

Performance Indices Based Optimal Tuning Criterion for Speed Control of DC Drives Using GA

Deepti Singh*, Brijesh Singh**, Nitin Singh***

* Departement of Electrical Engineering, Ashoka Institute of Technology and Management, Varanasi-India

** Departement of Electrical Engineering, IIT (BHU) Varanasi-India

*** Departement of Electrical Engineering, MNNIT, Allahabad-India

Article Info

Article history:

Received May 27, 2014

Revised Jul 2, 2014

Accepted Jul 25, 2014

Keyword:

DC motor drives

Gains tuning

Genetic Algorithm

Optimization

Performance indices

Speed controller

ABSTRACT

This paper presents a framework to carry out a simulation to tune the speed controller gains for known input of DC drive system. The objective is to find the optimal controller gains (proportional and integral) in a closed loop system. Various performance indices have been considered as optimal criterion in this work. The optimal gain values have been obtained by conventional and Genetic Algorithm (GA) based optimization methods. The study has been conducted on a simulink model of three phase converter controlled direct current (DC) drive with current and speed control strategy. The results show that the GA based tuning provided better solutions as compared to conventional optimization methods based tuning.

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Corresponding Author:

Brijesh Singh,
Departement of Electrical Engineering,
IIT (BHU) Varanasi, India-225001.
Email: singhb1981@gmail.com

1. INTRODUCTION

The introduction of variable-speed drives increases the automation, productivity and efficiency of process and control industries. Nearly 65% of the total electric energy has been consumed by electric motors world-wide. This is a known fact that the energy consumption can be reduced by decreasing the energy input or by increasing the efficiency of the mechanical transmission during processes. The system efficiency can be increases from 15 to 27 % using variable speed drives in place of constant speed drives. At present, most of the electric drives (75-80%) still run at constant speed. Only some smaller numbers of drives (20-25%) are used in process and control industries whose rate of change of speed and torque is varied to match the mechanical load. These drives are basically DC drives which have been used in electric traction. The DC motors can be considered as single input and single output systems (SISO) systems. In these motors, the torque/speed characteristics are compatible with most of the mechanical loads. The modern electric drives are capable to control the speed and obtained variable speeds for the loads. Mainly, an electric drive has various important parts such as electric motor, power electronic converter (PEC), drive controllers and load. A number of modern industries require variable speed drives for there efficient and economical operations. The variable speed DC motors have been frequently preferred by these industries. Also, the brushless DC motors, induction motors and synchronous motors have provides a variable speeds which is widly used in electrical traction. However, the behaviour of DC motors with respect to dynamic loading conditions is good as compared to thses motors and also there speed control strategies are simpler. Consiquently, the DC motors have also been provides a good ground to apply the advanced control algorithms in its speed control

operations. Therefore, DC drives using DC motors are more preferred as compared to AC drives in process and control industries.

Normally closed loop operation with PI controllers in the inner current loop and the outer speed loop is employed for speed control. In fact, the Proportional-Integral-Derivative (PID) controllers are widely used in the process industries even though more advanced control techniques have been developed. Mostly, these advanced control strategies have been used to determine the parameters of PID controller in single input single output (SISO) systems. In this work, a comparison has been presented in between applications of conventional and modern optimization techniques based on Gradient-Decent and Genetic Algorithm (GA) on speed control strategies of DC drives. A considerable number of works on application of GA in process and control industries have been reported by various researchers in different time frames. Mostly, the GA based methodology has been applied for identification of both continuous and discrete time systems [1]-[4]. First time, Man & tang was introduced applications of GA in engineering fields [5]. A design method which determines PI/PID parameters of motion control systems based on genetic algorithms (GAs) has been presented in [7]-[12]. These papers propose an analytical procedure to obtain the optimal PI/PID parameters. The implementational issue related to premature convergence of GA in some applications have been examined and reported in [13]-[16]. Thereafter, the applicability of GAs as an optimization tool for process controllers and the solution of premature converges in GA based optimization has been explained in [6]. The GA method can easily interact with other optimization techniques. A GA and neuro-fuzzy based optimizations have been presented to solve the speed control problems of DC motors [17]-[22]. A multi-objective and performance indices based optimization for tuning of PID controllers have been simulated by different researchers [24]-[32]. The speed control of a linear brushless DC motor using soft computing based optimization for determining the optimal parameters PID controller has been reported in [33]. Recently, some of the new advancements have been carried out in the field of brushless DC drive control using adaptive and robust control theories [40]-[42]. The work presents a study of steady-state behavior of DC motors supplied from power converters and their integration to the load. The paper was reported a comparative study of conventional PI controllers such as PI speed and current controller over GA based PI controller using transfer function approach.

In fact, the speed control methods of a DC drives are simpler and less expensive in comparison to AC drives. The speed control of DC drives below and above rated speed can also be easily achieved. The two types of controls have been used for controlling the speed of DC drives, armature control and field control. Sometimes, these methods have been combined to yield a wider range of speed control. Usually, the speed control operation of DC drives have been classified into three types; single, two and four quadrant operations. In each operation a unique set voltage and current have been applied to the armature and field winding of DC motors. In this work, the main emphasis has been given on two quadrant operation of DC drive [34]-[36]. In two quadrant operation, a converter-controlled separately excited DC motor has been used for obtaining the variable speed. The current or speed signals are processed through a proportional plus integrator (PI) controller to determine the control command which provides a desired speed operation. In this operation, the control command kept within the safe limits. These control commands also required proper scaling [37] and [38]. In this, if the rotor achieves a recommended value then the control command will settle down to a value which is equal to the sum of load torque and other motor losses. This condition is required to keep the motor in steady state condition. The proper selections of gains and time constants of the speed and current controllers is also utmost important criterion for meeting the dynamic specifications of drives [39]-[45]. In this work, the design of controllers and their implementation for DC drives have been presented. The system analysis and design of the motor drive are kept in perspective with regard to current practice. The present work uses the performance indices as one of the optimization criterions for optimal tuning of PID controllers in a DC drive system. The control algorithms and analysis have been developed to facilitate dynamic simulation with personal computers. Also, the applications of motor drives have illustrated with selections from industrial environment.

2. PROPOSED METHOD

In this work, separately excited DC motor drive has been considered as a test system model. To investigate the effects of conventional and GA based tuning, the MATLAB simulink model of a separately excited DC motor with speed and current controllers have been developed on the basis of mathematical formulations. The mathematical and simulink models for separately excited dc drive system using transfer function approach have been discussed in subsequent sections.

2.1. Mathematical Concepts of Speed Control of DC Motor using Electromechanical Coverison

For simplicity, the load is modeled as a moment of inertia, J , in $\text{kg} - \text{m}^2/\text{sec}^2$, with a viscous friction coefficient B_l in $\text{N.m}/(\text{rad}/\text{sec})$ then the acceleration torque, T_a , in N.m drives the load and is given by:

$$J(d\omega/dt) + B_l \omega_m = T_e - T_l = T_a \quad (1)$$

Where T_l is the load torque. Equation (1) constitutes the dynamic model of the DC motor with load. Now, the motor equation can be represented with neglecting all the initial conditions as:

$$I_a(s) = [V(s) - K_b \omega_m(s)] / [R_a + sL_a] \quad (2)$$

$$\omega_m(s) = [K_b I_a(s) - T_l(s)] / [B_l + sJ] \quad (3)$$

These equations can be represented in block-diagram forms as shown in Figure 1 [43]. Thus, the transfer functions $\omega_m(s) / V(s)$ and $\omega_m(s) / T_l(s)$ can be derived from block diagram shown in Figure 1.

These transfer fuctions are as:

$$G_{\omega v}(s) = \omega_m(s) / V(s) = K_b / [s^2(JL_a) + s(B_l L_a + JR_a) + (B_l R_a + K_b^2)] \quad (4)$$

$$G_{\omega l}(s) = \omega_m(s) / T_l(s) = - (R_a + sL_a) / [s^2(JL_a) + s(B_l L_a + JR_a) + (B_l R_a + K_b^2)] \quad (5)$$

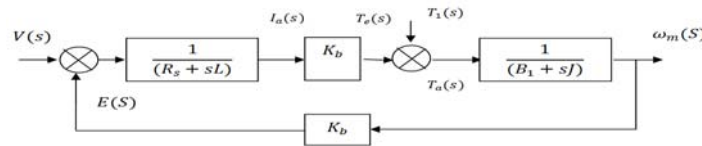


Figure 1. Block diagram of the D.C. motor

It is a known fact that the separately-excited DC motor is a linear system. Therefore, the variation in speed due to simultaneous voltage input and load torque disturbance can be written as a sum of their respective individual speeds.

$$\omega_m(s) = G_{\omega v}(s) V(s) + G_{\omega l}(s) T_l(s) \quad (6)$$

The induced voltage due to field flux and speed can be derived as:

$$e = K \Phi_f \omega_m \quad (7)$$

Where e = back e.m.f., K = motor constant, Φ_f = field flux and ω_m = motor speed.

Usually, the field flux is proportional to the field current if the iron is not saturated and is represented as.

$$\Phi_f \propto i_f \quad (8)$$

By substituting (7) in Equation (8), the speed is expressed as:

$$\omega_m \propto \frac{e}{\phi_f} \propto \frac{e}{i_f} \propto \frac{(v - i_a R_a)}{i_f} \quad (9)$$

Where v and i_a are the applied voltage and armature current, respectively. From (9), it is seen that the rotor speed is depece on the applied voltage and field current. Since, the voltage drop in resistive armature is very small as compared to the rated applied voltage and the armature current becomes a secondary effect. Mostly, in a current control operation, the armature current should create dominating effects and to make a dominating armature current, an external resistor has been connected in series with armature winding. The speed of the motor has been controlled by varying the value of external resistor in step wise. As an effect, the power dissipation in the external resistor leads to lower efficiency. Therefore, in the present work the converter control has been used to obtain the desire speed using optimal tunning of PI current and speed controllers. In the present work, two methods, armature voltage control and field current control have been

considered for speed control of a DC motor [36]. It is known that, the applied armature voltage is maintained constant during field current control method. Then the speed of motor can be represented as:

$$\omega_m \propto 1 / i_f \quad (10)$$

This equation shows that the rotor speed is inversely proportional to the field current. Since, by varying the field current, the rotor speed is changed and if the field current is reversed then the rotational direction has also been changed. Therefore, the speed can be increased or decreased by weakening or strengthening the field flux. Similarly, the field current is maintained constant in the armature control method and the speed is derived from (9) as:

$$\omega_m \propto (v - i_a R_a) \quad (11)$$

The speed of drive can be varying by changing the applied voltage across the armature windings. Equation (11) shows that the reversal of applied voltage changes the direction of rotation of the motor. The armature current control method has an advantage to control the armature current rapidly by adjusting the applied voltage. As a result, a wide range of speed control is possible by combining the armature and field control for speeds below and above the rated speed respectively. To obtain the speed lower than its rated speed, the applied armature voltage is varied while the field current is kept at its rated value in this combination. On the other hand, to obtain speeds above the rated speed, field current is decreased while keeping the applied armature voltage constant. Now, the torque of the motor can be derived as:

$$T_e = K \Phi_f i_a \quad (12)$$

Equation (12) can be normalized if it is divided by rated torque, which is expressed as:

$$T_{er} = K \Phi_{fr} i_{ar} \quad (13)$$

Where the additional subscript *r* denotes the rated or nominal values of the corresponding variables. Hence the normalized version of (12) is:

$$T_{en} = \frac{T_e}{T_{er}} = k \left(\frac{\Phi_f}{\Phi_{fr}} \right) \left(\frac{i_a}{i_{ar}} \right) = \phi_{fn} i_{an}, pu \quad (14)$$

Where the additional subscript *n* express the variables in normalized terms, commonly known as per unit (p.u.) variables.

2.2. Transfer Function Modeling of DC Drive System

In the present case study, a constant field flux has been considered for the DC motor operation. The DC motor parameters, rating and the mathematical models of different subsystems of the test model are as follows

DC motor specifications:

DC motor input voltage = 220V; Armature current rating = 8.3A; Rated speed = 1470 rpm; Armature resistance $R_a = 4\Omega$; Moment of inertia $J = 0.0607 \text{ kg} - \text{m}^2$; Armature Inductance $L_a = 0.072 \text{ h}$; Viscous friction coefficient $B_t = 0.0869 \text{ N} - \text{m/rad/ sec}$ and Torque constant $K_b = 1.26 \text{ V/rad/sec}$.

Converter specifications:

Supplied voltage = 230 V, 3 – phase A.C.; Frequency = 60 Hz; Maximum control input voltage is $\pm 10 \text{ V}$. The speed reference voltage has a maximum of 18 V. the maximum current permitted in the motor is 20 A. For the simulation, the transfer function of all subsystems of given plant model as follows:

Motor-Load connected system transfer function

$$K_1 = \frac{B_t}{k_b^2 + R_a B_t} = \frac{0.0869}{1.26^2 + 4 \times 0.0869} = 0.0449 \quad (15)$$

$$-\frac{1}{T_1}, -\frac{1}{T_2} = -\frac{1}{2} \left[\frac{B_t}{J} + \frac{R_a}{L_a} \right] \pm \sqrt{\frac{1}{4} \left(\frac{B_t}{J} + \frac{R_a}{L_a} \right)^2 - \left(\frac{K_b^2 + R_a B_t}{J L_a} \right)} \quad (16)$$

$$\begin{aligned}
 T_1 &= 0.1077 \text{ sec.} \\
 T_2 &= 0.0208 \text{ sec.} \\
 T_m &= \frac{J}{B_t} = 0.7 \text{ sec.}
 \end{aligned} \tag{17}$$

So the motor and load subsystem transfer functions are:

$$\begin{aligned}
 \text{Motor transfer function } \frac{I_a(s)}{V_a(s)} &= K_1 \frac{(1 + sT_m)}{(1 + sT_1)(1 + sT_2)} \\
 &= \frac{0.0449(1 + 0.7s)}{(1 + 0.0208s)(1 + 0.1077s)}
 \end{aligned} \tag{18}$$

$$\text{Load transfer function } \frac{\omega_m(s)}{I_a(s)} = \frac{K_b / B_t}{(1 + sT_m)} = \frac{14.5}{(1 + 0.7s)} \tag{19}$$

Converter transfer function:

The rated DC motor voltage required is 220 V, which corresponds to a control voltage of 7.09 V.

$$K_r = \frac{1.35V}{V_{cm}} = \frac{1.35 \times 230}{10} = 31.05 V / V \tag{20}$$

$$V_{dc}(\max) = 310.05V \tag{21}$$

The transfer function of the converter is:

$$G_r(s) = \frac{V_a(s)}{V_c(s)} = \frac{K_r}{1 + sT_r} \tag{22}$$

$$\begin{aligned}
 T_r &= \frac{60/2}{360} \times (\text{time period of one cycle}) \\
 &= \frac{1}{12} \times \frac{1}{f_s}, \text{sec.} = 1.388 \text{ms.} = 0.00138 \text{sec.}
 \end{aligned} \tag{23}$$

$$G_r(s) = \frac{31.05}{1 + 0.00138s} \tag{24}$$

Current controller transfer function:

$$G_c(s) = \frac{K_c(1 + sT_c)}{sT_c} \tag{25}$$

$$T_c = T_2 = 0.1077 \text{ sec.} \tag{26}$$

$$K = \frac{T_2}{2T_r} \tag{27}$$

So,

$$T_r = 0.00138 \tag{28}$$

$$K = \frac{0.1077}{2 \times 0.00138} = 38.8 \tag{29}$$

$$K_c = \frac{K T_c}{K_1 H_c K_r T_m} = 2.33 \quad (30)$$

So,

$$K = 38.8; T_c = 0.208 \text{ sec}; K_1 = 0.0449; H_c = 0.355 V / A \quad (31)$$

$$K_r = 31.05 V / V; T_m = 0.7 \text{ sec}. \quad (32)$$

$$\text{Therefore } G_c(s) = \frac{21.63(1 + 0.107s)}{s} \quad (33)$$

Current control loop approximation:

$$\frac{I_a(s)}{I_a^*(s)} = \frac{K_i}{1 + sT_i} \quad (34)$$

$$K_i = \frac{K_{fi}}{H_c} \cdot \frac{1}{(1 + K_{fi})} \quad (35)$$

$$K_{fi} = \frac{K_c K_r K_1 T_m H_c}{T_c} = 38.8 \quad (36)$$

$$K_i = 2.75 \quad (37)$$

$$T_i = \frac{T_3}{1 + K_{fi}} \quad (38)$$

where

$$T_3 = T_1 + T_r = 0.109 \quad (39)$$

$$T_i = 0.0027 \text{ sec}. \quad (40)$$

So,

$$G_c(s) = \frac{K_i}{1 + sT_i} \quad (41)$$

$$\text{Therefore with current loop approximation } G_c(s) = \frac{2.75}{1 + 0.0027s} \quad (42)$$

Speed controller transfer function:

$$G_s(s) = \frac{K_s(1 + sT_s)}{sT_s} \quad (43)$$

$$K_s = \frac{1}{2K_2 T_4}; K_2 = \frac{K_i K_b H_\omega}{B_i T_m} \quad (44)$$

$$T_4 = T_i + T_w; T_s = 4T_4 \quad (45)$$

$$T_4 = T_i + T_w = 0.0027 + 0.002 = 0.0047 \quad (46)$$

$$K_2 = \frac{K_i K_b H_\omega}{B_t T_m} = 3.70 \quad (47)$$

$$K_s = \frac{1}{2K_2 T_4} = 28.73 \quad (48)$$

$$T_s = 4T_4 = 0.0188 \text{ sec.} \quad (49)$$

$$G_s(s) = \frac{28.73(1 + 0.0188s)}{0.0188s} \quad (50)$$

Current transducer gain:

The maximum safe control voltage is 18V, and this has to correspond to the maximum current error. Here in present case study, it has been accepted as unity value. Therefore,

$$H_c = 1.0 \text{ V / A} \quad (51)$$

The Tacho-generator transfer function is given in problem''

$$G_\omega(s) = 1 \quad (52)$$

Now, develop a Simulink plant model in MATLAB/SIMULINK with these subsystem transfer functions, which is shown in Figure 2 and find the different simulation results for various cases on this plant model for a variable speed operation. Also, analyze the effect of different controller on dynamics of DC motor control operation.

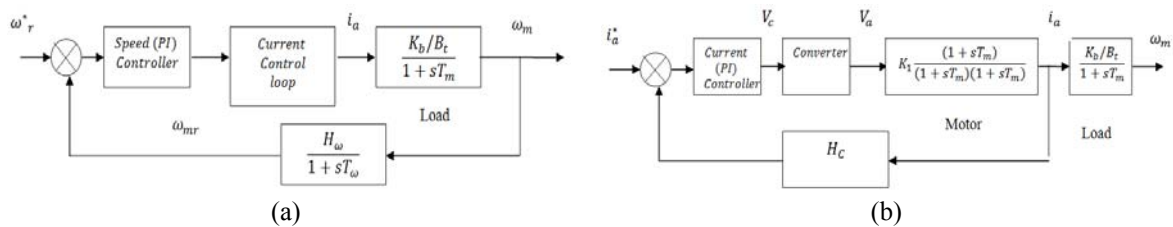


Figure 2. Typical Plant model with (a) speed and (b) current control based methodologies

2.3. Problem Objective and Optimal Criterion

The main objective function in this work is to minimize the steady state error, rise time, overshoot and settling time during speed control of DC drive. The objective function can be represented as:

$$\text{Minimize } J = \alpha_1(\text{Steady state error}) + \alpha_2(\text{Rise time}) + \alpha_3(\text{Maximum over shoot}) + \alpha_4(\text{Settling time}) \quad (53)$$

Where,

$$\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 = 1$$

In this, the objective function J provides an operating point which is generally a relation of four weighted terms of PID controller and depending on the values of weights α_1 , α_2 , α_3 and α_4 . The weights, α_1 , α_2 , α_3 and α_4 are the weighting factors of the steady state error, rise time, overshoot and settling time. In the present work, the performance indices of ITAE, ISE, IAE, ITSE, and IT²SE have been considered as optimization criteria. These performance indices are as follows:

- a) Integral of square of the error $ISE = \int_0^{\infty} e^2(t)dt$
- b) Integral of the absolute magnitude of the error $IAE = \int_0^{\infty} |e(t)|dt$
- c) Integral of time multiplied by absolute error $ITAE = \int_0^{\infty} t|e(t)|dt$
- d) Integral of time multiplied by squared error $ITSE = \int_0^{\infty} t|e^2(t)|dt$
- e) Integral of time squared multiplied by squared error $IT^2SE = \int_0^{\infty} t^2 e^2(t)dt$

The optimized controller parameters have been obtained by minimizing these performance indices. The main objective of this work is to improve the performance of the test system model.

3. RESEARCH METHOD

In this work, Ziegler-Nichols, Gradient-descent and Genetic Algorithm based optimization techniques have been used to tune the PI controller parameters for the test model of DC motor drive with various performance indices based optimization criterions. The results obtained through simulation using proposed techniques have been compared with each other. The MATLAB PID optimizer tool has been used to apply these optimization techniques for tuning the PI controllers. The proposed solution methodology based plant model has been shown in Figure 3.

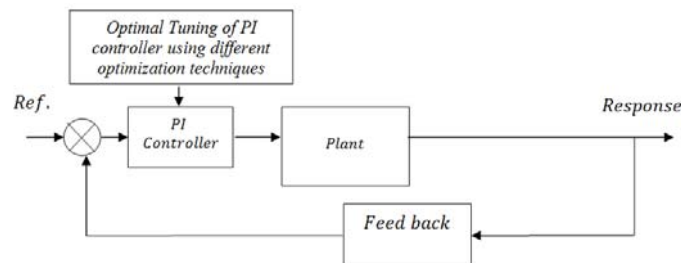


Figure 3. Proposed solution methodology based plant model

3.1. Ziegler-Nichols (Z-N) PID Tuning Using Trial and Error Based Optimization

In the present work, the Ziegler-Nichols (Z-N) tuning has been used to obtain the initial tuning values for PID controllers and then design the controllers for the study of system. Once, the initial tuned values of PID parameters have been obtained, and then it has been optimized by the trial and error method. This method is based on calculation of critical gain K_{cr} and critical period P_{cr} . Initially, the integral time T_i has been set to infinity and the derivative time T_d is to zero. This has been used to get initial PID setting for the test system. In Z-N method, only the proportional control action would be used and the K_p has been increased to a critical value K_{cr} which has been exhibited the case of sustained oscillations of system output. In this method, if the system output does not exhibiting the sustained oscillations then it is not useful for the application. These are the following steps to obtain the tuned value of PID parameter for a given plant.

- Step 1:* Substitute $T_i = \infty$ and $T_d = 0$ for reducing the complete transfer function of a close loop transfer system.
- Step 2:* Check that the system is marginally stable by Routh's Criterion:
If sytem output offeres sustained oscillation, *then* system is marginally stable,
Else not marginally stable.
- Step 3:* Determined the value of K_p by Routh's Stability criterion and set $K_p = \text{Critical gain } K_{cr}$.
- Step 4:* Calculate the frequency (ω) of sustained oscillation by substituting $j\omega$ in place of s in characteristic equation.
- Step 5:* Calculate the period of sustained oscillation as $P_{cr} = 2\pi / \omega$.
- Step 6:* Estimate the parameters of K_p , T_i and T_d by the second Z-N frequency method.
- Step 7:* Obtain the complete transfer function of PID controller.

3.2. A Classical Optimization Technique – Gradient-Descent Optimization Algorithm Based Approach

In fact, this is a first-order optimization method. The main idea of this optimization method is to reach the minima by the shortest path. In order to achieve the shortest path, the steepest gradient have moving down and then this will lead to reach the minima. Fundamentally, when the gradient changes from point to point then significantly choose a new direction and make changes accordingly to ensure the steepest path. In

this method, the minimization of the error function has been achieved by analyzing the function of error function. To find a local minimum of a function, select the steps at the current point in proportional to the negative of the gradient (or of the approximate gradient) function. This method is also known as steepest descent, or the method of steepest descent. Fundamentally, the gradient descent is based on the observation that if the multivariable function $F(x)$ is defined and differentiable in a neighborhood of a point a , then $F(x)$ decreases fastest if one goes from a in the direction of the negative gradient of F at a , $-\nabla F(a)$. It follows that, if $b = a - \gamma \nabla F(a)$ for $\gamma \rightarrow 0$ a small enough number, then $F(a) \geq F(b)$. Using this observation, the solution starts with a guess X_0 for a local minimum of F , and considered that the sequence X_0 and X_1 , such that $X_{n+1} = X_n - \gamma_n \nabla F(X_n), n \geq 0$. Here $F(X_0) \geq F(X_1) \geq F(X_2) \geq \dots$ and due to this the sequence (X_n) converges to the desired local minimum. It is also noted that the value of the step size γ is changes in every iteration with certain assumptions on the function F (for example, F convex and ∇F Lipschitz) and particular choice of γ (e.g., chosen via a line search that satisfies the Wolfe conditions). In this way the convergence to a local minimum can be guaranteed. Now, if the function F is convex then all the local minima have also been global minima then in this case the gradient descent has been converged to the global solution. This process has been illustrated by Figure 4. Here it is assumed that the function F has been defined on a plane and its graph has a bowl shape. In the Figure 4, the curves show the contour lines and these are lies on that region in which the value of F is constant. The arrow originating at a point shows the direction of the negative gradient at that point. It is noted that the (negative) gradient at a point is orthogonal to the contour line going through that point. It has been seen that gradient descent leads to the bottom of the bowl which is the point where the value of the function F is minimal.

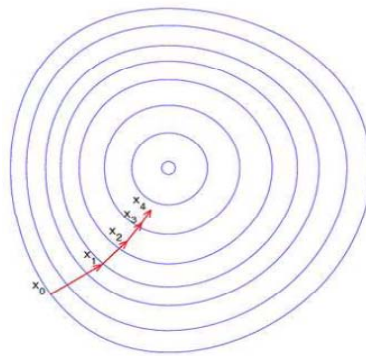


Figure 4. Illustration of gradient descent optimization technique

3.3. Genetic Algorithm Optimization Based Approach

Genetic algorithms (GAs) have been based on search mechanism based on biological organisms which have been adapted and flourished changing and highly competitive environment. This can also be applied to optimize the parameters of complex non-linear process controllers. The adaptability of non-linearity in the computational process makes it one of the more efficient techniques compared to other traditional optimization techniques. GAs plays an important role in process control applications for the optimization of parameters. This method can quickly solve the various complex optimization problems such as problems of reliability and accuracy. These are some of the major qualities of GAs are

- Genetic algorithms search a population of points in parallel, not from a single point.
- Genetic algorithms do not require derivative information or other auxiliary knowledge; only the objective function and corresponding fitness levels influence the direction of the search.
- Genetic algorithms use probabilistic transition rules, not deterministic rules.
- Genetic algorithms work on an encoding of a parameter set not the parameter set itself (except where real-valued individuals are used).
- Genetic algorithms may provide a number of potential solutions to a given problem and the choice of the final is left up to the user.

In the present work, some of the important issues have been considered for optimizing the plant behaviour with proper implementation of GA such as decision of population size. Mostly, the population size has been considered in between 20 to 30 chromosomes. It is a well known fact that the big population size consumes more computational time for finding the optimum solution and this may cause of deterioration in performance of GA. Sometimes, the problem of premature convergence has been arisen due to improper selection of crossover rates. The premature convergence problems have been minimized by considering the

recommended higher rate of crossover of about 85 percent to 95 percent. The low mutation rate of about 0.5 percent to 1 percent is generally recommended to obtain optimized results from GA. In fact, the mutation is an artificial and forced method of changing the numerical value of the chromosome. Mutation should be avoided as far as possible because it is totally random in nature. Small mutation rates prevent genetic algorithms from falling into local maxima or minima. Deciding of selection method for selecting good chromosomes is another important issue while applying genetic algorithms for process control applications. Rank selection method and roulette wheel selection methods have shown good results over other methods of selection.

4. RESULTS AND DISCUSSION

In the present work, conventional and optimal tuning methods of PI controller with both control strategies (speed control and current control) for DC motor drive system have been considered as test cases. In the conventional tuning method the trial and error based Z-N methodology has been used to tune the PI controllers. On the other hand, the Gradient-Descent (GD) and GA based optimization methods have been considered for PI tuning. The performance of suggested techniques has been tested on a DC motor drive system. The overall transfer function of system model has been reduced into second order transfer function system model using truncation based methodology. In this method, the higher orders have been neglected from the overall transfer function. As a result, the overall transfer function of converter and motor-load connected system or in other word the plant model for current control and speed control strategy has been given as:

$$\text{TF}(\text{Current control}) = \frac{0.9750s+1.3941}{0.0023 s^2+0.1299 s+1}$$

$$\text{TF}(\text{Speed control}) = \frac{14.1375s+20.2145}{0.09323 s^2+0.8299 s+1}$$

Case: 1 The PI Tuning by using conventional trial and error based Z-N methodology

The performance of the system with Z-N based tuning in the control loop has been tabulated in Table 1.

Table 1. Performance of system with trial and error method based on Z-N method

Performance parameters	Current control	Speed control
Set value (p.u.)	1	1 p.u.
Settling time (sec)	12.228	12.10
Overshoot	--	--
K _p	0.04463	0.00125
K _i	0.51939	0.0251

Case: 2 Optimal tuning of PI controller parameter using Evolutionary optimization based method (GD and GA based)

In this section, the results obtained using GD and GA based optimization algorithm has been discussed. These results have been analyzed for the smallest overshoot, fastest rise time and the fastest settling time response of the designed PI controller for test system. The best tuned values have been selected for the system operations. The responses obtained by GD designed PI and GA designed PI have been compared. The Table 2 and 3 shows the performance of system with GD based optimization method for current and speed loop respectively. Similarly, Table 4 and 5 shows the performance of GA based optimization for current control and speed control. The results shown in Table 1 to 5 are reveals that the GA based optimization provides better solutions using ITAE performance index as an optimal criterion as compared to GD based optimization method.

Table 2. Performance of system using GD based optimization in current control

Optimization criterion	K _p	K _i	M _p (p.u.)	T _s (Sec.)	e ² (t)	e ² (t)
ITAE	0.0390	0.4962	1.14	7.286	0.72	1.68
ISE	0.0781	0.5227	1.25	9.36	0.74	1.10
IAE	0.0504	0.5088	1.18	7.33	0.72	1.50
ITSE	0.0612	0.5103	1.2	7.88	0.72	0.70
IT ² SE	0.0448	0.4983	1.15	7.07	0.71	0.70

Table 3. Performance of system using GD based optimization in speed control

Optimization Criterion	Kp	Ki	Mp (p.u.)	Ts (Sec.)	$e^2(t)$	$ e^2(t) $
ITAE	0.0157	0.0330	1.03	6.35	0.048	1.4
ISE	0.0259	0.0354	1.17	10.85	0.048	1.2
IAE	0.0185	0.0336	1.03	6.11	0.049	1.5
ITSE	0.0222	0.0357	1.11	8.6	0.05	0.69
IT ² SE	0.0195	0.0350	1.06	6.13	0.049	0.73

Table 4. Performance of system using GA based optimization in current control

Optimization Criterion	Kp	Ki	Mp (p.u.)	Ts (Sec.)	$e^2(t)$	$ e^2(t) $
ITAE	0.0167	0.4793	1.08	6.775	0.72	1.55
ISE	0.0863	0.4996	1.21	9.29	0.73	1.13
IAE	0.0489	0.5118	1.19	8.72	0.71	1.5
ITSE	0.0710	0.5163	1.22	9.35	0.73	0.71
IT ² SE	0.0396	0.5120	1.17	7.6	0.72	0.79

Table 5. Performance of system using GA based optimization in speed control

Optimization Criterion	Kp	Ki	Mp (p.u.)	Ts (Sec.)	$e^2(t)$	$ e^2(t) $
ITAE	1.0133	0.0302	--	5.4	0.05	1.51
ISE	0.0203	0.0514	1.428	11.9	0.049	1.40
IAE	0.0311	0.0326	1.21	13.05	0.05	1.7
ITSE	0.0155	0.0429	1.25	10.93	0.05	1.0
IT ² SE	0.006	0.0212	--	7.3	0.06	2.5

5. CONCLUSION

In the present work, optimal PI tuning based controller using current control and speed control strategies have been modeled and simulated on MATLAB/SIMULINK package for complete DC drive system. These controllers have been tuned for motor load connected system by using current control and speed control loop of the transfer function models. The tuning of PI controllers has been tuned using Z-N, GD and GA based optimization techniques. The current control and speed control loop of the drive was simulated with a conventional PI controller in order to compare the performances to those obtained from the respective GD and GA based drive system. The steady state performance of the GA based controlled drive is much better than the conventional and GD based optimal PI controlled drives.

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BIOGRAPHIES OF AUTHORS



Deepti Singh belong to Allahabad, DOB is 04.10.1985, Recived her B.Tech in Electrical and Electronics Engineering in 2008 from UP Technical University, Lucknow. Presently she is working as faculty member in department of Electrical Engineering, AITM, Varanasi. Her field of interest includes optimization in control systems and AI applications.
(deeptisingh1434@gmail.com)



Brijesh Singh belong to Jaunpur, DOB is 05.12.1981, Received his B.Tech in Electrical Engineering in 2003 from IET, Purvanchal University Jaunpur, M.Tech (Power system) in 2009 from KNIT Sultanpur (UP). Presently he is Ph.D. (power system) research scholar in department of Electrical Engineering, IIT (BHU), Varanasi. His field of interest includes Power system operation & control, optimization and Artificial Intelligence.
(singhb1981@gmail.com)



Nitin Singh born in 20.08.1981, Recived his M.Tech. from D.I.E. Agra (UP). Presently he is working as faculty member in department of Electrical Engineering, MNIT, Allahabad. His field of interest includes Power systems, Artificial Intelligence and Electrical Machines.
(nitins@mnnit.ac.in)