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# Speed Control of BLDC Motor using PWM Technique

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***Abstract*— Efficiency and Reliability are the key features for the development of advanced motor drives. Residential and commercial appliances such as refrigerators and air conditioning systems use conventional motor drive technology. A brushless DC (BLDC) motor drive is characterized by higher efficiency, lower maintenance, and higher cost. Therefore, it is necessary to have a low-cost but effective BLDC motor controller. PWM has been widely used in power converter control. PWM control is the most power full technique that offer a simple method for controlling of analog system with processors digital output. PWM frequency depends on the target FPGA device speed and duty cycle resolution requirement. In this paper, BLDC motor drive controlled using FPGA controller.***

***Keywords* - Brushless DC (BLDC) motor drives, converters, field-programmable gate arrays (FPGAs), inverters, pulse width modulation (PWM).**

## I. Introduction

An electrical motor is defined as a mechanical transducer that converts electrical energy into mechanical energy. Electric motors are an integral part of industrial plants. Residential and commercial applications mostly use conventional motor drive technologies. Electric motors are responsible for consuming more than half of all the electrical energy used in the world. In every industry there are processes that require adjustment for normal speed. Such adjustments are usually accomplished with variable speed drive and it consists of electrical motor, power converter and controller. Typically, machines found in all appliances are single-phase induction motors or brushed dc machines which are characterized by low efficiency and high maintenance, respectively [1]. Single-phase induction motors are less efficient because of the ohmic loss in the rotor and due to the phase angle displacement between the stator current and back electromotive force (EMF). But the above losses are less in BLDC motor due to the absence of brushes and mechanical commutation. Different methods are available for speed control of BLDC motor, like DC link variable voltage, PWM technique, etc.

In this paper, PWM technique has been employed. Nowadays different PWM techniques are available, like Sinusoidal, multiple sinusoidal, 60° modulation etc. Here, sinusoidal PWM technique is used for controlling the speed of BLDC motor, because it is easy and less time consuming. This paper introduce speed control of BLDC motor has been achieved through variation of duty cycle. Simulation result is verified with FPGA (Field Programming Gate Array) based hardware.

## II. BLDC MOTOR: AN INTRODUCTION

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, which reduces the mechanic losses and improves the efficiency. Replacing the inefficient motors with more efficient BLDC motors will result in substantial energy savings. A BLDC has several advantages over other machine types. Most notably they require lower maintenance due to the elimination of the mechanical commutator. It also has high power density. Compared to induction machines, BLDC motors have lower inertia, allowing for faster dynamic response to reference commands [2].

The major disadvantage with permanent-magnet motors is their higher cost and relatively greater degree of complexity introduced by the power electronic converter used to drive them. 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. This is achieved by altering the duty cycle of the base PWM signal.

The use of PWM in power electronics to control high energy with maximum efficiency & power saving is not new but, interesting is to generate PWM signals using HDL and implementing it in FPGA. FPGAs are increasingly being used in motor control applications due to their robustness and customizability [3]. Microcontrollers have typically been used to implement motor controls, with computation algorithms executed by software. Some of the challenges in this implementation are response time, a fixed number of PWM channels, limited communication interfaces and pre-determined analog triggering.

## III. FIELD-PROGRAMMABLE GATE ARRAY

The Field Programmable Gate Array (FPGA) is an integrated circuit designed to be configured by a customer or a designer after manufacturing hence "field programming". The FPGA configuration is generally specified using a hardware description language (HDL), similar to that used for an application specific integrated circuit (ASIC)[3][4].The generic architecture of an SRAM-based FPGA as shown in Fig.1

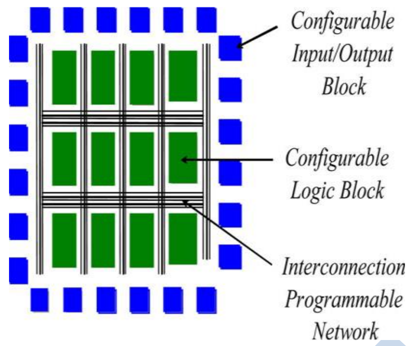



Fig. 1 Architecture of an SRAM-based FPGA

Nowadays, the FPGA technology received much attention by industrial researchers for designing and implementing high-performance ASIC digital controller.

## IV. INTELLIGENT POWER MODULE (IPM)

IPM based power module works as DC-DC Converter (Chopper) or DC-AC Converter (Inverter). It uses IGBT switches and works on the basis of software from DSP Processor. The power module can be used for studying the operation of chopper, three phase inverter, single phase inverter and speed control of all kind of motors.

IPM is an advanced hybrid power devices that combine high speed, low loss IGBTs with optimized gate drive and protection circuitry. Highly effective over-current and short-circuit protection is realized through the use of advanced current sense IGBT chips that allow continuous monitoring of power device current.

## V. DRIVE STRATEGY

BLDC motor have two types of driving strategies namely, uni-polar and bipolar drives. A three-phase (brushless) motor is driven by a three-phase bridge circuit, comprising of IGBTs as shown in Fig 2. The efficiency, which is the ratio of the mechanical output power to the electrical input power, is the highest, since in this drive an alternating current flows through each winding as an ac motor. This drive is often referred to as bipolar drive. Here, 'bipolar' means that a winding is alternatively 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, hall sensors, and optical sensors are used in sensor based techniques [5].The EMF can have a trapezoidal or sinusoidal waveform.

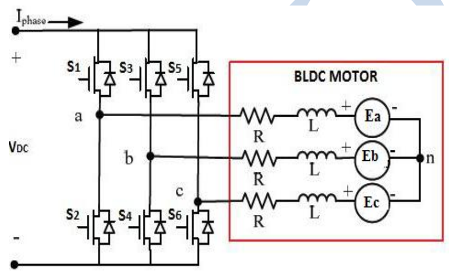



Fig. 2 Equivalent circuit of a BLDC motor connected to an inverter

Typical back EMF waveforms for a three-phase BLDC motor with trapezoidal flux distribution as shown in Fig.3.

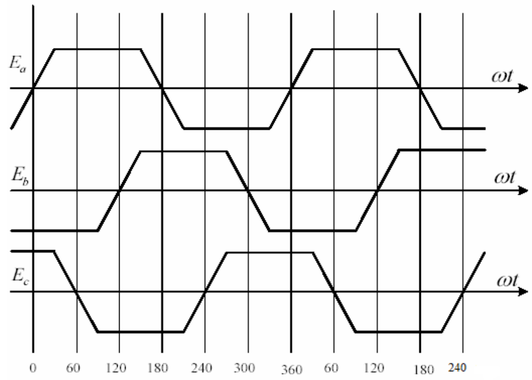



Fig. 3 Trapezoidal back EMF of three phase BLDC motor

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,

$$V_a = R_a I_a + L\left(\frac{dI_a}{dt}\right) + E_a \quad \text{.........................} \quad \text{..........} \quad (1)$$

$$V_b = R_b I_b + L\left(\frac{dI_b}{dt}\right) + E_b \quad \text{..............................} (2)$$

$$V_c = R_c I_c + L\left(\frac{dI_c}{dt}\right) + E_c \quad \text{...............................} (3)$$

Where,

$V_a, V_b, V_c$ are the phase voltage

$I_a, I_b, I_c$ are the phase current

$E_a, E_b, E_c$ are the back EMFs

The back EMFs can be expressed as,

$E_a = K_e \omega_m F(\theta_e)$ ......................................(4)

$E_b = K_e \omega_m F(\theta_e - \frac{2\pi}{3})$ .............................. .....(5)

$E_c = K_e \omega_m F(\theta_e + \frac{2\pi}{3})$............................................ (6)

Where,

$\omega_m$ is Angular speed of rotor.

$\theta_m$ is Mechanical angle of rotor.

$\theta_e$ is Electrical angle of rotor.

$F(\theta_e)$ is Back –EMF reference function of rotor position.

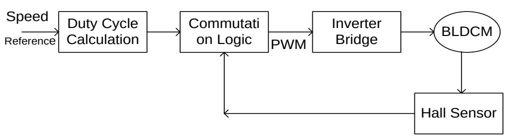



Fig. 4 Open Loop control of BLDC Motor

In this paper we consider that the rotor information is being collected using hall sensors. The Hall position sensors are placed 120 degree apart and they sense the actual rotor position.

## VI. CONTROL STRATEGY

PWM technique is one of the most popular speed control techniques for BLDC motor. In this technique a high frequency chopper signal with specific duty cycle is multiplied by switching signals of VSI. Therefore it is possible to adjust output voltage of inverter by controlling duty cycle of switching pulses of inverter [6]. The disadvantages of analog methods are that they are prone to noise and they change with voltage and temperature change. Also they suffer changes due to component variation [7].They are less flexible as compared to digital methods. PWM signals are generated from the Spartan-3A processor by writing VHDL program to control the inverter switches. The principle of generating PWM waveform is shown in Fig 5. Counter is used to generate triangular wave [6]. The value of compare register is compared with triangular wave. If the value of compare register is less than the value of triangular wave, then PWM is '1', else PWM is '0' [8].

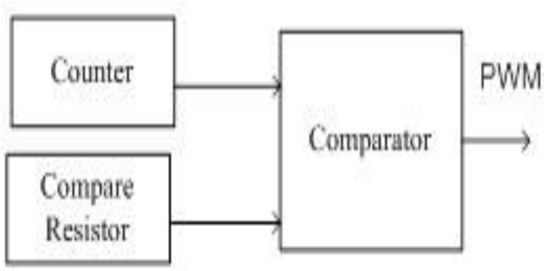



Fig. 5 PWM Generation Logic

## VII. SIMULATION RESULTS & EXPERIMENT VERIFICATION

Speed control of BLDC motor using variation of duty cycle, is shown in fig 6. Average output voltage is controlled through duty cycle of PWM. The relationship between average output voltage, duty cycle and input voltage is,

$V_{avg} = D\, V_{input}$.............................................................. (7)

Where,

D = Duty cycle

$V_{avg}$ = Average output voltage

$V_{input}$ = Input DC voltage

Table-I Experiment Parameters

| | | |
|---|---|---|
| Terminal voltage | Volts DC | 310 |
| Rated current | Amps | 4.52 |
| No of Poles | | 4 |
| Rated torque | N*m | 2.2 |
| Resistance | Ohms | 3.07 |
| Inductance | mH | 6.57 |
| Rotor inertia | Kg*m | 1.4-1.8 |
| IPM Module | PEC16D5M01 | |
| SPARTAN 3A KIT | FPGA | |
| Voltage Constant | Volts | 5 |
| Torque Constant | N*m | 0.49 |
| Auto Transformer Current Rating | Amps | 4 |

Table-II Clockwise sensor and Drive

| Sensor | | | Clockwise Direction | | | | | |
|---|---|---|---|---|---|---|---|---|
| HA | HB | HC | S1 | S2 | S3 | S4 | S5 | S6 |
| 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 |
| 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 |
| 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 |
| 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 |

Fig. 7 and 8 show stator current and back EMF of BLDC motor respectively. Three phase stator currents $(I_a, I_b, I_c)$ and back EMFs $(E_a, E_b, E_c)$ are 120° phase shifted with respect to each other. Back EMF is constant for each 60° interval. In Fig. 7 and Fig. 8, the stator current is 5.8A and the back EMF is 49V. Fig. 9 shows the rotor speed of BLDC motor at a rated torque; the speed is 1950 rpm.

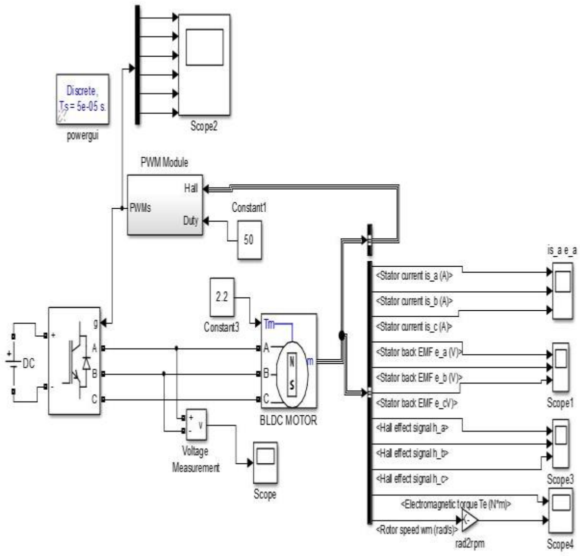



Fig. 6 Simulink diagram of BLDC motor

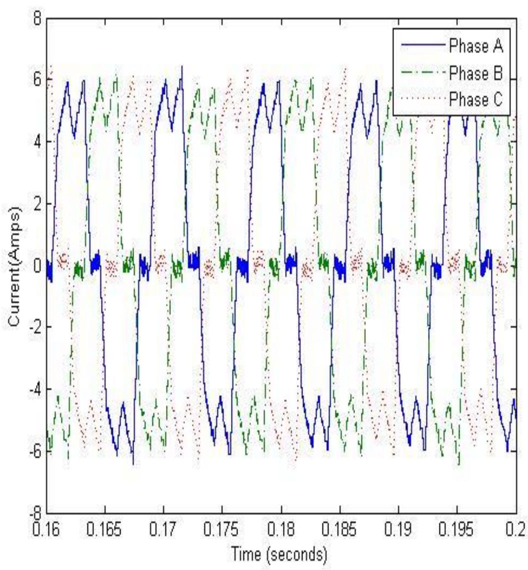



Fig. 7 Stator current of BLDC motor

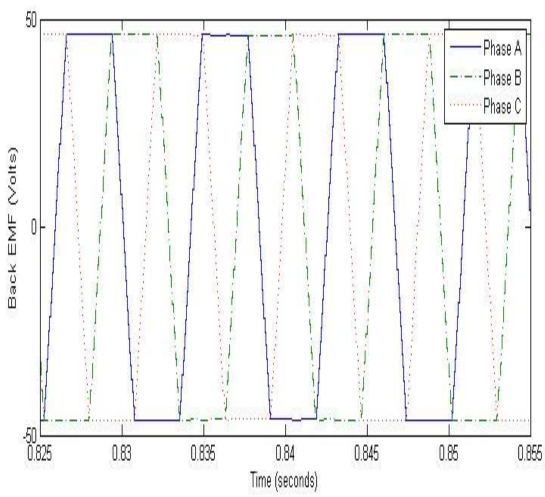



Fig. 8 Back EMF of BLDC motor

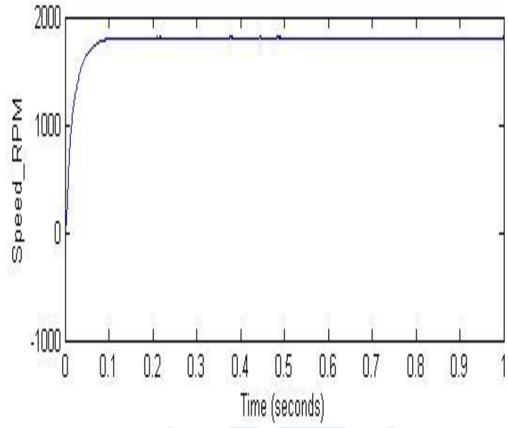



Fig. 9 Rotor speed of BLDC motor

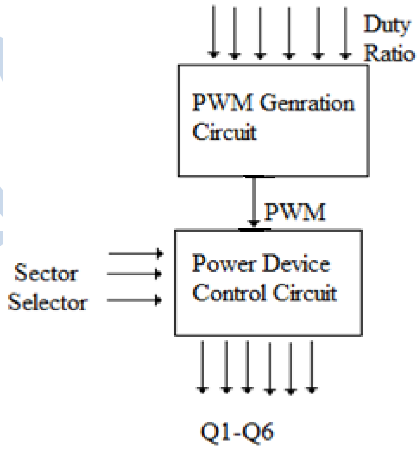



Fig.10 Block digram of FPGA implemation

Fig.10 shows the block diagram of software implementation of PWM technique. The block diagram includes two main parts; "PWM Generation Circuit", and other one is " Power Device Control Circuit".

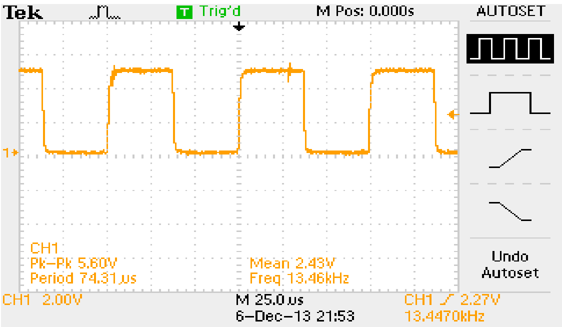
$$F_{pwm} = \left(\frac{F_{clock}}{2^N}\right) \qquad (8)$$

Where,

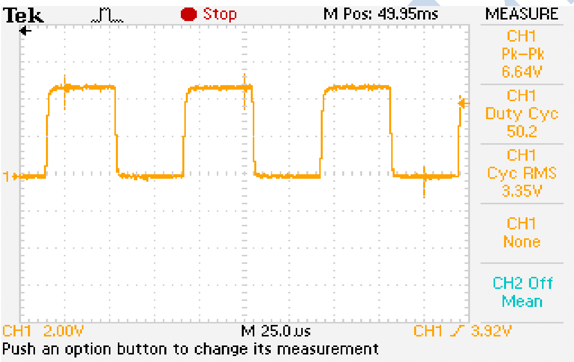
$F_{pwm}$ = pwm frequency
$F_{clock}$ = clock frequency
$N$ = resolution

For instance, 8-bit resolution and 100 KHz PWM frequency, then clock frequency is 25.6MHz. Fg.11 Shows the experiment setup for speed control of BLDC motor through FPGA kit.

Fig. 11 Pictorial view of experiment setup of BLDC motor

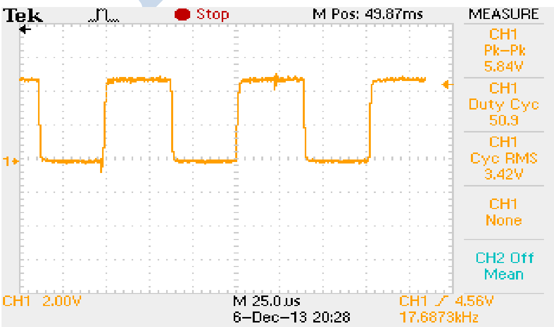



A

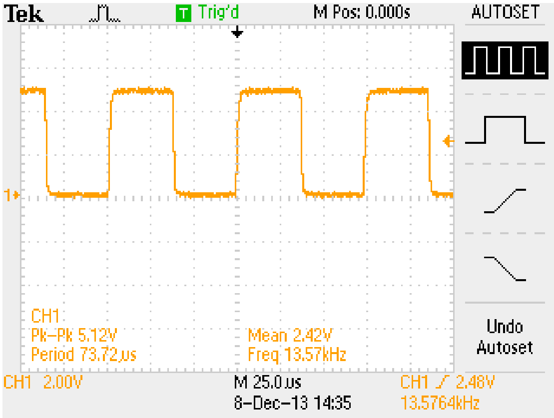



B

Fig. 12 PWM waveform capture on DSO




A




B

Fig.13 Hall sensor waveform capture on DSO

Fig. 12 & 13 shows the PWM and hall sensor waveform capture on DSO respectively.

Table - III Summary of the experiment result

| Sr.No | Duty Cycle (%) | Speed (RPM) |
|---|---|---|
| 1 | 15 | 1100 |
| 2 | 30 | 1600 |
| 3 | 50 | 1950 |
| 4 | 65 | 2300 |
| 5 | 80 | 2550 |

## VII CONCLUSION

This paper demonstrates the use of an efficient and lower cost controller based on FPGA programming to control the speed of BLDC motor. Due to the simplistic nature of this control, it has the potential to be implemented in a low cost application. The simulation results and that verified through experiment demonstrated the effectiveness of sinusoidal PWM technique for speed control of BLDC motor and its practical applications.

## VIII ACKNOWLEDGEMENT

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