Simulation and Implementation of Sensored Control of Three-Phase BLDC Motor Using FPGA

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Abstract -Three-phase BLDC motors are widely used for industrial applications that require medium and very high speeds and it is mostly preferred for electric vehicles as it provides high efficiency, low maintenance, long life, low weight and compact construction. This paper presents the implementation of sensored control of three-phase brushless DC motor using FPGA. The commutation is implemented using FPGA and it receives hall sensor output from BLDC motor (1KW) and generates the gate pulses which drive the IGBT switches of the three-phase inverter. A model of the BLDC drive is simulated in MATLAB and the sensored control is implemented on a FPGA platform. The simulation results are verified experimentally.

Keywords: Brushless dc motor, Field programmable gate array, Voltage source inverter

I. INTRODUCTION

Brushless dc motors have been widely used in industrial automation and consumer appliances because of their higher efficiency and power density. BLDC motor has permanent magnets in rotor assembly to generate steady state magnetic field, due to this it is advantageous compared to induction motors [1, 2]. Brushless dc motors, with their trapezoidal electromotive force profile, requires six discrete rotor position information for the inverter operation. These are typically generated by Hall-effect switch sensors placed within the motor.

Hall-effect position sensors typically provide the position information needed to synchronize the stator excitation with rotor position in order to produce constant torque. [3, 4] The rotor magnets are used as triggers for the Hall sensor.

MATLAB/SIMULINK is used for the implementation of the brushless dc motor circuit model and sensored control is implemented using FPGA. The simulation results are verified experimentally.

II. SENSORED CONTROL OF BRUSHLESS DC MOTOR

Brushless DC motor has a permanent magnet rotor and a wound field stator and which is connected to a power electronic switching circuit. The brushless DC motor drive system is based on the rotor position, and it is obtained at fixed points typically every 60 electrical degrees for six-step commutations of the phase currents. The brushless DC motor drives have higher efficiency, less maintenance cost, less noise and simple compact construction. In a brushless DC motor, the permanent magnets produce an air gap flux density distribution that is of trapezoidal shape waveform, and result in trapezoidal back-EMF waveforms [5, 6].

Brushless DC motors use electric switches to realize current commutation, and thus continuously rotate the motor. These electric switches are usually connected in a three-phase bridge structure for a three-phase BLDC motor. There are two types of control technique for using BLDC drive system. These are position sensor control and position sensor less control but this paper insists on a position sensor control technique [7, 8]. The block diagram is shown in Fig.1.

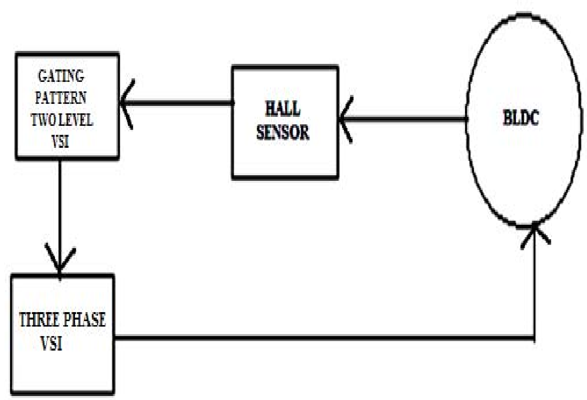

Figure.1: sensored control of three-phase brushless DC motor

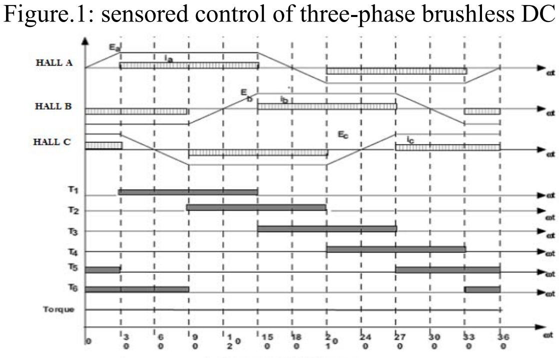

Figure.2: BLDC motor drive along with typical phase current and hall signal.

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A three- phase BLDC motor requires three Hall sensors to detect the rotor's position. Based on the physical position of the Hall sensors, there are two types of output: a 60° phase shift and a 120° phase shift. Combining these three Hall sensor signals can determine the exact commutation sequence [9, 10].

The commutation sequence of a three-phase BLDC motor driver circuit for counter-clockwise rotation. Figure 2 shows that the BLDC motor drive along with typical phase current and hall signal. Three Hall sensors A, B, and C are mounted on the stator at 120° intervals, while the three phase windings are in a star formation. For every 60° rotation, one of the Hall sensors changes its state; it takes six steps to complete a whole electrical cycle. In synchronous mode, the phase current switching updates every 60°.However, one signal cycle may not correspond to a complete mechanical revolution [11].

The number of signal cycles to complete a mechanical rotation is determined by the number of rotor pole pairs. Every rotor pole pair requires one signal cycle in one mechanical rotation. So, the number of signal cycles is equal to the rotor pole pairs.

Considering a BLDC motor with three stator phase windings connected in star. The BLDC motor is driven by a three-phase inverter in which the switches are triggered with respect to the rotor position.

III. SIMULATION RESULTS

The Simulink model of the sensored control three phase BLDC motor is shown in the

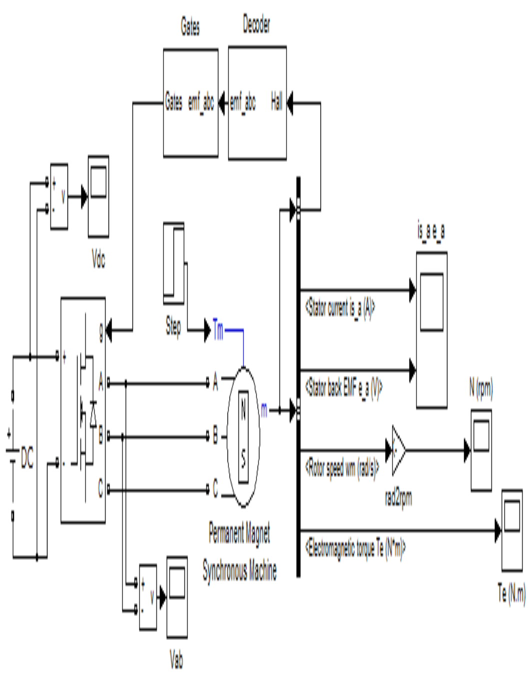

Figure .3: Simulink model of the sensored control three phase BLDC drive

Table 1 shows simulation parameter for three phase BLDC drive.

TABLE I. SIMULATION PARAMETERS THREE-PHASE VOLTAGE SOURCE INVERTER FED BLDC

Simulation parameters	**Values**
Three phase inverter	V_{in} = 60V
BLDC	P= 1KW, V= 36V, N=3000 rpm, T = 1.4 N/m

The simulated results (rotor speed, electromagnetic torque, stator current and back EMF) of brushless DC motor are shown in Figures [4-7] respectively.

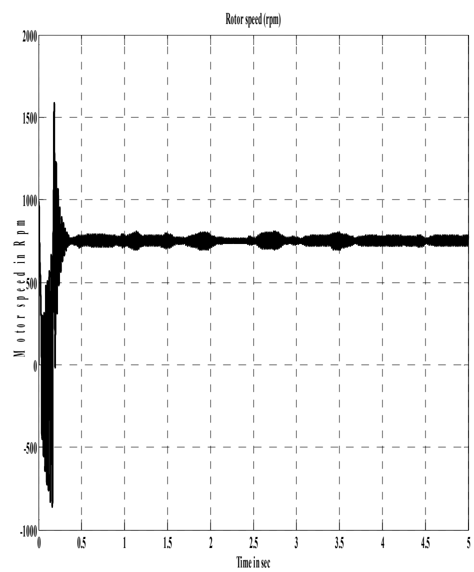

Figure.4: Rotor speed for three phase BLDC drive.

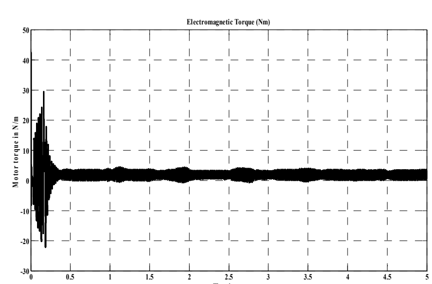

Figure.5: Motor torque for three phase BLDC drive.

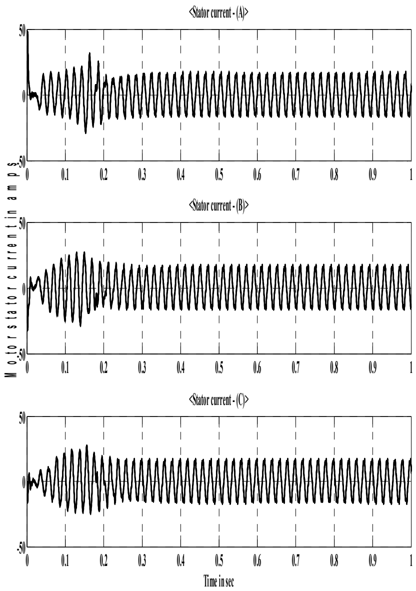

Figure.6: Stator current for three phase BLDC drive.

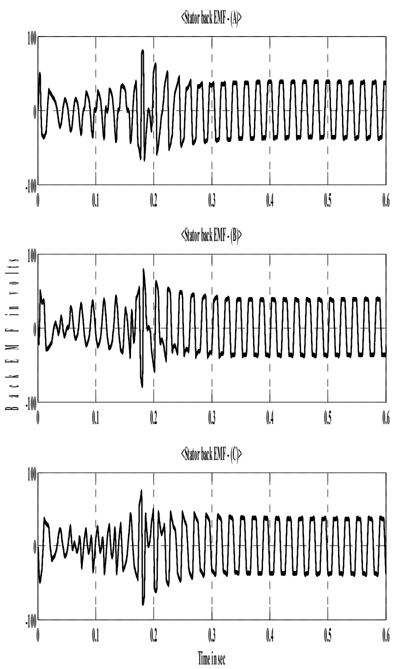

Figure.7: Back EMF for three phase BLDC drive.

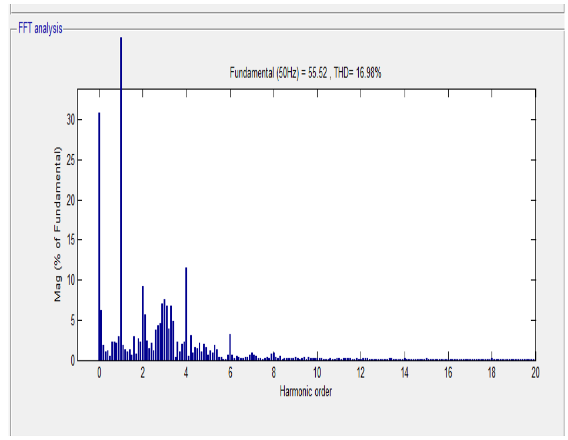

Figure.8: Stator current T.H.D for three phase BLDC drive

Figures 5 & 6 show that the BLDC motor speed is settled at 800 rpm and the BLDC motor torque is about 5 N/m. Figures 7 & 8 show that the BLDC motor stator current is about 15 Amps and the BLDC motor back emf voltage is about 40 Volts.Fig.8 shows that the stator current T.H.D of three phase BLDC drive which is about 16.96%.

IV. HARDWARE IMPLEMENTATION FOR THREE-PHASE VOLTAGE SOURCE INVERTER WITH BLDC DRIVE SYSTEM

The hardware prototype of the proposed three phase voltage source inverter is developed using IGBTs as power device, along with isolation and driver circuit etc. The gating pulses were obtained from a Xilinx-FPGA SPARTAN 3E whose input is supplied from the hall sensors. The hardware set-up for three phase voltage source inverter fed BLDC with FPGA is shown in Fig.9.

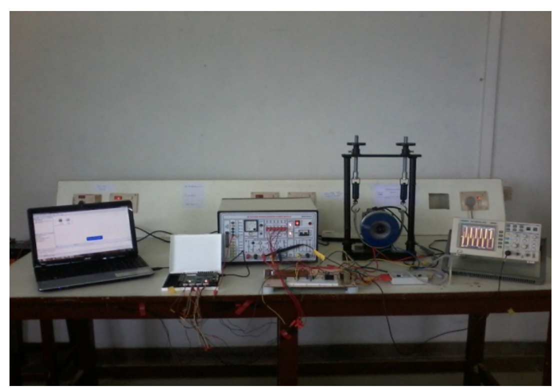

Fig.9.Hardware set-up for three phase VSI fed BLDC with FPGA

V. FPGA IMPLEMENTATION

The hardware prototype presents the development of Xilinx-FPGA SPARTAN 3E as a control circuit for three-phase voltage source inverter. Six I/O lines of SPARTAN 3E are used as PWM output lines for three phase voltage source inverter output voltage. VHDL language is used to model the PWM switching strategies and Xilinx ISE 14.1 software is used as a simulation and compiler tool. Generation of PWM pulses is obtained with Xilinx-FPGA SPARTAN 3E board. The VHDL code successfully embedded in FPGA is shown in Fig. 10.

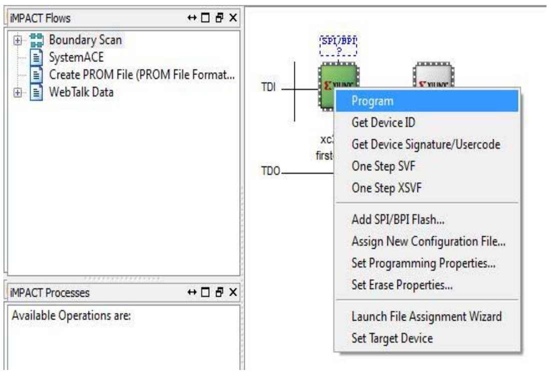

Fig.10. VHDL code successfully embedded in FPGA

Figs 11-13 show the phase voltage, line to line voltage and the difference in the line–line voltage of three-phase voltage source inverter.

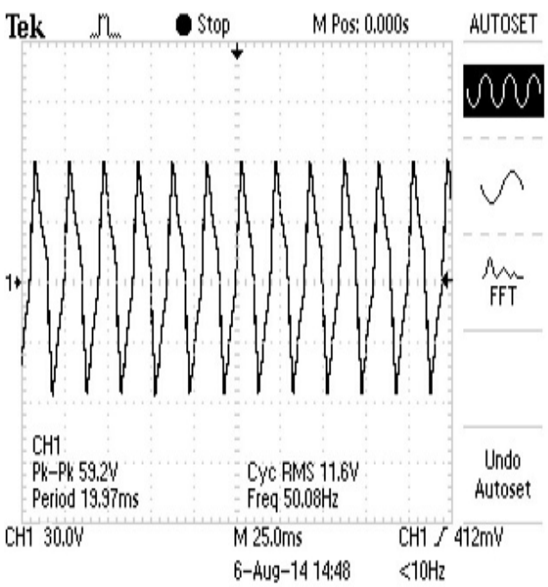

Fig.11.Output voltage of Three Phase VSI

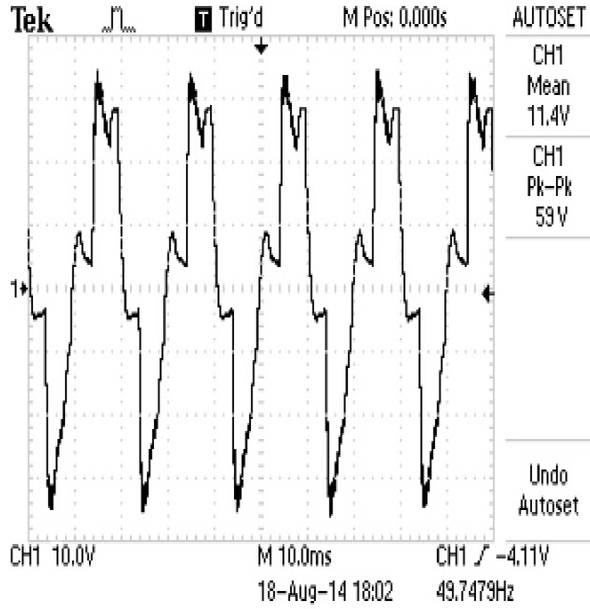

Fig.12.Line to line voltage of Three Phase BLDC drive.

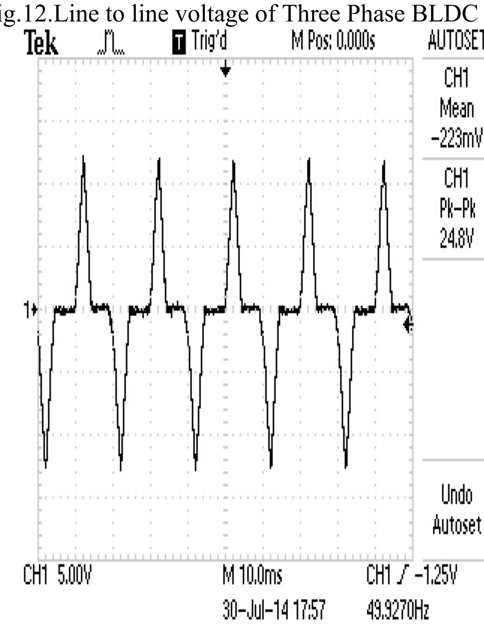

Fig.13.Line to line voltage difference of Three Phase BLDC drive.

VI. CONCLUSION

This paper has successfully presented the sensored control of BLDC motor using FPGA. By suitably developing the commutation logic in FPGA, appropriate phase and line to line voltage output was obtained for the three-phase voltage source inverter. Therefore, implementing the control using FPGA for a BLDC motor gives a better output and improved flexibility in design. The performance of the BLDC drive can be further improved by employing multilevel inverters.

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