

Optimum Induction Motor Speed Control Technique Using Genetic Algorithm

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Abstract Industrial processes are subjected to variation in parameters and parameter perturbations, which when significant makes the system unstable. In order to overcome this problem of parameter variation the PI controllers are widely used in industrial plants because it is simple and robust. However there is a problem in tuning PI parameters. So the control engineers are on look for automatic tuning procedures. In recent years, many intelligence algorithms are proposed to tuning the PI parameters. Tuning PI parameters using different optimal algorithms such as the simulated annealing, genetic algorithm, and particle swarm optimization algorithm. In this paper a scheduling PI tuning parameters using genetic algorithm strategy for an induction motor speed control is proposed. The results of our work have showed a very low transient response and a non-oscillating steady state response with excellent stabilization. The simulation results presented in this paper show the effectiveness of the proposed method, with satisfied response for GA-PI controller.

Keywords Genetic Algorithm, PI Controller, Induction Motor, Matlab, Simulink

1. Introduction

Induction motors play a vital role in the industrial sector especially in the field of electric drives and control. Without proper controlling of the speed, it is impossible to achieve the desired task for a specific application. AC motors, particularly the squirrel-cage induction motors (SCIM), enjoy several inherent advantages like simplicity, reliability, low cost and virtually maintenance-free electrical drives. However, for high dynamic performance industrial applications, their control remains a challenging problem because they exhibit significant nonlinearities and many of the parameters, mainly the rotor resistance, vary with the operating conditions[1]. Field orientation control (FOC) or vector control[2] of an induction machine achieves decoupled torque and flux dynamics leading to independent control of the torque and flux as for a separately excited DC motor. FOC methods are attractive, but suffer from one major disadvantage (they are sensitive to motor parametric variations such as the rotor time constant and an incorrect flux measurement or estimation at low speeds[3]).

Induction motors are widely used in various industries as prime work-horses to produce rotational motions and forces. Generally, variable-speed drives for induction motors

require both wide operating range of speed and fast torque response, regardless of load variations. The classical control is used in majority of the electrical motor drives. Conventional control makes use of the mathematical model for the controlling of the system. When there are system parametric variations or environmental disturbance, behavior of system is not satisfactory and deviates from the desired performance[4].

In addition, usual computation of system mathematical model is difficult or impossible. To obtain the exact mathematic model of the system, one has to do some identification techniques such as the system identification and obtain the plant model. Moreover, the design and tuning of conventional controller increases the implementation cost and adds additional complexity in the control system and thus, may reduce the reliability of the control system. Hence, the fuzzy based techniques are used to overcome this kind of problems. Efficient torque control of induction motor drives in combination with resonant DC-link input filters can lead to a type of stability problem that is known as negative impedance instability. To overcome this[5], proposed a solution to the above problem by using the concept of non-linear system stabilizing controller with the plant.

There are a number of significant control methods available for induction motors including scalar control, vector or field-oriented control, direct torque and flux control, sliding mode control, and the adaptive control[4]. Scalar control is aimed at controlling the induction machine

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to operate at the steady state, by varying the amplitude and frequency of the fundamental supply voltage[6]. A method to use of an improved V/f control for high voltage induction motors and its stability was proposed in[7]. The scalar controlled drive, in contrast to vector or field-oriented controlled one, is easy to implement, but provides somewhat inferior performance. This control method provides limited speed accuracy especially in the low speed range and poor dynamic torque response.

Many researchers had worked on the fuzzy logic based on-line efficiency control for an indirect vector controlled IM drive. Bimal Bose *et al.*[8] extended the same control technique to a stator flux oriented electric vehicle IM drive and then implemented the fuzzy controller by a dynamic back propagation algorithm using an ANFIS controller. They further verified the simulated results using a DSP based hardware. Haider *et al.*[9] Presented the design and implementation of Fuzzy-SMC-PI methodology to control the flux and speed of an induction motor. The Fuzzy-SMC-PI was basically a combination of Sliding Mode Control (SMC) and PI control methodologies through fuzzy logic, but the drawback being the chattering during the time of switching.

In[10] and[11], the researchers implemented a fuzzy logic controller to adjust the boundary layer width according to the speed error. The drawback of their controller is that it depends on the equivalent control and on the system parameters. Two researchers, Takagi and Sugeno developed a excellent control scheme for control of various applications in the industrial sector. This controller had many advantages over the other methods discussed so far. Many researchers started using their models for their applications. Zie, Ling and Jhang[12] presented a TS model identification method by which a great number of systems whose parameters vary dramatically with working states can be identified via Fuzzy Neural Networks (FNN). The suggested method could overcome the drawbacks of traditional linear system identification methods which are only effective under certain narrow working states and provide global dynamic description based on which further control of such systems may be carried out.

In the above mentioned paper, there were contribution for their research and they solved many problems but there are some limitation in the settling time of the responses and the proper selection of the rule base. The responses had taken a lot of time to reach the final steady state value.

Because of the simplicity and robustness, PI controllers are frequently used controllers in industries[13]. Parameter adjustment of PI controllers is an old challenge in the field of control system design. Some of methods have been proposed to select the PI coefficients, but they are not completely systematic methods and result in a poorly tuned controller that needs some trail and error. So far, finding new methods to automatically select PI parameters was interest of researches[14]. In this paper the idea of designing optimal PI

controller based on genetic algorithms is defined and applied. According to the controller type and location in closed loop control system. Then this idea can be verified and tested by simulation results.

In the early 1960s Rechenburg (1965) conducted studies at the technical university of Berlin in the use of an evolutionary strategy to minimize drag on a steel plate[15]. Genetic algorithms were used by Holland (1975) and his students at the University of Michigan in the late 1970s and early 1980s to analyses a range of engineering problems[15] and[16]. In particular, Goldberg (1983) used genetic algorithms to optimize the design of gas pipeline systems. Genetic algorithms are one of the efficient tools that are employed in solving optimization problems[15].

In this paper, a sincere attempt is made to reduce the settling time of the responses and make the speed of response very fast by designing an efficient controller using GA-PI control strategy. Here, we have control strategy for the speed control of IM, which has yielded excellent results compared to the others mentioned in the literature survey above. The results of our work have showed a very low transient response and a non-oscillating steady state response with excellent stabilization.

2. Modeling of Induction Motor

2.1. Mathematical Model of the Induction Motors

In this study, the mathematical model of the system consists of space vector PWM voltage source inverter, induction motor, direct flux and the torque control. An induction motor model to predict the voltage required achieving a desired output torque is given in[17]. Figure 1. shows the power circuit of the 3-phase induction motor and Figure 2. shows the equivalent circuit used for obtaining the mathematical model of the IM.

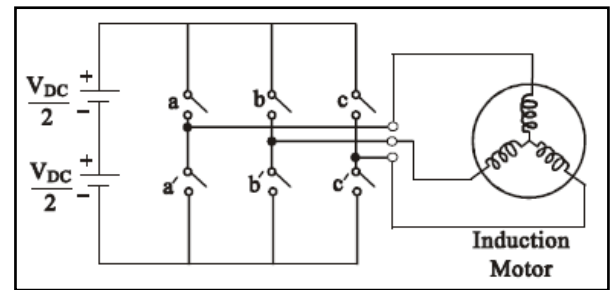
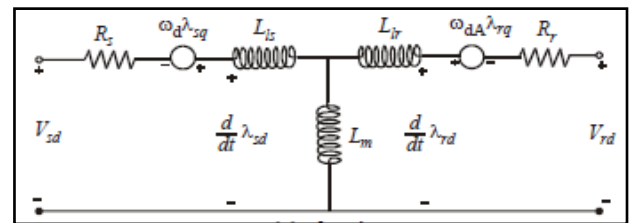


Figure 1. Power circuit connection diagram for the IM



(a) d-axis

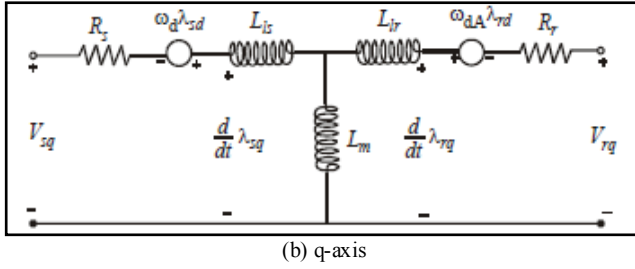


Figure 2. Equivalent circuit of induction motor in d-q frame

An induction motor model is then used to predict the voltage required to drive the flux, torque and the speed to the demanded values. This calculated voltage is then synthesized using the space vector modulation. The stator and rotor voltage equations are given by[16].

$$V_{sd} = R_s i_{sd} + \frac{d}{dt} \lambda_{sd} - \omega_d \lambda_{sq} \quad (1)$$

$$V_{sq} = R_s i_{sq} + \frac{d}{dt} \lambda_{sq} + \omega_d \lambda_{sd} \quad (2)$$

$$V_{rd} = R_r i_{rd} + \frac{d}{dt} \lambda_{rd} - \omega_{dA} \lambda_{rq} \quad (3)$$

$$V_{rq} = R_r i_{rq} + \frac{d}{dt} \lambda_{rq} + \omega_{dA} \lambda_{rd} \quad (4)$$

where V_{sd} and V_{sq} , V_{rd} and V_{rq} are the direct axes and quadrature axes stator and rotor voltages[16].

The squirrel-cage induction motor considered for the simulation study in this thesis, has the d and q-axis components of the rotor voltage zero. The flux linkages to the currents are related by the Equation (5) as

$$\begin{bmatrix} \lambda_{sd} \\ \lambda_{sq} \\ \lambda_{rd} \\ \lambda_{rq} \end{bmatrix} = M \begin{bmatrix} i_{sd} \\ i_{sq} \\ i_{rd} \\ i_{rq} \end{bmatrix}; M = \begin{bmatrix} L_s & 0 & L_m & 0 \\ 0 & L_s & 0 & L_m \\ L_m & 0 & L_r & 0 \\ 0 & L_m & 0 & L_r \end{bmatrix} \quad (5)$$

The electrical part of an induction motor can thus be described by a fourth-order state space model which is given in Equation (6), by combining equations (1-5) as[16]

$$\begin{bmatrix} \dot{v}_{qs} \\ \dot{v}_{ds} \\ \dot{v}_{qr} \\ \dot{v}_{qr} \end{bmatrix} = \begin{bmatrix} R_s + sL_s & -\omega_e L_s & sL_m & -\omega_e L_m \\ -\omega_e L_s & R_s + sL_s & -\omega_e L_m & pL_m \\ sL_m & (\omega_e - \omega_r) L_m & R_r + sL_r & (\omega_e - \omega_r) L_r \\ -(\omega_e - \omega_r) L_m & sL_m & -(\omega_e - \omega_r) L_r & R_r + sL_r \end{bmatrix} \begin{bmatrix} i_{qs} \\ i_{ds} \\ i_{qr} \\ i_{qr} \end{bmatrix} \quad (6)$$

Table 1. The inverter switching states

V_i	A	B	C	V_{An}	V_{Bn}	V_{Cn}
V_0	0	0	0	0	0	0
V_1	1	0	0	$2V_{DC}/3$	$-V_{DC}/3$	$-V_{DC}/3$
V_2	1	1	0	$V_{DC}/3$	$V_{DC}/3$	$-2V_{DC}/3$
V_3	0	1	0	$-V_{DC}/3$	$2V_{DC}/3$	$-V_{DC}/3$
V_4	0	1	1	$-2V_{DC}/3$	$V_{DC}/3$	$V_{DC}/3$
V_5	0	0	1	$-V_{DC}/3$	$-V_{DC}/3$	$2V_{DC}/3$
V_6	1	0	1	$V_{DC}/3$	$-2V_{DC}/3$	$V_{DC}/3$
V_7	1	1	1	0	0	0

where s is the laplacian operator. By superposition, i.e., adding the torques acting on the d-axis and the q-axis of the rotor windings, the instantaneous torque produced in the electromechanical interaction is given by

$$T_{em} = \frac{3}{2} \left(\frac{P}{2} \right) (\lambda_{rq} i_{rd} - \lambda_{rd} i_{rq}) \quad (7)$$

The electromagnetic torque expressed in terms of inductances is given by

$$T_{em} = \frac{3}{2} \left(\frac{P}{2} \right) L_m (i_{sq} i_{rd} - i_{sd} i_{rq}) \quad (8)$$

The mechanical part of the motor is modelled by the equation (9) as[16]

$$\frac{d}{dt} \omega_m = \frac{T_{em} - T_L}{J_{eq}} = \frac{\frac{3}{2} \left(\frac{P}{2} \right) L_m (i_{sq} i_{rd} - i_{sd} i_{rq}) - T_L}{J_{eq}} \quad (9)$$

where, ω_m is angular speed, T_{em} is electromagnetic torque, T_L is load torque, J_{eq} is equivalent moment of inertia, L_m is mutual inductance, L_r is rotor inductance, L_s is stator inductance, and V_{DC} is dc voltage .

2.2. Space Vector Pulse Width Modulation

The induction motor can be observed as a system of electric and magnetic circuits, which are coupled magnetically and electrically. A 3-Phase balanced sinusoidal voltages given by[19].

$$V_{An} = V_m \cos \omega t, \quad (10)$$

$$V_{Bn} = V_m \cos \left(\omega t - \frac{2\pi}{3} \right), \quad (11)$$

$$V_{Cn} = V_m \cos \left(\omega t + \frac{2\pi}{3} \right), \quad (12)$$

are applied to the IM using the equation

$$V = \frac{2}{3} [v_{an} + a v_{Bn} + a^2 v_{Cn}] \quad (13)$$

Through the 3-Phase bridge inverter shown in the Figure 1 which has got 8 permissible switching states. These 8 permissible switching states can be graphically represented as shown in the Figure 3. The table 1 gives the summary of the switching states and the corresponding phase-to-neutral voltages of the isolated neutral induction machine[23].

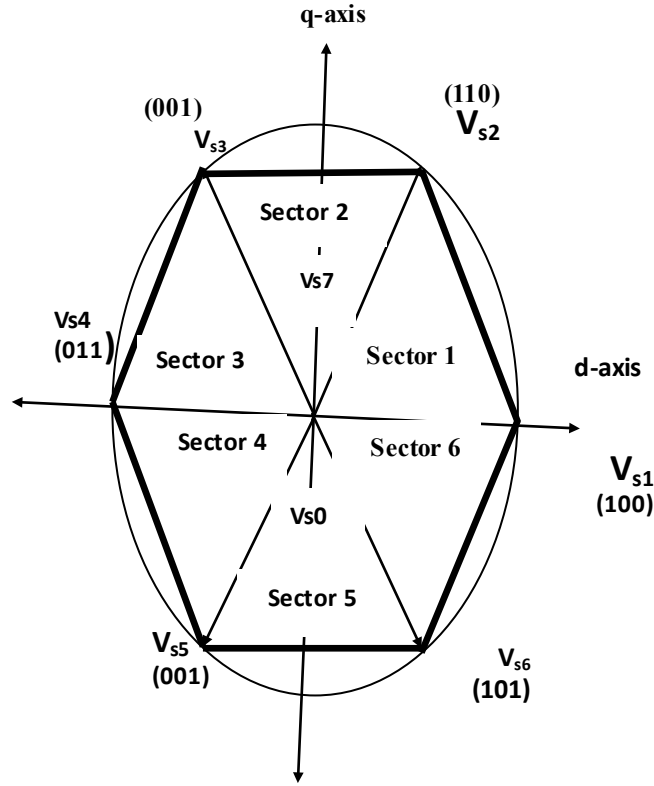


Figure 3. Diagrammatic representation of the sequence of the space vectors

3. Realization of GA-PI Controller Tuning Optimal Parameters

3.1. Proposed GA-PI Controller

It is possible to introduce and explain the following computing procedure based on genetic algorithm for optimal selection of controller parameters. This algorithm is clearly shown in Figure 4. And can be explained with the following steps:

1. Specify the controller type and location.
2. Start with a randomly generated population of size (MP \times NP). (i.e. population of controller parameters (gains) is randomly generated according to a specified parameters range).
3. Calculate the fitness $f(x)$ of each chromosome x in the population.
4. Apply elitism technique to retain one or more best solutions from the population.
5. Apply genetic algorithms operators to generate a new population:
 - a. Select a pair of parent chromosomes from the probability of selection being an increasing function of fitness. Selection is done with replacement, which means the same chromosome can be selected more than once to become a parent.
 - b. With probability PC, crossover the pair at a randomly chosen point (chosen with uniform probability) to form two

offspring.

c. Mutate the two offspring at each locus with probability Pm, and place the resulting chromosomes in the new population.

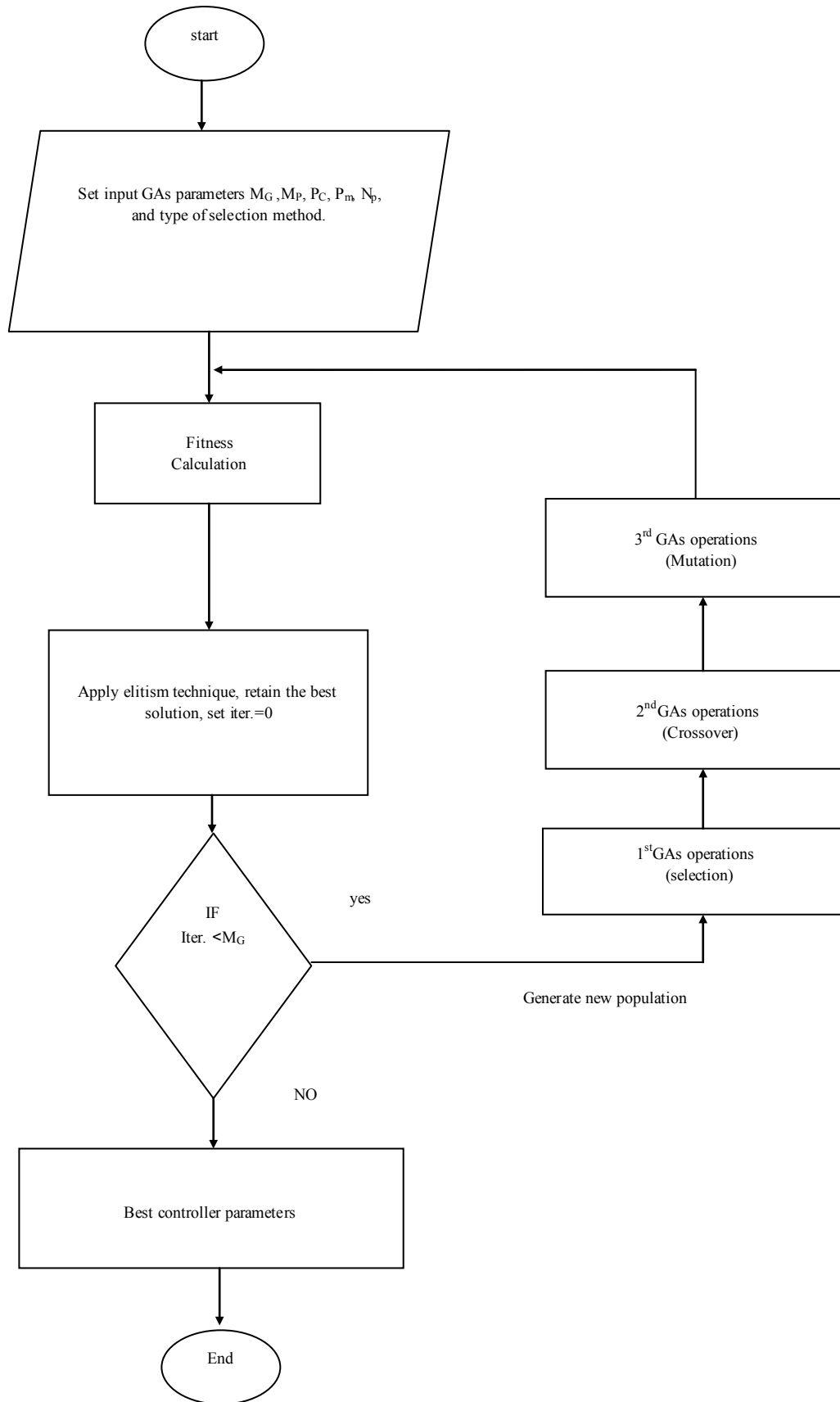
6. Replace the current population with the new population.

7. If stopping criterion such as maximum number of iteration is not met then go to step 3 (repeat steps 3-7).

8. Display results and stop program.

To understand this algorithm, we should define the overall system transfer function according to the type and location of the controller. In addition, it is important to determine the following parameters: Maximum population size MP, Maximum number of generations MG, Number of controller parameters NP, Range of controller parameters R, Probability of crossover PC, Probability of mutation Pm and The type of fitness function $f(x)$.

The stop criterion is maximum number of generations. In this paper a powerful design method based on real-coded genetic algorithms to solve the minimization of the ISE criterion is described. Genetic algorithms provide a much simpler approach to off-line tuning of such controllers than the rather complicated non-genetic optimization algorithms [18]. However, in particular PI controllers have many types and different structures, depending on the location of the proportional, integral control, which can be placed in forward path in cascade with the plant, or in the feedback path.

**Figure 4.** Flowchart of Genetic PI Controller Algorithm

3.2. Tuning Genetic PI Controller

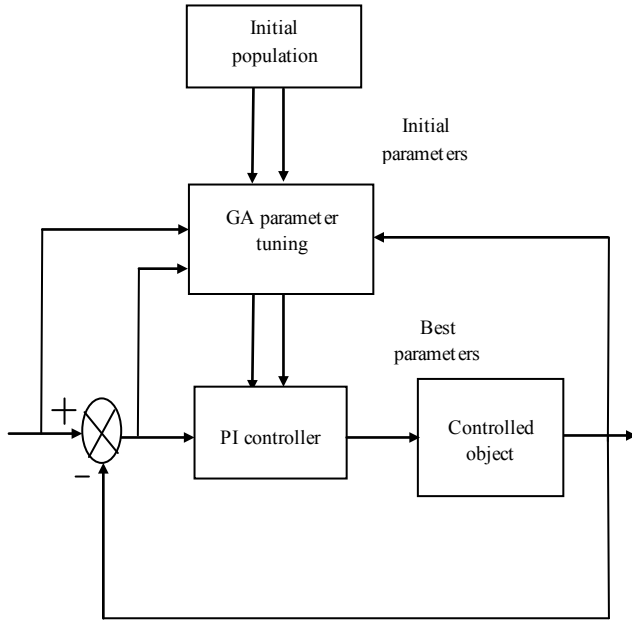


Figure 5. Tuning genetic PI Controller

Figure 5. Represent a block diagram of the feedback control system based on genetic PI controller. The controller parameters are tuned by genetic algorithms starting from initial population[14], which is generated randomly and now it is important to calculate the fitness of each chromosome in the population. This is achieved by setting these values to the PI controller, to test the system output response by using unit step input signal as shown in Figure 5.

3.3. Fitness Function

In PI controller design methods, the most common performance criteria are integrated absolute error (IAE), the integrated of time weight square error (ITSE), integrated of squared error (ISE) and integrated of time weight absolute error (ITAE) that can be evaluated analytically in the frequency domain[20, 21]. These four integral performance criteria in the frequency domain such as IAE, ISE, ITAE and ITSE performance criterion formulas are as follows:

$$IAE = \int_0^{\infty} |e(t)| dt \quad (14)$$

$$ISE = \int_0^{\infty} e^2(t) dt \quad (15)$$

$$ITAE = \int_0^{\infty} t \cdot |e(t)| dt \quad (16)$$

$$ITSE = \int_0^{\infty} t e^2(t) dt \quad (17)$$

In order study we will select the fitness function (FF) is reciprocal of the performance criterion, in the other words: FF= ISE.

In this paper a time domain criterion is used for evaluating the PI controller. A set of good control parameters P and I can yield a good response that will result in performance criteria minimization in the time domain. These performance criteria in the time domain include the overshoot, rise time, settling time, and steady-state error.

4. GA-PI Controller Selection

4.1. GA-PI Controller Parameter Selection

To control the speed of an induction motor at 150 rad/sec. Therefore it is desired to improve the system response by using genetic PI controller to enhance the transient response, or using PI controller to enhance both transient and steady state closed loop system response. Let us try to apply the algorithm step by step to show you the activity of the proposed algorithm. In addition the genetic algorithms which are introduced in this thesis uses roulette wheel selection method and the fitness function (ISE). It is desired to find genetically the parameters of the PI controller, but this need to define first the following genetic input parameters in Table 2 and Genetic Output Results show in table 3.

Table 2. Genetic input parameters

M_p	M_G	N_p	R	Crossover	Mutation	Selection method
20	10	2	-200 to 200	Single point	Uniform	Roulette Wheel

Table 3. variable of GA-PI controller. Genetic Algorithm values are given as ($K_i = 180.0888$, $K_p = 188.2371$).

The simulation results of GA-PI controller are shown in Figure 6. Figure 6 shows the best and mean fitness during generations. Note that an optimal solution is achieved after the 4th. The developed simulink model for the speed control of IM using GA-PI shown in Appendix A2 .

Table 3. Genetic output results

Genetic output Results		
K_p	K_i	ITSE
188.2371	180.0888	19.9119

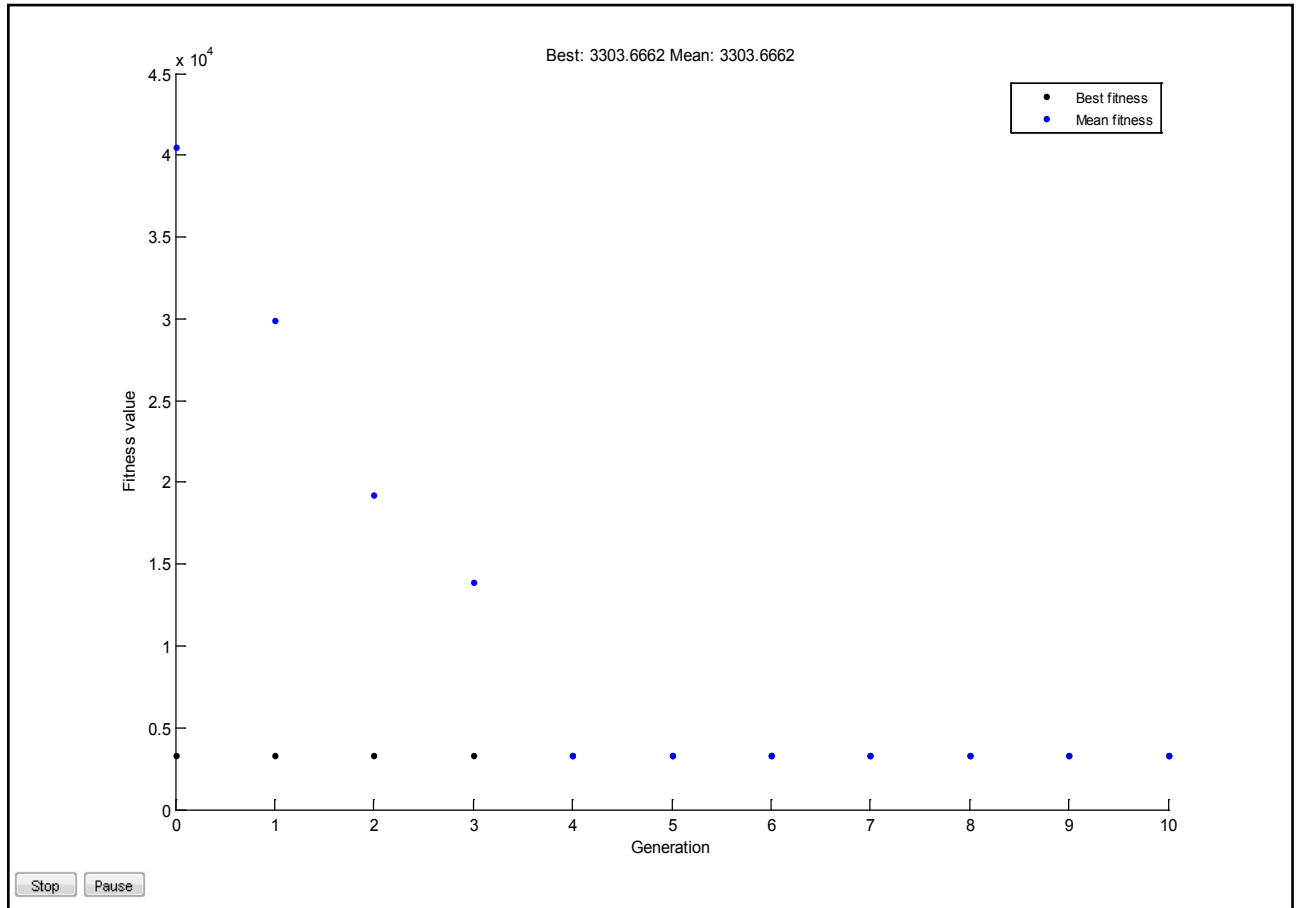


Figure 6. Variation of fitness during generations. Best fitness and Mean fitness

Simulations are carried out in Matlab. The response curves of flux, stator current, electromagnetic torque are shown in the Figures 7-9 respectively.

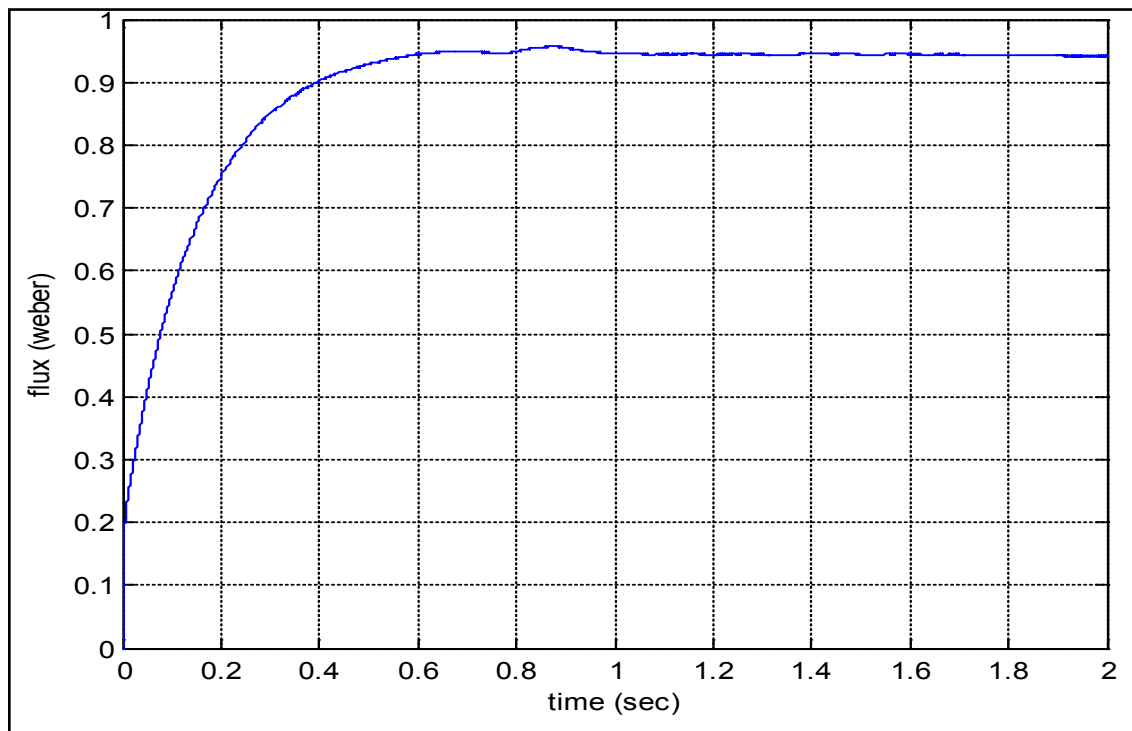


Figure 7. Flux in case of GA-PI ($T_L=2$ N.m at $t=0$ sec)

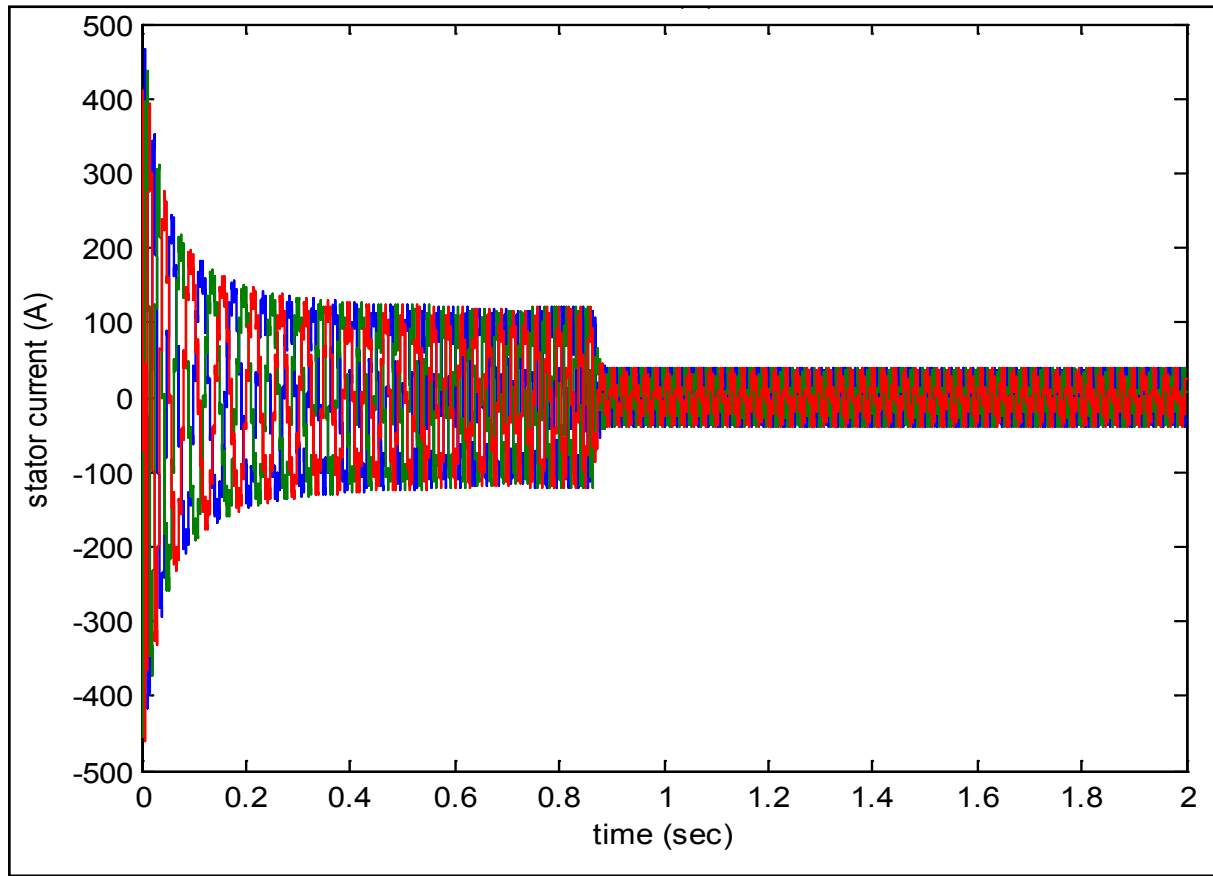


Figure 8. Stator current in case of GA-PI ($T_L=2$ N.m at $t=0$ sec)

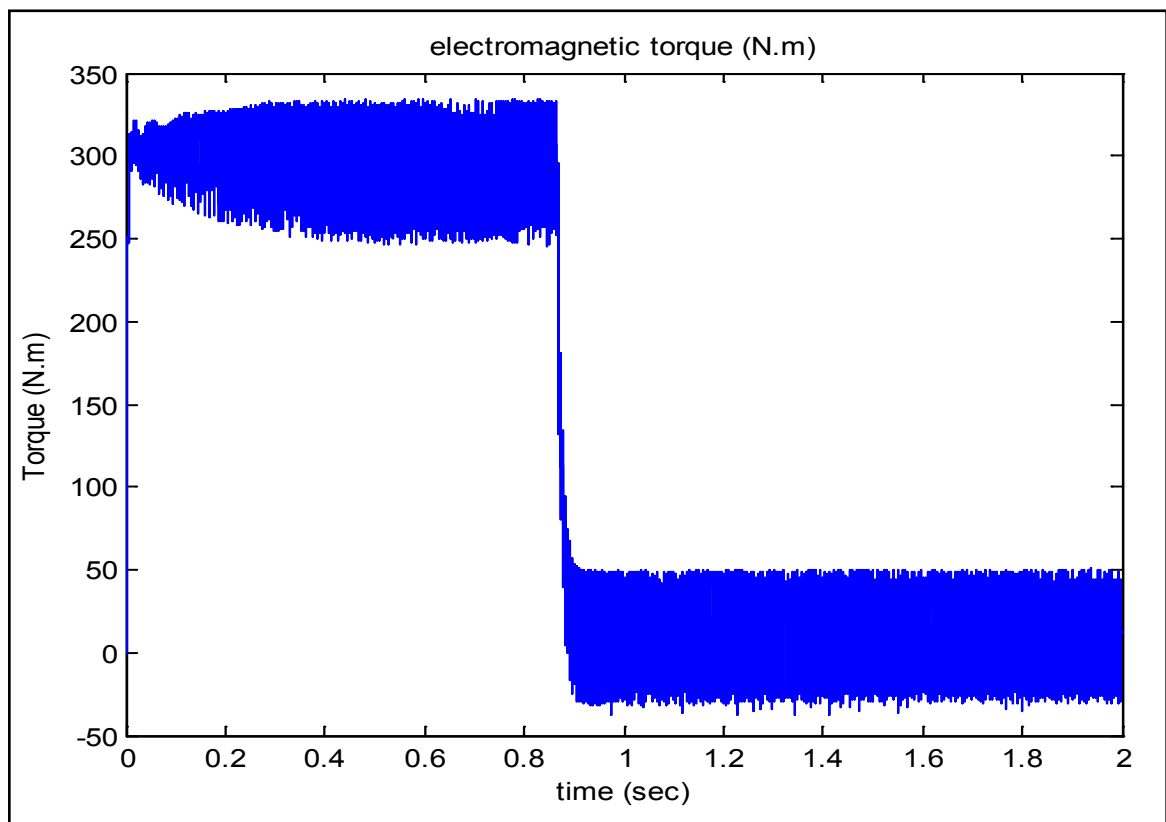


Figure 9. Torque in case of GA-PI ($T_L=2$ N.m at $t=0$ sec)

Figure 10 shows the rotor speed performance at $T_L=2\text{N.m}$ and time zero load condition.

From the simulation result shown in the Figure 10, it is observed that the response of the speed takes lesser time to reach settle value and obtains the desired value in a min time. A comparison study between the control performance using GA with another technique used Mamdani control strategy[22] shown in the Figure 11, for the same model and the same parameter. The comparison shows that the motor speed reached to 0.84 sec compared with other technique that reached to 1.4 sec (ITAE=19.9119).

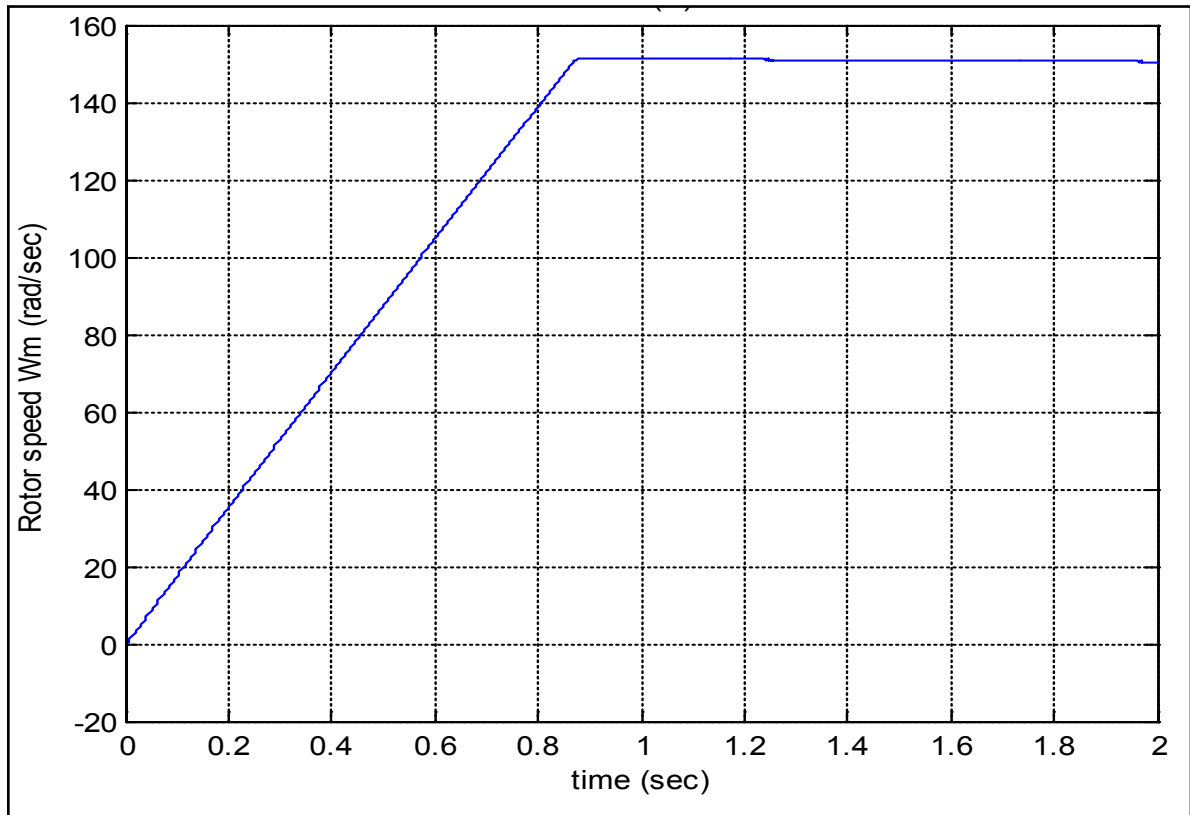


Figure 10. Speed in case of GA-PI ($T_L=2\text{ N.m}$ at $t=0\text{ sec}$)

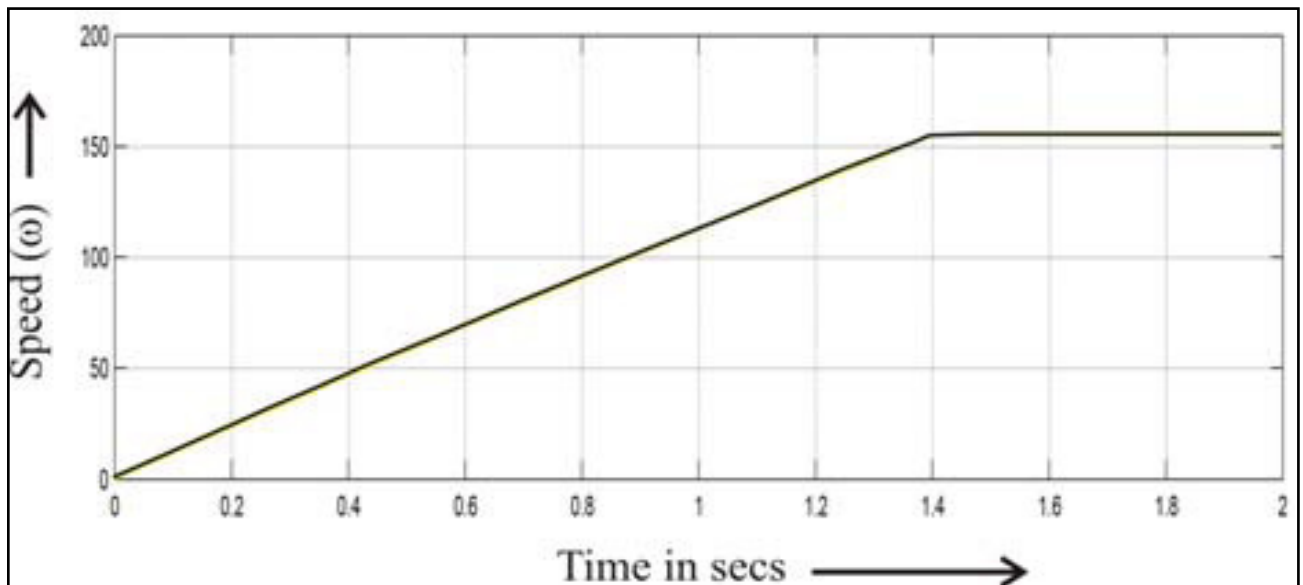


Figure 11. Speed in case of Mamdani control strategy[22]

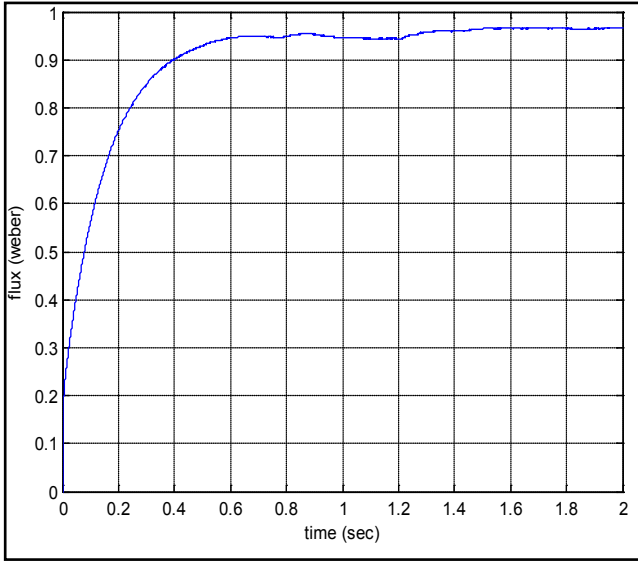


Figure 12. Flux in case of GA-PI ($T_L=200$ N.m at $t=1.2$ sec)

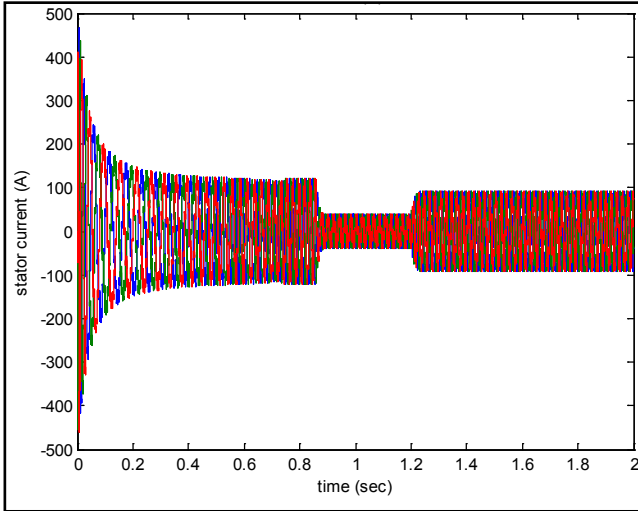


Figure 13. Stator current in case of GA-PI ($T_L=200$ N.m at $t=1.2$ sec)

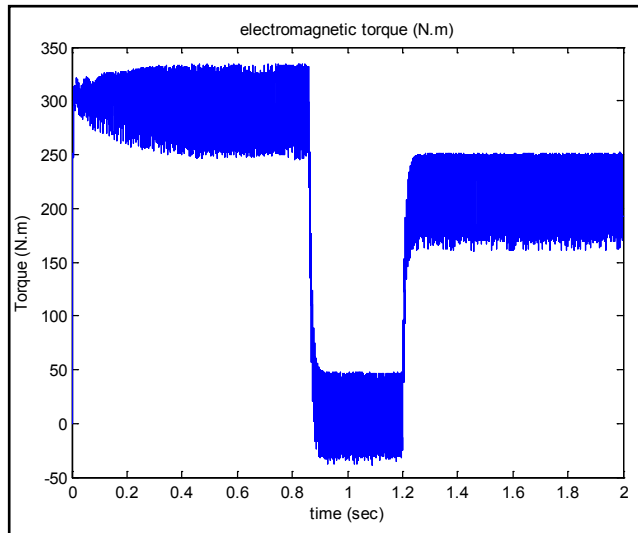


Figure 14. Torque in case of GA-PI ($T_L=200$ N.m at $t=1.2$ sec)

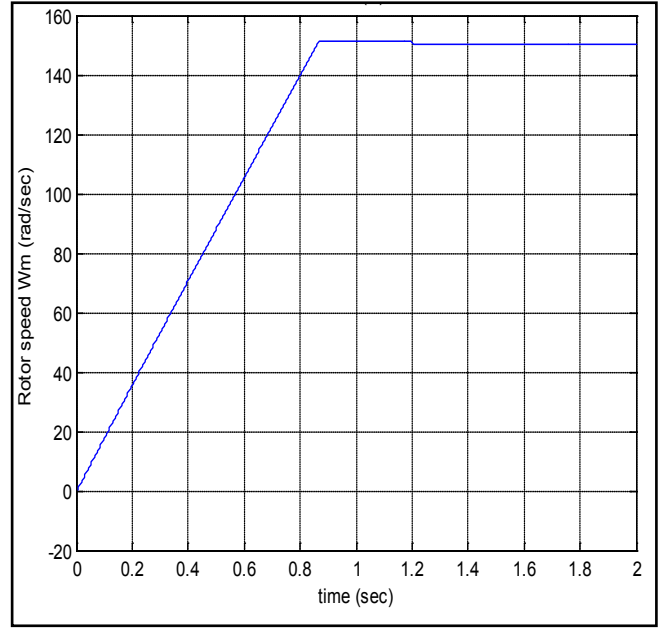


Figure 15. Speed in case of GA-PI ($T_L=200$ N.m at $t=1.2$ sec)

Another case study is taken to check the performance of GA. The test is accured at $T_L=200$, $t=1.2$ sec. The motor starts from standstill at load torque = 2 N.ms and, $t=0.0$ s, a sudden full load of 200 N.ms at $t=1.2$ sec is applied to the system controlled by GA-PI control.

Figures 12-15 flux, stator current, electromagnetic torque and speed characteristics during step change in load torque at $t = 1.2$ sec with GA-PI controller. These figures also show that the GA-PI-based drive system can handle the sudden increase in command speed quickly without overshoot, under-shoot, and steady-state error.

5. Conclusions

In this paper, a sincere attempt is made to reduce the settling time of the responses and make the speed of response very fast by designing an efficient controller using GA-PI control strategy. Here, we have control strategy for the speed control of IM, which has yielded excellent results. A comparison study between the control performance using GA with another technique used Mamdani control strategy [22], for the same model and the same parameter. The comparison shows that the motor speed reached to 0.84 sec compared with other technique used Mamdani control strategy[22] that reached to 1.4 sec. The results of our work have showed a very low transient response and a non-oscillating steady state response with excellent stabilization.

APPENDIX

A1. Squirrel Cage Induction Motor (SCIM) specs:

50 HP, 1800 rpm, 460 V, 60 Hz. 3-Phase, 2 pair of poles, Squirrel Cage type IM, $R_s=0.087 \Omega$, $L_s=0.8$ mH, $R_r=0.228$

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