# Adaptive PID Dc Motor Speed Controller With Parameters Optimized with Hybrid Optimization Strategy

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**ABSTRACT**
In this paper, an intelligent controller of DC Motor drive is designed using hybrid method of optimization (Genetic Algorithm and Pattern Search Algorithm) for the optimal tuning of proportional-integral-derivative (PID) controller parameters. A proportional–integral–derivative controller (PID controller) is a generic control loop feedback mechanism controller widely used in industrial control system. The parameters of motor, which vary with the operating conditions of the system, are adapted in order to maintain deadbeat response for motor speed. A Hybrid optimization algorithm is employed in order to obtain the controller parameters assuring deadbeat response at each selected load. The DC-Motor PID-HYBRID controller is modeled in MATLAB environment. The response of the developed controllers is compared to that of the controllers whose parameters are tuned using the well-known Ziegler-Nichols method. The developed methodology is more proficient in improving the controller loop response stability, the steady state error, the rising time and overshoot and hence the disturbances do not affect the performances of DC-motor.

**Keywords:** DC-Motor, Genetic Algorithm, Pattern Search Algorithm**,** PID Control, PID-HYBRID controller.

## 1.0 INTRODUCTION

In spite of the development of power electronics resources, the direct current machines are becoming more and more useful insofar as they have found wide application, i.e. automobile industry (electric vehicle), weak power using battery system (motor of toy), the electric traction in the multi-machine systems, etc. The speed of DC motor can be adjusted to a great extent so as to provide easy control and high performance [Raghavan S. (2005)].PID controllers are widely used in industrial plants because it is simple and robust. Industrial processes are subjected to variation in parameters and parameter perturbations, which when significant makes the system unstable. So the control engineers are on look for automatic tuning procedures. PID control is a fundamental control technology and it makes up 90% of automatic controllers on process control fields [Carl Knospe(2006):]. It is also necessary for the total energy saving system or the model predictive control to operate each single loop control system appropriately, and thus the PID control is absolutely essential. For an ideal control performance by the PID controller, an appropriate PID parameter tuning is necessary. In fact, PID parameter tuning depends on operator's know-how; therefore a PID parameter has not been frequently optimal from the viewpoint of qualities. From the control point of view, dc motor exhibit excellent control characteristics because of the decoupled nature of the field [Raghavan S. (2005)]. Recently, many modern control methodologies such as nonlinear control [Weerasooriya S., El-Sharkawi M. A. (1991)], optimal control [Reyer J.

A., Papalambros P. Y. (2000),], variable structure control [Lin F. J., Shyu K. K., Lin Y. (1999),] and adaptive control [Rubaai A., Kotaru R. (2000),] have been extensively proposed for DC motor. However, these approaches are either complex in theoretical bases or difficult to implement [Lin C. L., Jan H. Y. (2002),]. PID control with its three term functionality covering treatment to both transient and steady-states response, offers the simplest and yet most efficient solution too many real world control problems [Ang K., Chong G., Li Y. (2005),]. In spite of the simple structure and robustness of this method, optimally tuning gains of PID controllers have been quite difficult.

Several new optimization techniques like Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), Simulated Annealing (SA) and Bacterial Foraging have emerged in the past two decades that mimic biological evolution, or the way biological entities communicate in nature [M.A. Panduro et al(2009),]. Due its high potential for global optimization, GA has received great attention in control system such as the search of optimal PID controller parameters. The natural genetic operations would still result in enormous computational efforts. The premature convergence of GA degrades its performance and reduces its search capability. In this paper, Pattern search algorithm is used to improve the performance of GA such that it does not converge prematurely.

## 2.0 DC MOTOR MODEL

DC machines are characterized by their versatility. By means of various combinations of shunt, series, and separately-excited field windings they can be designed to display a wide variety of volt-ampere or speed-torque characteristics for both dynamic and steady-state operation. Because of the ease with which they can be controlled systems of DC machines have been frequently used in many applications requiring a wide range of motor speeds and a precise output motor control [ Capolino G.A., Cirrincione G., Cirrincione M., Henao H., Grisel R.(2001)]. In this paper, the separated excitation DC motor model is chosen according to his good electrical and mechanical performances more than other DC motor models. The DC motor is driven by applied voltage. Fig.1-a show the equivalent circuit of DC motor with separate excitation. The characteristic equations of the DC motor are represented as:

$$V_f=R_f i_f+L_f\frac{di_f}{dt} \qquad (1)$$

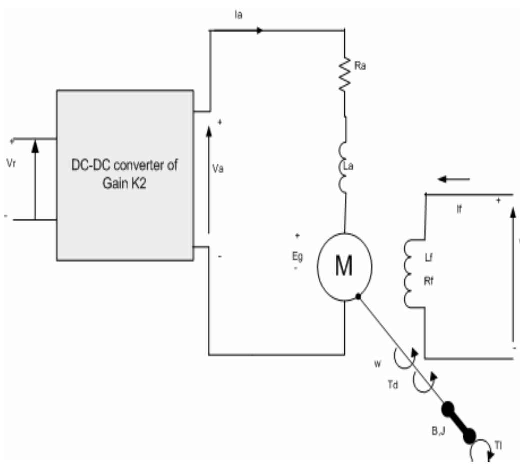
$$V_a = Raia + La\frac{di_a}{dt} + K_b\omega \qquad (2)$$

$$e_g=K_v\omega i_f \qquad (3)$$

$$T_d = K_t i_a i_f \qquad (4)$$

Consequently, the load torque could be given as

$$T_L = K_v T\omega \qquad (5)$$



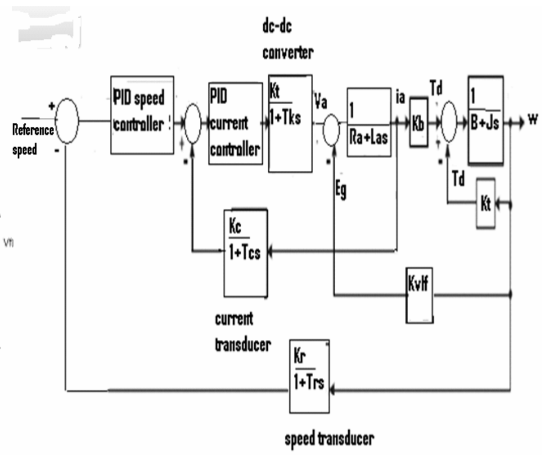




**Figure 2-a: Equivalent circuit of dc motor.** **Figure2-b: Block diagram of dc motor.**

The developed torque must equal the load torque;

$$T_d = J\frac{d\omega}{dt} + T_L + B\omega \tag{6}$$

Under steady state conditions, time derivatives are zero.
The developed power is;

$$P_d = T_d\omega \tag{7}$$

From (9) the speed of separately excited motor is;

$$\omega = \frac{V_a - R_aI_a}{K_vI_f} = \frac{V_a - R_aI_a}{K_vV_f/R_f} \tag{8}$$

where;

$\omega$=motor speed,rad/s
B=viscous friction constant,N.m/rad/s
$K_v$=voltage constant,V/A-rad/s
$K_t$=Kv=torque constant
$L_a$=armature circuit inductance,H
$L_f$=field circuit inductance,H
$R_a$=armature circuit resistance,$\Omega$
$R_f$= field circuit resistance,$\Omega$
$T_l$=load torque,N.m
Td= electromagnetic torque developed.Nm.(176)
$E_g$=back emf.V
$K_b$= emf constant V.sec.
J =Moment of inertia.$Kgm^2$

B=Coefficient of friction. N.m.sec/rad
$P_d$=developed power.W(5KW)

From (8) motor speed can be controlled by; armature voltage, field current, torque demand, which correspond to armature current $I_a$ for fixed field current $I_f$. In practice, for speed less than base speed the armature current and field current are maintained constant to meet torque demand, and armature voltage $V_a$ is varied to control the speed. For speed higher than base speed, armature voltage is made constant (at rated value) and field current is varied to control motor speed. However, the power developed by the motor remains constant.

## 3.0 OPTIMIZATION METHODS

### 3.1 Genetic algorithm

GA as a powerful and broadly applicable stochastic search and optimization technique, and is perhaps the most widely known type of evolutionary computation methods today. The genetic algorithm is an algorithm which is based on natural evolution and the survival of the best chromosome. There are three basic differences between genetic algorithm and optimization classical methods. Firstly, the genetic algorithm works on the encoded strings of the problem parameters. Each string is the representative of one answer to the problem, and the real quantities of the parameters are obtained from the decoding of these strings. Secondly, the genetic algorithm is a search algorithm which works on a population of search spaces. This quality causes the genetic algorithm to search different response spaces simultaneously reducing the possibility of being entrapped at local optimized points. Thirdly, the genetic algorithm does not need previous data from the problem response space such as convexity and derivable. It is only necessary to calculate a response function named fitness function. This function expresses the rate of response proximity to the goal function of the intended algorithm [Meng, Xiangzhong; Song, Baoye (2007)].

The genetic algorithm is a method for solving both constrained and unconstrained optimization problems that is based on natural selection, the process that drives biological evolution. The genetic algorithm repeatedly modifies a population of individual solutions. At each step, the genetic algorithm selects individuals at random from the current population to be parents and uses them to produce the children for the next generation. Over successive generations, the population "evolves" toward an optimal solution. You can apply the genetic algorithm to solve a variety of optimization problems that are not well suited for standard optimization algorithms, including problems in which the objective function is discontinuous, non-differentiable, stochastic, or highly nonlinear [Math works (2010)].

### 3.2 Pattern search algorithm

The Pattern Search (PS) optimization routine is an evolutionary technique that is suitable to solve a variety of optimization problems that lie outside the scope of the standard optimization methods. Generally, PS has the advantage of being very simple in concept, and easy to implement and computationally efficient algorithm. Unlike other heuristic algorithms, such as GA, PS possesses a flexible and well-balanced operator to enhance and adapt the global and fine tune local search. A historic discussion of direct search methods for unconstrained optimization is presented in reference [R. M. Lewis, V. Torczon, and M. W. Trosset (2000),]. The authors gave a modern prospective on the classical family of derivative-free algorithms, focusing on the development of direct search methods. The Pattern Search (PS), algorithm proceeds by computing a sequence of points that may or may not approaches to the optimal point. The algorithm starts by establishing a

set of points called *mesh*, around the given point. This current point could be the initial starting point supplied by the user or it could be computed from the previous step of the algorithm.
The mesh is formed by adding the current point to a scalar multiple of a set of vectors called a *pattern*. If a point in the mesh is found to improve the objective function at the current point, the new point becomes the current point at the next iteration. The Pattern search optimization algorithm will repeat the illustrated steps until it finds the optimal solution for the minimization of the objective function [A. K. Al-Othman (2007)].

### 3.3 Hybrid optimization method

A hybrid function is an optimization function that runs after the Genetic Algorithm terminates in order to improve the value of the fitness function. The hybrid function uses the final point from the Genetic Algorithm as its initial point. Genetic Algorithm can reach the region near an optimum point relatively quickly, but it can take many function evaluations to achieve convergence. The technique runs GA for a small number of generations to get near an optimum point. Then the solution from GA is used as an initial point for Pattern Search Algorithm which is faster and more efficient for local search [Math works (2010)].

## 4.0 REALIZATION OF A PID-GA/PSA CONTROLLER TUNING OPTIMAL PARAMETERS

### 4.1 Objective Function

The general equation of PID controller is:

$$U(t) = K_p e(t)\, d + 1/T_i \int e(t)dt + T_d de(t)/dt \qquad (9)$$

where: $K_p$ = proportional gain; $T_i$ = integral time; $T_d$= derivative time.

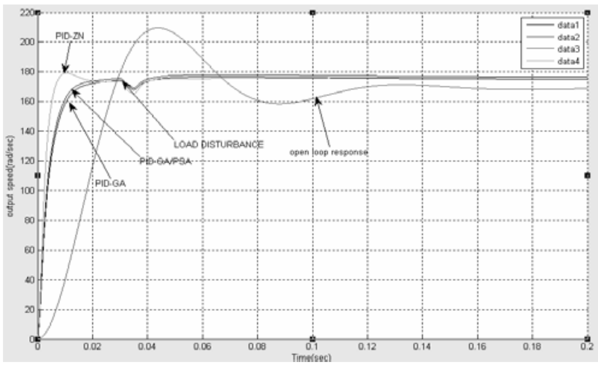
The variable *e (t)* represents the tracking error which is the difference between the desired input value and the actual output. This error signal will be sent to the PID controller and the controller computes both the derivative and the integral of this error signal. The signal *U (t)* from the controller is now equal to the proportional gain (*Kp*) times the magnitude of the error plus the integral gain (*Ki*) times the integral of the error plus the derivative gain (*Kd*) times the derivative of the error [Ang K., Chong G., Li Y.( 2005)]. In PID controller design methods, the most common performance criteria are integrated absolute error (IAE), the integrated of time weight square error (ITSE), and integrated of squared error (ISE). In this paper ITSE criterion is used as it has an advantage of providing higher weighting to errors occurring later in response than during initial stage. The ITSE performance criteria formula is as follows:

$$\text{ITSE (objective function)} = \int t e^2(t) dt \qquad (10)$$

A set of good control parameters P, I and D can yield a good step response that will result in performance criteria minimization in the time domain. These performance criteria in the time domain include the overshoot, rise time, settling time, and steady-state error.
In this paper, An PID controller used PSO Algorithms to find the optimal parameters of DC Motor speed control system. The structure of the PID controller with PSO algorithms is shown in Figure.5.2.

## 5.0 RESULTS

### 5.1 Performance graphs.



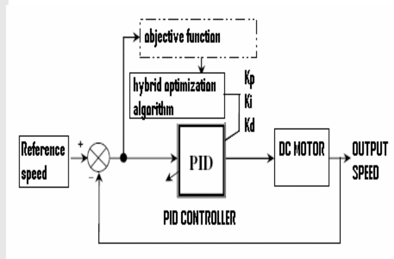




**Figure 5.1: performance graphs.**

**Figure 5.2: The block diagram of PID Controller with Hybrid algorithm.**

**Table A: Performance of controllers**

| | PID-ZIEGLER-NICHOLS(ZN) | PID-GA | PID-GA/PSA |
|---|---|---|---|
| *Tr*=Rising time[sec] | 0.005 | 0.01 | 0.08 |
| *Ts* Settling time[sec] | 2.37 | 0 | 0 |
| *p0* Overshoot ratio[%] | 0.05 | 0.03 | 0.025 |
| *Es* Steady state error[%] | 1 | 0 | 0 |
| Proportional gain-current controller | 4.444 | 2.234 | 2.449 |
| Integral gain-current controller | 100.45 | 124.2 | 123.791 |
| Derivative gain – current controller | 0.03 | 0 | 0.004 |
| Proportional gain-speed controller | 20 | 16.5 | 16.693 |
| Integral time gain-speed controller | 200.46 | 245 | 242.531 |
| Derivative gain-speed controller | 0 | 0 | -0.022 |

## 6.0 CONCLUSION

In this paper a new design method to determine optimal PID controller parameters using the Hybrid optimization method is presented. The speed of a DC Motor drive is controlled by PID-Hybrid controller. Obtained through simulation of DC motor; the results show that the proposed controller can perform an efficient search for the optimal PID controller. By comparison with open loop, PID-Ziegler-Nichols, PID-GA and PID-PSA controller, it shows that this method can improve the dynamic performance of the system in a better way as indicated in table.A and figure 5.1. The PID-Hybrid controller is the best which presented satisfactory performances and possesses good robustness (no overshoot, minimal rise time and Steady state error which is zero).

## 7.0 APPENDIX

### 7.1 Transfer function parameters of system components

Converter gain (Kt ) 0.6 V/V
Converter time constant (Tt ) 1 μs
Current transducer gain (Kc ) 0.85 V/A
Current transducer time constant (Tc ) 2 ms
Speed sensor gain (Kr ) 1.01 V.sec
Speed sensor time constant (Tr ) 2 ms

### 7.2 Motor Ratings

Power 5kW
Current 220A
Voltage 240V
Torque 176 N.m

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