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Fuzzy based Speed Control of Brushless DC Motor fed Electric Vehicle

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Abstract: *The aim of this paper is to provide a system for the speed control of a Brushless DC motor (BLDC) fed inverter with the electric vehicle. The fuzzy logic technique is used to estimate the speed of the BLDC motor under variable and fixed condition of the back-EMF. Finally, the speed can be controlled by using Proportional-Integral (PID) Controller with the help of fuzzy based estimation of the speed and rotor position. In order to Compare PI controller, PID and fuzzy controllers provide better speed response and having zero steady state error. Resonant inverter is used for DC-AC conversion with current resonance. The inverter used to regulate voltage and fed into the BLDC motor through a motor driver circuit. In this paper, the resonant inverter fed BLDC motor drive system simulated by using MATLAB/SIMULINK software tools.*

Keywords: *BLDC Motor, Fuzzy Logic Controller, PID Controller.*

1. INTRODUCTION

The Permanent magnet brushless motors are categorized into two types based upon the back EMF waveform, brushless AC (BLAC) and brushless DC (BLDC) motors. BLDC motors are rapidly becoming popular in industries such as Appliances, electric traction, aircrafts, military equipment, hard disk drive, Industrial automation equipment, Instrumentation because of their high efficiency, high power factor, silent operation, compact, reliability and low maintenance. BLDC motors have many advantages over DC motors and induction motors. [1-5]. Some of the advantages are better speed versus torque characteristics, high dynamic response, high efficiency, long operating life, noiseless operation, higher speed ranges. Fuzzy logic is widely used in machine control. The term "fuzzy" refers to the fact that the logic involved can deal with concepts that cannot be expressed as the "true" or "false" but rather as "partially true". Fuzzy logic is an approach to computing based on "degrees of truth" rather than the usual "true or false" (1 or 0) Boolean logic on which the modern computer is based Fuzzy logic can be considered as a mathematical theory combining multi-valued logic, probability theory. It has been reported that fuzzy controllers are more robust to plant parameter changes than classical PID or controllers and have better noise rejection capabilities In this paper, fuzzy logic controller (FLC) is used for the control of the speed of the BLDC motor [6-8].

To replace the function of commutators and brushes, the BLDC motor requires an inverter and a position sensor that detects rotor position for proper commutation of current. The rotation of the BLDC motor is based on the feedback of rotor position which is obtained from the hall sensors. BLDC motor usually uses three hall sensors for determining the commutation sequence. In BLDC motor the power losses are in the stator where heat can be easily transferred through the frame or cooling systems are used in large machines. BLDC motors have many advantages over DC motors and induction motors. Some of the advantages are better speed versus torque characteristics, high dynamic response, high efficiency, long operating life, noiseless operation; higher speed ranges. It has been reported that fuzzy controllers are more robust to plant parameter changes than classical PI or controllers and have better noise rejection capabilities. The aim of this paper is that it shows the dynamics response of speed with design the fuzzy logic controller to control a speed of motor for keeping the motor speed to be constant when the load varies. This paper is present design and implements a voltage source inverter for speed control of BLDC motor [9-10].

This paper also purposed a fuzzy logic controller to the PID in order to keep the speed of the motor to be constant when the load varies. Industrial drives require acute speed control and hence closed loop system with current and speed controllers coupled with sensors are required. Thus this paper presents a detailed comparison of BLDC motor with PID controller and fuzzy logic controller. The various performance parameters of the motor are observed under no load and loaded condition. The results of these were tabulated and analyzed for both the controllers. Finally

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the performance comparison between the PID controller and fuzzy logic controller is done. The graph is plotted with the speed response obtained from PID and fuzzy logic controller along with a reference speed of 2000rpm [11-15]. The reason why conventional controller has low efficiency such as PID controller because the overshoot is too high from the set point and it may takes delay time to get constant and sluggish response due to sudden change in load torque and the sensitivity to controller gains K_i and K_p and K_d. This has resulted in the increased demand of modern nonlinear control structures like Fuzzy logic controller [16-23] which was presented by Zadeh in 1965. Besides that, fuzzy logic controller is more efficient from the other controller such as controller.

2. BLOCK DIAGRAM

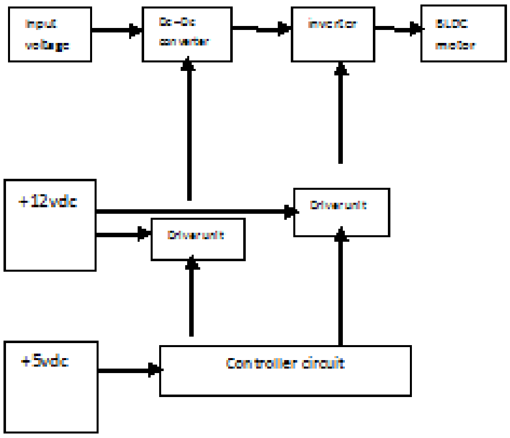

Figure 1: *Block diagram.*

The block diagram of speed control of BLDC motor using fuzzy logic and PID controller can be shown in the figure. The input voltage is given to the DC-DC converter. A DC-to-DC converter is an electronic circuit or electromechanical device that converts a source of direct current (DC) from one voltage level to another. It is a type of electric power converter. Power levels range from very low (small batteries) to very high (high-voltage power transmission).The output of the converter is given to the inverter. Inverters can also be used with transformers to change a certain DC input voltage into a completely different AC output voltage (either higher or lower) but the output power must always be less than the input power. Above it is seen next to such a transistor (06N03LA), probably driven by that driver. In electronics, a driver is an electrical circuit or other electronic component used to control another circuit or component, such as a high-power transistor, liquid crystal display (LCD), and numerous others. The driver circuit run by the +5,+12 volt supply.

3. CONSTRUCTION BLDC MOTOR

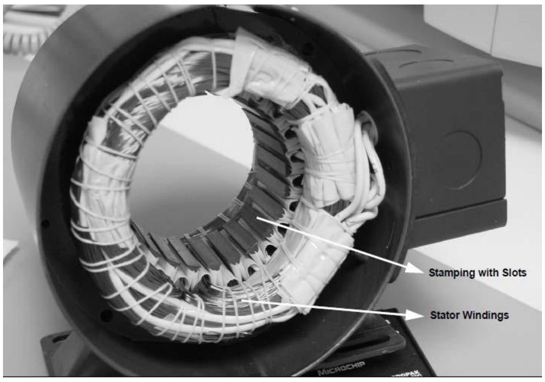

Figure 2: *Construction of BLDC motor.*

BLDC motors are a type of synchronous motor. This means the magnetic field generated by the stator and the magnetic field generated by the rotor rotates at the same frequency. BLDC motors do not experience the “slip” that is normally seen in induction motors. BLDC motor is constructed with a permanent magnet rotor and wire wound stator poles. The stator and rotor of the BLDC motor can be explained below.

3.1.Stator

The stator of a BLDC motor consists of stacked steel laminations with windings placed in the slots that are axially cut along the inner periphery as shown in Figure. Most BLDC motors have three stator windings connected in star fashion. Each of these windings is constructed with numerous coils interconnected to form a winding. Each of these windings is distributed over the stator periphery to form an even numbers of poles.

3.2. Rotor

The rotor is made of permanent magnet and can vary from two to eight pole pairs with alternate North (N) and South (S) poles. Based on the required magnetic field density in the rotor, the proper magnetic material is chosen to make the rotor. Ferrite magnets are used to make permanent magnets. Now a day, rare earth alloy magnets are gaining popularity.

4. HALL SENSOR

The commutation of a BLDC motor is controlled electronically. To rotate the BLDC motor, the stator windings should be energized in a sequence. It is important to know the rotor position in order to understand which winding will be energized following the energizing sequence. Rotor position is sensed using Hall Effect sensors embedded into the stator.

Most BLDC motors have three Hall sensors embedded into the stator on the non-driving end of the motor as shown in Figure. Whenever the rotor magnetic poles pass near the Hall sensors, they give a high or low signal, indicating the N or S pole is passing near the sensors. Based on the combination of these three Hall sensor signals, the exact sequence of commutation can be determined.

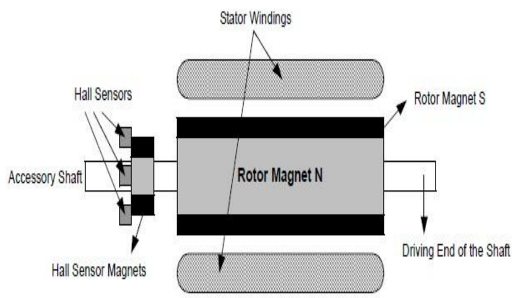

Figure 3: *Rotor and hall sensors of BLDC motor.*

5. SPEED CONTROLLERS

Many drive systems today employ a conventional controller such as a PID-type controller. This method works well, but only under a specific set of known system parameters and load conditions. However, deviations of the system parameters or load conditions from the known values cause the performance of the closed-loop system to deteriorate, resulting in larger overshoot, larger rise time, longer settling times and, possibly, an unstable system. It should be noted that the system parameters such as the system inertia and damping ratio might vary over a wide range due to changes in load conditions. Generally, a PID speed controller could be tuned to a certain degree in order to obtain a desired performance under a specific set of operating conditions. Less than ideal performance is then observed when these operating conditions vary. Thus, there is a need for other types of controllers, which can account for nonlinearities and are somewhat adaptable to varying conditions in real time. Other methods are now being employed, such as fuzzy logic, in order to achieve a desired performance level.

5.1. Fuzzy logic controller

Fuzzy logic control (FLC) is a rule based controller. It is a control algorithm based on a linguistic control strategy which tries to account the human's knowledge about how to control a system without requiring a mathematical model. Fuzzy logic uses linguistic variables instead of numerical variables. The process of converting a numerical variable (real number or crisp variables) into a linguistic variable (fuzzy number) is called Fuzzification. Here the inputs for Fuzzy Logic controller are the speed error (E) and change in speed error (CE). Speed error is calculated with comparison between reference speed and the actual speed.The reverse of Fuzzification is called Defuzzification. As the number of membership function increases, the quality of control improves. As the number of linguistic variables increases, the computational time and required memory increases. Therefore, a compromise between the quality of control and computational time is needed to choose the number of linguistic variables. The most common shape of membership functions is triangular, although trapezoidal and bell curves are also used, but the shape is generally less important than the number of curves and their placement.

The processing stage is based on a collection of logic rules in the form of IF-THEN statements, where the IF part is called the "antecedent" and the THEN part is called the "consequent". The knowledge base comprises knowledge of the application domain and the attendant control goals. It consists of a data "base" and a linguistic (fuzzy) control rule base.

The data base provides necessary definitions, which are used to define linguistic control rules and fuzzy data manipulation in an FLC. The rule base characterizes the control goals and control policy of the domain experts by means of a set of linguistic control rules. Decision making logic is the kernel of an FLC.

5.2. PID Controller

A controller that combines concept of Proportional, Integral and Derivative terms by taking the sum of product of error multiplied by corresponding gains.A combination of proportional ,integral and derivative actions is more commonly referred as PID action and hence the PID controller. These three basic coefficients are varied in each PID controller for specific application in order to get optimal response.

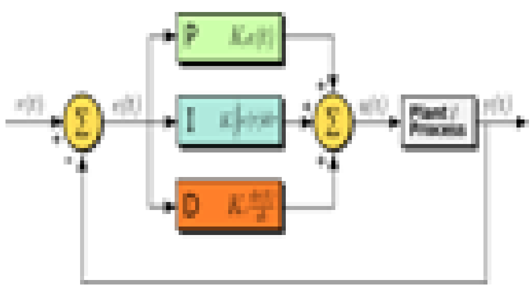

Figure 4: *block diagram of PID controller.*

In manual control, the operator may periodically read the process variable (that has to be controlled such as temperature, flow, speed, etc.) and adjust the control variable (which is to be manipulated in order to bring control variable to prescribed limits such as a heating element, flow valves, motor input, etc.). On the other hand, in automatic control, measurement and adjustment are made automatically on a continuous basis .All modern industrial controllers are of automatic type (or closed loop controllers), which are usually made to produce one or combination of control actions. These control actions include ON-OFF control, proportional control, proportional-integral control, proportional-derivative control and proportional-integral-derivative control.

In case of ON-OFF controller, two states are possible to control the manipulated variable, i.e., either fully ON (when process variable is below the set point) or Fully OFF (when process variable is above the set point). So the output will be of oscillating in nature. In order to achieve the precise control, most industries use the PID controller (or PI or PD depends on the application). Let us look at these control actions. PID Controller is a most common control algorithm used in industrial automation & applications and more than 95% of the industrial controllers are of PID type. PID controllers are used for more precise and accurate control of various parameters.

Most often these are used for the regulation of temperature, pressure, speed, flow and other process variables. Due to robust performance and functional simplicity, these have been accepted by enormous industrial applications where a more precise control is the foremost requirement. Let's see how the PID controller works.

6. MODELLING OF BLDC MOTOR

The motor is considered to have three phases even though for any number of phases the derivation procedure is valid. Modeling of the BLDC motor is done using classical modeling equations and hence the motor model is highly flexible. For modelling and simulation purpose assumptions made are the common star connection of stator windings, three phase balanced system and uniform air gap. The mutual inductance between the stator phase windings are negligible when compared to the self inductance and so neglected in designing the model. Modeling equations involves, Dynamic model equation of motion of the motor,

$$W_m = (T_e - T_l) / Js + B \quad (1)$$

T_e = electromagnetic torque, T_l = load torque,

J = moment of inertia, B = friction constant ,

Rotor displacement can be found out as,

$$\Theta_r = (P/2)\, W_m / s \quad (2)$$

P = Number of poles,

The Back EMF will be of the form,

$$E_{as} = k_b\, f_{as}(\Theta_r)\, W_m \quad (3)$$

$$E_{bs} = k_b\, f_{bs}(\Theta_r)\, W_m \quad (4)$$

$$E_{cs} = k_b\, f_{cs}(\Theta_r)\, W_m \quad (5)$$

K_b = back EMF constant

The Stator phase currents are estimated as,

$$i_a = (V_{as} - E_{as}) / (R+Ls) \quad (6)$$

$$i_b = (V_{bs} - E_{bs}) / (R+Ls) \quad (7)$$

$$i_c = (V_{cs} - E_{cs}) / (R+Ls) \quad (8)$$

R = resistance per phase,

L = inductance per phase,

Electromagnetic torque developed,

$$T_e = (E_{as}\, i_{as} + E_{bs}\, i_{bs} + E_{cs}\, i_{cs}) / W_m \quad (9)$$

7. SIMULATION AND RESULTS

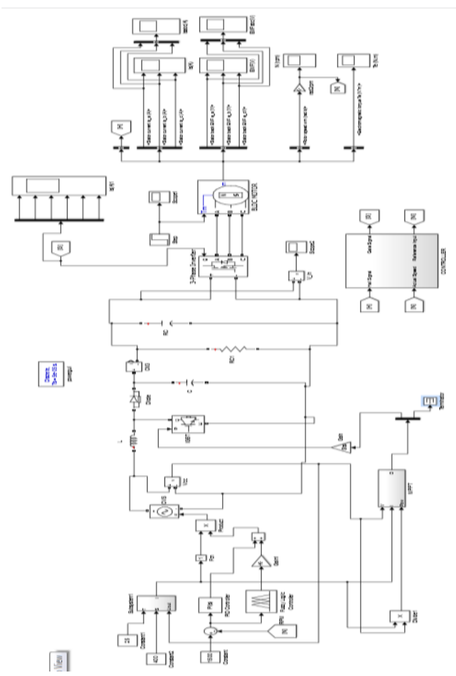

Figure 5: *simulation diagram of speed control of BLDC motor using Fuzzy logic and PID controller*

The simulation results includes variation of different parameters of BLDC motor like total output electrical torque, rotor speed, rotor angle, three phase stator currents, three phase back EMF's with respect to time.

Figure 6 shows the output speed of the BLDC motor, Figure 7 shows the simulated shows the electromagnetic torque.

Trapezoidal back EMFs waveforms are obtained because of the implementation of the proposed commutation scheme. The rotor position varies from 0 to 6.28 radians corresponding to 0° to 360°. The rotor speed is kept constant with the variable load torque. The waveforms shown here is with respect to variable load torque.

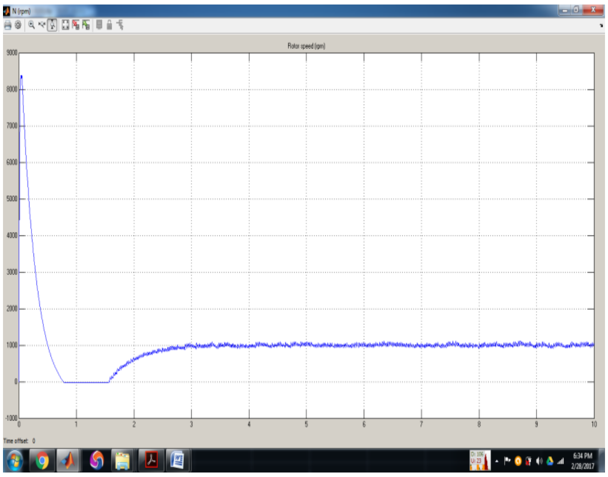

Figure 6: *Output speed in rpm*

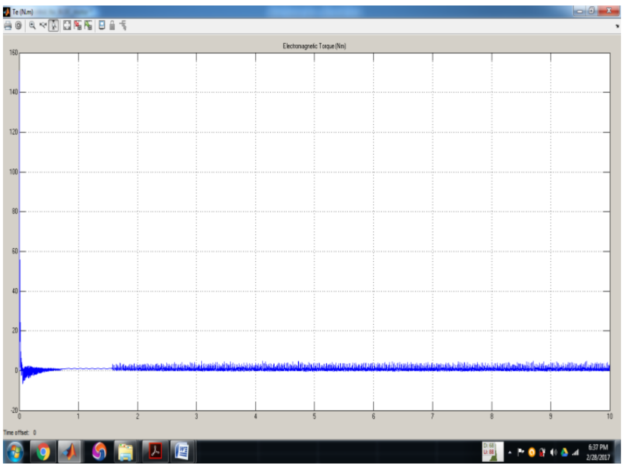

Figure 7: *Electromagnetic torque*

8. CONCLUSION

In this paper, the mathematical modeling of BLDC motor and the speed control of the BLDC motor by using fuzzy logic and PID controller has been proposed and verified. The simulation results was presented for control of BLDC motor in an electric vehicle.

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