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# Fuzzy Logic For Controlling Speed Of DC Motor

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**-----ABSTRACT-----**
*The paper deals with controlling the speed of dc motor accurately and efficiently. The paper gives idea of designing the high current driver circuit and an efficient algorithmic based control (Fuzzy Logic) to track the velocity.The motor driver circuit can be constructed using the MOSFET and employing the H- bridge circuit due to its simplicity. The control system uses the concept of FUZZY SET to control the error signal fed back to the system, which can be obtained by employing optical encoder as a speed sensor. Unlike the traditional analog PID control system, where OPAMPs are used, the paper utilizes the concept of the discrete control system by employing the controlling algorithm in the FPGA. The VHDL can be used to describe the digital system. In summary, this paper gives the capability of Fuzzy Logic in designing a control system for speed controller of DC Motor.*

***KEYWORDS*** *- Controlling algorithm in FPGA, Discrete Control System, Driver circuit for DC motor , Fuzzy logic controller, Fuzzy Controller using FPGA and VHDL, Speed control of DC motor.*

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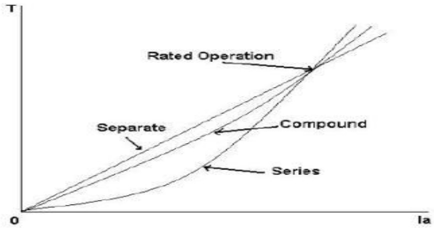
## I. INTRODUCTION

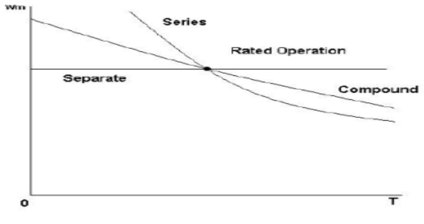
The main objectives of the paper are to design driver circuit for a DC motor to implement fuzzy logic in the speed control system. The motor driver circuit has been constructed using the MOSFET and employing the H- bridge circuit due to its simplicity. The MOSFET implemented was chosen considering the maximum current it can draw. The control system uses the concept of FUZZY SET to control the error signal fed back to the system, which is obtained by employing optical encoder as a speed sensor. Unlike the traditional analog PID control system, where OPAMPs are used, the project utilizes the concept of the discrete control system by employing the controlling algorithm in the FPGA. The VHDL has been used to describe the digital system. In summary, this paper gives the capability of Fuzzy Logic in designing a control system for speed controller of DC Motor. It also signifies the importance of the need for further research in the field of DC motor speed controller design.

## II. MATHEMATICAL ANALYSIS OF SEPARATELY EXCITED DC MOTOR

Total control over armature and field voltages separately in separately excited dc motor. The basic equations of the system are $E=K e\phi W m$ (1),$V=E+RaIa$ (2) $T= K e\phi\ Ia$ (3).Two most important characteristics of the dc motor are speed torque characteristics and torque current characteristics.




Torque-current curves




Speed-torque curves

From equation 3 equation of separately excited DC motor can be written as E= KeWm (4) ,V=E+RaIa (5),T= Ke Ia (6).The variable $\phi$ has been omitted from the equation because the field current remains constant thus it is incorporated in the value of Ke (the motor constant ). The above equation is the steady state equation .In the case of transient analysis the equation changes to V = RaIa+LadIa/dt+ KeWm (7).Where La=armature inductance. The equation describing mechanical behavior of the DC motor is T=BWm+JdWm/dt+Tl. (8)Where T(Nm)=Torque of motor,B(Nms)=coefficient of the friction of the motor,J(Nms2)=the moment of inertia of the motor, Tl.(Nm)=the load torque. Substituting Eq. (6) in (8), we have Ke Ia = Bwm + J dwm /dt +TL [9] Differentiation Eq. (9) gives Ke dIa /dt = B dwm /dt + J d2wm/dt2 + dTL /dt (10) Substituting in Eq. (7) for dIa /dt from Eq. (10)and rearranging the terms we get Ta d2wm /dt2 + (1 + Ta /Tm1 ) dwm /dt + wm /Tm2 = Ke V/JRa – (TL + Ta dTL /dt)/J (11). Differentiation Eq. (8) gives Ke dwm /dt = dV/dt – Ra dIa /dt – La d2Ia /dt2 (12) Substituting in Eq. (8) for dwm /dt from Eq. (12) and rearranging the terms we get Ta d2Ia /dt2 + (1 + Ta /Tm1 ) dIa /dt + Ia /Tm2 = (V + Tm1 dV/dt + Ke TL /B)/Ra Tm1 (13) where Ta = La /Ra armature circuit time constant (14),Tm1 = J/B mechanical time constant (15) Tm2 = JRa /(BRa +Ke2) second order term (16) The above equations are second order linear differential equations and can be solved if appropriate initial conditions are known. The most parameter necessary for the designing of the driver circuit is the peak current or the overshoot Current in the armature circuit. This overshoot happens in the circuit during the turning ON and OFF state. Therefore, we will be looking at these transient responses in depth. **Mode of Operation of DC motor** In electric drive, the motor has to be operated in different modes. These different modes include forward motoring, backward motoring, forward breaking and backward braking. These modes are can be attained through the implementation of H-bridge circuit. This circuit includes composition of four switching element as shown in figure 2.1

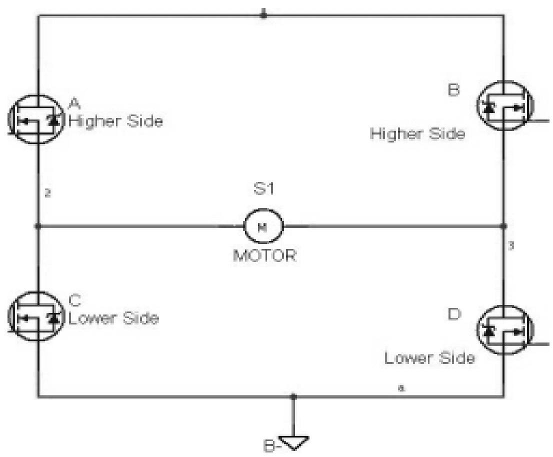



Fig. 2.1

The system is a closed loop system which consists of a command signal, processing unit plant and feedback as shown in figure2.1.1.

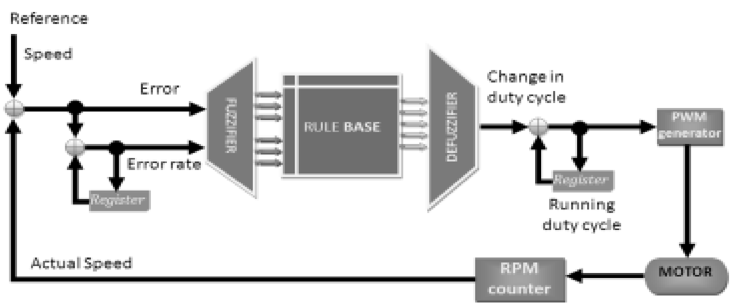


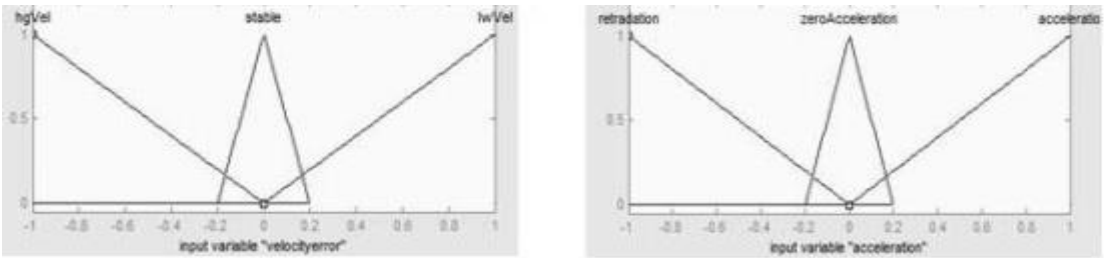

Fig 2.1.1

In the system, the command is reference velocity given through the computer using parallel port. The paper is not concerned with the means of command signal but instead with the controller only. Therefore the paper mainly focuses on the design of the entire block in the Fig. 2.1.1. The main block of the system is the core of the system – the controller. For the processing of the error signal fuzzy control has been employed due to its efficiency in design and its ease of execution. The Fuzzy Controller is implemented in FPGA using VHDL using the concept of Digital System Design.

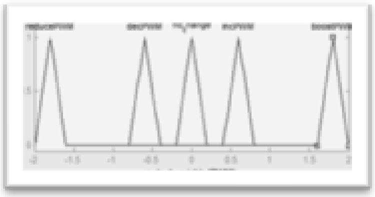
In other words, the system is a discrete control system. The controller generates a control signal i.e. PWM output to the Full Bridge DC-DC Converter. The DC-DC converter drives the motor is four quadrants (Motoring and Braking in both directions).
The velocity feedback is employed using the concept of optical encoder. The feedback signal is processed through the FPGA and the required error signal is generated.

## III. FUZZY IMPLEMENTATION

The fuzzy PID control is used as the working method. This method requires a mathematical model of the motor. Moreover we have used the fuzzy PI controller. The input to the controller is velocity error (e) and the change of this error (de). The inputs are then fuzzified, rule is applied and the fuzzy output is defuzzified to give a crisp output which is the change in the PWM width. Hardware implementation of the controller can be achieved in a number of ways. The most popular method of implementing fuzzy controller is using a general-purpose microprocessor or microcontroller. General, 8-bit microcontroller are more economical and flexible, but often face difficulties in dealing with control systems that require high processing and input/output handling speeds. As an option, the controller can be implemented on a FPGA, which is suitable for fast implementation and quick hardware verification. FPGA based systems are flexible and can be reprogrammed unlimited number of times. For designing the Fuzzy rules and simulating the rules Matlab® Ver. 7.8 can be used. Rules are written using its fuzzy tool and the dc motor‟s speed control using the fuzzy controller was simulated using Simulink. The input and output membership functions and rules used in the controller are shown below.

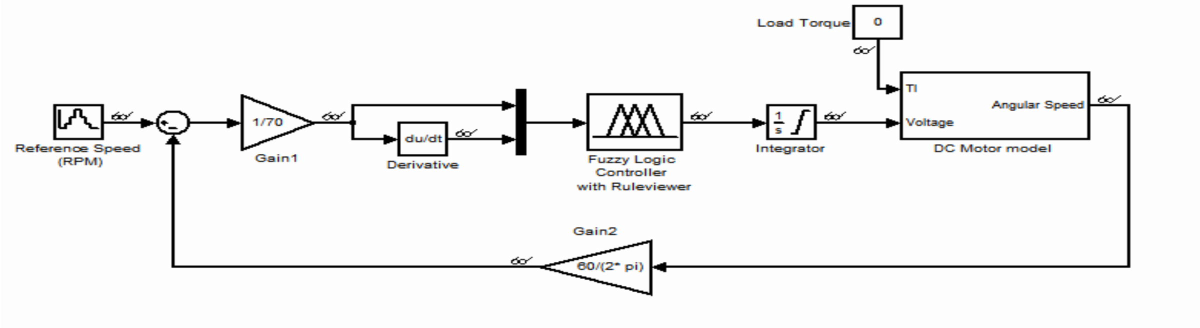



Membership functions of inputs

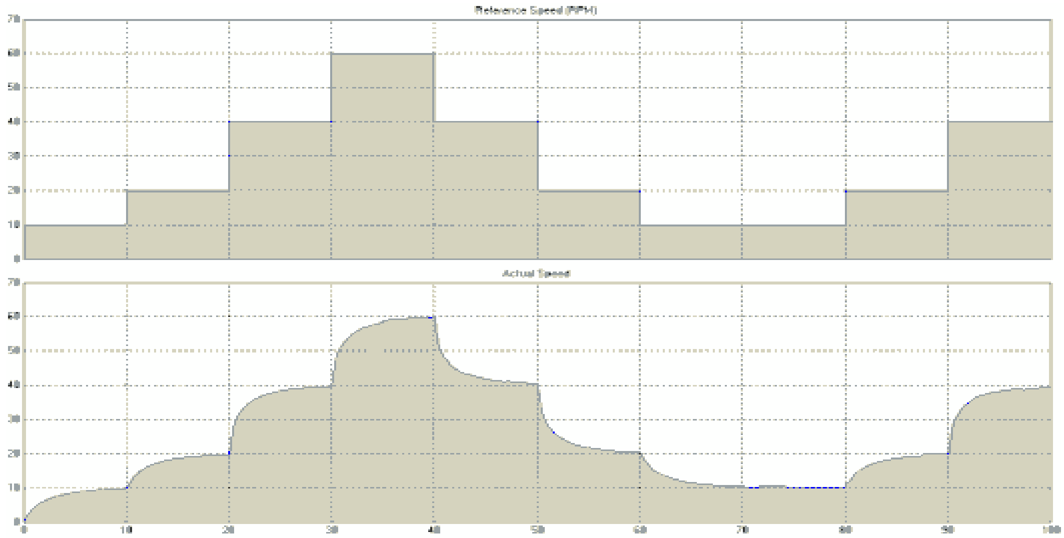


Membership Function of output Rule base for fuzzy inference system

Figure below shows the Simulink model of the controller and the result obtained. The result shows the desired speed and the actual speed obtained from the dc motor model.




Simulink model of Fuzzy controller

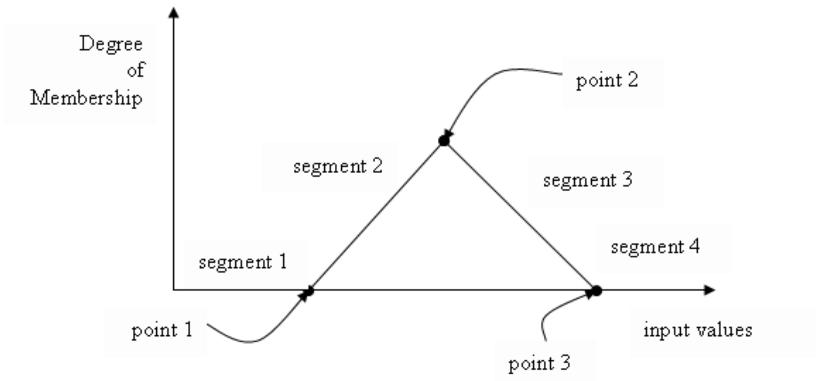


Speed set by fuzzy controller (top) Reference Speed (bottom) Actual Speed

The realization or the implementation of the fuzzy logic controller as described earlier was done in Very high speed integrated-circuit Hardware Description Language (VHDL). Each phase of the fuzzy inference system that is fuzzification, rule evaluationz and defuzzification were implemented sequentially in VHDL.

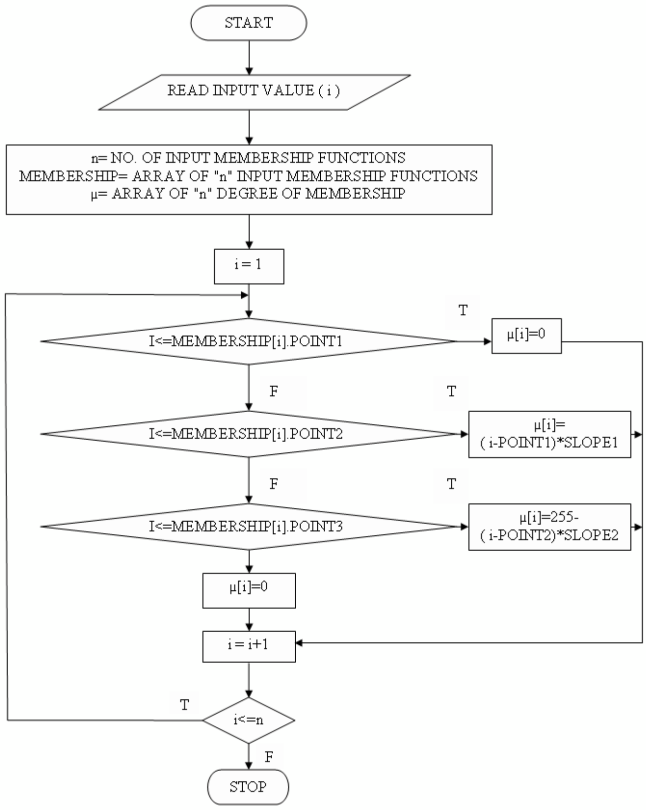
## IV. FUZZIFICATION

A member function can be singleton, triangular, trapezoidal, etc. In the project triangular menmbership function were implemented. A triangular membership function can be effectively and simply described by three points and two slopes. Hence the each membership function was divided into four segments by these three points namely segment 1, 2, 3, 4.




Representation of the triangular membership function

The calculation of the „degree of membership‟ can be hence different at these four segments. At segment 1, where „input value‟ ≤ point Degree of membership (μ) = 0. At segment 2, where „input value‟ < point2 Degree of membership (μ) = (input value – point1) * slope1 At segment 3, where „input value‟ < point3 Degree of membership (μ) = 1 – (input value – point2) * slope2. At segment4, where „input value≥point3Degree of membership (μ) = 0. The input value, three points, two slopes and the degree of membership were implemented using an 9-bit resolution computation. So, μ = 1 equals 1ff h or 511d. The fuzzification of the inputs was performed as shown below in the flowchart.



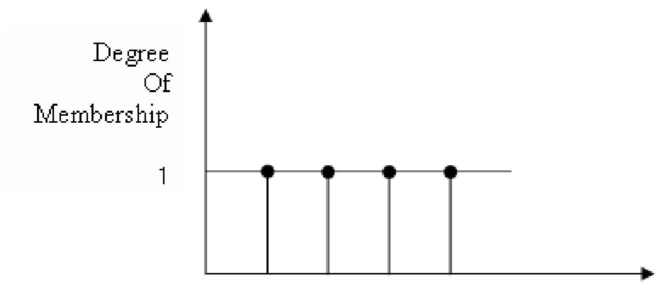

FlowChart of FUZZIFICATION

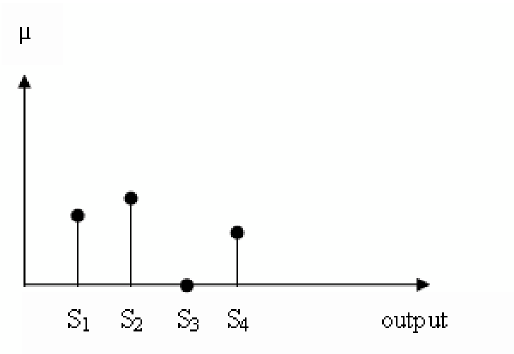
## V. RULE INTERFERENCE

After the inputs have been fuzzified, the necessary action i.e. Output required is determined from the linguistic rule. This method can also be termed as min-max inference. A rule typically is in the IF – THEN form. For an example, IF x is a AND y is b THEN z is c. It has "AND" operation between two fuzzy sets x and y which is actually the minimum operation between them. So,c=min(a,b) Also, if a output is observed from two rules, the implied "OR" operation between the two rules is used which is nothing more than simple maximum operation. Example: IF (x is a1 , AND y is b1 ) OR (x is a2 AND y is b2 ) THEN z is c. c = max (min (a1 , b1 ), min (a2 , b2 ))

## VI. DEFUZZIFICATION

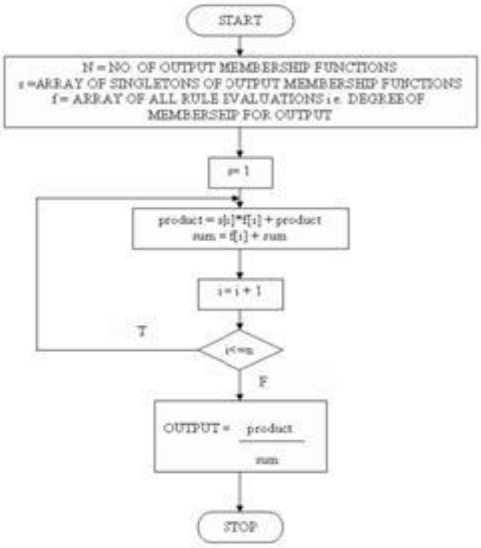
The result of the rule inference is also fuzzy and consists of no. degree of membership of the output. Defuzzification not only has to defuzzify the output but also combine all the output degree of membership into a single output value. The output from the defuzzification process is hence crisp and not fuzzy. For simplicity and ease, output membership functions have been taken as singletons (figure 3-10) that can be described by only a single point.






output of the fuzzy rule inference for output membership functions

The calculation of the crisp output from the no. of degree of membership was done by taking the weighted average.




FlowChart Representing DEFUZZIFICATION

## VII. FEEDBACK MECHANISM

The velocity feed back in terms of the revolution per minute (RPM) was sensed using an opto-interrupter (also known as beam breaker). Opto-interrupter consists of a infrared emitting diode and photo transistor aligned such that the emitted beam falls on photo sensitive base of the photo transistor. A slotted disk as shown in the figure below breaks the beam at regular interval and hence generates train of pulses. Then the no of system frequency (10 KHz) clock pulses that fall on these pulses (high or low) is counted. This count gives the width of a slot in terms of no of 10 KHz pulse ie, in terms of time. From the already known slots count (30 open and 30 closed slots) time for one revolution is determined by multiplying the slot width (in time) with slot count. Its reciprocal gives us the revolution per sec, from where RPM can be determined by multiplication with 60. Equation for finding the RPM; System frequency 2 x Count = Revolution per minute (RPM) Where, Count = no of system frequency clock pulses that fall on high or low pulse from the opto-interrupter

## VIII . CONCLUSION

The controller has accurate and efficient speed. It deals with the problem of high current driver circuit and an efficient algorithmic based control (Fuzzy Logic) to track the velocity. Hence, for the sake of prototyping the design, an appropriate model of the motor that draws maximum of 11A was used. The design was based on the choice of the MOSFET that could handle the required current. In order to drive the gate of the MOSFET, a method known as Bootstrap was used. The traditional analog control of the motor‟s speed requires the knowledge of the accurate mathematical model which is very difficult to determine and varies with each motor. This makes the design inflexible. But in contrast, the discrete control system has the advantage of employing complex mathematical algorithm that is efficient and accurate. Hence the choice of FPGA makes the best solution for the objective of accurate and efficient speed controller. In addition, the implementation of Fuzzy Logic in FPGA makes the system design easier. Also, it increases the flexibility of the controller to the change in system‟s parameter presented after the conclusion, if desired.

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**Biographies and Photographs**

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