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PID TUNING BY PARTICLE SWARM OPTIMIZATION TECHNIQUE AND COMPARISON WITH CLASSICAL METHODS

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Abstract - *The aim of this work is to optimal tuning of a Proportional-Integral-Derivative controller of a DC motor's equivalent transfer function using bio-inspired optimization technique i.e. particle swarm optimization (PSO).Here, model of a DC motor is considered as a forth order system for armature voltage control method of speed control. In this work bio-inspired optimization technique in controllers and their advantages over conventional methods is discussed using MATLAB/SIMULINK. This proposed optimization methods could be applied for higher order system also to provide better system performance with minimum errors. The main aim is to apply PSO technique to design and tune parameters of PID controller to get an output with better dynamic and static performance. The application of PSO to the PID imparts it the tuning itself automatically in an off-line process while the application of optimization algorithm to the PID controller makes it to give an optimum output by searching for the best set of solutions for PID parameters.*

Key Words: Particle swarm optimization, Ziegler-Nichols Method, Tyreus –Luyben Method, PID controller, parameters tuning.

1. INTRODUCTION

[1]DC motor drives are widely used in applications requiring adjustable speed, good speed regulations and frequent starting, braking and reversing. Some important applications are rolling mills, paper mills machine tools, traction, printing presses, textile mills, excavators and cranes where speed regulation and reached to the desired speed is so important and also in servomotor positioning control and tracking the applications of DC motor is very much appreciable. Although it is being predicted that there are some advantages of AC drives over DC drives. But these advantages are not able to make difference when it is about applications. DC drives are much more acceptable due to its lower cost, reliability and simple control. PID (proportional-integral-derivative) control is one of the earlier positions control strategy which has still wide range of applications in industrial control. So it has a very Simple procedure which is understand by plant operators and which they found relatively easy to tune. [5]The three parameters have three principle control effects. The proportional (P) action gives a change in the input directly proportional to the control error. The integral (I) action gives a change in the input proportional to the integrated error, and its main purpose is to eliminate offset. The less commonly used derivative (D) action is used in some cases to speed up the response or to stabilize the system.

1.1. Tuning Methods

The PID controller tuning methods are classified into two main categories-

- Open loop methods
- Closed loop methods

In open loop methods the controller operates in open state on the plant i.e. no feedback system is available in the system. Closed loop tuning techniques the controller tunes the plant automatically in the closed loop.

The open loop methods considered for simulation are:

-Cohen and Coon method

The closed loop methods considered for simulation are:

-Ziegler-Nichols method
-Modified Ziegler-Nichols method
-Tyreus -Luyben Method

And also particle swarm optimization technique is used in closed loop simulation.

The transfer function of PID controller is defined as

$$G_c(s) = K_p(1 + t_i/s + t_d.s)$$
$$= K_p + K_i/s + K_d.s)$$

Where,

K_p = Proportional gain
t_i = Integral time
t_d = Derivative time
K_i =Integral gain
K_d =Derivative gain

2. PARTICALE SWARM OPTIMIZATION

[3]Particle swarm optimization is a bio-inspired optimization method which is first observed by Doctor Kennedy and J.E berhart in 1995. It is developed from swarm intelligence and

is based on the research of bird flocking biological behavior. While searching for food, the birds are either scattered or go together before they locate the place where they can reach the source of food. While the birds are searching for food from one place to another, there is always a bird that can smell the food very well, or have the best chance to reach the location of food as soon as possible. That is, the bird can able to predict the location of food or having the better food location information than other birds. Because they are transmitting the information, especially the good information at any time while searching the food from one place to another and the rest of the birds follows the bird and eventually flock to the place where food can be found. As far as particle swam optimization algorithm is concerned, solution swam is compared to the bird swarm, the birds moving from one place to another is equal to the development of the solution swarm, good information is equal to the most optimist solution, and the food resource is equal to the most optimist solution during the whole process. The most optimist solution can be worked out in particle swarm optimization algorithm by the cooperation of each individual. The particle without quality and volume serves as each individual, and the simple behavioral pattern is regulated for each particle to show the complexity of the whole particle swarm. This algorithm can be used to work out the complex optimist problems. Due to its many advantages including its simplicity and easy implementation than any other optimization process that previously being discovered, the algorithm can be used widely in the fields such as function optimization, the model classification, filter design, automatic adaptation control and etc.

Basic Particle Swarm Optimization Algorithm

The basic of particle swarm optimization have the similarity that is been defined by numerical method where the solution of an equation is reached by first initialize the position and by trial and error method the boundary of the solution is minimized and ultimately reached the solution.

In PSO also this iteration is happened. But there is a major difference is that in PSO there are several numbers of initial conditions is taken into the consideration by which the optimum solution is reached very easily and very accurately.

In the basic particle swarm optimization algorithm, particle swarm consists of "n" particles, and the position of each particle stands for the potential solution in D-dimensional space. The particles change its condition according to the following three principles:

(1) To keep its inertia
(2) To change the condition according to its most optimist position
(3) To change the condition according to the swarm's most optimist position.

The position of each particle in the swarm is affected both by the most optimist position during its movement of individual experience and the position of the most optimist particle in its surrounding near experience. When the whole particle swarm is surrounding the particle, the most optimist position of the surrounding is equal to the one of the whole most optimist particle; this algorithm is called the whole PSO.

If the narrow surrounding is used in the algorithm, this algorithm is called the partial PSO. Each particle can be shown by its current speed and position, the most optimist position of each individual and the most optimist position of the surrounding. In the partial PSO, the speed and position of each particle change according the following equality (Shi Y, E berhart R C, 1998):

$$V^{K+1}_{id} = V^{K}_{id} + c_1 r_1^K (pbest_{id}^K - X_{id}^k) + c_2 r_2^K (gbest_d^K - x_{id}^K)$$
$$x^{K+1}_{id} = X_{id}^k + V^{K+1}_{id}$$

In this equality, V^K_{id} and X_{id}^k stand for separately the speed of the particle 'i' at its 'k' times and the d-dimension quantity of its position; $pbest_{id}^K$ represents the d-dimension quantity of the individual "i" at its most optimist position at its "k" times. $gbest_d^K$ is the d-dimension quantity of the swarm at its most optimist position. The solution will be the local optimism; c1 and c2 represent the speeding figure, regulating the length when flying to the most particle of the whole swarm and to the most optimist individual particle. If the figure is too small, the particle is probably far away from the target field, if the figure is too big, the particle will maybe fly to the target field suddenly or fly beyond the target field.

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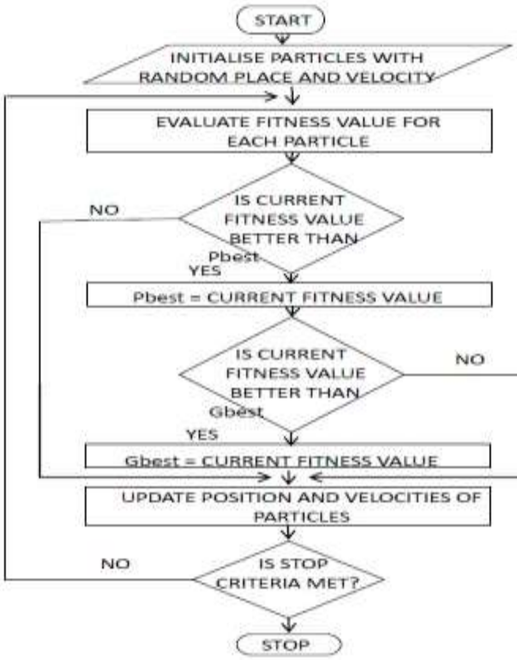
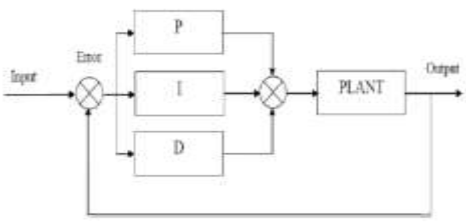
Fig -1: Algorithm for particle swarm optimization



3. CLASSICAL PID TUNING METHODS

The PID controller is the most common general purpose to control the plant in open loop as well as close loop control system. It can be used as a single unit or it can be a part of a distributed computer control system. After implementing the PID controller, now we have to tune the controller; and there are different approaches to tune the PID parameters like P, I and D. The Proportional (P) part is responsible for following the desired set-point while the Integral (I) and Derivative (D) part account for the accumulation of past errors and the rate of change of error in the process or plant, respectively.PID controller consists of three types of control i.e. Proportional, Integral and Derivative control.

Fig-2: Schematic of PID controller

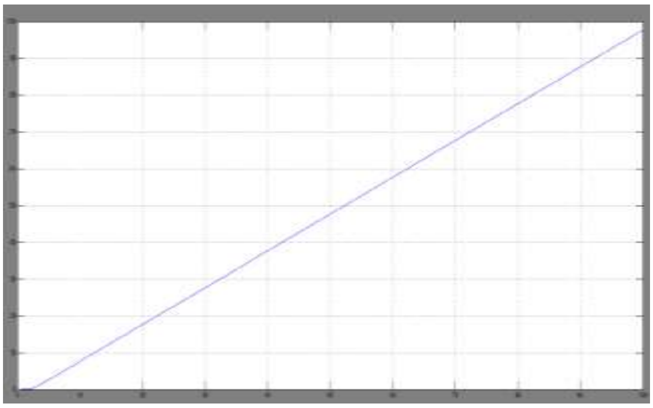


Problem formulation

The DC motor model is described in equation as we considered

$G_c(s)$ =**Error! Reference source not found.**

Graph -1: Response of dc model transfer function



3.1 [2]Ziegler- Nichols(Z-N) Tuning Method

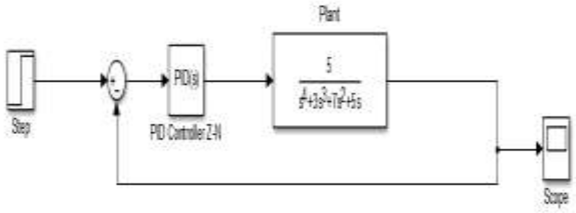
Table -1: Ziegler-Nichols tuning rule based on critical Gain (K_{cr}) and critical period (P_{cr})

Controller parameter	K_P	T_i	T_d
PID	$0.6K_{cr}$	$0.5P_{cr}$	$0.125P_{cr}$

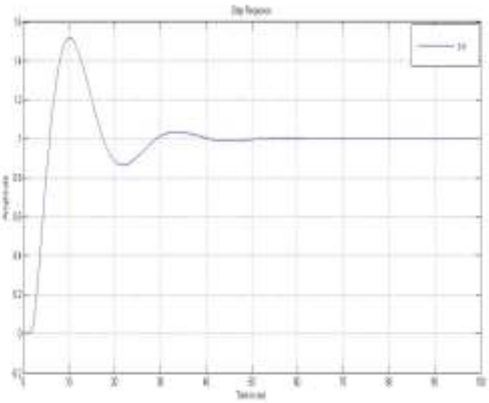
The PID tuning parameters as a function of the open loop model parameters K_{cr}, P_{cr} as derived by Ziegler-Nichols. Where, K_{cr} is critical gain and P_{cr} is period of sustained oscillation. The methods are based on determination of some features of process dynamics.

The controller parameters are then expressed in terms of the features by simple formulas. The method presented by Ziegler and Nichols is based on a registration of the open-loop step response of the system, which is characterized by two parameters. First determined, and the tangent at this point is drawn. A model of the process to be controlled was derived from these parameters. This corresponds to modeling a process by an integrator and a time delay. The behavior of the controller is as can be expected. The decay ratio for the step response is close to one quarter. It is smaller for the load disturbance. The overshoot in the set point response is too large.

Fig-3: PID controller for Z-N method



Graph -2: MATLAB simulation output of Ziegler-Nichols Method

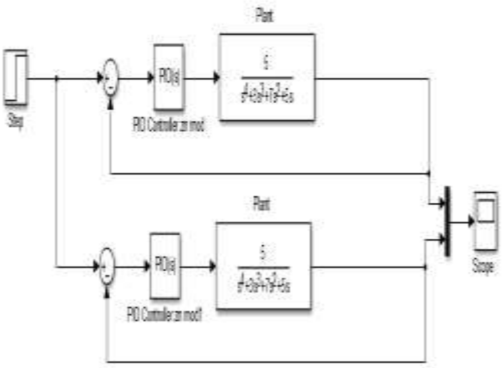


3.2 Modified Ziegler- Nichols Tuning Method

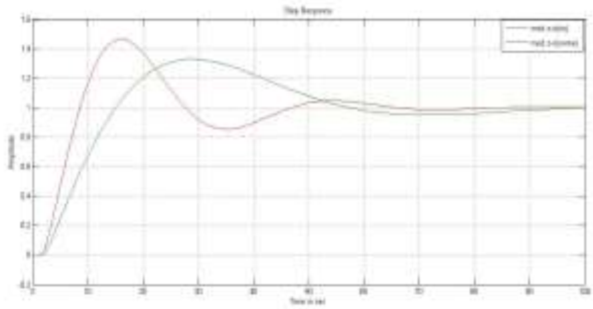
Table -2: Table for modified Ziegler-Nichols tuning rule based on critical Gain (K_{cr}) and critical period (P_{cr})

Controller parameter	K_P	T_i	T_d
Some Overshoot	0.33Kcu	P_{cr} /2	P_{cr} /3
No Overshoot	0.2Kc	P_{cr} 2	P_{cr} /3

Fig-4: Model for modified Z-N method



Graph -3: MATLAB simulation output of modified Ziegler-Nichols Method



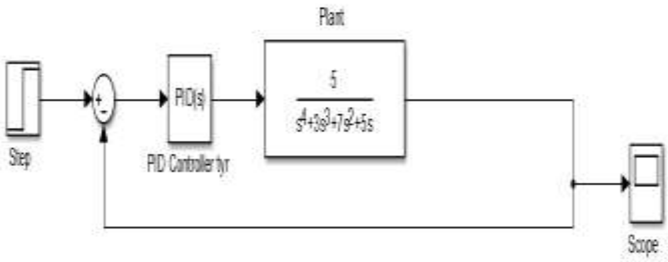
3.3 Tyreus- Luyben Method

Tyreus-Luyben procedure is quite similar to the Ziegler–Nichols method but the final controller settings are different. Also this method only proposes settings for PI and PID controllers.

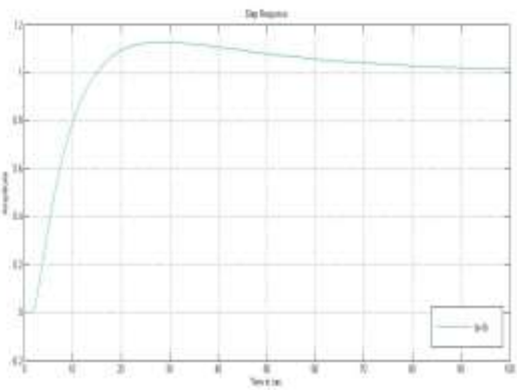
Table -3: Table for Tyreus-Luyben tuning rule based on critical Gain (K_{cr}) and critical period (P_{cr})

Fig-5: Model for Tyreus–Luyben Method

Controller parameter	K_P	T_i	T_d
PID	K_{cr}/3.2	2.2P_{cr}	P_{cr}/6.3



Graph -4: MATLAB simulation output of Tyreus – Luyben Method



4. PARTICALE SWARM OPTIMIZATION

Fig-6: Model for Particle swarm optimization

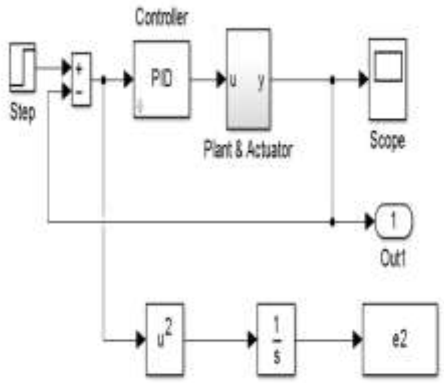
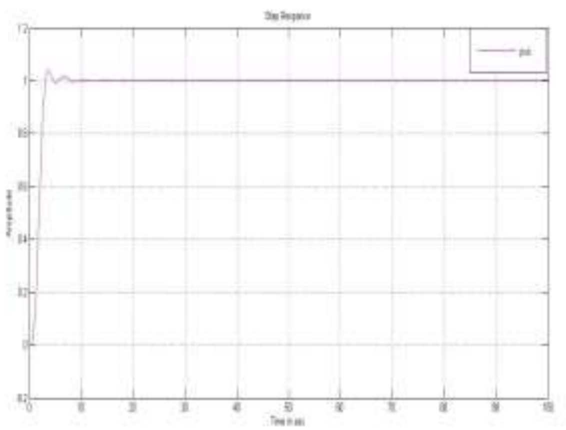


Table -4: Parameters of PSO

PARAMETER	VALUES
No. of particles	50
No. of iterations	100
Velocity constant C_1	0.12
Inertia(weighting -w)	0.9
Velocity constant C_2	1.2

Graph -5: MATLAB simulation output of PSO Method



It can be seen from the above comparison that while using the bio-inspired technique (Particle Swarm Optimization) the overshoots obtained is zero as compared to the case when the PID Controller was tuned via conventional methods. The settling time is also lesser in case of the Particle Swarm Optimization, also the rise time is reduced. The Particle Swarm Optimization PID controller tends to approach the reference speed faster and has, comparatively, a zero overshoot. It can be observed that the Conventional PID controller have overshoot from the reference speed and attain a steady state with larger settling time.

5. OVERALL COMPRESSION

As from the above tables and models for various methods we observe the response i.e. overshoot, rise -time, settling –time. So, we compare the PID parameters of various methods.

Table -5: Table for PID controller by various methods

PID tuning methods	K_p	K_i	K_d
Without controller	-	-	-
Ziegler-Nichols	0.2664	0.223	0.07925
modified Ziegler-Nichols(some –overshoot)	0.14652	0.18312	0.35224
modified Ziegler-Nichols(no –overshoot)	0.0888	0.07462	0.070448
Tyreus-Luyben	0.13875	0.0264	0.05841
PSO	0.8699	0.0007	0.5854

Chart -6: MATLAB simulation output of various methods

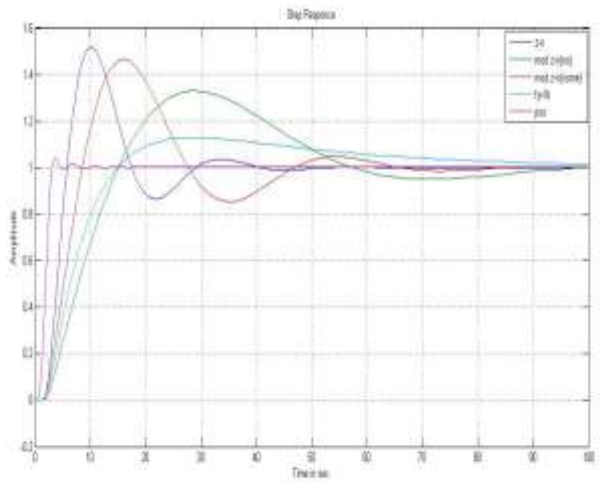


Table -6: Table for PID controller values by various methods

PID tuning methods	OVERSHOOT (PERCENTAGE)	RISE TIME(SEC.)	SETTLING TIME(SEC.)
Ziegler-Nichols	50	5	40
Modified Ziegler Nichols(some -overshoot)	45	7	45
modified Ziegler-Nichols(No –overshoot)	35	15	50
Tyreus-Luyben	10	15	60
PSO	**2**	**4**	**4**

6. CONCLUSIONS

Performance comparison of different controllers has been reviewed and it is found that Particle Swarm Optimization is best among the all methods which are used for tuning the parameter of PID controller for which settling time and rise is found to be less. The conventional controllers however are not recommended for higher order and complex systems as they can cause the system to become unstable. Hence, a heuristic approach is required for choice of the controller parameters which can be provided with the help of Bio inspired methods such as Particle Swarm Optimization, where we can define variables in a subjective way.

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