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Lab View FPGA Implementation of Pi Controller Based BLDC Motor Drives

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ABSTRACT

This Paper presents a novel hardware design methodology of BLDC motor speed control system. Simulation studies are conducted with the effect of a sudden change in reference speed and load are also included. Finally, the proposed PI (Proportional-Integral) based BLDC motor drive system with a rating of 3 phase, 30V, 400W, 3000 RPM is implemented using Spartan 3 Field Programmable Gate Array (FPGA) from Xilinx. Flexible FPGA module allows easily reuse of code used in development process during actual hardware implementation. Programmed FPGA with Laboratory Virtual Instrument Engineering Workbench (LabVIEW) is developed. The superiority of the proposed scheme on the aspects of the speed parameters is demonstrated using Lab VIEW monitoring.

Keywords : PWM, PIcontroller, FPGA, Speed Control, Spartan-3E

I. INTRODUCTION

Many of the industrialized drives depend on electric motors for their production, therefore an efficient speed control of the motor is necessary. The essentiality of the BLDC motor and its application is felt strongly worldwide [1]. The development of PI control theories has already 60 years so far, however, this method is still extensively used now. PI-controller and its modifications are the most common controllers in the industry. It is robust and simple to design, its operation is well known, it has a good noise tolerance, it is inexpensive and it is commercially available. In a conventional PI controller, tuning of control gains namely proportional gain (k_p) and integral gain (k_i) of a speed control system is the adjustment of its control parameters like overshoot and settling time. It is always desirable to get the optimum process response. So, PI controller is used with manual tuning methods like Ziegler-Nichols method for proper tuning of control gains k_p and k_i and to adjust the system to desired response and to maintain the control loop closed [1]. The modelling of conventional PI controller is done by using Matlab/Simulink, and the performance analysis is made at the different reference speeds and at various loads. The dynamic conditions of the motor drive system have also been simulated. Lab VIEW FPGA module is used to design the whole system that

include analog capture circuit to take out the analog signals (set point and process variable) from the real world, PI controller module, and PWM signal generator module to drive the motor[2]-[4].The physical implementation of the digital system is based on Spartan-3E FPGA from Xilinx. This work is to focus on PI controller design to improve the speed performance of BLDC motor drive system at various set speeds and at different load conditions. Using Matlab/Simulink model, speed parameters of drive system is also analysed. It is realized with the help of Very high speed integrated circuit Hardware Descriptive Language (VHDL) programming algorithm of digital Pulse Width Modulation (PWM) generator topology [5, 6].

II. CONVENTIONAL PI CONTROLLER

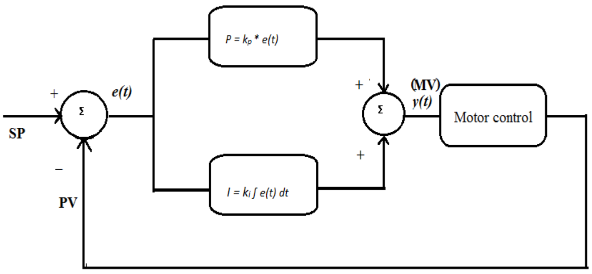


Fig1: Basic block of PI controller

The basic block of PI controller is shown in Fig1. The PI controller calculates an error value as the difference between a measured Process Variable (PV) and the desired Set Point (SP). The instantaneous value of controller output is given by

$$y(t) = MV = k_p e(t) + k_i \int e(t) \quad (1)$$

$$e(t) = SP - PV \quad (2)$$

where k_p is the proportional gain

k_i is the integral gain

e(t) is the instantaneous value of error

The PI controller can be modelled easily in Matlab/Simulink software using available tools like gain, summing block, subtraction block and integral block. Tuning the controller is necessary to get the optimum process response. There are several methods available for tuning the controller parameters. Here to adjust the system to the desired response, the parameters of controllers must be changed by the manual tuning methods like Ziegler-Nichols method for maintaining the closed loop system. Tuning the control gains k_p and k_i of a control system is the adjustment of its control parameters like overshoot, settling time to the optimum values for the desired control response.

III. SIMULATION

In BLDC motor drive, PI controller is used in speed control loop. Speed error is given as input to the PI controller. It determines the reference value of voltage V_{ref} to control the drive parameters. The controller gain in the PI controller is set as k_p=1and k_i=5 using Ziegler-Nichols method of PI tuning. Dynamic response of the drive is analysed, and it depends upon the reference voltage produced by the speed loop in PI controller of the drive system. The voltage reference from speed loop decides the PWM signal of a three phase inverter. Since the motor fed by the inverter, output voltage of the inverter decides the speed of the motor. The performance of the drive is analysed with various set speeds and various load conditions .Simulation model of BLDC motor drive using PI controller is shown in Fig 2.

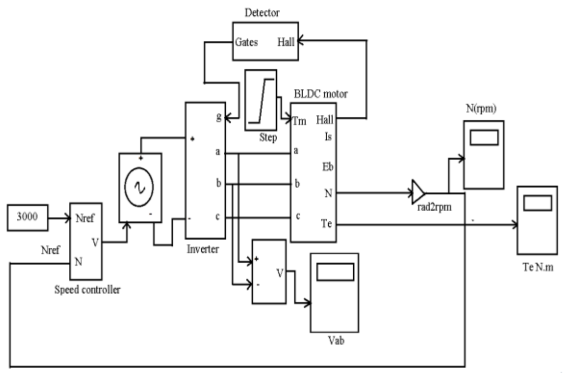
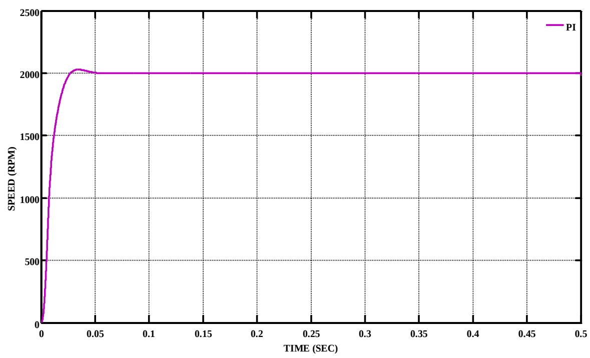


Fig2: Simulation model of BLDC motor drive drive using PI controller



FigError! No text of specified style in document.: **Speed responseof BLDC motor drive drive at no load using PI controller**

Speed response of BLDC motor drive at a reference speed of 2000 RPM is shown in Fig. During this analysis, the motor run at no load. Peak overshoot is high with a change in speed. At starting the motor gets oscillated due to change in speed of 2000 RPM. Then,it runs at set speed till the load is varied. The PI controller based drive gets oscillation when starting torque is high. It is the effect of poor control due to overshoot in the reference voltage produced by PI controller. This overshoots reflects on motor speed and settles to zero after some delay because the motor starts with no load.

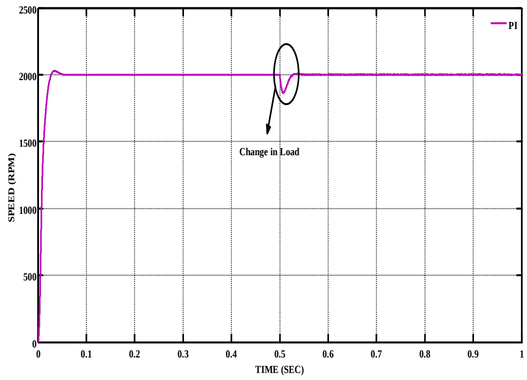


Fig 4: Speed response of BLDC motor drive at load of 1.2 Nm using PI controller

Speed response of BLDC motor drive drive at load of 1.2 Nm using PI controller is shown in Fig 4. The time taken to settle back to its reference speed after speed drop is stated as restoration time. It is evident that the restoration time has reduced. The speed drop is also high when there is a change in load. For variable load analysis, the load is increased from no load to 1.2 Nm at 0.5 sec and then torque settles at steady state condition at 0.54 sec. After load change, the motor settles with a restoration time of 0.06 sec. It can also be observed from the simulation results that performance of PI controller is poor during the case of speed variation.

Speed (RPM)	Peak Overshoot (%)	Steady state error (%)	Rise time (sec)	Peak time(sec)	Settling time(sec)	Speed drop during 0.6 0.6 Nm load change %)	Restoration time (sec) 0.6 Nm load change	Speed drop during 1.2 Nm load change (%)	Restoration time (sec 1.2 Nm) load change (%)

Table 1. Performance of BLDC motor drive using PI controller

1000	0.04	0.027	0.0177	0.0414	0.05	10.5	0.026	11.9	0.03
1500	0.53	0.018	0.0201	0.036	0.08	7.5	0.053	8.5	0.06
1800	1.03	0.017	0.0209	0.035	0.08	6.5	0.044	7.4	0.05
2000	1.4	0.015	0.0213	0.035	0.1	6.07	0.053	6.9	0.06
3000	3.33	0.01	0.226	0.035	0.115	4.7	0.07	5.3	0.08

Speed response of BLDC motor drive using PI controller at various speed is shown in Fig5. When the reference speed varies from 2000 RPM to 1500 RPM at t = 0.3 sec, speed error increases, the PI controller produces increased voltage as a reference voltage to attain the set speed. At the time of 0.5 Sec, the load is increased first to 50% and then to 100%, and the performance parameters are shown in Table 1. The speed drops when the load is increased. It causes an increase in error sensed by PI controller and it increases DC voltage to the inverter increase the speed and attains the set speed after restoration time. The motor settles at set speed with less overshoot. Speed drop during a load change produces oscillation in the speed performance of BLDC motor. When 0.6 Nm load and 1.2 Nm load is applied, torque of the machine gets increased with less overshoot. This oscillation exists up to 0.54 secat a speed of 2000 RPM.

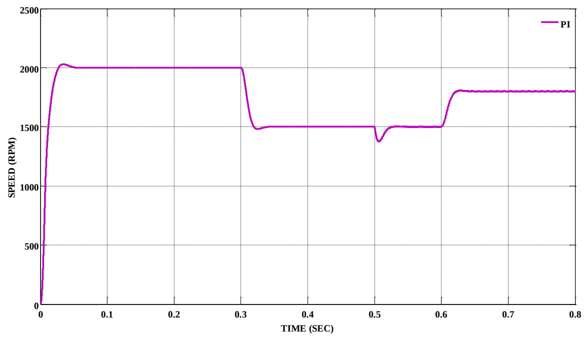


Fig 5: Speed response of BLDC motor drive using PI controller at various speed

Drop in speed again increases speed error, and it is compensated by PI controller by raising reference voltage. It shows that the motor follows the reference speed and produces minimum speed error. The perfect rise in voltage increases the speed and attains the set speed after the restoration time. Speed drop during load change in percentage value lies in the range of 11.9 to 5.3. Restoration time lies in the range of 0.03 sec to 0.08 sec.

IV. EXPERIMENTAL SETUP OF PMBLDC DRIVE

An experimental setup has been designed and the hardware has been realized using a Spartan3 FPGA for a BLDC motorof rating 400W, 3 phase, 30V, 3000 RPM. The block diagram of the hardware is shown in Fig6. It comprises of a Spartan 3 FPGA, which can build PWM generator and an Analog to Digital Converter (ADC) unit. The MOSFET IRF840 is used as the switching device. The keypad is interfaced with FPGA to choose algorithm and control of the motor. Control of motor includes setting speed required, ON and OFF of the motor.

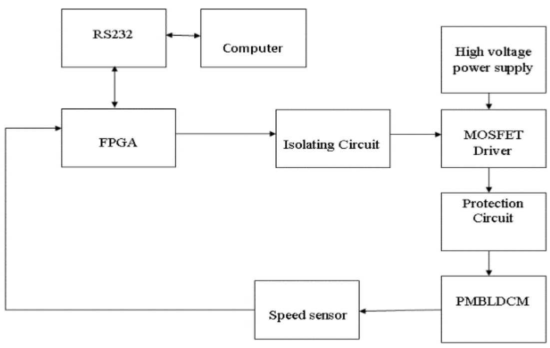


Fig 6: Block Diagram of BLDC motor drive [9]

4.1 Spartan 3 FPGA

The Spartan-3 family builds on the success of the earlier Spartan-3 family by increasing the amount of logic per I/O, significantly reducing the cost per logic cell. The Spartan-3 family features a rich network of traces that interconnect all five functional elements, transmitting signals among them. Each functional element has an associated switch matrix that permits multiple connections to the routing [9].

4.2 Lab VIEW

Lab VIEW is a type of graphical approach of programming that helps to visualize each and every aspect of the given application from National Instruments. Since this might be the case for multiple nodes simultaneously, lab VIEW as denoted by G is inherently capable of parallel execution [10]. This implies that each VI can be simply tested before being embedded into a larger program as a subroutine [11,12].A benefit of using Lab VIEW environment is the independent nature of the G-code, which is (with the exception of a few platform-specific functions) portable between the different Lab VIEW systems for different operating systems (Windows, Mac OS X, and Linux) [8,9]. National Instruments is increasingly focusing on the capability of providing Lab VIEW code onto an increasing number of targets including devices like Phar Lap OS based Lab VIEW real-time controllers, Pocket PCs, PDAs, Field Point modules and into FPGAs on special boards [14-17].

V. HARDWARE IMPLEMENTATION

. Experimental Setup of BLDC motor drive is shown in Fig7.

Set Speed	Peak overshoot%		Steady state error%		Speed drop during load%		Settling time after load Change Sec	
	SIM	EXP	SIM	EXP	SIM	EXP	SIM	EXP
1500	0.53	0.5	0.0018	0.2	8.5	9	0.06	0.19
2000	1.4	1.3	0.015	0.15	9	11	0.07	0.15
2500	2.2	2.8	0.0002	0.12	6	9.5	0.08	0.14

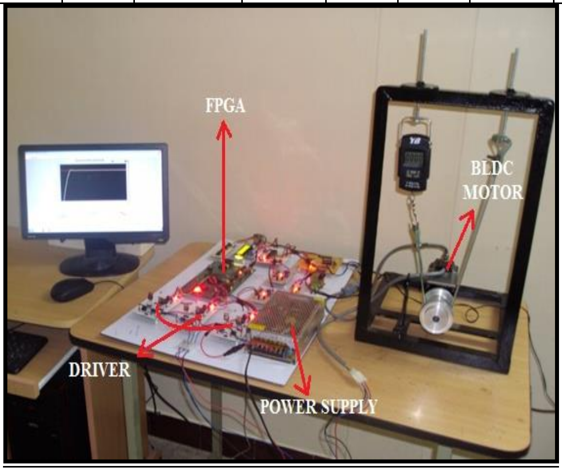


Fig 7: Experimental Setup of BLDC motor drive

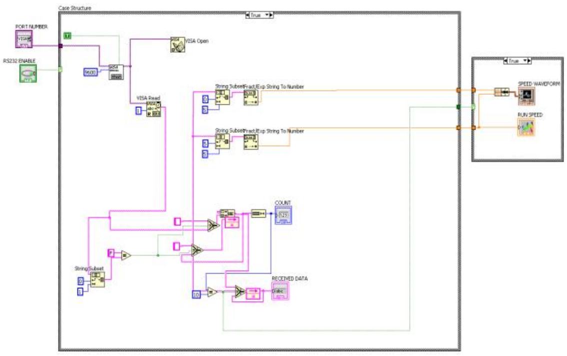


Fig 8: Block Diagram of BLDC motor drives when RS232 is disabled

The Lab VIEW program has two screens front screen and block diagram. The front screen consists of inputs and outputs. Block diagram consists of the control circuit. The block diagram of Lab VIEW program using VISA tool is shown in Fig8. It states the condition when RS232 is enabled. The speed graphs in LABVIEW at speed reference as 1500 RPM are shown in Fig10.Experimental results are given in Table 2.

Table 2. Experimental performance of PI controlled BLDC motor drive

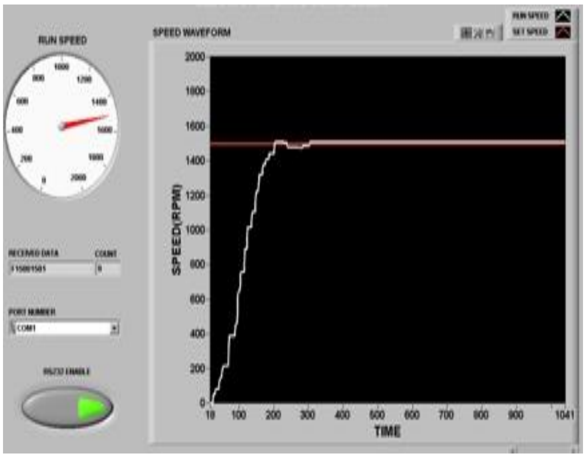


Fig 10: Speed performance using PI controller

II. CONCLUSION

In this paper, the speed control of BLDC motor drive with PI controller is studied. Using Matlab/Simulink, a simulation model has been developed. A BLDC motor of rating 3 phase, 30V, 400W, 3000 RPM is experimented using the Spartan 3 FPGA kit. Experimental setup of PI based BLDC motor drive using Spartan 3 FPGA is discussed. Experimental analysis is done with various loads of 1.2 Nm load, 0.6 Nm load, and no load. Speed drop during maximum load of 1.2 Nm change is only 3% at 3000 RPM. To demonstrate the learning capability and the applicability of the proposed controller, various test cases are performed under different operating conditions. The results validate that the experimental results are very close to the simulation results.

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