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A COMPARATIVE STUDY OF PV FED SPEED CONTROL OF DC MOTOR USING SOFT COMPUTING TECHNIQUES

Geerththanna Anantharajan*, Sarat Kumar Sahoo

School of Electrical Engineering,VIT University,Vellore,Tamil Nadu,India
**E-Mail: akeertha@gmail.com, TP: +94775428689*

Abstract: This paper proposes the design a of PID controller to improve the dynamic response of a DC motor using Particle Swarm Optimization and comparing it with that obtained from fuzzy logic. The parameters of the PID controller are tuned in such a way that the settling time, rise time, maximum overshoot in the response are reduced and is closer to the expected ideal response. The model for DC motor was created in MATLAB/Simulink environment and the stimulation results were obtained.

Keywords: DC motor, Fuzzy logic, particle swarm optimization, PID tuning, speed control;

1. Introduction

DC motors are increasingly popular than AC motors due to their applications related to better speed control. Their characteristics enable better torque control and since the rotation speed is independent of frequency they find many applications such as in automobiles, weak power using battery (motor of toy), and electric traction in multi machine system, etc. [1]. DC machines have a good dynamic speed command and better load regulation than AC machines. DC machines are simple in construction, have higher reliabilities and a favourable cost as well. DC machines have better speed torque characteristics and have superior control over speed than AC machines [2]. Many modern control technologies such as the nonlinear control, optimal control, variable structure control and adaptive control are available for controlling the speed of DC motor but, they are often complex and difficult to operate. Recently, many modern control methodologies such as nonlinear control [3], optimal control [4], variable structure control [5] and adaptive control [6] have been extensively proposed for DC motor. However, these approaches are either complex in theoretical bases or difficult to implement [7].

PID controllers are often used in motor applications because they are simple in structure and have comprehensible control algorithms [8]. PID controller uses three parameters known as the propotional, integral and the derivative values used to modify the feedback values to be fed back into the system. Monitoring and using the feedback provides better control on the output [9].

There are several soft computing methods to control the speed of drives [10, 11, and 12].Among various mechanisms to control the speed, one commonly used method is the voltage control method. In Fuzzy logic controller the required voltage sent to the DC motor depends on the Fuzzy rule base of motor speed error and the change of speed error. In fuzzy logic design different range of values of error and change in error will be used as input and a set of if else rules decide the output condition. In [13] Thepsatorn discusses about the better control over the output obtained while using Fuzzy. This paper discusses about the improvement towards a smooth response when using PSO optimization.

Particle Swarm Optimization (PSO) is used to compute the best parameters for PID values in the PID controller. PSO is an iterative technique where a comparative analysis using the fitness function helps compute the best set of PID parameters that give the best output. Best output refers to a smaller overshoot, smaller settling time and high rise time. This approach has superior features, including easy implementation, stable convergence characteristic and good computational efficiency [14].

2. PID controllers

PID controller is used to improve the dynamic response and reduce the steady state error [15]. The general equation of the PID controller is:

$$U(s) = \{\frac{K_p + s.K_d + \frac{K_i}{s}}{E(s)}\} \quad (1)$$

Where: E(S) is the difference between the expected output and the measured output

K_p is the propotional gain

K_i is the integral gain

K_d is the differential gain

This equation in a form of a block diagram will be cascaded with the plant model in the Simulink diagram.

The system under study consists of PV system acts as a voltage source for a connected DC separately excited motor. The input of PV system is the ambient temperature and radiation, while the output is the DC voltage. The proposed controller based on Fuzzy logic and PSO is used to control the duty cycle of DC/DC converter and consequently the voltage and speed of DC motor. The schematic block diagram is shown in Fig. 1.

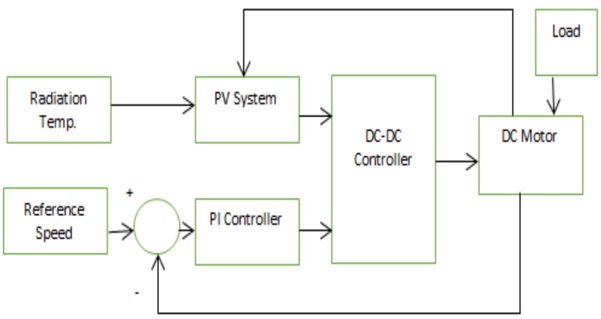

Fig. 1. Block diagram of overall system.

3. Plant model

The emf equation is given by:

$$E = \frac{NP\phi Z}{60A} \quad (2)$$

According to the given equation the speed (N) depends on the voltage (V) and the resistance(R) alone and not the flux, since flux is constant in a separately excited dc motor. The back emf of the motor depends on the rotational velocity. The dc motor model is given above, where both the electrical and mechanical equivalent systems needs to be considered. The back emf of a separately excited DC motor is proportional to rotational velocity [8]

$$V_{emf} = K.wm = K\frac{d\theta}{dt} \quad (3)$$

For the electrical system the kirchoffs equation is given by:

$$L_a . \frac{dI_a}{dt} + R_a . I_a = V_a - K\frac{d\theta}{dt} \quad (4)$$

Taking the Laplace transform of the above gives:

$$(L_a.s + R_a)\, I_a\,(s) = V_a(s) - K.s.\,\theta_m\,(s) \quad (5)$$

Similarly the Laplace of the mechanical equation of the system according to Newton's second law of motion will be given as:

$$J\frac{d^2\theta}{dt^2} + B\frac{d\theta}{dt} = K.I_a \quad (6)$$

Where: J=polar moment of inertia

B=damping constant

K=mechanical torque constant

Tl=load torque

These both represented in a single model would give the following

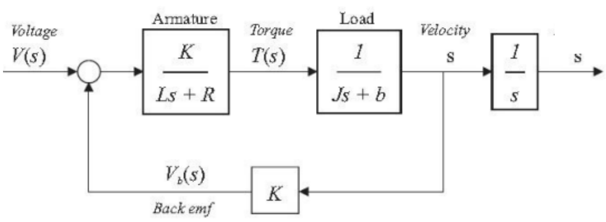

Fig.2. A closed-loop system representing a DC motor

And the transfer function of the above model would become:

$$P(s) = \frac{\theta(s)}{V(s)} = \frac{K}{s\{(Ls+R)(Js+B)+K^2\}} \qquad (7)$$

Table 1: The values of the parameters used is as below

Parameters	Value
Mutual inductance(L)	1.8H
Motor inertia(J)	1Kg.m²
Resistance(R)	0.6Ω
Motor torque constant(K)	1.88N.m/A
Damping Coefficient(b)	0.24N.m.s

4. The cascaded model:

The simplified model of the entire system is shown in Fig 3. Here, the PID controller model defined by equation (1) is cascaded with the plant model defined by equation (7). Optimization to find to obtain steady output for speed is done for the equivalent model shown in Fig 3.

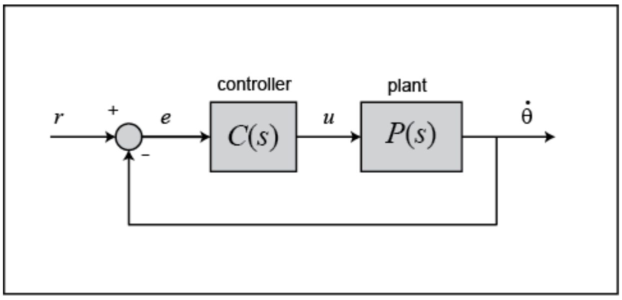

Fig.3. Cascaded model of the controlling unit (PID) and the plant

5. Fuzzy logic for speed control:

There have been many intelligent techiques that have been used to solve problems related to speed control. Fuzzy logic control received more attention because the control depends on defined rules, so is clearer, less time consuming and also donot require an accurate model of the plant. Since we develop rules based on the output, these rules donot require any information about the internal parameters of the dc motor. It was introduced by L.A Zadeh in 1973 and applied by Mamdami in 1974 in an attempt to control the system that are structuraly difficult to model. Fuzzy logic control can even be used in non-linear systems. Fuzzy set theory differs from Boolean theory that takes definite values like zero or one; fuzzy set theory takes values of continuous range of between zero and one (also called partial membership). It also has its disadvantage that fine tuning becomes hard. If fine tuning is more important to us then we can go global optimization techniques like particle swarm optimization and ant colony optimization.

Here each control variable is expressed in a fuzzy set notation using linguistic labels. The seven fuzzy set labels are:

LN (Large Negative)

SN (Small Negative)

ZE (or) Z (zero)

SP (Small Positive)

LP (Large positive)

They are used as triangular functions for the fuzzy input variables: error (E) and rate of change in error (CE). The Fuzzy logic control rests on a set of IF-THEN rules [16, 17, and 18] which represent an emphérical knowledge of the designer of the system. The control rules are given in the table 2. According to the rules given in the table the values of the output variables would vary.

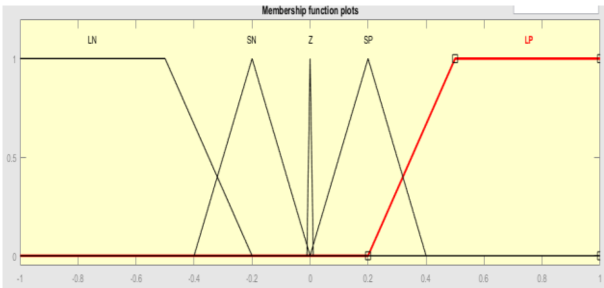

Fig.4. Triangular input membership function for error

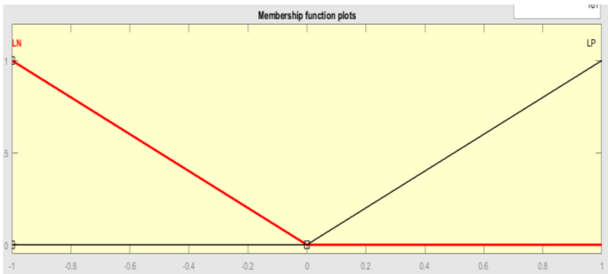

Fig.5. Triangular input membership function for change in error

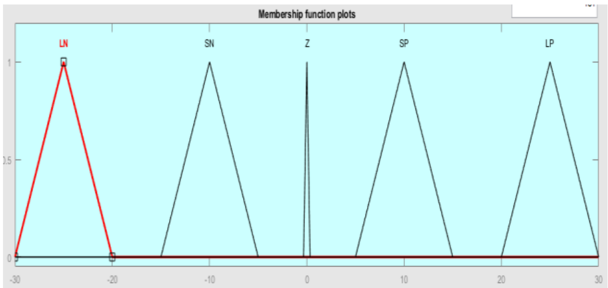

Fig.6. Triangular input membership function for output

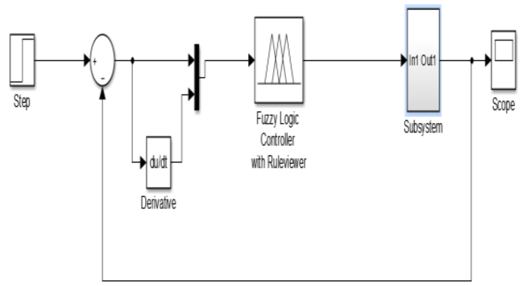

Fig.7. Stimulation diagram for PID controller with Fuzzy logic

Table 2: If-Then rule base for Fuzzy logic control

E / CE	LN	LP	Z	SN	SP
LN	LP	LN	SN	SN	SP
LP	LP	LN	SP	SN	SP

E=error, CE=change in error

The rule of fuzzy logic is implemented in MATLAB is as shown in Table 2. Even though the table seems to show that the output follows the input variable E(error) we should note that the range of the variables (LN,LP,SN,SP and Z) defined in the input E and the output are different according to the Figure 4 and Figure 6.

Without a fuzzy logic controller the response is as shown in Fig 8: where the number of oscillations and the amplitude of the oscillations is high. Here the PID parameters are taken as

Kp=1

Ki=1

Kd=1

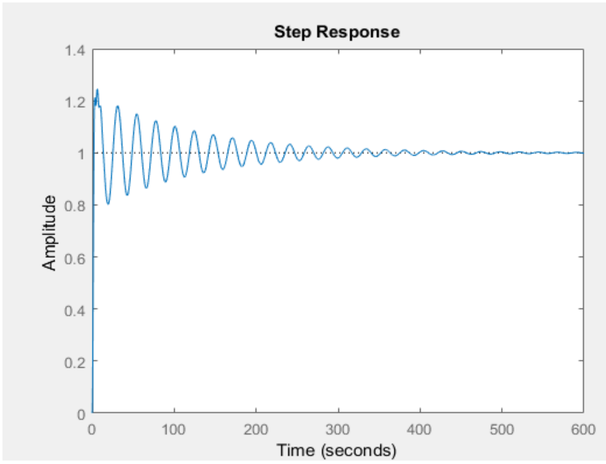

Fig.8. Output respose during stimulation without any control mechanism

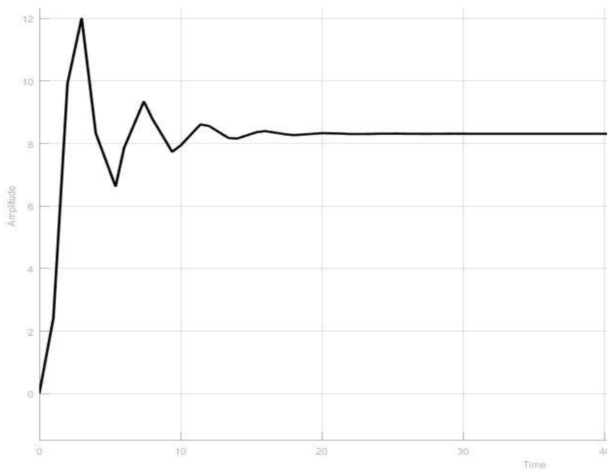

Fig.9. Output response for output using Fuzzy logic control

From the stimulation results it can concluded that the fuzzy logic controller provides better results than the conventional PID controller since there are less number of oscillations and the stability is obtained faster.

6. Particle swarm optimization:

This algorithm was proposed by Eberhart and Kennedy in the year 1995. First create a (n,3) matrix for both position and velocity. The position matrix is randomly generated and this represents the PID values for which we calculate the fitness function given by

$$F(i,1)=100*\exp(0.5)+5*M_p*M_p+10*t_s+t_r \quad (8)$$

Here M_P is the overshoot value and t_s and t_r are the settling time and the rise time respectively. Parameters of the PID controller has to be found such that the value obtained for the fitness function is a minimum. The settling time, rise time and the overshoot details are obtained from the graph plotted using the transfer function of the plant involving the PID parameters.

After obtaining then fitness function find out the parameters for which the fitness function was a minimum. During the first iteration the local and global best value will be the same. Till the maximum numbers of iterations are reached, update the position and velocity matrix according to the updated local and global best positions obtained and updates the global best each time by comparing the local best with the global best position.

$$V_{i,m}^{(t+1)} = W.V_{i,m}^{(t)} + c_1 * rand() * (Pbest_{i,m} - x_{i,m}^{(t)})$$
$$+ c_2 * Rand() * (gbest_m - x_{i,m}^{t})$$
$$x_{i,d}^{(t+1)} = x_{i,m}^{(t)} + v_{i,m}^{(t+1)} \quad \ldots\ldots (9)$$

where

i=1,2,…..,n; m=1,2,….,d

n : Number of particles in the group

$V_{im}^{(t)}$: velocity of particle at iteration i

W: is inertia weight;

$c_1$and c_2 are acceleration constants;

rand(): random number between 0 and 1

$X_{i,m}^{(t)}$:current position of particle i at iteration

$Pbest_{im}$:best previous position of the ith particle

$gbest_m$: best particle among all the particles in the swarm population

t :pointer of iteration

The values of the position that correspond to the best position is the value that needs to needs to be updated as the PID parameters [19, 20, and 21].

The output obtained was a follows when the constants c1, c2 are taken as 1.5 and the number of iterations as well as the number of birds are taken as 100.

In the output obtained here the overshoot has decreased considerably and a stable output is obtained. The rise time and the settling time has also improved. The PID parameters corresponding to this output is found to be:

K_d =0.3699

K_p =0.7219

K_i=0.1665

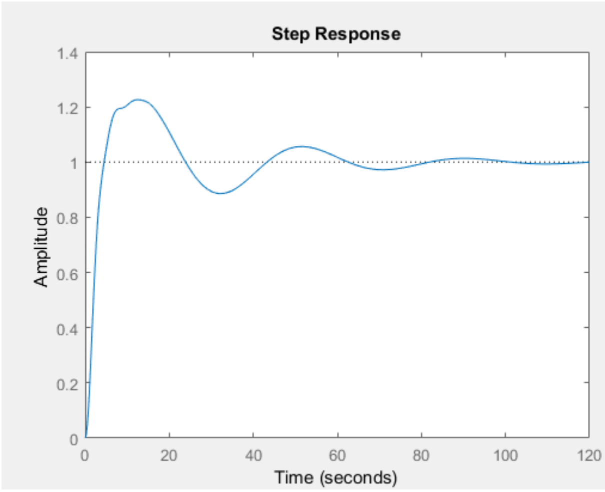

Fig.10. The output when PSO optimization is used

7. Results

Comparison of results w.r.t Fuzzy logic and PSO optimization techniques are shown in the following table 3.

Table-3

Parameters	PSO	FUZZY LOGIC
Rise time	2.88	0.75
Settling time	75.8	23.7
%Overshoot	22.6	60.4

8. Conclusion

In this paper a PSO technique and Fuzzy Logic is used to tune the output response. The PID parameters obtained would improve the dynamic response of the DC motor. The use of an optimization technique to tune the response of the motor is necessary, but when considering which of the optimization technique is better, PSO technique is found to be better according to the results obtained in Table 3. When comparing the results we can see that the relative overshoot is very high when the speed control is done using Fuzzy logic but the rise time is less than that of the response obtained from PSO technique. And while using Fuzzy logic the system reaches stability faster, this is inferred from the smaller settling time when using fuzzy logic. However results obtained from PSO technique will be differ depending on the number of birds, the number of iterations chosen and the value taken for the constants.

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