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# Controlling a BLDC Motor using SIMULINK and FPGA for Quadcopter Applications

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***Abstract*: A new generation equipment has to be better in performance with respect to the previous generation, such as higher in efficiency, low power consumption, small in dimensions, lightless and so on. At the same time focusing on low maintenance cost. When it comes to the motor, these can be achieved by the "Brushless Direct Current (BLDC) motor or Permanent magnet synchronous motor (PMSM)". Employed even more from the last few years in many types of equipment in various application field. We designed and built a control system that controls the speed of the motor for given reference input or set point. Our proposed project involves both open-loop and closed-loop technique, for controlling of motor speed. Closed-loop control technique implies "MATLAB Simulink with PID" for the precisely controlled output. Similarly, open-loop control technique is designed and implemented on a "Spartan-6 Xilinx FPGA" kit, which is a raising technology with a flexible architecture.***
**Keywords***: Brushless DC (BLDC) motor, H-bridge inverter, PID, Hall- effect sensor, Back- EMF, ESC*

## I. INTRODUCTION

From past few years, engineers are researching to develop a low power consumption devices and machines, for industrial purpose and daily use products. Most of the electronics devices employ's an induction motor, DC motor or Stepper motor. These motors are low in efficiency, high power consumption, and high maintenance cost. When a Brushless DC motor was introduced, it had an advantage's over these parameters. According to survey if all the present motors are replaced with BLDC motor, almost 50% of power consumption of a country can be saved. But designing a cost-effective controller for BLDC is a challenge. Thus our project proposes is to control the motor with an effective, way to maintain a constant speed at the output, by Understanding the behavior and controlling the motor with help of control techniques. We make use of both close-loop & open-loop control technique. Closed-loop is implemented with MATLAB Simulink and open-loop with Spartan 6 Xilinx FPGA kit. In MATLAB Simulink with the help of Hall-effect sensor and Back-EMF, a pair of motor windings is energized respectively. A voltage control source is used to vary the voltage across the H-bridge inverter circuit, in order to vary the motor speed. Gates of the MOSFETs are switched based on the input from Back-EMF block circuit. An feedback from the motor output is fed back to the comparator, to compares the reference input with the feedback signal, to generate an error signal for the PID. PID controller varies the voltage across the inverter with respect to the error signal. Motor winding current are sensed by the Hall-effect sensor, in turn, it generates Back-EMF signal to operate the MOSFET inverter circuit, for energizing the next pair of winding of the motor. An FPGA based Spartan 6 kit is made use to generate PWM signal, to control the speed of the motor, by varying the duty cycle. An ESC (Electronic speed control) circuit is responsible for the switching of the MOSFET's and controlling the motor position, with respect to the Back-EMF signal. Featuring sections includes [2]component detailed description and parameters, [3] System architecture of Simulink, [4] PID controller, [5] hall effect sensor operation and functionality, [6] working operation with the expected result [7] we conclude the paper in the followed acknowledgment and references.

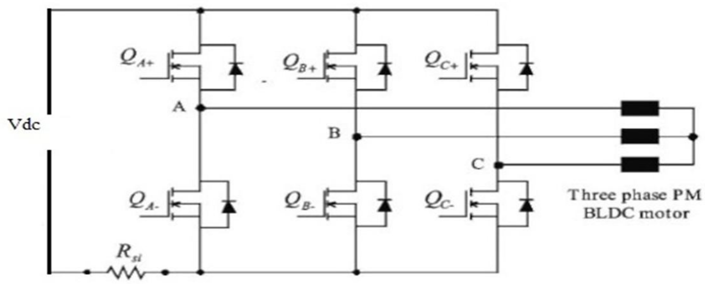
## II. SYSTEM ARCHITECTURE AND COMPONENTS

This section explains the methodology adopted in completing this project. Basically, our proposed project serves applications like a quadcopter, RC devices, and daily use equipment equipped with BLDC motor. The architecture in Simulink implies voltage control, whereas in hardware it implies the PWM control method.

### *A. Bldc Motor : Introduction*

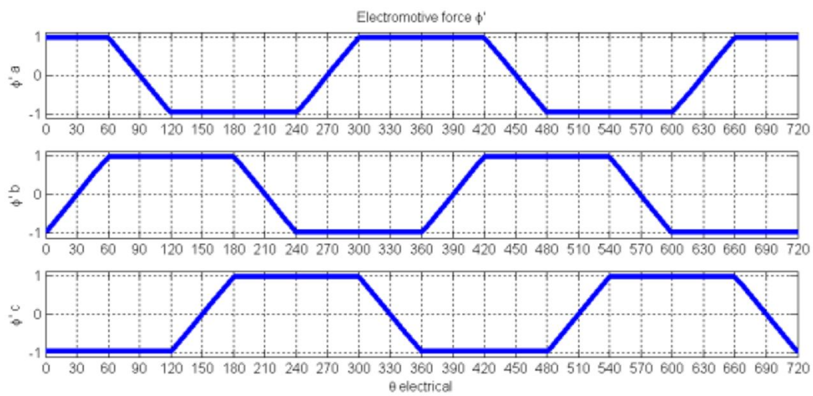
A BLDC motor is a brushless motor. The name itself implies that there are no brushes and commutator. In BLDC Motor the commutation is performed with the help of electronic circuit, it reduces the mechanic loss and improves the efficiency and performance. Replacing the inefficient induction and other motors with more efficient BLDC motors will result in substantial energy savings. BLDC has several advantages over other machine types, they require lower maintenance due to the elimination of brushes and commutator. It also has high power density. Compared to induction machines, BLDC motors have lower inertia, allowing for faster dynamic response to reference commands. The major disadvantage with PMSM motors is their higher cost and relatively greater degree of complexity introduced by the power converter used to drive them. The speed of the motor is directly proportional to the applied voltage. By varying the voltage across the windings, the speed can be altered.

A BLDC motor has two types of driving strategies namely, unipolar and bipolar. A three-phase BLDC motor is driven by a three-phase H-bridge inverter circuit, comprising MOSFETs Fig[1]. The efficiency which is the ratio of the mechanical output power to the electrical input power, since in this drive an alternating current flows through each winding. This refers to a bipolar drive. Here 'Bipolar' means a winding is alternately energized in the south and north poles. The bipolar driving strategy includes sensor-based and sensor-less techniques. Position encoders and back EMFs are used in sensor-less techniques. Whereas a hall effect sensors and optical sensors are used in sensor-based techniques. The EMF can have a trapezoidal or sinusoidal waveform.




Fig[1] Equivalent circuit of BLDC motor connected to an inverter

A typical Back-EMF waveform of a three-phase BLDC motor with trapezoidal flux distribution shown in.Fig[2]




Fig[2]Trapezoidal flux distribution of three-phase motor

As it can be seen, the back EMF induced per phase of the motor winding is constant for 120° and changes linearly with rotor angle before and after the constant part. The phase voltage equations of BLDC motor can be written as,

$Va = RaIa + L\,(dIa\ dt\,) + Ea$

$Vb = Rb\ Ib + L\,(dIb\ dt\,) + Eb$

$Vc = RcIc + L\,(dIc\ dt\,) + Ec$

Where,

, , $Vc$ are the phase voltage, $Ia$ , $Ib$ , $Ic$ are the phase current, $Ea$ , $Eb$ , $Ec$ are the back EMFs

The back EMFs can be expressed as, $Ea = Ke\omega mF(\theta e)$ ; $Eb = Ke\omega mF(\theta e - 2\pi\ 3\,)$ ; $Ec = Ke\omega mF(\theta e + 2\pi\ 3\,)$

Where,

ω m is the Angular speed of the rotor.

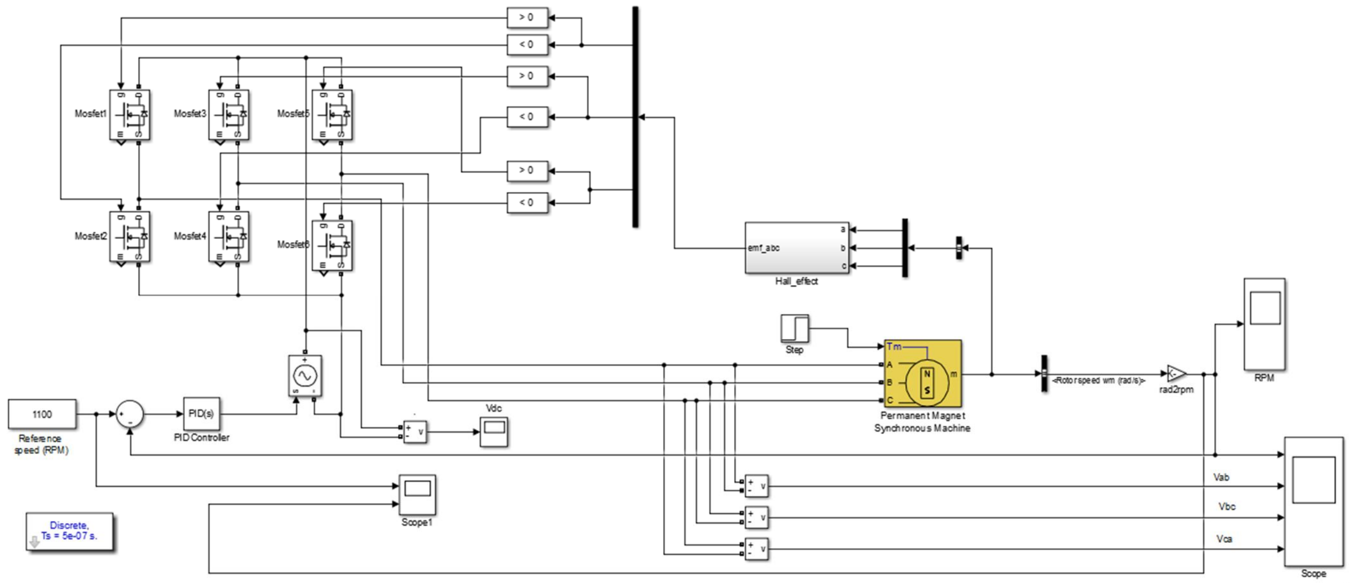
$\theta$m is Mthe echanical angle of rthe otor.

$\theta$e is Ethe lectrical angle of rthe otor.

F($\theta$e) is Back –EMF reference function of rotor

## III. SYSTEM ARCHITECTURE

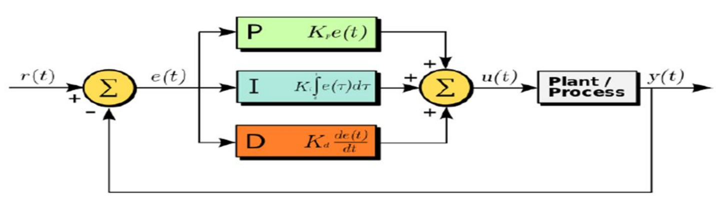
A Simulink system modeling of BLCD motor control with closed-loop control technique is shown in the Fig.[3]




Fig[3]Simulink diagram of BLDC motor with PID controller

## IV. PID CONTROLLER

A proportional–integral–derivative controller (PID controller or three term controller) is a control loop feedback mechanism widely used in industrial control systems and a variety of other applications requiring continuously modulated control. A PID controller continuously calculates an error value as the difference between a desired set-point (SP) and a measured process variable (PV) and applies a correction based on proportional, integral, and derivative terms (denoted P, I, and D respectively).Fig[4]




Fig[4] Basic PID controller block

Here PID is tuned to this given value shown in the below table Fig[5] , with this tuning a precise controlled output is obtained at the motor,

| PARAMETER | DESCRIPTION |
|---|---|
| Controller | PID |
| Form | Parallel |
| Time domain | Continuous – time |
| Source | Internal |
| Proportional (P) | 0.01035 |
| Integral (I) | 12.777 |
| Derivative (D) | 12.564 |
| Filter coefficient (N) | 0 |

Fig[8] PID tuning parameters

## V. HALL-EFFECT SENSOR

Implementation of Hall- effect sensor for the position control of the motor winding with respect to the previously energized windings. Based on the signal obtained from the Hall Effect sensor, a back- emf signal is generated. A truth table [4] is shown below, which indicates obtaining the back-emf signal from a received signal from Hall Effect sensor.

| Ha | Hb | Hc | emf_a | emf_b | emf_c |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 1 | 0 | -1 | +1 |
| 0 | 1 | 0 | -1 | +1 | 0 |
| 0 | 1 | 1 | -1 | 0 | +1 |
| 1 | 0 | 0 | +1 | 0 | -1 |
| 1 | 0 | 1 | +1 | -1 | 0 |
| 1 | 1 | 0 | 0 | +1 | -1 |
| 1 | 1 | 1 | 0 | 0 | 0 |

Fig[4] Truth table of hall effect sensor for generation of back-emf

This hall effect sensor model is designed and implemented with help of the above mention truth table, by applying K-map for obtaining a logical expression. The following K-map are shown below,

| h(ab)\hc | 0 | 1 |
|---|---|---|
| 00 | 0 | 0 |
| 01 | 1 | 1 |
| 11 | 0 | 0 |
| 10 | 1 | 1 |

emf_a = ~ha.hb + ha.~hb

| h(ab)\hc | 0 | 1 |
|---|---|---|
| 00 | 0 | 1 |
| 01 | 1 | 0 |
| 11 | 1 | 0 |
| 10 | 0 | 1 |

emf_b = hb.~hc + ~hb.hc

| h(ab)\hc | 0 | 1 |
|---|---|---|
| 00 | 0 | 1 |
| 01 | 0 | 1 |
| 11 | 1 | 0 |
| 10 | 1 | 0 |

emf_c = ha.~hc + ~ha.hc

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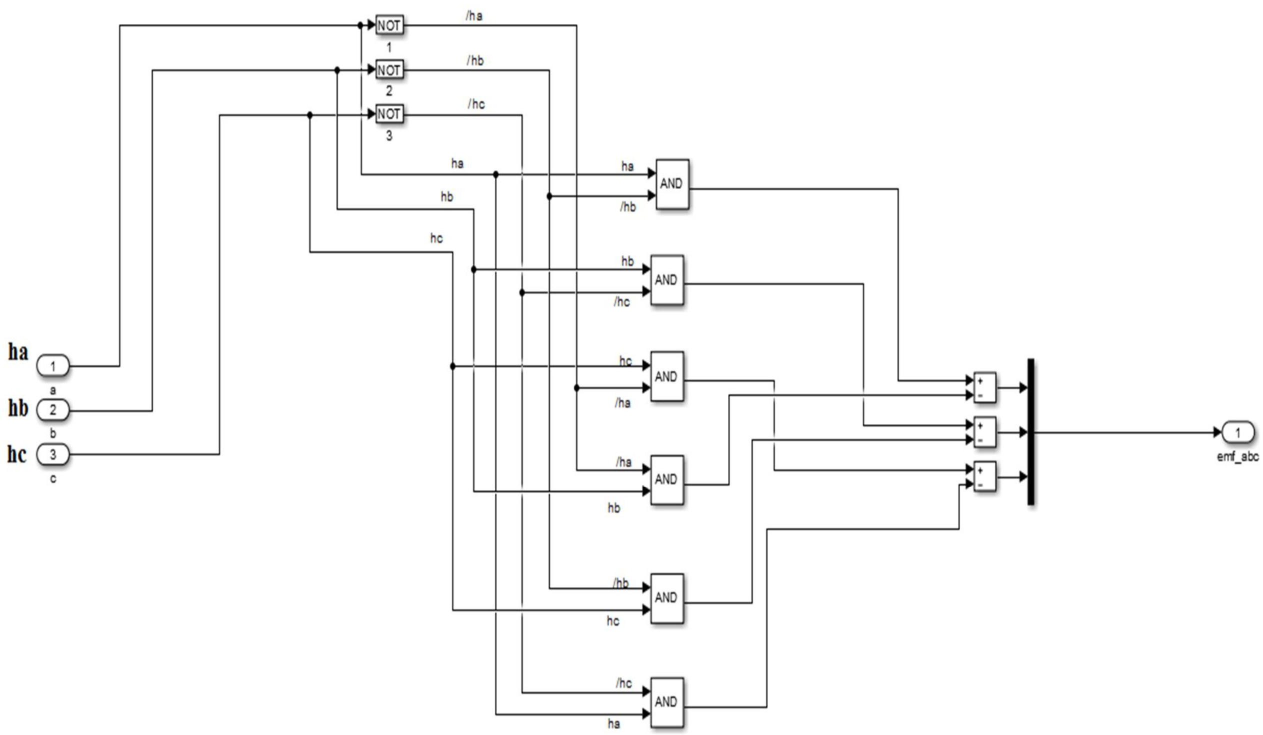
The Fig.[5] shows how hall effect sensor is modeled with the help of the truth table and K-map




Fig[5] Simulink modeling of hall effect sensor

Table.[1] BLD motor Simulink modeling experimental parameters :

| | |
|---|---|
| Number of Phases | 3 |
| Back- EMF waveform | Trapezoidal |
| Mechanical input | Torque Tm |
| Stator phase resistance (ohm) | 0.7 |
| Stator phase inductance Ls (H) | 2.73e-3 |
| Torque constant | 1 |
| Back-EMF flat area (degrees) | 120 |
| Step time | 0.1 |
| Initial value | 0 |
| Final value | 1 |
| Source type | DC |
| Initial amplitude (V) | 160 |
| Measurement | None |

## VI. WORKING OPERATION OF SIMULINK

*A.* From the above shown Fig[3] a reference input or constant input is applied to the motor through the PID controller, by the means of comparator and error is signal is generated with respect to the input value. Based on these error signal, a control signal is generated by the PID controller, which in turn control the voltage across the inverter circuit. This variation in voltage varies the motor speed.

*B.* A hall effect sensor outputs are obtained from the motor, by a selector block and with help of these signal, a back-emf control signal is generated. In Fig[4].

*C.* This back-emf is signal is decoded to operate the H-bridge inverter circuit, for energizing and position control of the motor windings.

## VI .SIMULINK EXPERIMENTAL RESULT

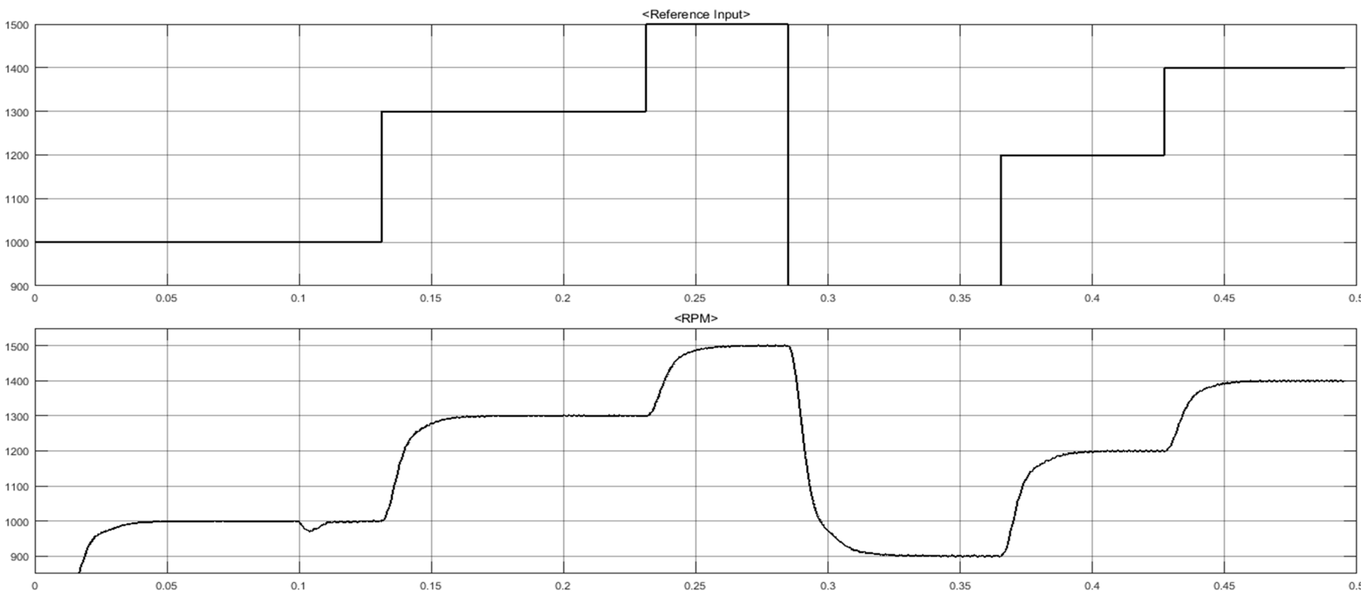



Fig. [6] Motor output with respect to the reference input in RPM

The torque remains constant for a BLDC motor when there is a variation in speed of the motor and also when an applied voltage is varied. These change in parameter has no impact on the torque constant. Changes made to the motor does not affect the torque constant which is another advantage of BLDC motor. Fig [7] shows the torque constant,

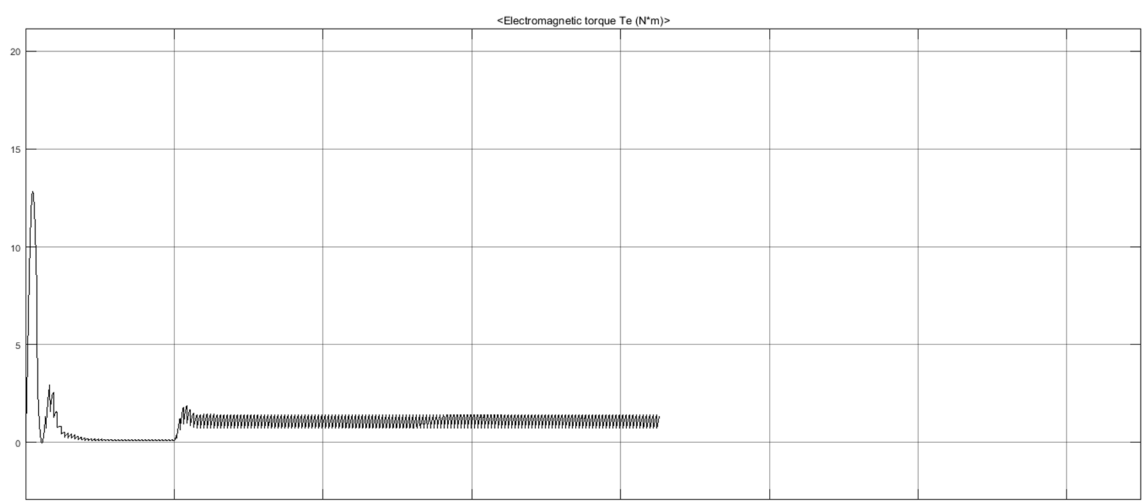



Fig [7] Torque constant of the BLDC motor

*A. Hardware Components*

1) *Field-Programmable Gate Array (Fpga):* The Field Programmable Gate Array (FPGA) is an integrated circuit designed to be configured by a customer or a designer after manufacturing, hence called "field programming". FPGA configuration is generally specified using a hardware description language (HDL), that is VHDL or VERILOG. similar to that used for an application specific integrated circuit (ASIC). The generic architecture of an SRAM-based FPGA as shown in Fig.[8]

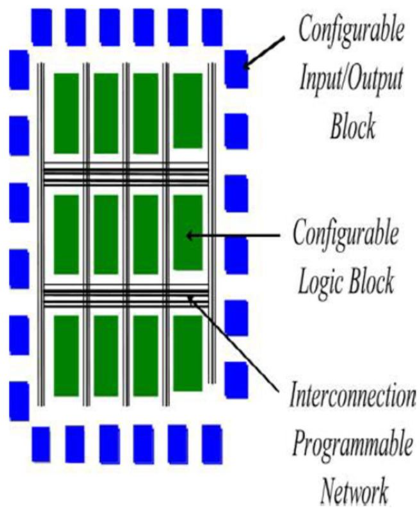



Fig [8] Architecture of S-RAM based FPGA

Nowadays, the FPGA technology received much attention by industrial researchers for designing and implementing high-performance ASIC digital controller. In our project, we made use of XILINX SPARTAN 6 FPGA.

*B. Electronic Speed Control (Esc)*

An electronic speed control follows a speed reference signal controlled by a throttle lever, joystick, or other manual input. By adjusting the duty cycle or switching frequency of the transistors, the speed of the motor is changed. The rapid switching of the transistors is what causes the motor itself to emit its characteristic high-pitched whine, especially noticeable at lower speeds.This is fully programmable 30A BLDC ESC with 5V, 3A battery eliminator circuit (BEC) . Can drive motors with continuous 30Amp load current. It has a sturdy construction with 2 separate PCBs for Controller and ESC power MOSFETs. It can be powered with 2-4 lithium Polymer batteries or 5-12 NiMH / NiCd batteries. It has a separate voltage regulator for the microcontroller for providing the good anti-jamming capability. It is most suitable for UAVs, Aircraft, and Helicopters. The specification explains the operation range of the ESC

1) Output: 30A continuous; 40Amps for 10 seconds
2) Input voltage: 2-4 cells Lithium Polymer / Lithium-Ion battery or 5-12 cells NiMH /NiCd
3) BEC: 5V, 3Amp for an external receiver and servos
4) Max Speed: 2 Pole: 210,000rpm; 6 Pole: 70,000rpm; 12 Pole: 35,000rpm
5) Weight: 32gms

In our experiment, we made use of this 30A ESC powered by 11v, 2200mA Lithium-ion battery
With help of the indication beep sound generated by the ESC, for understanding current operating mode that it has entered, by passing the high-frequency signal to the motor windings.

*C. Bldc Motor*

A The motor that made used in our experiment features a 3.2mm hardened steel shaft, dual ball bearings, and has 3.5mm gold spring male connectors already attached and includes 3 female connectors for your speed control.
Which is a simple quad copter BLDC motor made used for the experimental purpose, this motor was operated at 10v, 13A power with a speed of 1000 RPM/V or 1000 KV. Which had 80% efficiency operated at 13A for the 60s.

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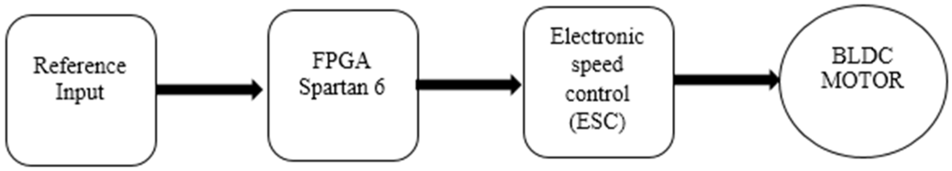


Fig [9] Basic hardware block diagram

A reference input is applied to the Spartan 6 FPGA, based on the reference input an equivalent PWM signal was generated. Which had a 50hz frequency with a pulse width of 1-2 msec.
Due to the incompatibility of the system, a required output could not be obtained with FPGA. An Arduino UNO was made use. Which was more compatible with the ESC and BLDC motor used in our project and desired output with speed control was achieved by Arduino UNO. As it was an experimental project for better and effective control of BLDC motor with rasing controller technology (FPGA), was not successful due to system incompatibility. It was fully functional with Arduino UNO ATMEGA with a proper control over the motor speed.

## VII. CONCLUSION & FUTURE SCOPE

As it was an experimental project for the effective control of BLDC motor, that could not be achieved due to the incompatibility of the hardware available. In future with greater up-gradation in the hardware, could control of BLDC motor in effectively with better control technique. It was compatible with Arduino UNO, but it is limited by its architecture. The main purpose of this project is to have better control over a BLDC motor using FPGA, because of its flexible architecture and in near future if any changed has to made with an upgrade, it could be achieved easily with FGPA. For a better performance and efficiency of BLDC motor in future with a greater upgrade in hardware, this project can be implemented.

## VIII. ACKNOWLEDGMENT

The project team of “Controlling a BLDC Motor using SIMULINK and FPGA for Quadcopter Applications " would like to express our honest sense of gratitude to our institution – New Horizon College of Engineering (NHCE). We wish to express our sincere thanks to Mr. Aravinda, Head of the Department of Electronics & Communication Engineering, NHCE for permitting us to pursue our project in college and encouraging us throughout the project. Our gratitude goes to all who have stood behind us and motivated and helped us accomplish the goal by sharing their knowledge and views on the topic. Among them is our guide Mrs.Dr.Nisha.K.C.R who has guided us throughout the task with her expertise and experience.

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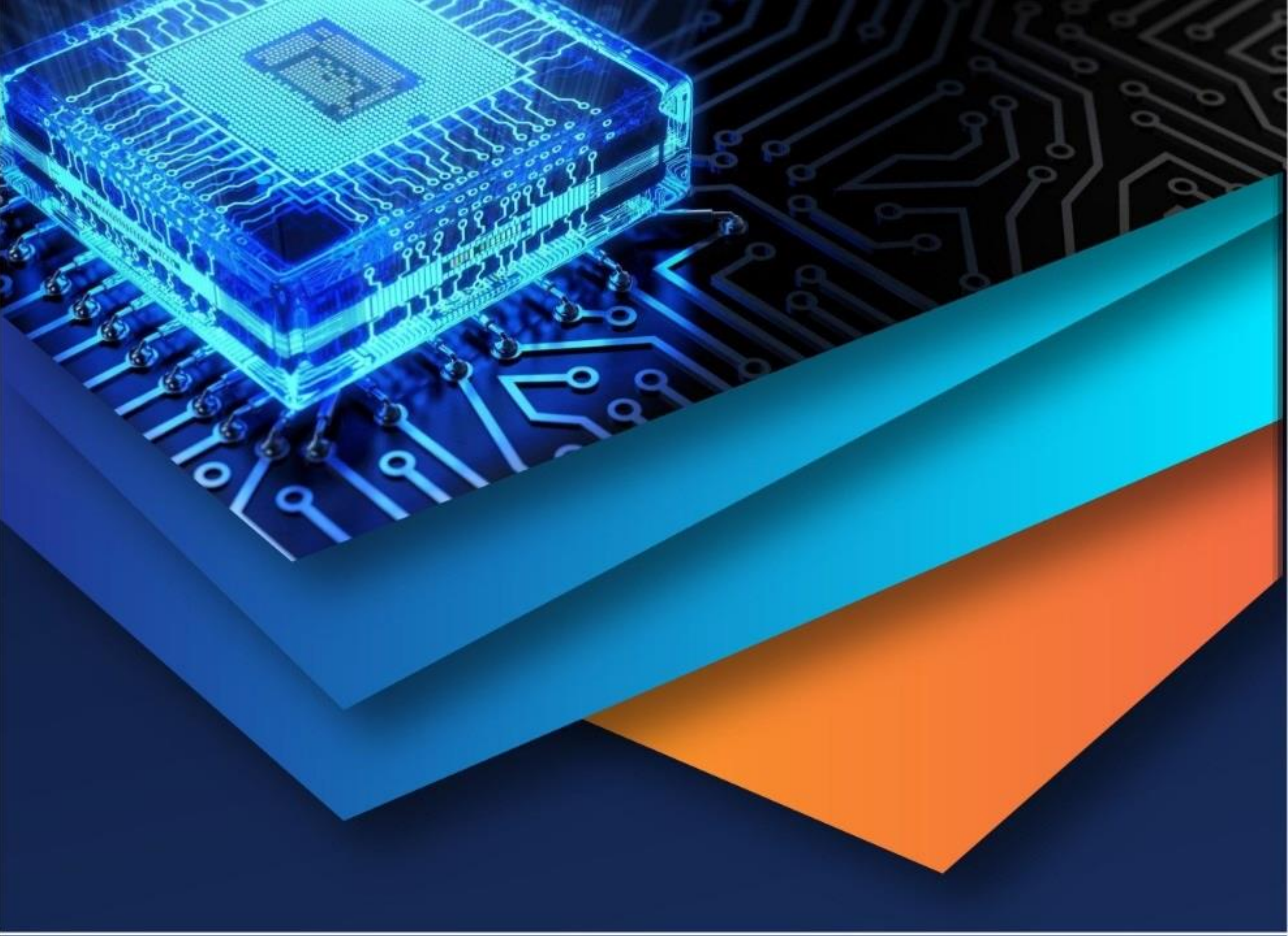


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