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Speed Control of BLDC Motor using PI & Fuzzy Approach: A Comparative Study

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***Abstract* — The Brushless DC (BLDC) motors are becoming more popular due to its furnished quality of electrical as well as mechanical characteristics. These motors are now replacing the brushed DC motors & induction motors in variety of applications. Various speed control strategies have been implemented by different researchers among these various methodologies, the speed control of BLDC motor using PI controller and Fuzzy controller have been studied and implemented in this paper. Most of the industrial applications uses conventional PI controller for speed control of BLDC motor but it gives poor outcome for non-linear condition as well as varying condition. Thus, to overcome this cumbersome behaviour a Fuzzy Logic controlled approach is used and a comparative analysis has been depicted in tabular form.**

Keywords — BLDC motor, Fuzzy Controller, fuzzy rules, PI controller, Permanent Magnet (PM)

I. INTRODUCTION

The Permanent Magnet motors are generally classified as

- Permanent magnet Synchronous motor
- PM BLDC motors,

This classification is done on the basis of shape of wave of the emf induced in the motor, the first category is named, if the shape of wave (emf) is sinusoidal and later is named as PM Brushless DC (BLDC) motor if the shape of emf wave is trapezoidal. The torque/motion of the motor is the result of combination of PM and Electromagnetic field. The stator of BLDC motor contains winding and rotor is made of PM. The brushes are absent and hence the motor incorporates commutation electronically i.e. with the help of semiconductor switches. The rotor position defines the change in current in the stator winding [1]. As the name infers, the BLDC motor don't have brushes for commutation process to occur rather it uses electronic switches for commutation. The BLDC motors have numerous focal points over an induction motor or brushed DC motors such as, quit operation, wide range of speed, higher efficiency, quick dynamic response, effective speed-torque characteristics etc. Because of higher torque to weight ratio, the BLDC motor can be used in the operations where weight and space are basic factors [2]. The cogging torque is one of the major disadvantages of permanent magnet DC motors. Cogging torque leads to cause vibrations and noise in the motor and is the result of interaction between stator teeth and magnet and can be eliminated by implementing magnet edge insert technique [3]. Back EMF zero crossing speed measurement technique is found to be an accurate speed estimation technique for BLDC motor, this method enhances the sensor-less speed estimation method of BLDC motor [4]. With improvement in the technology, the requirement of motor drives for industrial applications is increasing day by day, the urge to attend stability in operation, to achieve variable speed and for better transient response have made the improvement in the technology [5]. The DC motors can be categorized as traditional DC motors which uses brushes for commutation and BLDC motor which used permanent magnet and electronic commutation circuit [6]. The BLDC motor has many advantages over other motor drives and it is preferred for higher performance operations. The abrupt change in speed or load affects the performance of motor drive. But BLDC motor drive, as it has non-linear behavior requires a controlled input so as to achieve the better performance. For the same, modified/improved controller are required [7]. PI controller provides easy tuning and thus is preferred in most of the industrial applications; the error signal generated can help to change the input via closed loop control scheme. Later, the error is processed so as to reduce speed error and get better speed response. PI controller is less effective during dynamic condition of load [8].

Additionally, it has certain work condition issue. In comparison with the Fuzzy logic controller, the PI controller takes countless overshoot that effect the system execution. A significant issue is related with the regular controllers that are broadly utilized as a part of the industrial applications because of its basic control structure and simplicity of usage. Be that as it may, these controllers posture challenges under the states of nonlinearity [9].

A. Advantages of BLDC motor

The BLDC motor drive is used in variety of applications including, instrumentation, automotive industries, aerospace, bio-medical appliances and automation etc. besides variety of applications, it has several advantages listed below,

- High reliability
- High efficiency
- Wide speed range
- Admissible dynamic response
- Lower noisy
- Better speed/torque characteristics

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- Light in weight
- Longer life etc.

These advantages over induction motor and brushed DC motor, differs the implementation of BLDC motor drive for various selective applications.

II. CLOSED LOOP CONTROL SCHEME OF BLDC MOTOR DRIVE

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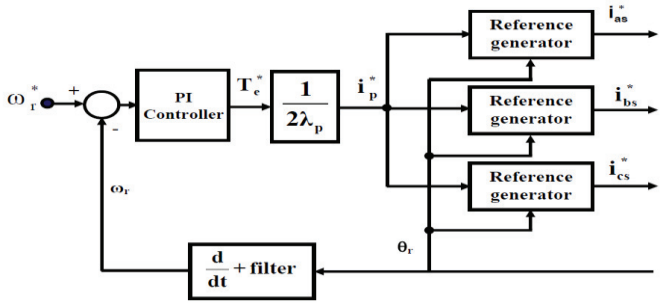

Fig. 1. Block diagram of speed controlled BLDC drive.

Figure 1 represents the basic block diagram of closed loop speed control scheme of BLDC motor drive. Generally, LVDT (Linear Variable Differential Transformer) and Tachogenerator are used as the position sensors for sensing the position of rotor. The loop control scheme is divided into three categories of loops i.e.

- Position loop
- Speed loop
- Current control loop.

The current location/position of rotor is firstly compared with the reference vale, later; the error in rotor position obtained is amplified with the help of PD controller. The current location/position of rotor is firstly compared with the reference value, later; the error in rotor position obtained is amplified with the help of PD controller. The output got is later used as reference value for speed. The PI speed controller compiles the values obtained from tachogenerator (speed reference & speed feedback) and generates the reference torque. The torque reference generated helps in generating current reference. With the help of freewheeling diode the semiconductor switches are operated and speed control can be done in closed loop scheme by controlling the current loop.

III. PERFORMANCE ANALYSIS

In order to carry out the performance analysis for speed control of BLDC motor, a MATLAB/Simulink model has been developed and firstly a PI controller scheme is used as mean to speed control and later a Fuzzy controlled approach is implemented and the results obtained are compared.

A. Performance analysis & results using PI controller

The Proportional Integral (PI) controller works on feedback mechanism. In any industrial application, PI controller sense the error between the measured quantity and desired quantity and convey the corrective action to continue the process. The error signal generated can be given as,

$$e_t = \textit{reference quantity (set)} - \textit{actual quantity}$$

The typical speed controller of BLDC motor drive consist of,

- Current generator (reference)
- Speed controller
- Pulse Width Modulated current controller.
- Voltage source inverter (IGBT Current controlled) &
- Position sensor to track the position of rotor.

The working of PI controller is stated in two categories of modes. The speed control of BLDC motor is done, by comparing speed of the motor to the reference value, later it is processed by PI controller and reference torque generated can be controlled by generating switching commands & setting the limits.

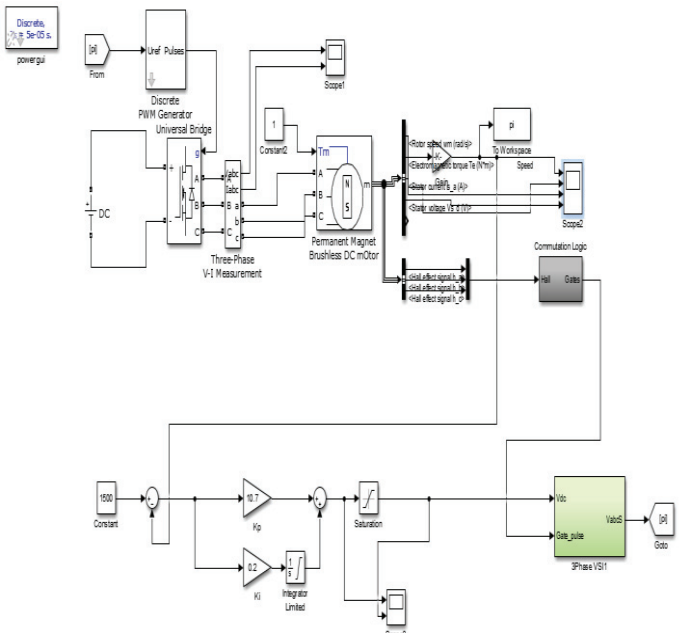

Fig. 2. MATLAB simulation model for speed control using PI controller

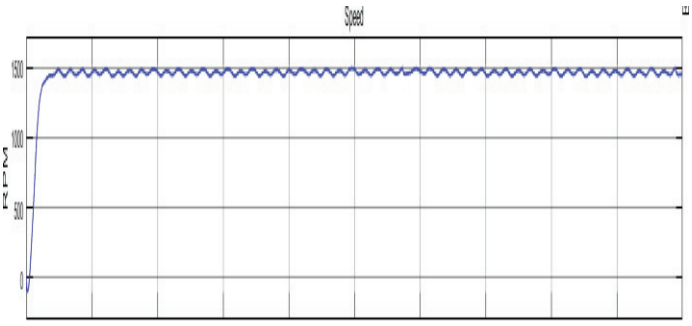

Fig. 3. Speed response characteristics of BLDC motor drive using PI controller.

At initial stage i.e. when load torque is 0.5 N-m, speed response is found to be steady and load torque oscillates between 0 to 1. When load is increased at t = 0.5s, load torque disturbances are observed to be risen accordingly. Similarly,

the stator current can be observed to be disturbing in nature when load torque increases.

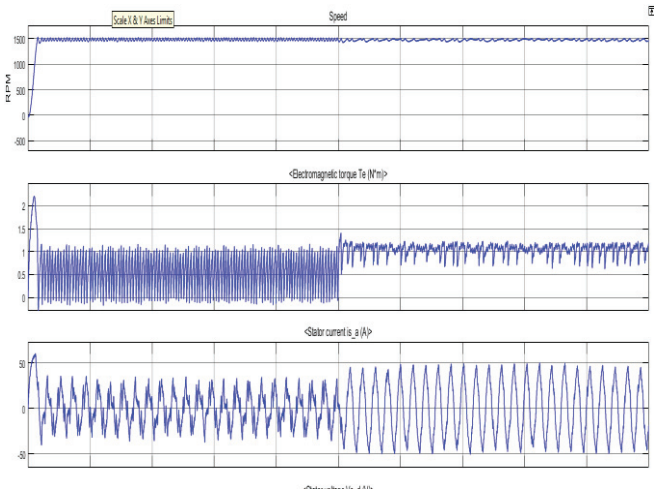

Fig. 4. MATLAB simulation model for speed control using PI controller

B. Performance analysis & results using Fuzzy Logic controller

With rising interest of FLC from the most recent couple of decades, the utilization of fuzzy theory and fuzzy logic in the control system is becoming more interesting. The working of FL controller is mainly divided in three sets namely,

- fuzzy fraction
- fuzzy processing and
- defuzzification.

The FLC uses programmable linguistic variables which sense good results compared to the use of a numeric variable. The process of converting a numerical set of variables into the fuzzy set i.e. programmable linguistic variable is called as fuzzification [6].

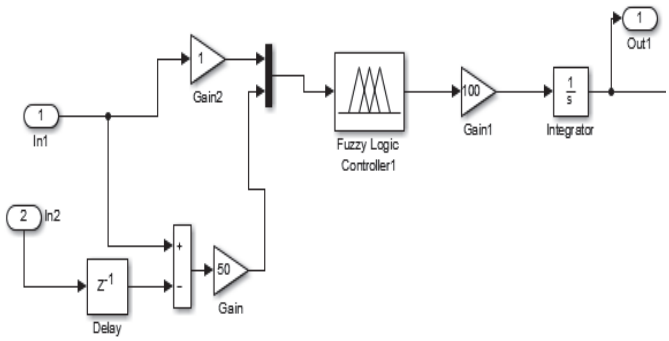

Fig. 5. Fuzzy controller

The control method used with an aim to provide gate pulse to voltage source inverter. Thus a voltage source inverter draws current containing opposite harmonics.

Later for better results a new technique is proposed which provides a control strategy using Fuzzy controller. Figure 5 depicts typical fuzzy controller and Figure 8 represents a MATLAB model developed for proposed system. Fuzzy logic control scheme is very much impressive compared to Boolean or other logic methods used for control system applications. A regulating DC voltage link is used to measure the power loss in Active Power Filter and set reference value of voltage is then compared with actual capacitor voltage. The error signal obtained is later processed by Fuzzy logic controller. The signals chosen by fuzzy controller are based on the error obtained in dc link. The 7*7 membership function is considered for input error and rate of change of error shown in figure 6 & figure 7.

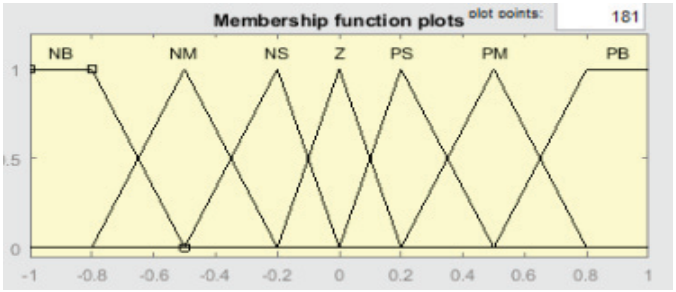

Fig. 6. Membership function for input error and change in error

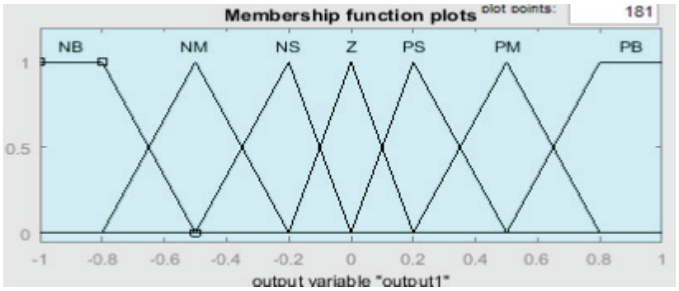

Fig. 7. Membership function for output regulation

The fuzzy controller mainly works on conversion of numeric variables into linguistics variables for the same a fuzzy control rules are developed and with the help of this rule an input and output variables are converted into linguistics variables. The control rules for fuzzy controller are shown in table I.

TABLE I. FUZZY LOGIC CONTROL RULES

ΔE / E	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NB	NM	NS	Z	PS
NS	NB	NB	NM	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

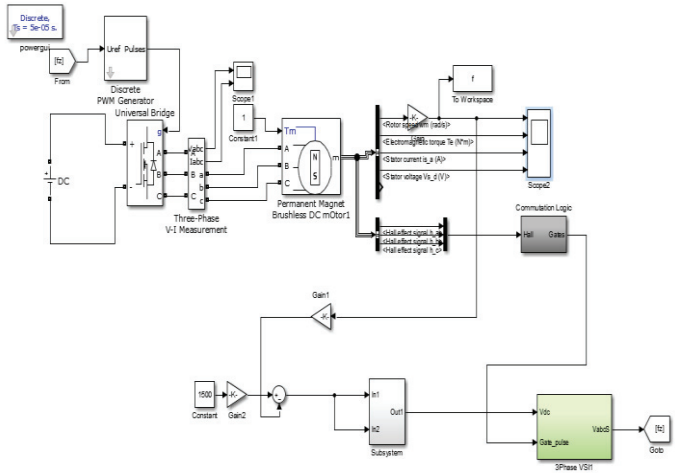

Fig. 8. MATLAB simulation model for speed control using FL controller

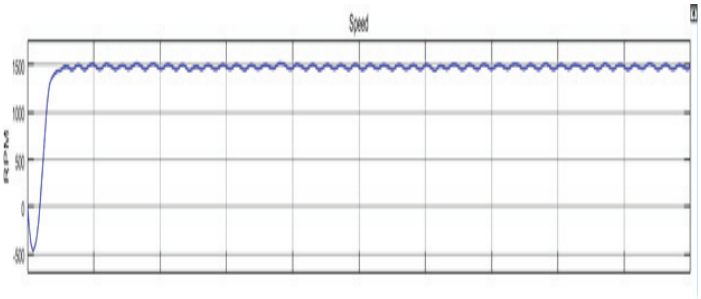

Fig. 9. Speed response characteristics of BLDC motor using Fuzzy controller

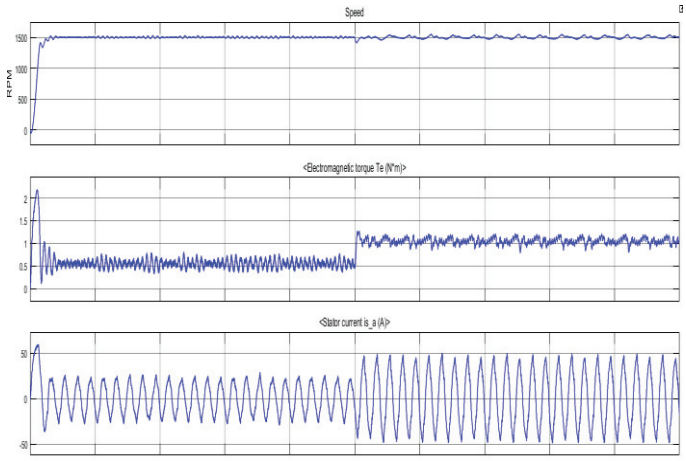

Fig. 10. MATLAB simulation model for speed control using FL controller

Figure 10 represents characteristics response obtained with fuzzy controller, here, at initial stage i.e. when load torque is 0.5 N-m it oscillates between 0 to 1 but when load is increased at t = 0.5s, the speed response remains steady and torque and stator current varies steadily.

TABLE II. SPEED RESPONSE CHARACTERISTICS

QUANTITY	PI CONTROLLER	FUZZY CONTROLLER
Rise Time (Rt)(mili seconds)	299.5835	298.2194
Settling Time Ts (Sec)	1.9794	1.2294
Overshoot	3.0116	2.4094

IV. CONCLUSION

In order to achieve better speed control response on BLDC motor, a fuzzy logic controller has been modeled /designed and performance analysis is done in this work. The fuzzy logic controller improves the performance of BLDC motor drive. The simulation results obtained from the developed model suggests implementing fuzzy controller. When FL controllers are used as speed control mean, they can cause a comparative reduction in the rise time. Similarly, the settling time decreases and overshoot can be observed to be risen compared to PI controller. This comparative study predicts the superiority of FL controller.

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