

HIGH-PERFORMANCE DOUBLE BOOST DC-DC CONVERTER BASED ON FUZZY LOGIC CONTROLLER

Moe Moe Lwin

Department of Mechatronics Engineering, Yangon Technological University, Yangon City, Myanmar

ABSTRACT

Difference types of DC-DC converter are used in various electronic devices and applications for so many years. But conventional converter cannot afford in high voltage and high current applications. Many researchers have been tried to full-fill the requirements. In this paper, dual stage double boost DC-DC converter is used for data center, high voltage vehicles and renewable system. Many control methods are developed for the control of DC-DC converter. To obtain a control method has the best performance under any condition is always demand. The main objective of this paper is to study the voltage mode control of proposed converter based on fuzzy logic controller (FLC) under the response of different parameters of proposed converter using Matlab/Simulink Software.

KEYWORDS

Dual Stage Double Boost DC-DC Converter, Data Centre, High Voltage Vehicle, Renewable Energy System, Voltage Mode Control, Fuzzy Logic Controller (FLC)

1. INTRODUCTION

DC-DC converters are used in many different applications like electric vehicles, distributed DC systems, electric traction, machine tools, fuel cell, special electrical machine drives and solar PV based applications. DC-DC converter can convert low input voltage to high output voltage (required voltage) [1]. But, the basic boost topology does not provide a high boost factor. This has led to many proposed topologies [1]. If a very high voltage gain is required, it may be more beneficial to use of two or more series connected (cascaded) boost converters. This approach gives some advantages, but it creates new challenges in the same time. Main advantages include a high voltage gain, a good power decoupling between the output and input, better utilization of semiconductors, presence of an intermediate DC bus. Main drawbacks are more complex circuit, more complex controls and a potential stability problem [2]. DC-DC boost converter is specialized making control in this paper. Schematic diagram of DC-DC boost converter in solar energy application system is described in Figure. 1.

The classical control methods employed to design the controllers for double boost converter depends on the operating point so that it is very difficult to select control parameters because of the presence of parasitic elements, time varying loads and variable supply voltages [3]. Conventional controllers require a good knowledge of the system and accurate tuning in order to obtain the desired performances [5]. Neural Network Controller (NNC) are gaining popularity in modeling, identification and control of power electronic converters [6]. The linear controllers such as Proportional (P), Proportional-Integral (PI) and Proportional-Integral-Derivative (PID) control were widely used to control the active performance of the converter [4]. However, the linear control of converter is not sufficient to face the changes in line voltage or load current. Hence non-linear controlling techniques such as Fuzzy Logic Control (FLC), Neuro-Fuzzy Logic

Control (NFLC), Adaptive Neural Network (ANN) and Genetic algorithm (GA) controlling techniques are implemented to increase the performance of the converter [7].

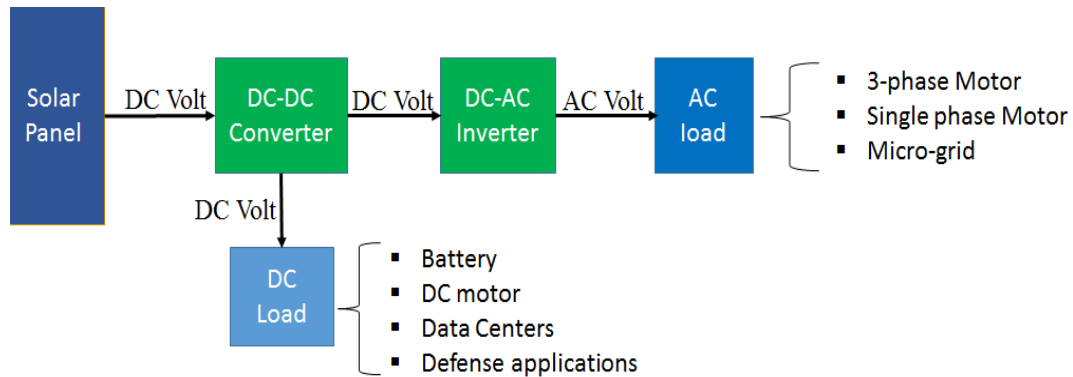


Figure 1. Schematic diagram of solar energy application system

In this regard, the objectives of this study are to propose a simple and efficient method of advanced converter based on the properties of simple boost converter topology and to analyse the performance of proposed method for the voltage loop. The main objectives are to make the constant output voltage to track and to regulate the output dc voltage to desired reference voltage.

2. Design Operation Of Double Boost DC-DC Converter

The double boost DC-DC converter will operate in Continuous Conduction Mode (CCM). The voltage gain of the converter is the product of the voltage gain of each stage. The transistor Q_1 and diode D_1 have to handle the intermediate voltage V_1 , while the transistor Q_2 and diode D_2 have to handle the output voltage V_{out} . For a large voltage gain cascading of two or more boost converters lead to significant reduction of the required transistors power rating, but in the same time it increases required diodes power rating by number of cascaded converter stages [8].

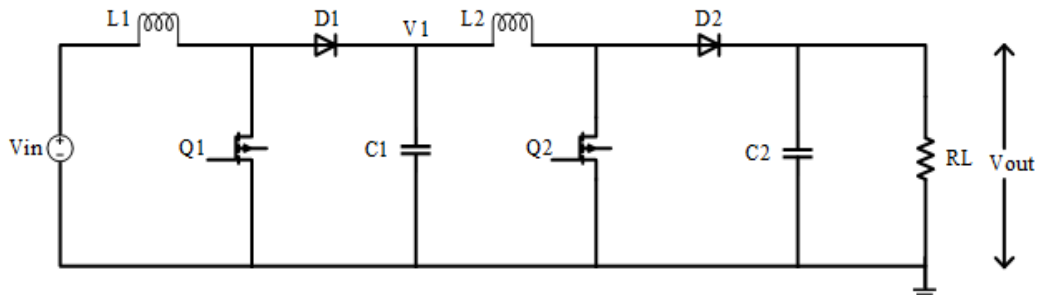


Figure 2. Double boost DC-DC converter

Figure 2. shows the Double Boost DC-DC converter. The inductors L_1 & L_2 have the same values, the diodes D_1 & D_2 are the same type and the same assumption is for the transistors (Q_1 & Q_2). Each inductor has its own switch and thus is similar with the cascading of two single/classic converters. The value two capacitors is different because different voltage storage of the each capacitor.

2.1. For switch ON state; (Discharge time)

When the transistors Q_1 & Q_2 are in ON state, energy transfer from the dc source V_{in} & V_1 into the inductors L_1 & L_2 as shown in Figure 3.

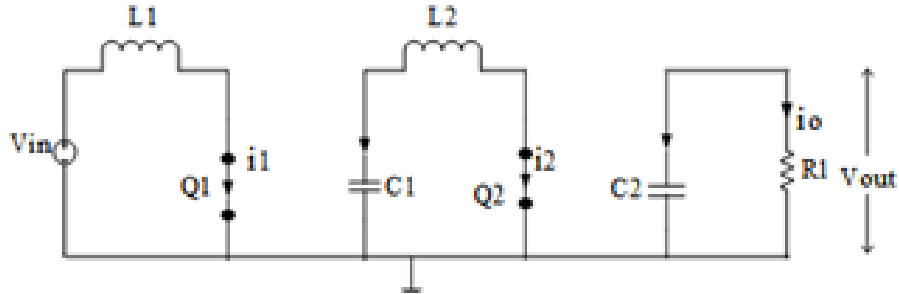


Figure 3. Double boost converter in ON state

$$\frac{di_{l1}}{dt} = \frac{V_{in}}{L_1} \quad (1)$$

$$\Delta i_{l1} = D_1 T \frac{V_{in}}{L_1} \quad (2)$$

$$\frac{di_{l2}}{dt} = \frac{V_1}{L_2} \quad (3)$$

$$\Delta i_{l2} = D_2 T \frac{V_1}{L_2} \quad (4)$$

Where i_1 is the current through inductor/transistor Q_1 , i_2 is the current through inductor/transistor Q_2 , i_o is the output current through load R_L and C is the smoothing capacitor.

2.2. For switch OFF state; (Charge time)

For the charging interval ($Q_1 = Q_2 = \text{OFF}$), the voltage across each inductor is V_{in} & V_1 and the currents $i_1(t)$ and $i_2(t)$ will be as following.

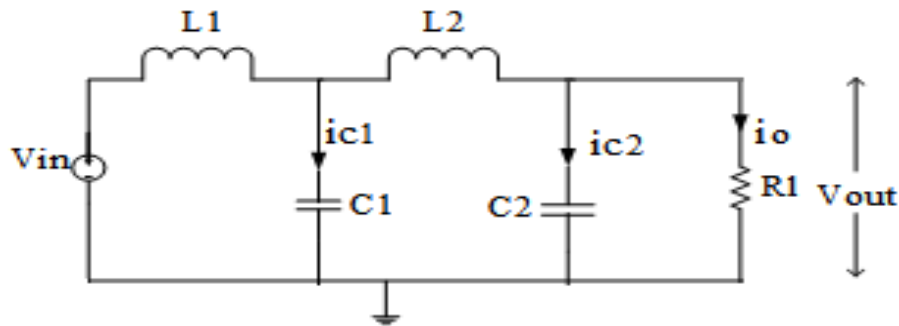


Figure 4. Double boost converter in OFF state

$$\frac{di_{i1}}{dt} = -\frac{V_1}{L_1} \quad (5)$$

$$\Delta i_{i1} = (T - D_1 T) \frac{-V_1}{L_1} \quad (6)$$

$$\frac{di_{i2}}{dt} = \frac{-V_{out}}{L_2} \quad (7)$$

$$\Delta i_{i2} = (T - D_2 T) \frac{-V_{out}}{L_2} \quad (8)$$

To get duty ratio for single converter;

By summing eq. (2) & eq. (6);

$$\Delta i_{i1} + \Delta i_{i2} = 0$$

$$\frac{V_1}{V_{in}} = \frac{1}{1 - D_1} \quad (9)$$

$$M_s = \frac{1}{1 - D_1} \quad (10)$$

To get duty ratio for double boost converter;

By summing eq. (4) & eq. (8);

$$\Delta i_{i1} + \Delta i_{i2} = 0$$

$$\frac{V_{out}}{V_1} = \frac{1}{(1 - D_1)} \quad (11)$$

$$\frac{V_{out}}{V_{in}} = \frac{1}{(1 - D_1)(1 - D_2)} \quad (12)$$

$$M_d = \frac{1}{(1 - D_1)(1 - D_2)} \quad (13)$$

So, the maximum output voltage of the double boost DC-DC converter is

$$V_{out(max)} = \frac{V_{in}}{(1 - D_1)(1 - D_2)} \quad (14)$$

The maximum output current is

$$I_{out(max)} = \frac{V_{in}}{R_{load} * ((1 - D_1)(1 - D_2))} \quad (15)$$

The inductor value can be chosen by using the following equations.

$$L_1 = \frac{V_{in} * D_1}{2 \Delta i_{i1} * f_{s1}} \quad (16)$$

$$L_2 = \frac{V_1 * D_2}{2 \Delta i_{i2} * f_{s2}} \quad (17)$$

Capacitor values can be selected according to the following equations.

$$C_1 = \frac{I_{2(\text{out})} * D_1}{\Delta V_1 * f_{S1}} \quad (18)$$

$$C_2 = \frac{I_{\text{out}(\text{max})} * D_2}{\Delta V_{\text{out}} * f_{S2}} \quad (19)$$

The table 1 in the following figure shows the chosen values of the components of the power section after sizing.

Table 1. Sizing values:

Component	Value or Reference type
Schottky Diode	STPS10M80C
Inductor L1 & L2	L= 4mH
Switch Q1 & Q2	MOSFET IRFP450
1 st Stage output capacity	C1 = 980 μ F
2 nd Stage output capacity	Cout = 1000 μ F
Load resistor	RL=3k Ω

3. METHODOLOGY OF THE PROPOSED SYSTEM

TS type fuzzy logic controller is implemented in the proposed system in form of cascaded design. It is used to control the voltage mode and to get constant output voltage in non-linear condition. TS controller has two input and one output for the double boost converter. The overall schematic diagram is shown in Figure 5.

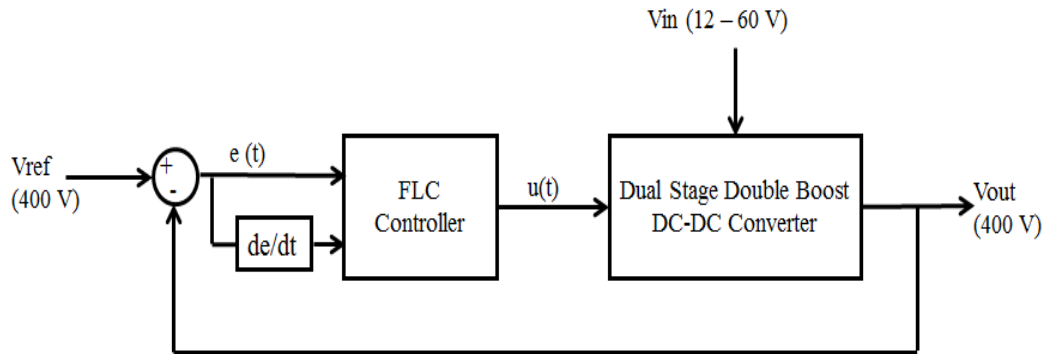


Figure 5. Control design of proposed converter system with FLC controller

The control command is based on a fuzzy logic technique, a relevant strategy offering outstanding performance. The input voltage range of converter is considered between 12 V and 60V. The voltage range of converter is setup from 12 to 400V.

4. FUZZY LOGIC CONTROLLER IMPLEMENTATION DETAILS

The FLC controller is very powerful in the non-linear system. Mamdani inference system and Takagi-Sugeno inference system are commonly used in the control system [7]. Takagi- Sugeno inference (TS) system is used in this paper. The step by step basic operation of the fuzzy logic controller is shown in Figure 6.

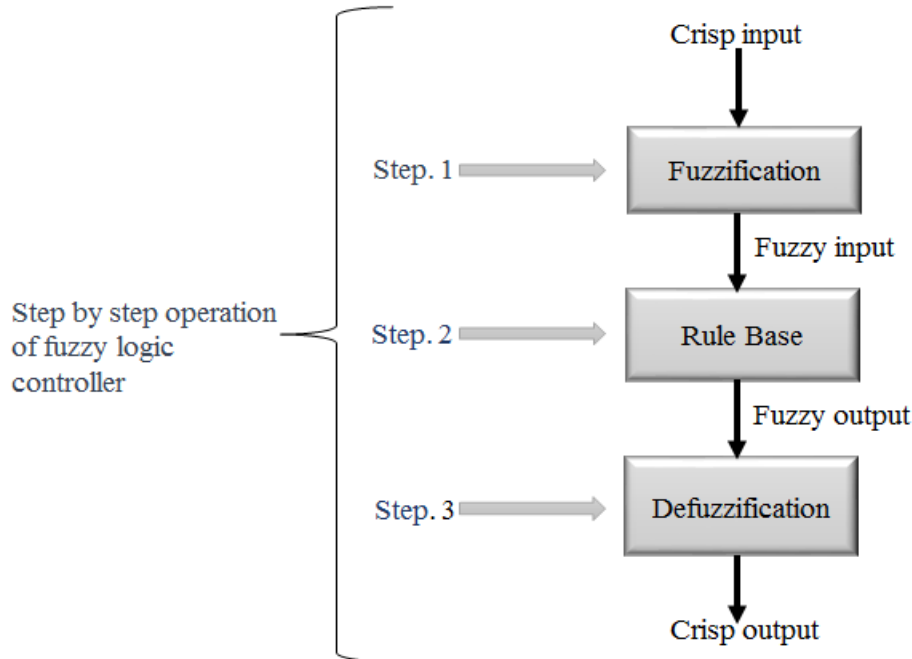


Figure 6. Basic operation of the fuzzy logic controller

4.1. Fuzzification

The membership function values are assigned to the linguistic variables using nine fuzzy subsets.



Figure 7. Fuzzification block

4.2. Inference engine

Sugeno method is used with Min-Max operation fuzzy combination. Fuzzy inference is based on fuzzy rules. Rules are framed in inference engine block. The output membership function of each rule is given by MAX (maximum) operator and MIN (minimum) operator.

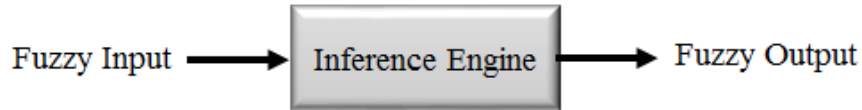


Figure 8. Inference engine block

4.3. Defuzzification

The output of fuzzy controller is a fuzzy subset. As the actual system requires a non-fuzzy value of control, defuzzification is required. Defuzzifier is used to convert the linguistic fuzzy sets back into actual value. Centriod defuzzification method is used in this system.

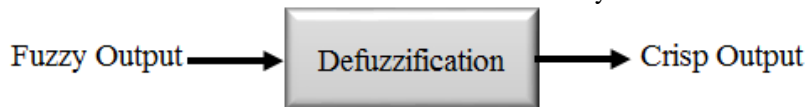


Figure 9. Defuzzification block

4.4. FLC input and output description

The inputs to the TS type FLC voltage mode controller are

- (1) The voltage error (EV) (reference voltage subtracted from actual output voltage) whose operating range is [-1 1]. (20)

$$EV = V_{ref} - V_{out}$$

- (2) The desired target reference voltage is 400V at the different range of input voltage. The change of the voltage error (CEV) whose range is [-1 1].

$$CEV = (EV(k) - EV(k-1)) / T \tag{21}$$

, where T is the period of sampling (and switching time).

We define seven linguistic values;

- (1) Negative Large (NL)
- (2) Negative Medium (NM)
- (3) Negative Small (NS)
- (4) Zero (ZE)
- (5) Positive Small (PS)
- (6) Positive Medium (PM)
- (7) Positive Large (PL)

In most of fuzzy controller antecedent part has multiple parts; the following rule is used in this system:

FR: If E is NVL AND CEV is PVL THEN U is ZE

E and CE are input variables which in design controllers defined by fuzzy logic input, U is output variable, NVL and PVL are the Linguistic variables that can be defined by fuzzy set, the part of “E is NVL” is called the antecedent part and the part of “U is ZE” is called the consequent or conclusion part. The rest of other rules are built in this way. The output of the FLC is U (duty cycle value). Inference system of all the rules is Min-Max operation. Centroid defuzzification method is used in TS controller. The input membership function of voltage error (EV), change in voltage error (CEV), the output membership function (duty cycle value (U)) and control surface of the proposed system are shown in Figure 10, 11 and 12.

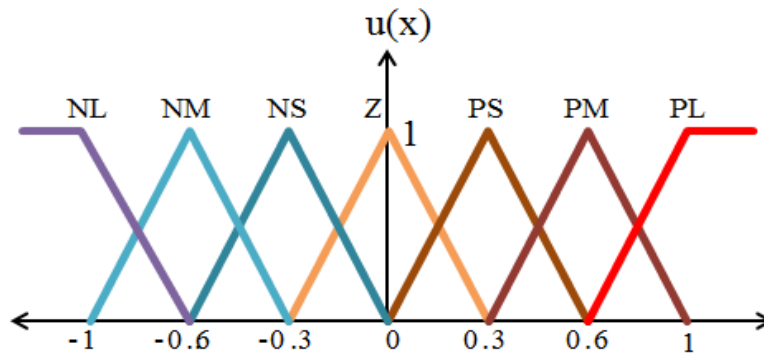


Figure 10. Membership function of voltage error (EV) and change of voltage error (CEV)

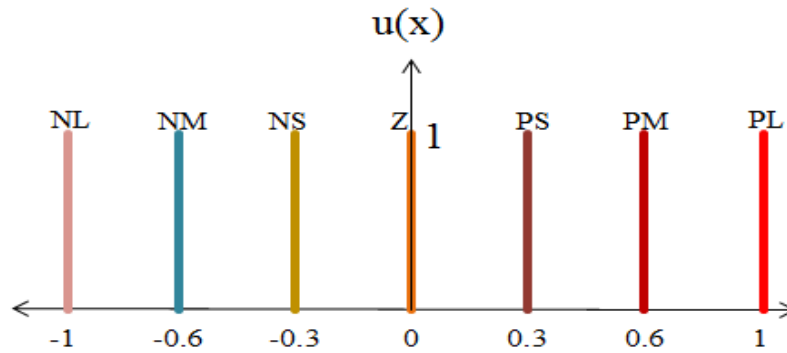


Figure 11. Membership function of output (U)

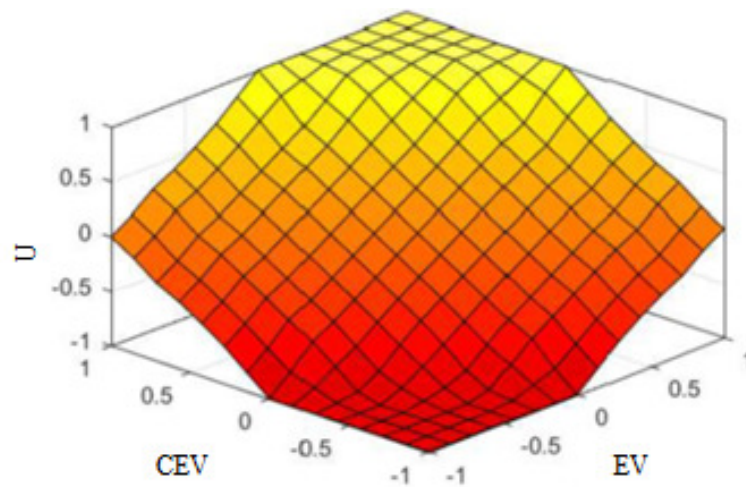


Figure 12. Control surface of the proposed system

The output for the fuzzy logic block is the duty cycle change in order to achieve the desired duty cycle. Seven membership functions are used for each input and output in fuzzification step. The choice of seven memberships gives to the system better representation and precision [5]. After that, the second step which is the fuzzy rule base comes which is a collection of rules that allows linking the fuzzy variables of input and output. The description of the control is via these rules. It collects various combinations between the membership functions of the two inputs to generate the appropriate duty cycle change value. After the inference step, the overall result is a fuzzy value. This result is defuzzified to obtain a final crisp or non-fuzzy output. Several defuzzification methods can be used such as center of gravity.

5. RESULT AND DISCUSSION

The power switching device that is used to develop the simulation of boost converter is MOSFET. This is because the characteristics of MOSFET are fast switching due to its operating frequency is very high. While designing the DC-to-DC boost converter, the parameters value of design requirement has been set. The voltage range of converter is setup from 12V to 400V, switching frequency that is used is about 48 kHz and the load resistor is fixed at 3000Ω. The overall proposed system simulation diagram is shown in Figure 13.

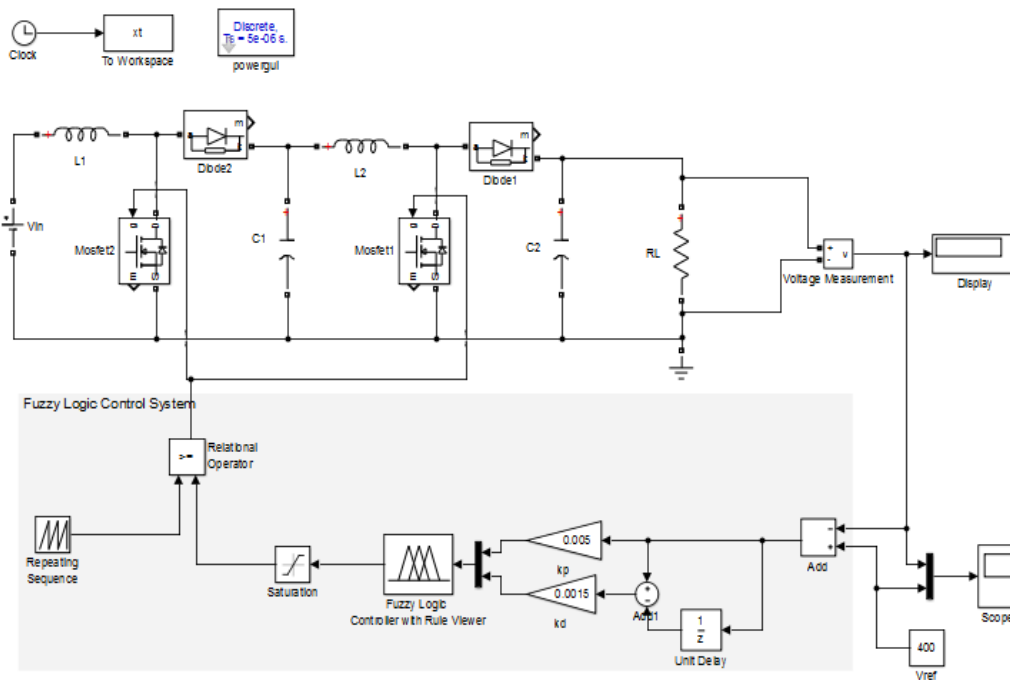


Figure 13. Simulation diagram of proposed system

The simulation results of output voltage for double boost converter with fuzzy logic controller have shown at Figure. 14-17. All of results are achieved from FLC with two scaling gain $k_p=0.005$ and $k_d=0.0015$. When different range of incoming DC voltage is supplied to converter system, the desired output voltage is achieved with the minimum overshoot/ undershoot effect.

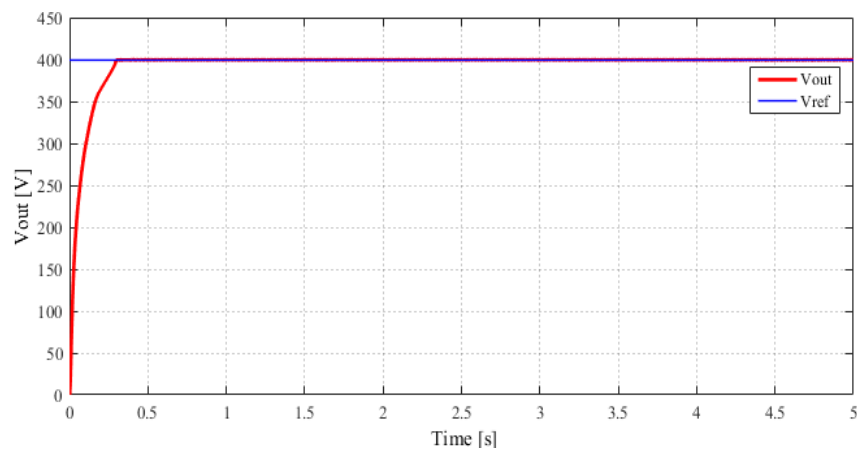


Figure 14. Output voltage for FLC controller closed loop circuit DC to DC boost converter with $V_{in} = 12V$

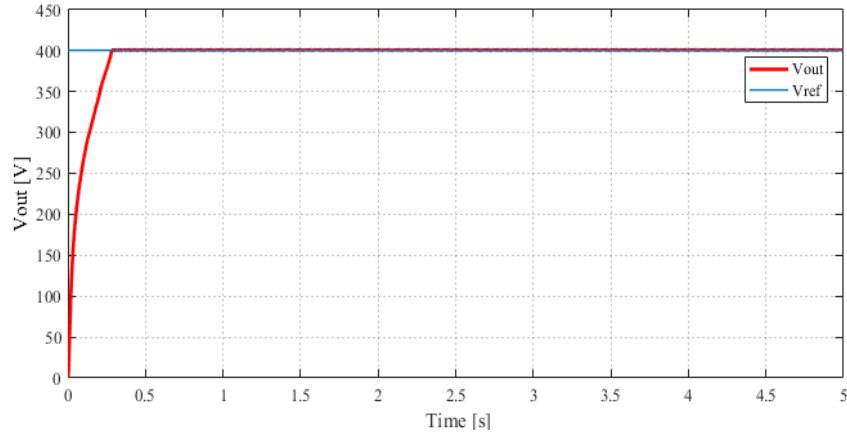


Figure 15. Output voltage for FLC controller closed loop circuit DC to DC boost converter with $V_{in} = 32V$

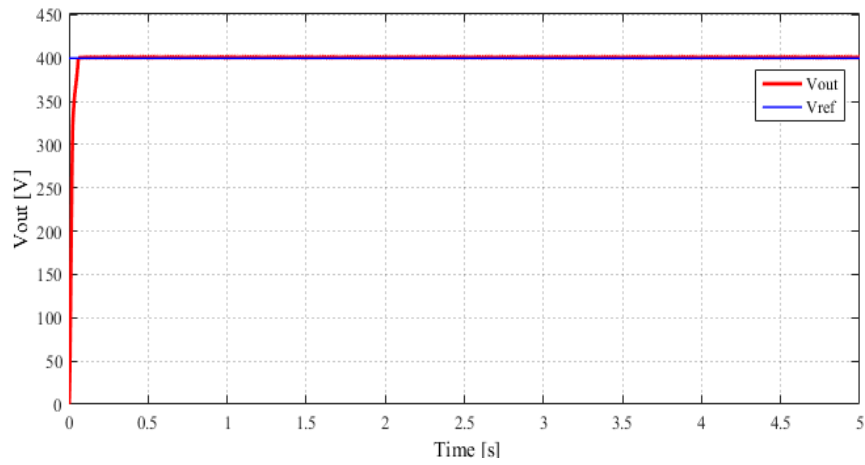


Figure 16. Output voltage for FLC controller closed loop circuit DC to DC boost converter with $V_{in} = 48V$

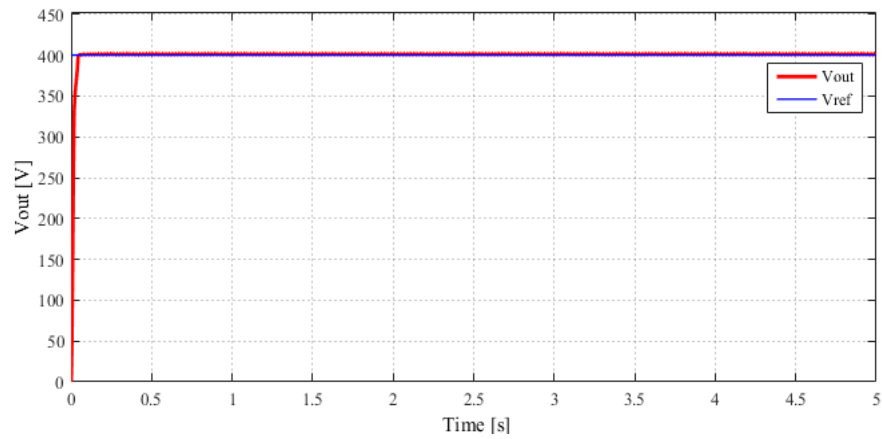


Figure 17. Output voltage for FLC controller closed loop circuit DC to DC boost converter with $V_{in} = 60V$

According to Table 2, the characteristic of different simulation results with different input voltages can be seen clearly.

Table 2. The reading on, rise time, settling time and voltage deviation from proposed system

Input Voltage [V]	Reference Voltage [V]	Output Voltage [V]	Rise Time [s]	Settling Time [s]	Voltage Deviation [V]
12	400	400.8	0.02	0.29	0.8
36	400	401.3	0.015	0.28	1.3
48	400	401.5	0.01	0.055	1.5
60	400	402	0.005	0.045	2

6. CONCLUSIONS

Control system is very important role in power electronic switching control system to stable the system performance. Fuzzy logic controller is designed in order to control the converter output voltage. This paper represents the proposed converter control design and TS Rule Base Model. Simulation results of the proposed system show the ease of applying fuzzy logic control to double boost dc/dc converters, as an interesting alternative to conventional techniques. According to the simulation, the output voltage of the converter with FLC has minimum overshoot and produces high output voltage gain. But this control design can very well operate even 12V input. This design can also work for other high input voltage range to get stable constant output voltage.

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AUTHORS

Moe Moe Lwin was born in Myanmar in 1987. She received her BE in Mechatronic engineering from Pyay Technological University(PTU) in 2009. In 2010, she started her job as demonstrator in her graduated university. In 2014, she received ME in Mechatronic engineering from Mandalay Technological University (MTU). She promoted to assistant lecturer (AL) in 2015. Currently, she is PhD student at Yangon Technological University (YTU), Myanmar. Her research interests include power electronic, artificial intelligent control and renewable energy system development.

