Comparative Study of PI Controlled and Fuzzy Controlled Buck Converter

Neetu Sharma[1], Dr.Pradyumn Chaturvedi[2], Rahul Dubey[3]

[1] PG final year scholar, Dept of Eelectrical Engg, Samrat Ashok Technological Institute, Vidisha, India,

[3] Assistant professor, Dept of CS and IT, Maulana Azad National Institute of technology, Bhopal, India

[2] Assistant professor, Dept of Eelectrical Engg, Samrat Ashok Technological Institute, Vidisha, India

***Abstract*— The main objective of this paper is to compare the performance between fuzzy controller and proportional integral controller in improving the performance of the DC-DC Buck Converter. The evaluation of the output has been carried out and compared by software simulation using MATLAB. This paper also evaluates the stability of the system with fuzzy controller and PI controller and concludes that the fuzzy controller is able to achieve faster transient response, has major stable steady state response and is more robust under different operating points**.

***Keywords*— DC-DC Buck converter, PI, FLC**

I. Introduction

DC-to-DC converters have been largely dominated controlled by analog integrated circuit technology and linear system design techniques. Recently, with the development of advanced high-speed digital circuits, digital control will regularly replace the current used of analog controller in high frequency switching converters [1]. Even though the analog controllers are gradually trade, there are some controllers still being used generally in industrial application

Task of power electronics is to process and control the flow of electrical energy by supplying voltages and currents that suited for optimally load's user. Figure 1.1 shows a power electronic system block diagram. The output of power processor is as desired by load. Generally, the feedback controller compares the output of the power processor unit with reference value, and the error between this two is minimized by the controller [2].

A. *Dc-Dc converter*

The name 'Buck Converter' most probably evolves from the fact that the input voltage is bucked/chopped or attenuated, in amplitude and a lower amplitude voltage appears at the output. In other names, a step-down voltage regulator provides non-isolated, switched-mode dc-dc conversion with accepts a DC input and uses pulse-width modulation (PWM) of switching frequency to control the output of an internal power MOSFET. An external diode, together with external inductor and output capacitor, produce the regulated dc output [3]. It is class of switching-mode power supply (SMPS) containing at least two semiconductor switches (a diode and a transistor) and at least one energy storage element. Filters made of inductor and capacitor combinations are often.

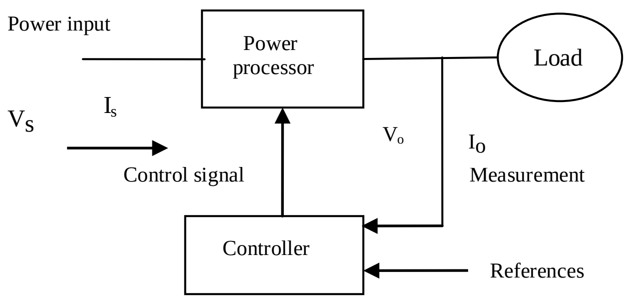

Fig 1.1 Block Diagram of Power Electronics System

Added to a converter's output to improve performance. It's also called the fly-back converter because the energy storage transfer, from source to a load, takes place only during the off period of the switch [4].The DC/DC converters can operate in two distinct modes, which are either in Continuous Conduction Mode (CCM) or Discontinuous Conduction Mode (DCM). The term continuous and discontinuous is referred to inductor current. Continuous means the inductor does not reach the zero value at the end of OFF period. Whereas, the current goes to zero when works in discontinuous mode. However, the DC-DC converters that operates in CCM is only considered for this purposed

1) Circuit Operation: Figure 1.2 shows the DC-DC Buck Converter circuit topology. The circuit operation can be divided into two modes. First mode (mode 1) begins when controlled switch (e.g. MOSFET) is switch on by pulse width modulation (PWM), the input current, which rises, flows through filter inductor, L filter capacitor, C and load resistor, R [5]. During mode 1, the diode reversed biased and resulted from flowing current, the input provides energy to the load as well as to the inductor [6]. The result is in positive inductor voltage, $\mathbf{V_L = V_s - V_o}$. It causes linear increase in inductor current. Mode 2 begins when the controlled switch is switch off. The freewheeling diode (uncontrolled switch), D conducts

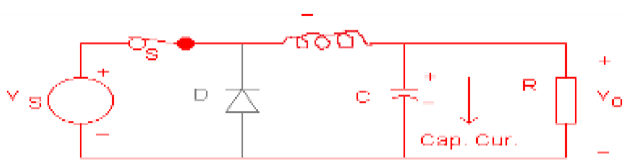

Fig 1.2 DC-DC Converter mode 1

due to energy stored in the inductor, L and the inductor current continues to flow through inductor, L capacitor, C, load, and diode, D [5]. During this interval, $\mathbf{V_L = -V_o}$ for time duration (1-D) T until the switch is turned on again [6] The circuit topologies for the converter during both modes are shows in Figure 1.2 and 1.3

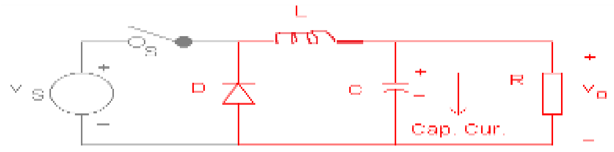

Fig 1.3 DC- DC converter mode 2

II. MATHEMATICAL MODELLING OF BUCK CONVERTER

Linear controller for dc-dc converter is often designed based on mathematical model. To achieve a certain performance objective an accurate model is essential. There is no of circuit modeling technique available in literature but the most commonly used method is state space averaging technique which is used in this dissertation work. So the mathematical model of buck converter with modified circuit to improve the performance of buck converter is described here:

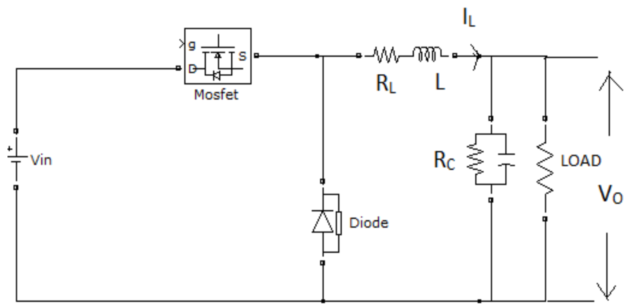

Fig 2.1:Buck Converter

A. *During ON period (when switch is on (fig 2.2(a)))*

From KVL Equation

$$R_L I_L + L\frac{dI_L}{dt} + V_C = V_{IN}$$

$$L\frac{dI_L}{dt} = V_{IN} - R_L I_L - V_C$$

$$\frac{dI_L}{dt} = \frac{V_{IN} - R_L I_L - V_C}{L}$$

From KCL Equation

$$C\frac{dV_C}{dt} + \frac{V_C}{R_C} + \frac{V_C}{R} - I_L = 0$$

$$\frac{dV_C}{dt} = I_L - \frac{V_C}{C}\left(\frac{1}{R_C} + \frac{1}{R}\right)$$

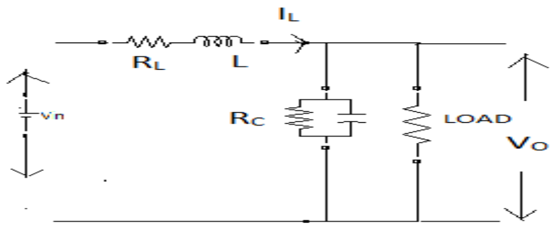

Fig 2.2(a): Buck Converter ON State

State Space Representation

$$\begin{bmatrix} \frac{dI_L}{dt} \\ \frac{dV_c}{dt} \end{bmatrix} = \begin{bmatrix} {-R_L}/{L} & {-1}/{L} \\ {1}/{C} & \left[{-1}/{R_C} - {1}/{R}\right]/{C} \end{bmatrix} \begin{bmatrix} I_L \\ V_C \end{bmatrix} + \begin{bmatrix} {1}/{L} \\ 0 \end{bmatrix} Vin$$

$$[Vo] = \begin{bmatrix} 0 & 1 \end{bmatrix} \begin{bmatrix} I_L \\ V_C \end{bmatrix}$$

B. *During OFF period (when switch is off (fig 2.2(b)))*

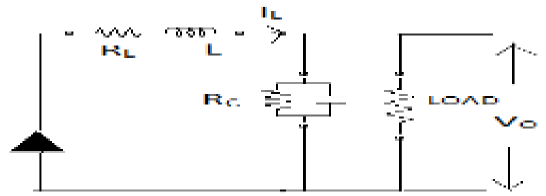

Fig 2.2(b): Buck Converter OFF State

State Space Representation

$$\begin{bmatrix} \frac{dI_L}{dt} \\ \frac{dV_c}{dt} \end{bmatrix} = \begin{bmatrix} {-R_L}/{L} & {-1}/{L} \\ {1}/{C} & \left[{-1}/{R_C} - {1}/{R}\right]/{C} \end{bmatrix} \begin{bmatrix} I_L \\ V_C \end{bmatrix} + [0]V_{IN}$$

$$[Vo] = \begin{bmatrix} 0 & 1 \end{bmatrix} \begin{bmatrix} I_L \\ V_C \end{bmatrix}$$

Assuming that initial condition is zero, we have taken

$$\begin{bmatrix} \frac{dI_L}{dt} \\ \frac{dV_c}{dt} \end{bmatrix} = \begin{bmatrix} -1449 & -14492 \\ 454 & -54 \end{bmatrix} \begin{bmatrix} I_L \\ V_C \end{bmatrix} + \begin{bmatrix} 14492 \\ 0 \end{bmatrix} Vin$$

$$[Vo] = \begin{bmatrix} 0 & 1 \end{bmatrix} \begin{bmatrix} I_L \\ V_C \end{bmatrix}$$

From above equations the matrix can be founded as following circuit parameter values to obtain the transfer function for the buck converter. Shown below

L = 0.069 mH, R_L = 0.1 Ω, R_C = 10 Ω, C = 2200 µF, LOAD = 50 Ω

$$A = \begin{matrix} -1449 & -14492 \\ 454 & -54 \end{matrix} \qquad B = \begin{matrix} 14492 \\ 0 \end{matrix}$$

$$C = \begin{matrix} 0 & 1 \end{matrix} \qquad D = \begin{matrix} 0 & 0 \end{matrix}$$

So from the state space model developed above, the transfer function of buck converter is derived as

$$\frac{V_0(s)}{V_i(s)} = \frac{6579368}{S^2 + 1503S + 6657614}$$

Stability analysis for the buck converter on the basis of above transfer function is described with the help of Bode Plot (as shown in fig. 2.3)

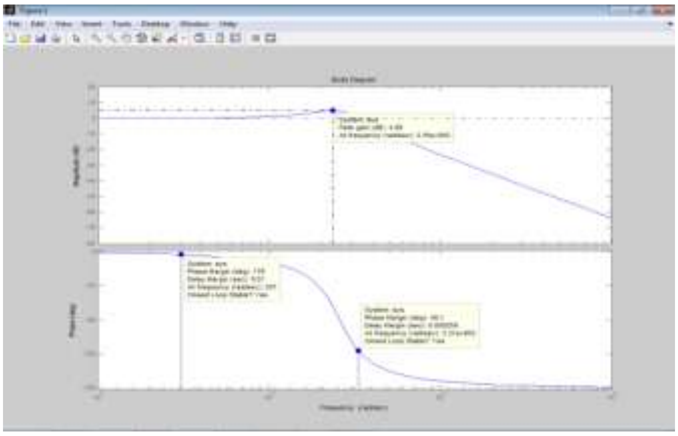

Fig 2.3: Bode Plot

Which states gain margin and phase margin both are positive , therefore, Closed Loop is Stable at Phase Margin (deg) - 176, Gain Margin (db)-4.98 at frequency 307&2.35e+003 respectively. When gain crossover frequency is less than the phase crossover frequency system will be stable

III. CONTROL METHODOLOGY

A. .PI controller

PI Controller (proportional-integral controller) is a special case of the PID controller in which the derivative (D) of the error is not used.

$$K_P + K_I \int \Delta dt$$

Where K_P , K_I is proportional and integral gain,Δ is the error or deviation of actual measured value (*PV*) from the set point (*SP*)

$$\Delta = SP - PV$$

The transfer function for the PI controller is given below

$$C = K_P + K_I/S$$

General approach to PI tuning:

1. Initially set integral gain equal to zero,
2. Increase K_P until satisfactory response has been obtained,
3. Add integral gain and adjust K_I until the steady state error is removed.

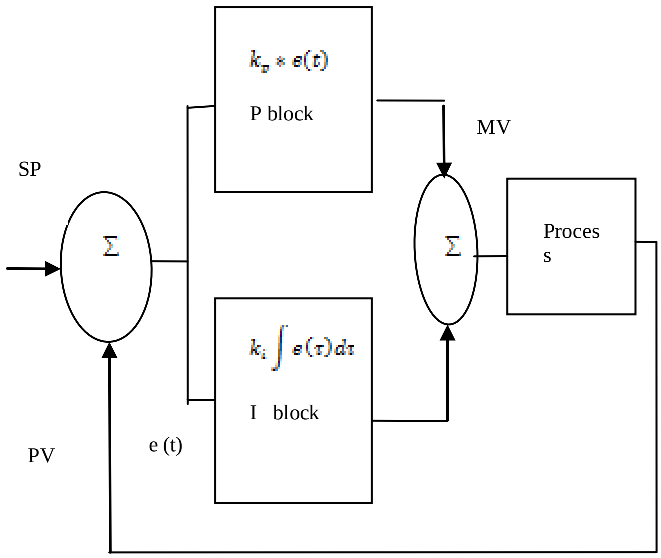

Fig: 3.1 Block Diagram of PI Controller

B. *Fuzzy controller*

Fuzzy logic, proposed by Lofty Zadeh in 1965, emerged as a tool to deal with uncertain, imprecise, or qualitative decision-making control problems. Controllers that combine intelligent and conventional techniques are commonly used in the intelligent control of complex dynamic systems. Therefore, embedded fuzzy controllers automate what has traditionally been a human control activity.

So Fuzzy logic control is a control algorithm based on a linguistic control strategy, which is derived from expert knowledge into an automatic control strategy. Fuzzy logic control doesn't need any difficult mathematical calculation like the other control system. So it is one of the available answers today for a broad class of challenging controls.

The general structure of FLC controller is shows in Figure 3.2. That comprises four principal components [10]:

1) Fuzzifier:
   A fuzzyfication interface which converts input data into suitable linguistic values.

2) Rule Base and Data Base:
   Both are known as knowledge base which consists of data base with necessary linguistic definition and control rule set.

3) Decision Making:
   A decision making logic which is simulating a human

Decision process, infers the fuzzy control action from he knowledge of the control rules and the linguistic variable definition. The inputs of the fuzzy logic controller are the error e and the change of error Ce, which are defined in equation 3.1

$$e = V_0 - V_{ref}$$

$$Ce = e_k - e \qquad (3.1)$$

Where V_O is the present output voltage, *Vref* is the reference output voltage, and subscript k denotes values taken at the beginning of the kth switching cycle. The output of the fuzzy controller is the duty cycle and is defined in equation 3.2

$$d_k = d_k - \alpha\delta d \qquad (3.2)$$

Where d_k is change in duty cycle with at kth sampling time and α is a gain factor of fuzzy controller by changing the α is the gain of fuzzy controller can be changed [10].

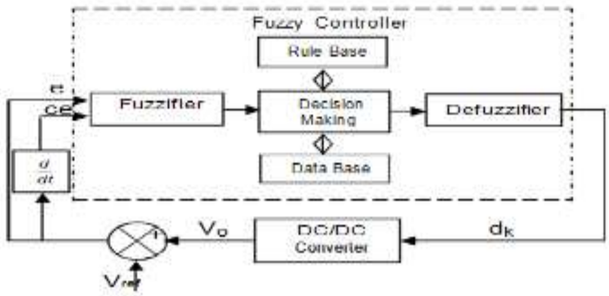

Fig.3.2: Basic configuration of FLC

The fuzzy logic control for DC-DC buck converter is made from 2 inputs and 1output variable, as shown in figure 3.3

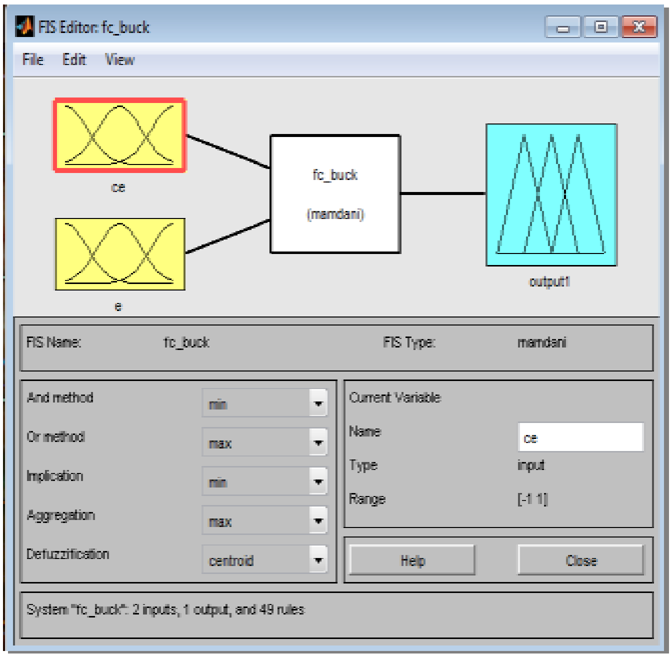

Fig. 3.3: The editor of fuzzy inference system

Which are error and change of error as input variables, and the duty cycle as output variable. Each variables control has been divided into five partitions. These partition, which are called as membership function has named into five fuzzy subsets: PB (Positive Big), PM (Positive Medium), PS (Positive Small), ZO (Zero), NS (Negative Small), NM (Negative Medium) And NB (Negative Big). The partition of fuzzy subsets and the shape of the membership function are shown in Figure 3.4 (error variable), Figure 3.5 (change of error variable), and Figure 3.6 (output variable).The triangular shapes of the membership function of this arrangement presume that for any particular input there is only one dominant fuzzy subset. From the combination of error and change of error, a maximum of four rules are applied. The rules for the fuzzy control's buck converter are tabulated in Table 3.1. From the tabulated table, the fuzzy rule base is formulated into 49 rules.

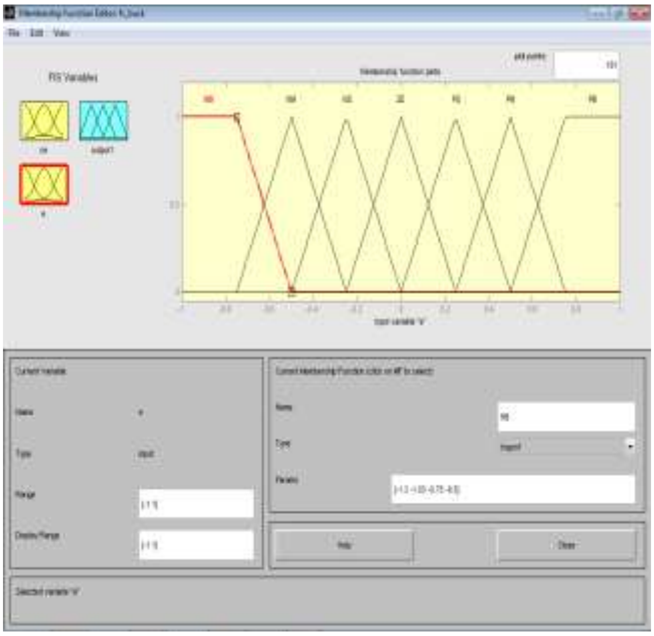

Fig. 3.4: Membership function of input variable 'error'

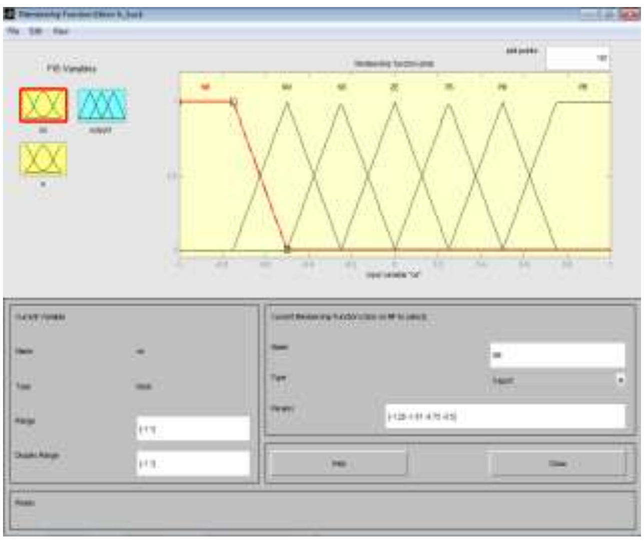

Fig. 3.5: Membership function of input variable 'change of error

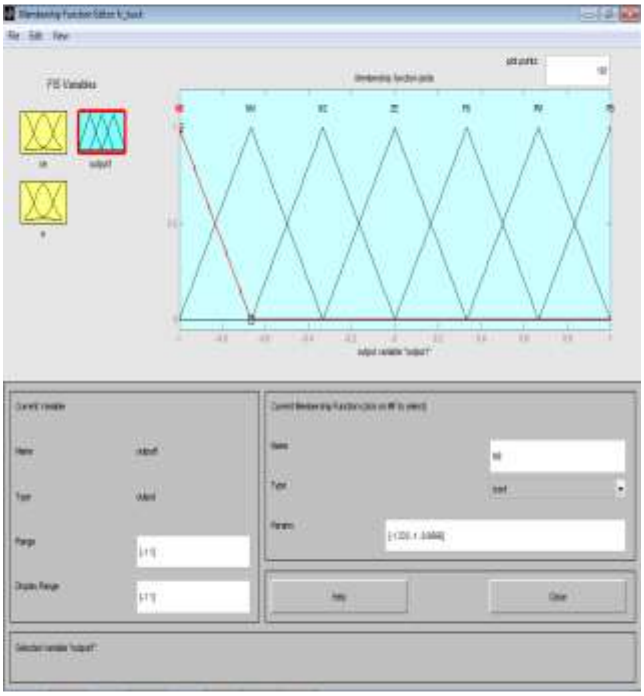

Fig. 3.6: Membership function of output variable

TABLE 3.1

THE RULE BASE WITH 49 RULES

e \ Ce	NB	NM	NS	Z	PS	PM	PB
NB	PB	PB	PB	PB	PM	PS	Z
NM	PB	PB	PB	PM	PS	Z	NS
NS	PB	PB	PM	PS	Z	NS	NM
Z	PB	PM	PS	Z	NS	NM	NB
PS	PM	PS	Z	NS	NM	NB	NB
PM	PS	Z	NS	NM	NB	NB	NB
PB	Z	NS	NM	NB	NB	NB	NB

IV. CONTROL METHODOLOGY

The simulation of work is conducted in matlab and following result with different technique is obtained which is given below

TABLE 4.1

SIMULATION PARAMETERS

PARAMETER	VALUES
Input voltage	20V
Output voltage	14V
Inductance (L)	0.069mH
Capacitance (C)	2200μF
R_L(inductive resistance)	0.1Ω
R_C (capacitive resistance)	10Ω
Resistance (load)	50Ω

A. With PI Controller

Circuit diagram of PI controlled buck converter is given below

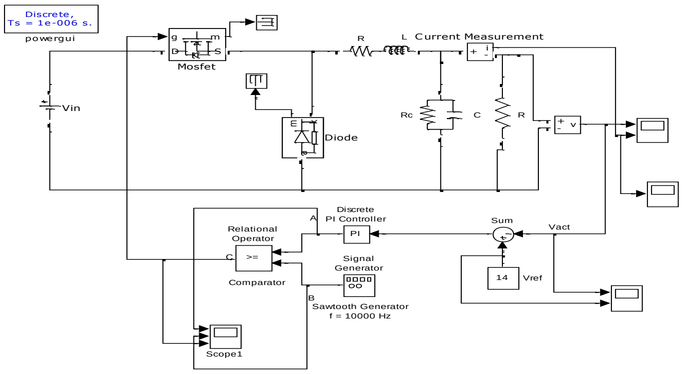

Fig. 4.1 Simulink Model of PI Controlled buck converter.

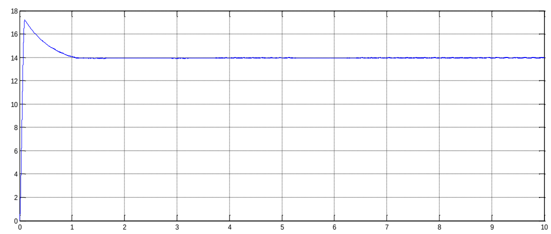

Fig: 4.2(a) Output Voltage Waveform of PI Controlled Buck Converter

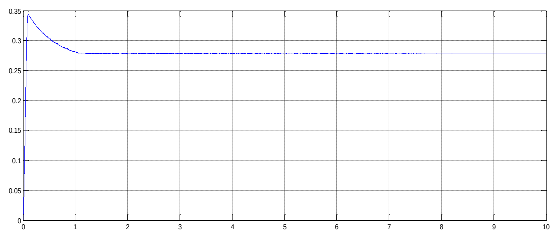

Fig: 4.2(b) Output Current Waveform of PI Controlled Buck Converter

In PI controlled buck converter Fig 4.2(a) shows that the dc output voltage rises up to 17 volts then at time t = 0.01sec it reach its steady state position i.e. voltage 14 volts. And in fig 4.2(b) dc output current rises up to 0.35 amp at time t = 0.01sec it reach its steady state condition i.e. at current 0.27 amp.

TABLE 4.2

PI CONTROLLED PARAMETERS

PARAMETER	VALUES
Rise Time (Tr)	.8ms

Peak Time (Tp)	1 ms
Settling Time (Ts)	10 ms
Maximum Peak Over Shoot	22.71%

B. With Fuzzy Controller

Circuit diagram of PI controlled buck converter is given below

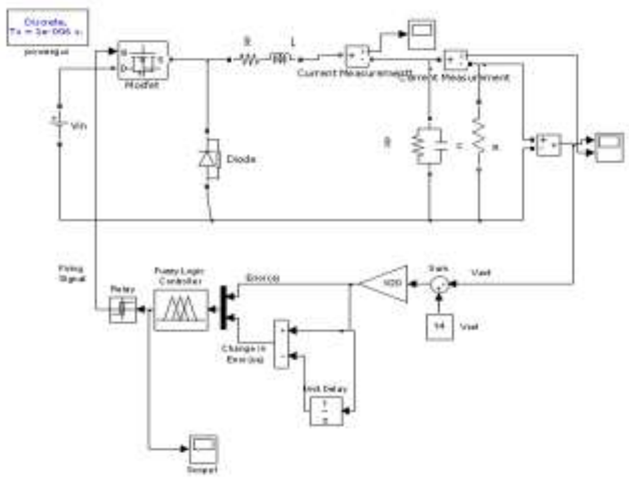

Fig. 4.3 Simulink Model of fuzzy Controlled buck converter

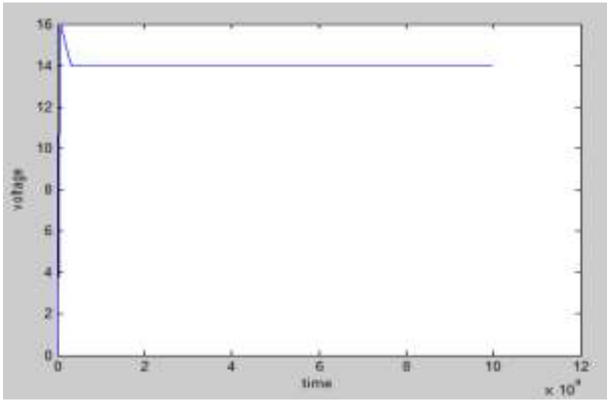

Fig: 4.4(a) output voltage of Fuzzy controlled buck converter

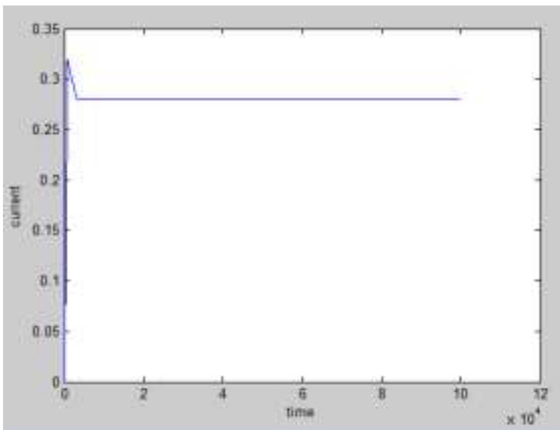

Fig 4.4(b) output current of Fuzzy controlled buck converter

In fig 4.4(a) the output voltage of Fuzzy controlled buck converter rises up to 16 volts and then reach its steady state condition at t = 0.005sec i.e. 14 volts and in fig 4.4(b) the output current rises up to 0.32amp and then reach its steady state condition at t =0.005sec i.e. 0.28amp

TABLE 4.3
PERFORMANCE PARAMETERS OF FUZZY LOGIC CONTROLLER

PARAMETER	**VALUES**
Rise Time (Tr)	.7ms
Peak Time (Tp)	.85 ms
Settling Time (Ts)	3.5ms
Maximum Peak Over Shoot	12.85%

C. Performance Comparision

Comparison has been made between the performance of PI controlled and Fuzzy logic controlled buck converter and is presented in Table 4.4. It clearly shows the improved performance of fuzzy logic controller over PI controller in terms of rise time, peak time, peak overshoot and overall system stability

TABLE4.4 COMPARISON OF PI AND FUZZY LOGIC CONTROLLED BUCK CONVERTER (INPUT VOLTAGE = 20VOLTS)

Parameter	**With PI Controller**	**With Fuzzy Controller**
Rise Time (Tr)	.8ms	.7ms
PeakTime (Tp)	1 ms	.85 ms
SettlingTime (Ts)	10 ms	3.5ms
Maximum PeakOver Shoot	22.71%	12.85%
Output Voltage	14	14
Output Current	0.28	0.28

V. CONCLUSIONS

Fuzzy logic controller (FLC) is much better in overall performance in terms of rise time, peak time, settling time and robustness as compared to PI controller. Fuzzy logic controller is a nonlinear control scheme with piecewise linear Proportional and integral gain to control the duty cycle of the system. Control of the duty cycle, in turn, controls the output voltage of the system. The fuzzy logic controller produced less voltage deviation. Small overshoot and sensitive to parameter variation makes fuzzy logic control results in better dynamic performance. FLC can also be applied to many converter topologies. FLC has advantages of fast response with higher accuracy. With all of these advantages, FLC has a potential to improve robustness of DC/DC Buck Converters. The transfer function of buck converter has been obtained with state-space averaging method. The controller is designed according to the transfer function model of buck converter. Simulation study has been carried out and a comparison has been made between PI and fuzzy controlled buck converter.

ACKNOWLEDGMENT

The author would like to express a gratitude especially to Mr. Shailendra Jain, for the support, belief, patience, fairness and for the feedback. The author would like to thank him for the opportunities and knowledge that he has given to the author.

REFERENCES

[1] Guang Feng, Wanfeng Zhang, Yan-Fei Liu." An adaptive current mode fuzzy logic controller for DC – DC converters, IEEE 2003, page 983-989

[2] Mohan, N., Underland, T.M., and Robbins W.P (2003). *Power Electronics – Converters, Applications, and Design*, 3rd edn. John Wiley & Sons M. Wegmuller, J. P. von der Weid, P. Oberson, and N. Gisin, "High resolution fiber distributed measurements with coherent OFDR," in *Proc. ECOC'00*, 2000, paper 11.3.4, p. 109.

[3] Anirban Dasgupta and Antip Ghosh, *Study and Design of Buck Converter*,http://www.scribd.com/doc/19037931/Buck-Converter#.

[4] R. Gurunathan, A.K.S. Bhat (1996). A Soft-Switched Boost Converter for High FrequencyOperation. IEEE Trans. 1999. 463-468.

[5] Muhammad h. Rashid, *Power Electronics: Circuits, Devices and Applications*, 3rd edition, chapter 5, page 187/

[6] Ned Mohan, Tore M. Undeland, William P. Robbins. *Power Electronics: Converter, Applications and Design*. Chapter 7, Page 164

[7] H. FeshkiFarahani " *Designing and Implementation of a Fuzzy Controller for DC-DC Converters and Comparing With PI Digital Controller*" proc Australian Journal of Basic and Applied Sciences ISSN 1991-8178.

[8] N.Rajarajeswari and K.Thanushkodi, "*A Bi-Directional DC- DC Converter with Adaptive Fuzzy Logic Controller* " Proc. ICGST-ACSE Journal, ISSN 1687-4811, Volume 8, Issue II, December 2008.

[9] M.J Yusoff, N.F Nik Ismail, Ismail Musirin, , N.Hashim , D. Johari, "*ComparativeStudy of Fuzzy Logic Controller and Proportional Integral Derivative Controller on DC-DC Buck Converter,"* Proc. International Power Engineering and Optimization Conf. (P EOCO2010), Shah Alam, Selangor, MALAYSIA: 23- 24 June 2010

[10] Paolo Mattavelli, Leopoldo Rossetto, Giorgio Spiazzi and Paolo Tenti (1997). *General- Purpose Fuzzy Controller for DC–DC Converters.* IEEE *Trans.* Vol. 12. Issue 1.79-86.

[11] Shyama M, P.Swaminathanf," Digital Linear and Nonlinear Controllers for Buck Converter,"International Journal of Soft Computing and Engineering (IJSCE) ISSN: 2231-2307, Volume-2, Issue-1, March 2012

[12] Shailendra jain, "Simulink and Modeling using MATLAB".