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Genetic Algorithms Based Intelligent Control Technique for Rotating Electrical Machine

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Abstract—
The demand for high-performance control of motor drives is rapidly increasing, particularly in the area of traction, electric vehicles and industry. Artificial intelligent controller (AIC) could be the best candidate for Motor control. The main aim of this paper is to analyse the implementation of Artificial intelligent (AI) techniques viz. Genetic Algorithm (GA) for optimal tuning of PID controllers parameters and enumerate their advantages over the conventional tuning methodologies. The technique was implemented and analysed on a third order plant model of a DC servomotor with the aim of developing a position controller. The results obtained from GA algorithm were compared with that obtained from Ziegler Nichols method. It was found that the Genetic Algorithms outperformed traditional tuning practices of Zeigler-Nichols at tuning of PID controllers.
Keywords— Intelligent Control, DC Servo motor, PID controller, PID Tuning, Ziegler Nichols (ZN), Genetic Algorithm (GA).

I. INTRODUCTION

In process control industry, majority of control system loops are based on Proportional-Integral-Derivative (PID) controllers. PID controllers are being widely used in industry due to their well-grounded established theory, simplicity, maintenance requirements, and ease of tuning. The basic structure of the PID controllers makes it easy to regulate the process output. Therefore, efficient design and tuning methods leading to an optimal and effective operation of the PID controllers in order to regulate the different parameters of the plant are economically vital for process industries.

The main goal of this paper is to analyse the implementation intelligent technique viz. Genetic Algorithm (GA) for optimal tuning of PID controllers parameters and enumerate their advantages over the conventional tuning methodologies.Genetic Algorithms (GA) are adaptive heuristic search based on evolutionary ideas of natural selection and genetics. Genetic Algorithms are effective and intelligent choice at finding the best solution among the space of all feasible solutions. Genetic Algorithms were used to evaluate the optimum PID controller gain values where performance indices ITAE, IAE, ISE and MSE were used as the objective functions The proposed methodology was verified using a third-order physical plant (Armature-controlled DC servomotor position control system) where tuning algorithms were driven mainly by the acquired system data and the desired performance parameters specified by the user are successfully satisfied. Resultant improvements on the step response behaviour of DC servomotor position control system are shown for two cases.

II. SYSTEM MODELLING

As a reference we consider armature controlled DC servomotor as shown in Figure 1. In the point of control system, DC servo motor can be considered as linear SISO plant model having third order transfer function. The DC servomotors are found to have an excellent speed and position control. A simple mathematical relationship between the shaft agular position ‗θ‘ and voltage input ‗$V_a(s)$‘ to the DC motor may be derived from physical laws.

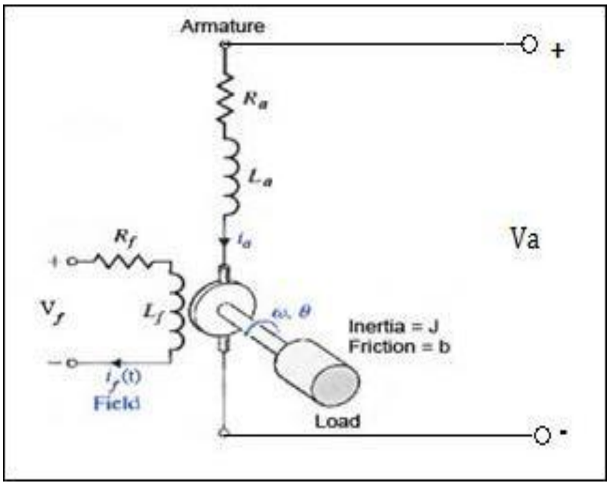

Fig.1 Schematic Diagram of armature controlled DC Servo motor

The dynamic behaviour of the armature current-controlled DC servomotor is given by the following equations [1].

The air gap flux ϕ of the motor is proportional to the field current so that

$$\phi = k_f i_f(t)$$

The torque developed by motor is assumed to be related linearly to air gap flux and the armature current as follows

$$T_m = k_1 \phi i_a(t) \quad (2)$$

or

$$T_m = k_1 k_f i_f(t) i_a(t)$$

where k_1 and k_2 are constants.

When a constant field current is established in a field coil, the motor torque is

$$T_m = k_m i_a(t) \quad (3)$$

In Laplace transform notification,

$$T_m(s) = k_m I_a(s) \quad (4)$$

The armature current is related to the input voltage applied to the armature by

$$V_a(s) = R_a I_a(s) + L_a s I_a(s) + V_b(s) \quad (5)$$

where $V_b(s)$ is back emf voltage proportional to the motor speed. Therefore, we have

$$V_b(s) = k_b \omega(s) \quad (6)$$

where $\omega(s) = s\theta(s)$ the transform of the angular speed and the armature is current is

$$I_a(s) = \frac{V_a(s) - k_b \omega(s)}{R_a + L_a s} \quad (7)$$

The motor torque is equal to the torque delivered to the load which may be expressed as

$$T_m(s) = T_l(s) + T_d(s) \quad (8)$$

where T_l is the load torque and T_d is the disturbance torque which is often negligible, so

$$T_l(s) = Js^2\theta(s) + bs\theta(s) \quad (9)$$

Therefore, the transfer function of the motor load combination, with $T_d = 0$, is:

$$\frac{\theta(s)}{V_a(S)} = \frac{k_m}{s[(L_a s + R_a)(Js + b) + (k_m k_b)]} \quad (10)$$

Or

$$\frac{\theta(s)}{V_a(S)} = \frac{k_m}{L_a J s^3 + (L_a b + R_a j)s^2 + (R_a b + k_m k_b)s} \quad (11)$$

Here the angular displacement $\theta(s)$ is considered the output and the armature voltage $V(s)$ is considered the input. The block diagram representation is shown in figure 2.

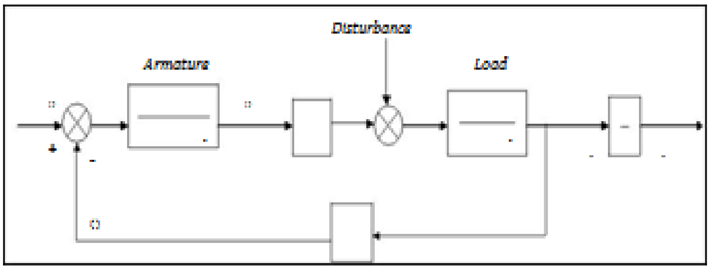

Fig.3 Block Diagram representation of a DC Servo motor

For the DC servomotor with parameters given in Appendix A, the overall transfer function of the system is given as:

$$\frac{\theta(s)}{V_a(s)} = \frac{0.01}{0.005s^3 + 0.06s^2 + 0.1001s}$$

III. PID CONTROLLER

The PID controller, represented by Fig.2, is well known and widely used to improve the dynamic response as well as to reduce or eliminate the steady state error. The Derivative controller adds a finite zero to the open loop plant Transfer function and improves the transient response. The Integral controller adds a pole at the origin, thus increasing system type by one and reducing the steady state error due to a step function to zero. PID controller consists of three types of control Proportional, Integral and Derivative control [6].

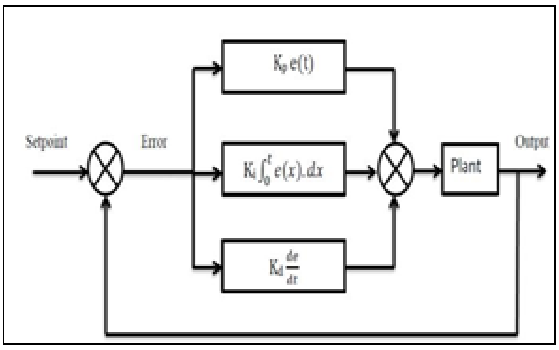

Fig.2 Block diagram of conventional PID controller

The PID controller output relating the error can be described by,

$$u(t) = k_p e(t) + k_i \int_0^t e(t)dt + \frac{k_d\, de(t)}{dt}$$

$e(t)$ is the error, $u(t)$ the controller output, and k_p , k_i k_d are the Proportional, Integral and Derivative gains. frequency domain, the relation between the controller input E (error signal) and output U (input to the plant) can be expressed by the following transfer function:

$$G_C(S) = \frac{U(S)}{E(S)} = k_p + \frac{k_i}{s} + k_d s$$

The closed loop transfer function is given by,

$$\frac{Y(S)}{R(S)} = \frac{G_C(S)G(S)}{1 + G_C(S)G(S)} \qquad (15)$$

The tuning of a PID controller consists of selecting gains Kp, Ki and Kd so that performance specifications are satisfied.

IV. TUNING OF PID CONTROLLER USING CONVENTIONAL APPROACH

A. Conventional Approach - Ziegler Nichols Method

Ziegler-Nichols (ZN) method for tuning of PID controllers, though a classic method, has been widely used for the design of various controllers. Ziegler and Nichols presented two methods, a step response method and a frequency response method. In this paper we have employed the frequency response method for tuning of the PID controller.

B. Implementation of ZN based PID controller

In this method, the integral time Ti will be set to infinity and the derivative time Td to zero. This is used to get the initial PID setting of the system. Thus the proportional control is selected alone. Increasing the value of the proportional gain until the point of instability is reached (sustained oscillations), gives the critical value of gain, Kc. Thereafter measurement of the period of oscillation of the response is used to obtain the critical time constant, Tc.

Once the values for Kc and Tc are obtained, the PID parameters can be calculated, according to the design specifications, as given in Table 1. Further the values of the PID gain coefficients *Kp*, *Ki* and *Kd* for the system described by equation (3), obtained after simulation in MATLAB are given in Table 2.

Table 1 Ziegler-Nichols PID tuning parameters

CONTROLLER	***Kp***	***Ti***	***Td***
P	*0.5Kc*	*Inf*	*0*
PI	*0.45Kc*	*0.833Tc*	*0*
PID	*0.6Kc*	*0.5Tc*	*0.125Tc*

Table 2 Ziegler-Nichols PID tuning values

Gain Coefficients	***Kp***	***Ki***	***Kd***
Values	*72.0720*	*102.6374*	*12.6486*

Here, and

From the above formulation the step response of the overall system with conventionally tuned PID controller is shown in Fig.4.

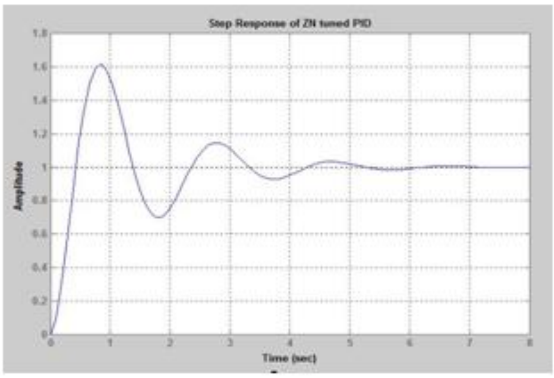

Fig 5 Step Response of DC Motor with ZN Tuned PID

IV. GENETIC ALGORITHMS

A. Overview

Genetic Algorithms (GAs) are heuristic search techniques based on an artificial simulation of the mechanisms underlying the evolution of living beings: natural selection and genetic.The simplest form of genetic algorithm involves three types of operators: selection, crossover, and mutation. GAs are population-based search methods that work through the following elements: populations of chromosomes, selection according to fitness, crossover to produce new offspring, and random mutation of new offspring.

The GA process consists in an iterative stepwise refinement of the performance of the individuals. The first step is the creation of a new population composed of individuals randomly generated. Then a fitness function evaluates and assigns to each individual a performance measure, or fitness value. The definition of the fitness function depends on the objective function. Then this population evolves for a number of iteration called generation until to satisfy a termination criterion.

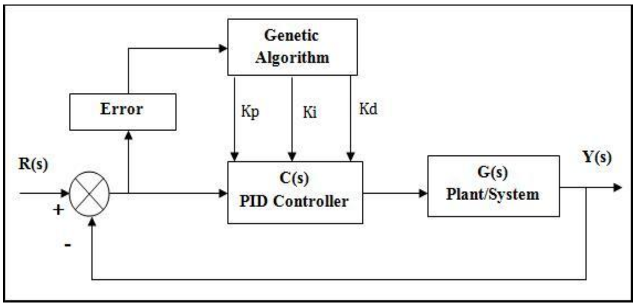

Fig.4 Block diagram for PID parameters tuning using GA.

B. GA-Based PID Controller Optimization

1) GA Tuning Parameters

The values in the Table 1 describe the GA settings used for this work.

TABLE 3: GA Tuning Parameters

PARAMETERS	***VALUES***
Lower bound [Kp Ki Kd]	***[0 0 0]***
Upper bound [Kp Ki Kd]	***[100 100 100]***
Stopping criteria (Iterations)	***100***
Population Size	***40***
Crossover Fraction	***4***
Mutation Fraction	***0.08***

2) Steps in GA-Based PID Controller Optimization

Step 1 % Establish initial population of individuals %

An initial random population having P(t) individuals is generated.

Step 2 % Evaluate the fitness of each individual in P(t)% Evaluate all the individual solutions with the fitness function, which can be the inverse of error function.

Step 3 % Select some highly fit solutions%

Select P‘(t+1) form intermediate population of fittest members from initial population P(t).

Step 4 % Apply crossover to selected solutions%

Pair off and mate individuals in P‘(t+1) as parents and perform crossover operation to generate offsprings.

Step 5 % Apply mutation%

Perform mutation by slightly changing some random solution.

Step 6 Steps 2–5 are repeated until the predefined value of the function or the number of iterations has been reached. Record the optimized Kp, Ki and Kd values

Step 7 Perform closed-loop test with the optimised values of controller parameters and calculate the time domain specification for the system.

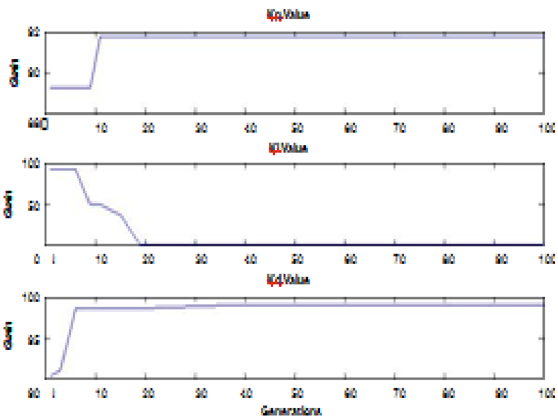

Fig.6 Convergence of Genetic Algorithm

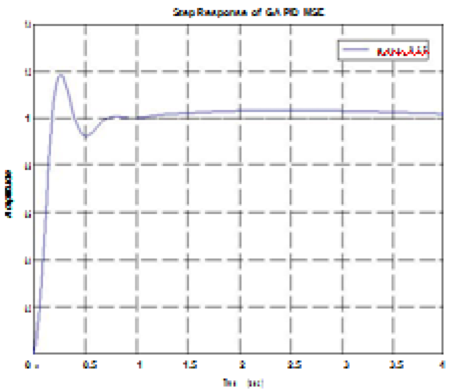

Fig 7 Step Response Curve for GA

Fig.6 shows the convergence of genetic algorithm through various generations for the three PID parameters, Kp, Ki and Kd. Fig.7 shows the step response of GA tuned controller parameter.

V. SIMULATION RESULTS

In order to improve the performance of the dc motor under transient and steady state condition, a PID controller is inserted in the forward path as shown in Fig 4. The parameters of the PID controller are now adjusted by using conventional method i.e. Ziegler-Nichols method and the response obtained for the DC servomotor is evaluated. Further again the parameters of PID controller are obtained using evolutionary computation of GA and the system step responses are evaluated.

The controller gains were computed by using the classical Zeigler-Nichols rules and evolutionary computation techniques i.e. Genetic Algorithm. The controller gains obtained from the methods are listed in Table 3.

TABLE 4: Comparison of steady state responses

TITLE	*ZN_PID*	*GA_PID*
Rise Time(sec)	***0.2901***	***0.1070***
Settling Time (sec)	***5.0139***	***1.0721***
% Overshoot	***61.7409***	***21.3911***
Peak Time (sec)	***0.8492***	***0.2395***
K_d	***12.6486***	***99.0275***
K_p	***72.0720***	***91.7813***
K_i	***102.6374***	***1.3092***

The comparative output responses of the system tune using GA-based PID controller and conventionally tuned PID controller using Zeigler Nichols (ZN) method is shown in figure 8. The GA tuned system exhibits greatly reduced overshoot, rise time and settling time.

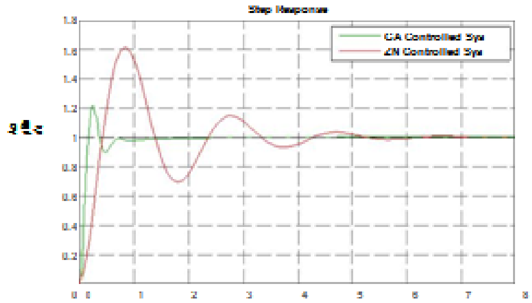

Fig.8 Comparitive step responses for GA and ZN tuned system

VI. CONCLUSIONS

In this paper, two different control techniques are used for the tuning controller which are, conventional Ziegler Nichols Method and Intelligent control technique(GA).Application of Intelligent technique (GA) to the optimum tuning of PID controller led to a satisfactory close-loop response for the system under consideration. Comparison of the results as shown in Table 4 clearly shows that the GA controller shows fast control response with DC Servo motor. The GA tuned system reduced overshoot, rise time and settling time. The same Intelligent technique(GA) can be implemented with the Induction motor drive for analysis of dynamic response .

REFERENCES

[1.] Dorf and Bishop, Modern Control Systems, 9th Ed., Prentice-Hall, Inc. 2001.
[2.] V. Rajinikanth and K. Latha, Tuning and Retuning of PID Controller for Unstable Systems Using Evolutionary Algorithm, Research Article, International Scholarly Research Network, Volume 2012, Article ID 693545, doi:10.5402/2012/693545
[3.] Ömer Gündoğdu, optimal-tuning of PID controller gains using
[4.] genetic algorithms, Journal of Engineering Sciences, pp 131-135, 2005 11(1).
[5.] Bhawna Tandon, Randeep Kaur, genetic algorithm based parameter tuning of pid controller for composition control system, International Journal of Engineering Science and Technology, ISSN:0975-5462, Vol. 3 No. 8 August 2011, pp 6705-6711.
[6.] F. M. Amaral, Ricardo Tanscheit, Marco A. C. Pacheco, Tuning PID Controllers through Genetic Algorithms, WSES International Conference on Evolutionary Computation, Feb 12-14, 2001, pp 6121-6124.
[7.] Neenu Thomas, Dr. P. Poongodi, Position Control of DC Motor Using Genetic

Algorithm Based PID Controller, Proceedings of the World Congress on Engineering 2009 (ISBN: 978-988-18210-1-0) Vol II WCE 2009, July 1 - 3, 2009, London, U.K.

[8.] Harinath Babu Kamepalli, The optimal basics for Gas, IEEE Potentials, 0278-6648/01/$10.00 © 2001 IEEE, April/May 2001 pp 25-27.

[9.] Tze-Fun Chan, and Keli Shi, ―Applied Intelligent Control of Motor Drives IEEE Willey Press, First edition, 2011.

[10.] P. M. Menghal, and Dr. A. Jaya Laxmi, ―Neural Network Based Dynamic Simulation of Induction Motor Drive ,IEEE.

[11.] L . Shi, T . F. Chan, Y. K. Wong and S. L . HO, "Modeling and simulation of the three phase induction motor Using SIMULINK," Int.J. Elect. Enging. Educ., Vol. 36, 1999, pp. 163–172.

[12.] P.C. Krause, "Analysis of Electrical Machinery and Drives System, "IEEE Willey Press, 2000.

[13.] P.C. Krause, "Analysis of Electrical Machinery and Drives System, "IEEE Willey Press, 2000.

[14.] Ned Mohan, "Advanced Electric Drives: Analysis, Control Modeling using Simulink, "MNPERE Publication ,2001.

[15.] Abbondanti, A. and Brennen, M.B. (1975)Variable speed induction motor drives use electronic slip calculator based onmotor voltage and currents. IEEE Transactions on Industry Applications, IA-11(5), 483–488.

[16.] Astrom , K.J. and A _ rz_en, K.E. (1993) Expert control, in An Introduction to Intelligent and Autonomous Control(eds P.J. Antsaklis, K.M. Passino, and MA. Norwell) Kluwer Academic Publishers, pp. 163–168.

[17.] Astrom, K.J. and Bjorn, W. (1995) Adaptive Control, Addison Wesley Publishing Company, Reading, MA.

[18.] Baader, U., Depenbrock, M. and Gierse, G. (1992) Direct Self Control (DSC) of inverter-fed induction machine:a basis for speed control without speed measurement. IEEE Transactions on Industry Applications, 28(3),581–589.

[19.] Blashke, F. (1972) The principle of field-orientation as applied to the new ‗transvektor' closed-loop control system for rotating-field machines. Simians Review, 34(5), 21–220.

[20.] Bose, B.K. (1981) Adjustable Speed AC Drive Systems, IEEE Press, New York.

[21.] Bose, B.K. (1993) Power electronics and motion control-technology status and recent trends. IEEE Transactions on Industry Applications, 29, 902–909.

[22.] Bose, B.K. (1997a) Expert system, fuzzy logic, and neural networks in power electronics and drives, in Power Electronics and Variable Frequency Drives: Technology and Applications (ed. B.K. Bose), IEEE Press, New Jersey.

[23.] Bose, B.K. (1997b) Intelligent control and estimation in power electronics and drives. The 1997 IEEE Internationa lElectric Machines and Drives Conference, USA, May.

[24.] Bose, B.K., Patel, N.R., and Rajashekara, K. (1997) A neuro fuzzy based on-line efficiency optimization control ofa stator flux oriented direct vector controlled induction motor drive. IEEE Transactions on Industrial Electronics,44, 270–273.

[25.] Chan, C.C., Leung, W.S., and Ng, C.W. (1990) Adaptive decoupling control of induction motor drives. IEEE Transactions on Industrial Electronics, 37(1), 41–47.

[26.] Simoes, M.G. and Bose, B.K. (1995) Neural network based estimation of feedback signals for a vector controlled induction motor drive. IEEE Transactions on Industry Applications, 31, 620–629.

[27.] S. Beierke, C. von Altrock, ―Fuzzy logic enhanced control of an induction motor with DSP , 5th IEEE International. Conf. on

[28.] Fuzzy Systems, New Orleans, LA, September 1996.

[29.] R.J. Spiegel, M.W. Turner, V.E. McCormick, ―Fuzzy-logic-based controllers for science optimization of inverter-fed induction motor drives , ELSEVIER Journal.

[30.] Kung, S.Y. (1993) Digital Neural Networks, PTR Prentice-Hall, Inc., New Jersey.

APPENDIX A: SYSTEM MODEL PARAMETERS

The parameters of the DC servomotor under consideration are as follows:

J	moment of inertia of the rotor	0.01 kg.m^2
b	motor viscous friction constant	0.1 N.m.s
k_b	back emf constant	0.01 V/rad/sec
k_m	motor torque constant	0.01 N.m/Amp
R_a	electric resistance	1.0 Ohm
L_a	electric inductance	0.5 H

NOMENCLATURE

i_a	Armature current in ampere,
i_f	Field current in ampere,
k_m	Motor torque constant,
k_b	Back emf constant,
V_a	Armature voltage in volts,
V_b	Back emf in volts,
J	Moment of inertia of rotor,
b	Viscous frictional constant of motor,
θ	Angular displacement of shaft in radians,
L_a	Armature inductance in henry,
R_a	Armature resistance in ohm
C	Positive acceleration constants (0–2)
$G_C(S)$	Controller model
$G_P(S)$	Process model
IAE	Integrated absolute error
ISE	Integral squared error
ITAE	Integral time absolute error
MSE	Mean square error
k_p	Proportional gain
k_i	Integral gain
k_d	Derivative gain
R	Random number (0-2)
R(s)	Reference input
Y(s)	Process output