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DESIGN OF FUZZY LOGIC CONTROLLER FOR ONLINE SPEED REGULATION OF DC MOTOR USING PWM TECHNIQUE BASED ON LABORATORY VIRTUAL INSTRUMENT ENGINEERING WORKBENCH

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ABSTRACT

This study details online speed regulation of DC motor using PWM technique based on LabVIEW. A fuzzy logic controller is designed to change the pulse width of switching signal applied to the converter and thereby the voltage fed to the armature of the separately excited DC motor to regulate the speed. The proposed system is connected to the server computer using a Data Acquisition Card (DAQ) and the server computer is configured to access remote client computer using Web publishing tool in LabVIEW. Now the speed of the DC motor can be controlled by a remote client computer with Internet connection. Laboratory Virtual Instrument Engineering Workbench (LabVIEW) is a graphical programming environment for creating custom applications that interact with real-world data or signals in fields such as science and engineering. The proposed online control system has been implemented to control the speeds of two different motors and the experimental results are plotted. The conventional controllers need design objectives such as steady state and transient characteristics of the closed loop system to be specified. But the designed fuzzy logic controller overcomes the problems with uncertainties in the plant parameters. The proposed online control technique saves time and reduces the manpower.

Keywords: LabVIEW, Fuzzy Logic Controller, Data Acquisition Card, Web Publishing Tool

1. INTRODUCTION

DC motors are widely used in cranes, hoists, conveyors, paper mills, textile mills and robotic manipulators. Because they are reliable for an extensive range of operating conditions and their speed regulation is relatively simple. General PI and PID controllers are extensively used for converter control and motor control applications. But they give unsatisfactory performance due to changes in the control parameters and loading conditions (Kumar *et al*., 2004). Neglecting the external disturbances and nonlinearities may affect the stability of the closed loop system. For the abovementioned reasons DC motor speed regulation based on PID or model based feedback controllers will be inadequate. If the nonlinearities of the motor are known functions, then adaptive tracking control methods with input-output linearization can be used (Ibbini and Zakaria, 1996; Kim *et al*., 1997; Rigatos, 2009). However when these nonlinearities or disturbances are unknown, neural or fuzzy control is more suitable for succeeding satisfactory performance of the closed loop system (Rahman and Hoque, 1998; Horng, 1999; Rubaai and Kotaru, 2000; Rubaai *et al*., 2002).

Kumar *et al*. (2008) have designed an artificial neuron controller for chopper fed embedded DC drives. The designed controller is trained by using the patterns

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gained from the conventional controller. The closed loop operation is simulated with the trained neural network to achieve the desired performance. They have implemented PI controller in a neural network and a neuron controller has been designed to reduce the steady state error, overshoot and settling time.

Jerome *et al*. (2005) have proposed LabVIEW based intelligent controllers for speed regulation of electric motor. They have developed an artificial neural network, fuzzy logic and neuro-fuzzy controllers to achieve accurate trajectory control of speed especially when DC drive and load dynamics are unknown. The nonlinear unknown dynamics are captured by training the artificial neural network and tuning the fuzzy control algorithm. Experimental results have been presented to demonstrate the effectiveness of these controllers.

Huang and Lee (2008) have presented a PC-based PID controller for speed control of DC motor. In their approach they have designed LabVIEW-aided PID controller to monitor and control the DC motor speed.

In this research work, a Fuzzy Logic Controller (FLC) is designed and implemented for online speed control of a DC drive. The designed FLC is used to achieve the desired speed and to reduce peak overshoot, settling time and steady state error. Initially mathematical model of DC motor with the H-bridge converter was developed and simulated. Then an FLC is designed and its performance is analyzed using different DC motors.

2. SYSTEM ARCHITECTURE

Figure 1 shows the Internet based control setup of the proposed system. A separately excited motor is connected to the server computer using a DAQ board. The server is connected to the Internet. The client system can be any PC with internet connection.

Figure 2 shows the block diagram of the proposed control system for motor. The system consists of H-bridge converter for driving the separately excited DC Motor in both forward and reverse direction. In the proposed system the actual speed is fed back and is compared with the set speed. After comparison, error signal and the change in error signal are produced. This error signal and change in error are given as input to the fuzzy logic controller. The fuzzy logic controller will attempt to reduce the error to zero by changing the pulse width of switching signal applied to the H-bridge converter and thereby the voltage fed to the armature of the separately excited DC Motor. Thus the speed of DC motor is regulated to the desired reference speed value which is selected by a remote client. Initially, LabVIEW model of the DC motor and the H-bridge converter was developed and simulated. The fuzzy controller was designed and the rules of the FLC were tuned until the desired performance is achieved.

3. DC MOTOR AND H-BRIDGE CONVERTER

The simulation of the motor and H-bridge converter has been done using equation models. The DC motor was modeled using Equation 1 and 2:

$$\frac{d^2\theta}{dt^2} = \frac{1}{J}\left[K_T i_0 - B\frac{d\theta}{dt} + T_L\right] \quad (1)$$

$$\frac{di_0}{dt} = \frac{1}{L}\left[Ri_0 + V_s - K_b\frac{d\theta}{dt}\right] \quad (2)$$

Where:

J = Moment of Inertia of the motor (kg m^2)
B = Friction coefficient of the motor (Nm/rad/sec)
K_T = Torque constant of the motor (Nm/A)
K_b = Motor back emf constant (V/rad/sec)
i_0 = Armature current (A)
V_s = Armature voltage applied (V)
R_0 = Armature resistance (ohms)
L = Armature inductance (mH)

The H-bridge converter was modeled using **Eq. 3** to **Eq. 6**. Mode 1 is when the SW1 and SW4 are ON and Mode 2 is when SW2 and SW3 are ON. The equivalent circuit for Mode 1 and Mode 2 are given in **Fig. 3**.

Mode 1: (When SW1 and SW4 are ON)

$$V_s = i_0 R_0 + L\frac{di_0}{dt} + k\omega \quad (3)$$

$$Ki_0 = J\frac{d\omega}{dt} + B\omega + T \quad (4)$$

Mode 2: (When SW2 and SW3 are ON)

$$-V_s = i_0 R_0 + L\frac{di_0}{dt} + k\omega \quad (5)$$

$$Ki_0 = J\frac{d\omega}{dt} + B\omega + T_L \quad (6)$$

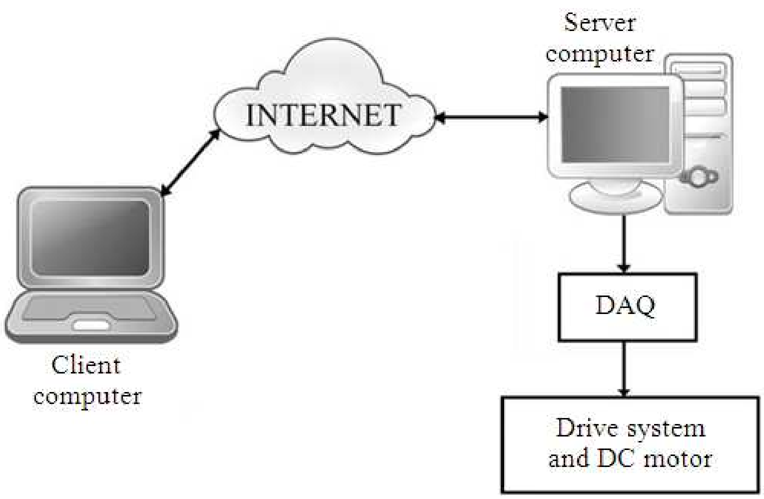


Fig. 1. Internet based control setup

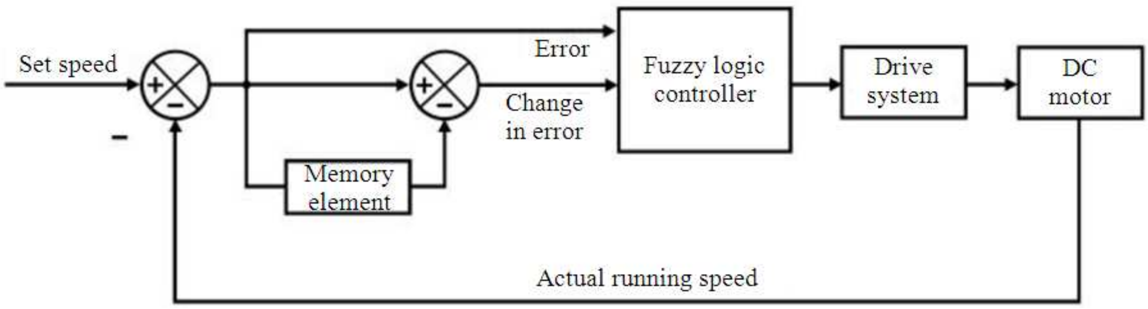


Fig. 2. Fuzzy logic controller

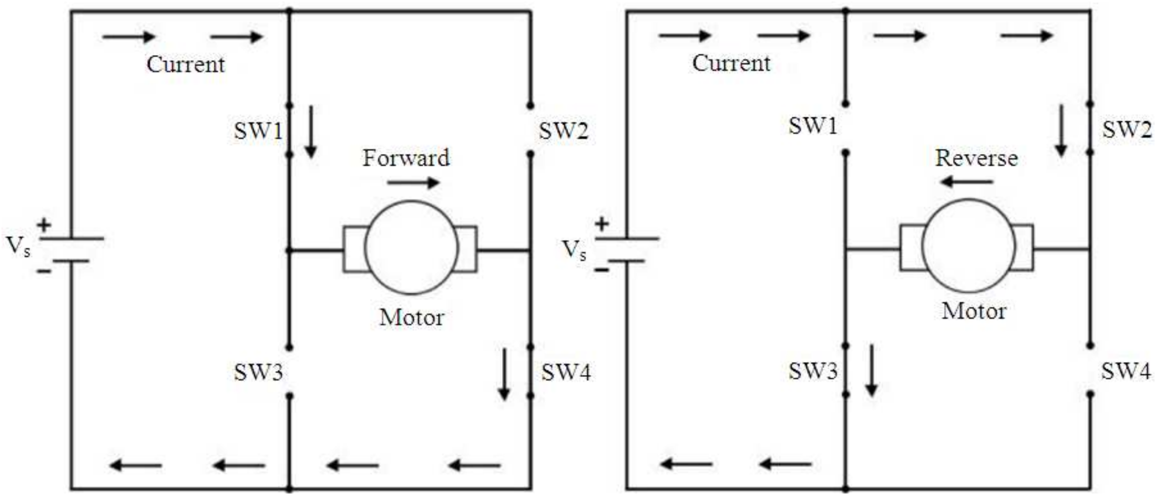


Fig. 3. Equivalent circuit of H-bridge converter in Mode 1 and Mode 2

4. FUZZY LOGIC CONTROLLER

4.1. Fundamentals of Fuzzy Logic Control

A fuzzy control system is a real-time expert system, implementing a part of a human operator's or process engineer's expertise which does not lend itself to express easily in PID-parameters or differential equations but rather in situation or action rules (Driankov *et al*., 2001). Fuzzy logic control is derived from fuzzy set theory. In fuzzy set theory, the transition between membership and non-membership can be gradual. Therefore, boundaries of fuzzy sets can be vague and ambiguous, making it useful for approximate systems. Fuzzy Logic Controller (FLC) is an attractive choice when precise mathematical formulations are not possible.

4.2. Fuzzification

The process of converting a crisp variable (real number) into a linguistic variable (fuzzy number) is called fuzzification. In this study, the error and change in error are fuzzified. The seven linguistic variables used for 'error' and 'change in error' are Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (Z), Positive Big (PB), Positive Medium (PM) and Positive Small (PS).

4.3. Defuzzification

The reverse of fuzzification is called defuzzification. That is the process of converting a linguistic variable in to a crisp variable is called as defuzzification. The Fuzzy Logic Controller (FLC) produces required output in a linguistic variable (fuzzy number). According to real world requirements, the linguistic variables have to be transformed to crisp output. Centre-of-Area method is the best well-known defuzzification method which has been used in this study.

4.4. Rule Table and Inference Engine

The rules are in the following format: If error is A_i, and change in error is B_i then output is C_i. Here, "if" part of a rule is called the rule-antecedent and is a description of a process state in terms of a logical combinations of fuzzy propositions. The "then" part of the rule is called the rule consequent and is a description of the control output in terms of logical combinations of fuzzy propositions. The rule table for the designed fuzzy logic controller is given in **Table 1**. From the rule table, the rules are manipulated as follows (Driankov *et al*., 2001). If error is NS and change in error is NM then output is NM.

Table 1. Rule table

Error	Change in error						
	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NM	NM	NM	NS	Z	PS
NS	NB	NM	NS	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PS	PM	PB
PM	NS	Z	PS	PM	PM	PM	PB
PB	Z	PS	PM	PB	PB	PB	PB

The Symbolic expression of k^{th} rule of the designed fuzzy logic controller is given as:

$$\text{If e is } LE^{(k)} \text{ is } \Delta e \text{ is } L\Delta E^{(k)} \text{ then } \Delta u \text{ is } L\Delta U^{(k)} \quad (7)$$

where, $LE^{(k)}$, $\Delta E^{(k)}$ an $\Delta U^{(k)}$ are linguistic values from term sets of error, change in error and change in output duty cycle respectively

The meaning of the above defined k^{th} rule in terms of mamdani type implication is given as a fuzzy relation $R^{(k)}$ is given by **Eq. 8.**

$$\mu_R{}^{(k)}(e,\Delta e,\Delta u) = \mu_{LE}{}^{(k)}(e)\Lambda\mu_{L\Delta E}{}^{(k)}(\Delta e)\Lambda\mu_{L\Delta U}{}^{(k)}(\Delta u) \quad (8)$$

The overall conclusion by combining the outputs of all the fuzzy rules can be written as shown in **Eq. 9.**

$$\mu_R(e,\Delta e,\Delta u) = \mu_R{}^{(1)}(e,\Delta e,\Delta u)V\mu_R{}^{(2)}(e,\Delta e,\Delta u)\ldots\ldots\ldots\ldots V\mu_R{}^{(k)}(e,\Delta e,\Delta u) \quad (9)$$

The value of $\mu_R{}^{(k)}$ for each value of k is defined in Equation 7.

The crisp value of change in duty cycle is computed using centre of area defuzzification method as given by **Eq. 8.**

$$\text{Duty cycle output} = u^* = \frac{\int u.\mu_U(u).du}{\int \mu_U(u).du} \quad (10)$$

Where:

u*	=	Defuzzified duty cycle
u	=	Duty cycle output
μ_U (u)	=	Union of the clipped control outputs

5. ONLINE CONTROL USING WEB PUBLISHING TOOL

The Web Publishing Tool is used to create an HTML document and embed static or animated images of the server computer's front panel in an HTML document, so a client computer can view and control the server computer's front panel remotely. The snapshot option in the Web publishing tool returns a static image of the front panel of a VI currently in memory on the server computer. The Monitor option in the Web publishing tool is used to return an animated image of the front panel of a VI currently in memory on the server computer. An Embedded option in the Web Publishing Tool is used to embed a front panel in an HTML document. The HTML document is created using Web Publishing Tool in the Tools menu. When the HTML document is created, an URL is generated as shown in **Fig. 4a and 4b**. Using the generated URL, a client can view and control the front panel remotely by a web browser.

6. COMPUTER SIMULATION AND HARDWARE IMPLEMENTAION

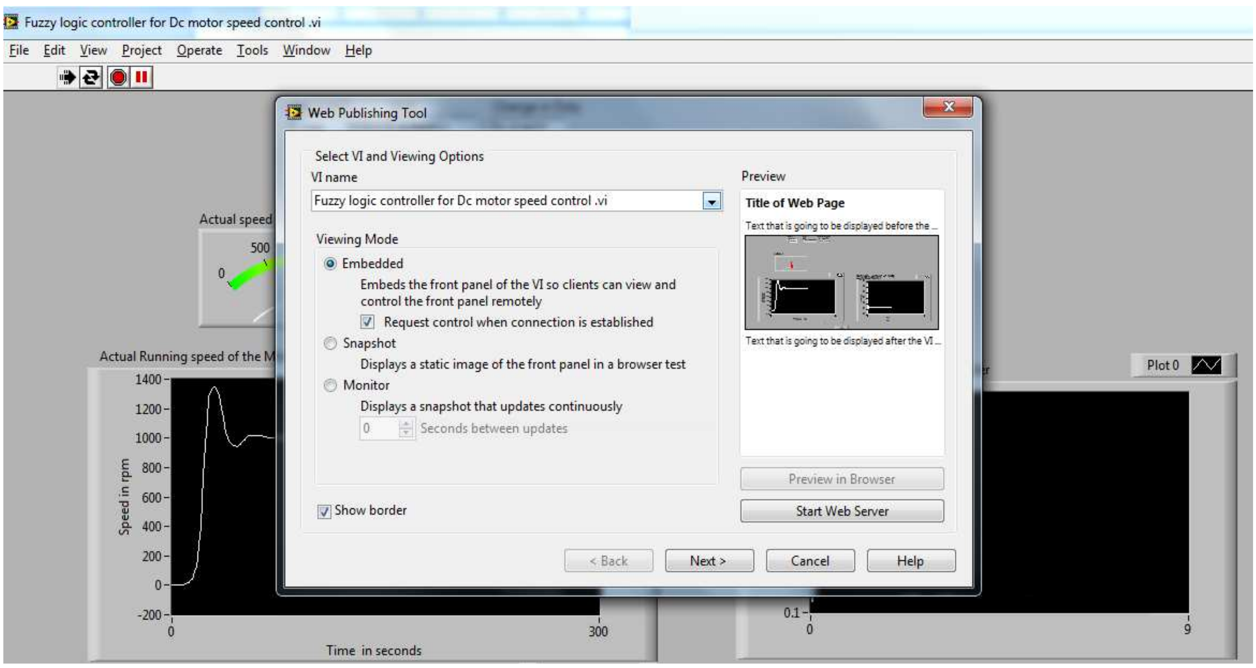
The simulation of H-bridge converter fed DC motor with the developed fuzzy controller was done based on equation modeling technique using LabVIEW software. The simulated models are given in **Fig. 5 and 6**. The fuzzy inference system is developed using control system design toolkit and the rules are defined using fuzzy system designer tool kit.

The developed fuzzy logic controller was implemented for speed control of DC motor using a server, client computers with Internet connection. It is seen that the speed is regulated according to the set speed value which is selected by a remote client.

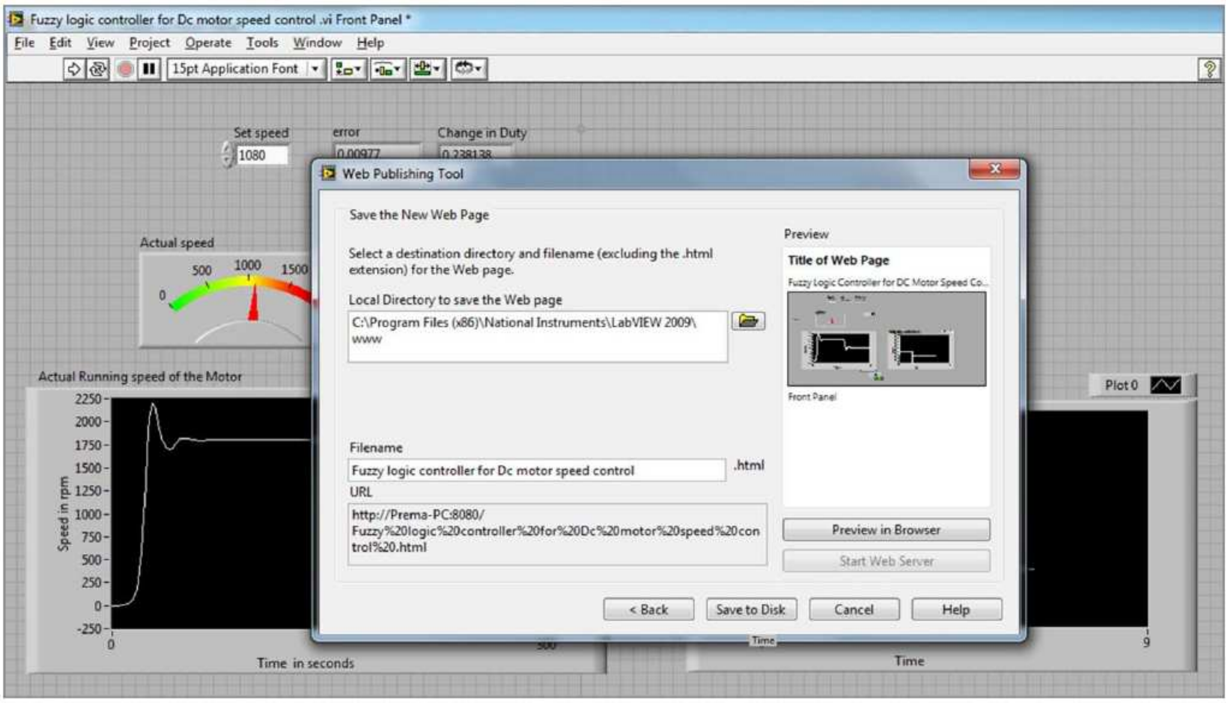
7. SIMULATION, EXPERIMENTAL RESULTS

The proposed system was simulated and tested practically with a 110V DC motor with the parameters given in **Table 2**. **Figure 7** shows the experimental response of 110V DC motor for a step change in motor reference speed from 100% of the rated speed to the 60% of the rated speed.

To illustrate the ability of the designed fuzzy logic controller, the proposed system is simulated and tested practically with a 220V motor with the parameters given in **Table 3**. **Figure 8** shows the experimental response of 220V DC motor for a step change in reference speed from 100% of the rated speed to the 60% of rated speed. The results justify that the proposed fuzzy controller can be used for any separately excited DC drive.



(a)



(b)

Fig. 4. (a) Configuration of server computer for remote clients using web publishing tool in LabVIEW, (b) Configuration of server computer for remote clients using web publishing tool in LabVIEW

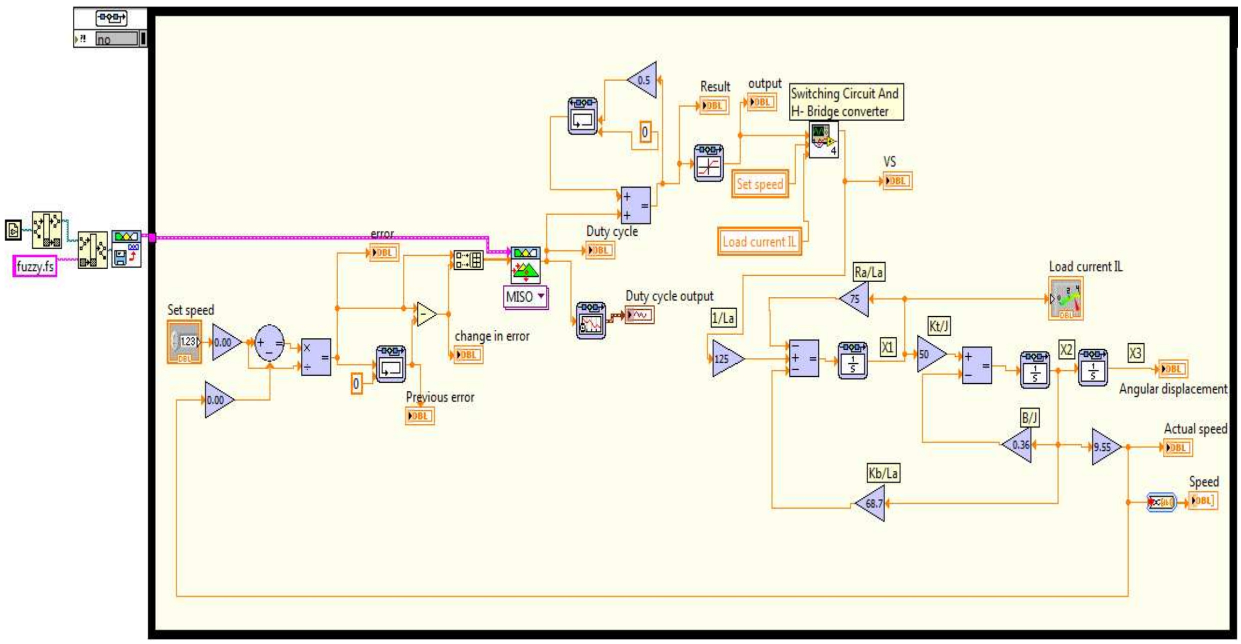


Fig. 5. Simulation block diagram of the proposed system in LabVIEW

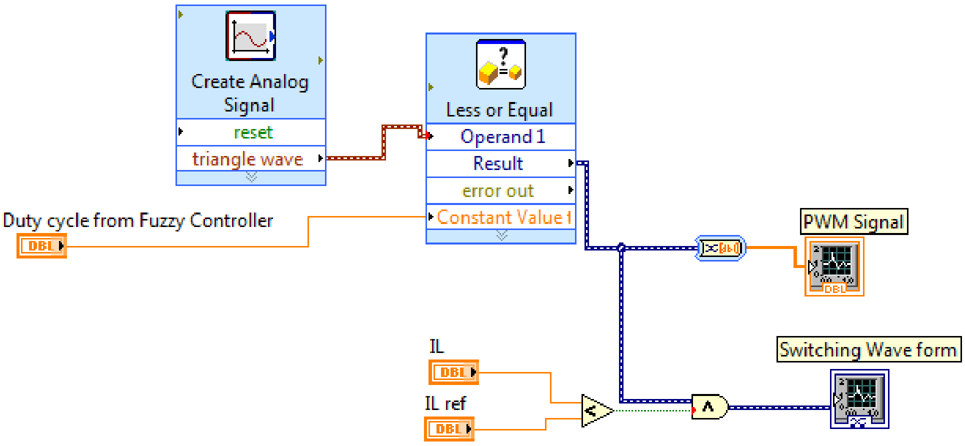


Fig. 6. Simulation block diagram of the PWM generation circuit

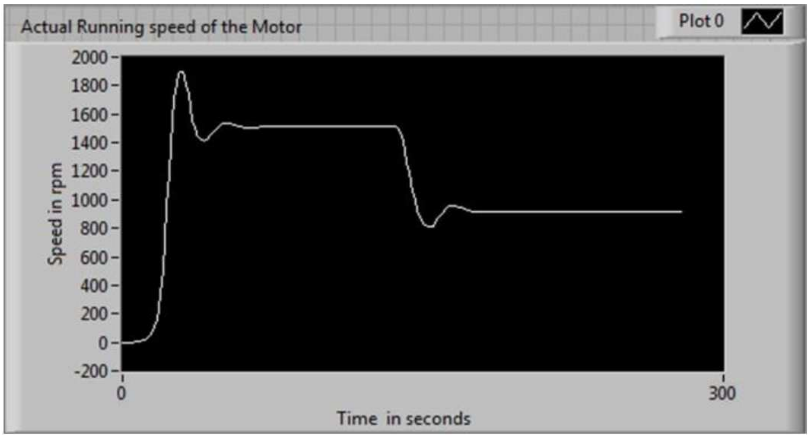


Fig. 7. Graph of speed variation of 110V motor for the step change in reference speed from 100% of the rated Speed to 60%

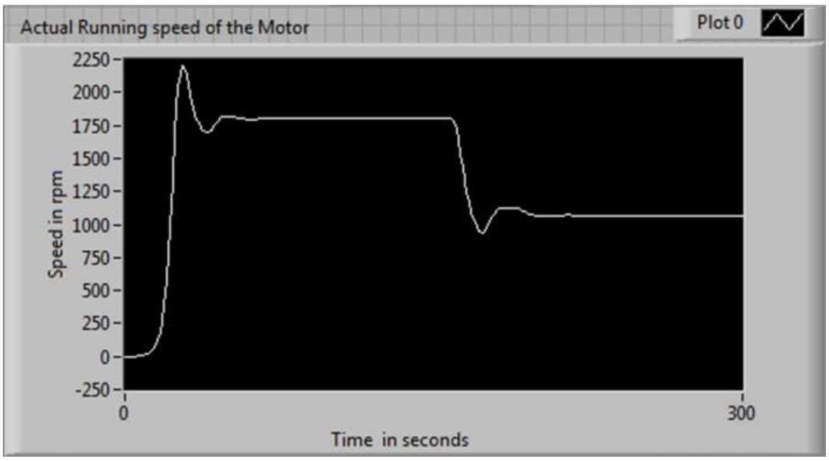


Fig. 8. Graph of speed variation of 220V motor for the step change in reference speed from 100% of the rated speed to 60%

Table 2. 110V DC motor parameters

DC motor parameters	Value
DC supply voltage	110 V
Armature resistance (Ra)	Ω
Armature inductance (La)	46 mH
Inertia constant (J)	0.093 Nm/(rad/s^2)
Damping constant (B)	0.008 Nm/rad/s
Torque constant (Kt)	0.55 Nm/A
Back emf constant (Kb)	0.55 V/(rad/s)
Speed	1500 rpm

Table 3. 220V DC motor parameters

DC motor parameters	Value
DC supply voltage	220 V
Armature resistance (Ra)	0.6 Ω
Armature inductance (La)	0.008 H
Inertia constant (J)	0.011 Nm/(rad/s^2)
Damping constant (B)	0.004 Nm/rad/s
Torque constant (Kt)	0.55 Nm/A
Back emf constant (Kb)	0.55 V/(rad/s)
Speed	1800 rpm

8. CONCLUSION

The overall purpose of this proposed system is to develop a fuzzy controller based online motor control system to monitor and control the performance of a DC drive from a remote place. The conventional controllers need design objectives such as steady state and transient characteristics of the closed loop system to be specified. But fuzzy logic control overcomes the problems with uncertainties in the plant parameters. The results confirm that the fuzzy controller performance is better in respect of overshoot, settling time and steady state error.

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