THE SPEED CONTROL OF DC SERVO MOTOR WITH PROPORTIONAL INTEGRAL, FUZZY LOGIC AND ADAPTIVE NEURO-FUZZY INFERENCE SYSTEMS

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Abstract

In this study DC servo motor's mathematical model and equations were extracted for solving the speed control problem. There were three different methods used for controlling the speed. It was created simulation model at the Matlab programme and implemented proportional-integral, fuzzy and adaptive neuro fuzzy inference system controllers respectively while it was working variable conditions. At the servo motor application it is expected that no overshoot, settling reference value quickly and minimum influence on the system stability.

Key-Words: DC Servo Motor, Proportional-Integral, Fuzzy, Adaptive Neuro Fuzzy Inference System

1. Introduction

DC servo motors have been used generally at the computers, numeric control machines, industrial equipments, weapon industry, speed control of alternators, control mechanism of full automatic regulators as the first starter, starting systems quickly and correctly.

While some properties of DC servo motors are the same, like inertia, physical structure, shaft resonance and shaft characteristics, their electrical and physical constants are variable. The velocity and position tolerance of servo motors which are used at the control systems are nearly the same. So they must be controlled according to the control system needs.

For this aim; it has implemented proportional-integral, fuzzy logic and adaptive neuro fuzzy inference system respectively at the variable working situations to the simulation model which has prepared at the Matlab programme for improvement the servo motor performance.

2. Control Methods

2.1. Proportional-Integral Control (PI)

PI control which uses frequently at the industrial application is math total of integration error and multiplying of error with constant. This situation depicted in equation 1.

$$u(t) = Kp.e(t) + K\imath\int_0^t e(t).dt \qquad (1)$$

Kp, Kı, u(t) and e(t) are proportional gain, integral gain, controller output and error signal, respectively. Steady –state error which occurs with proportional control can be reset manually or automatically. For automatic reset, electronic integrator circuits are used at the controller. The difference between measured and reference value which is called error signal is being integrated according to time. System is settled the reference value by increasing or decreasing the energy which has given by integrator circuit to the system. If working situations changes and response value is different from the reference value, error signal occurs as a result. Then integrator circuit repairs output. PI controller block diagram as illustrated in figure 1.

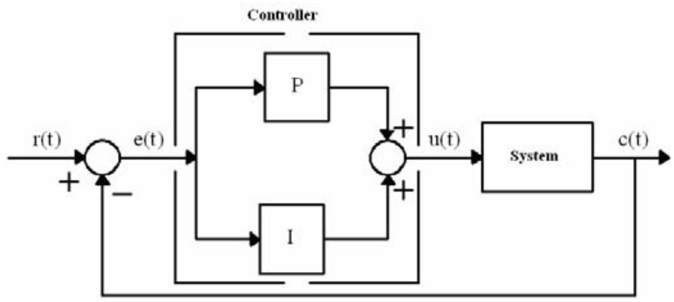

Figure 1: PI controller block diagram

2.2. Fuzzy Logic Control

First of all mathematical model is necessary while making experimentation for control systems but it may not be always possible in practice. Sometimes in spite of creating true model, using of this model makes some complicated problems at the implementation.

When confronted with like these problems, knowledge and experience of expert people is utilized. These people develop flexible control mechanism by using the words frequently in our life ,like “suitable”, ”not very suitable”, ”high”, ”a little high”, ”more”, “very more” which are defined special variable. Fuzz logic control which has experimentation of fuzzy cluster theories and fuzzy logic, has been set up like logical relatives.

A fuzzy logic system is based on 4 main parts which are illustrated in figure 2.

1-) Input units which has been known fuzzifier

2-) Rule base

3-) Inference mechanism

4-) Output units which has been known defuzzifier

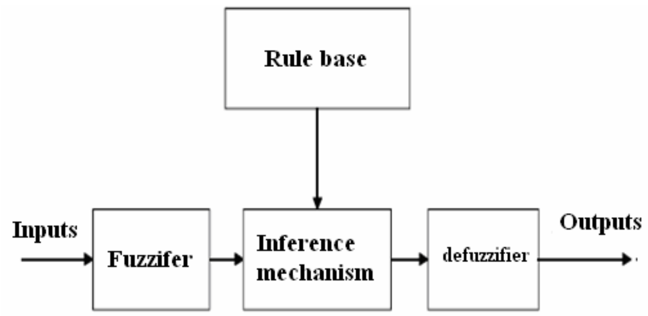

Figure 2: Block diagram of the fuzzy logic controller

2.3. Adaptive -Neuro Fuzzy Inference System

Anfis algorithm is composed of fuzzy logic and neural networks with 5 layers. Structure of Sugeno model with 2 inputs and 1 output is shown at table 1.

Inputs	x1	x2
Membership functions	A_1 , A_2	B_1 , B_2
Rules	IF x1 IS A_1 AND x2 IS B_1 THEN $f_1 = p_1(x1) + q_1(x2) + r_1$ IF x1 IS A_2 AND x2 IS B_2 THEN $f_2 = p_2(x1) + q_2(x2) + r_2$	

Table 1: Fuzzy-Sugeno model

Properties of layer described for x1, x2 as an input variables.

Layer 1: This is membership function layer where membership function degree has been calculated for every input variable.

($A_1(x1)$ and $A_2(x1)$; $B_1(x2)$ and $B_2(x2)$)

Layer 2: Second layer constitutes rule base of algorithm and fuzzy rules are defined in this layer. Nod inputs are degree of rules and outputs are normalized weightiness degrees. As a result, this layer’s mission is normalization of rule weightiness.

$$w_i = A_i(x1) \cdot B_i(x2) \tag{2}$$

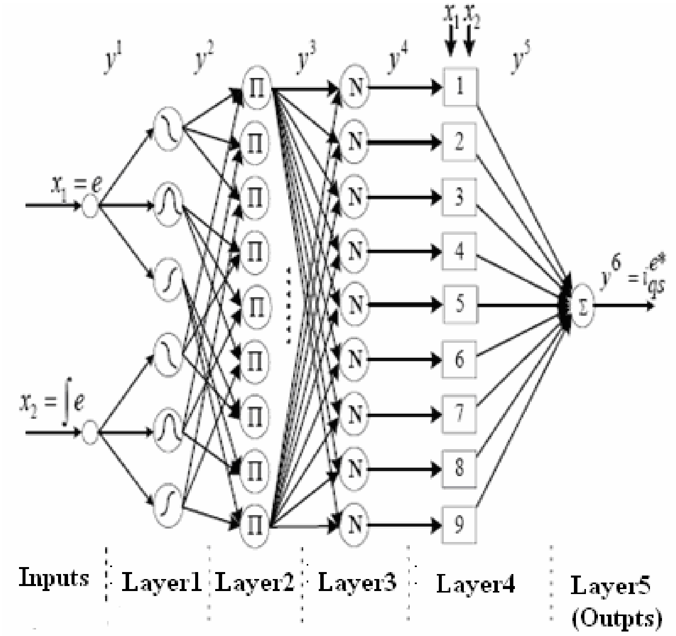

Figure 3: Structure of Anfis with 2 inputs, 1 output

Layer 3: This layer is called as normalization layer and it calculates degree decisiveness of fuzzy rules. The normalization process for i. node is division of degree decisiveness of i. fuzzy rules to sum of degree decisiveness of fuzzy rules. Model parameters are called as “defuzzifier” or “result parameters”.

$$\overline{w}_i = \frac{w_i}{\sum w} \tag{3}$$

Layer 4: Fourth layer of anfis is called as dimension degree of ignition of a rule. In this layer; fuzzy rule’s process is implemented by multiplying the ignitions degree of normalized rules with linear f function

$$\overline{w}_i \cdot f_i = \overline{w}_i \cdot (p_i \cdot x1 + q_i \cdot x2 + r_i) \tag{4}$$

Layer 5: This is output node of anfis and consists of only one node. This layer’s output is arithmetical average of 4 nodes former itself.

$$f = \sum \overline{w}_i \cdot f_i = \frac{\sum w_i \cdot f_i}{\sum w_i} \tag{5}$$

3. DC Servo Motor Mathematical Model

The velocity of the DC servo motor is controlled by changing the supply voltage. According to this theory if rewrites voltage and moment equations;

$$V_f = R_f . I_f + L_f \frac{di_f}{dt} \quad (6)$$

$$V = R.i(t) + L \frac{di(t)}{dt} + e(t) \quad (7)$$

$$M_e = j \frac{d\varpi(t)}{dt} + B.\varpi(t) + M_y(t) \quad (8)$$

$$e(t) = K.\varpi(t) \quad (9)$$

In order to create the block diagram of system; initial conditions are acquiescence zero and laplace transform is implemented to the equations.

$$.i(s)(Ls + R) = V(s) - K\varpi(s) \quad (10)$$

$$i(s) = \frac{V(s) - K.\varpi(s)}{R + Ls} \quad (11)$$

$$s.\varpi(s) = \frac{K}{j} i(s) - \frac{B}{j} \varpi(s) - \frac{M_y(s)}{j} \quad (12)$$

$$\varpi(s) = \frac{K.i(s) - M_y(s)}{B + sj} \quad (13)$$

V(s), $M_y(s)$, ω(s) motor voltage, load moment and angular velocity, respectively. According to these variable DC servo motor's closed loop block diagram is shown in figure 4.

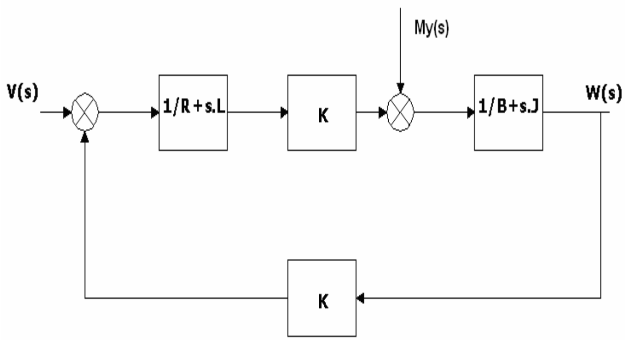

Figure 4: DC servo motor block diagram

4. Application

Proportional-integral controller which is known as a classical controller is created for DC servo motor. DC servo motor's current (I_a), angular velocity (ω_m) is simulated for constant and variable velocity position under the load at the Matlab programme. Then for the same working situations fuzzy and anfis based controllers are created for DC servo motor.

V=240 V	I=15 A	n=3000 rpm
M_y=5 Nm	B=0.02 Nms	J=0.05 kg m^2
K=5/15,3Nm/A	Ra=0,5 Ω	La=0,01 H

Table 2: Servo Motor Parameters

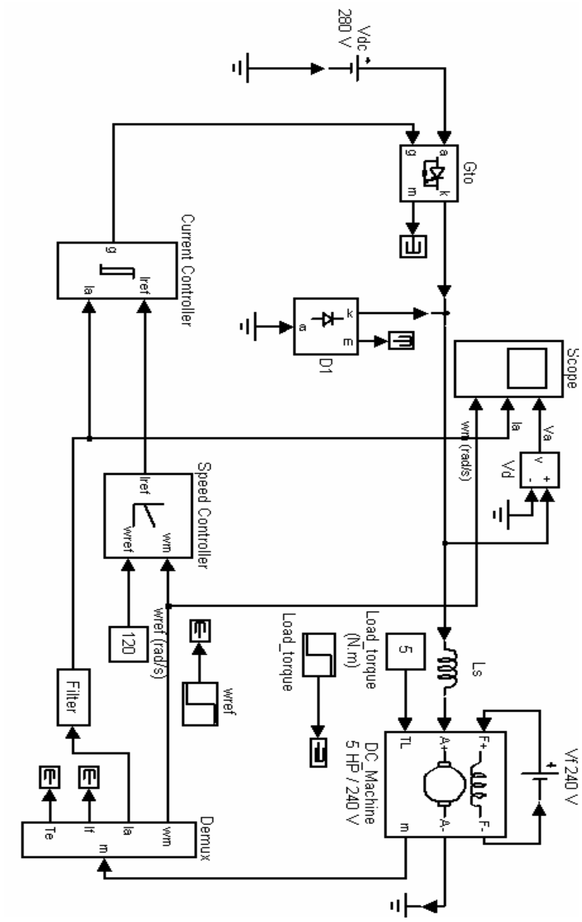

Figure 5: Servo Motor Simulation Model

In this simulation it is aimed to control motor velocity with the motor current and armature's voltage.

Z ω = ω - ω_{ref} which is called angular velocity error is used as an input variable. Armature current must be limit for soft start and protect the motor from high current. So that armature current was used as a second input variable.

Output fuzzy cluster is created as an output variable which regulates PWM duty period according to error between motor velocity information and reference value.

Membership functions represents the motor velocity information with the words "very small", "small", "ok", "much", "very much" and people experience is reflected to the system.

Rules used at the controllers which are based on human experience and information are:

1- If ω_{err}= "Very small" => output="increase"
2- If ω_{err}= "Small" => output="a little increase"
3- If ω_{err}= "Ok" => output ="Ok"
4- If ω_{err}= "More "=>output ="a little decrease"
5- If ω_{err}= "Most" => output ="decrease"

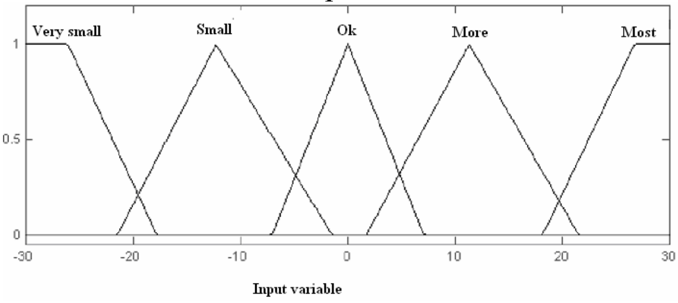

Figure 6: Membership functions relating to $\Delta\omega$ inputs

In figure 6 signal angular velocity error ($\Delta\omega$ range is limited between [-30, 30] values.

Negative zone defines motor velocity slower than the reference and positive zone defines faster.

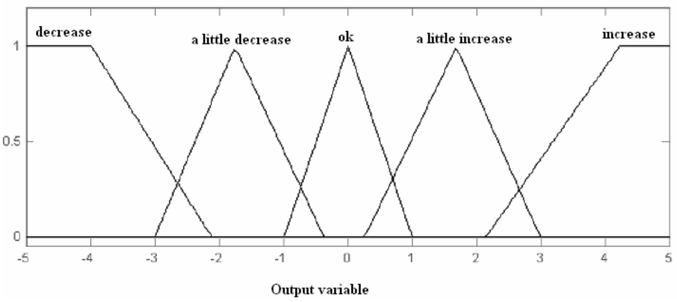

Figure 7: Membership functions belong to PWM Duty output

Output membership function represents how much the period of pwm duty shall increase or decrease. It includes 5 membership functions between [-5, 5] in range. Fuzzy clusters are defined as "decrease", "a little decrease", "ok", "a little increase" and "increase"

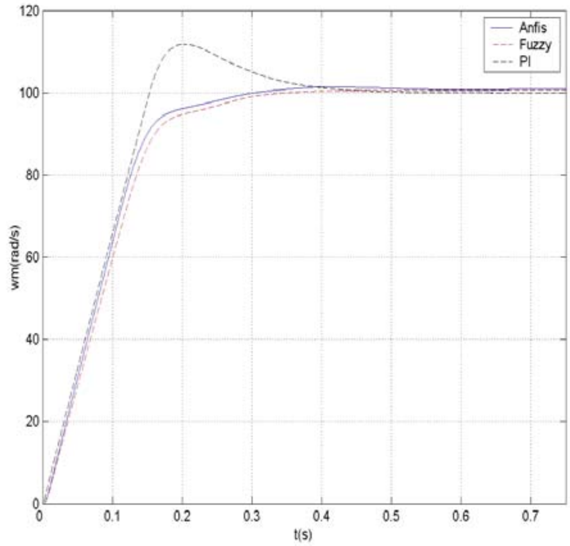

Figure 8: Controller output under the 3 Nm load and 100 radian/s reference velocity

At this reference velocity and load, although rising response of PI, fuzzy and anfis controller are nearly the same, overshoot is occurred for PI control. Anfis controller settling time is better than the others. Also there is no steady-state error for three methods.

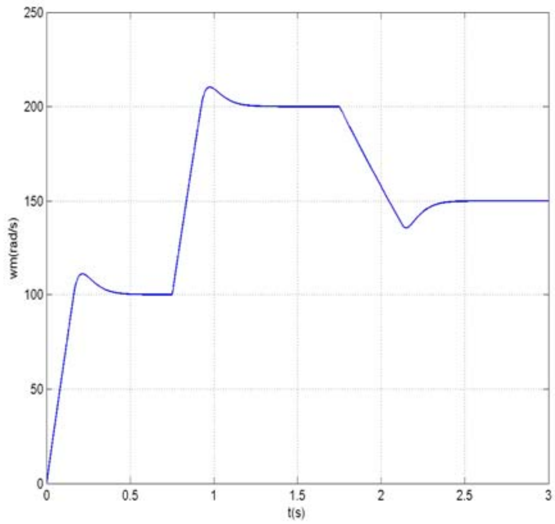

Figure 9: PI controller output under variable load and reference velocity.

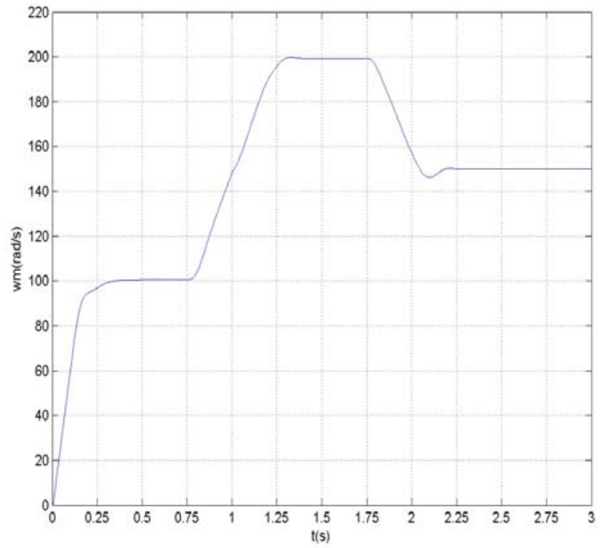

Figure 10: Fuzzy controller output under the variable load and reference velocity.

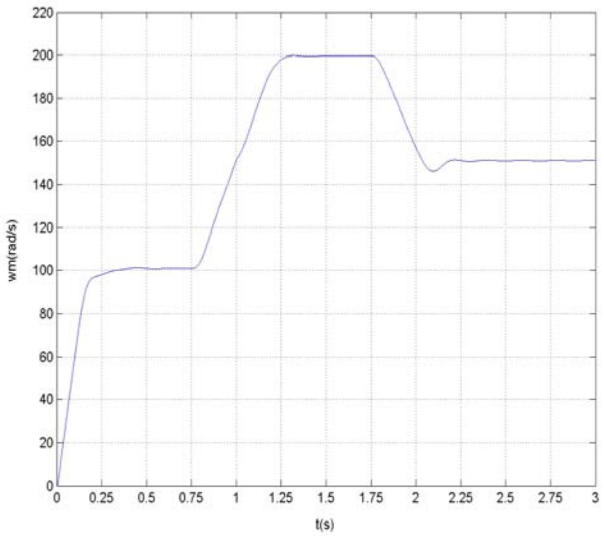

Figure 11: Anfis controller output under the variable load and reference velocity.

At figure 9, 10, 11 variable reference velocity and load response are illustrated for three controllers. When studied carefully these figures according to rising time, settling time, positive and negative overshoot best performance is belong to anfis.

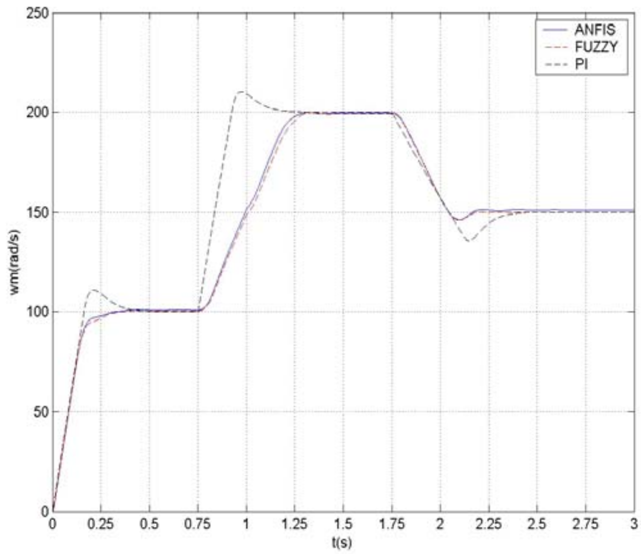

Figure 12: All controller output under the variable load and velocity.

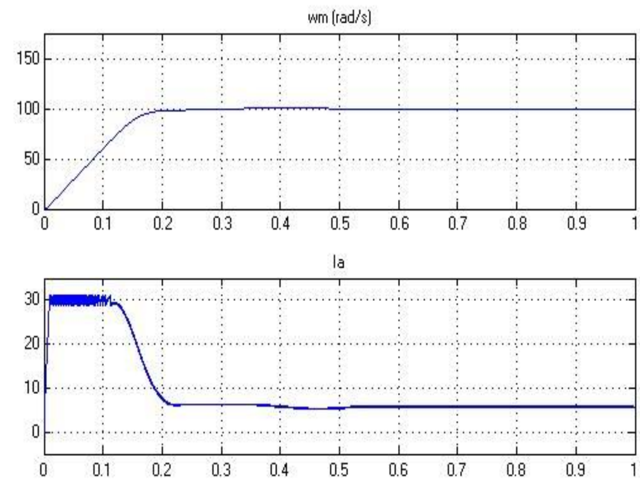

Figure 13: Fuzzy controller velocity-time, current-time response under the 3 Nm load and 100 radian/s reference velocity.

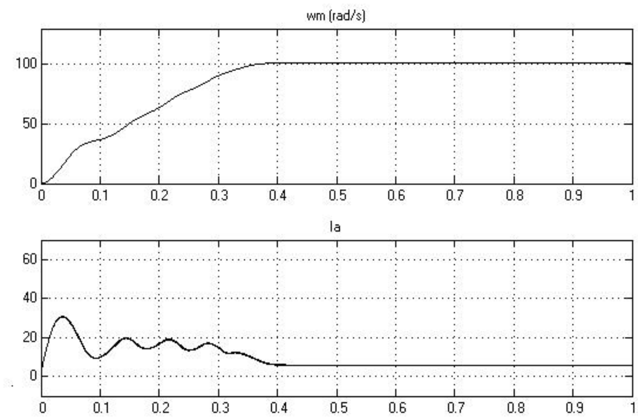

Figure 14: Anfis controller velocity-time, current-time response under the 3 Nm load and 100 radian/s reference velocity.

5. Conclusion

In this study, 3 and 5 Nm load under the variable and reference speed is implemented to the DC servo motor which is used as a model. At the 3 Nm load, although PI controller is stabilized position at 0.4 second overshoot is observed at response of system. At the same working conditions, it is observed no overshoot for fuzzy and anfis controllers, settling time for fuzzy and anfis controller is 0.38 and 0.33 seconds respectively.

When the load moment on DC servo motor's shaft increased 5 Nm and system response tested for variable velocity it is observed that the response of anfis controller is better than the others.

Current's responses are between reasonable values for three controllers at the test situation which is described above. Because of learning characteristic of error the performance of anfis controller is better than the others under variable load and velocity. But fuzzy and anfis controller's response are nearly the same because of the current limit. The control operation is not performed in the limited zone.

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