Adaptive Fuzzy Logic Tuned Controller for Separately Excited DC Motor

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Abstract: The non-linear characteristics of a separately excited DC motor must be controlled for the reliable and efficient operation of the motor. The objective of this paper is to adjust the controller parameters using fuzzy logic technique. The fuzzy logic based proportional- integral-derivative controller has been proposed for this particular purpose which is using rule-based Mamdani system to employ fuzzy sets in consequent part. The two input of the controller i.e. error in speed and the variations in speed are continuously measured to investigate the performance of the applied technique. The results obtained from the proposed method have lesser transients and minimum settling time for controlling the speed of motor in comparison with conventional PID controller.

Keywords: Separately excited DC (SEDC) motor, PID controller, Speed control, Mamdani, Fuzzy logic control.

I. Introduction

The AC and DC motors have widespread application area such as industrial, commercial and military, home and medical fields. Where the DC motors are especially used in robot arms, electric drills, electric vehicles, lifts, pumps, fans, saws, audio equipment, elevators, aircrafts, tractions, artificial limbs which are controllable, chemical injection and agricultural machinery due to simple design and high performance [1-5]. Moreover the DC drives are less expensive with a wide range of operation and use as adjustable speed machines. The operating characteristics of SEDC motors are much better than the characteristics of AC motors. It is convenient to control the acceleration and deceleration of high voltage SEDC motors provided the controller is tuned as per the application. The operation of DC motor gets effected by the nonlinearities in the load.

Therefore precise measurement of mechanical parameters of motor is vital for its reliable performance. The SEDC motors as compared to the permanent magnet motors of same size have high torque over their weight. Many control algorithms has been designed for PI, PD and PID by researchers to improve the settling and maximum overshoot time ultimately modified to behave in specific manner [6-9]. Proper tuning of PID controller provides robust and reliable performance. There are different tuning methods discussed in literature that are manual tuning, loop shaping, analytical tuning, self-tuning, optimization techniques based tuning and by arranging the pole placement in s-plane [8].

The fuzzy logic based self tuning process does not require the deep knowledge of motor parameters and are also ready to tune the systems which are structurally complex. This method provides high degree of tolerance gives smooth transitions/control of motor speed and reduces the effect of nonlinearities. Thus the paper is presented as follows. In section 2, the mathematical model of SEDC motor which is used in simulation has been discussed and the tuning of PID controller with fuzzy logic technique is elaborated and the section 3 includes the simulation results obtained by applying the proposed technique which are further compared with the conventional controller. The last section concludes the work presented in this paper.

2. Modelling of Motor with Fuzzy PID Controller

The speed of the dc motor can be kept under control by either controlling the field armature or field voltage. The armature field resistance must be reduced to increase the speed of the motor. However the flux never be reduced till maximum limit because that cause the speed of motor may gets out of control and may lead to impact the motor performance [9-ll]. Moreover, due to the weak main field the armature reaction is relatively large that may reach to instability.

On the other hand by keeping the field constant and by varying the applied voltage allows a range of no load speed. The conventional methods to vary the voltage by using voltage divider, solid state controlled rectifiers, Ward-Leonard method for speed control etc. Whereas the conventional PID controller used to achieve the optimal operating condition having fixed structure with fixed parameters has poor robustness [10]. These controllers cannot cop up with the nonlinear behavior of the DC motors such as frication and saturation.

Therefore a fuzzy logic technique is used to tune the controller parameters to achieve the inaccuracy or imprecision in the conventional controllers. This technique offers simpler and reliable solution to compensate the nonlinearities to provide the high level functionality of the controller [12-14]. The machine is mathematically modeled using following equations referring figure 1.

Using basic Kirchhoff's laws the armature voltage (V_a) is defined as:

$$V_a(t) = E_b + I_a R_a + L_a\,(dI_a/dt) \quad (1)$$

The mechanical torque developed is given equation (2)

$$T_m(s) = J_m d\omega(s)/dt + B_m \omega(s) + T_L \quad (2)$$

The friction in motor can be neglected i.e. $B_m = 0$

Hense the torque equation is

$$T_m = J_m d\omega(s)/dt + T_L \quad (3)$$

The back emf equation of motor is

$$E_b = K_\Phi\,\omega \text{ and } T_m = K_T I_a \quad (4)$$

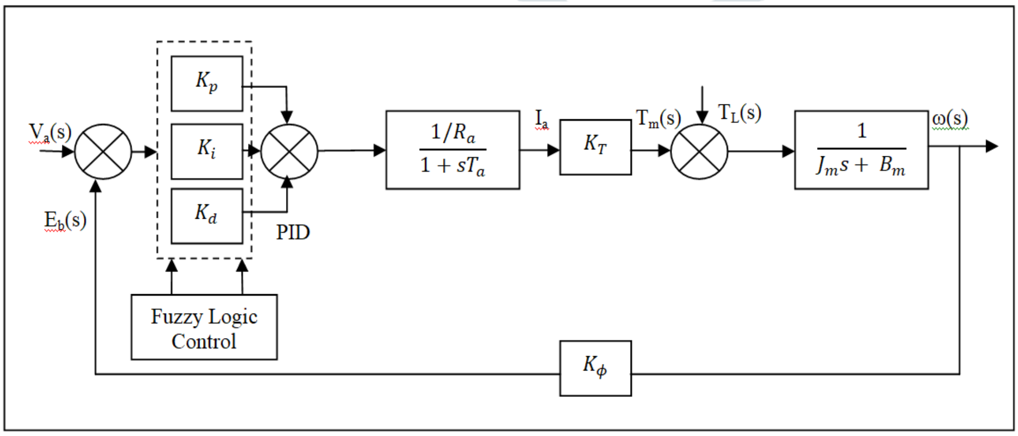

Figure 1. Fuzzy Logic based Controller for Motor Control

The overall transfer function is presented in equation (5) by simplifying the motor model,

$$\omega(s) / V_a(s) = [\{K_T / R_a\} / (J_m s * (1+T_a s)) / \{1 + (K_\Phi * K_T / R_a) / J_m s * (1+T_a s)\}] \quad (5)$$

Where the armature voltage (V_a in volts), the armature current (I_a in amperes), the armature resistance (R_a in ohms), the armature inductance (L_a in henrys) the back emf the motor (E_b in volts), the mechanical torque developed (T_m in N-m), the moment of inertia (J_m in kg/m²), the friction coefficient of the motor (B_m in Nm/(rad/sec)), the load torque (T_L in N-m) and the angular velocity (ω in rad/sec). However, when the load is balanced the load torque T_L has constant value, the voltage is constant at steady state, motor speed is constant, and while the load is unbalanced the load torque is represented below

$$T_L = T_1 + T_{2*} \operatorname{Sin} \theta \quad (6)$$

Where T_1 is constant torque and T_{2*} Sin θ is the oscillatory load torque with angular position (θ) of the rotor. Under balanced condition there are no oscillations in the speed of motor and the load torque coefficient T_2 is zero. On the other hand under unbalanced condition the T_2 is not zero and the motor speed oscillates around the constant speed.

The input to the controller is error in speed e(s) and change in speed error de(s). Using fuzzy logic rules the parameters of PID are modified and it became self tuned. The fuzzy relationship between the PID gains i.e K_p, K_i, K_d, speed error e(s) and change in speed error de(s) are defined so that the motor speed can be stabilized in dynamic and static conditions.

The membership functions are accustomed so that the controller performance can be improved. In order too produce finer control resolution the area of membership functions is narrow and nearer to the ZE region. Whereas, in case the area of membership functions is wider and away from the ZE region the response of the controller is faster. Moreover by changing the severity of rules the overall performance can be enhanced.

The variation in the controller parameters affect the rise time, peak overshoot and steady-state error around the expected speed of machine can be observed in the simulation results.

Table 1. Speed Error Fuzzy Membership Functions

Fuzzy set (Label)	Description	Numerical Range	Type of Membership Function
Negative Large (NL)	Large Speed difference in negative direction	-10 to 10 -10 to -3.35	Triangular
Negative Small (NS)	Small Speed difference in negative direction	-6.662 to -3.335 -3.335 to 3.333	Triangular
Zero (ZE)	Speed difference is zero	-3.335 to 0 0 to 3.333	Triangular
Positive Small (PS)	Small Speed difference in positive direction	-3.335 to 3.333 3.333 to 6.667	Triangular
Positive large (PL)	Large Speed difference in positive direction	3.333 to 10 10 to 10	Triangular

The fuzzy sets of the speed error and change in speed error variables are the input variables of the fuzzy system using Mamdani model are presented in table1 and table 2 respectively. The fuzzy sets with their numerical range for the output variables i.e. controller parameters K_p, K_i, K_d, are presented in table 3. For the tuning of the controller parameters the fuzzy rules within the acceptable range of high efficiency are given in table 3.

Table 2. Change in speed error fuzzy membership functions

Fuzzy set (Label)	Description	Numerical Range	Membership Function
Negative large (NL)	Large error difference in negative direction	-10 to -10 -10 to -3.332	Triangular
Negative small (NS)	Small error difference in negative direction	-6.668 to -3.332 -3.332 to 3.332	Triangular
Zero (ZE)	error difference is zero	-3.332 to 0 0 to 3.332	Triangular
Positive Small (PS)	Small error difference in positive direction	-3.332 to 3.332 3.332 to 6.668	Triangular
Positive large (PL)	Large error difference in positive direction	3.229 to 9.893 9.893 to 9.893	Triangular

Table 3. Fuzzy membership function of PID gains

Fuzzy set (Label)	Numerical Range (K_p)	Numerical Range (K_i)	Numerical Range (K_d)	Membershi p function
Positive very small (PVS)	0 to 0 0 to 19.99	0 to 0 0 to 0.3333	0 to 0 0 to 0.3333	Triangular
Positive Small (PS)	0.159 to 10.2 10.2 to 30.2	0 to 0.1667 0.1667 to 0.5	0 to 0.1667 0.1667 to 0.5	Triangular
Positive Medium small (PMS)	10 to 19.99 19.99 to 40.02	0.1667 to 0.3333 0.3333 to 0.6667	0.1667 to 0.3333 0.3333 to 0.6667	Triangular
Positive Medium (PM)	19.99 to 30 30 to 40.02	0.3333 to 0.5 0.5 to 0.6667	0.3333 to 0.5 0.5 to 0.6667	Triangular
Positive Medium Large (PML)	19.99 to 40.02 40.02 to 49.98	0.3333 to 0.6667 0.6667 to 0.8333	0.3333 to 0.6667 0.6667 to 0.8333	Triangular
Positive Large (PL)	30 to 49.98 49.98 to 60	0.5 to 0.8333 0.8333 to 1	0.5 to 0.8333 0.8333 to 1	Triangular
Positive very Large (PVL)	40.02 to 60 60 to 60	0.6667 to 1 1 to 1	0.6667 to 1 1 to 1	Triangular

Table 4: Fuzzy rule table for PID controller parameters

	Rules for K_p					Rules for K_i					Rules for K_d				
$dE_a(s)/E_a(s)$	NL	NS	NL	NS	ZE	PS	PL	ZE	PS	PL	NL	NS	ZE	PS	PL
NL	PVL	PVL	PVS	PMS	PM	PL	PVL	PM	PM	PM	PVS	PMS	PM	PL	PVL
NS	PML	PML	PMS	PML	PL	PVL	PVL	PMS	PMS	PMS	PMS	PML	PL	PVL	PVL
ZE	PVS	PVS	PM	PL	PL	PVL	PVL	PVS	PS	PS	PM	PL	PL	PVL	PVL
PS	PML	PML	PML	PVL	PVL	PVL	PVL	PMS	PMS	PMS	PML	PVL	PVL	PVL	PVL
PL	PVL	PVL	PVL	PVL	PVL	PVL	PVL	PM	PM	PM	PVL	PVL	PVL	PVL	PVL

3. Results and Discussions

The simulink model of the fuzzy logic control PID controller is given in figure 2 with input rated speed and output speed is observed on the scope. The variations in the parameters are analyzed and adjusted according to the desired motor speed.

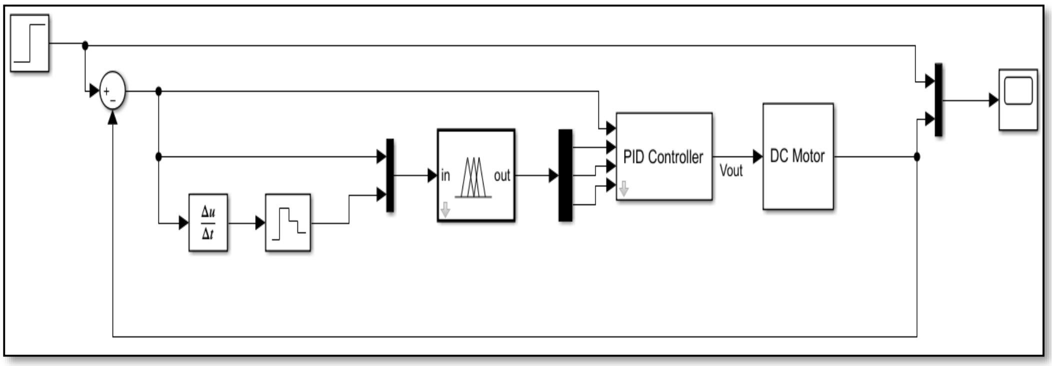

Figure 2. Fuzzy based PID controller for separately excited DC motor

Figure 3 is depicting the pink graph of output from the DC motor with the variation due to internal losses. The time taken by the motor to reach the steady state is maximum compare to the motor with PID controller and fuzzy based PID controller. The transient time is larger and the maximum overshoot of the first peak is high.

Figure 3. Response without any controller

Figure 4. Response with PID controller

In figure 4 the green graph explains the output speed of the machine controlled using PID controller. The speed increase gradually to attain the steady state and the time taken is around 0.9 seconds. Whereas the simulation result of motor speed with PID controller parameters tuned using fuzzy logic technique illustrates the superiority of the method to achieve the steady state within 0.07 sec, which in turns increase the overall system stability and reliability.

Figure 5. Response with fuzzy based PID controller

Conclusion

This paper presented the PID controller using fuzzy logic technique of mamdani's rule base that can tune itself. The controller gains are being adjusted as per the received output in the form of speed error and change in speed error. The simulations are carried out using MATLAB software and the controller is designed using fuzzy tool box in simulink. The dynamic response curve results shown have less response time, reduced overshoot, minimum steady state error, high accuracy. Thus the overall system stability and reliability is higher in comparison to the conventional PID controller.

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