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Conference Paper · October 2018

DOI: 10.23919/ICUE-GESD.2018.8635662

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Control of DC Motor Using Genetic Algorithm Based PID Controller

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***Abstract*—The paper deals with the optimized tuning of P.I.D controller which is used to control the D C Motor. In this research work different PID tunings techniques are discussed. D.C Motor due to its very simple regulated characteristics is used in this paper. Due to this fact D.C. Motors are widely used in many industrial applications like steel mills, electric trains and many more. Here G.A-P.I.D (Genetic Algorithm – P.I.D) with different performance indices namely Mean Square Error (M.S.E) and Integral of Time multiplied by Absolute Error (I.TA.E) optimization technique is compared with standard P.I.D parameter adjustment technique i.e. Ziegler & Nichols method. Comparison of results are based on standard step responses parameters i.e. maximum overshoot, steady state and rise time.**

Index Terms*— DC Motor position control, PID parameters tuning by G.A, Ziegler Nichols Method.

I. Introduction

PID control strategy is a regular feedback controlling technology and it covers 90% of regular controllers in engineering sector. The function of the controller is to implement an algorithm based on the control input and therefore output is maintained at certain point to make negligible discrepancy between the system method variable and the setpoint[1]. Due to their functional simplicity and reliability PID controllers delivers consistent and robust performance for almost every system dynamics and thus it can be tuned to guarantee an acceptable closed loop performance [2]. By using a PID controller transient response of a system improves by decreasing the rise time, eliminating the peak overshoot and shortening the settling time of a system [3]. Proper functioning of a system highly depends on PID parameters, so they should be optimized and tuned wisely. Many standard methods are introduced for parameter tuning includes Ziegler-Nichols Ultimate-cycle tuning [4], Cohen-Coon's [6], Astrom and Hagglund [5] and others.

The fact that D.C Motors have outstanding speed regulation and simple characteristics, these motors are broadly used in many industrial applications such as tractions, rolling mills etc. This encourage many researchers to develop several algorithms and techniques associated to speed and position control of D.C Motor. usually, a prohibitive performing motor drives system should have excellent dynamic response to enact angle and speed tracking. In addition to this motor drive should also follow real time load change[7, 8]. Proportional-Integral Derivative (PID) controllers because of their easy and good controlling performance are used for this purpose.

Conventional methods like Ziegler-Nichols, frequency domain and Time domain approaches of tuning PID for a given control system have their certain limitations. Therefore, this paper develops a design using Genetic Algorithm (G.A) in MATLAB tool box. A genetic algorithm (G.A) is an experimental quest or search model that is motivated by Charles Darwin's theory of natural evolution. This algorithm has a set of rules that gives the information of natural process of selection in which the best or fittest entities are designated work of reproduction to produce new offspring for the next generation.

By using genetic algorithms for tuning the controller will provide the best and most optimized result for the given control system when being evaluated every time. The main objective of this research is to reveal that when GA is employed for tuning purpose to any system , an optimized tuning parameter values can be realized. To show this, results obtained from GA optimized system and the classically tuned system (Ziegler Nichols Method) are compared and discussed. Subsequent section II gives the information of D.C Motor modelling and its parameters. The section III highlights on orthodox PID Controller tuning technique by Ziegler Nichols Method and Genetic Algorithm optimization technique is briefed in this same section. Section IV enlightens the results by comparing different simulations of each technique which are discussed in section III . Finally, section V contains conclusion and discussion part.

II. Modelling of Seperately Excited D.C Motor

To realize the D.C Motor drive as a control system transfer function, following steps to be done in MATLAB: First step is to characterize the equivalent DC motor circuit diagram. Then step 2 is to characterize system equations from the circuit diagram. Subsequently, step 3 is to derive transfer function from derived system equations. After that Step 4 is the Realization of the equivalent block diagram of system drive. Finally, in step 5 .m file is created for model simulation and to analyze the results.

A. DC Motor Equivalent Circuit

To execute the simulation of separately excited DC motor drive [9], the equivalent circuit diagram of motor's mechanical part and electrical portion must be obtained first as shown in Fig.1. Here left model represents the armature circuit of D.C motor and right model represents the field circuit which is separately excited.

Field excitation parameters are assumed to be fixed as it is separately excited. Therefore, to make this model simple to study and execute, here field excitation parameters of motor are not taken into account while analyzing the simulation model of motor.

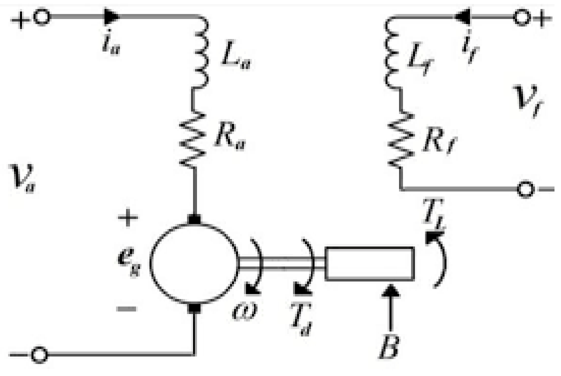


Figure 1. Equivalent DC Motor circuit.

B. DC Motor Equivalent Circuit

In the current research methodology, D.C motor model is modeled in which the rotor is assumed to be a single coil having equivalent inductance expressed as La and equivalent resistance as Ra, therefore representing generated back E.M.F represented as eb. In separately excited dc motor, flux remains constant. The electrical model of separately excited D.C Motor are described by following dynamic equations:

$$e_a = e_b + i_a . R_a L_a . \frac{di_a}{dt} \tag{1}$$

The analogy between generated torque T_m and armature current i_a is given by following equation:

$$T_m = K_m . i_a \tag{2}$$

The relation between generated back E.M.F eb and the angular speed is given by the following equation:

$$e_b = K_b . \omega \tag{3}$$

from equation (1) and (3), we get

$$e_a = K_b . \omega + i_a R_a L_a \frac{di_a}{dt} \tag{4}$$

The equivalent dynamic equation for mechanical system of motor is as follows:

$$T_m = K_m i_a = J \frac{d\omega}{dt} + K_f \omega + T_d \tag{5}$$

C. Model Block Diagram

Using Laplace transformation technique for equation (4) and (5), following equations are derived:

$$e_a(s) = K_b . \omega(s) + i_a(s) . R_a + L_a(s) . i_a \tag{6}$$

and subsequently

$$T_m(s) = K_m . i_a(s) = J . \omega(s) + K_f . \omega(s) + T_d(s) \tag{7}$$

Therefore, from equation (6), armature current is expressed as

$$i_a(s) = [e_a(s) - K_b . \omega(s)] / [R_a + L_a(s)] \tag{8}$$

and from equation (7), output speed is represented as:

$$\omega(s) = [T_m - T_d(s)] / [J + K_f] \tag{9}$$

Where,

e_a = Armature Voltage (V)
L_a = Armature Inductance (H)
I_a = Armature Current (A)
R_a = Armature Resistance (ohm)
J = Mechanical Inertia (kg-m^2)
e_b = Back EMF (V)
K_f = Friction Coefficient (N-m/ rad/ sec)
T_d = Torque Disturbance (N-m)
K_m = Motor Torque Constant (N-m/ rad)
ω = Angular Speed (rad/sec)
K_b = Back EMF Constant (V/rad/sec)
T_m = Mechanical Torque Developed (N-m)

The block diagram developed from previously stated equivalent circuit equations is as shown in Fig. 2.

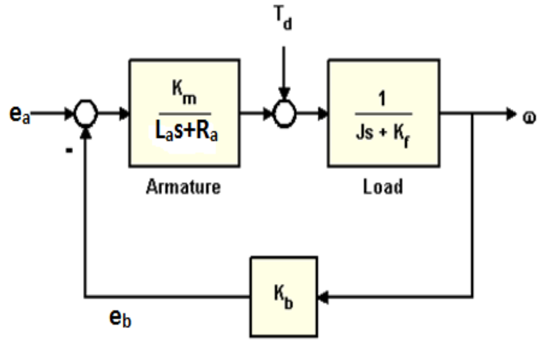


Figure 2. Block Diagram of DC Motor.

Control system closed loop system shown in Fig. 2 has the mechanical system Laplace function and electrical system Laplace function stated separately. They are further combined to realize the output motor speed (ω) and from which we can estimate the position of rotor. From this transfer function we can also study about output armature current of motor. Transfer thus obtained is of second order system. Then to control this control system, P.I.D. controller used in forward path.

From motor equivalent equations and by using specific standard values of parameters, D.C motor model is realized. The D.C motor parameters used in this research paper are defined in equation (10).

$$\begin{aligned} &K_f = .018, \\ &K_m = K_b = 1.4, \\ &Ra = 2 \text{ ohms}, \\ &La = 16.2 \text{ mH}, \\ &J = 0.117 \text{ KgM}^{2,} \\ &Va = 220 \text{ volts}, \\ &Td = 1 \text{ N-m}, \end{aligned} \tag{10}$$

Thus, the final of transform function is shown in equation (11).

$$\omega = \frac{1.4}{s^2(0.001895) + 0.2349s + 1.996} \tag{11}$$

By equation (11) the expression of rotor position of motor is also calculated. Analyzing the position of rotor of D.C Motor is also a very keen aspect and difficult because the transfer function of position is of third order control system. Position of rotor is expressed as ϴ expressed and its transfer function is expressed in equation (12).

$$\theta = \frac{1.4}{s^3(0.001895) + 0.2349s^2 + 1.996s} \quad (12)$$

Thus, this paper uses the transfer function of rotor position of motor as its plant function and to this PID controller is attached to control the position of motor.

III. PID PARAMETER TUNING STRATEGIES

In this section two PID parameter tuning strategies namely Ziegler Nichols Method and Genetic Algorithm which are discussed in this section.

A. Conventional Approach - Ziegler Nichols Method

The extremely substantial step for operating the PID controller is the adjusting of its parameters. The control dynamics of any system provides very poor performance result and its characteristics comes out to be impractical, if proper optimize tuning of controller is not done. Sometimes a stable control function becomes unstable system. Therefore, for proper and good performance proper choice of tuning parameters is a necessity of system.

Tuning of parameters includes the identification of best values of Kp, Ki, Kd when P.I.D controller is used in system. Identification of parameters generally is a subjective and iterative process and highly depends on the type of system and process therefore change and need to tune them accordingly. Ziegler Nichols Method is a broadly acknowledged technique mainly used for adjusting parameters. The idea is very simple and easy to implement. Initially there is a need to adjust only P (proportional gain Kp) to a minimal value. Now after this by changing load to a small value, results thus obtained are analyzed. If output result is very inactive or not up to mark this means Kp value is low. Then to make response active, value of parameter Kp needs to be increased by some multiple factor generally two and again analyze the response by changing load to small value. This process keeps on repeating until the output response of system becomes incessant oscillatory.

During this whole process the Integration and Derivative controller gain constants are adjusted to zero. The value of Kp at which system gives consistent oscillatory response is marked as Ultimate Gain of system (Kc). Oscillating period at this gain is termed as Period of Oscillation (Pu). Now from this Ultimate Gain and Period of Oscillation, value of Kp, Ki, Kd. The value of these parameter for the given D.C Motor control system transfer function is given in result section.

B. Genetic Algorithm for Optimal Tuning

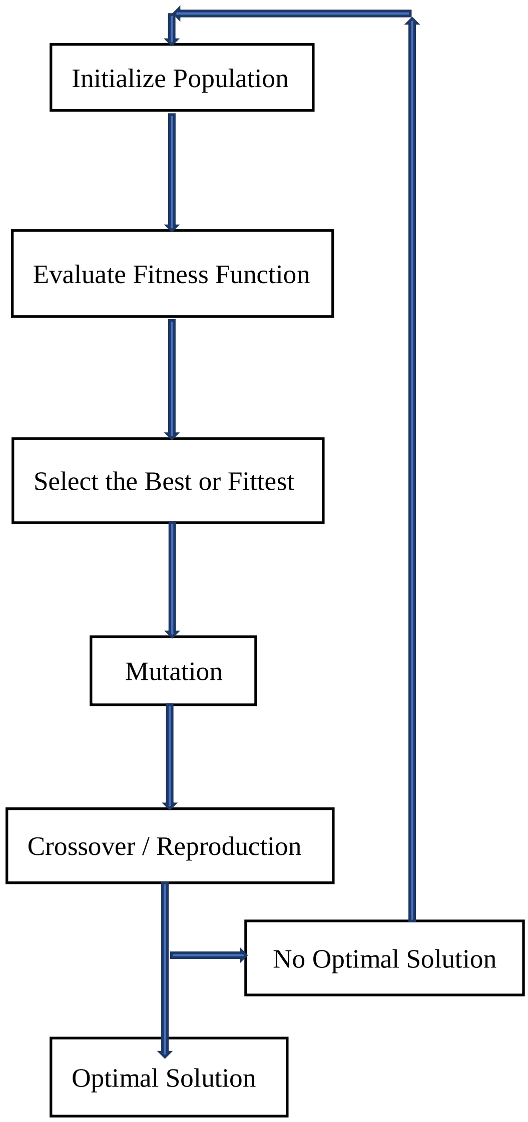
The genetic algorithm begins with zero prior inputs or any predefined information of the precise result and rely totally on outputs from its surroundings and progression parameters like reproduction, crossover and mutation to get the best possible optimized result. By initializing with different self-supporting objectives and hunting parallelly, the procedure thus escapes i.e. it does not stop at local minima value of system and therefore it converges to some semi optimized solutions.

By this procedure, GAs shows its capability of finding possible areas which have maximum performance index in complicated spheres and in addition to it does not encounter any issues regarding abnormal dimensionality, which may befall in other techniques like gradient decent or derivative information methods.

Genetic Algorithm in this research is used for the following two determinations:

1. To determine the optimized value of PI controller parameters namely Kp, Ki and Kd.
2. To reduce the error value between given higher order and obtained reduced order models.

The objective function is the most important and decisive part of Genetic algorithm to get the most optimized results. The objective function is employed in this algorithm to know how the individual parameters will perform for given objective. For minimization challenge, individuals which have the minimum numerical value according to the predefined objective function are selected.



s]

Figure 3. Flow chart of G.A.

TABLE I. OBJECTIVE FUNCTIONS

FUNCTION NAME	FUNCTION DEFINITION
Integral of Time Multiplied by Absolute Error (ITATE)	$f = \int_0^\tau \lvert t\, e(t) dt$
Mean of Squared Error (M.S.E)	$f = \frac{1}{t}\int_0^\tau (e(t))^2\, dt$

The flow chart shown in Fig. 3 explains the summary and step by step execution of Genetic Algorithm for a given system. Following is the procedure included for executing and realizing genetic algorithm:

1. Produce starting arbitrary group of individuals of a predefined size.
2. Then fitness of the individuals is being analyzed.
3. Now, the fittest members from population are selected.
4. Reproduction for next generations are then done by method of probability.
5. Afterwards, carry out the crossover strategy on generated chromosomes
6. Further, there is a need to apply mutation strategy with less probabilistic values.
7. Finally, to find pre stated convergence condition repeat rule 2 until final optimized solution not achieved.

Values of parameter used in evaluating Genetic Algorithm to find optimize results in this research are given in table II.

TABLE II. G.A PARAMETERS

GA PROPERTY	FUNCTION DEFINITION
POPULATION SIZE	40
MAXIMUM GENERATIONS	100
PERFORMANCE INDEX	M.S.E / I.T.A.T.E
SELECTION FUNCTION	Stochastic Uniform
PROBABILITY OF SELECTION	0.05
CROSSOVER METHOD	Scattederd
ELITE COUNT	2
CROSSOVER FRACTION	0.85
MUTATION METHOD	Adaptive Feasible
MIGRATION	Both Sides

IV. Results and Discussions

In this section, first all simulations and their respective output response is shown for each technique used in this research paper. Further a comprehensive comparison is done by putting all data in a tabular format.

A. Conventional Approach - Ziegler Nichols Method

The output step response of D.C Motor is calculated after doing extensive fined tuning by Z.N Method by following the procedure described in previous section, for this SISOTOOL Box in MATLAB software is used to perform Ziegler Nichols Method.

The transfer function of P.I.D controller (C) founded by applying this technique comes out to be as shown in equation (13).

$$C = 61.764 + ((1 + 0.12s) * (1 + 0.12s))/s \qquad (13)$$

From this P.I.D parameters are evaluated and are found to be

$K_P = 14.5$; $K_I = 61.8$; $K_D = 0.855$

The step response after using this controller is shown in Fig..4

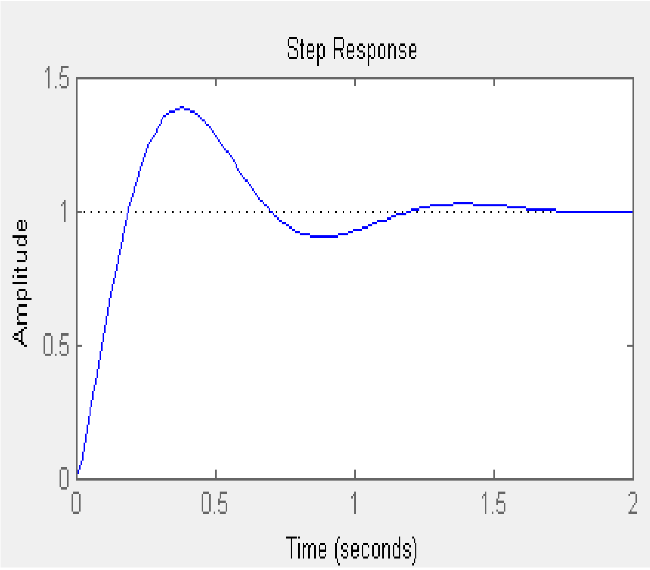


Figure 4. Step Response output using Z.N Method.

Table III shows the values of different step response parameter related to Fig. 4.

TABLE III. PERFORMANCE OF CLASSICAL Z-N METHOD

PARAMETERS	VALUES
Maximum Peak Overshoot	3.64%
Rise Time	0.0235 secs
Settling Time	3.64 secs

These values are further compared with results of Genetic Algorithm.

B. Genetic Algorithm Method

In Genetic Algorithm as described in this research uses two objective or fitness function which are I.T.A.E and M.S.E. The step response and their respective parameter values are stated as follows .

a) Mean of Squared Error (M.S.E) objective function.

Step response of D.C Motor control by using Genetic Algorithm with M.S.E as objective function is discussed. Values of PID control parameters in this case are evaluated and have following values

K_P = 14.463 ; K_I = 12.046 ; K_D = 15.9012

The step response after using this controller is shown in Fig..5

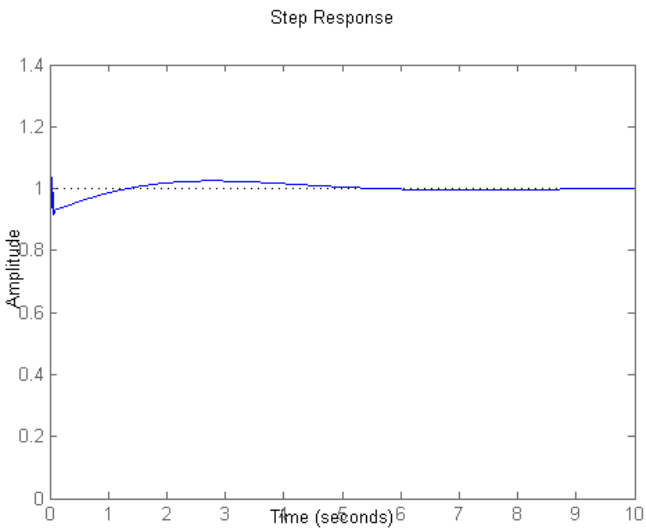


Figure 5. Step Response output using G.A using M.S.E function.

Table IV describes the values of step response parameter related to Fig. 5.

TABLE IV. PERFORMANCE OF M.S.E FUNCTION

PARAMETERS	VALUES
Maximum Peak Overshoot	38.4%
Rise Time	0.141 secs
Settling Time	1.5 secs

The values stated in Table IV are evaluated by M.S.E function therefore it is foremost important to state here the value of error in this control system i.e. value objective function. The value of fitness or objective function in this case is given in equation (14).

$$f = 1.7469 \tag{14}$$

This value also helps to compare the error function value between two objective function used in this research.

b) Integral of Time Multiplied by Absolute Error (I.T.A.T.E) objective function.

Step response of D.C Motor control by using Genetic Algorithm with (I.T.A.T.E) objective or fitness function is discussed here. Values of PID control parameters in this case are evaluated and have following values.

K_P = 11.7964 ; K_I = 12.1647 ; K_D = 13.5420

The step response after using this controller is shown in Fig..6.

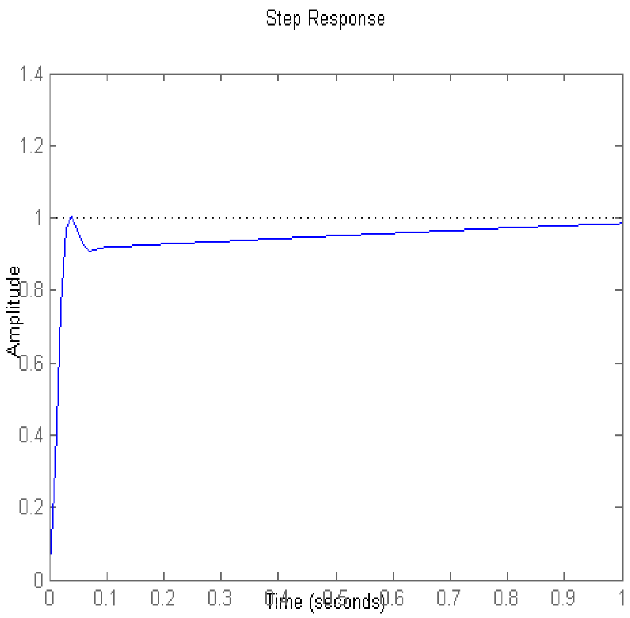


Figure 6. Step Response output using G.A using I.T.AT.E function.

Table V describes the values of step response parameter related to Fig. 6.

TABLE V. PERFORMANCE OF I.T.A.T.E FUNCTION

PARAMETERS	Z.N METHOD	G.A M.S.E	G.A I.T.A.T.E
K_P K_I K_D	14.5 61.8 0.855	14.463 12.046 15.901	11.796 12.164 12.542
Maximum Peak Overshoot (%)	38.4	3.64	0.408
Rise Time (secs)	0.141	0.0235	0.0202
Settling Time (secs)	1.5	3.64	0.917
Error Value	11.89	0.01883	1.7469

The values stated Table V are evaluated by I.T.A.T.E function therefore it is foremost important to state here the value error in this control system i.e. value objective function. The value of fitness or objective function in this case is stated in equation (15).

$$f = 0.01883 \quad (15)$$

The value of error in case of I.T.A.E function comes out to be less than M.S.E function.

Following are the main discussion points that can be made from the following results of this study.

1. Comparing with Z.N Method which have maximum overshoot in all the research simulations. Overshoot of any control system function is a keen parameter as it decides the performance of system. Overshoot ideally should not be more than 5% for a stable function. Through G.A algorithm this is achieved and is even less than that.

2. Similarly, G.A proves to be very good for rise time and settling time. For comparison purpose all values of conventional tuning method and G.A algorithm are listed in Table 7. G.A due to its heuristic searching technique found parameters that give very fast response having rise time very less than when compared to rise time in Z.N method.

3. When comparing within G.A on the basis of fitness or objective function, I.TA.T.E function better than M.S.E function. Results shows that in case of I.T.A.T.E function the maximum overshoot has value which is much lower than M.S.E function.

4. The importance objective function in this algorithm is high because mainly it finds best possible optimized parameters by minimizing the feedback error of control system. Here I.TA.T.E has error value stated in equation (13) which has far much lower value when compared to objective function value of M.S.E, having its value shown in equation(14).

TABLE VI. COMPARISION TABLE

PARAMETERS	VALUES
Maximum Peak Overshoot	0.408%
Rise Time	0.0202 secs
Settling Time	0.917 secs

V. CONCLUSION

P.I.D controller constructed in this paper with GA has far swifter response when being compared with standard or classical method. The classical method can be used to generate the initial values of P.I.D parameters which then used to evaluate optimized parameters through G.A based controller designed by using different objective functions give the better results in terms of maximum overshoot and rise time. By analyzing the results and discussions stated in this research, Genetic Algorithm is the finest algorithm for precise position or speed control of D.C Motor.

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