

FUZZY LOGIC CONTROLLER ON CONTROL BOOST DC-DC 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 software. The objective of this proposed methodology is to develop fuzzy logic controller on control boost dc-dc converter using MATLAB 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.

Keywords – Fuzzy Logic Controller, Boost Converter, Dc-Dc Converter, MATLAB Software

1.0 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.

1.1 Boost Dc-Dc Converter

The boost converter is one of the most important nonisolated step-up converters. A boost converter is a power converter with an output dc voltage greater than its input dc voltage [1]. It is a 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 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.

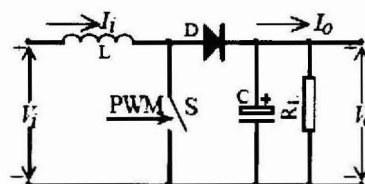


Figure 1: A basic Boost DC-DC Converter

1.2 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 [2].

1.3 Controller Element

Conventionally, 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 [3]. 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. The fuzzy logic controller serves as intelligent controller for this propose. This methodology can be easily applied to many dc-dc converter topologies such as Buck, Boost and Buck-Boost.

1.4 Literature Review

L. A. Zadeh presented the first paper on fuzzy set theory in 1965. Since then, a new language was developed to describe the fuzzy properties of reality, which are very difficult and sometime even impossible to be described using conventional methods. Fuzzy set theory has been widely used in the control area with some application to dc-to-dc converter system. A simple fuzzy logic control is built up by a group of rules based on the human knowledge of system behaviour. Matlab/Simulink simulation model is built to study the dynamic behaviour 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 figure 2 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 [4].

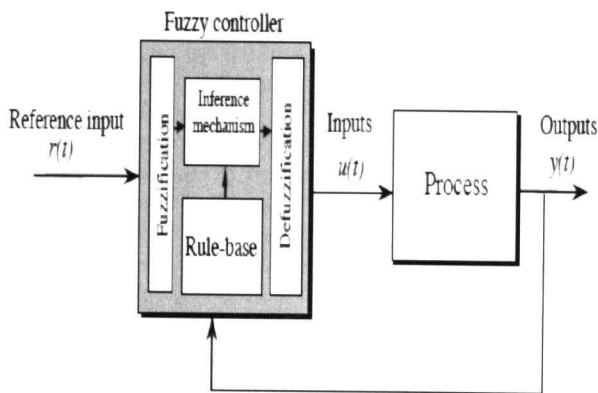


Figure 2: General structure of the fuzzy logic controller on closed-loop system [4].

The fuzzy control systems are based on expert knowledge that converts the human linguistic concepts into an automatic control strategy without any complicated mathematical model [5]. Simulation is performed in boost converter to verify the proposed fuzzy logic controllers.

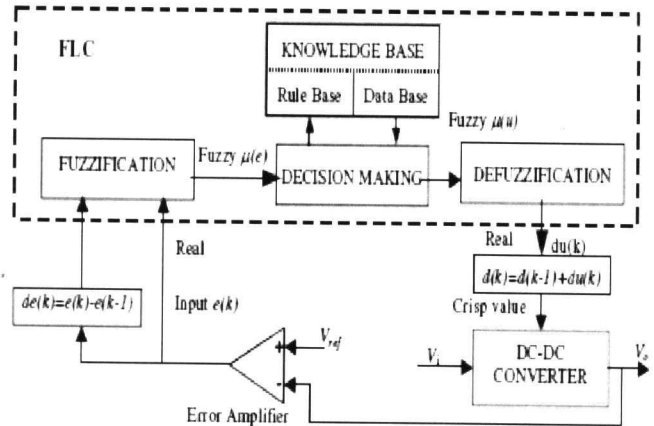


Figure 3: Block diagram of the Fuzzy Logic Controller (FLC) for dc-dc converters [5].

1.5 Scope of Work

This research is focusing on developing fuzzy logic controller on control boost dc-dc converter using MATLAB software. An open loop dc-dc converter will be tested for its performance. A closed loop version of the converter with FLC will also be tested. The comparison between open loop and closed loop converters efficiency is measured.

2.0 METHODOLOGY

This section explains the methodology to be employed in this project. Figure 4 shows the procedures that will be taken in the process of completing this project.

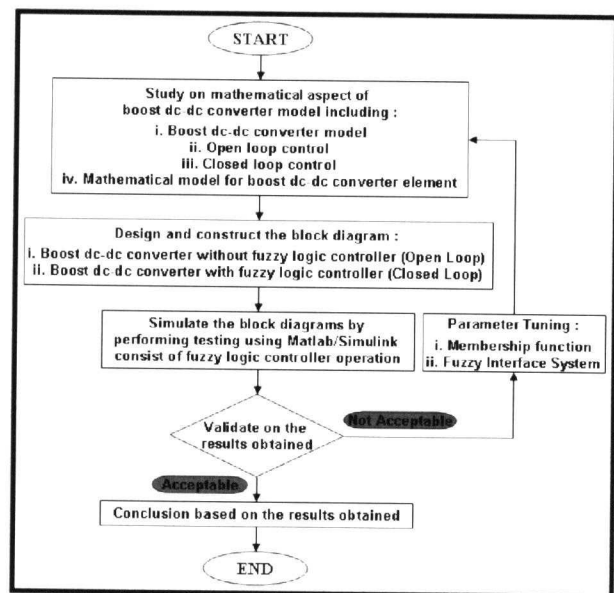


Figure 4: Methodology Flowchart.

2.1 MATLAB/Simulink

Many research reports on boost dc-dc converter on fuzzy logic controllers have been study. A group of commonly adopted input attributes stated chosen to construct the comparison fuzzy controller predictors in order to verify the validity of the adopted scheme.

In order to achieve above target, the simulation performed using the MATLAB/Simulink 7.0 will be introduced to carry out all signal processing and analyzing. MATLAB is a powerful tool for high performance language in technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. MATLAB features a family of add-on application-specific solutions called toolboxes. Very important to most of the users of MATLAB, toolboxes allow you to learn and apply specialized technology. Toolboxes are comprehensive collections of MATLAB functions that extend the MATLAB environment to solve particular classes of problems. Areas in which toolboxes are available including boost chopper, dc-dc converter, control systems, fuzzy logic, simulation, and many others.

2.2 Fuzzy Logic Controller for Boost Dc-Dc Converter

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. 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 [6].

2.3 Analytical Expressions

There are few types of power switches in order to develop the design. The common power switches are BJT, power MOSFET, IGBT etc. Since the characteristics of the MOSFET are fast switching and voltage driven, they have been chosen for the power switching in this designing requirement. In this case, the parameters value of design requirement for the boost dc-dc converter is been set. The value of the parameter can be determined as illustrated in Table I below:

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

Peak transistor current equals to, I_{in}

$$I_{in} = \frac{P}{V_{in}} \quad (1)$$

Voltage rating requirement equals to, V_{Tmax}

$$V_{Tmax} = V_{out} + V_F (\text{diode}) \quad (2)$$

Designing the inductor for boost converter, assumption made for ripple current at 15%. So that, the calculation on the change of the inductor current, ΔI_L

$$\Delta I_L = \frac{15}{100} I_L \quad (3)$$

Inductor minimum value is equals to, L

$$L = \frac{1}{f} (V_{out} + V_F - V_{in}) \left(\frac{V_{out} + V_F}{V_{in}} \right) \frac{1}{\Delta I_L} \quad (4)$$

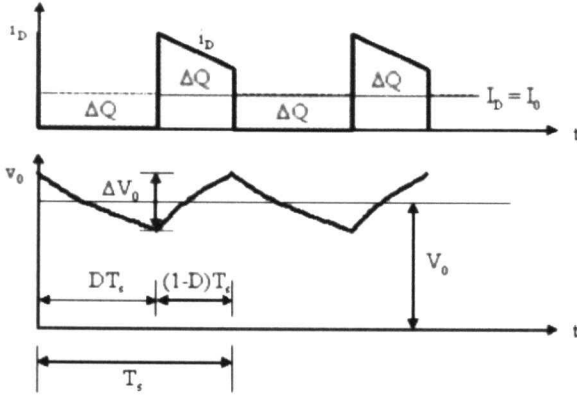


Figure 5: Output Voltage Ripple

By assuming the diode current, I_D is a square wave form in Figure 5, so that the peak diode current, $I_{D,peak}$

$$I_{D,peak} = \frac{I_o}{D} \quad (5)$$

RMS diode current, $I_{D,rms}$

$$I_{D,rms} = I_{D,peak} \cdot \sqrt{D} \quad (6)$$

RMS capacitor current, $I_{C,rms}$

$$I_{C,rms} = \sqrt{I_{D,rms}^2 - I_o^2} \quad (7)$$

Output voltage ripple, ΔV_o

$$\Delta V_o = \frac{\Delta Q}{C} = \frac{I_{C,rms} DT_s}{C} \quad (8)$$

Therefore the capacitance value is equals to, C

$$\therefore C = \frac{\Delta Q}{\Delta V_o} = \frac{I_{C,rms} DT_s}{\Delta V_o} \quad (9)$$

2.4 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 [7].

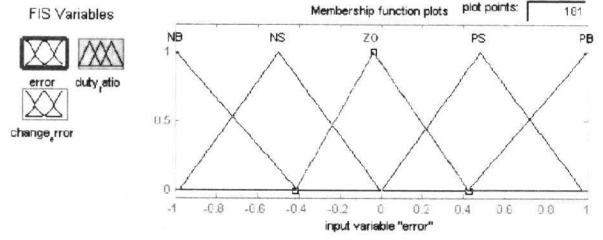


Figure 6: The Membership Function plots of error.

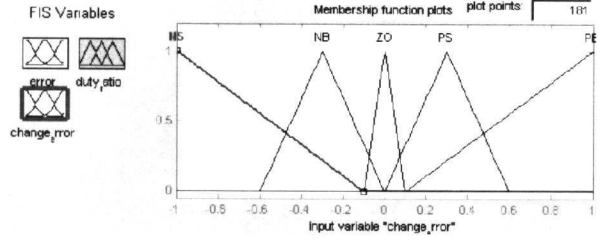


Figure 7: The Membership Function plots of change error.

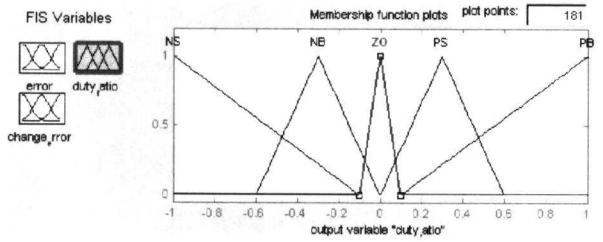


Figure 8: The Membership Function plots of duty ratio.

2.5 Fuzzy Logic Table Rules

The objective of this dissertation is to control the output voltage of the boost converter. The error and change of error of the output voltage will be the inputs of fuzzy logic controller. These 2 inputs are divided into five groups; NB: Negative Big, NS: Negative Small, ZO: Zero Area, PS: Positive small and PB: Positive Big and its parameter [8][9][10]. These fuzzy control rules for error and change of error can be referred in the table that is shown in Table II as per below:

Table II

Table rules for error and change of error.

(e) \ (de)	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

2.6 Block Diagrams Of Boost Dc-Dc Converter

By using Simulink in MATLAB the simulation has been carried on with two types of simulations, open loop circuit and closed loop circuit. Figure 10

shows the block diagram of boost dc-dc converter simulation open-loop circuit and Figure 11 shows the block diagram of boost dc-dc converter controlled with fuzzy logic controller simulation closed-loop circuit. These simulations have been executed and the results have been analyzed.

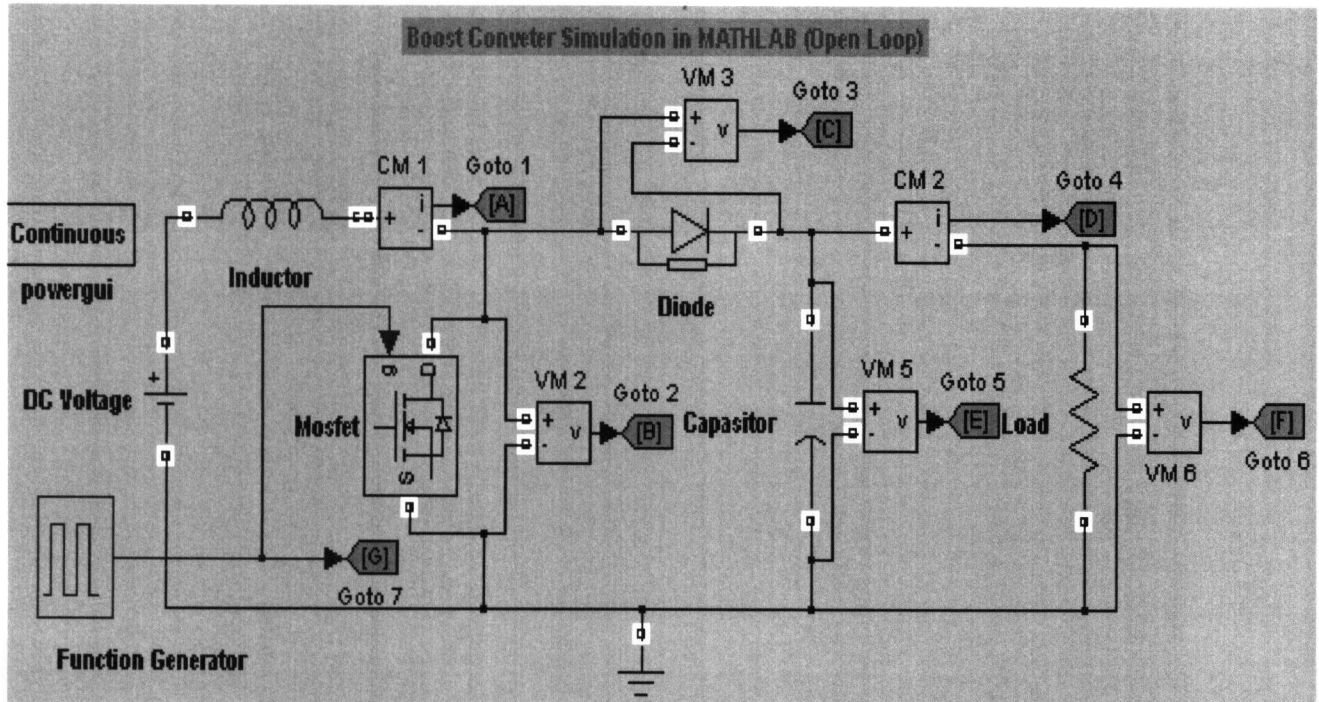


Figure 10: Block diagram of boost dc-dc converter simulation (Open Loop).

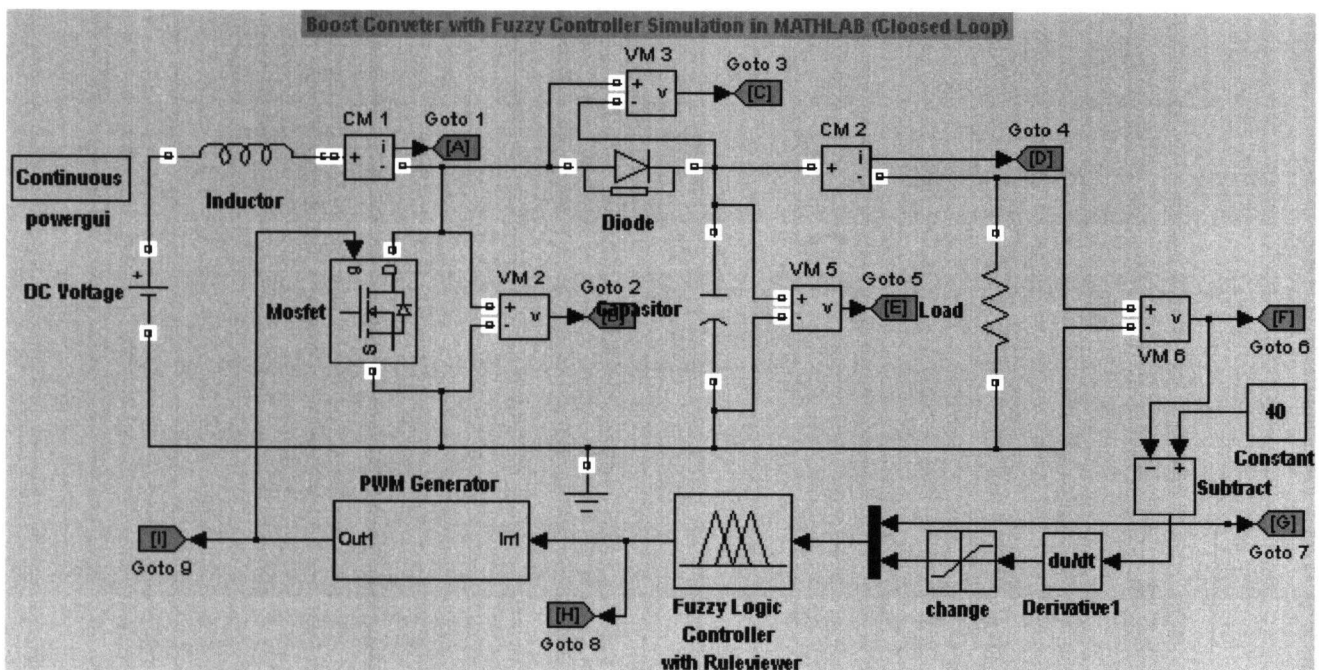


Figure 11: Block diagram of boost dc-dc converter with fuzzy logic controller simulation (Closed Loop).

3.0 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. The simulation had been carried out accordingly based on the calculated value as follows:

$$V_{in} = 20 \text{ volt}, V_{ref} = 40 \text{ volt}, R = 80 \text{ ohm}, C = 2100 \mu\text{F}, \\ L = 1.55 \text{ mH}, \text{Sample time}, T_s = 5 \mu\text{sec}, \text{PWM sample time } 10 \mu\text{sec}$$

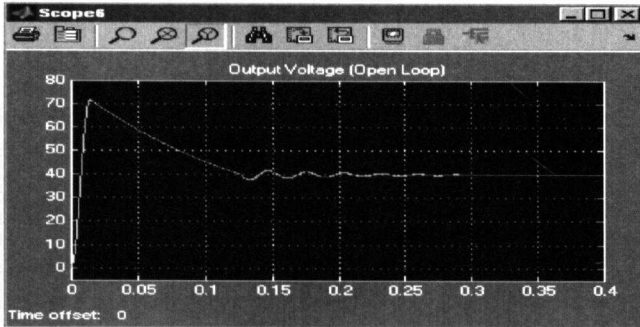


Figure 12 (a): Results on Output Voltage for open loop circuit boost dc-dc converter.

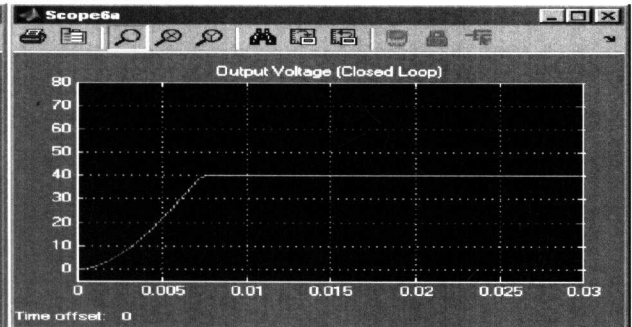


Figure 12 (b): Results on Output Voltage for closed loop circuit boost dc-dc converter.

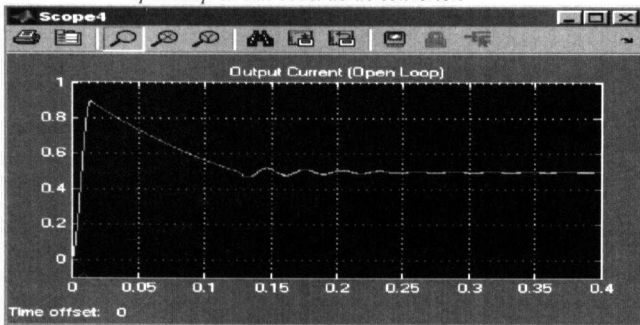


Figure 13 (a): Results on Output Current for open loop circuit boost dc-dc converter.

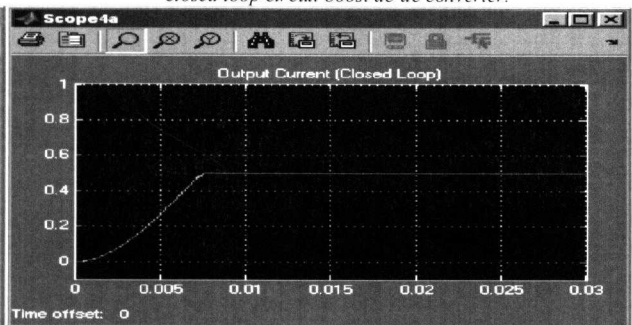


Figure 13 (b): Results on Output Current for closed loop circuit boost dc-dc converter.

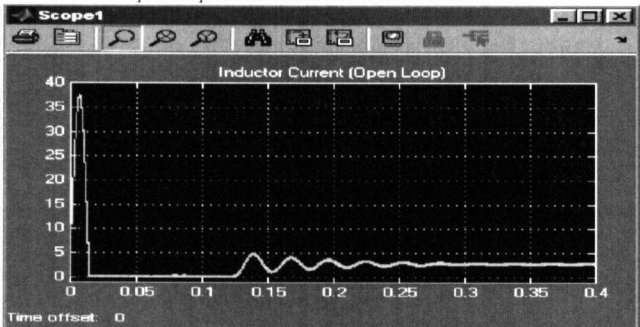


Figure 14 (a): Results on Inductor Current for open loop circuit boost dc-dc converter.

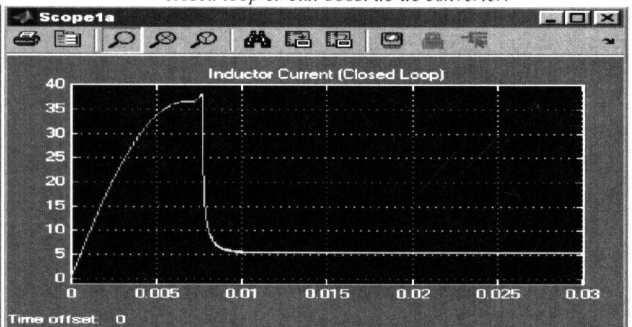


Figure 14 (b): Results on Inductor Current for closed loop circuit boost dc-dc converter.

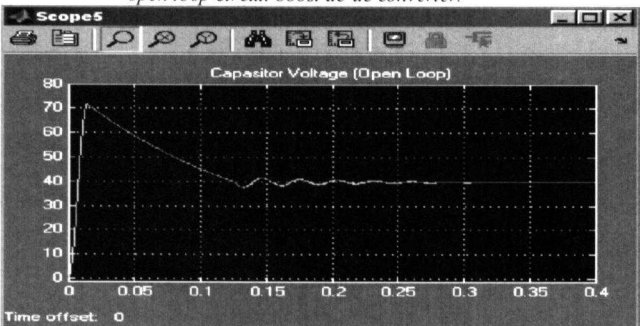


Figure 15 (a): Results on Capacitor Voltage for open loop circuit boost dc-dc converter.

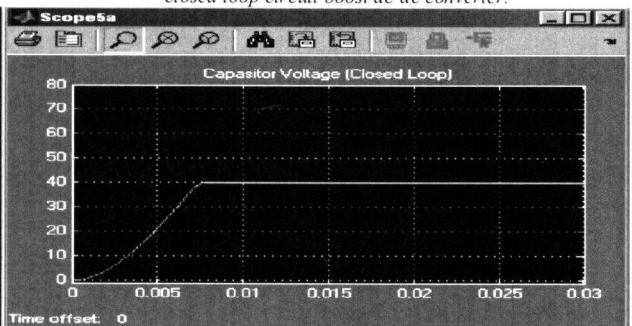


Figure 15 (b): Results on Capacitor Voltage for closed loop circuit boost dc-dc converter.

Figure 12 (a) and 12 (b) shows the simulation results on the output voltage of the open loop and closed loop circuit. At output voltage of the open loop circuit showed that voltage boost up for a value of 72 V. This showed that open loop circuit produced an overshoot voltage however this scenario did not happen in closed loop circuit. In closed loop circuit the output voltage boost up till 40 V. The fuzzy logic controller plays its role 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.

Next take a look at the output current simulation results on Figure 13(a) for open loop circuit and Figure 13(b) for closed loop circuit. 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. Figure 14(b) shows a constant value very fast. Neither happened on the inductor current of open loop circuit in Figure 14(a). It did not give a constant value very fast and moreover it also produces a high overshoot value on the early stage. Thus, the comparison 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 Figure 15(a) and 15(b). 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.

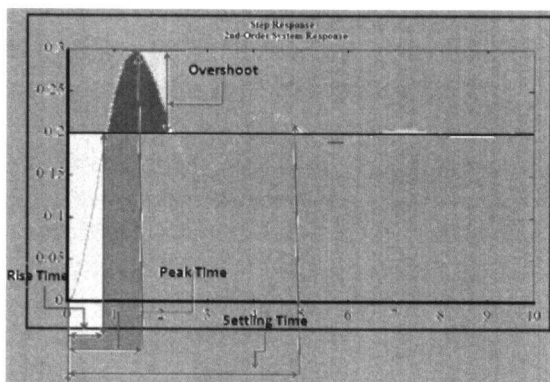


Figure 16: 2nd Order of Step Response Reading on Overshoot Ratio, Rise Time, Peak Time and Settling Time.

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. This analysis is shown as Figure 16 where the reading on overshoot ratio, rise time, peak time and settling time were taken.

Table III

The reading on Peak Overshoot Ratio, Rise Time, Peak Time and Settling Time from open loop circuit boost dc-dc converter.

Voltage Input (V)	Voltage Reference (V)	Peak Overshoot Ratio (%)	Rise Time (mS)	Peak Time (mS)	Settling Time (mS)
20	30	0.86%	5.5350	10.6000	391.2000
20	35	0.84%	6.2720	12.8000	363.4000
20	40	0.79%	7.4050	13.7000	311.4000

Table IV

The reading on Peak Overshoot Ratio, Rise Time, Peak Time and Settling Time from closed loop circuit boost dc-dc converter.

Voltage Input (V)	Voltage Reference (V)	Peak Overshoot Ratio (%)	Rise Time (mS)	Peak Time (mS)	Settling Time (mS)
20	30	0.17%	6.3784	6.4264	6.6648
20	35	0.15%	7.0102	7.0445	7.1615
20	40	0.08%	7.6852	7.7031	7.7345

Based on the simulation results obtained and shown in Table III and Table IV, those circuits shown that both are having a different rise time, peak time and also have a different settling time. However, the analysis shows that the closed loop circuit with fuzzy controller is having the faster rise time and settling time.

Table VI

The deviations of voltage resulted from open loop circuit boost dc-dc converter.

Voltage Input (V)	Voltage Reference (V)	Voltage Output (V)	Deviation (V)	Deviation (%)
20	30	29.8613	0.1387	0.46%
20	35	34.8551	0.1449	0.41%
20	40	39.8643	0.1357	0.34%

Table VII

The deviations of voltage resulted from closed loop circuit boost dc-dc converter.

Voltage Input (V)	Voltage Reference (V)	Voltage Output (V)	Deviation (V)	Deviation (%)
20	30	29.9497	0.0503	0.17%
20	35	34.9473	0.0527	0.15%
20	40	39.9684	0.0316	0.08%

The analysis on the deviation of voltage resulted that the difference between reference voltage setting and the output voltage is always lesser. The comparison between open loop and closed loop in Table VI and Table VII show that the open loop circuit having a bit higher on the deviation of voltage. The closed loop circuit boosts has a lesser deviation of voltage and proved that it is such a better performance on control the deviation of voltage during the boost mode.

4.0 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 0.5 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.

5.0 ACKNOWLEDGMENTS

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