DC Motor Torque Control using Fuzzy Proportional-Derivative Controllers

Shivanand Pandey, Bhagirath Pandey

Abstract— This paper demonstrates the design of a fuzzy logic control system to torque control of a DC motor by using fuzzy rules in Mamdani interference system. So, as to achieve the better control performing results, fuzzy rules and fuzzy sets optimize the input parameters as well as the parameters of fuzzy logic controller, which is defined by Membership Function (MFs). By using the torque- speed characteristic of DC motor we design the simulation model which shows the optimization of torque near to ideal value as well as comparable result between the output values with its input unit step value. The numbers of rule design are much enough to minimize the ripples in its output torque signal.The mathematical modeling of proposed DC motor is also presented. To achieve effective control output the simulink software is used. This proposed paper is able to obtain results for variable load torque. This paper is also describing the comparative description of conventional PID controller technique with fuzzy logic controller technique.

Index Terms- DC motor, Fuzzy logic controller, Torque control, Membership function, PID controller.

I. INTRODUCTION

DC motors are widely used in many industrial applications due to their high efficiency, high power density and ease of control [1]. The beginning of industrial revolution is supposed by the era of steam age. That was the signal of machines and gadgets to simplify the human efforts. Thus more researches takes place for new ideas of energy source. But the end of 18th century the researchers successful led to develop the electric charges which were a great invention of storage batteries for further work. This research made a milestone on the work on moving charges or currents. Then further soon researchers discovered (in 1820) that, these electric currents are also connected with magnetic field. Thus we get the invention of an electromagnet. Hardly after a year we get the phenomena that is “when a current carrying conductor placed in the magnetic field it experience forces” was invented. [2]. This phenomenon known as electromagnetic force, this phenomena termed as a born of a motor. For better explanations Faraday suggests law of induction in 1831. Which provide the way to form a useful machine like alternators, transformers and induction motors etc. [3] with the availability of storage batteries the DC generator (for conversion the mechanical energy into electrical energy) and direct current, DC motors (which converts mechanical power outputs from electrical energy). However the limitation of DC supply more understood as the power demand increased. DC supply needed the near generating station as well as smooth transmission of energy.

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Due to its few demerits researchers from the technique of alternating current, it is first implemented on Induction motor. Further Direct current, DC motor consist a marvelous control characteristics. Even in this era DC motor remains the first choice for its control aspects [2]. In the series of torque control of DC motor the conventional techniques are used. There are few more techniques developed to control the torque of DC motor. These techniques are such as proportional integral derivative, PID controller. We will discuss further about these techniques and its results in comparative nature. This DC motor is modeled and converted in a subsystem by Simulink model with the help of mathematical modeling. First, we design a sharp proportional integral derivative, (PID) controller & observe its result. By analyzing its demerits we try to design a model which is able to control its demerits. To do so, we use the controller as fuzzy proportional derivative controller. Using a Simulink block we design fuzzy logic controller to control torque of DC motor instead of conventional PID controller. Then a fuzzy proportional-derivative (FPD) controller was designed and system responses of FPDs by using different defuzzification methods. A disturbance (impulse) signal was also applied to the input of the control system. FPD controller succeeded to reject the disturbance signal without further tuning of the parameters whereby sharp PID controller failed. The torque control of DC motor is performed using fuzzy logic controller in MATLAB environment [4]. This controller consist 7 fuzzy logic rules to control its torque up to the ideal value. Finally the result shows that the fuzzy logic controller able to control the torque of DC motor as well as minimizes the ripples and harmonics, which shows more effectiveness and efficiency of fuzzy logic controller than conventional PID controller.

II. PID CONTROLLER

PID controller is also referred as proportional integral derivative controller. As its name suggest that the proportional integral derivative controller is the combination of proportional, integral and derivative controllers. This DC motor is modeled and converted in a subsystem by Simulink model with the help of mathematical modeling. First, we design a sharp proportional integral derivative, (PID) controller & observe its result. For PID control the actuating signal consists of proportional error signal added with derivative and integral of the error signal, therefore the actuating signal for PID controller is,

$U(t) = K_p e(t) + K_i \int e(t)dt + K_d \; d(e(t))/dt$ --------(1) [5]

We can solve this equation as,

$U(t) = K_p (e(t) + 1/T_1\{\int e(t)dt\}) + t_d \; d(e(t))/dt$ -----(2)

Where,

K_p = Proportional gain

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K_i = Integral gain
K_d = Derivative gain
T_1 = Integral time constant
t_d = Derivative time constant

Taking the Laplace Transform of equation (1) as follow,

$$U(s) = K_p\, e(s) + (K_i /s)\, e(s) + s\, K_d\, e(s);$$

By taking common to e(s) it can be written as,

$$U(s) = e(s)\ [\ K_p + K_i/s + s\, K_d] ;$$

By using integral time constant and proportional time constant we can write the equation as;

$$U(s) = e(s)\ [K_p + 1/(sT_1) + s\, T_d] ;$$

With the help of this equation we can make its block diagram. As shown in figure we design a torque control of DC motor with the help of PID controller [6].

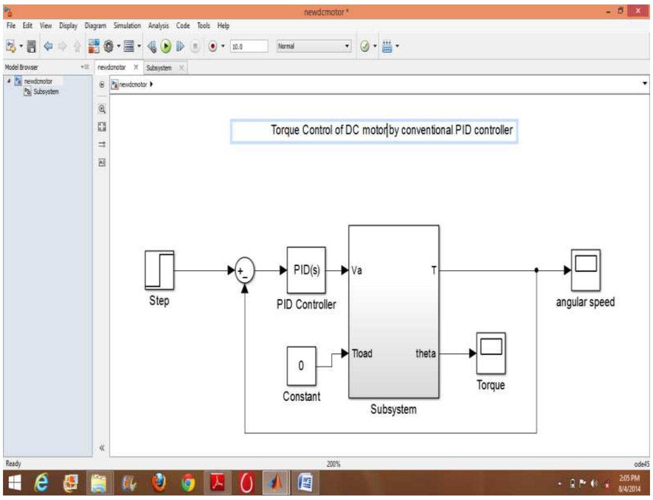

Fig. 1 Torque Control of DC Motor by PID Controller

To torque analysis of DC motor with the help of DC motor we design a closed loop system to analysis the torque-speed characteristic with the help of proportional integral derivative controller. As shown in the figure it is clearly explain that, we design a simulink model with the help of MATLAB. To achieve clearly understandable output we prefer the step signal, because it is easy to observe its mathematical and comparative result. This signal source is connected with the help of summer to the proportional integral derivative controller. This PID controller is connected with the DC motor. This DC motor is designed in mathematical expression. It controls the torque output as plotted. So with the help of its result we can see that the torque controlling result of DC motor is as shown in figure.

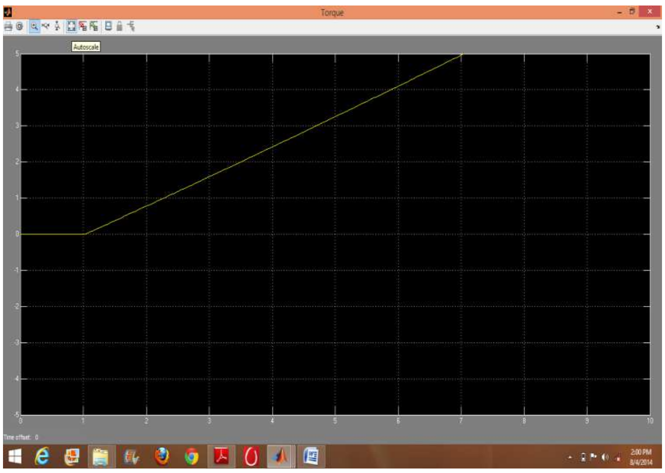

Fig. 2 Result of DC Motor Torque Control by PID Controller

As it is clearly seen that output signal is very far from its ideal input signal. So to minimize its unwanted result we proposed another technique in which we try to constant the torque as its constant values.

III. MATHEMATICAL EXPRESSION

We are using permanent magnet DC motor because of its various benefits, as we discussed before. So there is no need to state the equation like in separately excited DC motor, due to this reason less amount of losses takes place in permanent magnet DC motor than other type of DC motor.

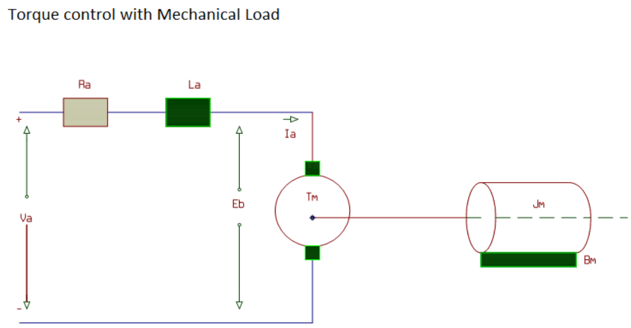

Fig. 3 DC Motor Torque Control with Mechanical Load [7]

So being the part of DC motor the stator (permanent magnet) is able to provide a constant magnetic field to the rotor. Let assume that rotor is made up by single coil which is characterized by,

V_a = Input voltage
L_a = inductance of the rotor
R_a =Resistance of the rotor
E_b = Back emf

So, we may express it as in mathematical equation; apply KVL in the in the above circuit, then

$$V_a\,(t) = I_a\, R_a + L_a\, dI_a/dt + E_b\,(t) \text{ --------------------- (1)}$$

By taking Laplace transform of above equation (1) Therefore,

$$V_b(s) = L_a\, s\, I_a\,(s) + R_a\, I_a\,(s) + E_b\,(s)$$

So,

$$V_a\,(s) – E_b(s) = I_a\,(s)\,(s\, L_a + R_a);$$

By solving the equation we may write as,

$$I_a\,(s) / (V_a\,(s) – E_b\,(s)) = 1/\,(s\, L_a + R_a) \text{ ------------- (2)}$$

The equation (2) may be written as,

$$I_a\,(s) / (V_a\,(s) – E_b\,(s)) = K_a/\,(1+ s\, t) \text{ -------------- (3)}$$

Where,

K_a = gain of rotor = $1/ R_a$
t = Time constant of rotor = L_a / R_a

A. Mechanical Equation of DC Motor

In electric system, when an electric motor drives a mechanical load .then mainly three factors is to be consider as;

- The torque developed by the motor
- The torque exerted by the load
- speed

As shown in figure it may be noticed that the torque T_m is exerted by DC motor while voltage is supplied on rotor, due to this torque acts on mechanical load ,which is characterized by the rotor inertia which is represented by ‘J_m’ and the viscous friction coefficient which is written as ‘B_m’.[5][7]. Due to the operation of mechanical load the load torque

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developed which is written as T_L. We may write the equation as,

$$T_M - T_L = J_m\, dw/dt + B_m\, W(t) \text{ -------------------------(4)}$$

Where,

$W(t)$ = angular speed (rad/s)

T_m = motor torque (Nm)

J_m = rotor inertia (kgm^2)

B_m = viscous friction coefficient (Nms/rad)

By taking Laplace transform of equation (4), the result will be;

$$T_M - T_L = s\, J_m\, W(s) + B_m\, W(s);$$

By solving the above equation we get,

$$T_M - T_L = W(s)\, \{s\, J_m + B_m\};$$

$$W(s)/(T_M - T_L) = 1/(s\, J_m + B_m) \text{ -----------------------------(5)}$$

This equation can be solved as;

$$W(s)/(T_M - T_L) = K_m/(1 + s\, t_1) \text{ ------------------------------(6)}$$

Where, K_m = mechanical gain $= 1/B_m$ [10]

t_1 = mechanical time constant $= J_m/B_m$

with the help of the equation (2),(3),(5) and (6) we can plot the block diagram as, where B_m is symbolized as D = viscous friction coefficient (Nms/rad)

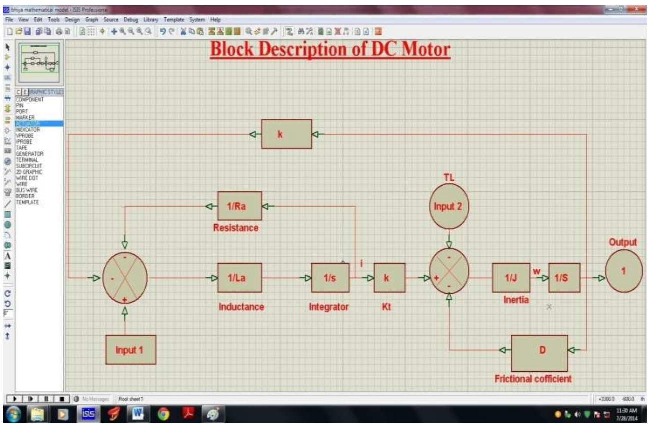

Fig. 4 Block Description of DC Motor

IV. FUZZY PROPORTIONAL CONTROLLER

Fuzzy logic controller has rapidly become one of the most successful in recently technology for developing no. of variety of application. Fuzzy logic controller is mainly the relative importance of precision. Fuzzy logic has two different meanings. In narrow senses, fuzzy logic is a logical system which is an extension of multi valued logic but, in wider sense fuzzy logic is almost same as the theory of fuzzy sets. The basic concept underlying Fuzzy Logic is that of a linguistic variable, that is, a variable whose values are in words rather than numbers. Due to this, computing with words exploits the tolerance for imprecision and thereby lowers the cost of solution. In this paper we proposed the technique to torque control DC motor due to random behavior of torque in DC motor because of conventional PID controller technique. We proposed the controlling technique of the fuzzy logic controller with the help of this technique we control the torque of DC motor towards the ideal value of input voltage. As shown in figure in its block diagram we saw that how we consider the mathematical modeling and its simulation model. In this series we discuss the steps of fuzzy logic model to control the DC motor torque control. To torque control with the help of Fuzzy logic controller to DC motor we categorized the following steps;

Step 1: Fuzzification:

This Fuzzification process takes place through following ways.

- First of all measured inputs necessarily mapped by fuzzy membership function this is known as fuzzify inputs**.** This fuzzify input means that it is the set of input variable which is define by continuous voltage error signal and derivative voltage error signal.
- This defined error signal in culmination form is known as fuzzy set.
- After forming the fuzzy set we provide the mathematical range by the help of membership function. As we discussed earlier about the theoretical portion of membership function in detail. Now, we consider the membership function of input variable as,

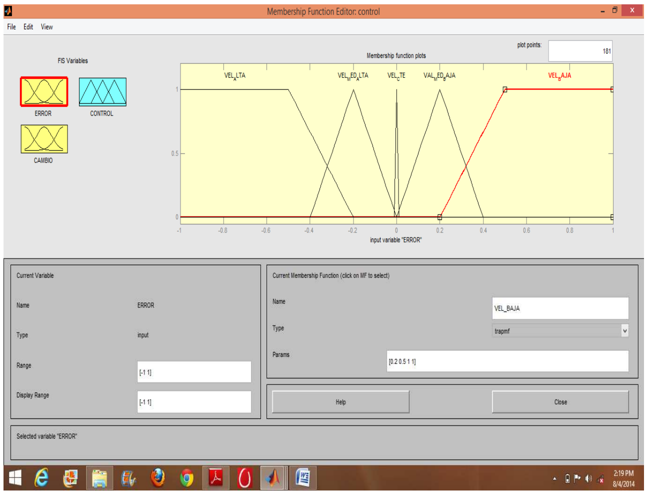

Fig. 5 Membership Function of Voltage Error Signal

- This continuous voltage error is represented by 'error'. We design this membership function with the help of two type of function. These functions are triangular function and trapezoid function. Because these function are very easy to define its mathematical range.
- All these function is defined by linguistic variable; it means that we expressed it in human language.
- Then we define another signal which is the derivative voltage error. This signal is defined as 'Cambio'. In this membership function we consider the triangular membership function. This membership function consist two error conditions that is low and high, which is defined by its range as shown as figure.

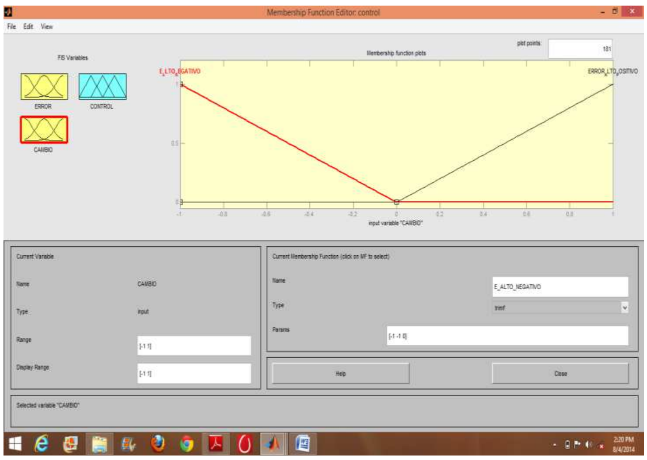

Fig. 6 Membership Function of Derivative Voltage Error

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Step 2: Fuzzy Inference Process:

Fuzzy inference is the process which used fuzzy logic to develop the mapping from a given input to a desired output. The mapping then renders a ground from which decisions can be made, or patterns discerned. Fuzzy inference process may defined by two processes that is Mamdani inference process and another inference process is Sugeno inference process. Mamdani-type inference outline started with to collect the information and make them on membership functions to be fuzzy sets. After collecting the processed data, there is a fuzzy set for each output variable that needs defuzzification. In most of the cases it is much more efficient, to use a single spike as the output membership function rather than a distributed fuzzy set [8]. To model any inference system in which the output membership functions are either linear or constant, Sugeno-type systems can be implemented. With the help of following figure we may see that there is clearly defined control technique, in which all its steps are mentioned as input, interference and output.

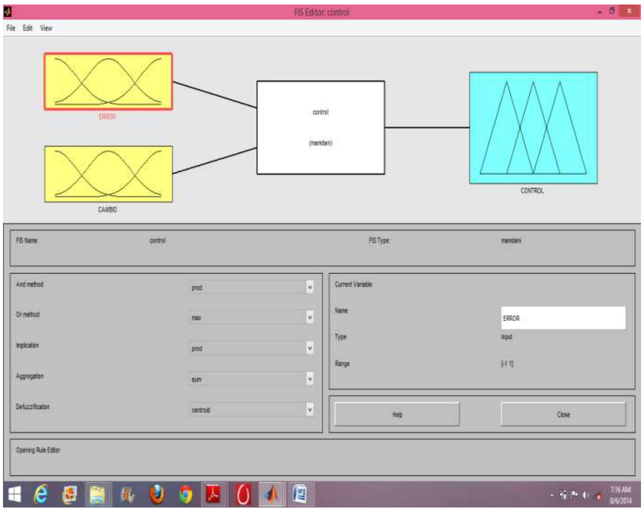

Fig. 7 Mamdani Inference Process

In this step we basically design the fuzzy rules with the help of interference system. These rules are basically based on the range of membership function & linguistic variable rules. These rules are formed by the help of AND, OR and NOT gates. These linguistic rules are digitized by the help of this logic operation. In the series to define variable we get the output variable as, following membership function.

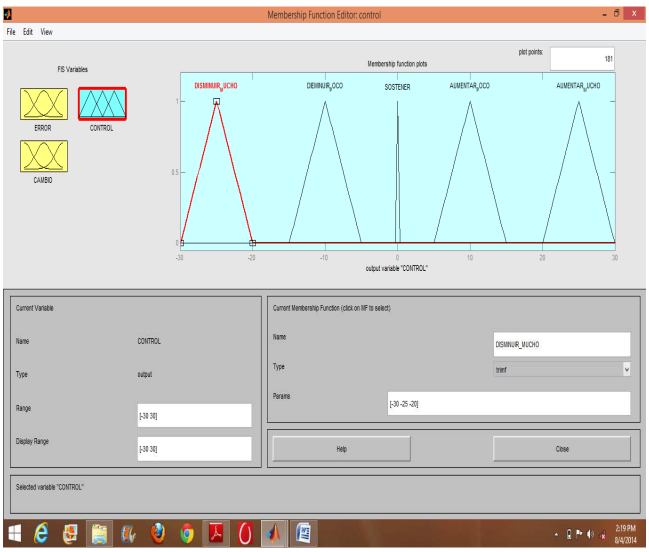

Fig. 8 Membership Functions of Output Control Torque

We may understand the rules by the help of following example as; “If (voltage error is average) or (derivative voltage error is low) then (torque control is low)”. Similarly these rules can be seen by the following figure as, These rules are based upon the logic gate operation which is designed by the help of two input linguistic variable and one output linguistic output variable. We design the seven rules for more accurate result.

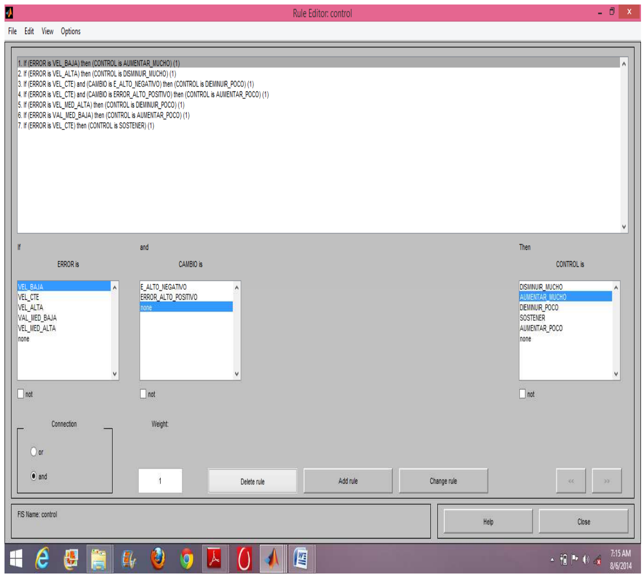

Fig. 9 Fuzzy Rule Design

Step 3: Defuzzification:

The input of defuzzify process is a fuzzy set (the net output fuzzy set) and the output of it is a single value. As much as fuzzy result helps the rule evaluation during the inference steps, the final appetite output for every variable is normally a single digit number. However, the average of a fuzzy set include in a range of output values, so it must be defuzzified in order to resolve a single digit output value from the fuzzy set.

V. RESULT ANALYSIS

A. Fuzzify Torque Control Output Result

As we consider the complete modeling with the help of conventional PID controller and fuzzy logic controller. So we can compare the PID result and the following result as,

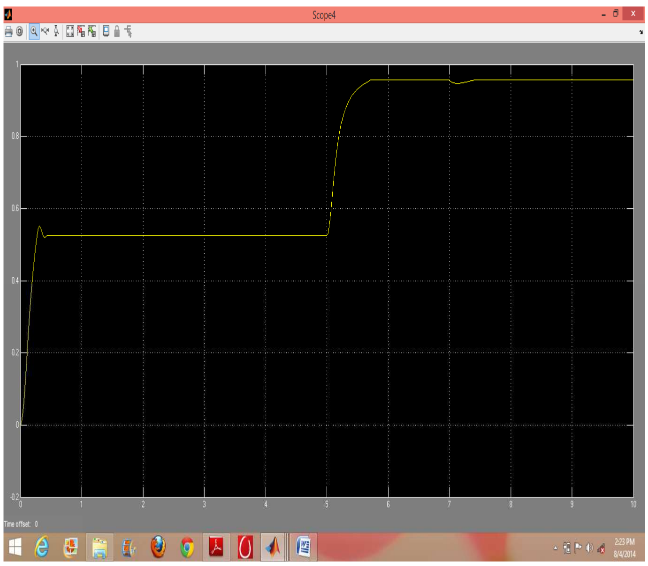

Fig. 10 Torque Control of DC Motor

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B. Comparable Result of Fuzzify Controlled Torque with Step Input

With the help of following result we can see that the ripples and harmonics are reduced by the help of fuzzy logic controller. And we minimized the torque ripples as much as can. This comparable result can be seen by following result. To get the following result we did the scaling 1500 times to consider the comparable result with step input signal. We did the scaling with the help of mathematical property of its step signal. We put the bus bar in place of multiplexer. We can define the bus creator as that it combines a set of signal into a bus. We use it because it can connect any type of signal to the inputs, including other bus signal. Thus the result is expressed as following figure as,

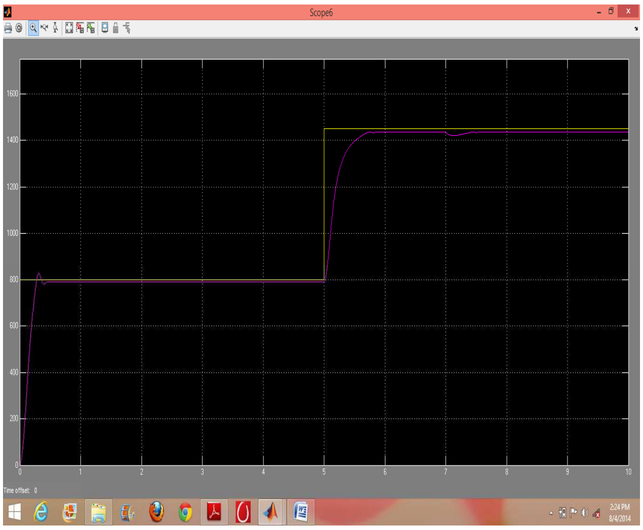

Fig. 11 Comparable Result of Fuzzify Torque Result with Step Input

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VI. CONCLUSION

With the help of this paper we can conclude that fuzzy logic controller is supposed to be one of the best controlled techniques for driving any DC motor. Its main principle, procedure of working, applications and its uses are deeply explained. It is also demonstrated in this paper that the controlling method of fuzzy logic controller also allows the control of DC motor, not only its torque as well as its speed characteristics too. We developed a SIMULINK/MATLAB model with the help of which we able to control torque of DC motor by reducing its ripples very near to its ideal value. From the results we can observe that fuzzy logic controller technique is much simpler to design and very much easy to do coding in it.

A. PID Logic Control

As we discussed in the thesis that despite of conventional method we were using PID logic controller to torque control. But the harmonics and ripples are not so much controlled, despite of this reason it also consist large number of complex mathematical equation which is necessarily to be solved. It consist main advantage that it can be analyze by various methods, such as bode plot, nyquist plot to check its stability.

B. Fuzzy Logic Control

As we notice that fuzzy logic controller (FLC) is very much simple method to control any type of control system. It does not require that any special type of coding method like ladder logic or programmable logic. It is just based upon the simple linguistic logic. Which works on the basis of universal logic gates NAND gate and NOR gate. Although it consist some demerits too, that it required so much data and much more calculation to minimize the ripples and error signal. After the completing its simulation part this thesis is focused on introducing another much better technique to control the torque – speed characteristics. . A Fuzzy Logic Controller is in charge of controlling this modulation between the selected active state and a null one. Therefore, it has been suggested and deeply described the Fuzzy Logic Controller, which is sufficient alone, and due to its properties it can be applicable with the combination technique with PID controller, artificial neural network etc. Finally, we studied about the theoretically, mathematically and with the help of simulation results we minimize the torque ripples of DC motor. The use of fuzzy logic control gave satisfactory results and reduces the computation burden by avoiding unnecessary complex mathematical modeling of the nonlinear systems.

C. FUTURE WORK

All future work can be briefly explained by following ideas:

- Develop a multipurpose fuzzy logic controller which is supported for every type of motor with following characteristics:
- Develop a completely adaptive controller for any motor.
- Try to reduce much more noise and harmonics, which is generally a main problem if any power drive.
- Study the torque-speed characteristic not only with the help of fuzzy logic controller but with the combination of several controlling techniques.
- Study and apply the fuzzy logic controller not only for DC motor as discussed in this thesis, but for the many more applications as power drives, medical appliances etc.

REFERENCES

[1] Theodore Wildi, " Electrical Machines, Drives and Power Systems," in Ed., 6th ed., Pearson Hall,2013

[2] Prof. Krishna Vasudevan, Prof. G. Sridhara Rao, Prof. P.Sasidhara Rao, "Electrical Machines I" in Indian Institute of Technology, Madras, India. pp. 1-8

[3] Naveen Joy and C. K. Vijayakumari , "Direct Torque Control of BLDC motor using Fuzzy Logic in Labview", Department of Electrical Engineering Rajiv Gandhi Institute of Technology, Kottayam, Kerala, India , Volume- 2, Issue- 1, Jan.-2014

[4] Zadeh L. A., "Outline of a New Approach to the Analysis of Complex Systems and Decision Processes", IEEE Transactions Systems, Man and Cybernetics, SMC-3, 1973, pp. 28-44.

[5] Manafeddin Namazov and Onur Basturk, "DC motor position control using fuzzy proportional-derivative controllers with different defuzzification methods", Cumhuriyet University, Faculty of Engineering, Turkish Journal of Fuzzy Systems , *May 26, 2010* , Vol.1, No.1, pp. 36-54, 2010.

[6] Vikas S. Wadnerkar , Mithun M. Bhaskar, Tulasi Ram Das and A.D.

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Raj Kumar, "A New Fuzzy Logic based Modelling and Simulation of a Switched Reluctance Motor", Journal of Electrical Engineering & Technology Vol. 5, No. 2, pp. 276 - 281, 2010.
[7] John D. Jackson. Classical Electrodynamics (Second Edition). John Wiley & Sons, New York, 1975.
[8] Fuzzy Logic Toolbox user's Guide R2012b, © COPYRIGHT 1995–2012, The MathWorks, Inc. Revised for Version 2.2.16 (Release 2012b) pp. 34-36, 109-144, September 2012, Available: http:// www.mathworks.com
[9] Glenn Vinnicombe, "Impulse responses, step responses and transfer functions." Part IB Paper 6: Information Engineering "LINEAR SYSTEMS AND CONTROL",pp. 3-22
[10] Allan R. Hambley, "*Electrical Engineering Principles and Applications*," Chapter 16.
[11] Giorgio Rizzoni, "*Principles and Applications of Electrical Engineering*," Chapter 17.
[12] John Mouton, "Brushed DC Motor Basics", Part 1 in a 4 part series of web seminars on "Controlling a Brushed DC Motor using a Microcontroller", AN905 "Brushed DC Motor Fundamentals.", Available: http:// Microchip.com.
[13] Luca Zaccarian, " DC motors: dynamic model and control techniques" pp. 9-15
[14] E.Kalika, "A High Performance Direct Torque Control of PMDC Motor Using Hybrid (GA Based Fuzzy Logic) Controller" – Springer , Power Electronics and Instrumentation Engineering Communications in Computer and Information Science Volume 102, 2010, pp. 96-99

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I like to work with various designing software as EAGLE & DIPTRACE. I also have interest in simulation software as PROTEUS. Apart from academic segment I successfully participated as an active member in the organizing committee in "*World Conference on Advances in Communication & Control System – CACCS'13"* from 06/04/2013 to 08/04/2013. I was an active member of IEEE Student Chapter from 16 august 2011 to 15 august 2012. & coordinate several Intra college technical events. I also worked as an active volunteer of SPICMCAY a voluntary movement that organizes events of classical music & art.

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