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FPGA Based Brushless DC motor Control

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ABSTRACT*:* Permanent Magnet Brushless DC machines have found immerse applications in automobile, automation, consumer electronics, medical and industrial applications due to their high efficiency, long operating life ratio of torque delivered to the size and fast dynamic response. In a brushless motor, the rotor incorporates the magnets, and the stator contains the windings. Commutation is implemented electronically with a drive amplifier that uses semiconductor switches to change current in the windings based on rotor position feedback. Commutation is implemented on FPGA as it provides greater flexibility and higher resources for implementing control algorithms. For the implementation of digital controller, we chose Xilinx Spartan 6 FPGA board. The digital controller algorithm is written using VHDL and is dumped on the FPGA. For this purpose, we use Xilinx ISE and iMPACT tools. FPGA receives hall sensor output from BLDC motor and generates the gate pulses which drive the IGBT switches. Actual speed of the motor is compared with the reference speed given and the error signal is processed in a pi controller to obtain the required pulse width. As the motor rotates, hall sensor signals are produced in accordance with rotor position. Three phase voltages are produced from the gates of IGBT switches after they receive the decoded signals. These voltages are fed as input to the motor and it rotates at required speed.

KEYWORDS*:* BLDC Motor, PWM, FPGA, VHDL, Speed Control.

I.INTRODUCTION

BLDC motors have received significant attention due to their high reliability, robust operation and increased efficiency in industrial, commercial and residential applications. For the same input power, a BLDC motor converts more electrical power into mechanical power than a brushed motor due to the absence of friction due to brushes. It uses permanent magnet as rotor and an electronic controller is required to continuously switch the phase of the winding which will keep the motor spinning. For accomplishing it a feedback sensor and power electronics switching circuit is required.

Control strategies for three-phase BLDC machines are typically implemented using a power converter. To generate appropriate control signals to perform the desired function, a special-purpose processor or a programmable logic device is usually necessary. Even though special purpose controllers are developing faster, they should be simpler, efficient and cost effective. The Field Programmable Gate Array (FPGA) features are growing vertically every day. Latest powerful FPGA devices could be used in BLDC drives. The speed of the motor is directly proportional to the applied voltage. By varying the average voltage across the windings, the speed can be altered. Since commutation is provided with the help of electronic switches, the duty cycle is controlled by using PWM signals

II.LITERATURE SURVEY

Permanent Magnet Brushless DC (PMBLDC) machines have found immerse applications in automobile, automation, consumer electronics, medical and industrial applications due to their high efficiency, long operating life ratio of torque delivered to the size and fast dynamic response. In a brushless motor, the rotor incorporates the magnets, and the stator contains the windings. The paper thereby deals with the development of a virtual BLDC motor controller in FPGA. Various other digital controllers are also discussed. A model of the BLDC motor is simulated, and its controller is implemented on a FPGA system. [1]This paper presents the fuzzy, PI controller for speed control of BLDC motor. The controller uses three fuzzy logic controllers and three PI controllers. The output of the PI controllers is summed and is given as the input to the current controller. The current controller uses P controller. The mathematical modelling of BLDC motor is also presented. The BLDC motor is fed from the inverter where the rotor position and

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current controller is the input. The fuzzy logic control is learned continuously and gradually becomes the main effective control. The Simulink software was used to simulate the proposed scheme. The results are obtained for variable load torque. [2] FPGA implementation has the capability of executing several processes in parallel. Hence, the total control of the inverter together with the motor can be implemented in a single FPGA chip. The use of Pulse Width modulation (PWM) in power electronics to control high energy with maximum efficiency & power saving is not new but, [3] interesting is to generate PWM signals using Hardware Descriptive Language (HDL) and implementing it in FPGA.FPGA implementation of PWM is selected because it has provided an economic solution &fast circuit response due to its simultaneous instead of sequential execution.

In this paper the FPGA based controller for BLDC motor is an experimental model implementation of Sinusoidal PWM strategy (SPWM) control scheme. The proposed control scheme can be realized and the Simulation results are verified using FPGA SPARTAN-3A DSP Trainer kit from Xilinx with the help of VHDL programming algorithm of digital PWM Generator topology.[4]Brushless DC motors drives have gained widespread use in electrical drives that are rapidly gaining popularity by its utilization in various industries, such as appliances, automotive, aerospace, consumer, medical, industrial automation equipment and instrumentation and industrial drives partly as result of demand for variable speed drives because of development of power electronics devices. It gaining popularity due to their low cost, ruggedness, good dynamic response and low maintenance and are widely used in different applications which requires high torque with good speed response? The existence of solid state power switching technology also stimulated an interest in possible alternative and simpler motor configurations. Most of the BLDC motor drives use Inverters which is simple and mostly used for industrial applications because of their simple and superior performance. The use of pulse width modulation in power electronics to control energy saving and the ease of PWM generation using Hardware Description language and implementing in FPGA board [5][6].

III.BLDC MOTOR

BLDC motors have many advantages over brushed DC motors and induction motors. A few of these are:
• Better speed versus torque characteristics
• Faster dynamic response
• High efficiency
• Long operating life
• Noiseless operation
• Higher speed ranges

BLDC motor consists of stator and rotor. Stator is consists of stacked steel laminations with winding placed in slots. Most BLDC motors have three stator windings connected in star fashion. Rotor is made up of permanent magnet and itcan be of two to eight pole pairs with alternate north and south. Permanent magnetic material for rotor is chosen based on magnetic field density required in rotor. Hall sensors working on Hall Effect principle are used for rotor position detection depending on hall voltage generated in them as rotor pole passes nearer to hall sensor. Hall sensors are embedded into stator in BLDC motor as shown infig1. According to sequence of hall sensors stator windings are energized in sequence.

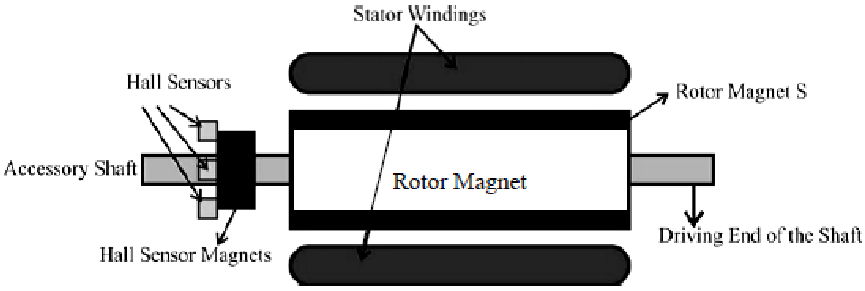

Fig. 1: BLDC Motor with Hall Sensors

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Each commutation sequence has one of winding energized to positive power, the second winding energized to negative and the third is in a non-energized condition. General circuit of BLDC motor with power converter is shown in fig 2. The speed and torque of motor depend on strength of magnetic field generated by energized windings of motor, which depend on current through them. Therefore, adjusting the stator winding voltage will change motor speed.
The analysis of BLDC motor is represented by following equations:

$$\begin{bmatrix} v_{an} \\ v_{bn} \\ v_{cn} \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L & 0 & 0 \\ 0 & L & 0 \\ 0 & 0 & L \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix}$$

where,

va, vb and vc are phase voltages, ia, ib and ic are the phase currents, ea, eb and ec are phase back-EMF waveforms.
R is phase resistance.
L is self-inductance of each phase and M is mutual inductance between any two phases.
Electromagnetic torque can be given as:
Te = (eaia + ebib + ecic) / ωr
where ωr is mechanical speed of the rotor.
The electrical speed ωe is related to mechanical speed for a motor with P number of poles is:
ωe = (p/2) ωr

IV.SPEED CONTROL ALGORITHM

The standard AC power supply is converted to a DC by using a 3-phase diode bridge rectifier. A voltage sourceInverter is used to convert the DC voltage to the controlled AC voltage. The output of Inverter is fed to Brushless DC motor. VHDL program is used in Xilinx software to generate the controlled PWM pulses at different duty ratio for Inverter to drive the Brushless DC Motor at different speed.
PWM signals are generated from the Spartan-6 FPGA processor by writing VHDL program to control the inverter switches. The switching signal parameters namely switching frequency, the duty ratio and the number of pulses are easily controlled via VHDL programming language.

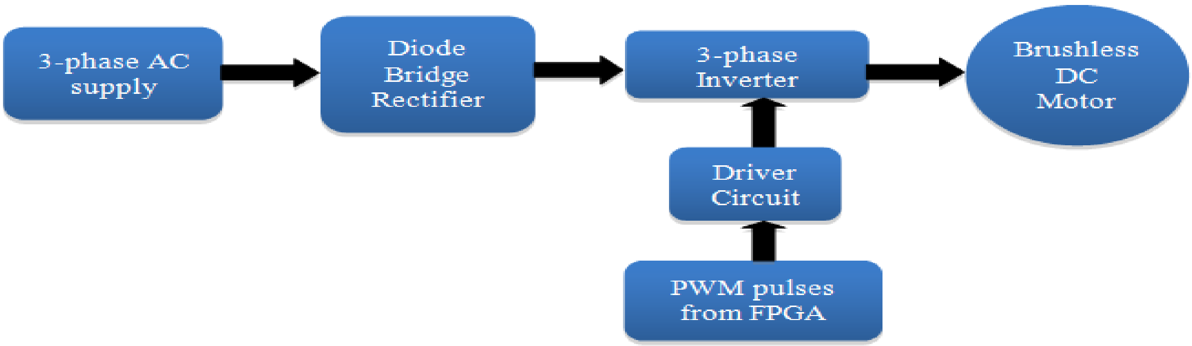

Fig 2: Block diagram

Basic speed control system of BLDC motor consist controller, inverter, BLDC motor and speed measurement unit. Speed is measured using hall sensors which are embedded on stator. Measured and reference speed are given to controller where difference between speeds is taken as an error. Controller works on that error and gives output to inverter block which decides which winding of BLDC motor is getting on. As per sequence of inverter gates windings of BLDC motor are getting on or off and hence field changes take place and
according to that rotor position will change. In this way speed can be controlled.

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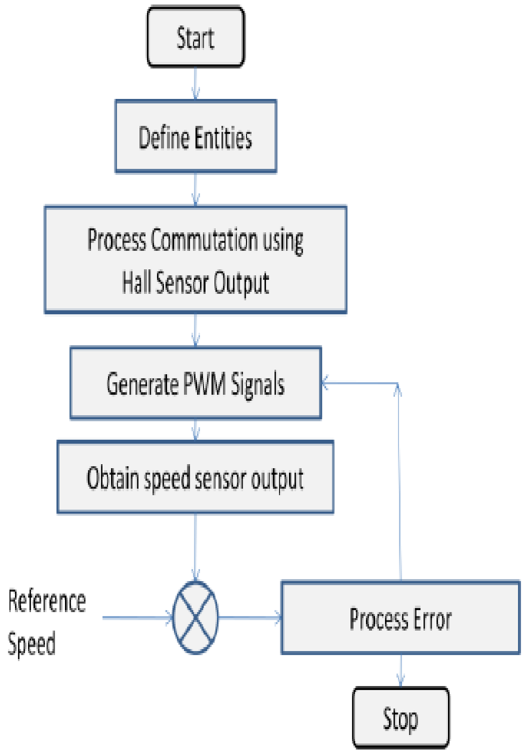

Fig 3: Flow Chart

V.SIMULATION RESULTS

Logic simulation in FPGA design environment plays a very vital role in verifying the functionality of the designs. Simulation is a powerful way to test
the system on a computer, before it is turned into hardware. Simulators let designer to check the values of signals inside the system.

1.VHDL simulation

Logic simulation in FPGA design environment plays a very vital role in verifying the functionality of the designs. Simulation is a powerful way to test the system on a computer, before it is turned into hardware. The ISE design software allows creating a test bench and simulating the design. The complete design is simulated using Isim Simulation tool, which has precompiled libraries for all Xilinx FPGAs. The inputs like Clock, Reset, Switch data and sensor are defined and the output is observed in the simulation window. Once all the signals are taken into the waveform window, the simulation is run for 50 ms. The simulation result is shown in figure.

2. Angle Estimation using Hall Sensor State

For proper commutation, the absolute rotor position information is very crucial in order to produce the synchronized voltage waveforms to the motor. To get fine position information, the motors will be equipped with Encoders or Resolvers, but these sensors add cost to the system. For low-cost simple solutions, the motors which have Hall sensors can be used. The design uses a motor that has four pole pairs. For every electrical cycle there are six Hall state changes and thus provides 60 degrees of precision. Each state corresponds to an electrical angle and has six angle steps.

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3. Speed Calculation using Hall State

The Hall state changes provide the information about the position of the motor. For every electrical cycle there will be six Hall state changes. If the time taken between the Hall state changes is available, then the speed can be computed. A moving average technique is used to calculate the speed. Using this technique, we can take the average of the six previously calculated speed values.

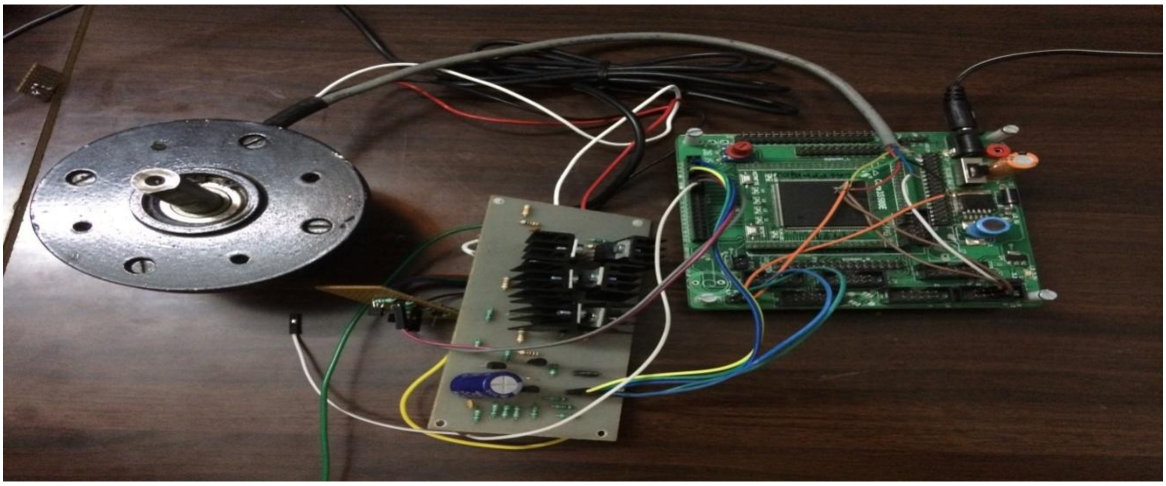

Fig 4: Proposed hardware

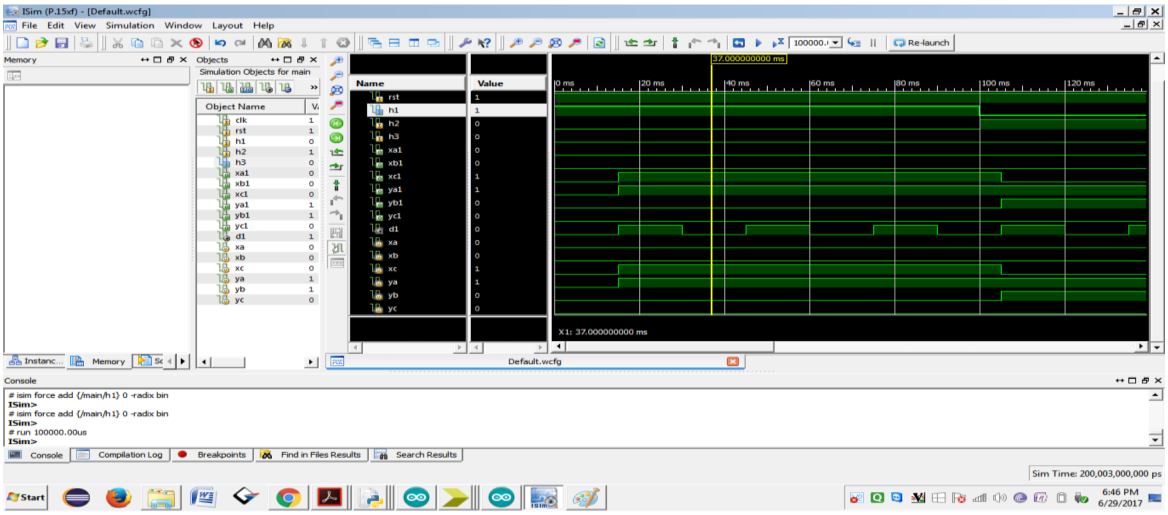

Fig 5: Simulation Diagram

VI.CONCLUSION

FPGA based implementation of PWM control of brushless DC motor was carried out in simulation and real timeexperiment. BLDC have better speed versus torque characteristics, high dynamic response, high efficiency, longoperating life, noiseless operation, higher speed ranges, rugged construction and so on. Also, torque delivered to the motor size is higher, making it useful in applications where space and weight are critical factors.

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The PI control of BLDC motor is successfully implemented on the FPGA and its performance is tested on a BLDC motor speed control system for real time control. According to the experiment done
it is observed that, in the simulation, when the set speed is changed, the motor speed locks to the set speed, when the current error becomes zero. In brief, the role of FPGA, in measurement and control point of view, is to acquire the data from sensor through analog to digital converter, do the processing on the acquired data and then generate control signals to the actuator, which intern controls the parameter being measured. FPGAs ensure ease of design, lower development costs, more product revenue, and the opportunity to speed products to market. Building PID controllers on FPGAs improves speed, accuracy, power-efficient, compactness and cost effectiveness over other digital implementation techniques.

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