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Fuzzy PID Control for Networked Control System of DC Motor with Random Design

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ABSTRACT

Separately excited DC motor speed can be controlled using PID controller and fuzzy logic controller. The proportional, integral and derivate (KP, KI, KD) gains of the PID controller are adjusted according to FUZZY LOGIC. First, the fuzzy logic controller is designed according to fuzzy rules so that the systems are fundamentally robust. There are 25 fuzzy rules for self-tuning of each parameter of PID controller. The FLC has two inputs. One is the motor speed error between the reference and actual speed and the second is change in speed error (speed error derivative).Secondly, the output of the FLC i.e. the parameters of PID controller are used to control the speed of the separately excited DC Motor. The study shows that both precise characters of PID controllers and flexible characters of fuzzy controller are present in fuzzy self-tuning PID controller. The fuzzy self-tuning approach implemented on a conventional PID structure was able to improve the dynamic as well as the static response of the system. Comparison between the conventional output and the fuzzy self-tuning output was done on the basis of the simulation result obtained by MATLAB. The simulation results demonstrate that the designed self-tuned PID controller realize a good dynamic behavior of the DC motor, a perfect speed tracking with less rise and settling time, minimum overshoot, minimum steady state error and give better performance compared to conventional PID controller.

1. INTRODUCTION

The development of high performance motor drives is very important in industrial as well as other purpose applications such as steel rolling mills, electric trains and robotics. Generally, a high performance motor drive system must have good dynamic speed command tracking and load regulating response to perform task. DC drives, because of their simplicity, ease of application, high reliabilities, flexibilities and favorable cost have long been a backbone of industrial applications, robot manipulators and home appliances where speed and position control of motor are required. DC drives are less complex with a single power conversion from AC to DC. Again the speed torque characteristics of DC motors are much more superior to that of AC motors. A DC motors provide excellent control of speed for acceleration and deceleration. DC drives are normally less expensive for most horsepower ratings. DC motors have a long tradition of use as adjustable speed machines and a wide range of options have evolved for this purpose. In these applications, the motor should be precisely controlled to give the desired performance. The controllers of the speed that are conceived for goal to control the speed of DC motor to execute one variety of tasks, is of several conventional and numeric controller types, the controllers can be: proportional integral (PI), proportional integral derivative (PID) Fuzzy Logic Controller (FLC) or the combination between them: Fuzzy-Neural Networks, Fuzzy-Genetic Algorithm, Fuzzy-Ants Colony, Fuzzy-Swarm[10]. The proportional – integral – derivative (PID) controller operates the majority of the control system in the world. It has been reported that more than 95% of the controllers in the industrial process control applications are of PID type as no other controller match the simplicity, clear functionality, applicability and ease of use offered by the PID controller [3], [4]. PID controllers provide robust and reliable performance for most systems if the PID parameters are tuned properly.

The major problems in applying a conventional control algorithm (PI, PD, PID) in a speed controller are the effects of non-linearity in a DC motor. The nonlinear characteristics of a DC motor such as saturation and fiction could degrade the performance of conventional controllers [1], [2].Generally, an accurate nonlinear model of an actual DC motor is difficult to find and parameter obtained from systems identification may be only approximated values. The field of Fuzzy control has been making rapid progress in recent years. Fuzzy logic control (FLC) is one of the most successful applications of fuzzy set theory, introduced by L.A Zadeh in 1973 and applied (Mamdani 1974) in an attempt to control system that are structurally difficult to model.

Since then, FLC has been an extremely active and fruitful research area with many industrial applications reported [5].In the last three decades, FLC has evolved as an alternative or complementary to the conventional control strategies in various engineering areas. Fuzzy control theory usually provides non-linear controllers that are capable of performing different complex non-linear control action, even for uncertain nonlinear systems. Unlike conventional control, designing a FLC does not require precise knowledge of the system model such as the poles and zeroes of the system transfer functions. Imitating the way of human learning, the tracking error and the rate change of the error are two crucial inputs for the design of such a fuzzy control system [6], [7].

2. SPEED CONTROL OF SEPARATELY EXCITED DC MOTOR

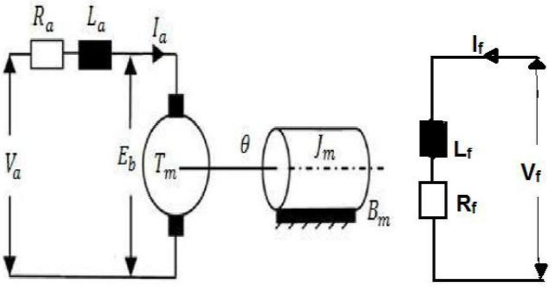

Fig 1: Model of DC Separately Excited Motor

DC motors are most suitable for wide range speed control and are there for many adjustable speed drives. Intentional speed variation carried out manually or automatically to control the speed of DC motors.

$\omega \propto (Va - IaRa)/\phi$
$\omega = (Va - IaRa)/Ka\phi$
Where ϕ = Field flux per pole
Ka= Armature constant = $PZ/2\pi a$
Where P = No. of poles, Z = Total no. of armature conductor,a = No. of parallel path
From the equation (1) it is clear that for DC motor there are basically 3 method of speed control.
They are:-
1- Variation of resistance in armature circuit.
2- Variation of field flux.
3- Variation of armature terminal voltage.

3. MODELING OF SEPARATELY EXCITED DC MOTOR

From fig.1The armature voltage equation is given by:
$Va = Eb + IaRa + La\,(dIa/dt)$
Now the torque balance equation will be given by
$Tm = Jm d\omega/dt + Bm\omega + TL$ ----I

Taking field flux as Φ and Back EMF Constant as K.
Equation for back emf of motor will be
$E_b = K\phi\omega$ -------II

$T_m = K\phi I_a$-------III

Taking laplace transform of the motor‟s armature voltage equation
$Ia(S) = (Va – Eb)/ (Ra + LaS)$
Now, taking equation (ii) into consideration, we have:
$Ia(s) = (Va – K\Phi\omega)/ Ra\,(1+ LaS/Ra)$
And $\omega(s) = (Tm - TL) /JS = (K\Phi Ia - TL) /JmS$
(Armature Time Constant) $Ta= La/Ra$

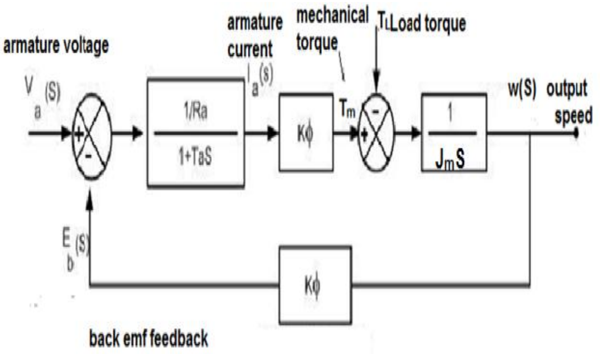

Fig 2: Modelling Block diagram of DC Separately Excited Motor

After simplifying the above motor model, the overall transfer function will be
$\omega(s) / Va(s) = [K\Phi /Ra] /JmS(1+TaS) /[1 + (K^2\Phi^2 /Ra) /JmS(1+TaS)]$

$Tm = Jm d\omega/dt = K\Phi Ia$

$\omega(s) = [(Ra / Km) Ia(s) - TL\, Ra / (Km)^2] (1/Tem(s))$

Now, Replacing $K\Phi$ by Km in equation (v), we will get:
$\omega(s) /Va(s)=(1/Km) / (1+STem+S^2TaTem)$
The armature time constant Ta is very much less than the electromechanical time constant Tem, (Ta << Tem)
Simplifying, $1 + STem + S^2TaTem \approx 1 + S\,(Ta+Tem) + S^2TaTem = (1 + STem)(1 + STa)$
The equation can be written as:
$\omega(s) /Va(s) = (1/Km)/((1 + STem)(1 + STa))$
Tem and Ta are the time constants of the above system transfer function which will determine the response of the system. Hence the dc motor can be replaced by the transfer function obtained in above equation in the DC drive model.

Table 1. Parameters of the separately excited DC Motor

Description of the parameter	Parameter value
Armature resistance (Ra)	0.5Ω
Armature inductance (La)	0.02 H
Armature voltage (Va)	200 V
Mechanical inertia (jm)	0.1 Kg.m2
Friction coefficient (Bm)	0.008 N.m/rad/sec
Back emf constant (k)	1.25 V/rad/sec
Rated speed	1500 r.p.m
Motor torque constant	1 N.m/A

3. Fuzzy Logic Controller

Fuzzy systems are knowledge based or rule based systems. The heart of a fuzzy system is a knowledge base consisting of the so- called If-Then rules. A fuzzy If-Then statement in which some words are characterized by continuous membership functions. After defining the fuzzy sets and assigning their membership functions, rules must be written to describe the action to be taken for each combination of control variables. These rules will relate the input variables to the output variable using If-Then statements which allow decisions to be made. The If (condition) is an antecedent to the Then (conclusion) of each rule. Each rule in general can be represented in the following manner:

If (antecedent) Then (consequence).

For example:

If the speed of the car is high, then apply less force to the accelerator.

If pressure is high, then volume is small

A fuzzy logic controller has four main components as shown in Figure:

a) Fuzzification

b) Inference engine

c) Rule base

d) Defuzzification

In order to define fuzzy membership function, designers choose many different shapes based on their preference and experience. There are generally four types of membership functions used:

1: Trapezoidal MF

2: Triangular MF

3: Gaussian MF

4: Generalized bell MF

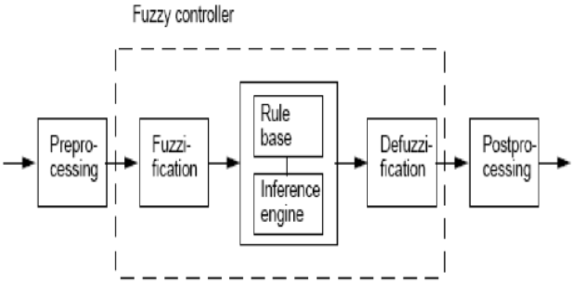

Fig 3: Structure of fuzzy logic controller

Implementation of an FLC requires the choice of four key factors
1: Number of fuzzy sets that constitute linguistic variables.
2: Mapping of the measurements onto the support sets.
3: Control protocol that determines the controller behavior.
4: Shape of membership functions.

PID parameters fuzzy self-tuning is to find the fuzzy relationship between the three parameters of PID and "e" and "de", and according to the principle of fuzzy control, to modify the three parameters in order to meet different requirements for control parameters when "e" and "de" are different, and to make the control object a good dynamic and static performance [12].

3.1 Adjusting fuzzy membership functions and rules

In order to improve the performance of FLC, the rules and membership functions are adjusted. The membership functions are adjusted by making the area of membership functions near ZE region narrower to produce finer control resolution. On the other hand, making the area far from ZE region wider gives faster control response. Also the performance can be improved by changing the severity of rules [15]. An experiment to study the effect of rise time (Tr), maximum overshoot (Mp) and steady-state error (SSE) when varying KP, KI and KD was conducted. The results of the experiment were used to develop 25-rules for the FLC of KP, KI and KD are the out put variables and from error and change of error are the input variables. Triangular membership functions are selected.

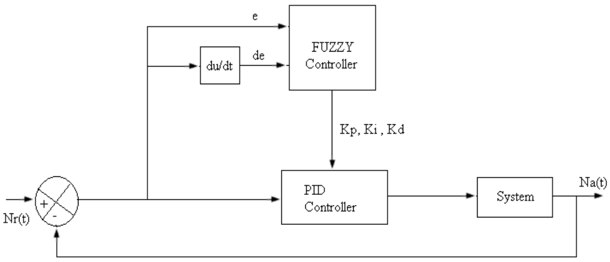

Fig 4: Block diagram of self-tuning fuzzy PID controller.

3.2 Rule Base for PID parameters

Table 2. Rule base for tuning KP Parameters

de / e	NL	NS	ZE	PS	PL
NL	PVL	PVL	PVL	PVL	PVL
NS	PML	PML	PML	PL	PVL
ZE	PVS	PVS	PS	PMS	PMS
PS	PML	PML	PML	PL	PVL
PL	PVL	PVL	PVL	PVL	PVL

Table 3. Rule base for tuning Ki

de / e	NL	NS	ZE	PS	PL
NL	PM	PM	PM	PM	PM
NS	PMS	PMS	PMS	PMS	PMS
ZE	PS	PS	PVS	PS	PS
PS	PMS	PMS	PMS	PMS	PMS
PL	PM	PM	PM	PM	PM

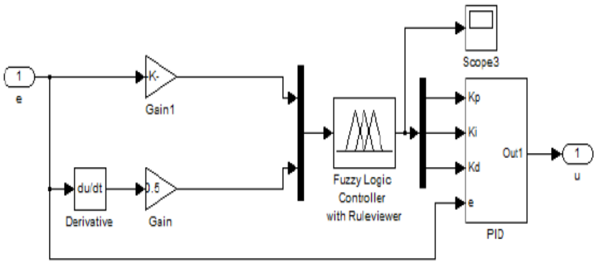

Fig 5: Simulink diagram of fuzzy-PID controller

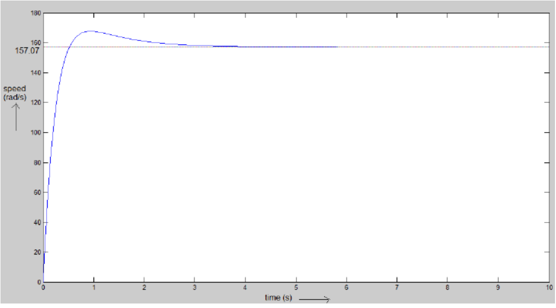

Fig75: Speed Vs time response of fuzzy tuned PID controlled DC motor.

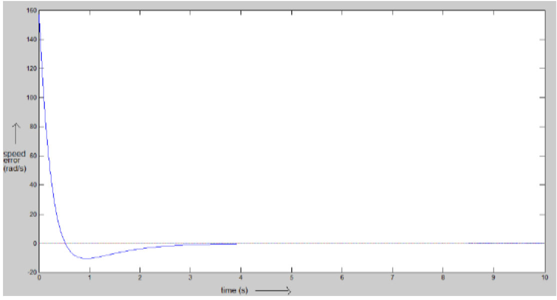

Fig 8: Error Vs time response of fuzzy tuned PID controlled DC motor.

Table 4. Rule base for tuning Kd

de / e	NL	NS	ZE	PS	PL
NL	PVS	PMS	PM	PL	PVL
NS	PMS	PML	PL	PVL	PVL
ZE	PM	PL	PL	PVL	PVL
PS	PML	PVL	PVL	PVL	PVL
PL	PVL	PVL	PVL	PVL	PVL

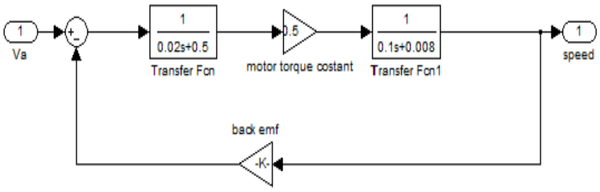

Fig 6: Simulink diagram of separately excited dc motor

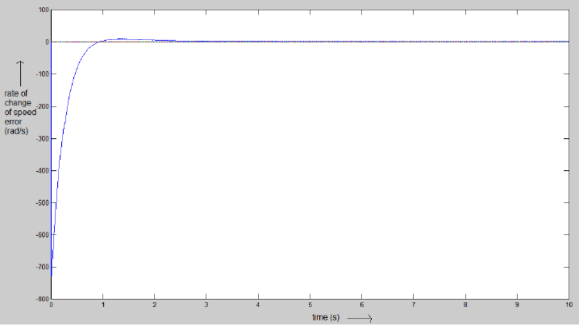

Fig 9: Change of speed Vs time response of fuzzy tuned PID controlled DC motor

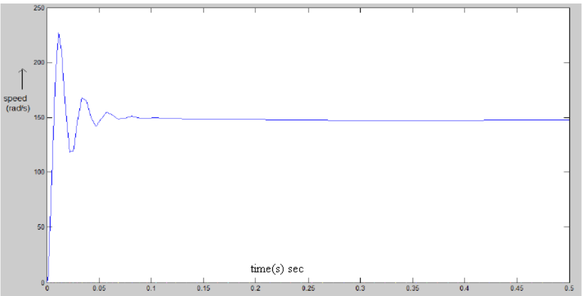

Fig 10: Speed Vs time response of PID controlled DC motor

4. CONCLUSION

Self-tuned tuning PID controller is less in quality of operation and performance compared to conventional PID controller. The three parameters "KP", "KI", "KD" of conventional PID control need to be constantly adjust adjusted online in order to achieve better control performance. Fuzzy self-tuning PID parameters controller can automatically adjust PID parameters in accordance with the speed error and the rate of speed error-change, so it has better self-adaptive capacity fuzzy PID parameter controller has smaller overshoot and less rising and settling time than conventional PID controller and has better dynamic response properties and steady-state properties. Steady state error in case of self tuned fuzzy PID is less compared to conventional PID controller.

Design method of two inputs and three outputs self-tuning fuzzy PID controller and make use of MATLAB fuzzy toolbox to design fuzzy controller. The fuzzy controller adjusted the proportional, integral and derivate (KP, KI, KD) gains of the PID controller according to speed error and change in speed error .From the simulation results it is concluded that ,compared with the conventional PID controller, self-tuning PID controller has a better performance in both transient and steady state response. The self tuning FLC has better dynamic response curve, shorter response time, small overshoot, small steady state error (SSE),high steady precision compared to the conventional PID controller.

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