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PID Tuning for any Plant Model using Adaptive Neuro Fuzzy

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Abstract –**The aim of this paper is to develop the PID tuning of a plant model using Adaptive Neuro Fuzzy Controller. In order to solve this problem a PID controller under Adaptive Neuro Fuzzy Controller with self–tuning is applied, which will perform high efficiency position control. The efficiency of Control Algorithm is presented through a simulation and compared with the quality of PID controller and it was found that the proposed PID parameters adjustment by the Adaptive Neuro Fuzzy Controller gives better performance. This method could be applied to the higher order system also.**

Keywords –**Adaptive Neuro Fuzzy Controller, Neuro Fuzzy Controller, PID controller, PID tuning.**

I. Introduction

In most of the industrial processes like electrical, mechanical, construction, petroleum industry, iron & steel industry, power sectors, development sites, paper industry, beverages industry, etc. the need for higher productivity is placing new demands on mechanisms connected with electrical motors. They lead to different problems in work operation due to fast dynamics and instability. That is why control is needed by the system to achieve stability and to work at desired set targets. The robust speed and position control of electrical motors is of outmost importance due to various non-linear effects like load and disturbance that affected the motor to deviate from its normal operation.

The position control of electrical motors is most important due to various nonlinear effects like load and disturbance that affects the motor to deviate from its normal operation. The position control of the motor is to be widely implemented in machine automation. Currently, more than half of the controllers used in industry are PID controllers. In the past, many of these controllers were analog; however, many of today's controllers use digital signals and computers. When a mathematical model of a system is available, the parameters of the controller can be explicitly determined. However, when a mathematical model is unavailable, the parameters must be determined experimentally. Controller tuning is the process of determining the controller parameters which produce the desired output. Controller tuning allows for optimization of a process and minimizes the error between the variable of the process and its set point.

Controller tuning involves the selection of the best values of K_c, T_i and T_d. This is often a subjective procedure and is certainly process dependent. A number of methods have been proposed in the literature over the last 50 years. However, recent surveys indicate,

- 30 % of installed controllers operate in manual.
- 30 % of loops increase variability.
- 25 % of loops use default settings.
- 30 % of loops have equipment problems.

A possible explanation for this is lack of understanding of process dynamics, lack of understanding of the PID algorithm or lack of knowledge regarding effective tuning procedures. This section of the notes concentrates on PID tuning procedures. The suggestion being that if a PID can be properly tuned there is much scope to improve the operational performance of chemical process plant. When tuning a PID algorithm, generally the aim is to match some preconceived ‘ideal’ response profile for the closed loop system.

The main objective of the work is to design a controller of any plant model by selection of PID parameters using Adaptive Neuro Fuzzy Controller.

II. PID Controller

PID controller consists of Proportional Action, Integral Action and Derivative Action. It is commonly refer to Ziegler-Nichols PID tuning parameters. It is by far the most common control algorithm. Under this heading, the basic concept of the PID controls will be explained. PID controller’s algorithm are mostly used in feedback loops. PID controllers can be implemented in many forms. It can be implemented as a stand-alone controller or as

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part of Direct Digital Control (DDC) package or even Distributed Control System (DCS).

It is interesting to note that more than half of the industrial controllers in use today utilize PID or modified PID control schemes. A diagram illustrating the schematic of the PID controller is shown below. Such set up is known as non-interacting form or parallel form.

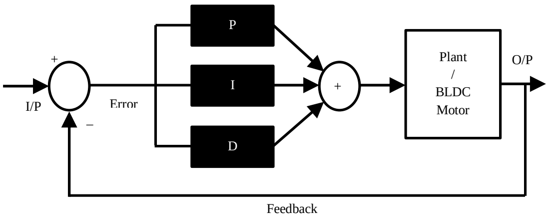

Figure 1: Schematic of the PID Controller

In proportional control,

$$P_{term} = K_P * Error \quad (1)$$

It uses proportion of the system error to control the system. In this action an offset is introduced in the system.

In Integral control,

$$I_{term} = K_I * \int Error\, dt \quad (2)$$

It is proportional to the amount of error in the system. In this action, the I-action will introduce a lag in the system. This will eliminate the offset that was introduced earlier on by the P-action.

In derivative control,

$$D_{term} = K_D * \frac{d(Error)}{dt} \quad (3)$$

It is proportional to the rate of change of the error. In this action, the D-action will introduce a lead in the system. This will eliminate the lag in the system that was introduced by the I-action earlier on.

Optimizing using Zeigler & Nichols Method

For the system under study, Zeigler-Nichols tuning rule based on critical gain Ker and critical period Per will be used. In this method, the integral time T_i will be set to infinity and the derivative time T_d to zero. This is used to get the initial PID setting of the system. This PID setting will then be further optimized using the Basic Design mode and Extended Design mode.

In this method, only the proportional control action will be used. The K_p will be increased to a critical value Ker at which the system output will exhibit sustained oscillations. In this method, if the system output does not exhibit the sustained oscillations hence this method does not apply.

From the response below, the system under study is indeed oscillatory and hence the Z-N tuning rule based on critical gain Ker and critical period Per can be applied.

The transfer function of the PID controller is:

$$G_C(s) = K\,(1 + 1/sT_i + sT_d) \quad (4)$$

The objective is to achieve a unit-step response curve of the designed system that exhibits a maximum overshoot of 25 %. If the maximum overshoot is excessive says about greater than 40%, fine tuning should be done to reduce it to less than 25%. The system under study above has a following block diagram.

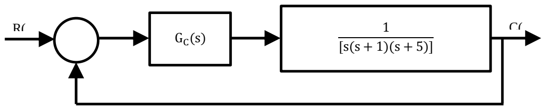

Figure 2: Block diagram of Controller and Plant

Since the $T_i = \infty$ and $T_d = 0$, this can be reduced to the transfer function of:

$$R(s)/C(s) = K_p/\,s(s+1)(s+5) + K_p \quad (5)$$

The value of K_p that makes the system marginally stable so that sustained oscillation occurs can be obtained by using the Routh's stability criterion. Since the characteristic equation for the closed-loop system is:

$$s^3 + 6s^2 + 5s + K_p = 0 \quad (6)$$

From the Routh's Stability Criterion, the value of K_p that makes the system marginally stable can be determined. The table below illustrates the Routh array.

Table 1: Routh Array

s^3	1	5
s^2	6	K_p
s^1	$(30 - K_p)/6$	0
s^0	K_p	0

By observing the coefficient of the first column, the sustained oscillation will occur if, $K_p = 30$.

Hence the critical gain Ker is

$$Ker = 30$$

Thus with K_p set equal to Ker, the characteristic equation becomes

$$s^3 + 6s^2 + 5s + 30 = 0 \quad (7)$$

The frequency of the sustained oscillation can be determined by substituting the s terms with $j\omega$ term. Hence the new equation becomes:

$$(j\omega)^3 + 6\,(j\omega)^2 + 5\,(j\omega) + 30 = 0 \quad (8)$$

This can be simplified to,

$$6\,(5 - \omega)^2 + j\omega\,(5 - \omega) = 0 \quad (9)$$

From the above simplification, the sustained oscillation can be reduced to,

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$$\omega^2 = 5 \text{ or } \omega = \sqrt{5}* \quad (10)$$

The period of the sustained oscillation can be calculated as,

$$Per = 2\pi/\sqrt{5} = 2.8099 \quad (11)$$

From Ziegler-Nichols frequency method of the second method, the table suggested tuning rule according to the formula shown. From these we are able to estimate the parameters of K_p, T_i and T_d.

Table 2: Recommended PID Value Setting

Type of controller	K_p	T_i	T_d
P	$0.5\,Ker$	∞	0
PI	$0.45\,Ker$	$(1/1.2)\,Per$	0
PID	$0.6\,Ker$	$0.5\,Per$	$0.125\,Per$

Hence from the above table, the values of the PID parameters K_p, T_i and T_d will be $K_p = 30$

$$T_i = 0.5 \times 2.8099 = 1.405 \quad (12)$$

$$T_d = 0.125 \times 2.8099 = 0.351 \quad (13)$$

The transfer function of the PID controller with all the parameters putting in below equation,

$$G_C(s) = K(1 + 1/sT_i + sT_d) \quad (14)$$

From the above transfer function, we can see that the PID controller has pole at the origin and double zero at $s = -1.4235$. The block diagram of the control system with PID controller is as follows.

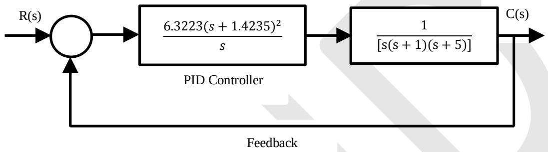

Figure 3: Illustration of the Closed Loop Transfer Function

III. MOTOR MODELLING

Brushless DC motors have the field coil in parallel (Brushless) with the armature. The current in the armature and field coil are free of each other. Therefore, these motors have fabulous speed and position control. Henceforth BLDC motors are commonly utilized that oblige five or more HPs (Horse Power). The equations depicting the vibrant performance of the BLDC motor are given as under.

$$v = Ri + L\frac{di}{dt} + e_b \quad (15)$$

$$T_m = K_T i_a(t) \quad (16)$$

$$T_m = J\frac{d^2\theta(t)}{dt^2} + B\frac{d\theta(t)}{dt} \quad (17)$$

$$eb = e_b(t) = K_b\frac{d\theta(t)}{dt} \quad (18)$$

Where, R = Armature resistance in ohm.
L = Armature inductance in henry.
$i = i_a$ = Armature current in ampere.
v = Armature voltage in volts.
eb = Back EMF voltage in volts.
K_b = Back EMF constant in volt / (rad/sec).
K_T = Torque constant in N-m/Ampere,
T_m = Torque developed by the motor in N-m.
$\theta(t)$ = Angular displacement of shaft in radians.
J = Moment of inertia of motor and load in Kg-m2/rad.
B = Frictional constant of motor and load in N-m / (rad/sec).

On the basis of the equations stated above, we realized a MATLAB / SIMULINK model for the brushless DC motor as shown in Figure 4.

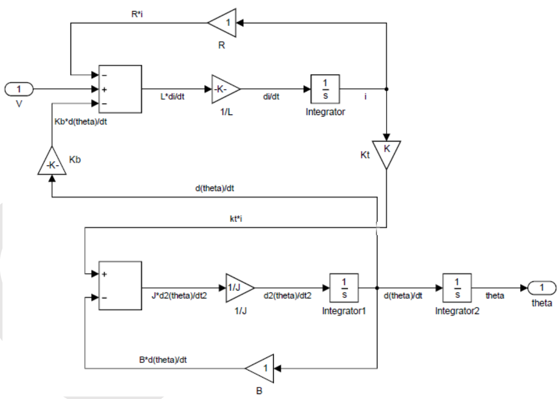

Figure 4: Simulink model for brushless DC motor

IV. NEURO-FUZZY CONTROLLER

Figure 5 exhibits the basic block diagram for proposed Neuro fuzzy controller based PID tuning system for a plant model.

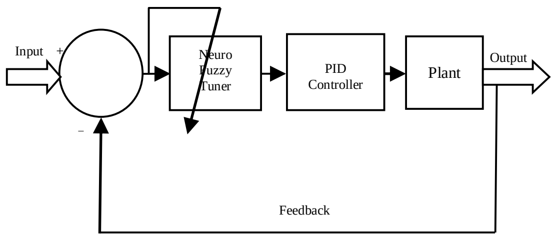

Figure 5: Basic block diagram for proposed Neuro fuzzy controller based PID tuning system for a plant model

To get the favourable circumstances of fuzzy and neural networks and to beat their limitations, it is wised to utilize the mixture of both, which prompts Neuro-Fuzzy Controllers (NFC). The on-line supervised learning algorithm performs exceptionally well when the training information are accessible on-line. The error between the reference and BLDC motor output is utilized to change the weights. This controller is an Adaptive Network-based Fuzzy Inference System (ANFIS) [19].

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Supervisory Learning in ANFIS

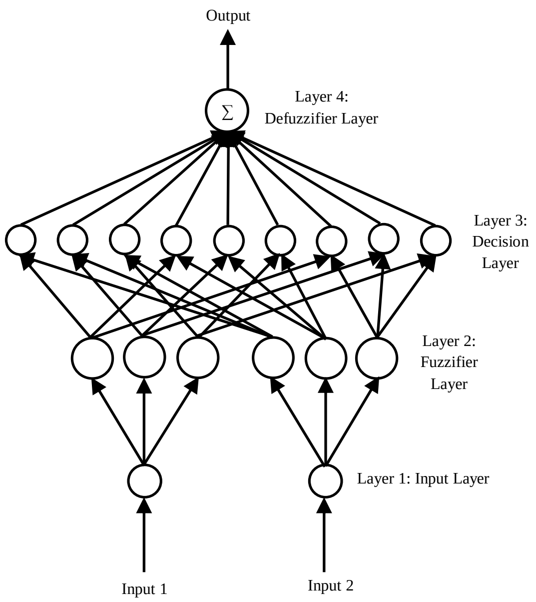

Figure 6: Neuro-Fuzzy network structure [19]

In a few circumstances it might be interesting to outline an automatic controller, which emulates the activity of the human. This has been called supervised control. A Neural Network gives one opportunity to this. Training the network is comparative on a fundamental level to taking in a system forward model. For this situation, then again, the system information compares to the sensory input data got by the human. The network target outcomes utilized for training relate to the human control input to the framework. Figure 6 demonstrates the NFC as a supervisory controller.

The Error Back Propagation Through Plant (EBP-TP) method is one of the universal methodologies for neural networks training. In EBP-TP procedure, output error of the controller is passed through the BLDC motor, and redesigning law of the weights is attained. In any case, this system has a few imperfections, for example, noise affect-ability, unsettling influence and learning rate coefficient.

V. Simulation And Results

The performance of proposed algorithms has been studied by means of MATLAB simulation.

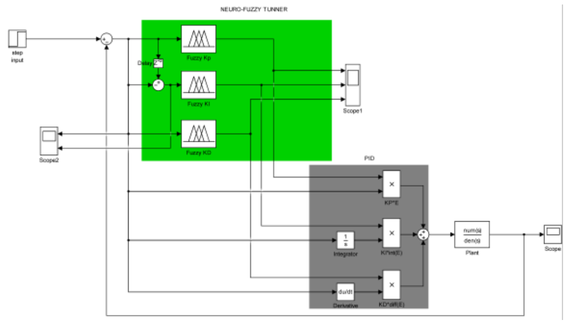

Figure 7: Simulink model for proposed system

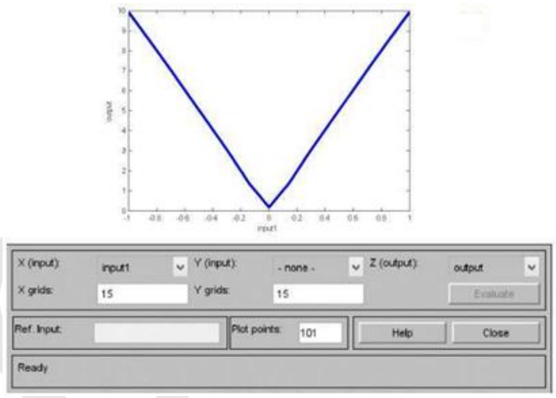

Figure 8: Fuzzy surface for K_p

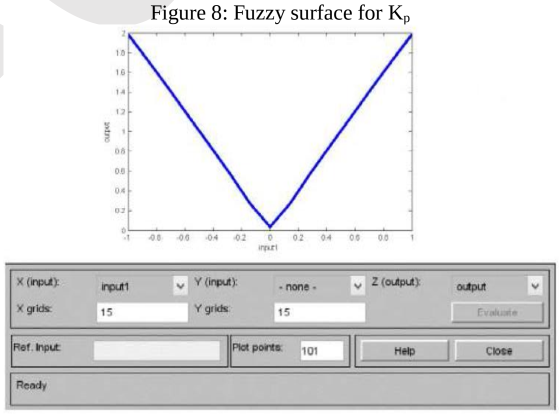

Figure 9: Fuzzy surface for K_i

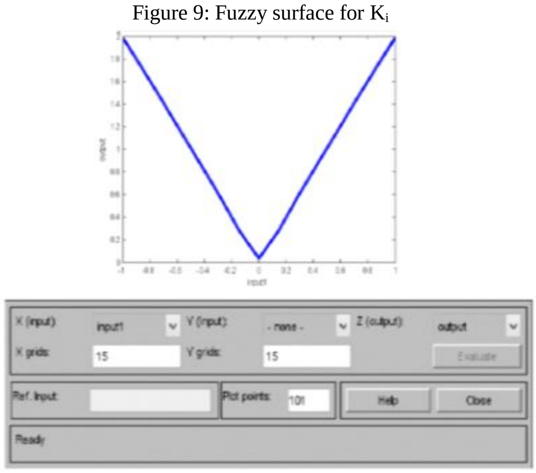

Figure 10: Fuzzy surface for K_d

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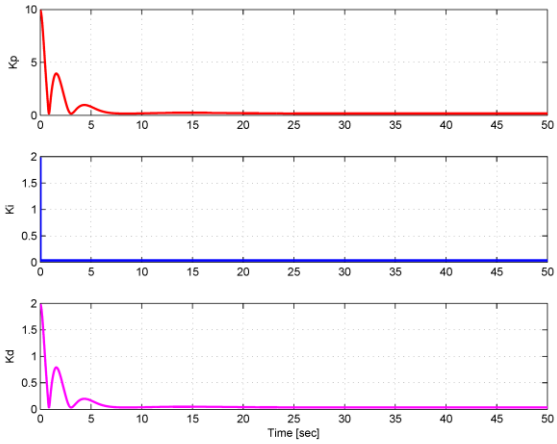

Figure 11: PID parameters by Neuro Fuzzy

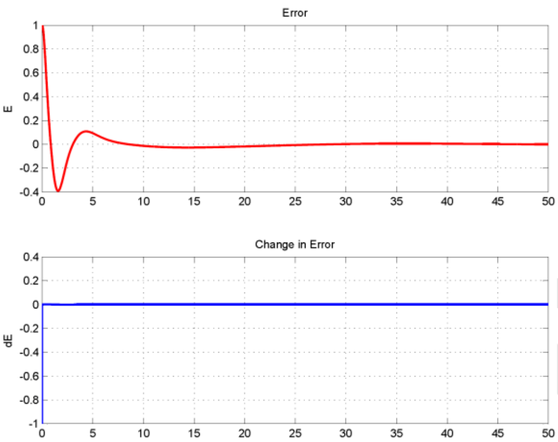

Figure 12: Change in Error

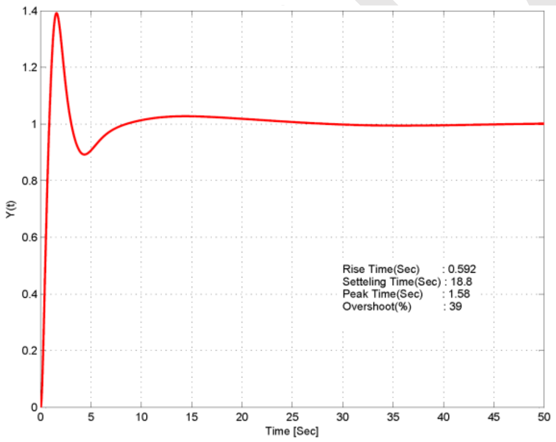

Figure 13: Step response for plant

VI. CONCLUSION

This paper demonstrated the implementation of auto tuning of PID controller in MATLAB/SIMULINK. The outcome of paper is that the designed PID with Adaptive Neuro Fuzzy Controller (ANFC) has faster response. However the ANFC designed PID with plant model is much better in terms of the rise time and the settling time. Finally the Adaptive Neuro Fuzzy Controller provides much better results compared to the conventional methods. And also the error associated with the ANFC based PID is much lesser than the error calculated in the conventional scheme.

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