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Vector Controlled Induction Motor Drive Using Genetic Algorithm Tuned PI Speed Controller

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***Summary*: In this paper, tuning and optimization of the proportional and integral (PI) gains of speed controller is achieved using Genetic Algorithm (GA) for improving the performance of the induction motor drive because higher the quality of the controller lesser is the ripples produced in the torque and speed responses. The developed GA program has multi-objective minimization functions. The optimized values of PI gains are incorporated in vector controlled induction motor model for performance analysis during sudden disturbances like speed reversal, load application and load removal. GA tuning method outstandingly surpasses the conventional and most widely used Ziegler Nichols Tuning method. GA tuned PI controller reduces the peak overshoot almost by 60% and quickly brings the system to steady state value. The simulated results obtained from GA tuned PI controller can be realized and validated through experimental results in future work.**

Keywords:
Genetic Algorithm, Vector Control, Tuning of PI, Ziegler Nichols Tuning Method

1. INTRODUCTION

Induction motor is the pillar of almost all the industrial applications. Therefore, betterment of its torque and speed characteristics in normal and disturbing conditions is the need of the hour. In this regard, design of controller forms a major part of the motor control system. Lot of design techniques are devised to obtain a perfect controller characteristic using artificial intelligent schemes, particle swarm technique [1]. 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 [2]. To eliminate the demerits of Z-N method, artificial intelligence techniques were introduced like fuzzy logic (FL), neural network (NN), genetic algorithm (GA) either offline or online. FL scheme when used for tuning showed good results under parameter variation conditions whereas GA scheme gave improved responses under normal conditions for vector controlled induction motor drive [3].

Z-N tuning technique is considered as the reference for designing PI speed controller. Thus, this paper not only compares Z-N and GA schemes for vector controlled induction motor drive but also considers its performances for different disturbances like speed reversal, sudden load application and removal. It is established, from the transient and steady state responses of the torque and speed, that GA scheme of tuning is much more efficient, gives better performance at the minimized controller cost. The GA program developed in MATLAB considers two objective functions one controller cost and other performance index for obtaining the optimum PI gain parameters. This is achieved in the same single program. This drastically reduces the memory space which otherwise is a drawback of multi-objective GA programming scheme. The modeling and simulation are done using MATLAB.

2. VECTOR CONTROLLED INDUCTION MOTOR DRIVE (VCIMD)

The recent speed control scheme of induction motor drive viz the vector control is the breakthrough invention in the area of speed control for obtaining accurate and wide range of control. The MATLAB model of vector controlled (VC) induction motor drive is shown in Figure 1.

In the figure the actual speed is compared with the reference speed to yield an error. This speed error is fed to the PI speed controller and limiter to give an equivalent reference torque (t_e^*). This t_e^* in turn provides the torque component of current (i_q^*). The flux component of current (i_d^*) is calculated from flux controller. With the help of transformation, these decoupled d-q quantities are converted into phasor values i.e. i_{abc}^*. These reference phasor currents are utilized in generating gating signals for the inverter connected to the induction motor to give it the desired value of voltage. Thus, VC IMD makes use of inherent decoupling quality of DC motor drive in order to have independent control of electromagnetic torque and flux as depicted by the equation 1:

$$T_e = 0.75 * P * L_m (i_{qs} i_{dr} - i_{ds} i_{qr})$$
$$\lambda_{dqr} = L_r i_{dqr} + L_m i_{dqs} \qquad (1)$$

Where:

L_m, L_r — are the magnetizing inductance and rotor inductance,

P — is the number of poles,

i_{qs}, i_{ds}, i_{qr}, i_{dr} — are the q and d axes stator and rotor currents respectively [4].

Thus, in a VC scheme, stator currents are the controlling quantities.

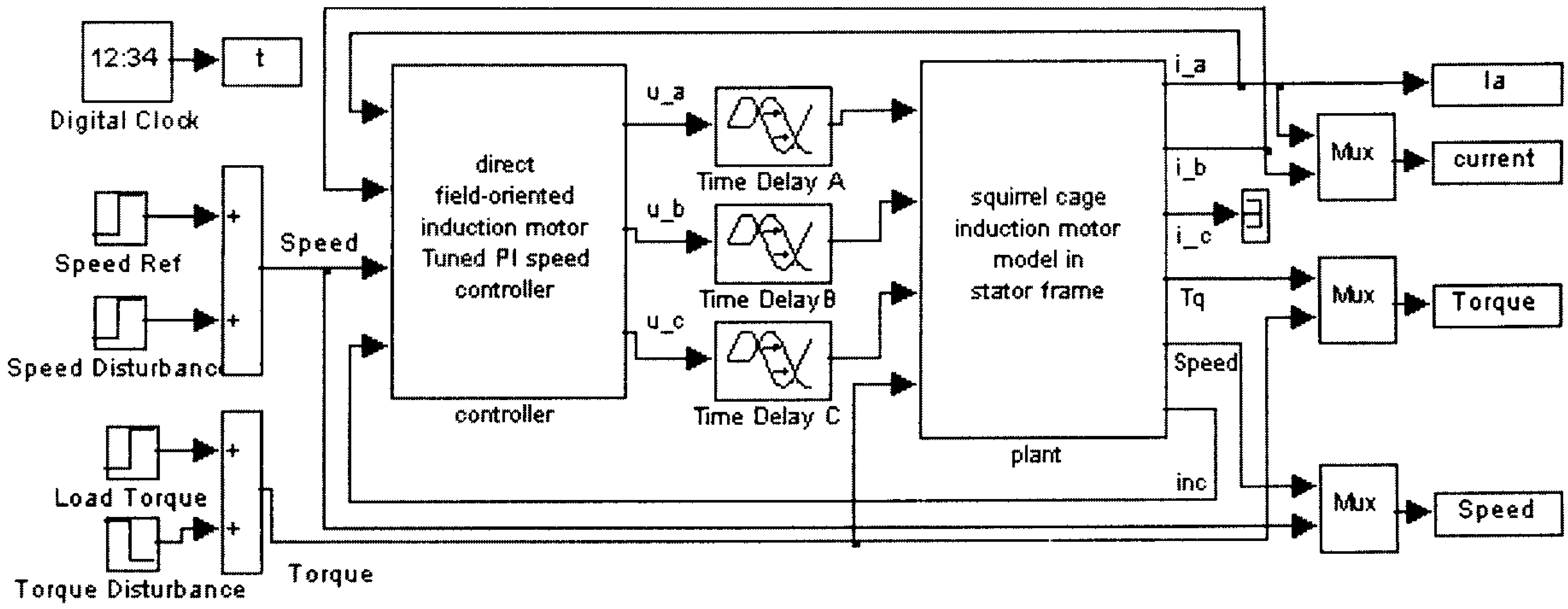

Fig. 1. Direct Vector Control of Induction Motor Block Diagram

3. TUNING OF PI SPEED CONTROLLER

The gain of PI controller plays a very important role in improving the performance of the motor. The transient response specifications viz peak overshoot, rise time, settling time are required to be improved along with the steady state error to obtain the finest performance of the system. For this the gains, both integral and proportional, are required to be optimized according to the requirement of speed. TThere are various optimization tools available of which the latest is the Artificial Intelligence tool i.e. Genetic Algorithm (GA) [5]. The process of optimization of gains is given the name Tuning of PI controller. The tuning of these controllers is governed by system nonlinearities and continuous parameter variations.

This research work has targeted the weak link of conventional tuning method and has arrived at the finest tuning using recent technique of optimization-Artificial Intelligence (AI) Technique. Of all the AI techniques, GA has emerged as one of the best optimization tools. The work has developed a simplified general GA program considering two objective functions to optimize the controller parameters at minimized cost and least performance indices (PINs). This has resulted in a design of a controller which is economical as well as efficient in terms of performance. The optimized controller gain values thus, obtained is put in the plant model for analysis and simulation of the responses.

4. GENETIC ALGORITHM: A MATLAB IMPLEMENTATION

The optimization of the parameters forms the basis in tuning PI controller. There are a number of optimization techniques and tools available [6] but genetic algorithm is found to be the most efficient and is able to solve most difficult problems that do not possess properties like continuity, differentiability etc. the algorithm searches the best solution based on "survival of the fittest" concept. This developed GA program in m file provides more flexibility and is user friendly and can easily be collaborated with the SIMULINK model. In certain applications, single objective with several constraints may not adequately represent the problem being faced, in such situations number of functions are required to be minimized with different priorities [7, 8]. None of the papers considered dealt with multi-objective optimization in the designing of PI controller for various speed control schemes of induction motor [1, 4, 6, 9, 10].

When a controller is designed for high power industrial application drives for achieving accurate responses, the operating cost, depending on controller parameters variation starts dominating. As the performance improves, it requires efficient and high quality grade controller. If controllers of high grade are used it shoots up the cost so a compromise is made between the optimized gain values and cost of the controller. This work not only uses two objective functions viz operating cost and performance index in a single GA code program but also has successfully implemented the optimized values in the model to simulate out the best performance controller. First the PI gains are calculated using the conventional tuning technique- Zeigler Nichols and then the cost function, which is a function of these gains, is minimized using GA iterative method to generate the controller transfer function for optimized values of PI gains. The flowchart of the algorithm incorporated is shown in Figure 2.

After this, the performance index to be minimized is considered as objective function to get the desired responses. The program compares the step responses for all the PINs and conventional PI tuning technique. The plot shows the transient response specifications like peak overshoot, rise time, settling time and steady state error in the same graph, suggesting the best performance index to be used for the controller design to achieve minimum cost and efficient performance simultaneously. The developed program is user friendly, depending upon the application for which the controller is being used, the open loop transfer function, the type of controller and the type of performance index to be minimized are provided at the user end as inputs.

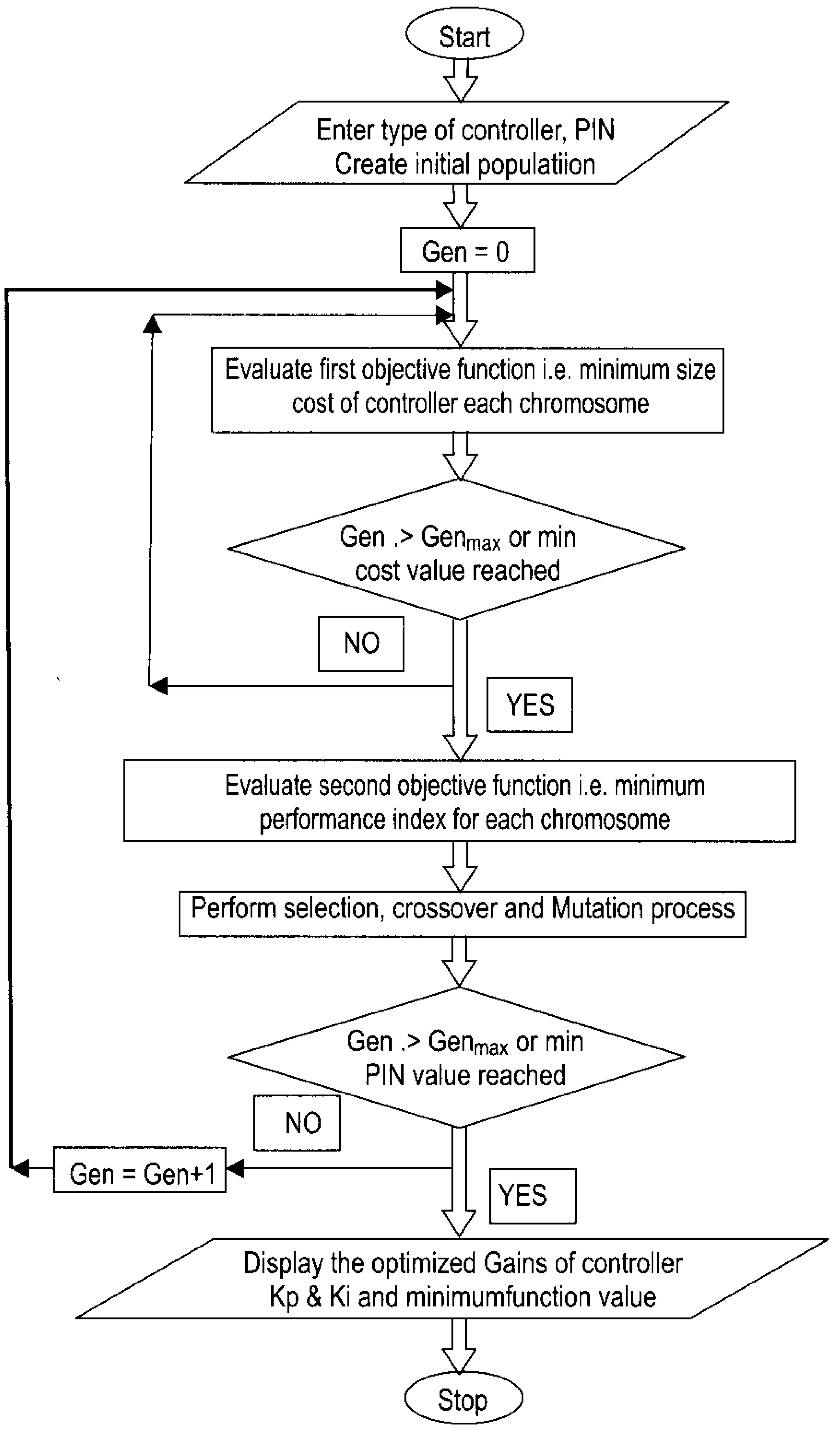

Fig. 2. Flowchart of GA used in the tuning of PI controller

5. RESULTS AND SIMULATIONS

The simulation is done on the following induction motor and inverter parameters:

a) Motor Parameters:

- Frequency $f = 50$ Hz
- No. of Poles P = 4
- Moment of Inertia Constant = 63.9 kg-m^2
- Coefficient of Viscous friction B = 0
- Rotor Resistance R_r = 0.0532, Stator Resistance R_s = 0.179
- Rotor Inductance L_r = 1.63, Stator Resistance L_s =1.63
- Mutual Inductance L_m = 1.455

b) Inverter Parameters:

- DC voltage V_{dc} = 875 V
- AC Voltage available V_{cm} = 585 V
- Switching Frequency f_s = 1000 Hz

5.1. Step Response of Closed Loop System including the Plant and Controller for Various Performance Indices:

The GA program developed for off line tuning purpose gives the output response of the closed loop system for various performance indices viz i) Integral Square Error (ISE) ii) Integral Absolute Error (IAE) iii) Integral Time Square Error (ITSE) and iv) Integral Time Absolute Error (ITAE) as shown in Figure 3.

The output is compared with the most widely used conventional tuning method- Zeigler Nichols [2]. The result obtained from the tuning of PI controller using GA technique reduces the peak overshoot and decreases the settling time and steady state error unlike obtained from the Z-N tuning

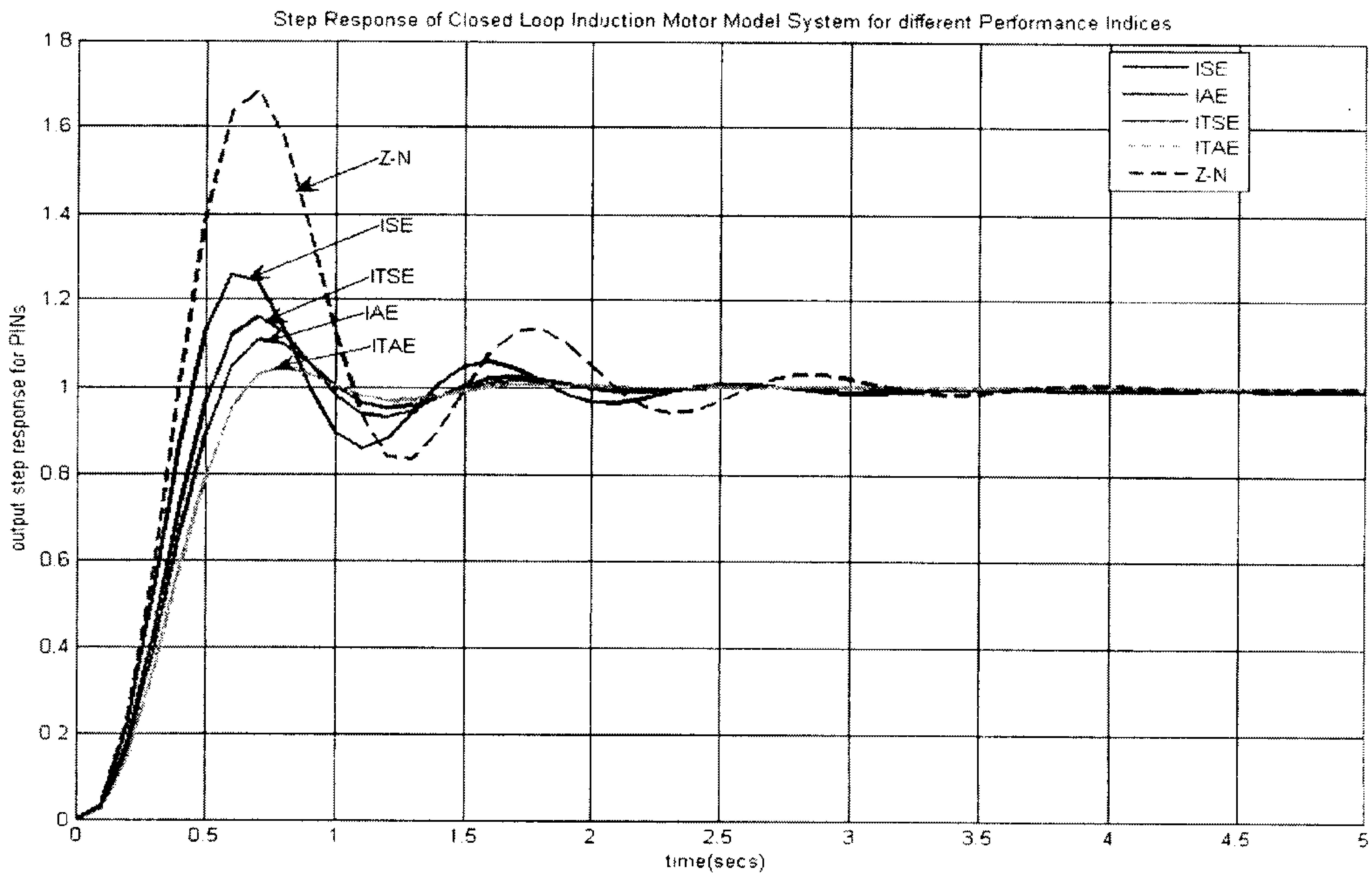

Fig. 3. Output Response of the Closed System for Various PINs for a Unit Step Input

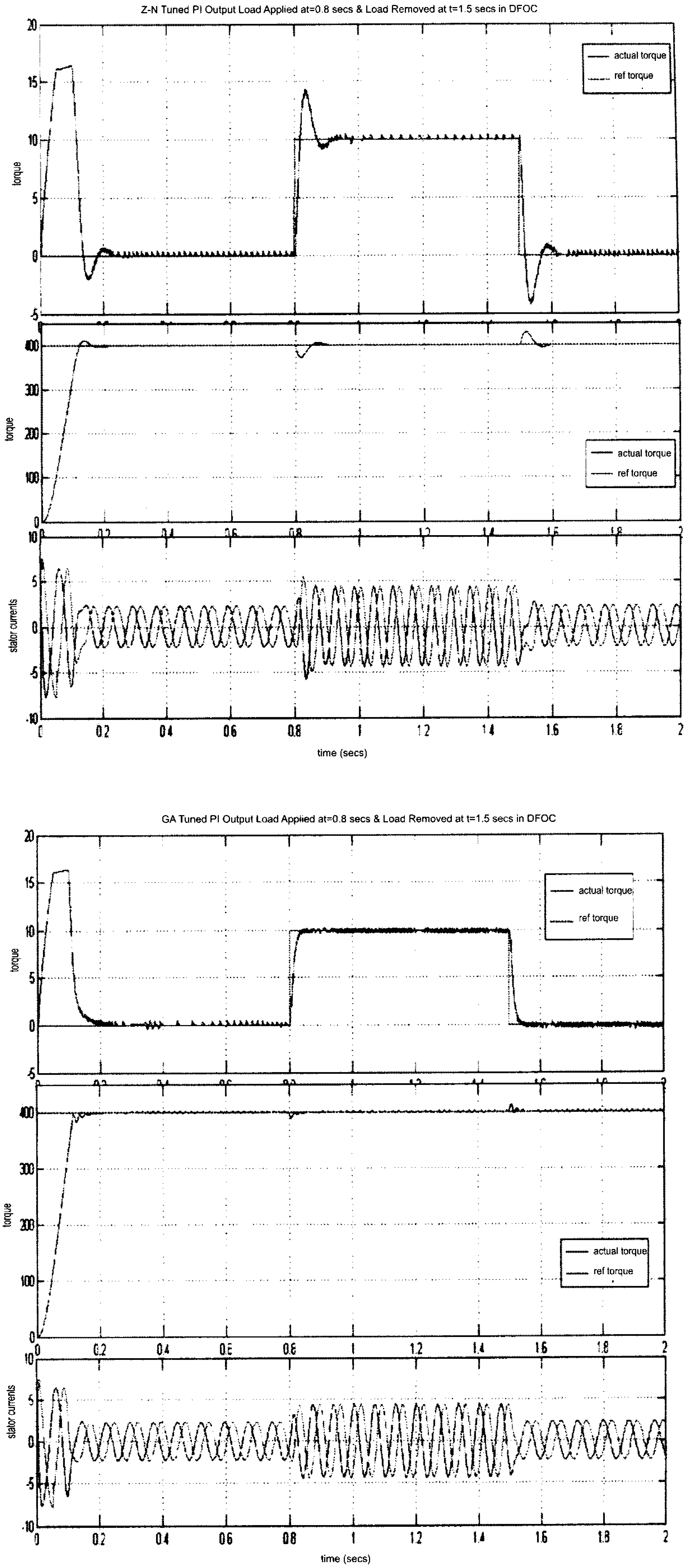

Fig. 4. Starting, Load Application and Load Removal Characteristics of Z-N & GA Tuned PI Output for DFOC IM

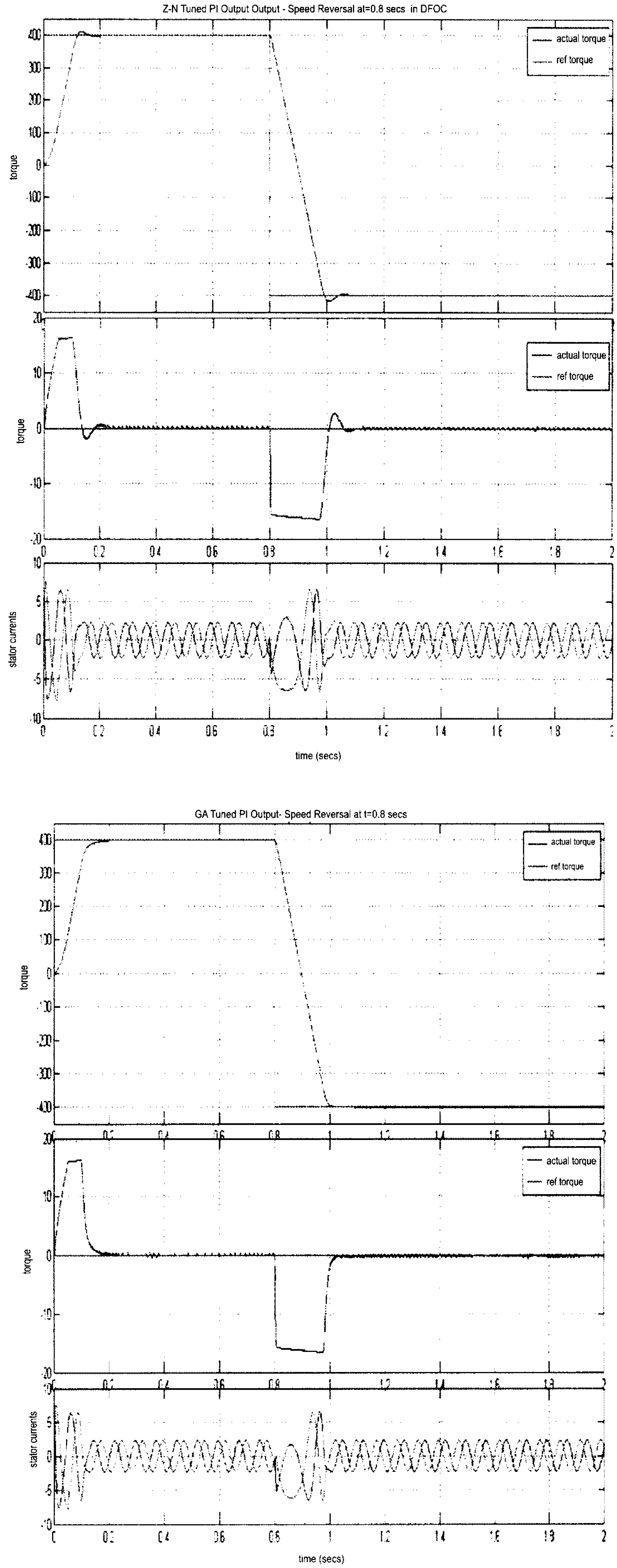

Fig. 5. Z-N & GA tuned PI Output of Speed Reversal Characteristic in DFOC IM

method. The basis of comparison is the ISE performance index. In totality, the overall time response of the closed system, comprising of transient and steady state responses, is drastically improved which in turn improves the efficiency and smoothens out the performance of the induction motor drive after the incorporation of the optimized K_p & K_i gain values obtained from the tuned controller as given in Table 1.

5.2. Performance of the Direct Vector Control Induction Motor Model (Figure 1)

a) **Starting, Load Application and Load Removal**: Figure 4 compares the incorporation of tuned PI gain values obtained from Zeigler Nichols method and GA optimization method respectively in the direct vector control or direct field oriented induction motor (DFOC IM) model. The results obtained from GA technique are satisfactory and shows drastic improvement in the performance and responses of the induction motor as compared to Z-N method. The motor is started at $t = 0.0$ secs, suddenly load is applied at $t = 0.8$ secs and removed at $t = 1.5$ secs.

b) Speed Reversal: Figure 5 shows the response of the DFOC IM model with Z-N tuned and GA Tuned PI gain values, with GA optimization technique superseding the conventional Z-N method of tuning in both steady state and transient responses. In GA tuning scheme the peak overshoot in speed is reduced by almost 60% while in the torque it is absent unlike Z-N tuning method.

6. CONCLUSION

The results obtained from the direct vector control model using GA tuned PI Controller and Z-N tuned PI Controller is compared. The application of Genetic Algorithm as an optimization tool for tuning parameters improves and smoothens out the ripples in the motor torque and stator currents and also reduces the cost of the controller which is both PI gain and performance index dependent. It also facilitates in limiting the magnitude of the torque and current values within the specified range in any kind of disturbance, either provided by the speed removal, sudden application and removal of load torque as in indirect vector control scheme. The simulated results of GA implementation in tuning of PI speed controller are very much encouraging for the researchers to experiment them in the real time frame in near future.

List of Symbols used

T_e — electromagnetic torque
P — number of poles
L_m — magnetizing inductance
i_{qs} — q axis stator current
i_{ds} — d axis stator current
i_{qr} — q axis rotor current
i_{dr} — d axis rotor current
λ_{dqr} — rotor flux linkage of d-q axes
L_r — rotor leakage inductance
i_{dqr} — d-q axes rotor currents
i_{dqs} — d-q axes stator currents

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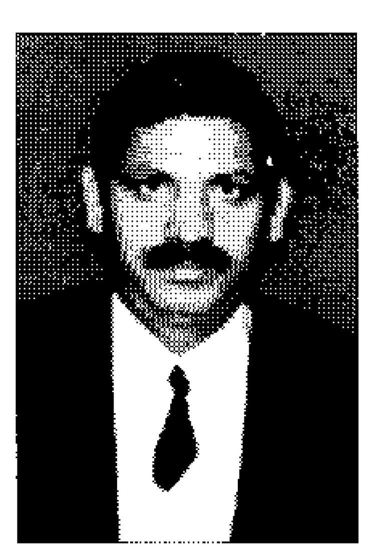

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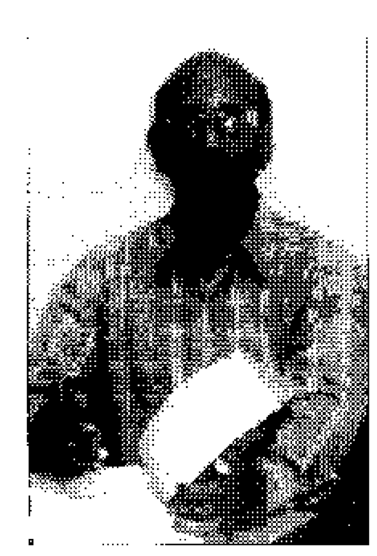

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