Comparative Analysis of PID and Fuzzy Logic Controller for Buck Converter

ISSN (e) 2520--7393
ISSN (p) 5021-5027
Received on 28th Jan, 2018
Revised on 15th Jan, 2018
www.estirj.com

Shafquat Hussain Bhellar[1], Zubair Ahmad Memon[2], Tayab Din Memon[3], Yasir Ali Bhutto[4], Abdul Majeed[5]

[1,2,4,5] *Department of Electrical Engineering Mehran University of Engineering and Technology Jamshoro*
[3]*Department of Electronics Engineering Mehran University of Engineering and Technology Jamshoro*

Abstract: In this paper, the two works are presented, one work is comparative analysis of PID and fuzzy logic controllers using Matlab Simulink and other work is the FPGA based design of PID controller for DC-DC buck converter. In the first works, PID controller which is designed using Xilinx system generator (XSG) is easy to design and can be tested for its hardware use with the help of hardware co-simulation as compare to the Matlab Simulink based designed fuzzy logic controller. The fuzzy logic controller better has rise time, settling time and lower overshoot. The other work is hardware co-simulation of PID controller for a DC-DC converter, in which we use NEXYS3 Spartan6 FPGA device and verify the DC-DC buck converter result using that FPGA device. Furthermore, Spartan6 and virtex5 are compared using parameters area performance, resource utilization and power consumptions with the help of using XILINX ISE design suite14.7. This work results in Virtex5 use less resource utilization as compared to the Spartan6 so Virtex5 is more efficient and it consumes less power and is more efficient as compared to Spartan6 as shown in results. The other advantage of using FPGA based PID controller over the fuzzy logic controller that its hardware implementation is very beneficial simple and less time-consuming and can be tested without providing any loss to the system.

Keywords: Xilinx system generator (XSG); FPGA; PID controller; DC-DC buck converter; Hardware Co-simulation

1. Introduction

As the PV technology grows day by day the need of dc-dc converter is increased for the regulated process of batteries. Via linear system technologies and analog IC technologies, they have been controlled for a long time. But due to the advent of new semiconducting devices, their operation improves. The non-linear characteristic of the buck converter has been given great attention but some hindrance came due to the design of non-linear controllers [1]. The DC-DC converters used to change the dc voltage levels by varying the duty cycle of given main switches of the circuit. These converters can be used in motor drives dc power supplies etc. with the help of these converters, we can obtain a required level of output voltage by converting the unregulated input voltage to the output controlled dc voltage [2]. The DC-DC buck convertersconsist of various solid-state semiconducting devices and acts as a switch, so switching of these electronics switches make the dc-dc converter non-linear in characteristic. For the operation of such converters, need a controller possess some good dynamic response [3].The PID controller is a simple controller which compares the measured quantity with a reference or required quantity and makes difference called the error signal, which actuates the system to maintain the stable or required conditions [4]. On another hand, there is fuzzy logic controller is non-linear type of controller for the buck converter to be controlled in varying power supplies and load changing conditions. The fuzzy logic controller is mostly preferred as compared to other controllers because it does not require exact mathematical model but it requires awhole concept of the system to control it [5].

2. Basics of DC-DC Buck Converter

This buck converter is stepping down DC-DC converter well known as a chopper. The DC-DC buck converter consists of devices like MOSFET, diode, inductor, load resistor and capacitor as shown in figure1.

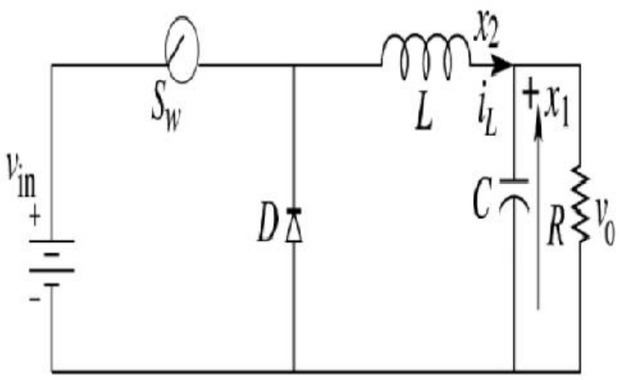

Figure.1. Basic circuit of DC-DC buck converter [6]

Corresponding author Email address: *hussainshafquat@hotmail.com*

The current to the input of buck converter is pulsating or discontinuous and current to the output of the converter side is non-pulsating or continuous this due to the current passes through some inductor and capacitor combination.

3. Methodology

3.1 System model

In order to get the required the required step downDC-DC voltage the DC-DC buck converter is required. The whole model of the DC-DC buck converter is presented in below given figure 2. It consists of solid semiconducting switches like Mosfet and diode for performing switching action while L and C used as low pass filter to remove high frequency components in other words it allow only low frequency components. In closed loop control the PID and fuzzy logic controllers perform their functions and finally PWM block generates pluses to control duty cycles of the switch all these components make a whole system which can be show in the figure 2.

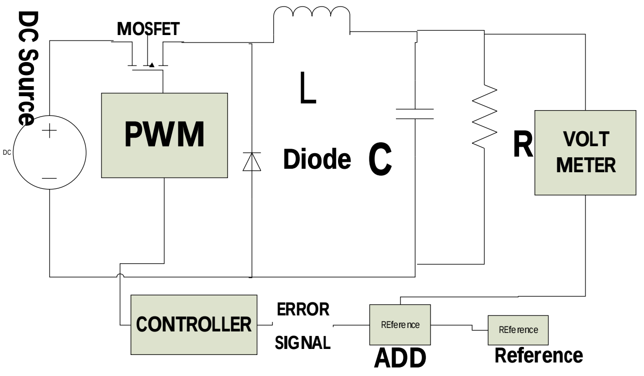

Figure.2. Conversion system of DC-DC buck converter

The efficient fast transient response of controller is necessary because of the non-linear nature of the DC-DC buck converter.

3.1.1 Design of fuzzy logic controller

Lofty Zadeh in1965 first of all proposed the idea of fuzzy logic in order to deal with the control problems of uncertainty, imprecision and qualitative decision-making. The mathemaical model for system should not not be precise in fuzzy logic controller but it wants the whole understanding of the system to control it [7]. Fuzzy controller has 2 inputs for the DC-DC buck converters. The one input is the error signal (e) which is the difference of the actual output voltage and the reference voltage as shown in below equation (1). The second input is the change of error shown mathematically in equation (2).

Error signal = Output Voltage – Reference value … (1)
Change of error = error signal – current error signal … (2)

Two scaling factors go and g1 are multiplied by the two given input and then feed to fuzzy controller. The other gain factor represented by h will be multiplied by the output of the fuzzy controller. Then the output of the fuzzy logic controller is fed to the PWM technique to generate pulses for the MOSFET. By the scaling factors go, g1 and h suitable response of the buck converters can be achieved [8] [11].

The simulation circuit for Fuzzy logic controlled DC-DC buck converter is show in the figure 3.

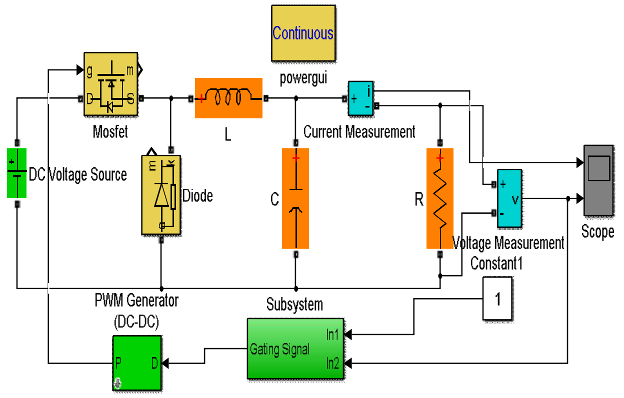

Figure.3. Simulation circuit for Fuzzy logic controlled DC-DC Buck converter

3.1.1.1 Membership Functions of Fuzzy Logic Controller

The output voltage of buck converters is regulated by the fuzzy logic controller. The two inputs for the fuzzy controller they are (1) error input which is show in the figure 4.And (2) change of error input which shown in the figure 5, and the duty cycle is the output for the fuzzy controller shown in the figure 6. For each inputs variables and output variable, there must be some defined fuzzy sets. Three fuzzy subsets chosen for two inputs and single output, named 1st is NB (negative big), 2nd is negative medium (N M), 3rd is negative small (N S), 4th is zero (Z E), 5th is positive small (P S), 6th is positive medium (P M), 7th is positive big (P B) with triangular shaped membership functions. With the help of suitable scale factors normalized range for the inputs and output variables is [0 1].

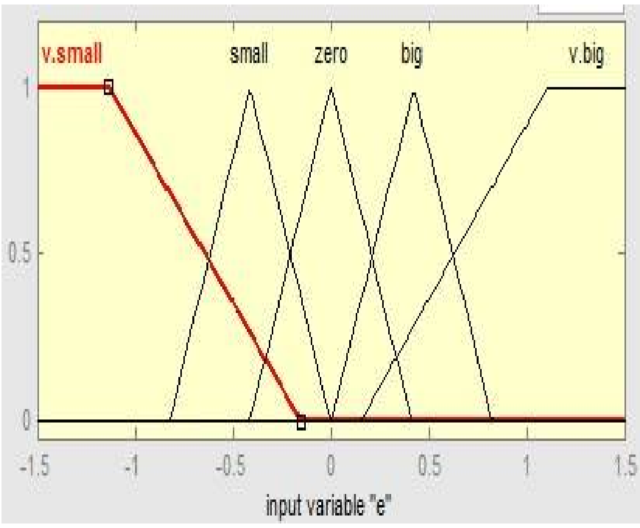

Figure.4. Error input's Membership functions.

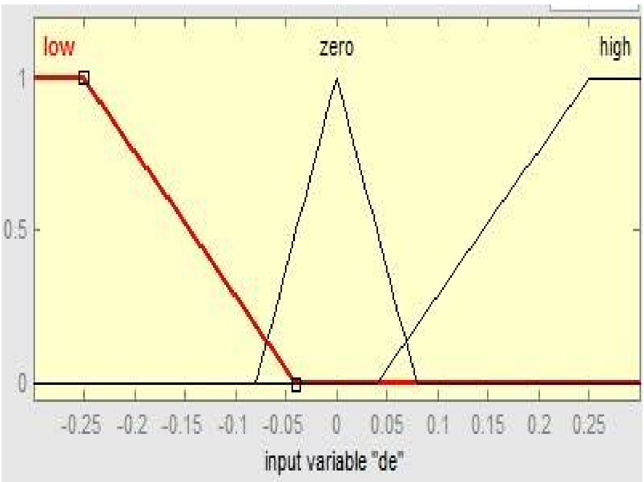

Figure.5. Change of error input's Membership Functions

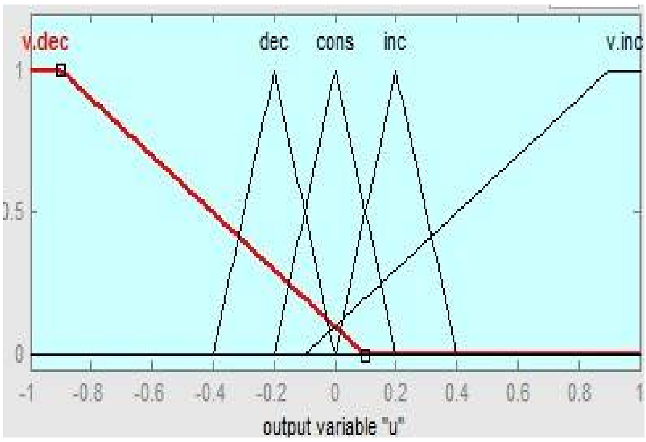

Figure.6. Duty cycle output's membership functions

3.1.1.2 Fuzzy Logic Rule Table

Rule table is used show the values of changing duty cycle output of the buck converter.

E/E*	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	PS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

Table.1. Fuzzy Logic Rule Table

Design of FPGA based PID Controller

The PID type of controller is linear controller used in buck converters circuit. PID controller consists of three different parameters like proportional and represented by 'P', Integral this is represented by 'I' and derivative which is represented by 'D'. PID controller provides particular control action to the process by tuning these three parameters of PID controller. Out of the various tuning methods, the convention is the trial and error method [9].

The mechanism for controlling the feedback loop is actually the PID controller. A PID controller correct error of the actual value and a reference , first calculating and then release corrective actions for the process. The simulation circuit for PID controlled buck converter is shown in the figure7 and PID controller is design using Xilinx system generator (XSG) in Matlab and Xilinx ISE design suite which is show in Fig.8.

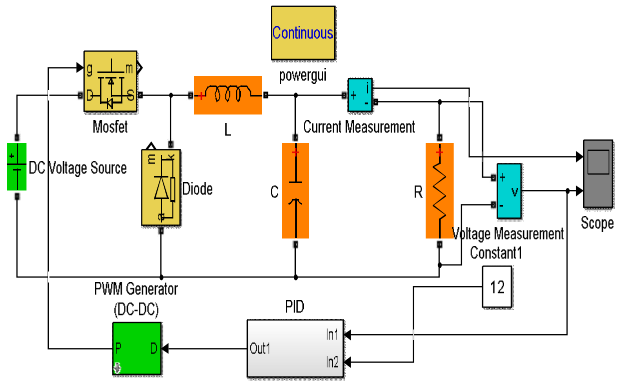

Figure.7.Simulation circuit for FPGA based PID controlled DC-DC buck converter

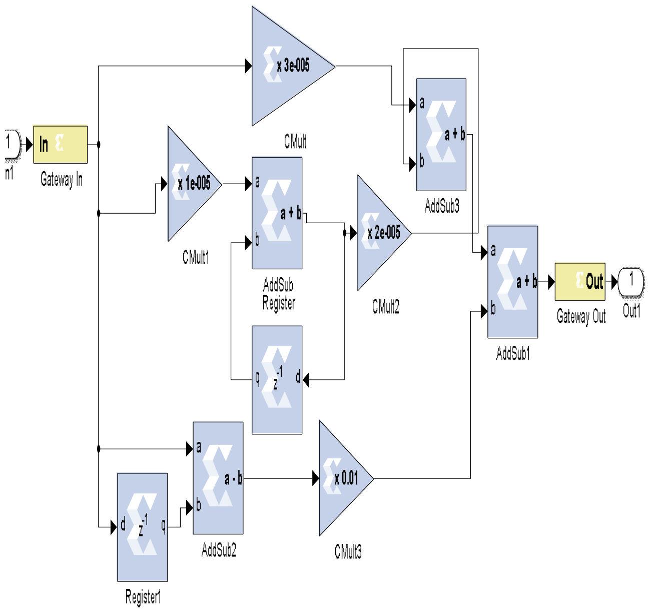

Figure.8. PID controller subsystem using Xilinx system generator

4. Results and Discussion

The DC-DC buck converter perform function by giving as input of 24V as an input it gives step down DC voltage of 12V by using FPGA based PID controller and fuzzy logic controller. The result of each controller is shown in below figures.

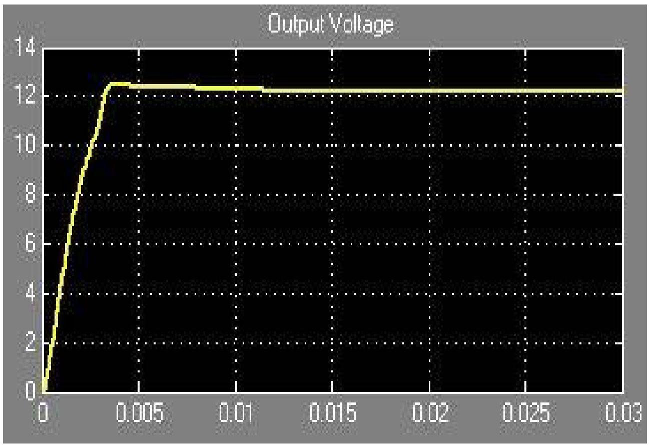

Figure.9. Output Voltage waveform fuzzy logic controlled DC-DC buck converter

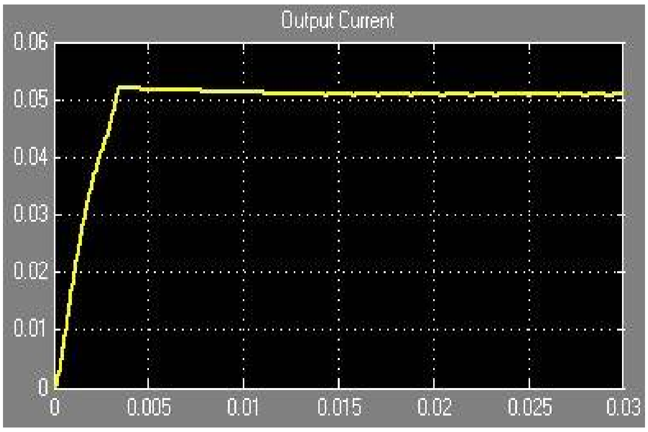

Figure.10. output current waveform of fuzzy controlled DC-DC buck converter

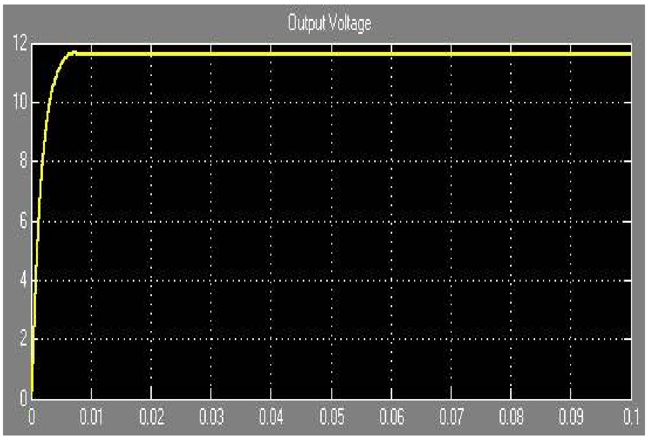

Figure.11. Output Voltage of PID controlled buck converter

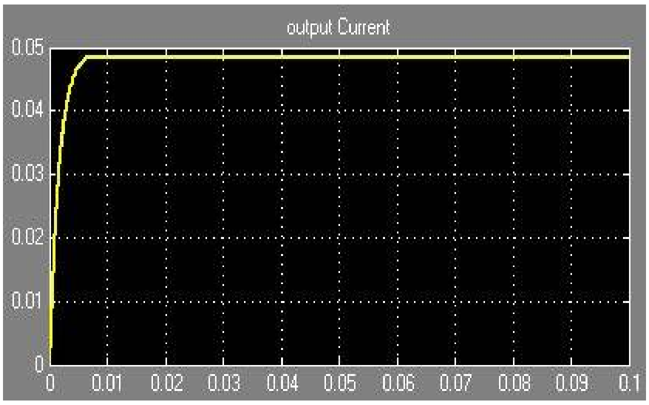

Figure.12. Output Current waveform of PID controlled Buck converter

FPGA Resource utilization

The proposed system has been synthesized for FPGA sparten6 and virtex5.

FPGA resource utilization for both above FPGAs is listed in the following table.

Table.2. FPGA resource utilization

Resources	Spartan6			Virtex5		
	XC6SLX16-CSG-324-2			XC5VLX50T-FF1136-1		
	used	Available	Utilization	Used	available	Utilization
Number of Slice Registers	93	18224	<1%	92	28800	<1%
No. of Slice LUTs	3307	9112	36%	3307	28800	11%
No. of occupied Slices	992	2278	44%	963	7200	13%

FPGA Power Consumption

Power consumption due to static, power consumption due to dynamic and total power consumptions for Spartan6 and virtex5 are shown below.

- **Virtex5**

Total Power is 0.528W, dynamic power consumption is 0.080W and static power consumption is 0.449W.

- **Spartan6**

For Virtex5 is total power consumption is 0.107W dynamic power consumption is 0.086W and static power consumption is 0.021W.

The chart for the power consumption of FPGA is shown below.

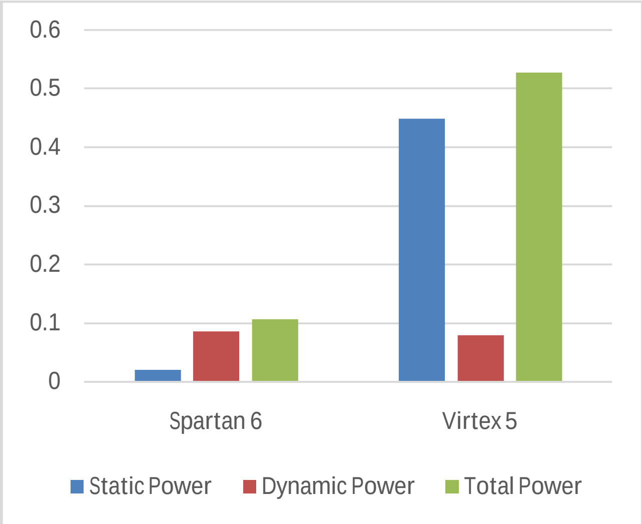

Chart No.1. Power Consumption for Virtex5 and Spartan6

Hardware Co-simulation

Purpose of Co-simulation: To verify the functionality, hardware and software before fabricating the ASIC [10].The Matlab simulation generates and provides input vectors then these inputs go into the FPGA board through (XSG) Xilinx system generator design blocks. The FPGA after processing send the output signals Matlab to display the result

Hardware Co-simulation Procedure

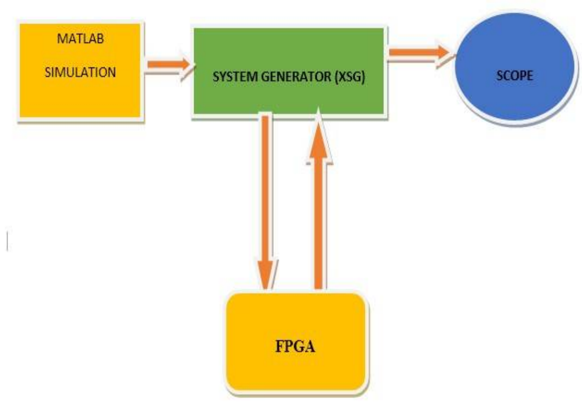

Figure.13. Block diagram of Hardware co-simulation

Performing Hardware Co-simulation

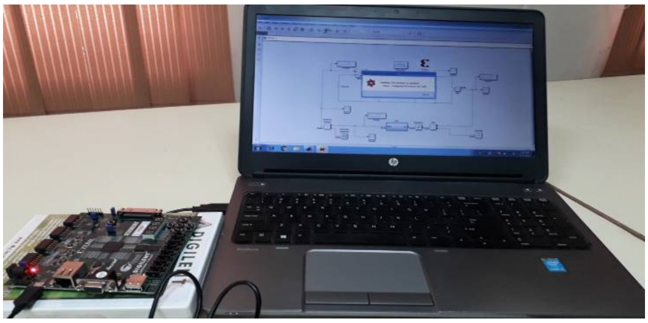

Figure.14. Hardware co-simulation using FPGA

Using FPGA performing hardware co-simulation for PID controlled DC-DC buck converter is performed hence got the exact result using FPGA as did performed Using Xilinx system generator (XSG) through Matlab. The result of that performed hardware co-simulation is show in the figure below.

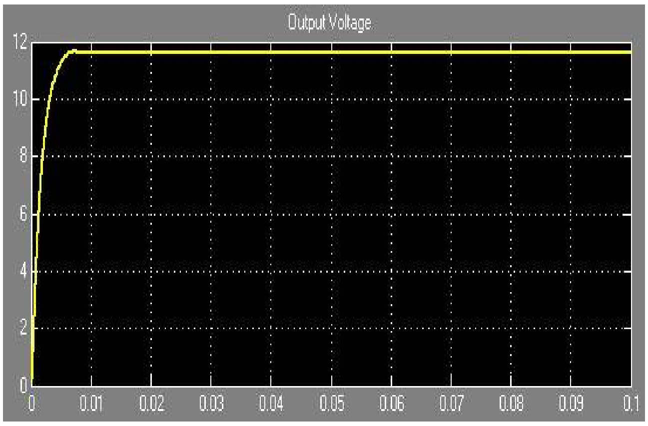

Figure.15. output voltage of buck converter hardware co-simulation

5. Conclusion

As from previous literature, the comparative study between the Fuzzy logic controller and PID controller results in better performance of fuzzy logic controller than PID controller because PID controller has large overshoots but in this work, the fuzzy logic controller has no small overshoot small rise time, small peak time and small settling time but on the other hand the FPGA based designed PID controller has small losses no delay time for FPGA based PID controller and we can easily design the PID controller for hardware use because of advantage of using the hardware co-simulation for FPGA based PID controller. So the Fuzzy logic controller has better performance as compared to FPGA based PID but fuzzy logic controller has more complexity and PID is simple to design and can be tested for its hardware use using hardware co-simulation .

Future Work: we can further increase this work in different fields like in design of Inverters or rectifiers used in UPFC, IPFC, STATCOM and SSSC etc. and besides that work the other controllers can also the designed using FPGA and other more advanced controlled techniques like current programmed control (CPM).

References

[1] S. Subiramoniyan, S. J. Jawhar, "Design and implementation of modern digital controllers for D.C- D.C buck converter," *International Conference on Computing, Electronics and Electrical Technologies (ICCEET)*, Kumaracoil, 2012, pp. 279-287.

[2] Sandeep Kumar Singh et al, "A Comparative Analysis of PI and PID controlled buck converter using Matlab Simulink," GJCAT, Vol. 3(1), 2013, pp.1214-1217.

[3] Chetan P.Ugale, R.B.Dhumale and V.V Dixit, "DC-DC converter using a fuzzy logic controller,"International Research Journal of Engineering and Technology(IRJET), 04 July 2015, pp. 593-996.

[4] Ankita Pandey, Dr. Dharmendra Singh, "A Buck Converter Based on PID Controller for Voltage Step down Applications,"International Journal Science and Research (IJSR), 2013, pp.1164-1167.

[5] Bhagyashri U.Patil and Satyawan R.Jagtap, "Adaptive Fuzzy Logic Controller for Buck Controller,"International Conference on Computation of Power, Energy, Information and communication, 2015, pp.0078-0082.

[6] Puspendu Maji, Prof. G K. Panda and Prof. P K. Saha, "Performance Analysis for DC-DC Buck Converter with Fuzzy and Robust Controller," International Journal of Advance Research in Electrical, Electronics and instrumentation Engineering, Vol.4, Issue5, May 2015, pp.4127-4135.

[7] Neetu Sharma, Dr. Pradyumn Chaturvedi and Rahul Dubey, "Comparative Study of PI Controlled and Fuzzy Controlled Buck Converter," International Journal of Engineering Trends and Technology, Vol4, Issue3, 2013, pp.451-457.

[8] M.J Yusoff, N.F Nik Ismail, Ismail Musirin, N. Hashim and D. Johari, "Comparative Study of Fuzzy Logic Controller and Proportional Integral Derivative Controller on DC-DC Buck Converter," The 4th International Power Engineering and Optimization Conf.(PEPCO2010),Shah Alam,Salengor,MALAYSIA,23-24 June 2010 pp.142-148.

[9] Ms. Kashmira Rathi(Kasat) and Dr. M.S.Ali, "Design and Simulation of PID Controller for Power Electronics Converter Circuits," International Journal of Innovative and Emerging Research in Engineering, Volume3, Issue2, 2016 pp.26-31.

[10] Introduction to co-sim CPSC489-501, Hardware-Software Co-design of Embedded Systems, Mahapatra-TexasA&M-Fall'00.

[11] Mumtaz Aziz Kazi, Mukhtiar Ahmed Maher, Irshad Rahim Memon and Muhammad Farrukh Shaikh " *Minimization of Transients in Buck Converter using Casecade Control techniqure"* Engineering Science and Technology International research Journal-ESTIRJ-Vol.1, No.4, Dec, 2017 pp-(1-8).

About Authors

Shafquat Hussain Bhellar received the B.E degree in Electrical Engineering department from Mehran University of Engineering and Technology Jamshoro and also M.E degree in Electrical Engineering department from Mehran University of Engineering and Technology Jamshoro and his research area is Power converter topologies, FPGA, FACTS devices.

Dr. Zubair Ahmad Memon received his B.E and M.E degree in Electrical Engineering department from Mehran University of Engineering and Technology Jamshoro and then Ph.D. degree in Electrical Engineering department from Mehran University of Engineering and Technology Jamshoro and his research area is Modeling & simulation of Power Electronic Topologies and Electrical Power Quality.

Dr. Tayab Din Memon received his B.E and M.E in Electronic Engineering department from Mehran University of Engineering and Technology Jamshoro and Ph.D. from RMIT Australia and his research area is FPGA.

Yasir Ali Bhutto received his B.E in Electrical Engineering department from Qaid-e-Awam University of Engineering Science and Technology Nawabshah and M.E in Electrical Engineering department from Mehran University of Engineering and Technology Jamshoro and research area is Photo voltaic Analysis, power electronics, power quality.

Abdul Majeed received his B.E in Electrical Engineering department and also completed his M.E in Electrical Engineering from Mehran University of Engineering and Technology Jamshoro. His Research Interest is FACTS devices.