Proc. IEEE Conference on Emerging Devices and Smart Systems *(ICEDSS 2017)*
3-4 March 2017, Mahendra Engineering College, Tamilnadu, India.

Modeling and Simulation of Closed Loop Speed Control for BLDC Motor

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Abstract—BLDC motors characterized as permanent magnet synchronous motors. Since it has its own unique characteristics such as long life, good efficiency, remarkable starting torque, it has gained good momentum in market hence it is widely used in leading automobile industries. These motors nowadays greatly used in industrial sectors because their construction that suitable for any safety and critical application. They have several advantages over other motors like DC motor and induction motor. BLDC motor does not need any mechanical commutation. In this proposed method, the classical PID controller and fuzzy logic controller is used to make the system stable. Among the two types of fuzzification methods viz. Sugeno and mamdani, mamdani method of tuning is well suited. An Angle value of theta is given as gate signal for BLDC motor. The feedback controllers are directly connected to the inverter to find error which is directly given as input to the BLDC motor for getting a desired output speed. The various dynamic characteristics of BLDC motor such as speed, current and back emf are analyzed using MATLAB - SIMULATION.

Keywords— BLDC motor, Fuzzy logic controller, PID controller, Inverter circuit model).

I. INTRODUCTION

Brushless DC motor (BLDCM) is in wide use due to its swift response, high power factor, noiseless operation, compact size, reliablility, good efficiency and low maintenance cost. BLDC motor does not need any brushes for commutation, because the BLDC motors are electronically commutated. This motor produces trapezoidal back EMF and quasi rectangular current waveform. PID controller is most commonly used for controlling the BLDC motor[2].The open loop analysis is made considering the stability factor. The modeling and the simulation of BLDC motor speed and its torque consequences are analyzed for various values of Pulse Width Modulation (PWM) using PID controller [3]. The simulation result shows that compare to other conventional controllers, fuzzy logic controller is seems to be better interms of rise time, damping ratio, settling time, peak time . Considering the few drawbacks of fuzzy controller, it is being combined with PID controller for better performance. From the simulation it is clearly observed that, PID based fuzzy controller gives faster settling time with minimal peak overshoots/undershoots and less steady state error, even at sudden load variations [4].

Superior performance and good robustness for various parameter variation is able to witness when compare to the conventional controllers [5]. In this work, to ensure high performance in BLDC motor, a hybrid fuzzy/PI controller that switches between fuzzy and PI controller is implemented. Based on the oscillations, overshoot and other frictional losses , output switching logic is generated through pulse width modulation (PWM) [6]. The speed of the BLDC motor is controlled by controlling the frequency, amplitude of the stator voltage to maintain the ratio of stator voltage to frequency at constant value. Here a model of the fuzzy control system is implemented in actual time with a Xilinx FPGA XC3S 400E processor. It is introduced to maintain speed at constant value under various load conditions [7]. The proposed controller yields an earlier dynamic response, negligible overshoot and offset free command tracking for motors of different ratings. The effectiveness of the proposed control is demonstrated in comparison with some commonly employed control methods, and is verified using MATLAB/SIMULINK Sim Power Systems toolbox [8].

In this paper since the error voltage is given as feedback to the inverter itself, control signal is directly given to the BLDC motor to maintain the speed at desired level.

II. BRUSHLESS DC MOTOR

This electronic controller energizes motor winding by turning transistor ON or other solid state switches to rotate the motor continuously. BLDC motor can be operated in both single phase and three phase. Figure 2.1 shows the simple BLDC motor drive circuit which consists of MOSFET Bridge, electronic controller, Hall Effect sensor. The stator voltage and torque equations of a motor are given in equations 2.1-2.3.

$$V_{ab} = R(i_a - i_b) + L\frac{d}{dt}(i_a - i_b) + (e_a - e_b) \qquad - (2.1)$$

$$V_{ca} = R(i_c - i_a) + L\frac{d}{dt}(i_c - i_a) + (e_c - e_a) \qquad - (2.2)$$

$$V_{bc} = R(i_b - i_c) + L\frac{d}{dt}(i_b - i_c) + (e_b - e_c) \qquad - (2.3)$$

Equation of motion is given as,

$$Ta = BW_m + J\frac{d}{dt}W_m + T_L \qquad - (2.4)$$

The voltage equations becomes,

$$V_{ab} = R(i_a - i_b) + L\frac{d}{dt}(i_a - i_b) + (e_a - e_b) \qquad - (2.5)$$

$$V_{bc} = R(i_b - 2\, i_b) + L\frac{d}{dt}(i_b - 2\, i_b) + (e_b - e_c) \quad - \ (2.6)$$

In the figure 2.1, Hall-effect sensors are used for position and speed control. In addition to the switching for a rated speed of the motor, an additional electronic circuitry changes the motor speed based on requirement. These speed control units are generally implemented with PID controller to have accurate control. It is also possible to produce four-quadrant operations from the motor while maintaining a good efficiency throughout the speed variations using modern drives.

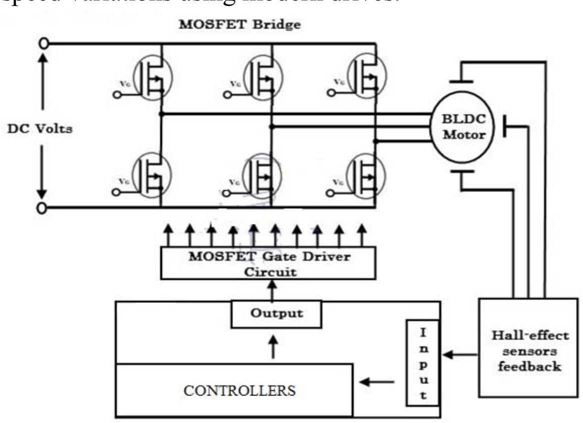

Fig 2.1 Circuit diagram of brushless DC motor drive

III. CONTROLLERS

A. PID CONTROLLER

Proportional – Integral - Derivative controller (PID controller) is a commonly used conventional controller used for various applications to control parameters like speed, temperature, flow, pressure and other process variables. Figure 3.1shows a basic functional block diagram of PID controller.

Transfer function of PID controller: $K_P + \frac{K_i}{s} + K_d S$

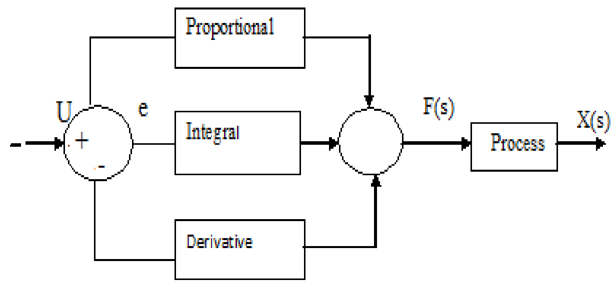

Fig 3.1 Block diagram of PID Controller.

B. FUZZY CONTROLLERS

The four basic elements of any Fuzzy logic control system is shown in Fig 3.2. These are fuzzification interface, fuzzy interference engine, fuzzy rule matrix, defuzzification interface.

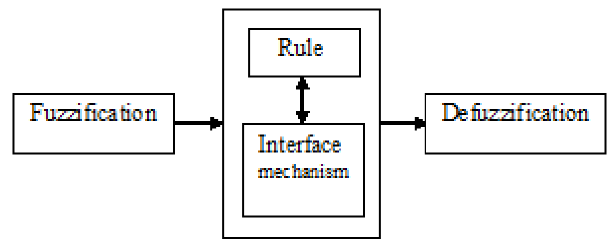

Fig 3.2 Fuzzy Logic Controller

- Fuzzification: The parameters to be used are fuzzified using pre defined membership function. Though there are various membership functions like the most common are triangular, tropezoidal, sinusoidal and exponential.
- Rule Matrix: The rule matrix is used to explain fuzzy sets and fuzzy operators in the form of qualified statements.
- Inference mechanism: Interference mechanism allows mapping between input and output using the fuzzy logic. The most common types of inference mechanisms are Mamdani and Sugeno. In this work mamdani type of fuzzy inference mechanism is used.
- Defuzzification: Defuzzification is the process of converting the result of fuzzy reasoning mechanism into the required crisp value.

IV. MODELING AND SIMULATION OF BLDC MOTOR SPEED CONTROL

A. CIRCUIT DIAGRAM

The Fig 4.1 shows the function circuit for Brushless DC motor speed control by using efficient controller are fuzzy and PID controller.

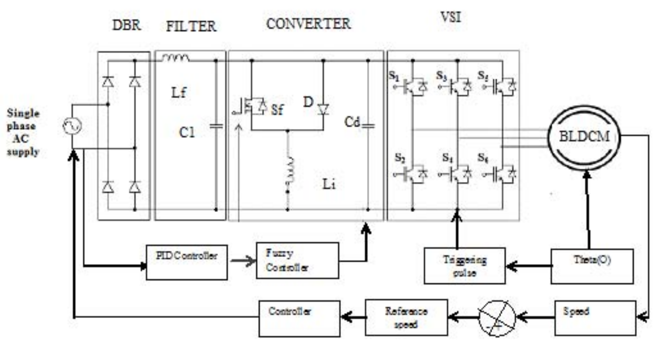

Fig 4.1 circuit diagram for BLDC motor speed control

It consists of four main blocks named BLDC model block, Inverter circuit block, Controller block and Subsystem 1.

In this work, Fuzzy and PID controller is implemented for speed control of the BLDC motor. Figure 4.1 shows the model of the three phase brushless DC motor.

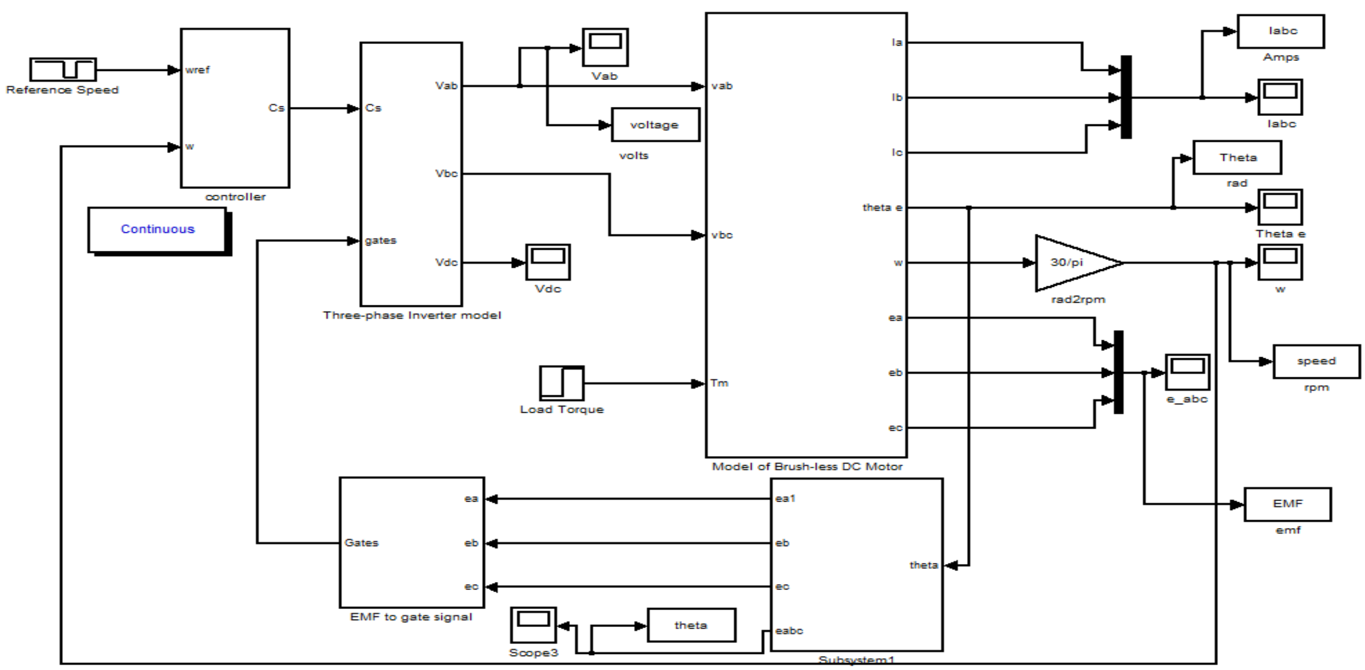

Fig 4.1 BLDC Motor Simulation Model

For sub system1, gate signal is given in the form of angle (θ). The performance of BLDC motor is analyzed by using MATLAB / Simulink. The duty cycle of power electronics devices such as IGBT, MOSFET are controlled by PI controller.

The feedback is given to the PID controller along with reference speed. For additional backup 48V battery is connected in inverter block. Inverter model of BLDC motor speed control device is shown in Fig 4.2**.** Inverter block itself consists of fuzzy and PID controller to produce control signal corresponding to the received input voltage**.**

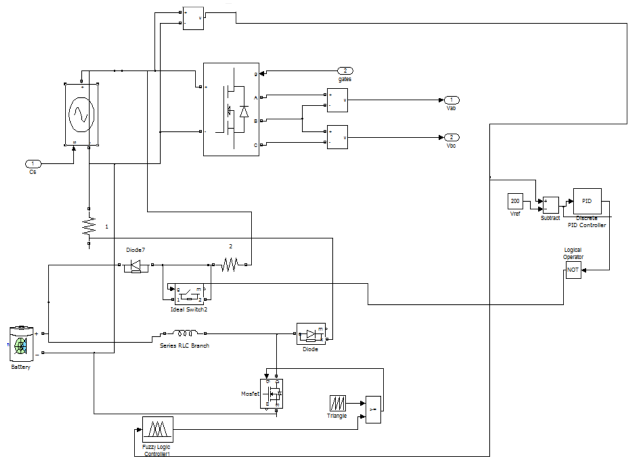

Fig 4.2 Inverter Block

V. PERFORMANCE ANALYSIS OF BLDC MOTOR

A. PHASE CURRENT

The characteristics of phase currents i_a, i_b, i_c is depicted in the figure 5.1. Phase current is sinusoidal in nature and there may be phase difference of 120 degree between each other. Phase current waveforms for the three phase BLDC motor is as shown in fig.5.1.

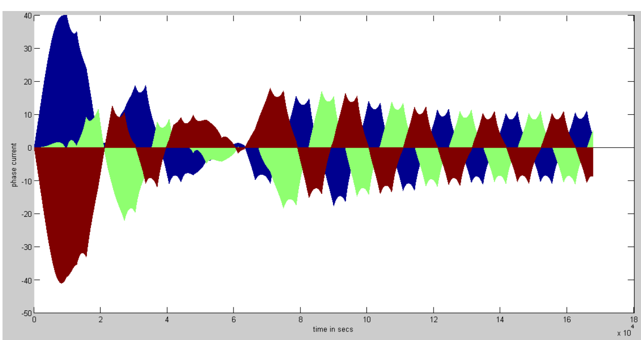

Fig 5.1 Phase current Waveforms of BLDC motor

B. BACK EMF

Figure 5.2 shows the wave form of back emf in the shape of tropezoidal. Here 120^0 mode of operation is considered. Back emfs are improved in stator winding due to mutual induction between permanent magnet and stator winding. Due to trapezoidal back emf, torque developed by the BLDC motor is regular and having less ripples than sinusoidal back emf.

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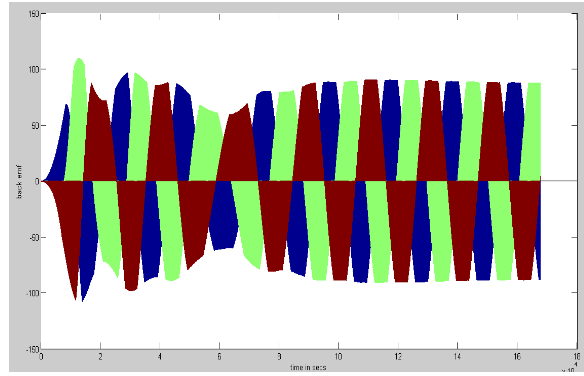

Fig 5.2 Waveform of back EMF

The angle value of Theta (θ) is given as a gate signals and interms of degree. Figure 5.3 shows the waveform of Theta(θ).

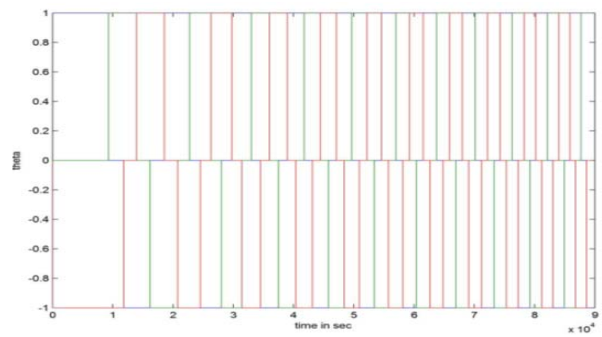

Fig 5.3 Waveform of theta

C. SPEED/TIME WAVEFORM

TABLE 1

Reference speed Vs Time for closed loop

Reference time(s)	Reference speed(rpm)
0	1500
0.02	1000
0.03	1000
0.04	1500

Figure 5.4 shows the speed of BLDC motor at NO LOAD condition. Here reference speed is set at 1500 rpm and the motor attain the reference speed at time=0.04s and remains in steady state.

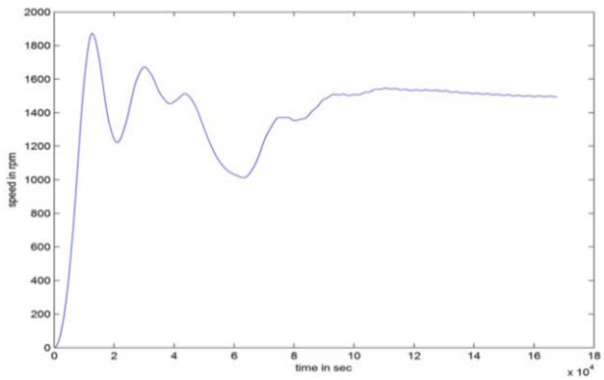

Fig 5.4 Waveform of speed

VI. CONCLUSION

In this work speed control of BLDC motor under various load conditions are verified by simulation using PID and Fuzzy based controller. Here speed of the motor is controlled via controlled voltage obtained from inverter. Triggering gate signal is given for various load conditions. The dynamic characteristics such as speed, current, back EMF are analyzed under various load condition using MATLAB/SIMULINK software. Simulation result shows improved performance when the proposed control is used a wide rang of operating conditions comparatively.

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