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Simulation of PWM DC-DC Boost Converter Using Fuzzy Logic Controller

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Abstract

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 semiconductor and at least one energy storage element. Boost converter is a dc-to-dc converter that steps up the dc voltage from its fixed low level to a desired high level. Crucial with these demands, many researchers or designers have been struggling to find the most economical, reliable and stable controller to meet these demands. This paper describes the simulation of Pulse Width Modulation (PWM) DC-DC Boost Converter using Fuzzy Logic control. The output voltage was feedback to the input to significantly improve the dynamic performance of boost dc-dc converter. The objective of this proposed methodology is to develop fuzzy logic controller to 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 objective of the work has been achieved successfully. The proposed converter was implemented where the voltage was stepped up from 24v to 48v and controlled by the fuzzy logic controller.

Keywords: Fuzzy Logic Controller, Boost Converter, Pulse width Modulation (PWM), MATLAB Simulink Software

I. Introduction

Digital control of dc-dc converters is an active research topic in power control. Many controllers have been demonstrated (Kelly & Rinne, 2005). DC-DC power converters are employed in a variety of applications, including power supplies for personal computers, office equipment, spacecraft power systems, laptop computers, and telecommunications equipment, as well as dc motor drives. The input to a dc-dc converter is an unregulated dc voltage (Erickson, R. W., & Macsimovic, 2017) . Crucial with these demands, many researchers or designers have been struggling to find the most economical 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. 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 (Ismail, 2010). It is a class of switching-mode power supply (SMPS) containing at least two semiconductor switches 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 DC–DC converters are inherently variable structured because of the switching action (Guo et al., 2012). Therefore, variable structure control with sliding mode is a suitable control solution for DC–DC converters. However, several disadvantages exist for variable structure control with sliding mode. An assumption for sliding mode control is that the control can be switched from one value to another infinitely fast. In practice, it is impossible to change the control infinitely fast because of the time delay for control computations and physical limitations of switching devices (Singh et al., 2013).

As a result, the duty cycle oscillates in steady state, which induces oscillation in the output voltage. With some implementations, the switching frequency is not constant. These practical issues prevent variable structure control from being extensively applied to DC–DC converters (Ismail , 2010). Boost converter is a dc-to-dc converter that steps up the dc voltage from its fixed low level to a desired high level. The controller used in this proposed design is fuzzy logic controller. Indeed, the applications of fuzzy logic, once thought to be an obscure mathematical curiosity, can be found in many engineering and scientific works. Fuzzy logic has been used in numerous applications such as facial pattern recognition, air conditioners, washing machines, vacuum cleaners, anti-skid braking systems, transmission systems, control of subway systems and unmanned helicopters, knowledge-based systems for multi objective optimization of power systems, weather forecasting systems, models for new product pricing or project risk assessment, medical diagnosis and treatment plans, and stock trading.

Fuzzy logic has been successfully used in numerous fields such as control systems engineering, image processing, power engineering, industrial automation, robotics, consumer electronics, and optimization. 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 (Ismail, 2010). Simulation is performed in boost converter to verify the proposed fuzzy logic controller. Many researchers reported successfully adopted Fuzzy Logic Controller (FLC) to become one of intelligent controllers to their appliances (Manuel et al., 2018).

II. II. LITERATURE REVIEW

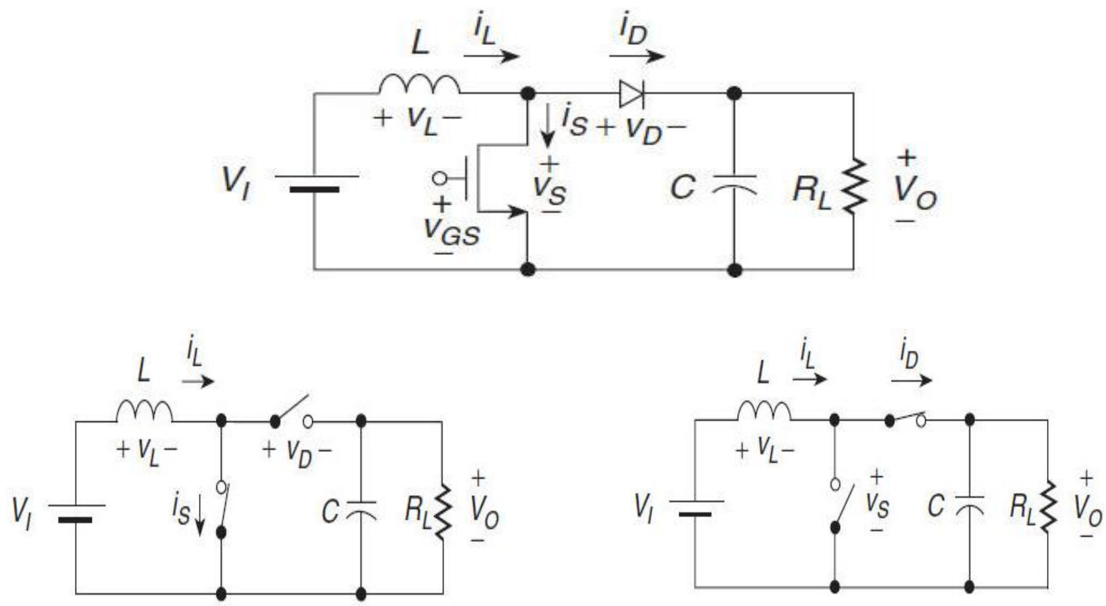
Control of DC-DC converters by direct pole placement and adaptive feed forward gain adjustment was proposed by (Kelly & Rinne, 2005). The control strategy, to eliminate steady-state errors. Mohammed & Devaraj, (2014) design, and simulate of Microcontroller based DC-DC boost converter using Proteus design suite. The microcontroller was used for generating the pulse width (Placeholder1) modulation in open loop mode with fixed duty cycle. The output obtained has a higher percentage of overshoot and smaller time for steady state. Guo et al., (2012) presents the design of a fuzzy controller using variable structure approach for application to DC–DC converters which eliminates much of the trial-and-error commonly associated with fuzzy systems. The comparison shows the startup transient response of fuzzy control with variable structure approach is superior to the startup transient response of fuzzy control with trial and error, while both control methods obtained similar load transient response.

Performance Analysis of Boost Converter Using Fuzzy Logic and PID Controller was proposed by (Shinde & Sankeshwari, 2016). CFLC and PID are applied to the boost converter system to regulate the boost converter output voltage where performance of both closed loop systems are obtained and Comparison of both systems shows the difference. FLC has stable output above applied voltage PID controller has stable output below CFLC and PID controller are used to regulate the boost converter output voltage. Simulation results of the systems shows the responses for the same load change 5 Ω, 10 Ω and their difference with the applied voltage 10 V. This suggests that FLC has stable output above an applied voltage and the boost converter boosted the output voltage on the other hand the PID controller has stable output below an applied voltage. Ismail et al., (2010) developed a Fuzzy Logic Controller on DC / DC Boost Converter. The feedback for significantly improves the dynamic performance of boost dc-dc converter by using MATLAB Simulink software. Fuzzy rules parameter, is showing to be more convenient than the circuit without fuzzy (Kazimierczuk, 2018).

III MATERIALS AND METHOD

1. PWM Boost Converter

The circuit of the PWM Boost DC-DC Converter is shown in Figure 1. Its output voltage V_o is always higher than the input voltage V_I for steady-state operation. It 'boosts' the voltage to a higher level. The converter consists of an inductor L, a power MOSFET, a diode D1, a filter capacitor C, and a load resistor R_L. The switch S is turned ON and OFF at the switching frequency fs = 1/T with the ON duty ratio D = t_{on}/T, where t_{on} is the time interval when the switch S is ON. The boost converter can operate in either continuous or discontinuous conduction mode (CCM or DCM), depending on the waveform of the inductor current. Figure 1 (a-c) shows equivalent circuits of the boost converter for CCM when the switch S is ON and the diode is OFF, and when the switch is OFF and the diode is ON, respectively. Idealized waveforms of the currents and voltages that explain the principle of operation of the converter (Kazimierczuk, 2008.).



(a)

(b) (c)

Figure 1. PWM boost converter and its ideal equivalent circuits for CCM. (a) Circuit. (b) Equivalent circuit with switch ON and the diode is OFF. (c) Equivalent circuit with switch OFF and the diode is ON.

The parameters of the boost converter is shown in table I.

Table I. Component values of the DC-DC Converter

Parameters	**Component Value**	**Unit**
Inductance, L	250	mH
Capacitance, C	1000	µF
Load Resistance.R	25	Ω
Frequency	10000	Hz
Duty Ratio	0.5	---
Input DC Voltage	24	V
Output DC Voltage,	48	V

2. Principle of Operation of PWM Boost Converter

For the time interval $0 < t \leq DT$, the switch is ON. Therefore, the voltage across the diode is $V_D = -V_O$, causing the diode to be reverse biased. The voltage across the inductor is $v_L = V_I$. As a result, the inductor current increases linearly with a slope of VI /L. Consequently, the magnetic energy also increases. The switch current is equal to the inductor current. At t = DT, the switch is turned off by the gate-to-source voltage. The inductor acts as a current source and turns the decreases with a slope of $(V_I - V_O)/L$. The diode current equals the inductor current. During diode on. The voltage across the inductor is $V_L = V_I - V_O < 0$. Hence, the inductor current this time interval, the energy is transferred from the inductor L to the filter capacitor C and the load resistance R_L. At time t = T, the switch is turned on again, terminating the cycle

3. Fuzzy Logic Controller

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 (Ismail, 2010).

The basic Fuzzy Controller Structure and Detailed Block Diagram is shown in figure 2. Figure 3 is the proposed Fuzzy Controller Block Diagram for Boost Converter.

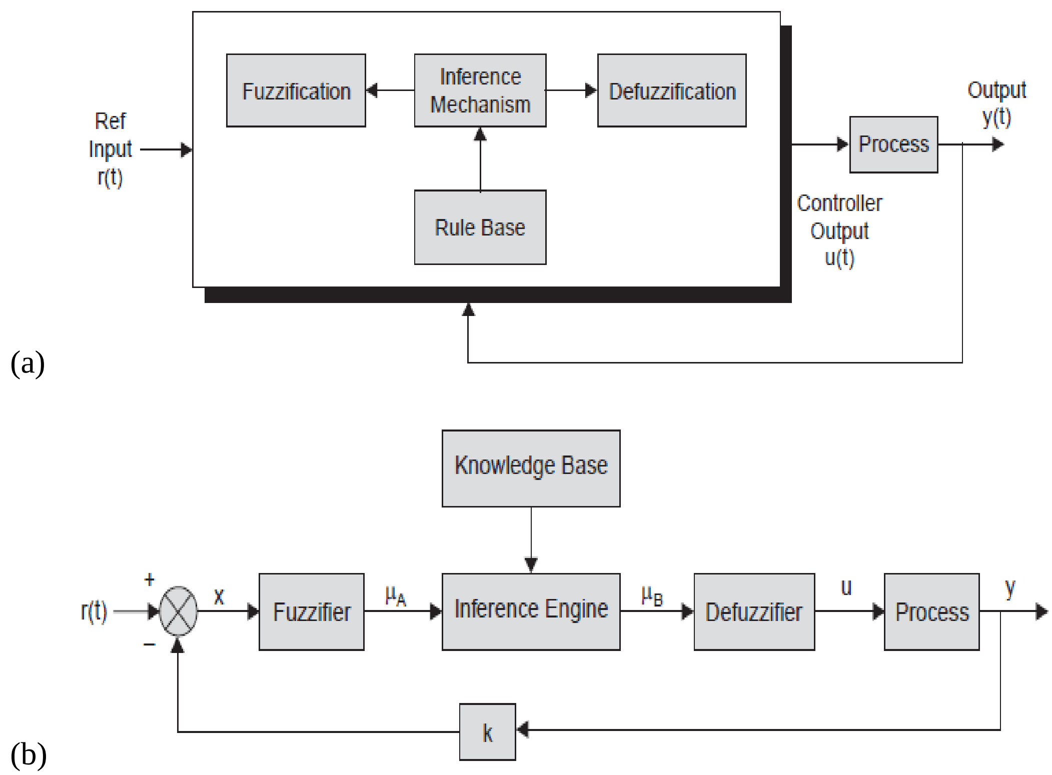


Figure 2. Basic Fuzzy Controller (a) Structure of Fuzzy controller (b) Detailed Block Diagram

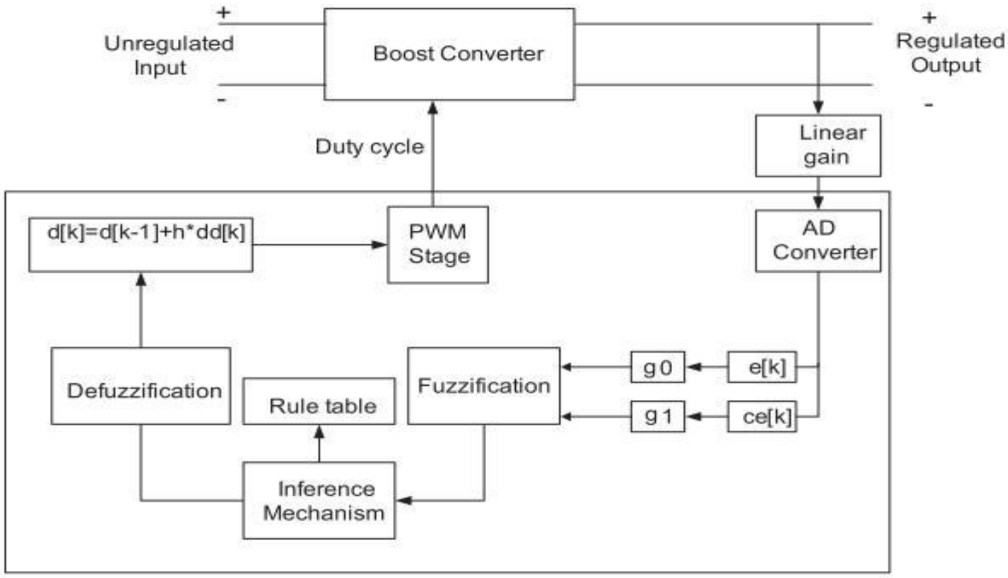


Figure 3. Fuzzy Controller for Boost Converter

The DC-DC boost 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 was designed to control the output of DC-DC boost 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.

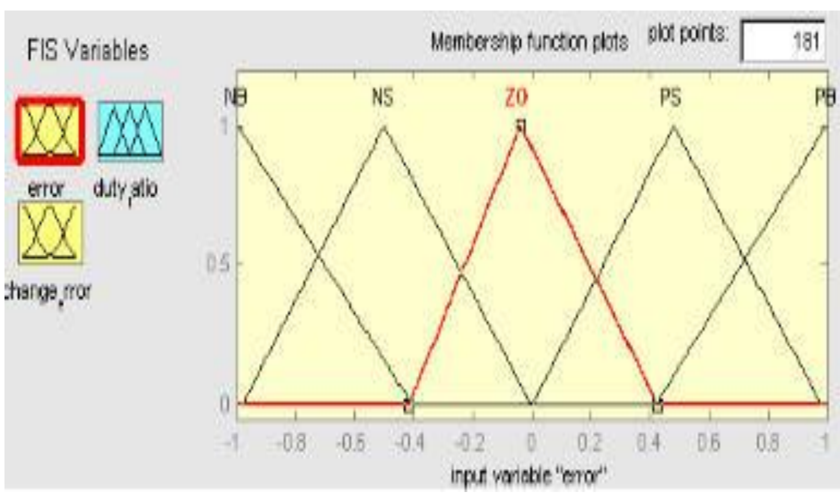


Figure 4: The Membership Function plots of error

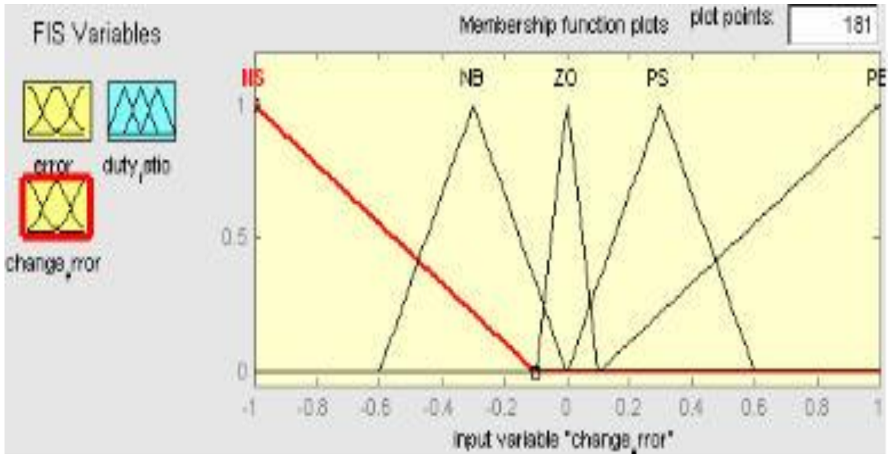


Figure 5. The Membership Function plots of change error

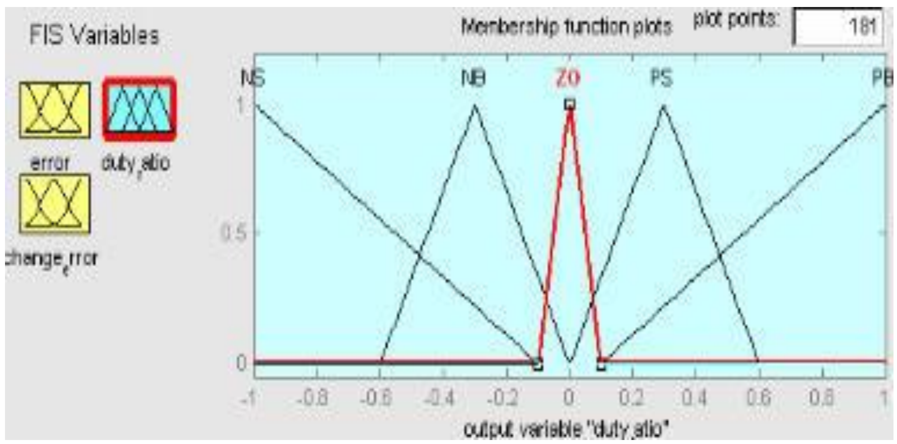


Figure 6: The Membership Function plots of duty ratio

The objective of this work 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. These fuzzy control rules for error and change of error can be referred in the table II below.

Table II. Fuzzy 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

IV. RESULTS AND DISCUSSION

From the result obtained, 24V was applied at the input and a regulated 48V was measured at the output of the Converter with feedback using fuzzy logic controller.

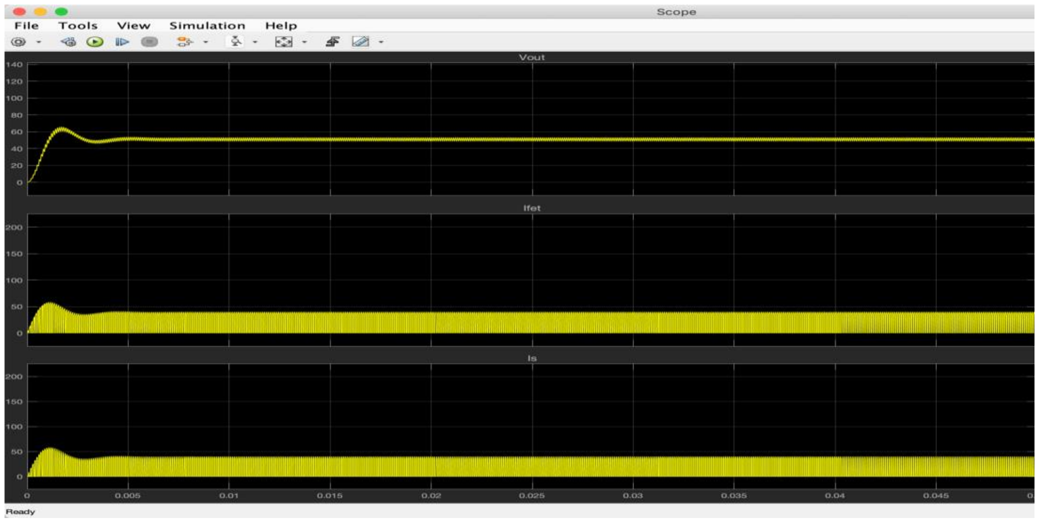


Figure 7. The Output Voltage of the Open-Loop Boost Converter with MOSFET Current and Diode Current

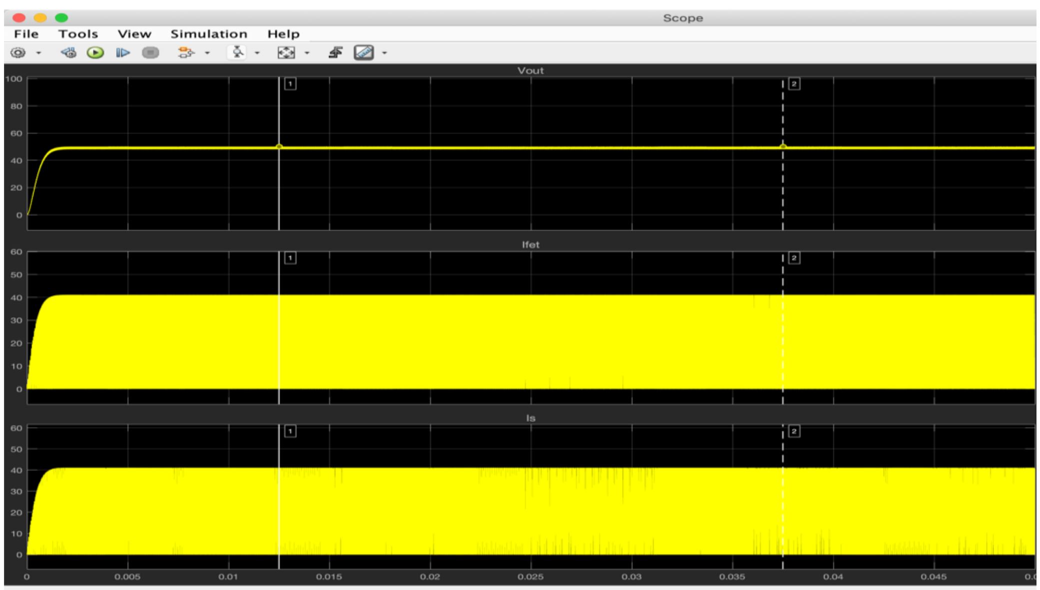


Figure 8. The Output Voltage of the Closed-Loop Boost Converter with MOSFET Current and Diode Current

The voltages of open-loop and closed loop boost converter are shown in figure 9, where the open-loop whose amplitude is 48 V has a very high overshoot of 36.30% and a settling time of 69.34mS. The graphical result and the measurement indicates the instability of the open-loop boost converter.

The closed-loop boost converter using fuzzy logic controller has a more stable output of 48V, an overshoot of 0.09% and a rise time of 0.762mS. Stability has been achieved using the fuzzy logic controller.

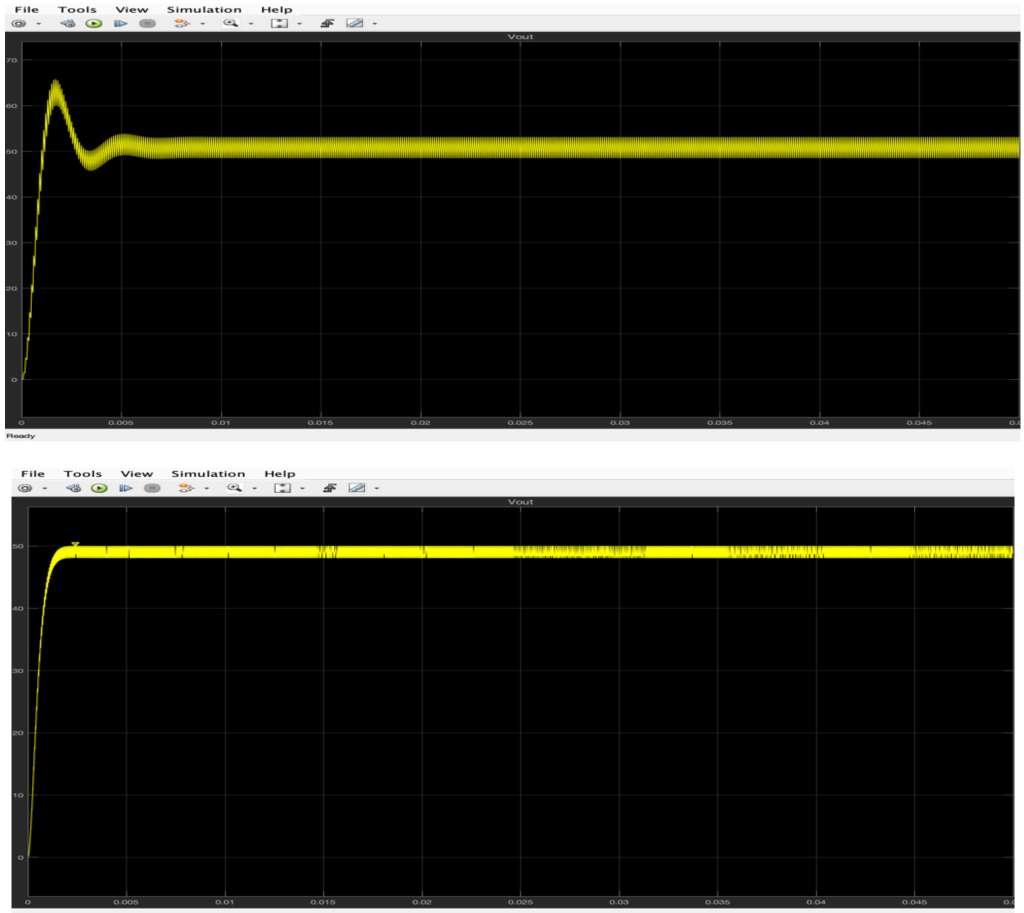


Figure 9. Open-loop and closed-loop Output voltages of Boost Converter

Table III. Measured and Graphical Characteristcs for Open Loop Boost Converter

Input Voltage (V)	Peak Overshoot (%)	Rise Time (mS)	Settling Time (mS)
24	0.80	69.34	34.21

Table IV. Measured Values of Different Reference Voltages and Graphical Characteristcs for Closed Loop Boost Converter with Fuzzy Logic Control

Input Voltage (V)	Reference Voltage (V)	Peak Overshoot (%)	Rise Time (V) (mS)	Settling Time (mS)
24	28	0.20	0.552	0.504
24	38	0.16	0.633	0.559
24	48	0.09	0.762	0.452

From tables III and IV, we can deduce that overshoot is less in closed loop than open loop. The rise time and settling time are also higher in open loop. As the reference voltage decreases, the percent overshoot, rise and settling time decreases.

IV. CONCLUSION

Design of a fuzzy logic controller on PWM DC-DC boost converter by using MATLAB, has been achieved successfully. 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. The closed loop circuit shows less overshoot than the PWM DC-DC open loop circuit. Using a closed loop circuit with fuzzy logic controller confirms that the boost converter gives a more stable, regulated and reliable voltage at the output. These studies could solve many types of problems of stability because as we know that fuzzy logic controller is an intelligent controller to our appliances. It is recommended that future research should look into a hybrid controller for much better performance.

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