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Implementation and Performance of Fuzzy Logic Controller on DC-DC Boost Converter

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***Abstract*— This paper describes the design of a fuzzy logic controller using voltage output as feedback for significantly improving the dynamic performance of boost dc-dc converter by using MATLAB @ Simulink software. The objective of this proposed methodology is to develop fuzzy logic controller on control boost dc-dc converter using MATLAB @ Simulink software. The fuzzy logic controller has been implemented to the system by developing fuzzy logic control algorithm. The design and calculation of the components especially for the inductor has been done to ensure the converter operates in continuous conduction mode. The evaluation of the output has been carried out and compared by software simulation using MATLAB software between the open loop and closed loop circuit. The simulation results are shown that voltage output is able to be control in steady state condition for boost dc-dc converter by using this methodology.**

***Index Terms*— Fuzzy Logic Controller, Boost Dc-Dc Converter, Ziegler Nicholas method, PI controller MATLAB Simulink Software.**

I. INTRODUCTION

Nowadays, the control systems for many Power Electronic appliances have been increasing widely. Crucial with these demands, many researchers or designers have been struggling to find the most economic and reliable controller to meet these demands. The idea to have a control system in dc-dc converter is to ensure desired voltage output can be produced efficiently as compared to open loop system.

II. DC/DC CONTROLLER

DC-to-DC converters have been dominating controlled by analogue integrated circuit technology and linear system control design techniques. In recent years, with rapidly development of advanced high-speed digital circuits, digital control will slowly replace the currently used analogue controller in high
frequency switching converters. The intelligent power supplies are expected to play an important role in aerospace, communication, and automobile industries in the near future.

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2.1 BOOST DC/DC CONVERTER

The Boost Converter is one of the most important non isolated step-up converters. A Boost Converter is a power converter with an output dc voltage greater than its input dc voltage. It is a class of switching-mode power supply (SMPS) containing at least two Semi conductor switches like diode and transistor and at least one energy storage element. Filters made of inductor and capacitor combinations are often added to a converter's output to improve performance. Boost converter is a dc-to-dc converter that steps up the dc voltage from its fixed low level to a desired high level

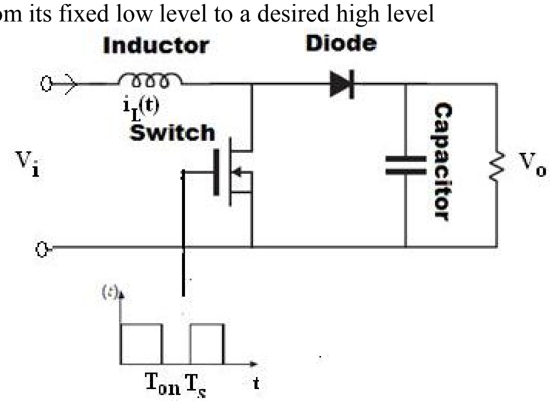

Fig. 1: Circuit Diagram of Boost DC-DC Converter

Mode 1 begins when MOSFET' is switched on at t = 0 and terminates at $t = t_{on}$. The equivalent circuit for the model is shown in Fig 1. The inductor current I_L(t) greater than zero and ramp up linearly. The inductor voltage is V_i.
Mode 2 begins when MOSFET is switched off at $t = t_{on}$ and terminates at $t = t_s$. The inductor current decrease until the MOSFET is turned on again during the next cycle. The voltage across the inductor in this period is V_{in}-v_{out}. In steady state time integral of the inductor voltage over one time period must be zero.

$$V_i * t_{on} + (V_i-V_o) * t_{off} = 0 \ldots\ldots\ldots(1)$$

Where
V_i = The input voltage, V.
V_o =The average output voltage, V.
t_{on} = The switching ON time of the MOSFET, sec
t_{off} = The switching OFF time of the MOSFET, sec

Dividing both sides by T_S and re-arranging items

$$\frac{Vo}{Vi} = \frac{Ts}{Toff} = \frac{1}{1-D} \ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Where,
T_s : The switching period, s.
D : The duty cycle

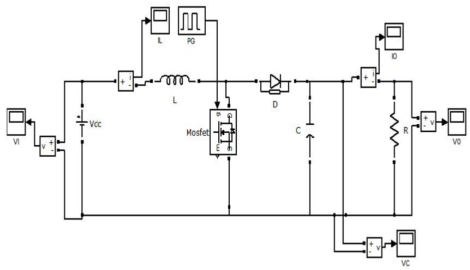

Fig.2: Open loop simulation model for Boost DC-DC Converter

III. CLOSED LOOP CONTROL USING PI CONTROLLER

Conventionally, PI, PD and PID controller are most popular controllers and widely used in most Power Electronic closed loop appliances. The PI control is the most popular control system; it is versatile and can be tuned adjusting three constants. PI is a well proved and successfully applied in many control systems

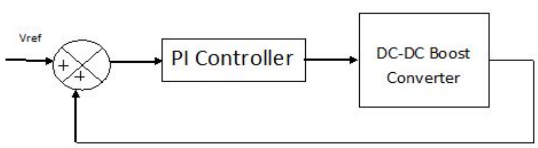

Fig. 3: Block Diagram for closed loop control using PI controller

3.1 TRANSFER FUNCTION OF BOOST CONVERTER

Basic circuit of the boost converter is shown in Fig.4. Here, L is the inductor and R is the resistor which is consider as a load. I_S is the current flow through the circuit. Switch is triggered by the pulse which is generated by PWM technique. Switch remains on during T_{ON} cycle and off during T_{OFF} cycle so triggering is depends on the duty cycle. V_{dc} is the D.C. input voltage supply which is taken from the bridge rectifier which converts A.C. input voltage into D.C. output voltage. V_{out} is the output of the boost converter which is larger than the input V_{in} .

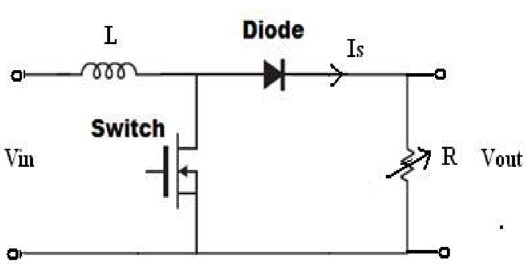

Fig.4 : Basic Circuit of Boost DC-DC Converter

When switch turns on the current is passing through switch which increases the current level in the inductor. At the end of T_{on} time current stored into the inductor is I_s .

$$V_{in} = L * \frac{dI_s}{dt} \text{……………………(3)}$$

Using Laplace Transformations,

$$V_{in} = L * S * I_s(s) \text{……………..(4)}$$

From Figure 4, V_{out} can be given as

$$V_{out}(s) = I_s(s) * R \text{……………..(5)}$$

$$\frac{V_{out}(s)}{V_{in}(s)} = \frac{R}{L*S} \text{……………………(6)}$$

3.2 TRANSFER FUNCTION OF CLOSED LOOP SYSTEM

Now to achieve proper objective of converter, it is need to measure and maintain output voltage at required voltage level. So for that purpose it is needed to use feedback loop into the system that is shown in Fig.5.

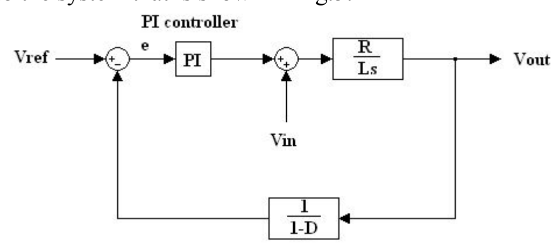

Fig.5:Block diagram of Boost Converter using PI Controller

In this Fig.5, V_{out} is given to the Pulse Width Modulator. The output of the PWM is compared with V_{ref} which is given to the PI controller. Then it is added with V_{in} which is given to the system.

From Fig.5,

$$V_{out} = \left(\frac{R}{L*S}\right) * [V_{in} + (K_p + \frac{Ki}{s}) * e] \text{…………(7)}$$

Taking $V_{ref} = 0$

$$V_{out} + [(\frac{R}{L*S}) * (K_p + \frac{k_i}{s}) * (\frac{1}{1-D}) * V_{out}] = V_{in} * (\frac{R}{L*S}) \text{ .(8)}$$

$$\frac{V_{out}}{V_{in}} = \frac{R/(L*S)}{[1+\{(\frac{R}{L*S})*(Kp+\frac{Ki}{S})*(\frac{1}{1-D})\}]} \text{…………..(9)}$$

Here, the equation 9 is the transfer function of the closed loop system

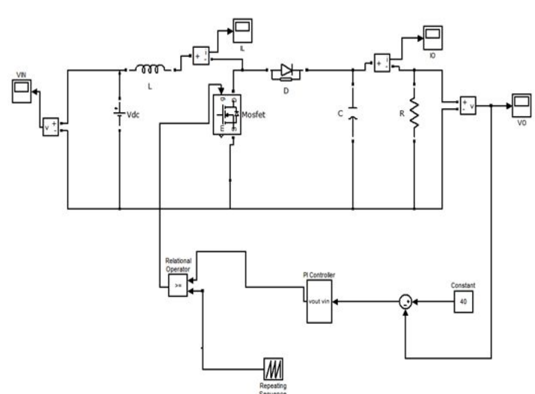

Fig.6:Closed loop Simulink model for Boost Converter using PI controller.

Table I: The parameters and values for the boost dc-dc converter.

Parameter	Value
Voltage Input, V_{in} (V)	20 V
Voltage Output, V_o (V)	40 V
Output Power, P_{out} (W)	10 W
Diode Forward Voltage, V_F (V)	1.05
Duty Cycle, D	0.5
Switching Frequency, f (kHz)	20
Inductor Current Ripple (%)	15
Capacitor Voltage Ripple (%)	0.1
Input Current, I_{in} (A)	0.50
Output Current, I_o (A)	0.20

IV. DESIGN OF FUZZY LOGIC CONTROLLER

Traditionally, PI, PD and PID controller are most popular controllers and widely used in most power electronic closed loop appliances however recently there are many researchers reported successfully adopted Fuzzy Logic Controller (FLC) to become one of intelligent controllers to their appliances. With respect to their successful methodology implementation, control closed loop boost converter and opened loop boost converter will compare the efficiency of the converters. This kind of methodology implemented in this paper is using fuzzy logic controller with feed back by introduction of voltage output respectively. The introduction of voltage output in the circuit will be fed to fuzzy controller to give appropriate measure on steady state signal[1]. This methodology can be easily applied to many dc-dc converter topologies such as Buck, Boost and Buck-Boost.

A simple fuzzy logic control is built up by a group of rules based on the human knowledge of system behavior. Matlab/Simulink simulation model is built to study the dynamic behavior of dc-to-dc converter and performance of proposed controllers. Furthermore, design of fuzzy logic controller can provide desirable both small signal and large signal dynamic performance at same time, which is not possible with linear control technique. Thus, fuzzy logic controller has been potential ability to improve the robustness of dc-to-dc converters.

The basic scheme of a fuzzy logic controller is shown in Fig.7 and consists of four principal components such as: a Fuzzification interface, which converts input data into suitable linguistic values; a knowledge base, which consists of a data base with the necessary linguistic definitions and the control rule set; a Decision-Making logic which, simulating a human decision process, infer the fuzzy control action from the knowledge of the control rules and linguistic variable definitions; a Defuzzification interface which yields non fuzzy control action from an inferred fuzzy control action.

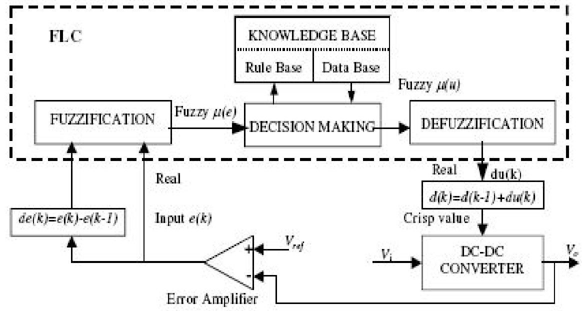

Fig.7:Block diagram of the Fuzzy Logic Controller (FLC) for dc-dc converters

An analysis of boost converter circuit revealed that the inductor current plays significant task in dynamic response of boost converter. Additionally, it can provide the storage energy information in the converter. Thus, any changes on the inductor current may affect output voltage and output voltage will provide steady state condition information of converter[2]. However, the three main parameters need to be considered when designing boost converters are power switch, inductor and capacitor. In this objective to achieve the desired output voltage and the stability is by designing the power switch.

4.1 FUZZY LOGIC MEMBERSHIP FUNCTION

The boost dc-dc converter is a nonlinear function of the duty cycle because of the small signal model and its control method was applied to the control of boost converters. Fuzzy controllers do not require an exact mathematical model. Instead, they are designed based on general knowledge of the plant. Fuzzy controllers are designed to adapt to varying operating points. Fuzzy Logic Controller is designed to control the output of boost dc-dc converter using Mamdani style fuzzy inference system. Two input variables, error (e) and change of error (de) are used in this fuzzy logic system. The single output variable (u) is duty cycle of PWM output.

Fuzzy sets must be defined for each input and output variable. As shown in Fig.8, five fuzzy subsets PB (Positive Big), PS (Positive Small), ZE (Zero), NS (Negative Small), NB (Negative Big) have been chosen for input variables error (e) and change of error (de). The Triangular and trapezoidal shapes have been adopted for the membership functions; the value of each input and output variable is normalized in [-1,1] by using suitable scale factors.

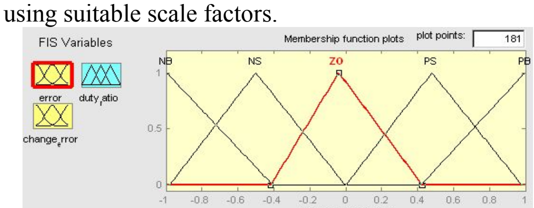

Fig.8 : The Membership Function plots of error.

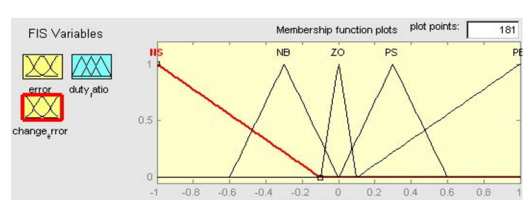

Fig.9 : The Membership Function plots of change error

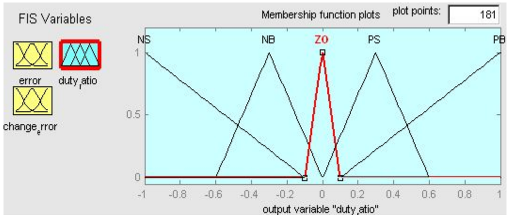

Fig.10 : The Membership Function plots of duty ratio

4.2 FUZZY LOGIC TABLE RULES

Fuzzy control rules are obtained from the analysis of the system behavior. In their formulation it must be considered that using different control laws depending on the operating conditions can greatly improve the converter performances in terms of dynamic response and robustness.

First, when the output voltage is far from the set point i.e error (e) is PB or NB, the corrective action done by the controller must be strong i.e duty cycle close to zero or one in order to have the dynamic response as fast as possible, obviously taking into account current limit specifications.

Second, when output voltage error approaches zero i.e error (e) is NS, ZE, PS the current error should be properly taken into account similarly to current-mode control, in order to ensure stability around the working point. Finally, when the current approaches the limit value, suitable rules must be introduced in order to perform the current limit action while preventing large overshoots.

These fuzzy control rules for error and change of error can be referred in the table that is shown in Table II

Table II : Table rules for error and change of error

(de) \ (e)	NB	NS	ZO	PS	PB
NB	NB	NB	NB	NS	ZO
NS	NB	NB	NS	ZO	PS
ZO	NB	NS	ZO	PS	PB
PS	NS	ZO	PS	PB	PB
PB	ZO	PS	PB	PB	PB

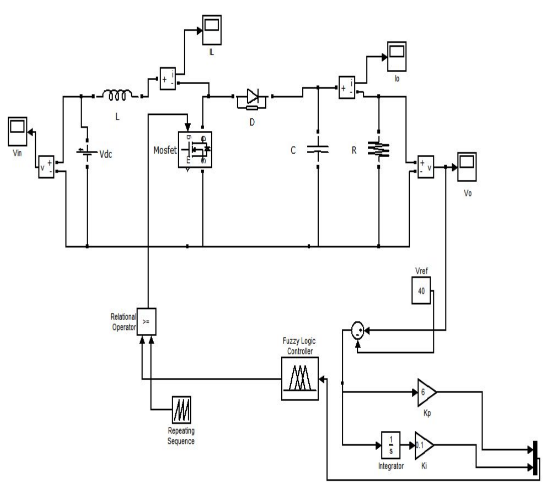

Fig.11: Closed loop simulink model of Boost converter using Fuzzy logic Controller

V. RESULTS AND DISCUSSION

The evaluation on this dc-dc boost converter, analyzes had been performed. The input voltage was set at 20 V and the voltage reference was set at 40 V. The output voltage, output current, inductor current, capacitor voltage, MOSFET voltage, diode voltage, step response etc for the open loop and closed loop circuit had been evaluated and the simulation results were taken.

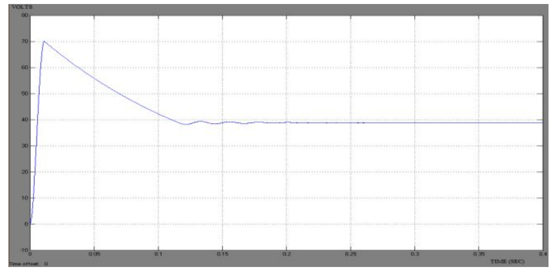

Fig.12: output waveform for Boost convereter using open loop control

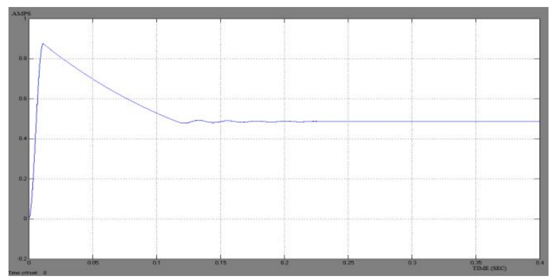

Fig.13: output current for Boost Converter using open loop control

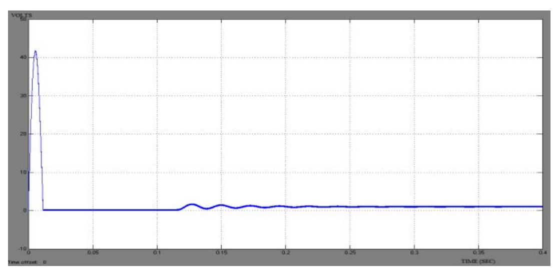

Fig.14: Inductor current for Boost Converter using open loop control

From Fig.12, the output voltage of the open loop circuit showed that voltage boost up for a value of 72 V and after some time it settles down to 39.345v. This showed that open loop circuit produced an overshoot voltage however this scenario did not happen in closed loop circuit. From Fig.13, shows the output current for Boost converter. The current first reaches to 0.8 Amps and comes to 0.5Amps. From Fig.14, shows the inductor current for Boost converter.

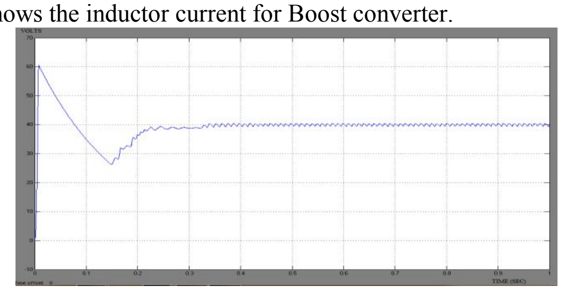

Fig.15 : Output voltage for Boost Converter using PI controller

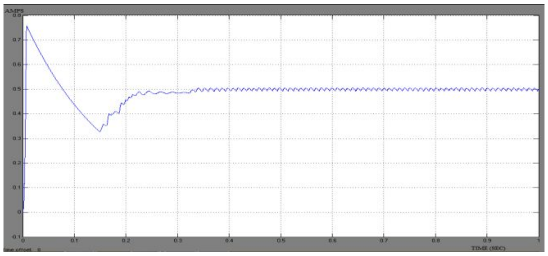

Fig.16: output current for Boost converter using PI controller

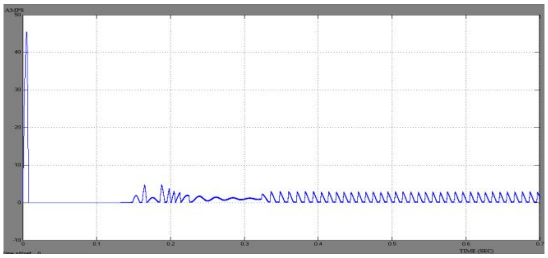

Fig.17: Inductor current for Boost converter using PI controller

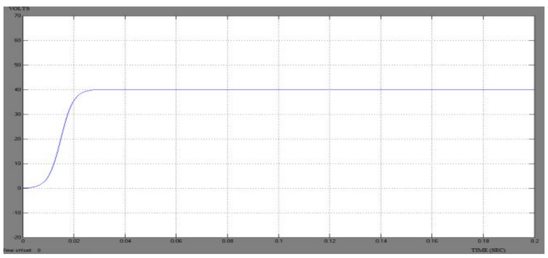

Fig.18: output voltage for Boost converter using FLC

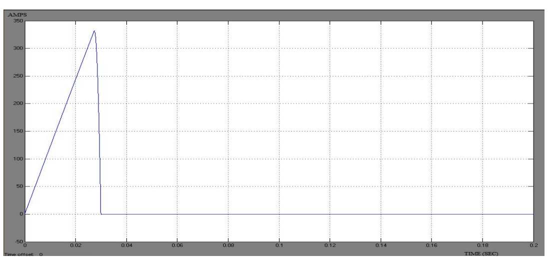

Fig.19: Inductor current for Boost converter using FLC

In closed loop circuit the output voltage boost up till 40 V. The fuzzy logic controller plays it roles to control the voltage output as the desired requirement. It proved that the fuzzy logic controller successfully control the overshoot value better than system without fuzzy logic controller with the same input voltage 20V and the settling time for the closed loop converter is much faster.

The system with fuzzy logic controller had controlled the current of output by driving it to produce the desired current that needed by the system and eliminating the overshoot current. The scenario is at the inductor current simulation results when the inductor current closed loop circuit and the settling time for the closed loop converter is much faster.

VI. COMPARISONS

The comparisons on simulation results between open loop circuit and closed loop circuit obviously can be continued in determining on the others components in the circuit such as capacitor voltage results in Fig.12 and Fig.18. All the simulation results between open loop circuit and closed loop circuit shows that the closed loop circuit gives a fast settling time value that was controlled by fuzzy logic controller. This purposely achieved in order to correspond on the output desired of the system

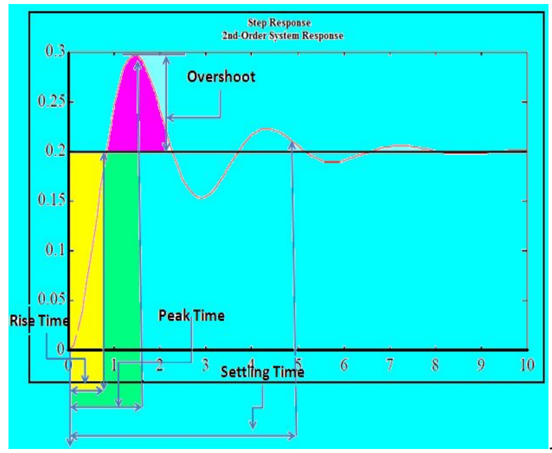

Fig. 20: 2nd Order of Step Response Reading on overshoot Ratio, Rise Time, Peak Time and Settling Time.

The comparison analysis between open loop and closed loop were continue on the simulation result based on the output voltage deviation, voltage overshoot percentage, rise time, peak time and settling time. This comparison is based on the 2nd order Step Response System.

Table III: Comparision of open loop and closed loop control for Boost convereter using Time Domain Specifications

Type of Control method	Delay Time (T_d)	Rise Time (T_r)	Peak Time (T_p)	Peak Overshoot Ratio (%)	Settling Time (T_s)
Open Loop Control	0.01	0.02	0.03	0.79%	0.16
Fuzzy logic Controller	0.05	0.01	0.015	0.07%	0.03

Table IV: Deviations in voltages for open loop and closed loop control for boost converter.

Type of control method	Input Voltage (v)	Ref voltage (v)	Output voltage (v)	Deviation (v)	Deviation (%)
Open Loop Control	20	40	39.864	0.1357	0.34%
Fuzzy Logic Controller	20	40	39.968	0.0316	0.08%

CONCLUSION

Design of a fuzzy logic controller on control boost dc-dc converter by using MATLAB has been successfully achieved. A simple algorithm based on the prediction of fuzzy logic controller, possibly using the fuzzy rules parameter, is showing to be more convenient than the circuit without fuzzy. As the 20 V input on the output voltage for the closed loop circuit with fuzzy logic controller with 0% overshoot shows the better performance compared to the open loop circuit without fuzzy logic controller whereby it has 80% overshoot. Moreover, the value of the output current also improving corresponds to the system and produce a constant value for the output current as 0.2 A. This scenario would not happen to the output current of the open loop circuit. Using a closed loop circuit with fuzzy logic controller, it is confirmed that the boost dc-dc converter gives a value of output voltage exactly as circuit requirement. Hence, the closed loop circuit of boost dc-dc converter controlled that by fuzzy logic controller confirmed the methodology and requirement of the proposed approach. These studies could solve many types of problems regardless on stability because as we know that fuzzy logic controller is an intelligent controller to their appliances.

REFERENCES

[1] " Fuzzy Logic Controller on Dc - Dc Boost Convereter ", N.F Nik Ismail, I. Musirin, D.Johari, 2010 International Conference.

[2] Maksimovic D, Stankovic AM, Thottuvelil VJ verghese GC. "Modelling and simulauion of power electronic converters". Proceedings of the IEEE volume 89, issue 6, June 2001 Page(s):898-912.

[3] W.C. & Tse C.K "Development of a fuzzy logic controller for DC/DC converters: Design, computer simulation, and experimental evaluation". IEEE Transactions on Power Electronics.

[4] V.S.C.Raviraj, P.C.Sen "Comparative study of Proportional-Integral, Sliding mode and Fuzzy Logic Controllers for Power Converters".IEEE Trans on Industry Applications, vol.33, No.2, March/April 1997.

[5] Ranganathan Gurunathan and Ashoka K.S.Bhat. "A Zero-voltage Transition Boost Converter Using a Zero-Voltage Switching Auxiliary Circuit".Power Electronics, IEEE Transactions ov Vol.17,Issue 5,Sept.2002 Page(s):658-668.

[6] K.Viswanathan, D.Srinivasan, and R.Oruganti, "A Universal Fuzzy Controller for a Non-linear Power Electronic Converter" IEEE International Conference on Fuzzy Systems, 2002.Vol.1.