Pages: 220-231

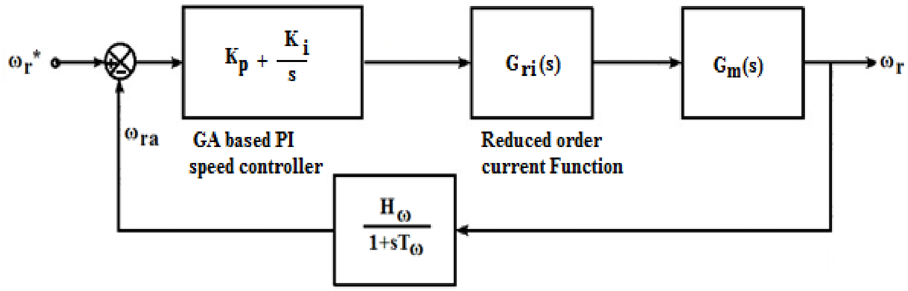

Fig. 5: The speed loop with the reduced order current loop.

The initial values of K_p and K_i obtained through the reduced order model are fine tuned using GA based on the minimal settling time criteria. The resultant values of K_p and K_i are obtained as,
K_p = 8.7928, K_i =18.1848.
These controller gains are used for the design of speed controller for reduced system and exact system. The speed loop with the reduced current loop is shown in Fig. 6.

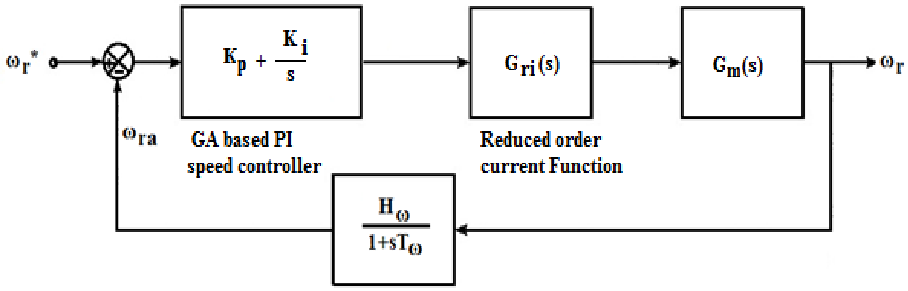

Fig. 6: The speed loop with the reduced order current Loop.

From Fig. 6, the closed loop speed transfer function with the reduced order current loop is obtained as

$$G_{s(ri)}(s) = \frac{\omega_r(s)}{\omega_r^*(s)} = \frac{6677s^3 + 3360000s^2 + 11010000s + 2696000}{0.00066s^5 + 1.232s^4 + 461.5s^3 + 172100s^2 + 561900s + 134800} \quad (46)$$

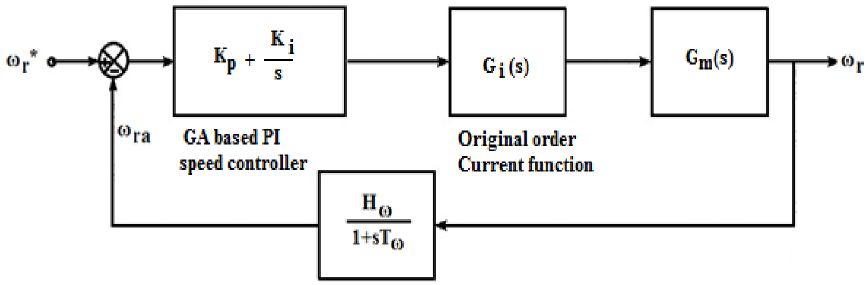

Fig. 7: The speed loop with the original order current loop function.

From Fig. 7, the closed loop speed transfer function with the original order current loop is obtained as

$$G_{s(oi)}(s) = \frac{\omega_r(s)}{\omega_r^*(s)}$$

$$= \frac{23.5s^3 + 11830\,s^2 + 38760\,s + 9492}{5.662 \times 10^{-10} s^6 + 2.697 \times 10^{-6} s^5 + 0.004338\,s^4 + 1.624\,s^3 + 605.8s^2 + 1978\,s + 474.60} \quad (47)$$

The step response of closed loop speed transfer function with the reduced and original order current loop is shown in Fig. 8. The steady state response of the closed loop speed transfer function with reduced order current loop is exactly matching with that of the original current loop speed transfer function. This can be analyzed with the help of time domain specifications such as overshoot, rise time and settling time which are given in Table 2. The magnitude plot and phase plot of speed transfer function with original and reduced current loop are shown in Fig. 9 and Fig. 10 respectively.

Table 2: Comparison of step response of Speed loop with Original and Reduced current loop function.

Strategy of Control	Rise time in sec	Settling time (t_s) in sec	% Overshoot
Speed loop with original current loop	0.00268	0.035	31.7
Speed loop with reduced current loop	0.00291	0.035	30.3

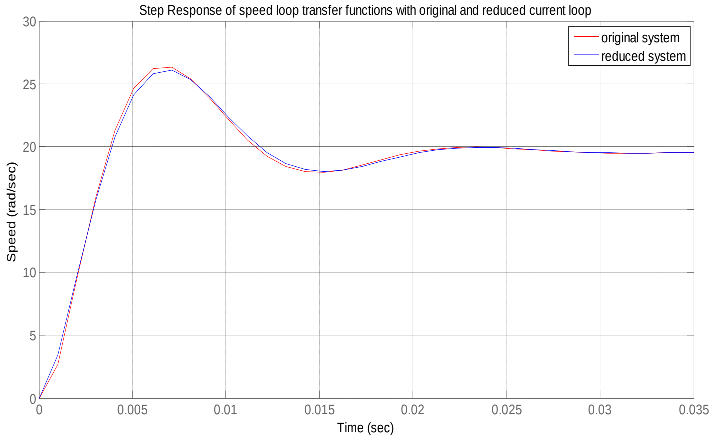

Fig. 8: Step response of speed loop transfer functions with original and reduced current loop.

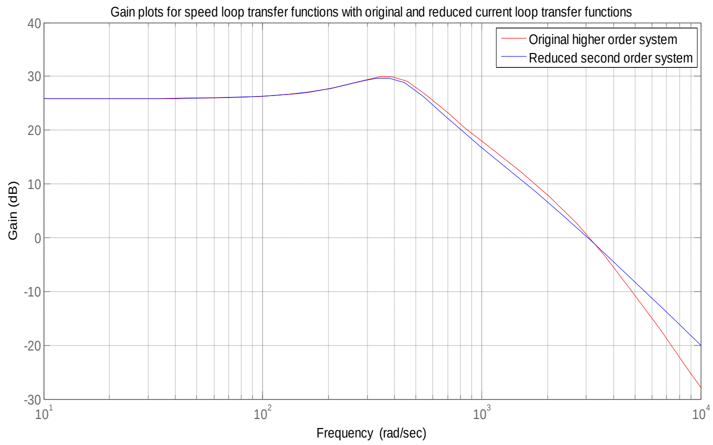

Fig. 9: Gain plots of speed loop transfer functions with original and reduced current loop.

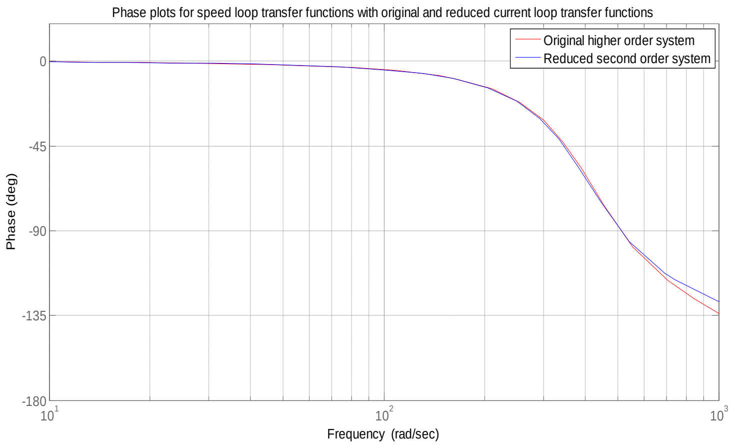

Fig. 10: Phase plots of speed loop transfer functions with original and reduced current loop.

RESULTS AND DISCUSSION

In this section, the design of speed controller for inverter fed indirect vector controlled induction motor drive using MOR-GA is compared with conventional symmetric optimum based PI speed controller method (Krishnan, R., 2002). Fig. 11 shows the comparison of step response of speed loop transfer function using original current loop with symmetric optimum principle and model order reduction technique with genetic algorithm tuned controller gains. This can be analyzed with the help of time domain specifications such as rise time, settling time, steady state value and peak value which are given in Table 3. The step response of the speed loop transfer function with original current loop using proposed model order reduction technique with genetic algorithm tuned controller gains method gives better time domain specifications than the conventional symmetric optimum principle method. The peak time results state that Genetic Algorithm based PI controller is 9 times lesser than SO PI speed controller. With consideration over the rise time the Genetic Algorithm PI controller is efficient giving 10.45 times lesser time.

Table 3: Comparison of step response of Speed loop using Original current loop function.

Strategy of Control	Rise time (t_r) in sec	Settling time (t_s) in sec	% Overshoot
Conventional SO method	0.028	0.26	34.5
Proposed MOR-GA method	0.00268	0.307	31.7

Fig. 12 shows the comparison of step response of speed loop transfer function using reduced order current loop with conventional symmetric optimum method and model order reduction technique with genetic algorithm tuned controller gains. This can be analyzed with the help of time domain specifications such as overshoot, rise time and settling time which are given in Table 4.

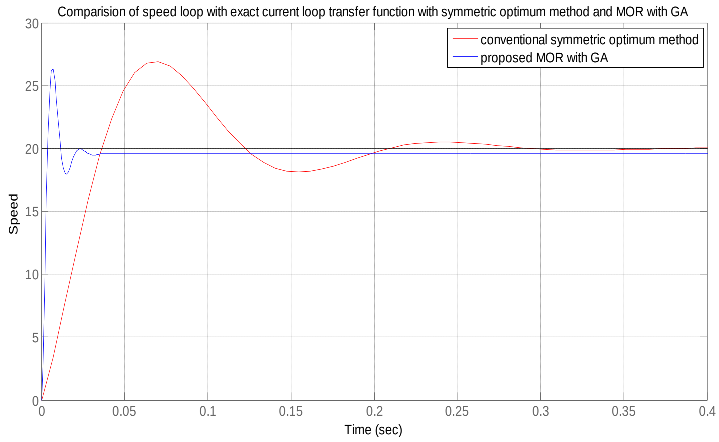

Fig. 11: Comparison of speed loop function using original current loop with SO and MOR-GA.

The step response of the speed loop transfer function with reduced order current loop using proposed model order reduction technique with genetic algorithm tuned controller gains method gives better time domain specifications than the conventional symmetric optimum method of speed controller.

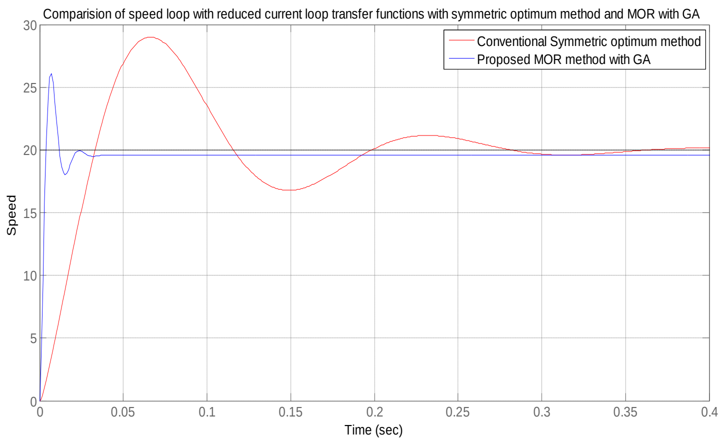

Fig. 12: Comparison of speed loop using reduced Current loop with SO and MOR-GA.

Table 4: Comparison of step response of Speed loop using reduced current loop function.

Strategy of Control	Rise time (tr) in sec	Settling time (ts) in sec	% Overshoot
Conventional SO method	0.00251	0.321	45
MOR technique with GA	0.00291	0.33	30.3

Conclusion:

In this paper a model order reduction technique is used to reduce the higher order system into an equivalent reduced order model and controllers designed to the reduced order model. Controllers gains are tuned by genetic algorithm optimization technique. The tuned controller is attached with the original higher order system and the closed loop response is observed for stabilization process. The steady state performance of proposed PI controller with the help of GA has been compared with the conventional (SO) PI controller. It is observed that the conventional symmetric optimum method has peak overshoot 45% while that of the proposed method is 30.3%. The settling time for the conventional method is around 0.321sec, whereas the proposed method has the settling time around 0.33sec.The step response of the speed loop transfer function with reduced order current loop using proposed model order reduction technique with genetic algorithm tuned controller gains method gives better time domain specifications than the conventional symmetric optimum principle method.

Apendix:

The induction motor with the inverter and load parameters are given below.
Motor field current,I_f = 6A,
Supply frequency, f_s = 2000 Hz,
Total friction coefficient, B_t = 0.05,
Gain of the speed filter, H_ω = 0.05,
Time constant of the speed filter, T_ω = 0.002,
Maximum control voltage, V_{cm} = 10V,
Total moment of inertia, J = 0.0165 kg-m^2,
DC link voltage, V_{dc} = 285 V,
Gain of the current transducer, H_c = 0.333 V/A.

REFERENCES

Aguirre, L.A., 1994. Partial least-squares Pade reduction with exact retention of poles and zeros. *International Journal of Systems Science*, 25(12): 2377-2391.

Arunima Dey, *et al*., 2009. Vector Control of three-phase induction motor using artificial intelligent technique. *ARPN Journal of Engineering and Applied Sciences*, 4(4): 57-67.

Bhagat, S.K., *et al*., 2004. Some mixed methods for the simplification of Higher order single input single output systems. *IE (I) J.-EL*, 85: 120-123.

Bousserhane, I.K., A. Hazzab, 2000. Direct Field-oriented Control Design Using Nonlinear Backstepping Strategy for Induction motor machine control. *IEEE proceeding of the 14th Meditarean Conference on Control and Automation*, Ancona, Italy, pp: 1-6.

Chandra, D., *et al*., 2004. Improved Routh-Pade Approximants: A Computer-Aided Approach. *IEEE Transactions on Automatic Control*, 49(2): 292-296.

Devender Kumar Saini, Rajendra Prasad, 2010. Order Reduction of Linear Interval Systems Using Genetic Algorithm. *International Journal of Engineering and Technology*, 2(5): 316-31.

Hazzab, A., *et al*., 2005. Design of Fuzzy sliding mode controller by genetic algorithms for induction machine speed control. *Third IEEE international conference on systems, Signal & Devices SSD'05*,Tunisia.

Kranthi Kumar, D., *et al*., 2011. Model Order Reduction of Interval Systems Using Mihailov Criterion and Cauer Second Form. *International Journal of Computer Applications*, 32(6): 17-21.

Krishnan, R., 2002. Electric motor drives modeling, analysis and control, PHI, New delhi.

Krishnan, R., A.S. Bharadwaj, 1991. A review of parameter sensitivity and adaptation in indirect vector controlled induction motor drive systems. *IEEE transactions on Power electronics*, 6(4): 695-703.

Manigandan, T., *et al*., 2005. Design of PID Controller using Reduced Order Model. *Academic Open Internet Journal*, 15.

Mansouri, A., *et al*., 2004. Power Nonlinear Observer associated with Field-oriented Control of an Induction Motor. *International Journal of Applied Mathematics and Computer Science*, 14(2): 209-220.

Meziane, S., *et al*., 2008. Nonlinear Control of Induction Machines Using an Extended Kalman Filter. *Acta Polytechnica Hungarica*, ISSN 1785-8860, 5(4): 41-58.

Mittal, S.K., *et al*., 2009. The Effects of Time-Moments and Markov- Parameters on Reduced- Order Modeling. *ARPN Journal of Engineering and Applied Sciences*, 4(5): 8-14.

Nagaraj, B., *et al*., 2008. Tuning Algorithms for PID Controller Using Soft Computing Techniques. *International Journal of Computer Science and Network Security*, 8(4): 278-281.

Ramesh, K., *et al*., 2004. Order reduction of LTIV continuous MIMO system using stability preserving approximation method. *International Journal of Computer Applications*, 36(8): 01-08.

Sivanandam, S.N., S.N. Deepa, 2009. A Comparative Study Using Genetic Algorithm and Particle Swarm Optimization for Lower Order System Modelling. *International Journal of Computer, the Internet and Management*, 17(13): 1-10.

Wang, Y.G., H.H. Shao, 2000. Optimal Tuning for PI controller. *Automatica*, 36: 147-152.