International Journal of Research in Science and Technology http://www.ijrst.com

(IJRST) 2016, Vol. No. 6, Issue No. II, Apr-Jun e-ISSN: 2249-0604; p-ISSN: 2454-180X

FPGA BASED DIGITAL PWM SPEED CONTROLLER FOR 3 PHASE INVERTER FED BLDC MOTOR

A.Deepa, D.Shanmugavel, S.Deepika, M.Kalidasan, S.Mohanram

Department of E.E.E,

Pollachi Institute of Engineering and Technology

Pollachi, Coimbatore, India

ABSTRACT

Field programmable Gate Arrays are extensively used in the field of Industrial Automation especially in Speed control of BLDC motor for its hardware design flexibility. This paper discusses the digital Pulse Width Modulation (PWM) control implemented in FPGA for a BLDC drive in motoring mode of operation. The design and simulation of closed loop control system using PID algorithm is done on Xilinx Spartan 3E FPGA kit. The system controls the speed of three phase BLDC by using feedback from hall sensors. Simulations are done using VHDL with Modelsim software.

Keywords: BLDC motor, Speed Control, Modelsim, VHDL, PID, FPGA

INTRODUCTION

Brushless DC (BLDC) motors dominate their brushed counterparts and are used nowadays extensively for the advantages they offer. Good efficiency, high torque to weight ratio, reduced noise, elimination of sparks from commutator, and lower susceptibility to mechanical wear are the prominent advantages of using BLDC motors.

The above said advantages come at the cost of complex electronic controller design and shaft position sensing using sensors. Electronic commutation of Brushless motors can be implemented on FPGA as it provides good flexibility, reconfigurable computing, higher resources for implementing control algorithms and on-chip parallelism. The Hall Effect sensor gives feedback about the position of the rotor to the control circuitry.

Mostly BLDC motors have three Hall sensors inside the stator. Hall-effect sensors are embedded into the stator every 120° to sense the rotor position. The Hall sensor give a high / low signal whenever the rotor magnetic poles pass near them indicating the N or S pole is passing. The Hall Sensor Decoder in the FPGA uses the combination of these three Hall sensor signals, to determine the exact sequence of commutation.

The electronic controller, based on the Hall Sensor decoder output, in turn controls the flow of current in a phased sequence to stator windings in order to produce required torque and speed and ensures that the motor runs at peak efficiency. The frequency at which the current is switched determines the brushless motor's velocity and not on the voltage, hence current controlled technique is used.

The paper is arranged as follows. The three phase commutation of BLDC motor is explained in Section 2. Section 3 gives detailed explanation of PID algorithm. Section 4 describes the implementation of PID Algorithm in FPGA to control the speed of motor. The simulation and validation results of the implemented design can be found in Section 5. Section 6 gives the conclusions and references are listed in Section 7.

ELECTRONIC COMMUTATION OF THREE PHASE MOTOR

Figure 1 shows the electronic commutation arrangement of BLDC motors. The Brushless motors, are driven by three phase Bridge which comprises of six Transistor/MOSFETs/IGBTs. The stator windings are 120° apart and connected either in Star or Delta fashion. In the bridge, one branch is provided a constant voltage (signals PWM A, PWM B & PWM C) and in the other branch PWM pulses (signals PWM $\bar{A}$, PWM $\bar{B}$ & PWM $\bar{C}$) are applied.

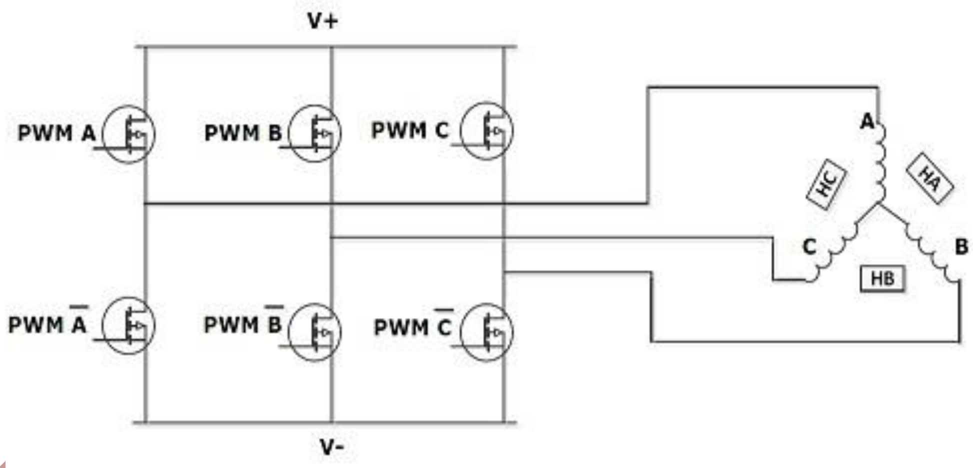

Figure 1: Bridge Circuit of Motor Driver

Hall sensors placed on the non-driving end of the stator detect the position of rotor and their outputs exactly 120 degree apart from each other, along with each terminal phase sequence is shown in Figure 2.

(IJRST) 2016, Vol. No. 6, Issue No. II, Apr-Jun **e-ISSN: 2249-0604; p-ISSN: 2454-180X**

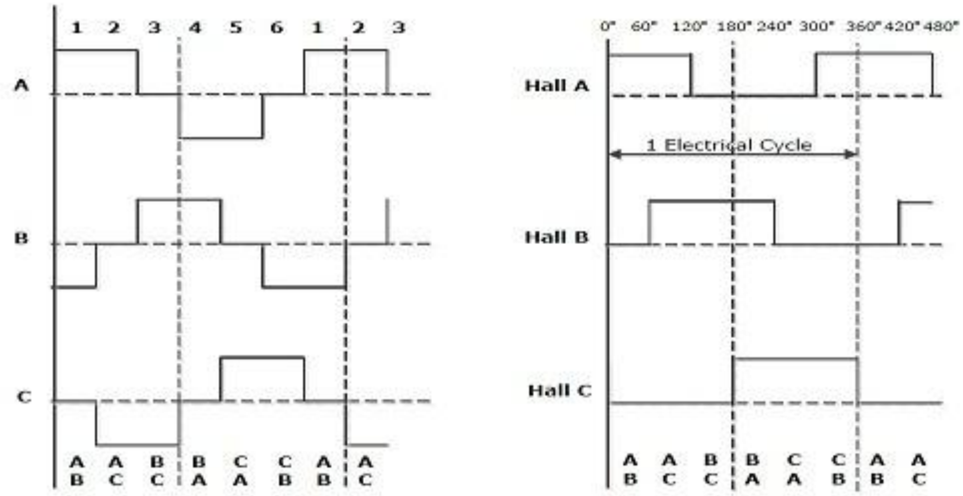

Figure 2: Three Phase commutation and Hall Sensor outputs

When a three-phase BLDC motor is driven by a three-phase bridge circuit, comprised of either MOSFETs or IGBTs, the efficiency is the highest, since in this drive an alternating current flows through each winding as in ac motor. This drive is effectively a bipolar drive because the stator winding is energized in the south and north poles alternatively. The bipolar driving strategy includes sensor technique and uses Hall sensors.

PID ALGORITHM

In closed loop method of speed control as shown in Figure 3, the actual motor speed is tracked and is compared with the reference speed and motor speed is controlled by updating the PWM duty cycle. System stability and reduced sensitivity for dynamic load variations are the main advantages of closed loop method.

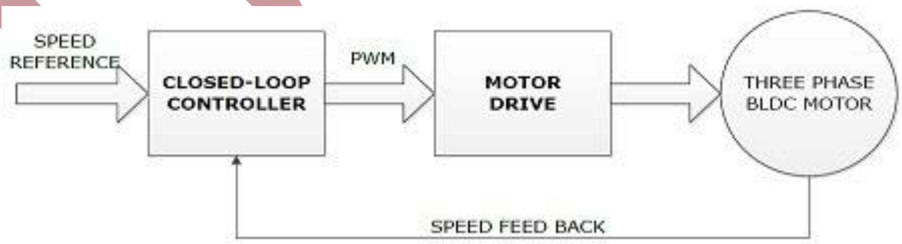

Figure 3: Closed Loop control method

PID (Proportional Integral Derivative) shown in Figure 4 is the most widely used controller in closed-loop control system to ensure constant brake torque. The error difference between the actual speed and the reference speed is calculated and given as an input to PID controller.

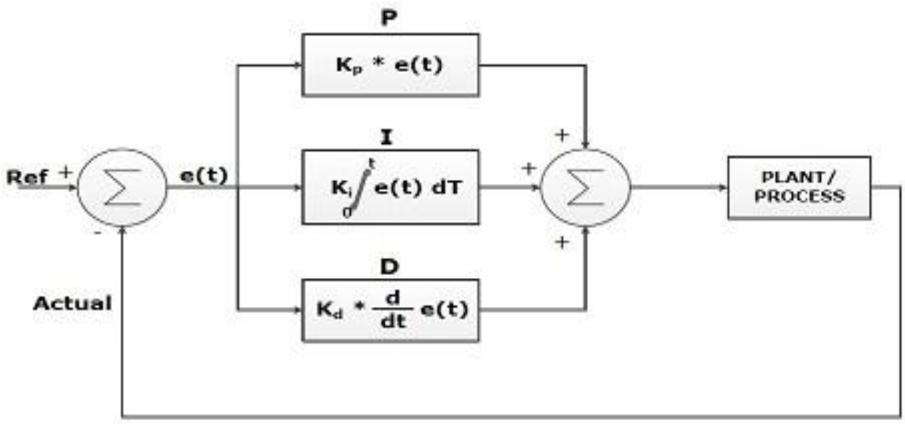

Figure 4: Block diagram of a system with PID Controller and feedback loop

PID controller works on following equation:

$$u(t) = K_p * e(t) + K_i \int_0^t e(t)\, dT + K_d * \frac{d}{dt} e(t) \qquad (1)$$

Where, Error - e(t), Proportional gain - K_p, Integral Gain - K_i, Derivative Gain - K_d

PID parameters affect system's overall performance. Tuning of PID controller, i.e. proper values for parameters (K_p, K_i, K_d) is done by using several tuning methods like manual tuning, Ziegler-Nicholas tuning, Tyreus Luyben tuning, Åström-Hägglund tuning and Cohen-coon tuning.

The effects of PID parameters (K_p, K_i, and K_d) are:

- K_p reduces System Rise time and provides faster response in variable load condition
- K_i reduces the Steady state error, hence the motor speed is pushed near to reference speed
- K_d reduces the Settling time and overshoot, hence provides faster response.

For digital implementation of equation (1), discrete time transformation is required. Laplace transform and then z transform is applied on each individual term, to achieve the discrete form. Table 1 lists the transformation for each individual term.

Table 1: PID Transformations

Term	Time Domain Equation	Laplace Transformation	Z Transformation (Discrete time transformation)
Proportional (P)	$u(t) = K_p * e(t)$	$u(s) = K_p * e(s)$	$u(z) = K_p * e(z)$
Integral (I)	$u(t) = K_i \int_0^t e(t)\, dT$	$u(s) = \frac{K_i}{s} * e(s)$	$u(z) = \frac{K_i}{(1-z^{-1})} * e(z)$
Derivative (D)	$u(t) = K_d * \frac{d}{dt} e(t)$	$u(s) = K_d * s * e(s)$	$u(z) = K_d * (1-z^{-1}) * e(z)$

By replacing values of z transformations from table 1 to equation (1), we get

$$u(z) = \left[\frac{(K_p + K_i + K_d) + (-K_p - 2K_d) * z^{-1} + K_d * z^{-2}}{(1-z^{-1})} \right] * e(z) \quad (2)$$

By converting equation (2) in to difference equation, we get following equation (3), which is implemented with basic digital blocks of adders and multipliers in FPGA.

$$u(k) = u(k-1) + (K_p + K_i + K_d) * e(k) - (K_p + 2K_d) * e(k-1) + K_d * e(k-2) \quad (3)$$

PID controller works on the error and PWM Generator based on the error produces pulses of varying duty cycle to three phase Inverter. The speed regulation of motor is done with PID controller algorithm written using VHDL and dumped in the FPGA. When the motor runs, the hall sensor captures the rotor position and produces signals correspondingly. Hall Sensor decoder receives hall sensor output from BLDC motor.

Actual motor speed is compared with the reference speed provided and the error signal is processed in a PID controller to obtain the required pulse width. The generated gate pulses are used to drive the IGBT switches of the three phase bridge circuit. The gates of the IGBT switches produce three phase voltages after they receive the decoded signals. The produced voltages are fed as input to the motor to make it rotate at required speed and thus speed control of the brushless motor is achieved.

IMPLEMENTATION OF PID ALGORITHM

PID algorithm based closed loop speed control system is implemented using Xilinx Spartan3E. Figure 5 shows the block diagram for implementation.

A. Hall Sensor Decoder

Different combination of hall inputs will be available based on rotor position. Hall input's combinations will repeat in successive manner for an electrical cycle as shown in Figure 2. By

(IJRST) 2016, Vol. No. 6, Issue No. II, Apr-Jun **e-ISSN: 2249-0604; p-ISSN: 2454-180X**

decoding the sequence of hall sensors, we will get information about change in electrical cycle as well as the commutation sequence.

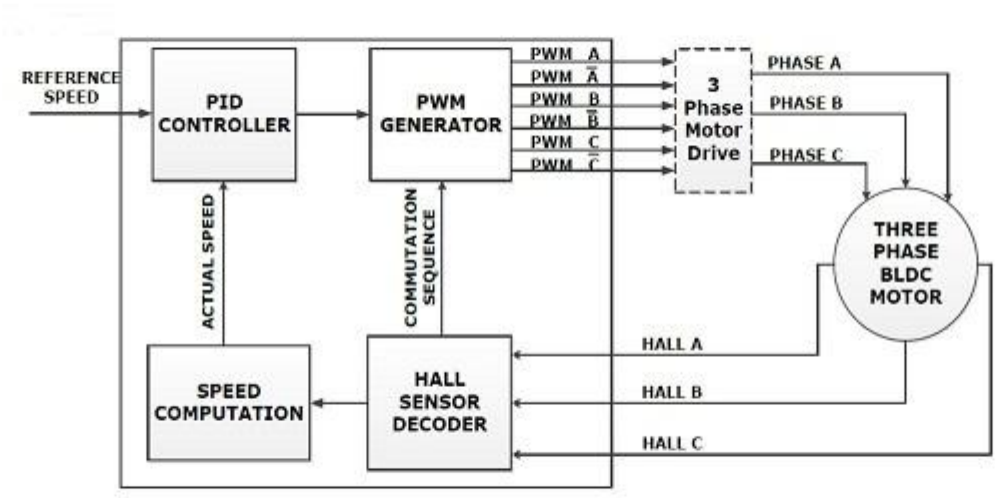

Figure 5: Implementation block diagram

B. **Speed Computation**

Actual speed of motor is calculated based on electrical cycles. An electrical cycle has direct relation with RPM (Revolution Per Minute) of motor, as an example for single pole motor, one electrical cycle represent one revolution (1 RPM) of motor.

C. **PID Controller**

As described in section 3, PID algorithm is simplified to Equation (3) and is digitally implemented with use of multipliers and adders. PID processes the incoming error per electrical cycle. For implementation of this motor control application, the tuning of the PID parameter values (K_p, K_i and K_d) are derived from a mathematical model.

D. **PWM Generator**

The speed of motor is controlled by varying the motor torque. Motor Torque can be varied by changing average voltage across the motor windings. For varying average voltage across the windings the PWM method is used where the duty cycle of wave is varied according to require speed. The variation of applied PWM wave is based on hall sensor decoder output to recognize which phase is to be energized. Here, on one branch; level signal is applied (PWM Ā, PWM B¯& PWM C¯) and on another branch PWM signal is applied (branch PWM A, PWM B and PWM C) which is shown in Figure 6.

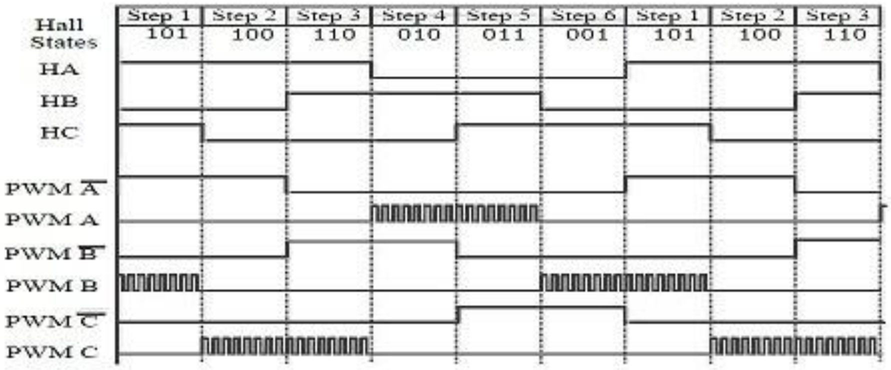

Figure 6: Commutation sequence based on Hall Sensor

The Flow Chart for VHDL coding is shown in Figure 7.

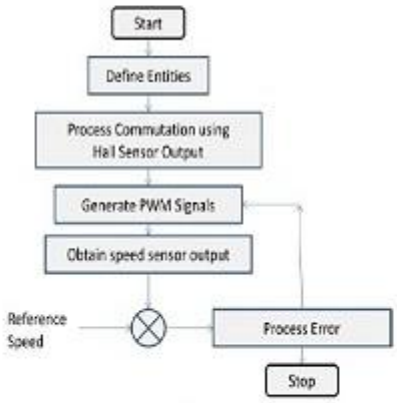

Figure 7: Flow Chart

SIMULATION RESULTS

Figure 8 represents simulated waveform for FPGA control logic integrated in system. H_a, H_b and H_c the hall sensor inputs and reference speed are the test inputs provided through test bench. PID continuously processes the input error at every electrical cycle and based on PID output PWM waves are generated for the three phase windings.

Figure 8: Simulation results

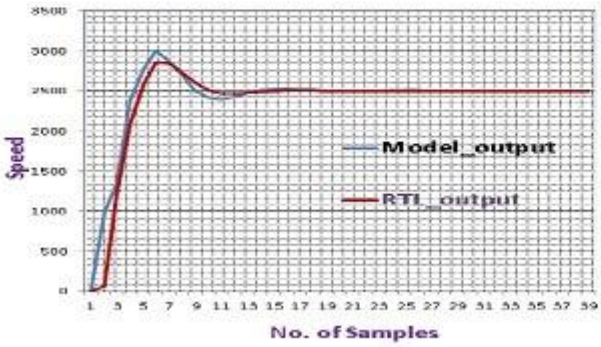

Figure 9: Model output vs RTL Implementation output

Digital FPGA based implementation with integer arithmetic produces response very close to mathematical model response as shown in Figure 9. The Table 2 shows the ac voltage, current, input power, efficiency of the machine under different load conditions.

Table 2

V (Volt)	I (Amp)	Power (Watt)	Efficiency	Torque (N-m)	Power (Watt)	PF	Speed (rpm)
230	0.831	130.3	80.92	0.489	103.4	0.89	2000
230	0.976	159.8	86.80	0.710	137.7	0.90	1995
230.4	0.994	186.9	83.90	0.799	159.3	0.902	1839
230.4	1.011	202.11	85.70	0.902	175.4	0.925	1795
229	1.137	241.7	86.80	1.200	250.4	0.955	1675
230	1.359	290.9	85.82	1.738	297.7	0.936	1579
230.7	1.583	344.5	86.76	1.987	320.9	0.959	1474
230.2	1.720	375.8	85.30	2.310	343.9	0.950	1339
230	1.827	399.9	84.45	2.510	367.3	0.964	1239
230.1	1.868	430	83.22	2.890	377.8	0.958	1224
230.4	2.08	450.7	81.46	2.99	389.7	0.954	1219
0.5	2.145	470.8	77.30	3.153	389.5	0.943	1189
230.1	2.250	495.5	72.96	3.396	389.2	0.967	1098

From Table 2, it has been understood that by varying the load the efficiency increases speed reduces, Power factor increases but after certain percentage of loading the speed decreases marginally, efficiency reduces, input current increases.

CONCLUSION

Through this paper, Hall sensors based closed loop implementation for speed control of BLDC motor is discussed. The PID 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. Simulation results of implemented PID based BLDC motor controller shows accurate results. Use of PID in the closed loop implementation minimizes torque ripples and adds efficiency and stability to systems. The FPGA based implemented motor controller can be used for system critical applications where the system stability and motor speed accuracy are the determining factors. PID controllers implemented on FPGAs improves speed, accuracy, power-efficient, compactness and cost effectiveness when compared to other techniques.

REFERENCES

[1]. K. Giridharan, Gautham.R, "FPGA Based Digital Controllers for BLDC Motors", IJERA, Vol. 3, Issue 2, March -April 2013, pp.1615-1619.

[2]. Alecsa, B.; Onea, A.;, "Design, validation and FPGA implementation of a brushless DC motor speed controller," *Electronics, Circuits, and Systems (ICECS), 2010 17th IEEE International Conference on*, vol., no., pp.1112-1115, 12-15 Dec. 2010.

[3]. Jiancheng Fang; Xinxiu Zhou; Gang Liu; , "Instantaneous Torque Control of Small Inductance Brushless DC Motor," *Power Electronics, IEEE Transactions on* , vol.27, no.12, pp.4952-4964, Dec. 2012.

[4]. Nikola Milivojevic, Mahesh Krishnamurthy, Yusuf Gurkaynak, Anand Sathyan, Young-Joo Lee and Ali Emadi,"Stability Analysis of FPGA-Based Control of Brushless DC Motors and Generators Using Digital PWM Technique. *IEEE Trans. Ind. Electron.*, vol. 56, no. 8, pp.3040-3049, Aug.2011.

[5]. Microsemi "Speed Control of Brushless DC Motors-Sinusoidal Commutation with Hall Sensors" user guide.

[6]. Patella, A. Prodic, A. Zirger,D. Maksimovic. High Frequency digital PWM controller IC for DC-DC converters, IEEE Transaction on Power Electronics 18 (2003) 438-446.

[7]. JayaramBhasker, "VHDL-Primer", 3rd Edition Pearson Prentice Hall, 1999.

[8]. EftichiosKoutroulis, ApostolosDollas, Kostas Kalaitzakis, "High-frequency pulse modulation implementation using FPGA and CPLD IC‟s", Elsevier journal of system architecture, October 2005.

[9]. Nalin Kant Mohanty, Ranganath Muthu, "A Novel Implementation of Xilinx FPGA Based Four Switch Three Phase IGBT Inverter Fed Induction Motor Drive Using PWM" European Journal of Scientific Research- Euro Journals Publishing,

Inc. 2011, Vol.48 No.3 (2011), pp.424-433.