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Design of DE Optimized PI and PID Controller for Speed Control of DC Drives

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***Abstract*: The use of DC motor drive system has been in tradition for quite a long time. The reason being its good regulation of speed, starting is frequent, can be reversed and braked easily. As it is used in many industrial applications many of them require its speed to be controlled. Hence, the two method for controlling its speed is Armature voltage control and field control. The use of Armature voltage method has been demonstrated here in DC separately excited Motor drive. To further modifies its speed regulation process a controller is used. Two controllers are implemented Proportional Integral (PI) and Proportional Integral Derivative (PID). The parameters of these controllers are processed and enhanced via the use of Differential Evolution Algorithm (DE).**

The main objective of the present work is to have minimum rise and settling time while minimizing the maximum overshoot. To verify the performance of the given DE based PI and PID controller used in DC drive system, the result of these are compared with each other and the other traditional techniques.

Using the MATLAB/SIMULINK environment the system is analyzed for different conditions which are base case, effect of parameter variations, effect of load torque, effect of set point & load torque variations, and effect of set point variation. The results have been tabulated and shown to proof the given DE based controller's good transient response & efficiency of system. It verifies the effectiveness of DE based PI and PID controller as compared to the results of other optimization based techniques.

***Keywords*: DC Drives, PI Controller, PID Controller, Differential Evolution Algorithm (DE)**

1. Introduction

Drives system utilizing DC motor are in extensive use. The reason for it be its good regulation of speed, starting is frequent, can be reversed and braked easily. When DC motor is started, it takes high current because at stand still condition the only resistance present in the circuit is the armature resistance which is small and hence generates no back emf. Therefore, it takes large amount of current when started with full voltage across its terminal that could damage motor owning to the sparing in commutators giving rise to huge heat generation. It means, some measure has to be taken as precaution to prevent such a condition. So, its speed is controlled by variable resistance method limiting the starting high current [4].

In many industrial application and operation machineries DC motor use is quite common. In general DC motor speed irrespective of its type can be control either by controlling its armature voltage or controlling the field voltage. Depending upon the suitability of the method, the either one are used. To add on to its controlling performance, a separate controller can be used so as to make the system a closed loop. This will in turn results in better response from the drive system in use. The commonly used controllers are Proportional Integral (PI) and Proportional Integral Derivative (PID). Both of which have their own distinct advantages [2].

To achieve the desired result from these controllers, parameters of them have to be tuned correctly. This was first done by Ziegler-Nichols tuning. Later on many other techniques have come forward to swerve the purpose. Some of these are, Genetic Algorithm, neural network, fuzzy based approach, particle swarm optimization techniques etc. [1].

The work in this these focus around the controlling the speed of separately excited DC motor. For the purpose both the above mentioned controllers have been implemented one by one. To further, improve the performance the parameters of both the controllers are optimized with the use of Differential Evolution (DE) algorithm. The whole system has been modeled and developed using MATLAB/Simulink [3].

A. *Objective Function*

The plant in the current scenario is DC motor and is a third order. Optimization of the both controller will give the desired specification. The performance index is depicted via Integral Time Absolute Error (ITAE),

$$\mathrm{ITAE} = \int_0^\infty t|e(t)|dt \quad (1)$$

Therefore, for PI and PID controller DE based objective function would be utilized so as to get minimized performance index of control system with feedback. e(t) is the error that has to be minimized for desired output which in this case is the speed of DC motor (ω).

For PI,

$$u(t) = K_p e(t) + K_i \int_0^t e(t)d(t) \quad (2)$$

For PID,

$$u(t) = K_p e(t) + K_i \int_0^t e(t)d(t) + K_d \frac{de(t)}{dt} \quad (3)$$

u(t)=controller output and t=sampling time.

2. System model

A. Tuning of PI and PID Controller via DE Algorithm for DC Motor Speed Control

The above fig. 1, demonstrates the block diagram of DC motor speed control via DE tuned PI and PID controller. DE algorithm used here optimizes the parameters of these controllers.

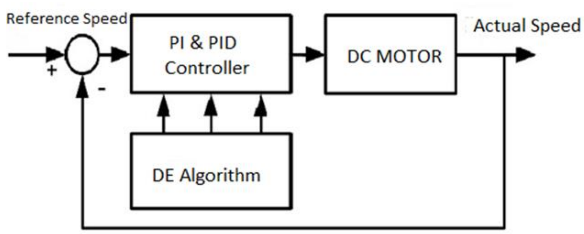

Fig. 1. DE tuned PI & PID Controller

This modification based on the comparison made, can be achieved manually or some controller can be utilized in this regards. The most popular controllers are PI and PID controller. These controllers can modify the error and will in turn give command to the process of speed control. To further enhance the performance of the system in terms of response speed, DE algorithm is used to optimize the parameters of the controller used here [7].

3. Differential evolution tuned controllers

A. Differential Evolution

Optimization is the process of getting the solution which is best applicable at a time. There are many ways; one of it is metaheuristic techniques that improve the given solution by iteration with respect to quality of measures. It uses no or very few assumption about the concerned problem and can search through large space of candidate solution. But it doesn't ensure optimal solution [13]. One such technique falling under this category is Differential Evolution (DE). It utilizes real valued functions that are multidimensional. Although, it doesn't involve gradient of the problem in optimization i.e. it doesn't require problem to be differentiable as with the case in classical optimization. Therefore, optimizations of non-continuous and noisy problem are possible through it.

The process of optimization is very simple. Here, it maintains the Candidate solution population. Also, it creates new candidate solution by combining existing ones via simple formulae. Then, keeping the candidate solution which ever has the best score on the given problem to be optimized. Hence, optimization problem served the purpose of measures of quality. It is a population based stochastic algorithm given by Storm and Price in 1996. The optimization problem can be stated as, [13]

Minimize f(X)

Where $X=[x_1, x_2, x_3,\ldots, x_d]$, d= number of variables.

DE is different from Evolution algorithm in the matter of application of mutation, as it is applied first to obtain the trial vector. Then, it is used within the crossover for the production of one offspring. Also, mutation steps are not sampled from the already known probability distribution function.

B. Process

DE is different from Evolution algorithm in the matter of application of mutation, as it is applied first to obtain the trial vector. Then, it is used within the crossover for the production of one offspring. Also, mutation steps are not sampled from the already known probability distribution function.

C. Algorithm

Fig.2 present DE flow chart

Let population size = N

Population matrix,

$$x_{n,i}^{g} = [x_{n,1}^{g}, x_{n,2}^{g}, x_{n,3}^{g}, \ldots, x_{n,d}^{g}] \quad (4)$$

g= number of generation and n= 1,2,3,….,N

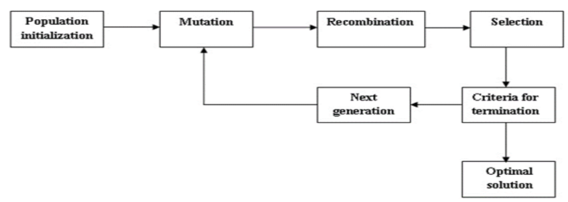

Fig. 2. DE flow Chart

4. Result and discussions

The given chapter shows the result of responses of DE algorithm application on PID controller to regulate the DC motor speed. Here DE is applied to get optimal parameters of controller. One of the main target lies here is to get low transient response in terms of rise, settling time along with overshoot. By achieving the minimum value for each of the parameters mentioned DC motor speed can be controlled with better response and performance. The objective function is also defined based on the above mentioned factor from output step response. This technique is very good and good efficiency as compared to the other traditional system. Table 1 shows DC motors parametes of motor1 & motor 2.

Table 1
DC Motor Parameter

Parameters	Motor 1	Motor 2
Armature Resistance R_a (Ω)	2	2
Armature Inductance L_a(H)	0.5	0.5
Moment of Inertia J (Kgm^2)	0.02	1.2
Friction Constant B (Nms)	0.2	0.2
Torque Constant K_T(Nm/A)	0.015	0.2
EMF Constant K_a (V_s/rad)	0.01	0.2

A. *Case-1: Base Case*

This base case condition dc motor study with some standard parameters and find out dc motor speed response with PI-DE & PID-DE controller. Both conditions parameters are same and shows various waveform. Finally find out PID-DE shows superior response than PI-DE. Table 1 shows PI, PID parameters of dc motor drives. Fig. 3 & 4 shows speed response of PI-DE & PID-DE.

Table 2
Different Controller parameters of PI-DE and PID-DE

S. No.	Parameters	DE-PI Controller	DE PID Controller
1	K_P	100	500
2	K_I	0.1000	0.0100
3	K_D	----	3.0366

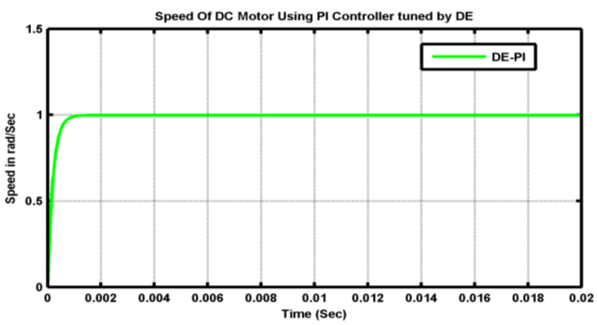

Fig. 3. Speed Response of DC Motor Using PI Controller Tuned by DE

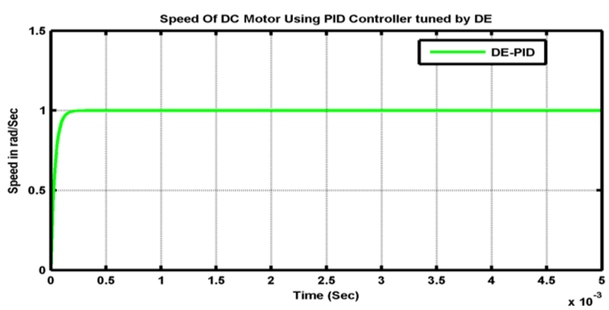

Fig. 4. Speed Response of DC Motor Using PID Controller Tuned by DE

B. *Case-2: Effect of Parameter Variations*

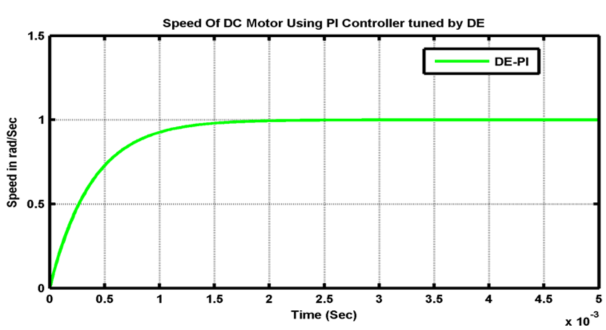

Fig. 5. Speed Response of DC Motor Using PI Controller Tuned by DE

The different parameters of dc motor switch to motor 1 to motor 2 and the name of various parameters shift to motor 2 as moment of inertia, torque constant, emf constant. Finally, we found various response of dc motor with PI-DE & PID-DE controller. Both conditions to vary parameter and show various waveform. Finally find out PID-DE shows superior response than PI-DE. Fig. 5 & 6 shows PI, PID speed response of DC motor drives.

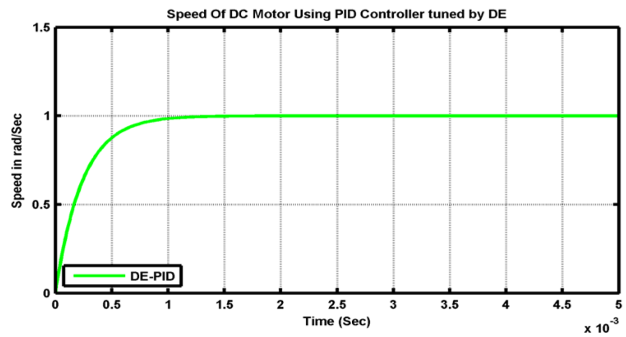

Fig. 6. Speed Response of DC Motor Using PID Controller Tuned by DE

C. *Case-3: Effect of Set Point & Load Torque Variations*

Fig 7 and 8 shows effect of set point and load torque variations at PI and PID controller conditions. The various graph shows as speed input, output, control signal and load torque with respect to time. When we apply change in input and load torque variations our controller efficiently work and no effect in speed variations and speed almost constant. In this condition output speed follow input speed response. So both case controller response very effective and system shows superior response. The PID controller shows better response than PID controller. This condition the controller role is very important and response clearly reflected in graph.

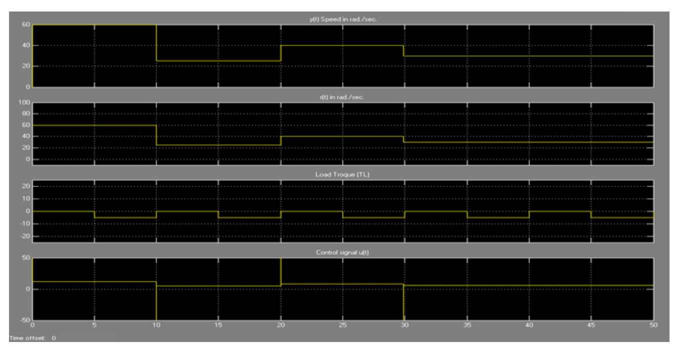
Fig. 7. Effect of Load Torque at PI Controller

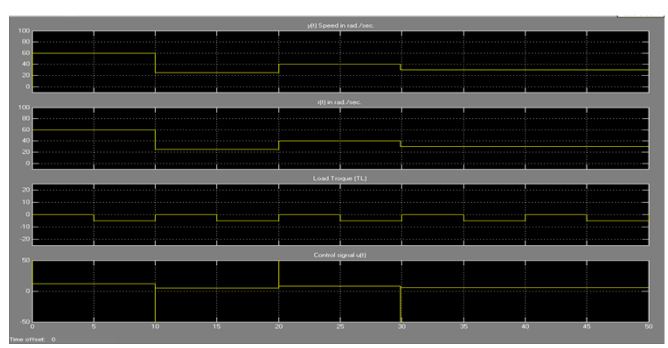
Fig. 8. Effect of Load Torque at PID Controller

D. Case-4: Effect of Set Point Variations

Fig 9 and 10 shows effect of set point variations and load torque constant at PI and PID controller conditions. The various graph shows as speed input, output, control signal and load torque with respect to time. When we apply change in input and load torque constant our controller efficiently work and no effect in speed variations and speed almost constant. In this condition output speed follow input speed response.

So both case controller response very effective and system shows superior response. The PID controller shows better response than PID controller. This condition the controller role is very important and response clearly reflected in graph.

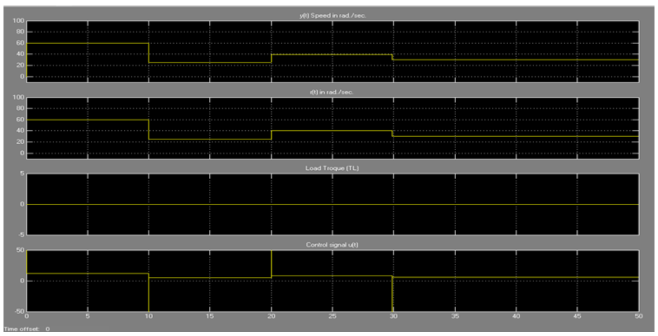

Fig. 9. Effect of Set Point Variations at PI Controller

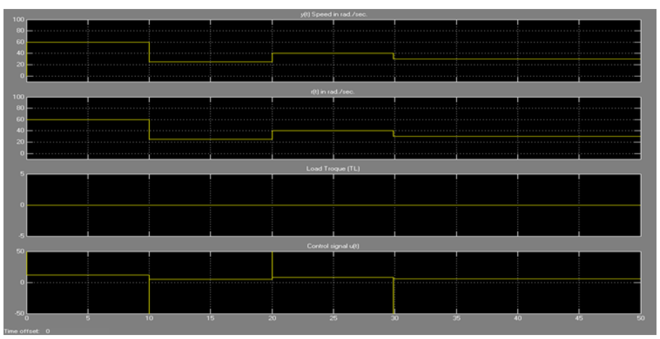

Fig. 10. Effect of Set Point Variations at PID Controller

5. Conclusions

In this paper the response of DC motor drive system developed here was taken for different conditions. These conditions are Base Case, parameter variation effects, set point & load torque variation effect and set point variation effect. In every condition, the DC drive system is examine with DE based PI and DE based PID individually. Taking load torque effect, set point & load torque variation effect and set point variation effect in consideration too PID controller has better response. Hence, the proposed DE-PID has the most superior result as compared to the other method based controllers. It was followed by the DE-PI controller in terms of response.

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