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Different Control Schemes for Sensor Less Vector Control of Induction Motor

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ABSTRACT

This paper deals with the design of different control schemes for sensorless vector control of induction motor.Induction motor is most widely used A.C. Motor but the major draw back is flux and torque cannot be controlled individually.This can be obtained by implementing sensorless vector control methods.The control strategy of induction motor is by different controllers like conventional control methods and artificial intelligence control methods.The conventional control methods are sensitive to parameter changes and will not be accurate. This paper proposes to design a controller to over come the above draw backs by using intelligent control techniques like fuzzy logic, artificial neutral networks (ANN) and genetic algorithm (GA). The above conventional control methods are compared with intelligent control techniques. The simulation studies are carried out using Matlab/Simulink and the wave forms for speed, torque and voltage components for various controlles are plotted. Numerical analysis for speed and torque components considering parameters like peakover shoot and peak time are presented.

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1. INTRODUCTION

In the field of industrial sector induction motor drives are major contributors, the simulation of these drives can be done in several methods, one of such kind is Simulink model [1]-[2].Mathematical modeling of induction motor drives are involved in conventional methods where the system diverts from required performance due to system variable variation[3].The conventional methods like kalman filter,PI Controller are used by many researchers to develop *dq0 & abc* models [4]. The Kalman filter controller uses numerical analysis based on predictor-corrector approximation [5] and PI controller based on linearity concept for unique operating points which resulted in attaining high performance was discussed [6] by several authors. These methods are sensitive to rotor time and correct flux estimationis required.Sensor less Vector control gains its significance where induction motor can modelled similar to D.C Motor using Field orientation control where torque and flux are independently controlled.With the rapid development of power electronics and digital computation the errors in the above methods are nullified with adaptation of artificial intelligence methods,like Fuzzy controller,Artifical neural networks and Genetic Algorithms .Many authors created a control signal employing fuzzy systems [7], these controllers relay on firing rules which are framed by past experiences. Thus, the outcome of the controller is also random and optimal results are based on selecting the right rule depending on the situation.Artifical Neural networks was used to developed an adaptive speed control of drives and to predict the operating voltage and frequency when the load torque and speed of the IM were changed [8].These Controllers work on back-propagation algorithm. The accuracy of this method lies in the right structure of a neural network which is a complex problem [9]. In recent era GA has emerged as a power ful optimization tool in application to machine theory.The basic advantage of GA is that it gives global minimum where as non linear solutions yield local minimum values and at the same time does not use derivatives. This method was used for efficiency optimization based on DC link power measurement [10].GA was used as a tool to optimize inertia of the rotating part as a single objective function and for tuning of PI controller by conventional Ziegler-Nichols method as it has greater accuracy along with convergenc [11]. This paper deals with different control schemes for sensorless vector control of induction motor.Conventional methods like kalman filter and PI Controller,Artifical intelligence methods like fuzzy controller,neural network,and genetic algorithms are considered.The simulation studies are carried out using Matlab/Simulink and the wave forms for speed ,torque and voltage components for various controlles are plotted.Numerical analysis for speed and torque components considering parameters like peakover shoot and peak time are presented in this paper.

2. D-Q MODEL OF INDUCTION MOTOR

The *d-q* model of induction motor is framed from Clark and Parks transformations where induction motor is modelled equivalent to a D.C.Motor.In this modeling the 3-ϕ stator currents are shifted to 2-ϕ synchronous reference frame of stator and to 2-ϕ reference frame of rotor. After clark's transformation the voltage equations in matrix form are given as shown in Equation (1).

$$\begin{bmatrix} v_{as} \\ v_{bs} \\ v_{cs} \end{bmatrix} = \begin{bmatrix} cos\theta & sin\theta & 1 \\ cos(\theta - 120°) & \sin(\theta - 120) & 1 \\ \cos(\theta + 120°) & \sin(\theta + 120) & 1 \end{bmatrix} \begin{bmatrix} v_{qs}^{s} \\ v_{ds}^{s} \\ v_{os}^{s} \end{bmatrix} \quad (1)$$

After inverse Clarks transformation the above equations reduced to the form shown in Equation (2)

$$\begin{bmatrix} v_{qs}^{s} \\ v_{ds}^{s} \\ v_{os}^{s} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} cos\theta & \cos(\theta - 120°) & \cos(\theta + 120°) \\ sin\theta & \sin(\theta - 120°) & \sin(\theta + 120°) \\ 0.5 & 0.5 & 0.5 \end{bmatrix} \begin{bmatrix} v_{as} \\ v_{bs} \\ v_{cs} \end{bmatrix} \quad (2)$$

Set θ = 0, so that the q – axis is aligned with the a-axis. The voltage equations in abc reference frame are given as shown in Equations (3) to (5),

$$v_{as} = v_{qs}^{s} \quad (3)$$

$$v_{bs} = -\frac{1}{2} v_{qs}^{s} - \frac{\sqrt{3}}{2} v_{ds}^{s} \quad (4)$$

$$v_{cs} = -\frac{1}{2} v_{qs}^{s} + \frac{\sqrt{3}}{2} v_{ds}^{s} \quad (5)$$

And inversely the equations in *d-q* reference frame are given as shown in Equations (6) and (7).

$$v_{qs}^{s} = \frac{2}{3} v_{as} - \frac{1}{3} v_{bs} - \frac{1}{3} v_{cs} = v_{as} \quad (6)$$

$$v_{ds}^{s} = -\frac{1}{\sqrt{3}} v_{bs} + \frac{1}{\sqrt{3}} v_{cs} \quad (7)$$

On applying Parks transformation the voltage equations are reduced to as shown in Equation (8).

$$\begin{bmatrix} v_{qs} \\ v_{ds} \end{bmatrix} = \begin{bmatrix} cos\theta_e & -sin\theta_e \\ sin\theta_e & cos\theta_e \end{bmatrix} \begin{bmatrix} v_{qs}^{s} \\ v_{ds}^{s} \end{bmatrix} \quad (8)$$

The electrical transient model in terms of voltage and currents can be given in matrix form is given as shown in Equation (9).

$$\begin{bmatrix} v_{qs} \\ v_{ds} \\ v_{qr} \\ v_{dr} \end{bmatrix} = \begin{bmatrix} R_s + SL_s & \omega_e L_s & SL_m & \omega_e L_m \\ -\omega_e L_s & R_s + SL_s & -\omega_e L_m & SL_m \\ SL_m & (\omega_e - \omega_r) L_m & R_r + SL_r & (\omega_e - \omega_r) L_r \\ -(\omega_e - \omega_r) L_m & SL_m & -(\omega_e - \omega_r) L_r & R_r + SL_r \end{bmatrix} \quad (9)$$

Here ‘s’ refers to Laplace function, for an induction motor which is single fed the relation $v_{qr} = v_{dr} = 0$.Holds good and the torque expression in *d-q* reference frame can be modelled as shown in Equation (10).

$$T_e = \frac{3}{2}\left(\frac{P}{2}\right) L_m\left(i_{qs} i_{dr} - i_{ds} i_{qr}\right) \tag{10}$$

The relation between electromagnetic torque (T_e) and rotor speed is given by Equation (11) as:

$$T_e = T_L + J\frac{d\omega_m}{dt} = T_L + \frac{2}{P} J \frac{d\omega_r}{dt} \tag{11}$$

By making stator direct and quadrature axises currents i_{ds} and i_{qs} related to field and armature currents I_f and I_a of a dc maotor the expression for torque can be written as shown in Equations (12) and (13).

$$T_e = K_t \hat{\Psi}_r * i_{qs} \tag{12}$$

$$T_e = K_t' i_{ds}\ i_{qs} \tag{13}$$

The stator current I_s can be expressed as shown in Equation (14) by making the rotor flux $\hat{\Psi}_r$ similar to air gap flux $\hat{\Psi}_m$ and analyzing $\hat{\Psi}_r$ and ψ_r as absolute and peak valuesof the sinusoidal space vector and neglecting L_{1r} (rotor leakage inductance).

$$I_s = \sqrt{\left({i_{ds}}^2 + {i_{qs}}^2\right)} \tag{14}$$

In the above expression for stator current shown in Equation (14) i_{ds} and i_{qs} refer to flux and torque components of stator currents flowing through the inductance L_m and rotor circuit.The rotor position (Θ) is crucial for sensor less control as the unit vector signals ($\cos\theta_e$ and $\sin\theta_e$) are to be generated.since synchronous reference frame d^s-q^s axes are aligned to the stator which is stationary but d^r-q^r axes are align to rotor moving at a speed ω_r. The d^s-q^s axes are rotating ahead of the d^r-q^r axes by the positive slip angle θ_{sl} corresponding to slip frequency ω_{sl}. Since the rotor pole is placed on rotating reference frame the angular speed is given as $\omega_e = \omega_r + \omega_{sl}$, *which* can be expressed in terms of Θ as shown in Equation (15).

$$\theta_e = \int \omega_e \, dt = \int(\omega_r + \omega_{sl}) dt = \theta_r + \theta_{sl} \tag{15}$$

For decoupling of stator current into flux and torque components the torque component is supposed to align along quadrature axis ie q_e-axis and flux component along direct axis ie d_e axis and the expressions for flux and currents can be rewritten in Equations (16)-(19).

$$\Psi_{dr} = L_r i_{dr} + L_m i_{ds} \tag{16}$$

$$\Psi_{qr} = L_r i_{qr} + L_m i_{qs} \tag{17}$$

$$i_{dr} = \frac{1}{L_r}\Psi_{dr} - \frac{L_m}{L_r} i_{ds} \tag{18}$$

$$i_{qr} = \frac{1}{L_r}\Psi_{qr} - \frac{L_m}{L_r} i_{qs} \tag{19}$$

Substituting the relations for rotor flux and current in above rotor equations we get modified Equations obtained are given in Equations (20) and (21).

$$\frac{d\Psi_{dr}}{dt} + \frac{R_r}{L_r}\Psi_{dr} - \frac{L_m}{L_r} R_r i_{ds} - \omega_{sl}\Psi_{qr} = 0 \tag{20}$$

$$\frac{d\Psi_{qr}}{dt} + \frac{R_r}{L_r}\Psi_{qr} - \frac{L_m}{L_r} R_r i_{qs} - \omega_{sl}\Psi_{dr} = 0 \tag{21}$$

Tthe total rotor flux $\hat{\Psi}_r$ is diverted to the de-axis by substuting ωsl = ωe – ωr and $\Psi_{qr} = 0$ i.e. $\frac{d\Psi_{qr}}{dt} = 0$ for decoupled control. The rotor expressions are given in Equation (22).

$$\frac{L_r}{R_r}\frac{d\hat{\Psi}_r}{dt} + \hat{\Psi}_r = L_m i_{ds} \; and \; \omega_{sl} = \frac{L_m R_r}{\hat{\Psi}_r L_r} i_{qs} \tag{22}$$

Considering $\hat{\Psi}_r = \Psi_{dr}$ and $\hat{\Psi}_r$ = constant in steady state the above equation is reduced to $\hat{\Psi}_r = L_m i_{ds.}$ which implies that rotor flux is directly proportional to current i_{ds} .

3. CONVENTIONAL CONTROL TECHNIQUES

3.1. Kalman Filter Method

The kalman filter method is most popular and commonly used tool for stochastic estimation. It uses a set of mathematical equations that implement a predictor-corrector type estimator. A simple predictor–corrector method can be constructed from the Euler method and the trapezoidal rule. For this method of control , the induction motor is modelled in the rotor reference frame by using the flux and speed estimator blocks.To get difference in time constants for current and speed two P-I controllers in a nested fashion has been used. The block diagram of above controller are shown in Figure 1. The variables of PI controller considered are listed in Table 1.

Table 1. Kalman filter controller parameters

Parameters	Flux	Speed	Torque
K_p	151.24	0.26	100
K_i	43640	1.98	29877

The accuracy of this method lies in exact calculation of step size and no of iterations considered. The block diagram of the above controller is shown in Figure 1.

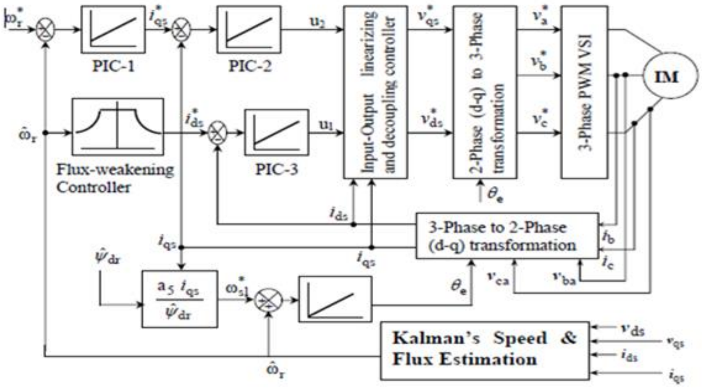


Figure 1. Block diagram of kalman filter controller.

3.2. Tuning of controller by Z-N Method.

A Conventional PI Controller can be obtained from the basic law governed by the expression given in Equation (23).

$$T = K_p + \int K_i \, dt \tag{23}$$

The torque can be varied by varying the controller variables (K_p and K_i).which are to be selected by framing a set of rules called tuning process. .The commonly adopted method is the Ziegler-Nichols where plant response decides the control parameters.

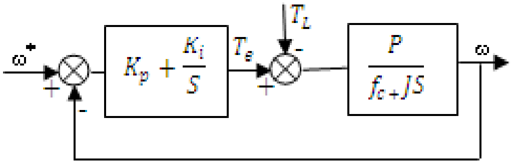


Figure 2. Block diagram of sensor less control of induction motor by PI controller

The modeling of induction motor by P-I control is given in Figure 2. The transfer function considered for modeling is as given in Equation (24). The This modeling employs machine parameters and initial values for controller in closed loop operation can be obtained by considering load torque as zero.

$$G(s) \ = \frac{(KP\ s + Ki)P/J}{S2 + \frac{fc + Kp}{L^r} s + \frac{K_i}{J}} \tag{24}$$

The characteristic equation of the above transfer function is shown in Equation (25) as:

$$P(S) = S^2 + \frac{(f_c + K_p\ P)}{J} S + \frac{K_i\,\mathrm{P}}{J}\,\mathrm{S} = 0 \tag{25}$$

Where $K_i = \frac{2J\rho^2}{P}$ and $K_{p=}\ \frac{(2J\rho - f_c)}{P}$. In the above expressions given in Equation (25) ρ is a constant value which is positive. By pole placement method the control variables (K_p and K_i) are obtained and are shown in Table 2

4. INTELLIGENT CONTROL TECHNIQUES

4.1. Fuzzy logic controller

With the rapid advancement of power electronics and digital computers many intelligent control methods have emerged which can give solutions to over come draw backs of above methods.In the proposed method of fuzzy control the controller adopts on-line efficiency optimization concept.By proper selection of step size of excitation current fast convergence can be attained and by a feed forward compensation algorithm. The generation of low-frequency pulsating torque is reduced. This method employs Mamdani method for fuzzification and centroid method for defuzzification. Selection of the proper membership functions and in turn selecting the right rule base depending on the situation are the major considerations for this method. Thus, the outcome of the controller is also random and optimal results may not be obtained which is a drawback.

4.2. Artificial neural network controller

Artifical neural network controller is based on integrated method of approach. It uses back-propagation algorithm where selection of the proper membership functions and in turn selecting the right rule base depending on the situation is ensured.It involves 4 major steps ie selection of inputs (i_1, i_2 … i_n) and weighted sum (w_1, w_2 … w_n), comparision of product of inputs and weighted sum with athresh hold value, scaling and addition of offset.The accuracy of this method lies in selection of right structure for neural network which is a complex problem. Figure 5 shows the block diagram of artificial neural network controller (ANN).

4.3. Genetic algorithm controller

Genetic algorithm has emerged as a powerful optimization tool by which minimal or maximum value of any function can be easily attained. In this method GA is employed to give optimal values of K_p and K_i for tuning of controller from which accurate position of rotor can be obtained to get desired torque and flux components of current .Here the first step involves in initialization of K_p & Ki values by Z-N method.For the generated population the error functions are arranged in decreasing order of their value. By using Roulette wheel criteria of selection and range of 0.5 the 10 least error population is declared as parent for off spring generation and and finally their fitness is verified.The process is repeated over entire cycle and to create a difference in off spring characteristics over the cycles a mutation value of 0.1 is generally considered.Now the value of variables which give least error are declared as optimal values of the function and these values of PI controller are used to analyse speed and torque parameters of the simulated induction motor. The obtained values are compared with the above values for better performance. Figure 6 shows the block diagram of above GA based Controller. Table 3 shows parameters employed and the values for controller obtained by GA approach.

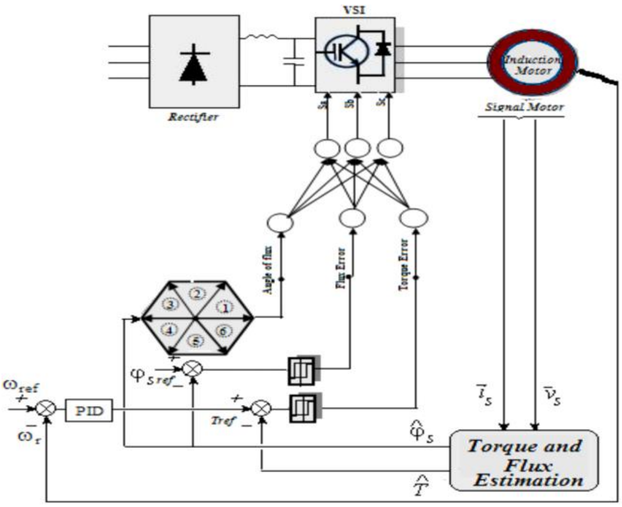


Figure 4. Block diagram of ANN controller

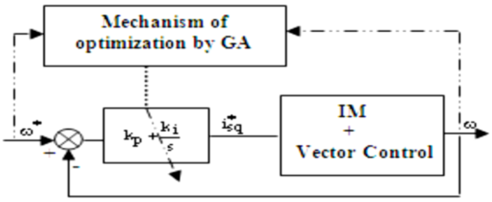


Figure 6. Block diagram of GA based controller.

Table 3. GA Parameters

GA property	Value
Population size	60
Max no of generations	100
Cross over probability	0.8
Mutation probability	0.1
Tolerance	$10e^{-6}$
Kp	0.9232
ki	7.8216

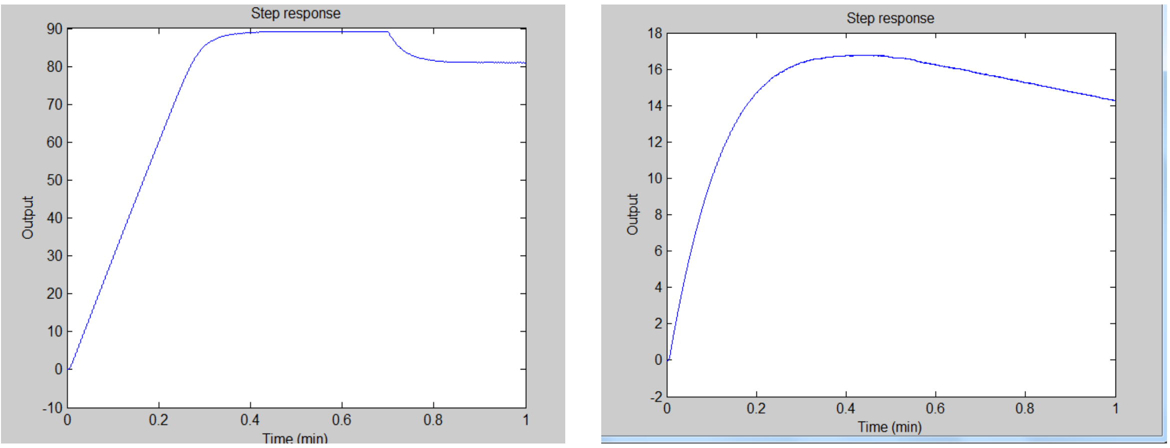
5. RESULTS AND ANALYSIS

The parameters of induction motor considered for the above analysis are shown in Table 4

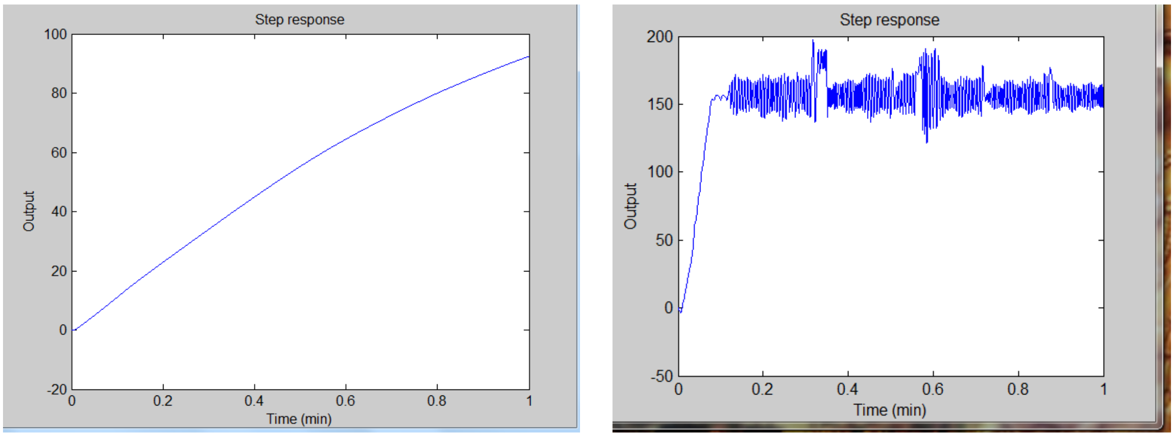
Table 4. Parameters Involved for Consideration of Induction Machine

Power rating(HP)	Voltage applied (Volts)	Frequency (HZ)	Speed in RPM	No of poles	Stator Resistance	Rotor Resistance	Stator Leakage Resistanc	Rotor Leakage Resistance	Mutual Inductance
5	440V	50HZ	1500	2	0.406**Ω**	0.478**Ω**	2.13mH	2.13mH	49.4mH

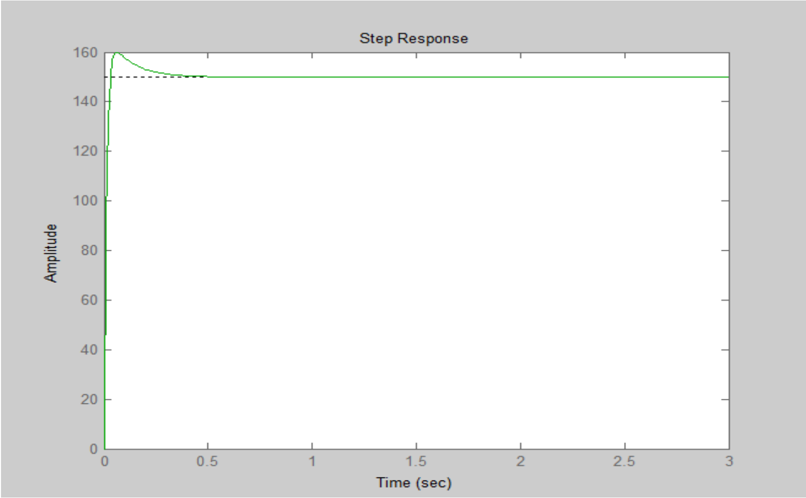
The wave forms for speed and torque components for various sensorless vector control methods discussed above are shown in Figure 7 and 8 respectively. For the above analysis of speed and torque a simulation time of 1 sec, reference torque of 12Nm and reference speed of 155rad/sec are considered.



(a)Kalman filter controller (b) Conventional PI Controller

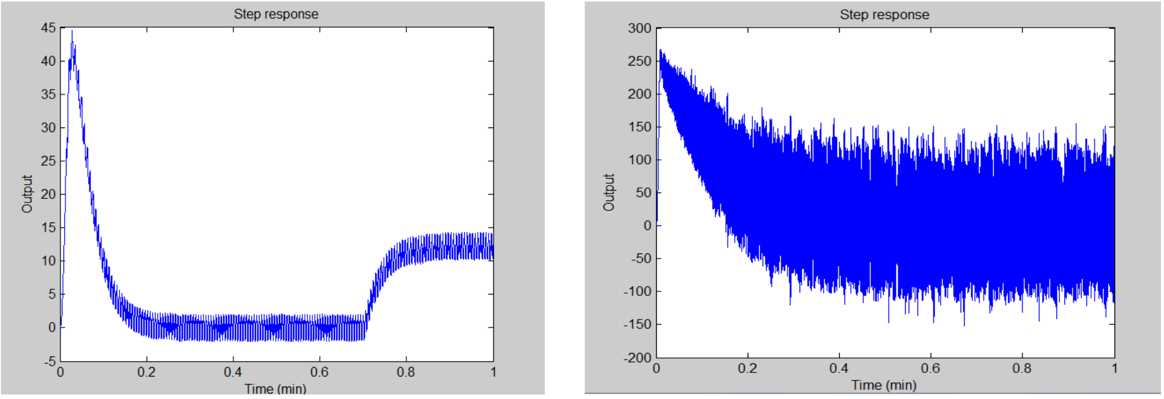


(c) Fuzzy Controller (d) ANN Controller

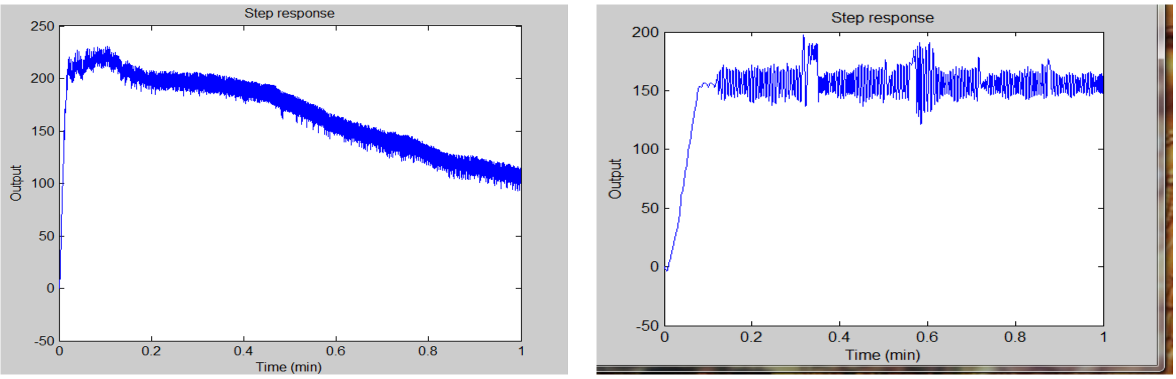


(e) GA Tuned PI Controller

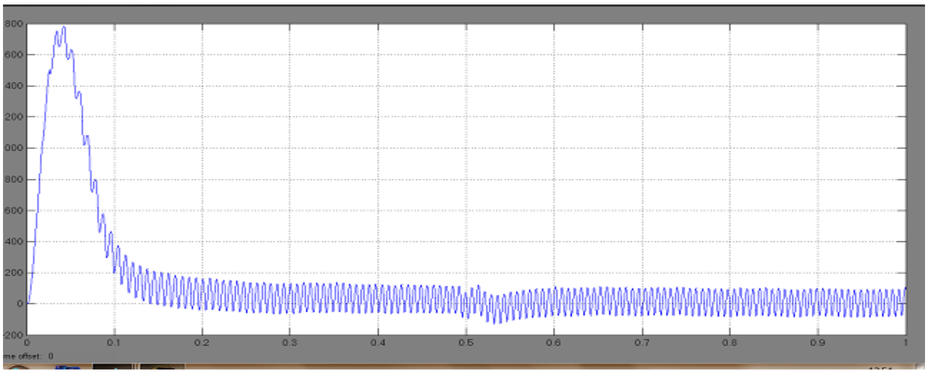
Figure 7. Simulation results of induction motor for speed response using different controllers



(a) Kalman filter controller (b) PI Controller



(c)Fuzzy Controller (d) ANN Controller



(e) GA Tuned PI Controller

Figure 8. Simulation results of induction motor for torque response using different controllers

5.1. Comparision of Various Sensorless Control Methods

From the above wave forms for speed and torque components of various control methods considered the numerical analysis for parameters of peak over shoot and peak time are analysed and are shown in Table 5 and 6.

Table 5. Numerical analysis of speed response of different controllers

Parameter	Kalman Filter	Fuzzy Controller	Ann Controller	Conventional Pi Controller	Ga Tuned Pi Controller
Peak Overshoot	$0.79283e^{+4}$	$0.60234e^{+3}$	$0.58742e^{+3}$	$0.61469e^{+3}$	$0.067753e^{+3}$
Peak Time	0.6747	1	0.3175	0.995	0.4340

Table 6. Numerical analysis of torque response of of different controllers

Parameter	Kalman Filter	Fuzzy Controller	Ann Controller	Conventional Pi Controller	Ga Tuned Pi Controller
Peak Overshoot	$22.0619e^{+3}$	2.2066^{+3}	$8.4313e^{+3}$	$1.907e^{+3}$	$2.576e^{+3}$
Peak Time	0.0811	0.0106	0.5813	0.0363	0.0106

From the numerical analysis for speed and torque components for sensor less vector control of induction motor it can be concluded that the peak over shoot and peak time of the proposed Genetic algorithm method are least compared to other methods ie peak over shoot is reduced from 0.7928 to 0.06 for speed and 22.06 to 2.57 for torque and peak time is reduced from 1 to 0.43 for speed and 0.58 to 0.01 for torque.Hence it can be concluded that GA method is best method of all methods considered.

6. CONCLUSION

For the purpose of analysis, the induction motor is modelled in d-q reference frame and the rotor position(ϴ) using various controllers is found.The performance for speed and torque parameters along with numerical values for peak over shoot and peak time are obtained. Conventional methods like kalmanfilter and PI controller are compared with artificial intelligence methods like fuzzy, Artifical neural network and Genetic algorithms. The accuracy lies in exact calculation of step size for kalman controller and proper selection of K_p and K_i values for PI Controller. Various intelligent control methods like fuzzy, ANN, and GA are considered.By using a Fuzzy controller employing efficiency optimization technique fast convergence is achieved by selecting adaptive step size of the excitation current. ANN Controller using back propagation algorithm based on integrated method of approach is considered.In the artificial intelligent methods discussed the accuracy lies in selection of right rule base for fuzzy controller and right structure of neural network for ANN which is a complex problem. Hence in the last method a genetic algorithm approach is used for optimization of error function to find kp and k_i values for tuning of PI controller.From the above analysis it can be concluded that compared to conventional methods artificial intelligence methods are better options for optimal control and the genetic algorithm approach is the best method of all the above discussed methods.

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