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Speed Control of Permanent Magnet Brushless DC Motor with Parameter Optimization

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Abstract - *Permanent Magnet Brushless DC motor (PMBLDC) have variable speed applications. There is use of advance high energy permanent magnet used and latest power electronics technology increase used of BLDC motor. Due to low maintenance cost, high efficiency, and smart controllability of BLDC motor increase the use. Also simultaneously this motor has replacement of brush set as compared with brushed DC motor. The parameter optimization of this BLDC motor done using Fuzzy logic controller also speed control of motor done with fuzzy logic controller. This proposed system optimized the different parameters of BLDC motor using MATLAB simulink with Hardware approach implementation using Arduino controller. The main objective of this proposed approach is to improve the performance of speed control of BLDC motor using fuzzy logic controller with proper parameter optimization. This proposed approach has been by design, tested and analyzed on a 10000KV, 30 Amp permanent magnet brushless motor drive.*

Key Words: *BLDC motor, Fuzzy Logic, Arduino*

1. INTRODUCTION

Brushless motor also called as permanent Magnet Brushless DC motor and which very much used recently for various applications like industrial, servo, robotics operation, etc. BLDC motor is most popular due to their low noise, stability, and high performance applications for all electrical small applications. Length of BLDC motor is small as compared with normal dc motor because of absence of commutator construction in motor.

BLDC motor reduce the electromagnetic interference as compared with other motors like three phase induction motor and brushed dc motor. BLDC motor has better speed verses torque characteristics, high efficiency operation, long life operation, noiseless operation and high speed operation. Also, PMBLDCM is not required any electrical connections between stator and rotor of motor. Also it is characterized by permanent magnet mounting and back EMF effects.

Modeling of any moor is difficult task for control of speed of that modeled motor. Also mathematical modeling is requires for controlling of any motor. But use of intelligent controller is not required any mathematical modeling for speed controlling of any machine. There are many types of intelligent controllers are available like fuzzy logic controller, neural network, adaptive nuero fuzzy inference controller. But fuzzy logic controller provides high efficiency and accuracy in high performance motor drive system without any mathematical modeling requirements.

Fuzzy logic controller normally applied to nonlinear system which required embedded coders hence fuzzy logic controller is better choice when mathematical modeling design is difficult for any controlling system. Recently various fuzzy logic controller was developed and design for various application or drive control.

2. PROPOSED METHODOLOGY

2.1. Block diagram

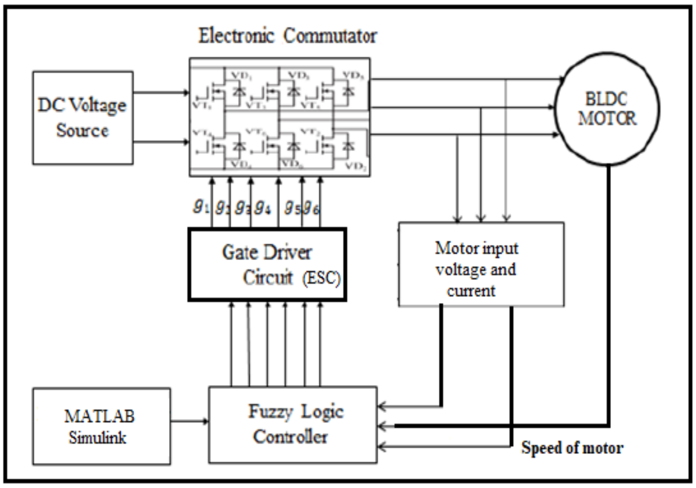

Fig-1: Block diagram of proposed approach

Figure 1 shows the complete block diagram of proposed fuzzy logic controller based BLDC motor in which fuzzy logic controller system is design in MATLAB 2019 simulink software. Speed of BLDC motor control with help of Electronics Speed Controller (ESC) by controlling their duty cycle. Duty cycle is control using fuzzy logic controller by comparing the motor input voltage, current and output speed of motor.

Fig. 1 presents the block diagram of the proposed fuzzy logic base speed control and parameter optimization system for BLDC motor. This system consists of AC to DC converter which converts AC supply into DC at required level for inverter input. Then with help of fuzzy logic controller firing pulse of inverter controller and then input supply of BLDC motor control by inverter. This is the closed loop operation of BLDC speed control method minimized the parameter optimization effort and provides better speed control performance.

Major components used in hardware model are:

1. BLDC Motor (42212/10T)
2. Electronics speed controller (ESC) 40Amp
3. ACS 712 Current sensor (10 Amp DC)
4. Voltage sensor for arduino (25 V DC)

3. PROJECT IMPLEMENTATION

3.1 Hardware configuration

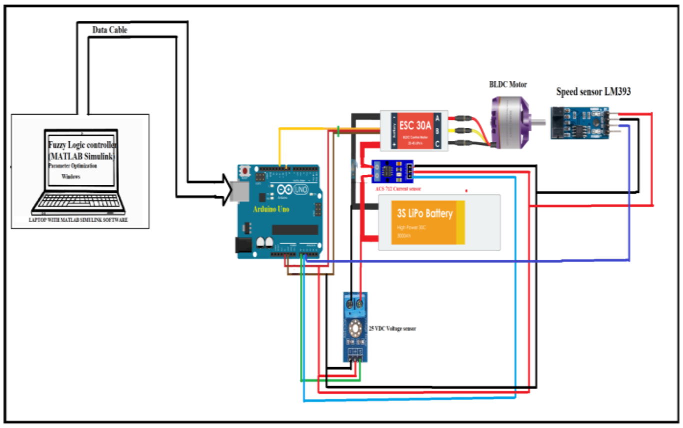

Fig-2: Hardware connection diagrams for BLDC motor control using matlab simulink based Fuzzy controller modeling

Figure 2 shows the connection diagram of hardware model for fuzzy logic controller based BLDC motor. In which fuzzy logic controller is design in MATLAB simulink software using Fuzzy logic tool box and fuzzy logic controller output connect with hardware with help of hardware simulink support package for arduino.

The fuzzy logic controller output is send to arduino digital pin D11 which PWM pulse width modulation based pin. The duty cycle or ON time of pulses of D11 pin is control using FLC. Fuzzy logic controller control the D11 duty cycle by controlling the logic from 0 to 255. If logic 0 then duty cycle is zero means speed of machine 0. While logic 255 then speed of motor is 14000 RPM that means maximum.

Then D11 digital pin send the duty cycle or PWM controlled output to the throttle pin of ESC controller and hence the firing pulses of EAC is controlled. The fuzzy logic controller send the logic 0 to 255 bases on input DC voltage and current of BLDC motor as well as output speed measurement signal. The rule base are design in fuzzy logic controller which is based on three inputs variations and output becomes varies from 0 to 255 based on input and selected rule base. Figure 3 shows the hardware configuration of figure 2 implementation.

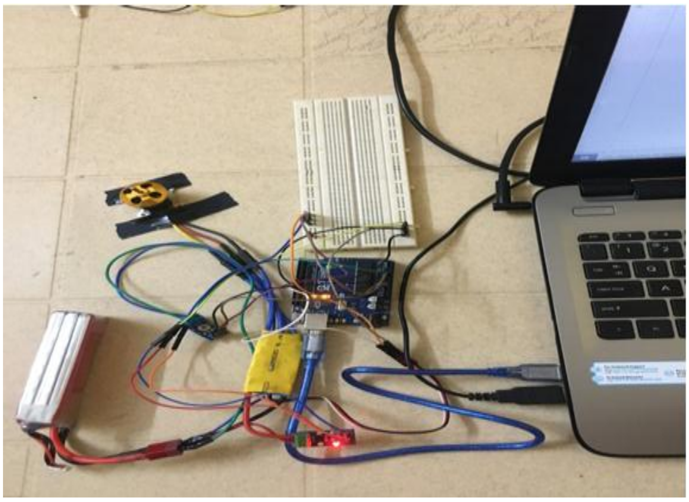

Fig-3: Actual hardware connections with arduino and MATLAB simulink software

3.2 Software Configuration

Figure 4 shows the MATLAB simulink model of PID controller based BLDC motor using Arduino Hardware simulink support package in matlab simulink in which PID controller is designing. The system is design using arduino simulink package tools and PID controller simulink model. The inputs for PID controller are input dc voltage and current of BLDC motor as well as output speed of motor as third input while output of PID controller is 0 to 255 logic which control the duty cycle of PWM Digital D11 pin of arduino.

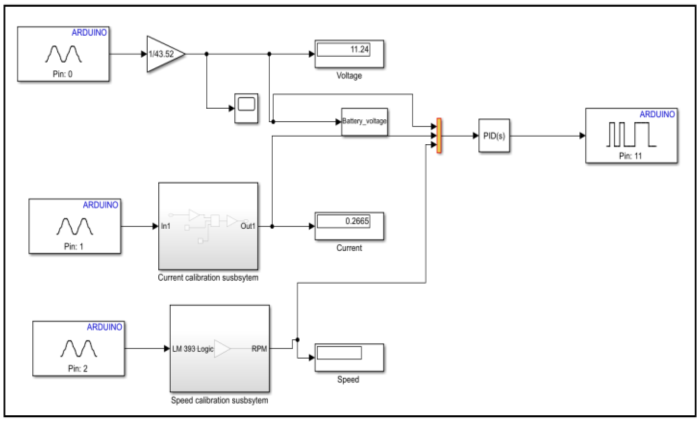

Fig-4: MATLAB simulink model of PID controller based BLDC motor using Arduino Hardware simulink support package in matlab simulink

Figure 5 shows the MATLAB simulink model of fuzzy logic controller based BLDC motor using Arduino Hardware simulink support package in matlab simulink in which fuzzy logic controller is designing. The system is design using arduino simulink package tools and fuzzy logic controller design using fuzzy toolbox which discussed in next section 3.3.

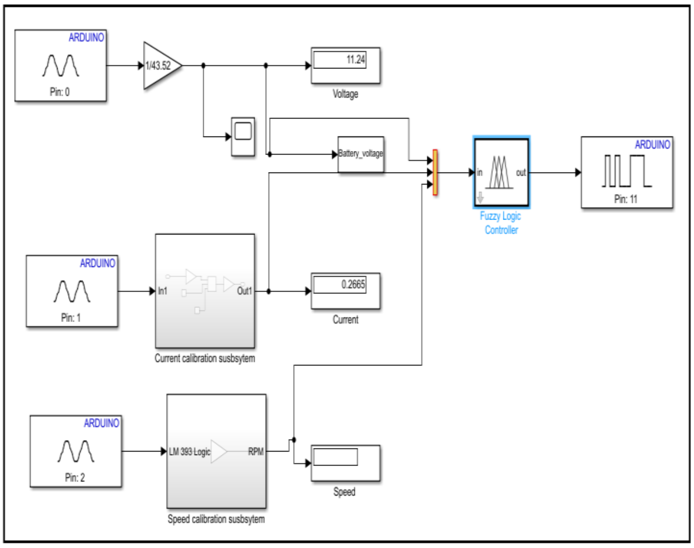

Fig-5: MATLAB simulink model of fuzzy logic controller based BLDC motor using Arduino Hardware simulink support package in matlab simulink

The inputs for FLC controller are input dc voltage and current of BLDC motor as well as output speed of motor as third input while output of PID controller is 0 to 255 logic which control the duty cycle of PWM Digital D11 pin of arduino.

3.3 Fuzzy logic controller designing

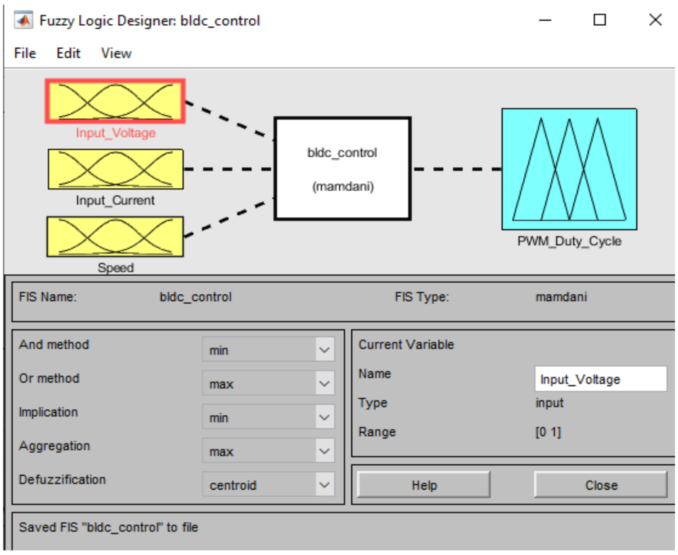

Fig-6: Fuzzy logic designer window in matlab simulink for design fuzzy logic controller

Figure 6 shows the fuzzy logic designer window in matlab simulink in which there are three inputs like dc input voltage, dc input current and speed while single output that is PWM duty cycle logic. Each inputs are three linguistic variable like Low, Medium and High and details of each inputs shown in table 5.1 to 5.3 while single output are three linguistic variable like Low, Medium, High.

Table 1 shows the details of input-1 i.e. dc input voltage membership function while this figure 5.6 shows the designing of input-1 membership function for fuzzy logic controller.

Table 2 shows the details of input-2 i.e. dc input current membership function while this figure 7 shows the designing of input-2 membership function for fuzzy logic controller.

Table-1: Input-1 voltage membership function details

Name of Linguistic variable	Type of Membership Function	Range of Membership Function
Low	Triangular	0 to 2 to 4
Medium	Triangular	4 to 6 to 8
High	Triangular	8 to 10 to 12

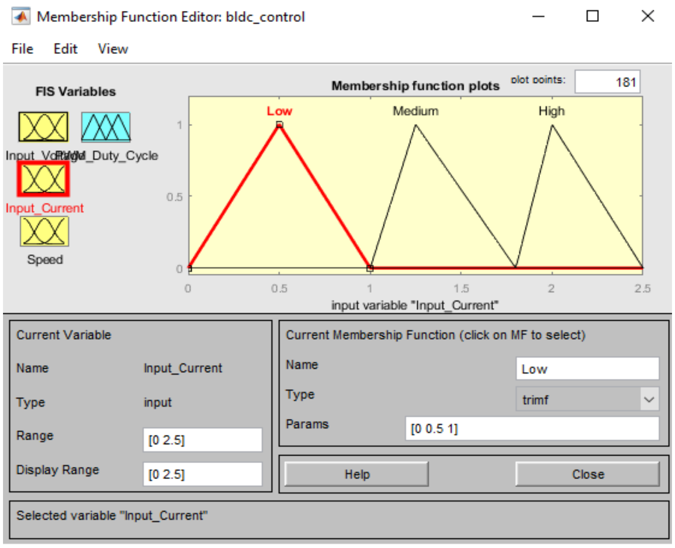

Fig-7: Input current membership functions design in fuzzy toolbox

Table-2: Input-2 current membership function details

Name of Linguistic variable	Type of Membership Function	Range of Membership Function
Low	Triangular	0 to 0.5 to 1
Medium	Triangular	1 to 1.25 to 1.8
High	Triangular	1.8 to 2 to 2.5

Table-3: Input-3 speed membership function details

Name of Linguistic variable	Type of Membership Function	Range of Membership Function
Low	Triangular	0 to 2000 to 4500
Medium	Triangular	4500 to 6500 to 8500
High	Triangular	8500 to 11000 to 14000

Table 3 shows the details of input-3 i.e. output speed of motor membership function while this figure 8 shows the designing of input-3 membership function for fuzzy logic controller.

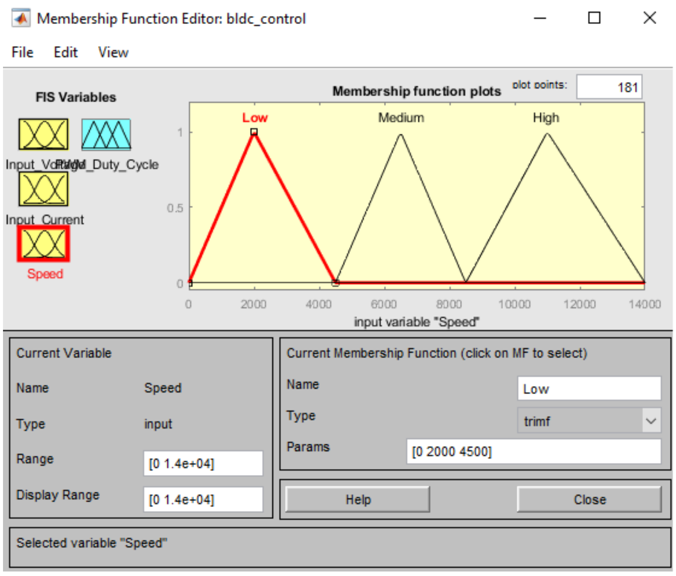

Fig-8: BLDC Motor speed membership functions design in fuzzy toolbox

Table 4 shows the Output control membership function for fuzzy logic controller in which there are three linguistic variables Low, Medium, High and the range of each membership function shown in table 5.4.

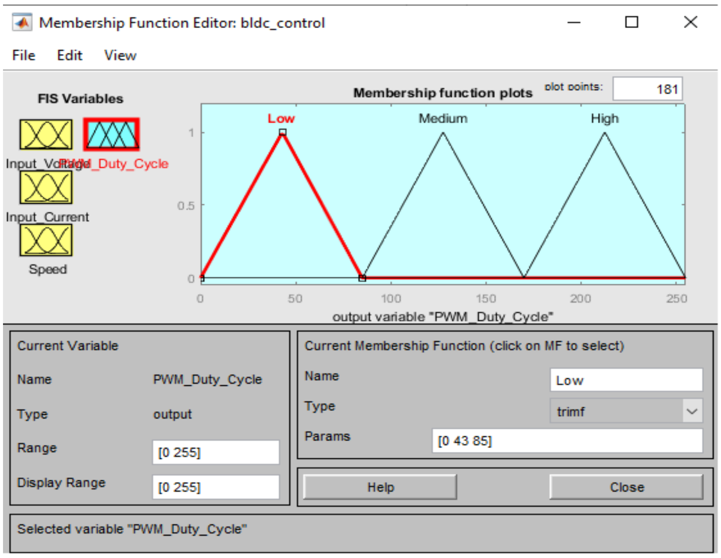

Fig-9: Output membership function for controlling duty cycle of ESC

Table-4: Output membership function details

Name of Linguistic variable	Type of Membership Function	Range of Membership Function
Low	Triangular	0 to 43 to 85
Medium	Triangular	85 to 127.5 to 170
High	Triangular	170 to 212.5 to 255

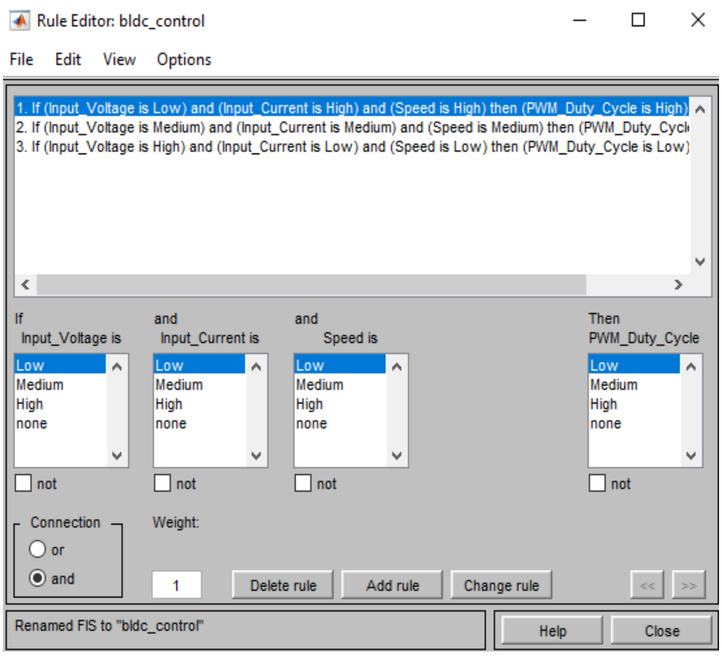

Fig-10: Fuzzy rule editor in matlab software

Figure-5: Fuzzy logic controller rule base

Rule Number	Input Voltage	Input Current	Output motor speed	Output of Fuzzy logic
Rule-1	Low	High	High	High
Rule-2	Medium	Medium	Medium	Medium
Rule-3	High	Low	Low	Low

Figure 10 shows the fuzzy rule base designer window in MATLAB simulink software in which Fuzzy "If-Then Rule" with AND and OR logic. There are three fuzzy rule base design for controlling the firing pulses or duty cycle of ESC controller based on three inputs voltage, current and speed of motor. Table 5 shows the three IF-THEN-AND rules for fuzzy logic controller.

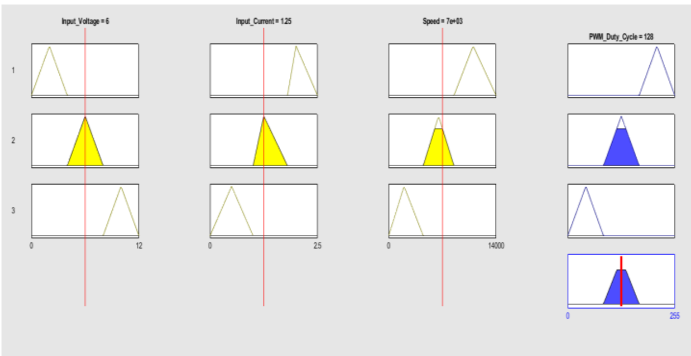

Fig-11: Fuzzy logic membership function for all fuzzy rule base

Figure 11 shows the all fuzzy rules base with all three inputs with each membership function representation. In which each three inputs are triangular membership function and output action also triangular membership function. Here we can also test the fuzzy logic controller action or output for corresponding sets of input. The output defuzzification done using centroid method shown in last coulomb of figure 11.

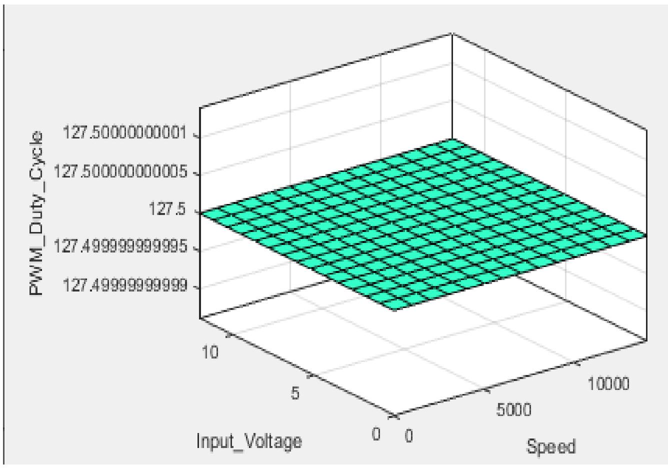

Fig-12: Controlling surface between speed and Input voltage Verses PWM duty cycle

Figure 12 shows the fuzzy logic controller output controlling surface with respect to two inputs input-1 i.e. voltage and input-3 i.e. speed of motor. It is observed that if input voltage is 5 Volt and speed is 5000 rpm then output becomes 127.5 duty cycle logic for D11 pin of arduino.

Figure 13 shows the fuzzy logic controller output controlling surface with respect to two inputs input-2 i.e. current and input-3 i.e. speed of motor. It is observed that if input voltage is 2.3 Amp and speed is 5000 rpm then output becomes 127.5 duty cycle logic for D11 pin of arduino.

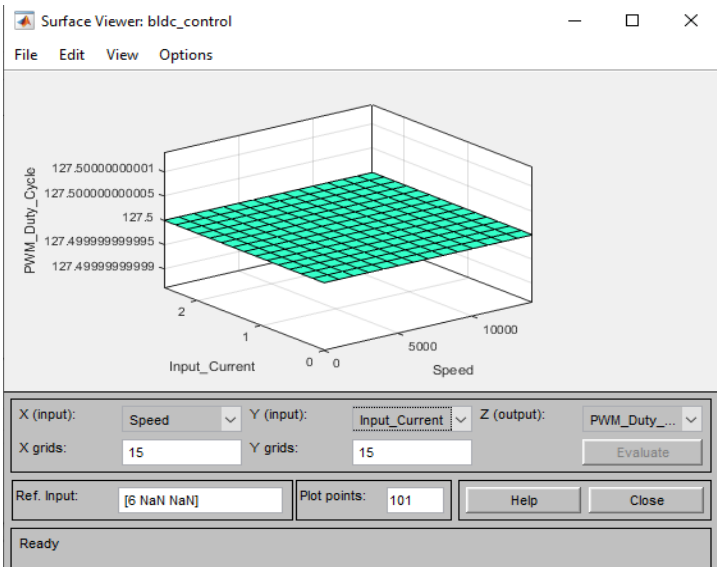

Fig-13: Controlling surface between speed and Input current Verses PWM duty cycle

The complete system is design using hardware model and software model in matlab simulink software. The hardware contents the measurement subsystem for BLDC motor and BLDC motor configuration. While software includes the MATLAB simulink model of fuzzy logic controller which controls the hardware with the help of arduino controller interconnection between hardware and software.

4. EXPERIMENTAL RESULTS AND DISCUSSION

4.1 Parameter of BLDC motor

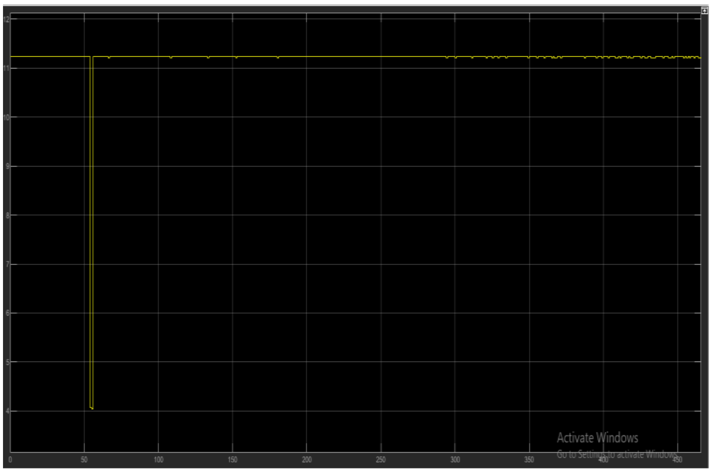

Fig-14: Graph of Time verses input voltage of BLDC motor

Figure 14 shows the input voltage verses simulation time graph for BLDC motor in which it is observed that the voltage of motor is constant around 11.40 V and after some time voltage decreases with very small rate.

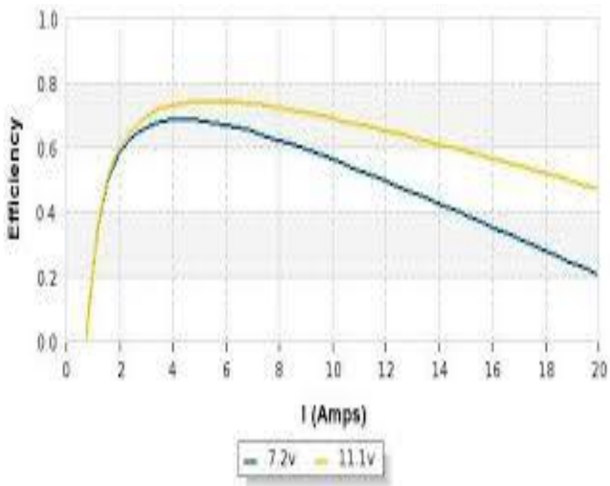

Fig-15: Input current verses efficiency of BLDC motor at different voltages

Figure 15 shows the BLDC motor input current verses output efficiency of BLDC motor in which it is observed that for input voltage of 11.1 V DC the efficiency and performance of BLDC motor is best as compared with 7.2 V input DC voltage.

4.2 Speed control of BLDC motor

4.2.1 At constant speed operation

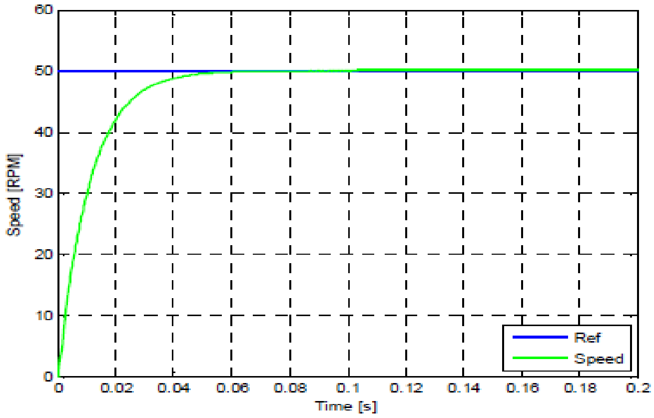

Fig-16: Speed control of BLDC motor using Fuzzy logic controller (Simulation results)

Figure 16 shows the speed verses time graph for BLDC motor using fuzzy logic controller for matlab simulation model. It is observed that there is smooth speed control operation of motor. But transient period time is 0.06 sec and after 0.06 sec time BLDC motor achieve the reference speed i.e. 50 RPM.

Figure 17 shows the speed verses time graph for BLDC motor controlled using fuzzy logic controller with parameter optimization for matlab simulation model. It is observed that there is smooth and fast speed controlling operation as compared with figure 16 operations. Also motor transient period time is 0.02 sec and after 0.02 sec time BLDC motor achieve the reference speed i.e. 50 rpm speed. Hence fuzzy optimization technique required less time to achieve the reference speed as compared with only fuzzy controller based speed controlling technique shown in figure 16.

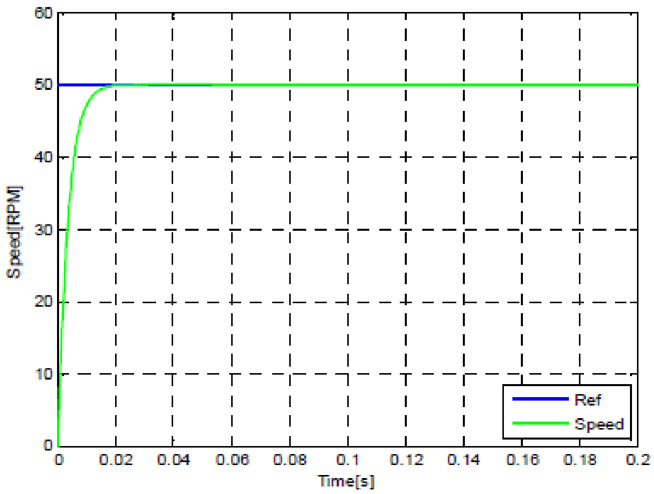

Fig-17: Speed control of BLDC motor using Fuzzy logic controller after parameter optimization (Simulation results)

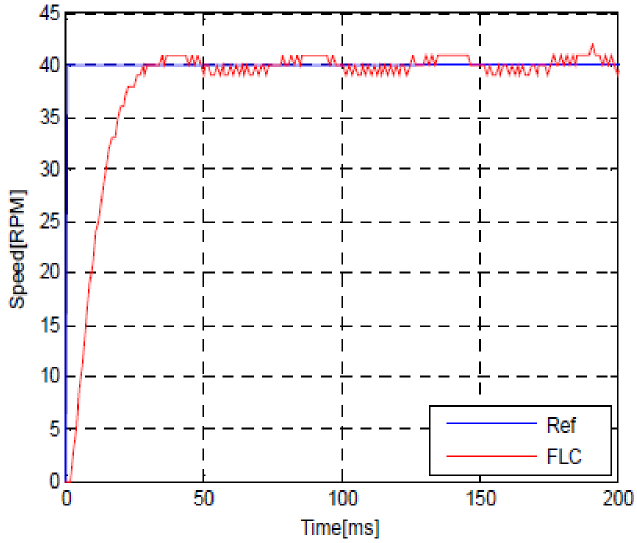

Fig-18: Speed control of BLDC motor using Fuzzy logic controller (Hardware model experimental result)

Figure 18 shows the speed verses time graph for BLDC motor using fuzzy logic controller for hardware model. It is observed that there is smooth speed control operation of motor. But transient period time is 40 millisecond and after 40 millisecond time BLDC motor achieve the reference speed i.e. 40 RPM.

Figure 19 shows the speed verses time graph for BLDC motor controlled using fuzzy logic controller with parameter optimization for hardware model. It is observed that there is smooth and fast speed controlling operation as compared with figure 18 operations. Also motor transient period time is 25 millisecond and after 25 millisecond time BLDC motor achieve the reference speed i.e. 40 rpm speed. Hence fuzzy optimization technique required less time to achieve the reference speed as compared with only fuzzy controller based speed controlling technique shown in figure 18.

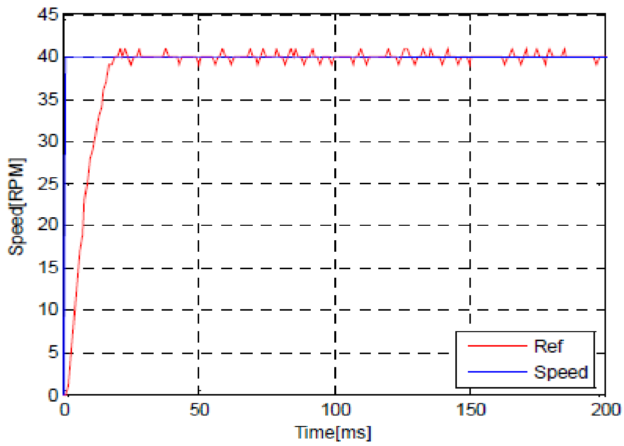

Fig-19: Speed control of BLDC motor using Fuzzy logic controller after parameter optimization (Hardware model experimental result)

4.2.2 At variable speed operation

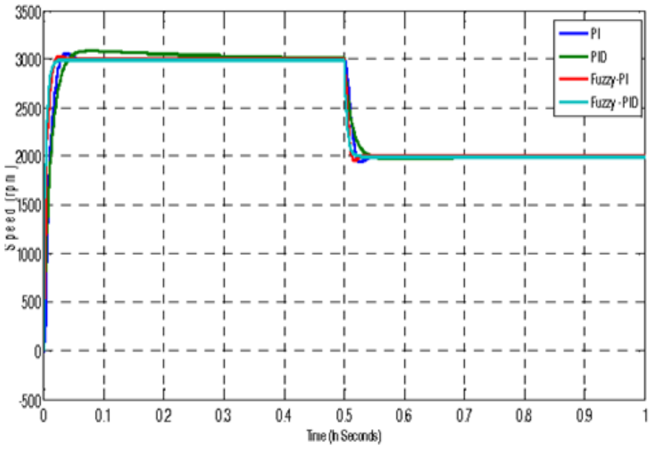

Fig-20: Speed control by fuzzy logic controller, PI controller, PID controller from 3000 to 2000 RPM speed variation

Figure 20 shows the speed verses time characteristics of BLDC motor hardware model using PI controller, PID controller, Fuzzy Logic controller. It is observed that speed changes form 3000 rpm to 2000 rpm for motor at 0.5 second simulation time. It is observed that smooth speed changes occurs using fuzzy logic controller.

4.3 Comparison of different controller

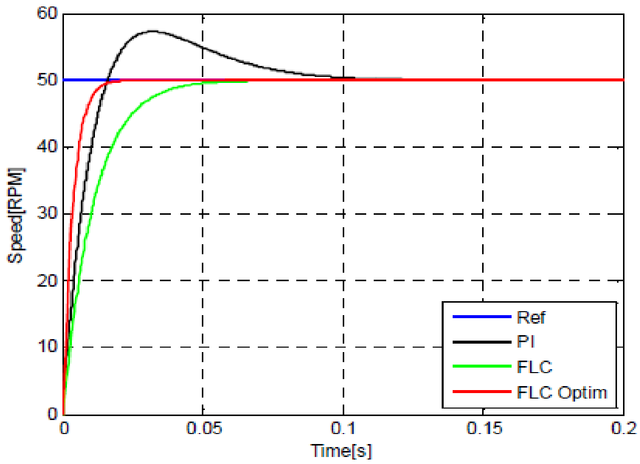

Fig-21: Speed verses time graphs for BLDC motor output speed controlled by fuzzy logic controller, PI controller, and Fuzzy with parameter optimization (Simulation results)

Figure 21 shows the speed verses time characteristics for simulation model BLDC motor for constant speed operation using PI controller, fuzzy logic controller and fuzzy logic controller with parameter optimization. Hence it observed that from figure, fuzzy logic controller with parameter optimization method is good and fast method for speed control of BLDC motor.

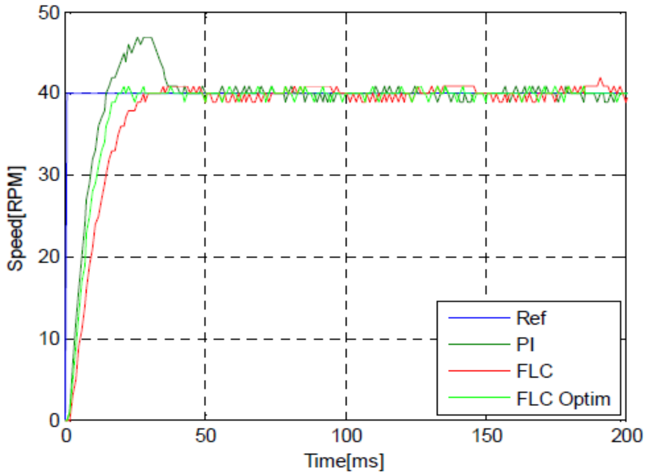

Fig-22: Speed verses time graphs for BLDC motor output speed controlled by fuzzy logic controller, PI controller, and Fuzzy with parameter optimization (Hardware experimental Results)

Then after second fast system is simple fuzzy logic controller. Hence fuzzy logic controller with parameter optimization technique is best and fast technique for speed control of hardware model of BLDC motor using matlab simulation based fuzzy logic controller. But we need to select and design proper parameter design system for smooth and fast speed controlling operation.

Figure 22 shows the speed verses time characteristics for hardware model BLDC motor for constant speed operation using PI controller, fuzzy logic controller and fuzzy logic controller with parameter optimization. Hence it observed that from figure, fuzzy logic controller with parameter optimization method is good and fast method for speed control of BLDC motor. Then after second fast system is simple fuzzy logic controller. Hence fuzzy logic controller with parameter optimization technique is best and fast technique for speed control of hardware model of BLDC motor using matlab simulation based fuzzy logic controller. But we need to select and design proper parameter design system for smooth and fast speed controlling operation

5. CONCLUSIONS

This method present, real time speed control of BLDC motor using fuzzy logic controller and also simultaneously parameter optimization for BLDC motor done. For implementation of this project we have to design hardware model for BLDC motor using arduino Uno, Arduino Due controller which control the motor input supply based on fuzzy controller decision. The decision of matlab simulink fuzzy controller link with hardware BLDC motor done using Arduino Due controller.

From results it is observed that, real time BLDC motor different parameters are easily calibrated using this method. Hence, speed control of PMBLDC motor is effectively for variable load speed application using fuzzy logic controller

(FLC) with real time hardware and simulink model approach.

From result analysis it clear that conventional PI and PID controller control the speed of BLDC motor is slow and not accurate with respect to reference speed of motor. In PID and PI controller, there are more transient period in motor during starting of BLDC motor. Hence more oscillation occurs in speed of motor from start to achieve steady state speed.

From results analysis, it clear that fuzzy logic controller easily control the speed of BLDC motor in smooth manner from starting (transient period) to normal speed achievement (Steady state periods)

Also fuzzy logic controller allow to sudden change of speed of BLDC motor from higher RPM to lower RPM or viscera. But this not smooth operation in PI and PID controller. Also simultaneously different parameters of motors like speed, input voltage and current are analyzed at different speed and different loading condition. Which helps to parameter optimization of BLDC motor for proper selection and design of motor in particular applications.

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