Position Control of DC Motor by using PID, FLC, ANN Controller Techniques and the Comparison of Performances

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***Abstract*— Growing needs of industry for higher productivity is placing new demands on mechanisms connected with electric motors. This is leading to different problems in work operations due to fast dynamics and instability. The stability of the system is essential to work at desired set targets. The non-linear effects caused by motor frequently reduce stability, which reduces the controller's ability to maintain speed or position at set points. Hence number of industrial applications requires position control of DC motor. The position control of DC motor allow the DC motor to move to a precise position and remain there even if an external force tries to move it. Position control of DC motor is widely used for the robotic arm control, aerospace automation, mechatronics, cranes etc. The position control of DC motors can be achieved using various techniques including PID Controller, Fuzzy Logic Controller, ANN Controller, etc. In this paper MATLAB/SIMULINK is used to perform the position control of the DC motor using PID Controller, FLC and ANN Controller techniques and the comparison of their performances.**

Keywords*— Proportional-Integral-Derivative, FLC- Fuzzy Logic Controller , ANN-Artificial Neural Network, Kp–Proportional Gain

I. INTRODUCTION

A DC motor is a motor that takes in the DC power and converts it to rotational motion. The DC motors are widely used for the industrial applications. The PID Controllers are widely commonly used for the position control due to simple structures and comprehensive operations. However the designing and tuning of the PID for the position control of the DC motor might not be adequate to achieve the desired objectives. In contrast the intelligent control techniques such as the FLC and the ANN controllers are widely used. The FLC control has emerged one of the most active areas of research in industrial processes that relies on logical system which are much closer to the human thinking. FLC is based on the fuzzy logic provides a means of converting a linguistic control strategy based on expert knowledge into automatic control strategies. And the ANN is a massively parallel distributed processor made up of simple processing units that have a natural propensity for storing experiential knowledge and make it available for use.

II. MOTOR MODEL

In position control of DC motor, DC motor acts as an actuator in control systems. It provides rotary motion, and coupled with drums and wheels can provide translational motion.

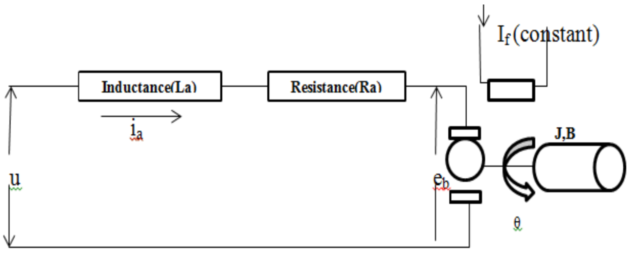

Fig.1: The electric circuit of the armature and the free body diagram of the rotor

The input to the system is the voltage applied to the motors armature (v), while the output is the angular position of the shaft (θ).

A. System Equations

The voltage loop equation is-

$$u(t) = La\frac{dia(t)}{dt} + Ria(t) + eb(t)$$

Where

L_a= inductance of armature windings (Henrys)

R_a= Resistance of armature windings (ohms)

i_a = armature current (Amperes)

e_b= back emf(volts)

u= applied armature voltage (volts)

The torque balance equation is-

$$Tm(t) = \frac{Jd\omega(t)}{dt} + B\omega(t)$$

Where $\frac{d\theta(t)}{dt} = \omega(t)$

Tm= torque developed by motor (Newton-m)

J= equivalent moment of inertia of motor and load referred to motor shaft (kg-m^2)

B= equivalent viscous friction coefficient of motor and load referred to motor shaft ((Newton-m)/(rad/sec))

ω= angular velocity of motor shaft (rad/sec)

For the armature controlled motor, the field current I_f is held constant. Therefore the torque Tm developed by the motor, is expressed as-

$T_m(t)= K_T\, i_a(t)$

Where, K_T= motor torque constant ((Newton-m/amp))

The counter electromotive force e_b-

$e_b(t)= K_b\, \omega(t)$

Where, K_b= back emf constant

Using above equations we obtain:

$$J\ddot{\theta}(t)+B\frac{d\theta(t)}{dt} = K_T\, i_a(t)$$

& $La\frac{dia(t)}{dt} + Ria(t) + eb(t)$

Taking Laplace of above equations we obtain:

$s(Js + B)\,\theta(s) = K\,I(s)$

$(Ls + R)\,I(s) = U(s) - Ks\theta(s)$

Transfer Function is obtained by dividing above two equations is

$$P(s) = \frac{\theta(s)}{U(s)} = \frac{K}{s((Js+B)+(Ls+R)+K^2)} \quad \{\frac{rad}{v}\}$$

B. Assumption of Various Physical Parameters

Moment of inertia of Rotor (J)= 3.1894E-6 kg.m^2;
Motor viscous friction constant (B)= 3.8155E-6 N.m.s;
Electric Resistance (R)=8Ω;
Electric Inductance (L)=2.89E-6H;
Motor Toorque constant (K_t)=0.0579 N.m/Amps;
Electromotive force constant (K_b)= 0.0274 V/rad/sec;

III. POSITION CONTROL OF DC MOTOR USING PID

The PID controller is the most common form of feedback. It was an essential element of early governors and it became the standard tool when process control emerged in the 1940s. In process control today, more than 95% of the control loops are of PID type, most loops are actually PI control and few are propotional control aswell. Today PID controllers are found in all areas where control is used because of their low cost and comprehensive operation.

A. Proportional Controller

In the proportional control algorithm, the controller output is proportional to the error signal, which is the difference between the set point and the process variable.

Mathematical Expression:

$u(t) = K_p\,e(t)$

Where

$u(t)$ = Output of the proportional controller
K_p = Proportional gain
$e(t)$ = Error at time t.

By applying the MATLAB Code for different values of K_p i.e ranging from 1 to 21 we obtained the response to the step disturbance as follows:

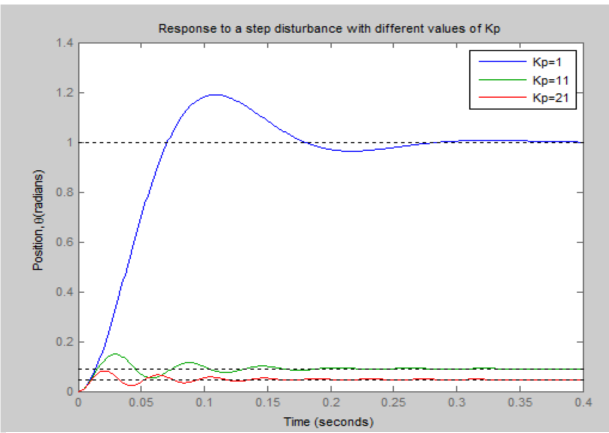

Fig.2: Response to a step disturbance with different values of K_p

From above it can be concluded that the system has significant steady state error in presence of disturbance. In order to have the zero steady state in the presence of disturbance, the disturbance response should decay to zero. The larger the value of Kp, the smaller the steady state error is due to disturbance, but it can never reach zero. Furthermore the increasingly larger value of Kp has adverse effects of increasing the overshoot and the settling time.. By adding the integral term the system can reduce the steady error and the derivative term can reduce the overshoot and the settling time.

B. Proportional- Integral Controller

A PI Controller (proportional-integral controller) is a special case of the PID controller in which the derivative of the error is not used.

Mathematical Expression:

$u(t) = K_p e(t) + K_I \int e(t)dt$

Where

K_I = Integral gain

By applying MATLAB Code for PI Control for step disturbance with Kp fixed to 25 and Ki ranging from 100 to 500 we obtained following results:

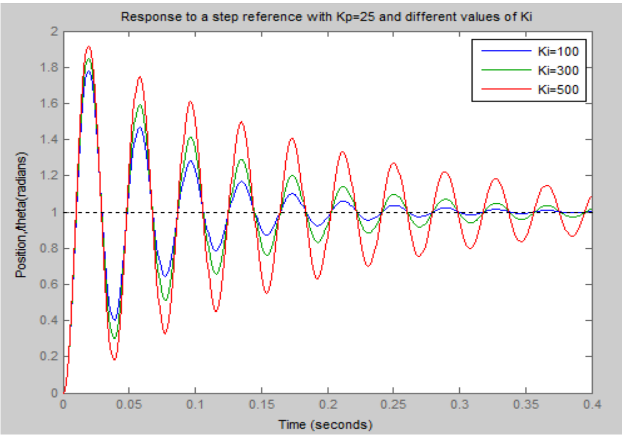

Fig.3: Response to a step disturbance with Kp=25 and different values of K_i

From the above plot it can be concluded that the integral control has reduced the steady state error to zero in the presence of step disturbance. The plot shows that larger the value of Ki, faster the error decays to zero as for Ki=500, the error due to disturbance decays to zero quickly, even though the response has larger settling time and longer overshoot, which can be further fixed by using the derivative term to the controller.

C. Proportional-Integral-Derivative Controller

Adding a derivative term to the PI controller means that we now have all three terms of the PID controller.

Mathematical expression:

$u(t) = K_p e(t) + K_I \int e(t)dt + K_D \frac{de(t)}{dt}$

Where K_D = Derivative gain

By applying the Matlab Code for PID control for Kp=25, Ki=500 and different values of Kd we obtained:

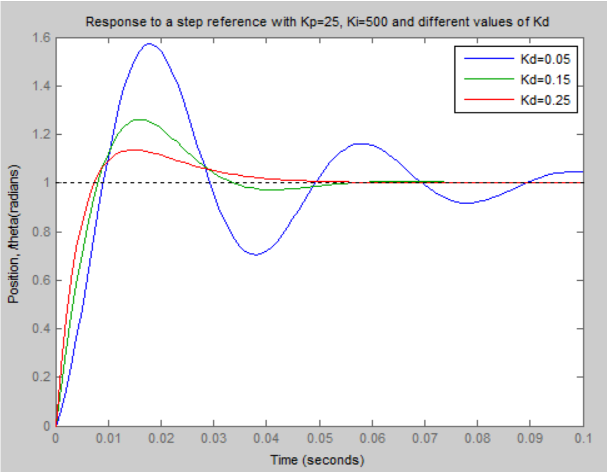

Fig.4: Response to a step distgurbance with K_p=25, K_i=500 & different values of K_d

Parameters obtained for Kd= 0.15:

RiseTime: 0
SettlingTime: 0.0338
SettlingMin: 2.3649e-05
SettlingMax: 0.0397
Overshoot: 12.1139
Undershoot: 0
Peak: 0.0397
PeakTime: 0.0203

From the above it can be concluded that the response to the step disturbance has a settling time of roughly 34 ms, overshoot of 12% and no steady error.

IV. POSITION CONTROL OF DC MOTOR USING FUZZY LOGIC MODEL

FLCs are complex, nonlinear controllers. Therefore it's difficult to predict how the rise time, settling time or steady state error is affected when controller parameters or rules changed. A fuzzy logic controller has four main components fuzzification interface, inference mechanism, rule base and defuzzification interface.

A. Simulink Model

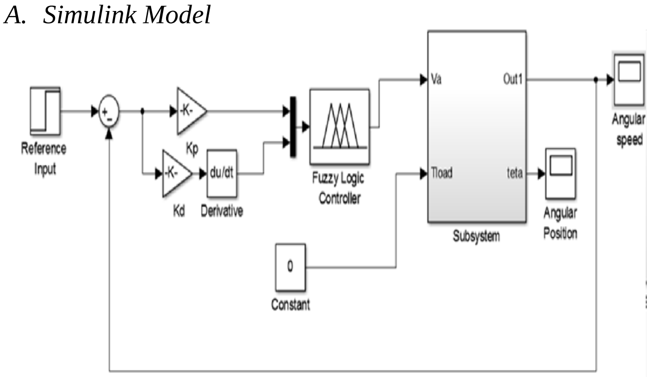

Fig.5: Simulink Model used for the Position Control of DC Motor Using Fuzzy MATLAB Toolbox

B. Input and Output Membership Functions

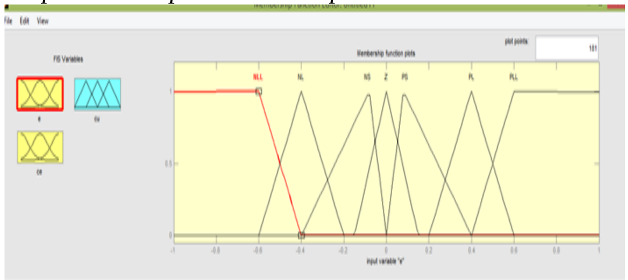

Fig.6: Membership Functions for input **e** using Mamdani Inference

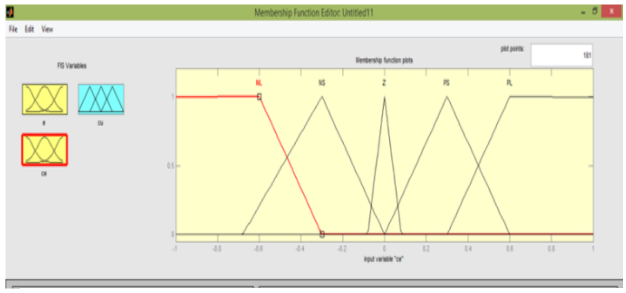

Fig.7: Membership Functions for two inputs **ce** using Mamdani Inference

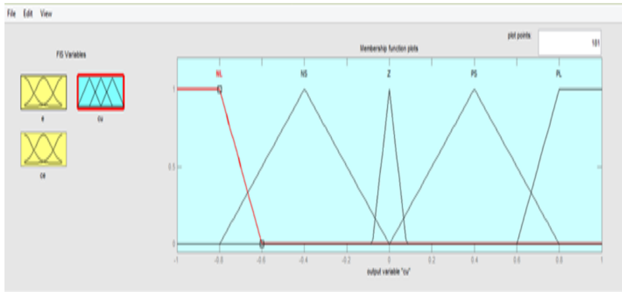

Fig.8: Membership Function for output **cu** using Mamdani Inference

C. Result obtained

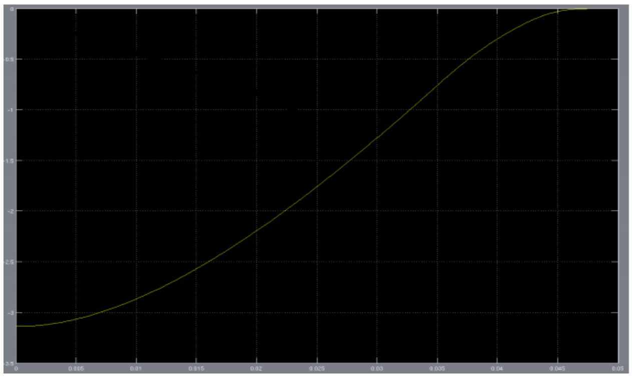

Fig.9: Response obtained from the proposed scheme

From the above obtained plots it can be concluded that the response time obtained is less than 30ms with an approximate steady state error of zero without any overshoot

V. POSITION CONTROL OF DC MOTOR USING NEURAL NETWORKS

A neural network is a machine that is designed to model the way in which the brain performs a particular task or function of interest; the network is usually implemented by using electronic components or is simulated in software on a digital computer. The derives its computing power through, first its massively parallel distributed structure and second, its ability to learn and therefore generalize.

A. Simulink Model

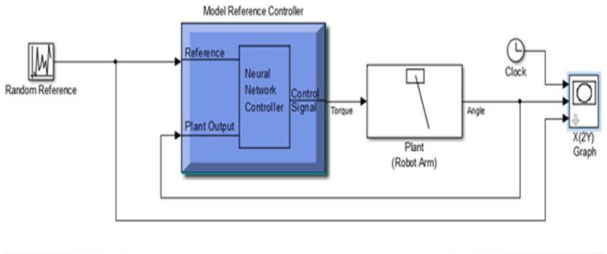

Fig.10: Simulink Model used for the Position Control of DC Motor

B. Training Data for Neural Network Model Reference Control

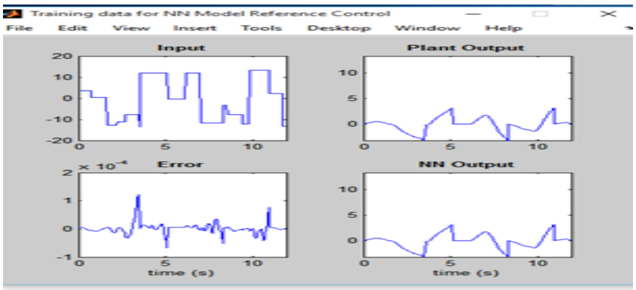

Fig.11: Training data for the neural netwok model

C. Output Simulation Result

The output simulation result has time on X-axis and amplitude level on Y-axis. The step signal is the input reference signal and the curve is the controlled angular position of DC motor to a given step input. It is observed that the output of the plant follows the input reference signal with the desirable results

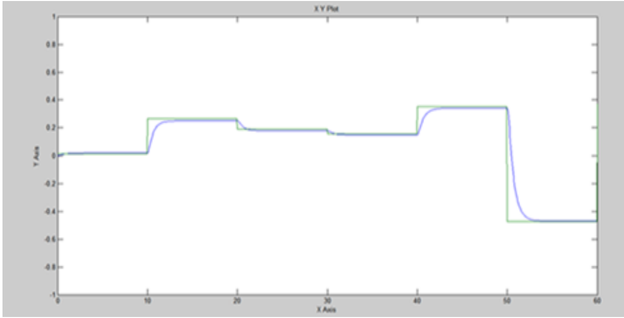

Fig.12: Output curves obtained from simulation

VI. CONCLUSION

It can be inferred that as the neural network control learns from experience as the neural network is trained through data set under supervised learning. Therefore the neural networks control is more responsive to the uncertainties in the system and proves out to be more accurate than the PID and the fuzzy control systems for the industrial applications. Also the controller as in case of the Fuzzy Controller the response time and the overshoot is much less as compared to PID Controller and the steady state error is zero. This makes the Fuzzy Logic Controller a better system for position control of DC motor than a PID Controller.

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