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Design and Development of BLDC motor drive for speed control of EV application

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Abstract **—** The increasing popularity of Brushless DC (BLDC) motors can be attributed to their high-quality electrical and mechanical features. Induction motors and brushed DC motors are currently being replaced by these motors in a number of applications. A number of studies have employed diverse speed control tactics; of these approaches, the study and application of PI and fuzzy controllers for the speed control of BLDC motors is presented in this publication. Conventional PI controllers are used in most industrial applications to regulate the speed of BLDC motors; however, they perform poorly in non-linear conditions and under changing conditions. Therefore, a Fuzzy Logic controlled strategy is applied to overcome this laborious behavior, and a tabular comparison analysis has been provided.

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

1. INTRODUCTION

- The Permanent Magnet motors are generally classified as
- Permanent magnet Synchronous motor
- PM BLDC motors,

The first category is the PM Brushless DC (BLDC) motor if the emf wave is sinusoidal, and the second is the PM Brushless DC (BLDC) motor if the emf wave is trapezoidal. This classification is based on the shape of the emf wave induced in the motor. The combination of the PM and the electromagnetic field produces the motor's torque and motion. The BLDC motor's rotor is made of PM, and the stator contains winding. Since there are no brushes in the motor, commutation is done electronically, via semiconductor switches. The change in current in the stator winding is determined by the position of the rotor [1]. The BLDC motor uses electronic switches rather than brushes for the commutation process, as the name suggests. In comparison to brushed DC or induction motors, BLDC motors offer a number of advantages, including stop operation, a wider speed range, improved efficiency, quick dynamic response, efficient speed-torque characteristics, and others. On account of higher force to weight proportion, the BLDC engine can be utilized in the activities where weight and space are fundamental variables [2]. Permanent magnet DC motors have a number of major drawbacks, one of which is their cogging torque. The interaction between the stator teeth and the magnet causes cogging torque, which results in motor vibrations and noise and can be eliminated using the magnet edge insert technique [3]. It has been discovered that the back EMF zero crossing speed measurement technique is an accurate method for estimating BLDC motor speed. This method improves the sensor-less speed estimation method of BLDC motor [4]. The need for motor drives in industrial applications is growing at an ever-increasing rate as a result of technological advancements [5]. The desire to maintain operational stability, achieve

variable speed, and improve transient response have all contributed to technological advancements. The DC engines can be sorted as customary DC engines which utilizations brushes for substitution and BLDC engine which utilized super durable magnet and electronic compensation circuit [6]. The BLDC motor is preferred for higher-performance operations due to its numerous advantages over other motor drives. The motor drive's performance is impacted by an abrupt change in speed or load. Yet, BLDC engine drive, as it has non-direct way of behaving requires a controlled info in order to accomplish the better exhibition. A modified or enhanced controller is required for the same [7]. PI regulator gives simple tuning and in this manner is liked in a large portion of the modern applications; Through a closed loop control scheme, the generated error signal can assist in modifying the input. Later, the error is processed to improve speed response and reduce speed error. PI regulator is less compelling during dynamic state of burden [8].

Additionally, it has some issues with the working environment. The PI controller has many more overshoots than the fuzzy logic controller, which affects how the system runs. The standard controllers, which are widely used in industrial applications due to their straightforward control structure and ease of use, pose a significant problem. In spite of this, these controllers face difficulties in nonlinear states [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 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.

2. CLOSED LOOP CONTROL SCHEME OF BLDC MOTOR DRIVE

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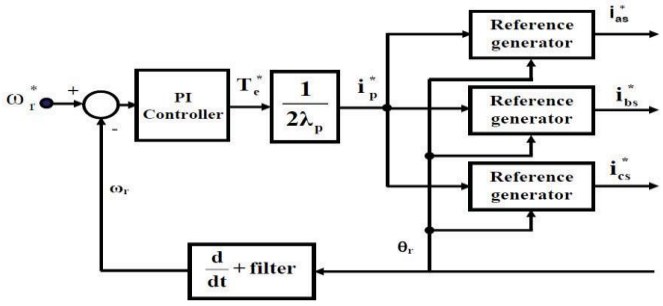

Fig. 1. Block diagram of speed controlled BLDC drive.

The fundamental block diagram of the BLDC motor drive's closed-loop speed control mechanism is shown in Figure 1. Typically, position sensors used to detect the position of the rotor are LVDTs (Linear Variable Differential Transformers) and tachogenerators. The loop control technique is separated into three sorts of loops i.e.

- Position loop
- Speed loop
- Current control loop.

Initially, the present location/position of the rotor is compared to the reference value; thereafter, the PD controller is used to increase the inaccuracy in the rotor position obtained. The rotor's present location and position are first compared to the reference value, and then the PD controller is used to increase the error in the rotor position that was found. The output obtained is then used as the speed reference value. The reference torque is produced by the PI speed controller by combining the data from the tachogenerator (speed reference & speed feedback). The generated torque reference aids in the generation of the current reference. The freewheeling diode is used to run the semiconductor switches, and by regulating the current loop, a closed loop speed control method can be implemented.

PERFORMANCE ANALYSIS

A MATLAB/Simulink model has been constructed to do the performance analysis for speed control of a BLDC motor. Initially, a PI controller scheme is employed as the means to control speed. Subsequently, a fuzzy controlled technique is implemented, and the acquired results are compared.

3. Performance analysis & results using PI controller

The feedback mechanism is how the Proportional Integral (PI) controller operates. A PI controller detects the discrepancy between the required and measured quantities in any industrial application and signals the necessary corrective action to carry out the process. The resulting error signal can be expressed as

- 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 thelimits.

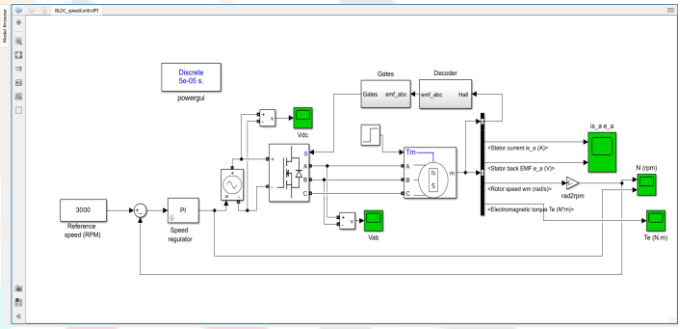

Fig. 2. MATLAB simulation model for speed control using PI controller

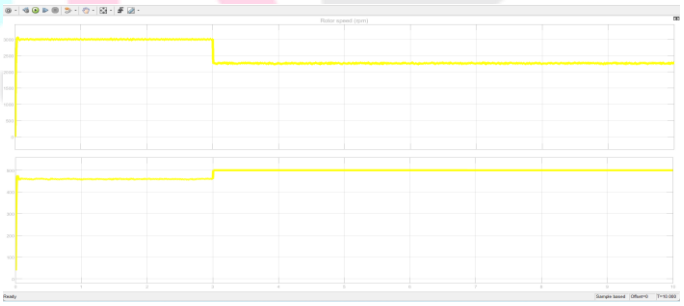

Fig. 3. Speed response characteristics of BLDC motor drive using PIcontroller.

The speed response is found to be stable at the beginning stage, or when the load torque is 0.5 N-m, and the load torque oscillates between 0 and 1. It is discovered that load torque disturbances grow in proportion to load increases at t = 0.5s. Likewise, when the torque applied to the load grows, it is seen that the stator current becomes disruptive.

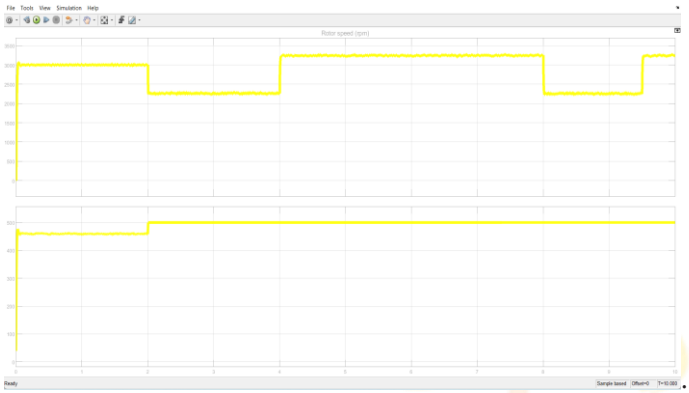

Fig. 4. MATLAB simulation model for speed control using PI controller

4. 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.

Compared to using a numerical variable, the FLC produces better outcomes by using programmable linguistic variables. Fuzzification is the process of transforming a numerical collection of variables into a fuzzy set, or programmable linguistic variable. [6]

.TABLE I fuzzy logic rule base

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

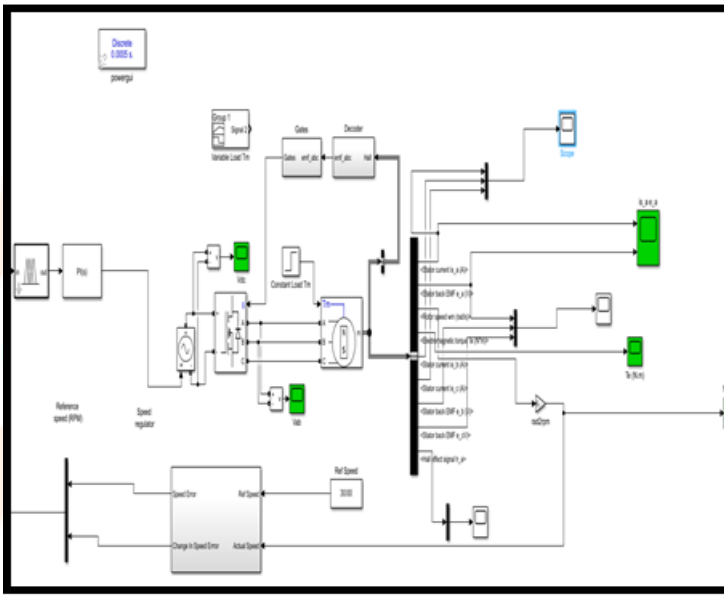

Fig. 8. MATLAB simulation model for speed control using FL controller

The control strategy used to send a gate pulse to the voltage source inverter. As a result, inverse harmonic current is drawn by a voltage source inverter. Later for improved results another method is proposed which gives a control technique utilizing Fluffy regulator. Figure 5 portrays normal fluffy regulator and Figure 8 addresses a MATLAB model produced for proposed framework. When compared to Boolean or other logic approaches utilized in control system applications, the fuzzy logic control scheme is significantly more impressive. In the Active Power Filter, a regulating DC voltage link is used to measure the power loss, and the set reference value of the voltage is then compared to the actual voltage of the capacitor. The fuzzy logic controller then processes the obtained error signal. The dc link error serves as the basis for the fuzzy controller's selection of signals. Input error and rate of change in error are taken into account using the 7*7 membership function, as shown in figures 6

and 7.

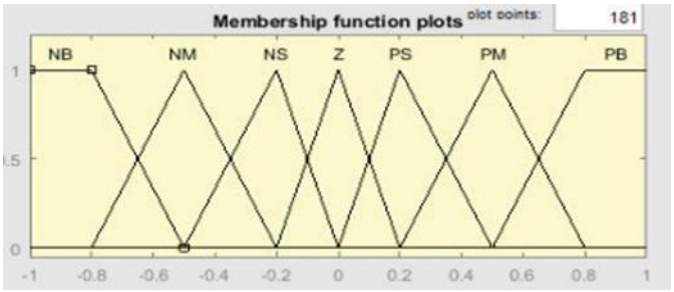

Fig. 6. Membership function for input error and change in error

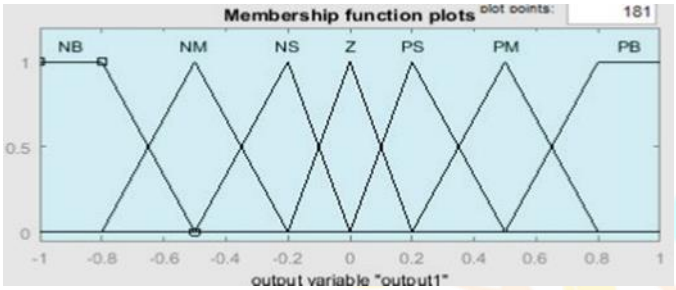

Fig. 7. Membership function for output regulation

The primary function of the fuzzy controller is the transformation of numerical variables into linguistics variables. To accomplish this, fuzzy control rules are developed, and this rule is used to transform input and output variables into linguistics variables. Table I displays the fuzzy controller's control rules.

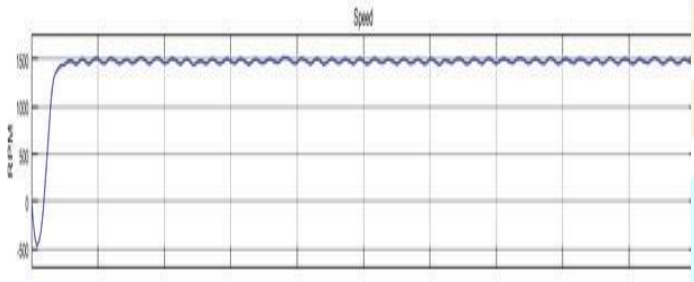

Fig. 9. Speed response characteristics of BLDC motor using Fuzzy controller

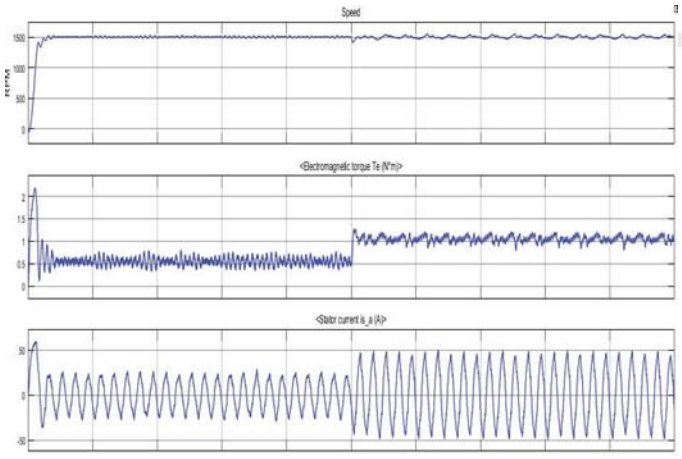

Fig. 10. MATLAB simulation model for speed control using FL controller

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

5. CONCLUSION

A fuzzy logic controller has been modeled or designed, and performance analysis is conducted in this work to improve speed control response on BLDC motors. The BLDC motor drive's performance is enhanced by the fuzzy logic controller. Implementing a fuzzy controller is suggested by the model's simulation results. The rise time can be reduced significantly when FL controllers are used as a speed control mean. Essentially, the settling time diminishes and overshoot can be seen to be risen contrasted with PI regulator. The FL controller is predicted to be superior in this comparison study.

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