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## SPEED CONTROL OF BRUSHLESS DIRECT CURRENT (BLDC) MOTOR USING DIGITAL CONTROLLERS

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### Abstract

*Brushless direct current (BLDC) motor is having various advantages over the conventional brushed DC motor as well as induction motor. It is singly fed synchronous speed motor and having advantages such as lower maintenance and longer life. Since speed response of any motor must be improved and hence controllers are incorporated. While adopting any controller for motor, knowledge of the requirement of the speed tracking must be there, this paper presents the speed control of BLDC motor using digital controllers which includes conventional controllers, fuzzy logic controller, and hybrid controllers. Time response parameters for each controller is presented in tabular form and comparative analysis is given. After comparative analysis best controller based on simulation results is also suggested. For simulation purpose MATLAB/SIMULATION environment is used.*

**Keywords:** BLDC motor, Buck Converter, FLC, Fuzzy-PI controller, Fuzzy-PID controller, Hall effect sensor, P controller, PI controller, PID controller, PWM, VSI.

### 1. INTRODUCTION

BLDC motor can be treated as a flipped version of brushed DC motor. In BLDC motor permanent magnet acts as a rotor while electromagnet is on stator. BLDC motor having many advantages such as low maintenance, higher efficiency due to absence of mechanical commutation as in case of brushed DC motor. In BLDC motor instead of mechanical commutation, electronic commutation is used and hence having a complex control mechanism. To provide an electronic commutation sensor, commutation logic, and voltage source inverter (VSI), and a dc voltage source. To rotate BLDC motor at variable speed, variable source voltage is required. Pulse width modulation is used, which is having an averaging effect to generate variable source voltage based on the duty cycle applied to buck converter. MATLAB/SIMULINK software is used for modeling the system and simulation purposes. All the elements of the whole control assembly can be easily modeled and the speed response of the motor using each controller can be seen by using the scope.

To study the speed control of BLDC motor, information from various literatures is used. Speed control of low inertia motor using model predictive control algorithm is presented in (Darba A., De Belie F., D'haese P. & Melkebeek J. A. (2016)). Hybrid fuzzy-BB controller used to control BLDC motor is described in (Rubaai A. & Jerry J. (2014)). Speed control by using digital pulse width modulation control is presented in (Sathyan A., Milivojevic N., Lee Y., Krishnamurthy M. & Emadi A. (2009)). BLDC motor control based upon the four switch topology and single neuron adaptive PI controller is presented in (Xia C., Li Z. & Shi T. (2009)). Robust gain controller for BLDC motor for adaptive controller gain change is described in (Xuan Ba D., Yeom H., Kim J. & Bae J. (2018)). A novel speed regulator using conduction angle control and current mode control is

presented in (Rodriguez F. & Emadi A. (2007)). Modeling of permanent magnet synchronous motor using field circuit adaptive parameter is presented in (Luo G., Zhang R., Chen Z., Tu W., Zhang S. and Kennel R. (2016)). BLDC motor control using tunable PID controller is described in (Cheshmehbeigi H. M. & Afjei E. (2013)). Novel wavelet controller is used for controlling speed of BLDC motor and compared with the PID controller in (Daya J. L. F., Sanjeevikumar P., Blaabjerg F., Wheeler P.W. & Ojo J. O. (2015)). Details regarding Hall effect sensor and error in position sensing of rotor due to the misplacement and uneven magnetic flux density is presented in (Lim J. S., Lee J., Seol H., Kang D., Lee J. & Go S. (2018)). Fuzzy logic controller is used to control BLDC motor using Takagi-Sugeno type is described in (Xu J., Guo Z. & Lee T. H. (2013)). Fault tolerant control for defective Hall effect sensor for BLDC motor is presented in (Aqil M. & Hur J. (2020)). Mathematical model for fast calculations of the steady state operation of BLDC motor is presented in (Jagiela M., Garbiec T., Gwozdz J. & Kolodziej J. (2016)). Fuzzy logic controller and self tuning fuzzy logic controller are used to speed control of induction motor along with comparative analysis is described in (Farah N. et al. (2019)). Filtering of Hall effect sensor for minimizing the issues related to the positioning of hall effect sensor which leads to nonideal current waveforms for driving BLDC motor is presented in (Alaevinov P. & Jatskevich J. (2012)). Comparison between speed response of BLDC motor controlled using PI controller, fuzzy logic controller and fuzzy PI controller is presented in (Khanke P. K. and Jain S. D. (2015)). While designing fuzzy logic controller rules plays an important role so for obtaining same results with the minimum set of rules are important hence comparative analysis between complex rules and simplified rules are presented in (Tarbosh Q. A. et al. (2020)). Uncertainty in the input while adopting

fuzzy logic controller is addressed and resolved by using non-singleton type-2 fuzzy logic system is presented in (Zaheer S. A., Choi S., Jung C. & Kim J. (2015)). PID versus FLC is used to control BLDC motor along with considering different uncertainty and highlighting the usefulness of FLC in such uncertain condition is described in (Shanmugasundram R., K. Zakariah K. M. & Yadaiah N. (2014)). The use of BLDC motor using ferrite magnet for water pump is presented in (Sashidhar S. and Fernandes B. G. (2017)). Speed control of BLDC motor based on PI controller and fuzzy logic controller with their comparative analysis presented in (Walekar V. R. & Murkute S. V. (2018)). The optimal commutation control proposed for reducing error in torque and obtaining back EMF closed to the ideal back EMF is described in (Chen X. & Liu G. (2020)). Regenerative braking system for electric vehicle is design and implemented by BLDC motor which is controlled by PID controller and fuzzy logic controller is presented in (Nian X., Peng F. & Zhang H. (2014)). Electro-mechanical braking system using BLDC motor and adopting fuzzy sliding mode control is described in (Peng X., Jia M., He L., Yu X. & Lv Y. (2018)). PID controller with fine tuning for application to speed control of servomotor is described in (Tu Y. and Ho M. (2012)).

This paper first present overview of the six controllers used to control speed of the BLDC motor and then present simulation results for speed response of the BLDC motor using each controller. Also presents performance parameter in tabular form for comparison and finally ends with the conclusion.

## 2. CONTROLLERS

To control speed of BLDC motor, various controllers are available. Each controller having its own advantages and disadvantages. the controller should be used based on application and after analyzing the transient and steady-state response. It is advisable to use best suitable controller for controlling any system to get best possible results. To control the speed of BLDC motor, the input to the controller is the Error signal ( $E(t)$ ). Error signal is defined as the difference between desired speed and measured speed which is achieved by using feedback. The output of the controller known as actuating signal ( $A(t)$ ) and in this case it is duty cycle of the buck converter.

### 2.1 Proportional Controller

The proportional controller (P controller) is having direct proportional relation between the actuating signal and the error signal. Mathematically this relation is given as

$$A(t) = K_p * E(t) \quad (1)$$

Where  $K_p$  is called as proportional constant or proportional gain. To amplify the error signal, generally the value of  $K_p$  need to be kept greater than 1. A proportional controller usually used to reduce steady-state error thus stability of the system increases. P-controller is having one disadvantage that it can

reduces the error upto some limit after that there will be no reduction in error but transient stability is worsened.

### 2.2 Integral Controller

An integral controller (I controller) is having direct proportional relation between actuating signal and the integral of the error signal. Mathematically this relation is given as

$$A(t) = K_i * \int_0^t E(t) dt \quad (2)$$

Where  $K_i$  is called as proportional constant or controller integral gain. Integral controller is used to upgrade steady-state response but it worsens the transient response.

### 2.3 Derivative Controller

A derivative controller (D controller) is having direct proportion relation between actuating signal and the derivative of the error signal. Mathematically this relation is given as

$$A(t) = K_d * \frac{dE(t)}{dt} \quad (3)$$

Where;  $K_d$  is known as proportional constant or controller derivative gain. The derivative controller is used to upgrade transient response of the system but it worsens the steady state response of the system.

### 2.4 PI Controller

It is a combination of P controller and I controller. Mathematically actuating signal is given as

$$A(t) = K_p * E(t) + K_i * \int_0^t E(t) dt \quad (4)$$

PI controller is having advantages of both and hence there is drastic reduction in steady state error can be seen by using PI controller. PI controller is not able to upgrade the transient response in the best way this is one of the disadvantages of PI controller.

### 2.5 PID Controller

It is the combination of a P controller, I controller, and D controller and the actuating signal mathematically is given as

$$A(t) = K_p * E(t) + K_i * \int_0^t E(t) dt + K_d * \frac{dE(t)}{dt} \quad (5)$$

PID controller is having advantages of all three controller and upgrade transient as well as steady state response but it is subjected to condition that the values of  $K_p$ ,  $K_i$ , and  $K_d$  should be tuned properly. In this paper, the manual tuning method is adopted for tuning P, PI, and PID Controllers. Though it takes time for tuning, it is less hectic in comparison to the automatic tuning method.

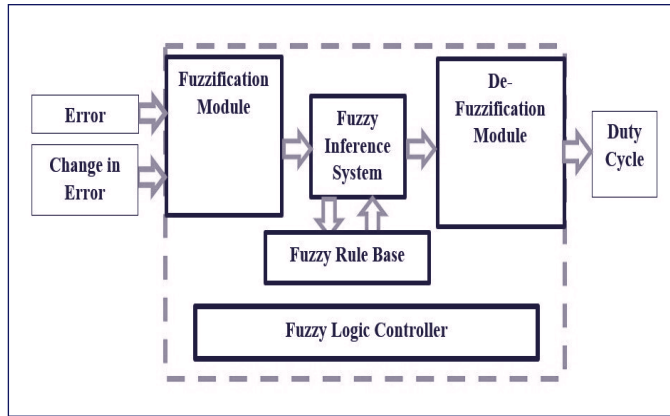
### 2.6 Fuzzy Logic Controller (FLC)

Prof. Lotfi A. Zadeh was proposed Fuzzy Logic in 1965. Fuzzy logic is a type of expert system which uses human deductive thinking and it is multivalued logic instead of crisp value or Boolean logic. Fuzzy logic controller (FLC) also known as

fuzzy reasoning is one of the applications of fuzzy theory.

Block diagram for FLC which is consist of basically two input and one output is shown in Figure 1.

**Figure 1: Block Diagram for Fuzzy Logic Controller (FLC)**



Input to the fuzzy logic controller are two crisp values that are error and change in error and output is the duty cycle of the buck converter. Mathematically error (Er) and change in error (CEr) are given as

$$Er = Er_{(k)} = N_{\text{desired}} - N_{\text{measured}} \quad (6)$$

$$CEr = Er_{(t)} - Er_{(t-1)} \quad (7)$$

These crisp values are converted into fuzzy set using the Fuzzification module using the triangular membership function. Crisp values error and change in error are converted into three triangular membership functions. By using equation (21) error is positive if measured speed ( $N_{\text{measured}}$ ) is less than desired speed ( $N_{\text{desired}}$ ). Error is negative if measured speed ( $N_{\text{measured}}$ ) is greater than the desired speed ( $N_{\text{desired}}$ ). Error is zero if measured speed ( $N_{\text{measured}}$ ) is equal to the desired speed ( $N_{\text{desired}}$ ). By using this logic three membership functions for error (Er) are defined as negative error (NEr), zero error (ZEr), and positive error (PEr). Consider desired speed is 100 rpm then the maximum positive error will be 100 rpm if the measured speed is 0 rpm. The maximum negative error will be -100 rpm that's why the membership function for error (Er) is between -100 to +100 rpm and it is universe of discourse for error. By using equation (22), change in error (CEr) is positive if error at past instant ( $Er_{(t-1)}$ ) is less than error at present instant ( $Er_{(t)}$ ). change in error (CEr) is negative if error at previous instant ( $Er_{(t-1)}$ ) is greater than error at present instant ( $Er_{(t)}$ ). Change in error (CEr) is zero if error past instant ( $Er_{(t-1)}$ ) is equal to error at present instant ( $Er_{(t)}$ ). Using this logic, membership functions for change in error is defined as negative change in error (NCEr), zero change in error (ZCEr), and positive change in error (PCEr). Mamdani fuzzy inference system (FIS) is selected for this FLC because the input to the Mamdani FIS is Fuzzy set and output is also fuzzy set. The output of FIS is duty cycle but it is in fuzzy set before the Defuzzification block. Three triangular membership functions are considered as decrement (DC), no change (NC), and increment (IC) as fuzzy set and universe of discourse is considered from 0 to +100%. The rule base is important in FLC for computing the output which is given to defuzzification module. Table 1 shows the rule base for FIS showing relation

between input and output of the FIS. As there are two inputs with three membership functions for each input and one output with three membership functions hence there are nine possible rules.

**Table 1: Rule Base for Fuzzy Logic Controller**

CEr \ Er	NEr	ZEr	PEr
NCEr	DC	DC	IC
ZCEr	DC	NC	IC
PCEr	DC	IC	IC

The method used for defuzzification is the Centroid of Area (COA) also known as Centre of Gravity (COG). The formula for obtaining crisp value by using the COA/COG method is given as

$$x^* = \frac{\int_{X=0}^{100} u(x) * dx}{\int_{X=0}^{100} u(x)} \quad (8)$$

Where;  $x^*$  is a crisp value.  $u(x)$  is a degree of membership function of linguistic function  $x$  having universe of discourse  $X$ .

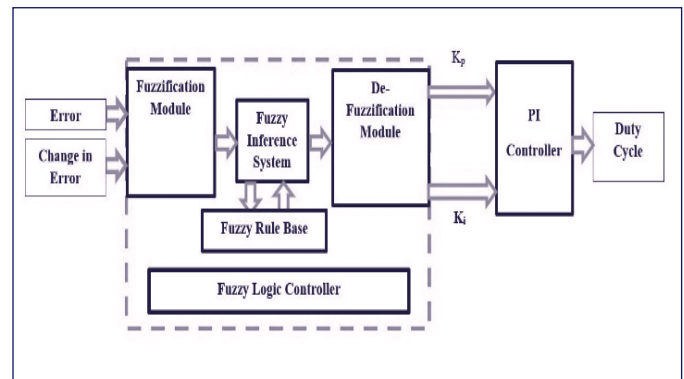
## 2.7 Hybrid Controllers

Hybrid controller is a combination of conventional controllers and Fuzzy logic Controllers. Hybrid controllers gives excellent improvement in the speed response of the BLDC motor. In this paper two hybrid controllers are used which are mentioned below.

### 2.7.1 Fuzzy-PI Controller

Fuzzy proportional integral (Fuzzy-PI) controller has advantages of the fuzzy logic controller as well as PI-controller.

**Figure 2: Block Diagram for Fuzzy PI Controller**



The block diagram of fuzzy-PI controller is shown in Figure 2. Inputs to the fuzzy-PI controller are error and change in error and outputs are  $K_p$  and  $K_i$ . This  $K_p$  and  $K_i$  are given as input to the PI controller so there is no need to tune the PI controller manually. FLC provides optimal value of  $K_p$  and  $K_i$  for PI controller. The PI controller is having output as duty cycle of the buck converter.

2.7.2 Fuzzy-PID Controller

Fuzzy proportional integral and derivative (Fuzzy-PID) controller gives advantages of the FLC as well as PID controller.

Figure 3: Block Diagram for Fuzzy-PID Controller

The block diagram of fuzzy-PID controller is shown in Figure 3. Error and change in error are given as inputs to the fuzzy controller while outputs are values of  $K_p$ ,  $K_i$ , and  $K_d$  from fuzzy logic controller and then given as inputs for tuning PID controller. The output of the PID controller is duty cycle of the buck converter.

3. RESULTS AND DISCUSSION

In this paper, MATLAB/SIMULINK environment is used for modeling and simulation and it is used to investigate the speed control of BLDC motor using P controller, PI controller, PID controller, FLC, Fuzzy-PI controller, and Fuzzy-PID controller.

Figure 4: MATLAB Model for Speed Control of BLDC Motor

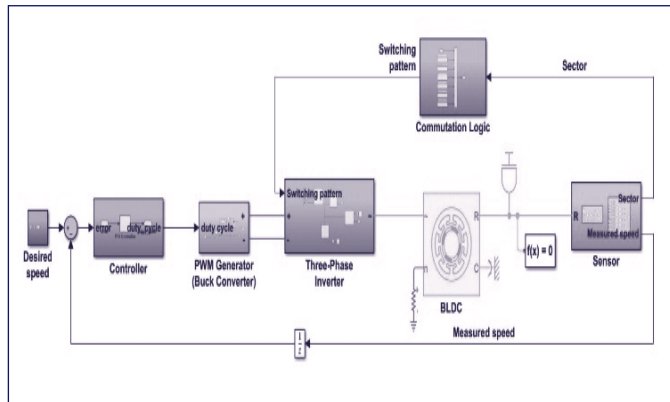
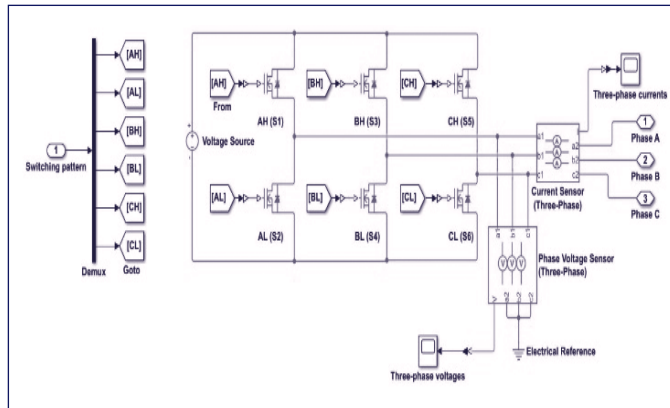


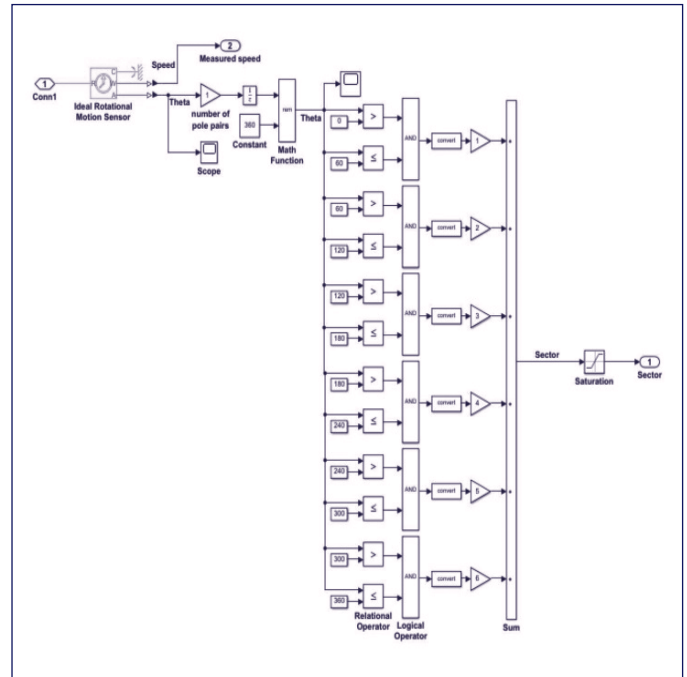
Figure 4 shows the speed control model of BLDC motor using MATLAB. There are seven main blocks which are desired speed, controller, buck converter, three phase inverter, BLDC motor, sensor, and commutation logic. BLDC motor's stator winding is excited by using output of the voltage source inverter for creating rotating magnetic field. The subsystem for three phase inverter is shown in Figure 5.

Figure 5: Subsystem for Three Phase Inverter



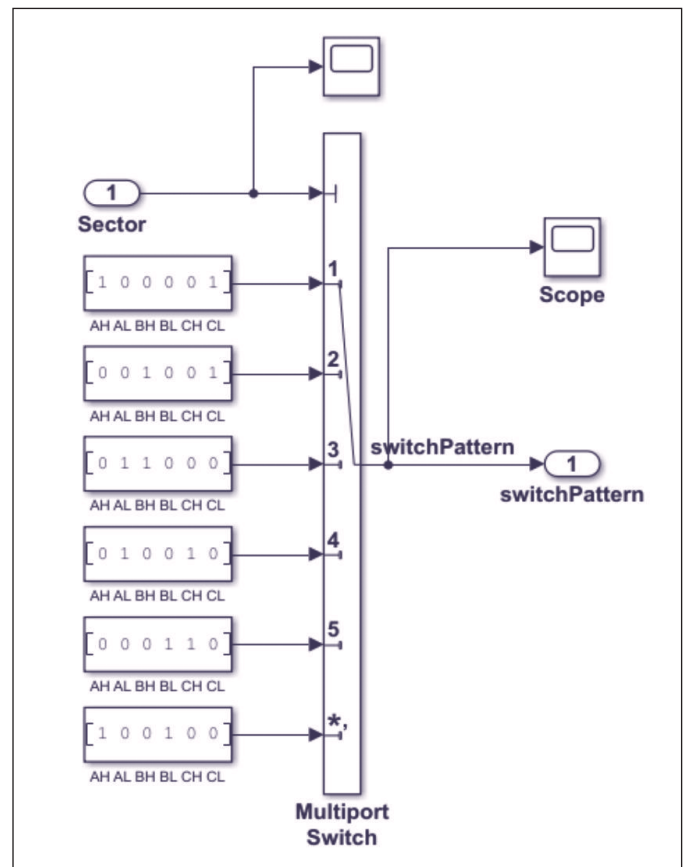
Sensor is basically a Hall effect sensor which conveys rotor position. The subsystem for Hall effect sensor is shown in Figure 6.

Figure 6: Subsystem for Hall Effect Sensor



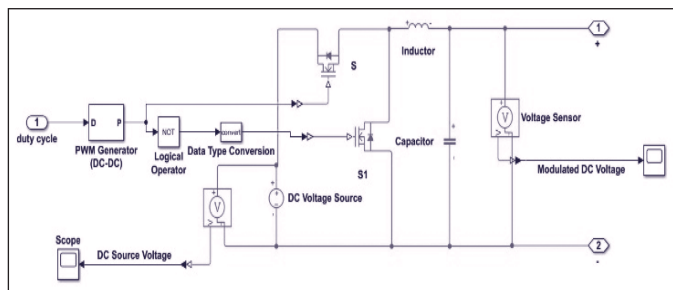
The output of the sensor is given to the commutation logic, commutation logic is having relation between sector and switches of the inverter need to be on for continuous rotation of motor. The subsystem for commutation logic is shown in Figure 7.

Figure 7: Subsystem for Commutation Logic



For providing variable speed input voltage need to be variable which is done by PWM generator and buck converter by adjusting its duty cycle as per speed requirement. The subsystem for PWM generator and buck converter together called as PWM generator subsystem is shown in Figure 8.

Figure 8: Subsystem for PWM Generator



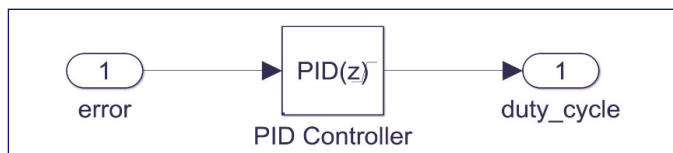
Controller is used to control duty cycle of buck converter to minimize error between desired speed and measured speed. Feedback is used to calculate difference between desired speed and measured speed. Controller from this model can be changed and its Desired Speed versus measured speed response can be seen on scope for analyzing transient and steady state performance. The parameter of the BLDC motor is given in Table 2.

Table 2: BLDC Motor Parameters

Sr. No.	Parameter	Sym- bol	Value	Unit
1	Stator per phase resistance	R	1.43	$\Omega$
2	Stator per phase inductance	L	9.4	mH
3	Inertia constant	J	$5.5 \cdot 10^{-3}$	$\text{Kg-m}^2$
4	Friction coefficient	B	$2 \cdot 10^{-3}$	
5	Rotor flux	$\emptyset$	0.2158	Wb
6	Desired speed	N	100	rpm

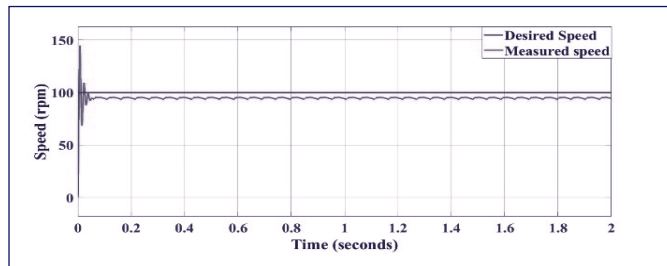
The performance of the BLDC motor is investigated by using Time response analysis. Time response parameters involve delay time ( $t_d$ ), rise time ( $t_r$ ), peak time ( $t_p$ ), % peak overshoot ( $\% M_p$ ), settling Time ( $t_s$ ), and Steady state error ( $E_{ss}$ ).

Figure 9: Subsystem for P Controller, PI Controller, and PID Controller



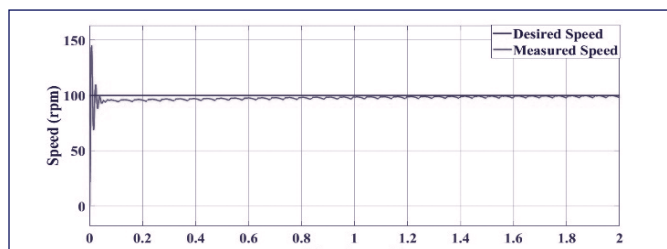
Controller subsystem of P controller, PI controller and PID controller is shown in Figure 5. Subsystem for P controller, PI controller, and PID controller is same only difference is in tuning parameters such as for P controller out of  $K_p$ ,  $K_i$ , and  $K_d$  only  $K_p$  need to be tuned. Similarly for PI controller  $K_p$  and  $K_i$  need to be tuned and for PID controller all three i.e.,  $K_p$ ,  $K_i$ , and  $K_d$  need to be tuned to improve performance.

Figure 10: Speed response of P Controller based BLDC Motor



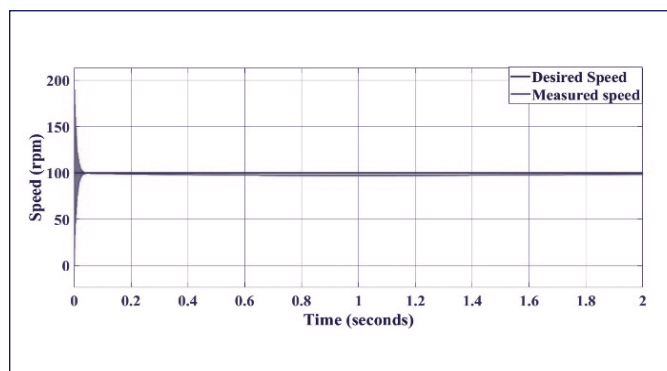
The graphical representation between speed of BLDC motor and time using P controller is shown in Figure 6. The proportional constant value is taken as 1. The value of delay time and rise time obtained from graph are 0.00277 sec and 0.00447 sec, respectively. Peak overshoot time is 0.00759 sec and having peak overshoot 44.74 %. Settling time and steady state error are 1.94 sec and 5.715 rpm, respectively. The steady state error and settling time are quite high and by increasing the value of proportional constant these values not going to decrease in most extent and that is a limitation of P controller.

Figure 11: Speed response of PI Controller based BLDC Motor



The graphical representation between speed of BLDC motor and time using PI controller is shown in Figure 7. The proportional constant and integral constant values both are taken as 1. The value of delay time and rise time obtained from graph are 0.00277 sec and 0.00446 sec, respectively. Peak overshoot time is 0.00759 sec and having peak overshoot 45.07 %. The values of delay time, rise time and peak time are almost same as compared to the P controller but slight increase in peak overshoot. Settling time and steady state error are 1.89 sec and 1.934 rpm, respectively. Settling time and steady state error improved and BLDC motor tracks desired speed fast as compared to using PI controller.

Figure 12: Speed response of PID Controller based BLDC Motor



The graphical representation between speed of BLDC motor and time using PID controller is shown in Figure 8. The proportional constant and derivative constant values both are taken as 1 while value of integral constant taken as 1.5. The value of delay time and rise time obtained from graph are 0.000257 sec and 0.000394 sec, respectively. Delay time and rise time are improved which indicated BLDC motor catch desired speed faster as compared to the P controller and PI controller. Peak overshoot time is 0.00743 sec and having peak overshoot 89.72 %. Which again indicates fast tracking of desired speed but at the cost of double the peak overshoot. So, if peak higher output speed spike is not the issue with the application of BLDC motor then PID controller will be the best as compared to the P controller and PI controller. Settling time and steady state error are 1.64 sec and 1.35 rpm, respectively. Settling time and steady state error also improved and BLDC motor tracks desired speed faster as compared to using P controller and PI controller.

Figure 13: Subsystem for FLC

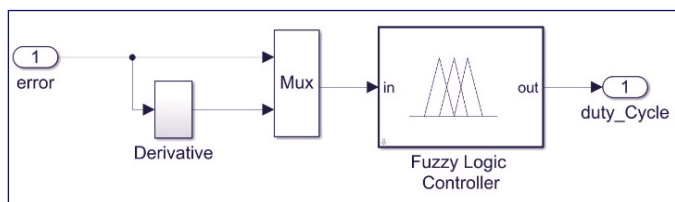


Figure 14: Speed response of FLC based BLDC Motor

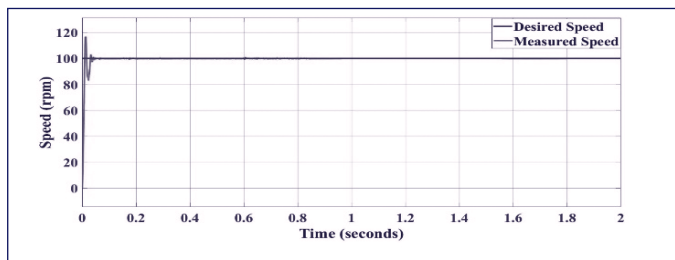


Figure 9 shows the MATLAB/SIMULINK subsystem for FLC and the graphical representation between speed of BLDC motor and time using FLC is shown in Figure 10. The value of delay time and rise time obtained from graph are 0.00584 sec and 0.00972 sec, respectively. Delay time and rise time are degraded and which indicated BLDC motor catch desired speed slower as compared to the all controllers discussed before. Peak overshoot time is 0.013 sec and having peak overshoot 16.62 %. Which again indicates slow tracking of desired speed but there is the impressive improvement in peak overshoot. The peak overshoot is nearly 2.5 times less as compared to the P controller and PI controller. When compared to the PID controller, FLC is having peak overshoot almost 5.5 times less. So, if peak overshoot is the main concern in specific application of BLDC motor and slow response is allowable then FLC be the best controller as compared to the P controller, PI controller, and PID controller. Settling time and steady state error are 0.04 sec and 0.15 rpm, respectively. Settling time and steady state error also having impressive results which indicated BLDC motor settles at desired speed faster with least error between

desired and measured speed as compared to using P controller, PI controller, and PID controller.

Figure 15: Subsystem for Fuzzy-PI Controller

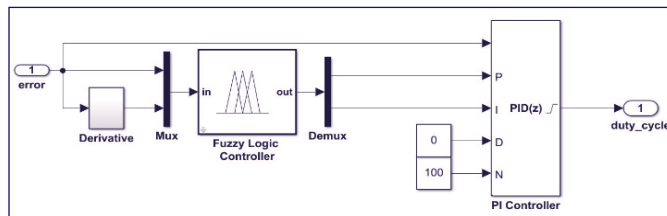


Figure 16: Speed response of Fuzzy-PI Controller based BLDC Motor

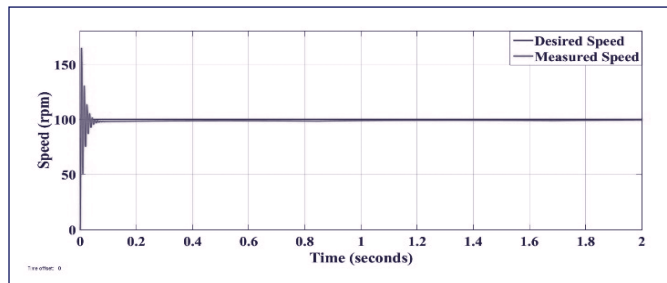
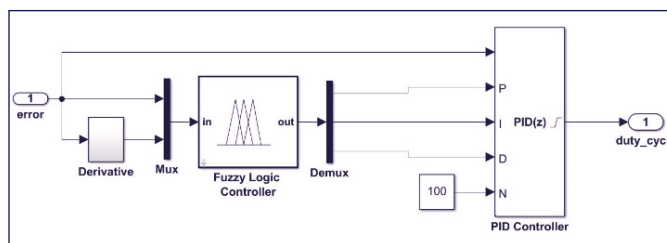


Figure 11 shows the MATLAB/SIMULINK subsystem for Fuzzy-PI controller and the graphical representation between speed of BLDC motor and time using Fuzzy-PI is shown in Figure 12. The value of delay time and rise time obtained from graph are 0.00167 sec and 0.00261 sec, respectively. Delay time and rise time are superior as compared with P controller, PI controller and FLC but inferior as compared to PID controller. Peak overshoot time is 0.005 sec and having peak overshoot 58.32 %. Which indicates improved peak time as compared to the P controller, PI controller and FLC but degraded performance as compared to the PID controller. Settling time and steady state error are 0.25 sec and 1.55 rpm, respectively. Steady state error seems to be in between 2 % band. Up to this discussion Fuzzy-PI is seems to be best as compared to the P controller, PI controller, and FLC if delay time, rise time, peak time, and settling time considered. So, for specific application of BLDC motor speed response having parameters like delay time, rise time, peak time, and settling time as concern parameters then Fuzzy-PI be the best controller than P controller, PI controller and FLC. If peak overshoot is considered then it is higher than P controller, PI controller, and FLC but less than PID controller. So, peak overshoot is the concern parameter for speed response of the BLDC motor for specific application then Fuzzy-PI must be chosen wisely as it is not best and not worst.

Figure 17: Subsystem for Fuzzy-PID Controller



**Figure 18: Speed response of Fuzzy-PID Controller based BLDC Motor**

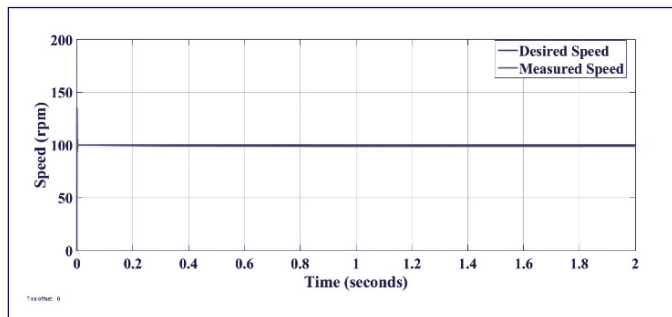


Figure 13 shows the MATLAB/SIMULINK subsystem for Fuzzy-PID controller and the graphical representation between speed of BLDC motor and time using Fuzzy-PID is shown in Figure 14. The value of delay time and rise time obtained from graph are 0.000185 sec and 0.000369 sec, respectively. Delay

time and rise time are best as compared with all controllers discussed till this point. Peak overshoot time is 0.0005 sec and having peak overshoot 40.44 %. Which indicates improved peak overshoot time as compared to the all-other controllers discussed before and peak overshoot is only greater than FLC and less than all other controllers which is good. Settling time and steady state error are 0.00207 sec and 1.39 rpm, respectively. Steady state error is between 2 % band. So, Fuzzy-PID is seems to be best controller as compared to the any other controller discussed in this paper if delay time, rise time, peak time, and settling time are considered as parameters of concern and BLDC motor provide best speed performance if Fuzzy-PID controller is used to control speed of BLDC motor. Tabular representation between time response parameters of speed versus time response of BLDC motor using P controller, PI controller, PID controller, FLC, Fuzzy-PI controller, and Fuzzy-PID controller is given in Table 3.

**Table 3: Comparison between Controllers**

Controllers	Transient and Steady State Response Parameters					
	Delay Time $t_d$ (sec)	Rise Time $t_r$ (sec)	Peak Time $t_p$ (sec)	Percent Peak Overshoot $\%M_p$ (%)	Settling Time $t_s$ (sec)	Steady State Error $E_{ss}$ (rpm)
P	0.00277	0.00447	0.00759	44.74	1.94	5.715
PI	0.00277	0.00446	0.00759	45.07	1.89	1.934
PID	0.000257	0.000394	0.000743	89.72	1.64	1.351
FLC	0.00584	0.00972	0.013	16.62	0.04	0.15
Fuzzy-PI	0.00167	0.00261	0.005	58.32	0.25	1.55
Fuzzy-PID	0.000185	0.000369	0.0005	40.44	0.00207	1.39

From the table, Delay time, rise time, peak time, and settling time for Fuzzy-PID controller is least among the all the six controllers. Settling time is reduced in a such extent that it is getting in millisecond while with other controllers are having settling time for speed response in second. Due to decrease in settling time BLDC motor tracks desired speed in a best way than any other controller but peak overshoot getting higher than Fuzzy logic controller only but less than that of all conventional controller as well as fuzzy-PI controller. If steady state error is taken into consideration, then it is within 2 % band.

#### 4. CONCLUSION

Speed control system for BLDC motor is successfully modeled by using six types of controllers which are classified as conventional controllers, fuzzy logic controller, and hybrid controllers. Speed response characteristics of BLDC motor is investigated using each controller with the help of MATLAB/SIMULINK environment. The simulation results given in Table 3 shows that each controller having some pros and some

cons hence before selecting any controller for BLDC motor understanding of application of BLDC motor is necessary. If overall performance is considered then Fuzzy-PID controller be the best choice based upon transient and steady state parameters.

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