DC-DC Boost Converter Using Fuzzy Logic Controller

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***Abstract*— The switching power supply market is thriving quickly in today's high-tech world. People aren't always supplied with the desired amount of voltage they need in order to make their design work. Therefore this paper presents a DC-DC Boost converter using Fuzzy Logic Controller. Boost converter is used to operate such that the output voltage which produces is sufficient for design work. The converter will be simulated in Matlab software in open loop system (analog circuit) and closed loop (digital control) system. In closed loop system, output of the converter is controlled by using fuzzy logic technique. Result of both systems is compared to demonstrate the closed loop system was producing the accurate value and minimize the overshoot of the output voltage. It also reduces the rise time for converter to achieve the steady-state condition.**

***Keywords*—** Boost Converter, Direct Current (DC), Fuzzy Logic Controller, Insulated Gate Bipolar Transistor (IGBT), Pulse Width Modulation (PWM).

1.0 INTRODUCTION

Task of power electronics is to process and control the flow of electric energy by supplying voltages and currents in a form that is optimally suited for user load [5]. Figure 1.1 shows a power electronic system block diagram. The output of the power processor is a function of voltage, current, frequency, and the number of phases is desired by load. Feedback controller is commonly used to compare the output of the power processor unit with a reference value. Hence, the difference is the error between the two can be minimized by the controller.

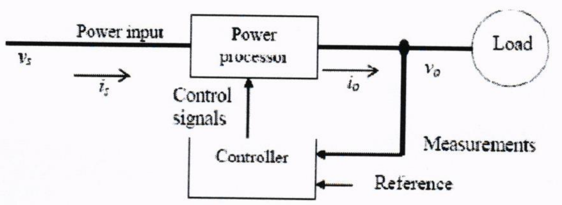


Figure 1.1
Block Diagram of Power Electronic System

In this paper boost converter will be demonstrate to solve the problem for insufficient voltage supplied in order to make design work. A boost converter is a power converter with an output dc voltage greater than its input dc voltage[5]. 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. It is also called the fly-back converter because the 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. It is also called the fly-back converter because the energy transfer, from the source to the load, takes place only during the off period of the switch [9].

Its circuit topology is given in Figure 1.2.

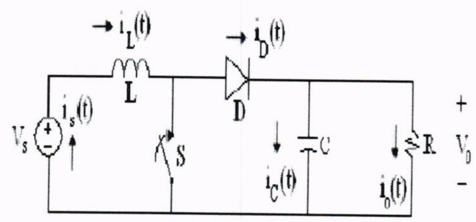


Figure 1.2
Boost Converter

The switch S is usually an electronic device that operates either in the conduction mode (on) or the cut-off mode (off). The on and off time-periods are controlled by the suitably $T_{ON}=DT$, where D is the duty cycle.

The equation which relates the output voltage with input voltage is;

$$V_D = \text{——} \qquad (1)$$

Equation *1* states that the output voltage of the boost converter is indirectly proportional to (1-D) and directly proportional to the source voltage. Since the duty cycle is usually less than unity, the output voltage is greater than the applied voltage. This is the reason why a boost converter is commonly called the step-up converter.

In classic(open loop) topology of boost converter, output voltage fully control by duty ratio on switch. If supplied voltage decrease than previous value, at that moment duty ratio are need to change so that the value of output voltage is still acquired.

Next things are in open loop circuit, output voltage is not produce precisely near to desired value. Furthermore, it will produce transient voltage due to power switching during the rise time to reach steady state condition.

Therefore digital control is implemented in boost converter in order to control the output and resolve the problem as above. There are several digital control such as PID, Posicast control, FLC, and etc. FLC is chosen due to their performance.

Fuzzy logic Control was proposed by Dr. Lofti Zadeh in 1964[2]. In this paper, FLC is used to control the output of converter by acting as feedback to the PWM to adjusting the duty ratio automatically in order to produce output voltage as accurate as possible and also to decrease the value of transient voltage.

Figure below show the propose circuit which can used to control the converter

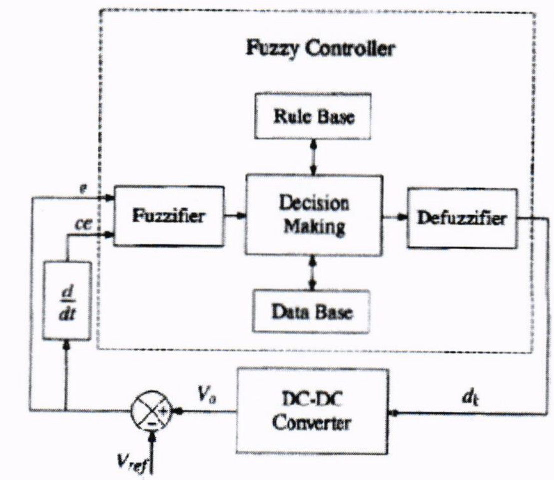


Figure 1.3
Block diagram of the fuzzy control[2]

2.0 METHODOLOGY

This work is divided into 4 categories (A, B, C and D). Figure 2.1 is illustrating the flowchart of entire process in completing the task.

STUDY OF POWER ELECTRONIC CONVERTER ESPECIALLY IN DC-DC CONVERTER

↓

DETERMINE THE PARAMETER FOR BOOST CONVERTER

↓

SIMULATION THE BOOST CONVERTER IN OPEN LOOP SYSTEM (ANALOG CIRCUIT) BY USING MATLAB SOFTWARE

↓

DESIGNING THE CONTROLLER (FUZZY LOGIC CONTROL)TO CONTROL THE OPERATION OF BOOST CONVERTER

↓

SIMULATION THE BOOST CONVERTER IN CLOSE LOOP SYSTEM (DIGITAL CONTROL) BY USING MATLAB SOFTWARE

↓

RESULT OF BOTH SIMULATION IS COMPARED TO DEMONSTRATE THE ADVANTAGE OF FUZZY LOGIC CONTROLLER IN CONTROL THE OPERATION OF CONVERTER

Figure 2.1
Methodology Flow Chart

A. DESIGNING THE PARAMETER OF CONVERTER

In designing a boost converter, there are three main parameters that need to be considered namely, power switch, inductor and capacitor. With the aim of achieving the desired output voltage and stability, power switch is designed in such requirement as tabulated in Table 2.1.

Parameter	Value
Voltage Input, V_{in} (V)	24
Voltage Output, V_o (V)	40
Output Power, P_{out} (W)	10
Duty Cycle, D	40
Switching Frequency, f (kHz)	20
Inductor Current Ripple (%)	15
Capacitor Voltage Ripple (%)	0.1
Input Current, I_{in} (A)	0.5
Output Current, I_o (A)	0.2
Capacitor	220 uF

Inductor	22 mH

Table 2.1
Table of parameters and values for the boost converter

B. SIMULATION THE OPEN LOOP SYSTEM (ANALOG CIRCUIT) IN MATLAB

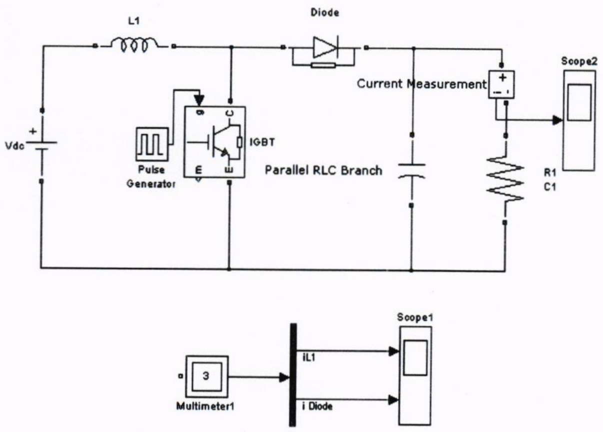


Figure 2.2
Open loop simulation circuit

As shown in Figure.2.2 the boost converter is constructing with Matlab software using simulink function. This is done when all the parameters mentioned in sec. 2A is set to the topology. IGBT is selected as the switch for the converter because of its high current carrying capabilities, fast switching and high efficiency. The Pulse Width Modulation (PWM) device is applied in order to control the duty ratio D of the converter operation.

This system is considered as open loop system because it operation is function of one output only and their output result did not feedback to their input to make correction if desired output did not achieved. It means, the whole operation of open loop system is manually control by people since the output result of converter is depend on duty ratio and input supplied. So, to reach the needed output value, people should control those elements by himself.

C. DESIGNING THE DIGITAL CONTROLLER

There are several ways to digitally control the analog circuit. Figure 1.3 above illustrates the block diagram of the fuzzy control that can be used to control the output voltage of the DC-DC converter such as boost converter.

The fuzzy controller will be used to be the inputs of the error and change of error output voltage of the converter and it feedback to pulse generator (PWM) to correct the duty ratio to make the converter produce the voltage to be exact as required.

Fuzzy controller was designed and simulated with MATLAB –**Fuzzy Inference System** (FIS). To start using FIS in MATLAB, need to paste fuzzy logic controller block Figure 2.4 from simulink library to the model.

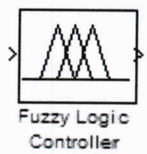


Figure 2.3
Fuzzy Logic Controller Block

Output of converter is set as error and change of error. error and change of error of the output voltage will be the inputs of fuzzy logic controller. These 2 inputs are divided to five groups; NB: Negative Big, NS: Negative Small, ZO: Zero Area, PS: Positive small and PB: Positive Big and its parameter respectively Figure 2.4.

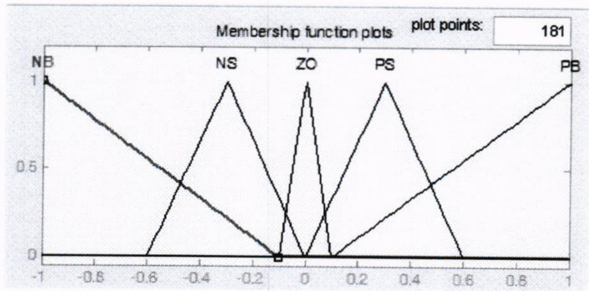


Figure 2.4
Input fuzzy: Error and change of error

And to make this design work, rules is set using If-Then logic. Below is is rule which used to make system operate such as required:

1. If (error is NB) and (change of error is NB) then (duty cycle is NB).
2. If (error is NB) and (change of error is NS) then (duty cycle is NB).
3. If (error is NB) and (change of error is ZO) then (duty cycle is NB).
4. If (error is NB) and (change of error is PS) then (duty cycle is NB).
5. If (error is NB) and (change of error is PB) then (duty cycle is NB).
6. If (error is NS) and (change of error is NB) then (duty cycle is ZO).

7. If (error is NS) and (change of error is NS) then (duty cycle is NS).
8. If (error is NS) and (change of error is ZO) then (duty cycle is NS).
9. If (error is NS) and (change of error is PS) then (duty cycle is NS).
10. If (error is NS) and (change of error is PB) then (duty cycle is NS).
11. If (error is ZO) and (change of error is NB) then (duty cycle is PS).
12. If (error is ZO) and (change of error is NS) then (duty cycle is ZO).
13. If (error is ZO) and (change of error is ZO) then (duty cycle is ZO).
14. If (error is ZO) and (change of error is PS) then (duty cycle is ZO
15. If (error is ZO) and (change of error is PB) then (duty cycle is NS).
16. If (error is PS) and (change of error is NB) then (duty cycle is PS).
17. If (error is PS) and (change of error is NS) then (duty cycle is PS).
18. If (error is PS) and (change of error is ZO) then (duty cycle is PS).
19. If (error is PS) and (change of error is PS) then (duty cycle is PS).
20. If (error is PS) and (change of error is PB) then (duty cycle is ZO).
21. If (error is PB) and (change of error is NB) then (duty cycle is PB).
22. If (error is PB) and (change of error is NS) then (duty cycle is PB).
23. If (error is PB) and (change of error is ZO) then (duty cycle is PB).
24. If (error is PB) and (change of error is PS) then (duty cycle is PB).
25. If (error is PB) and (change of error is PB) then (duty cycle is PB).

This entire rule is set in the mamdani section in FIS system on Matlab such figure below.

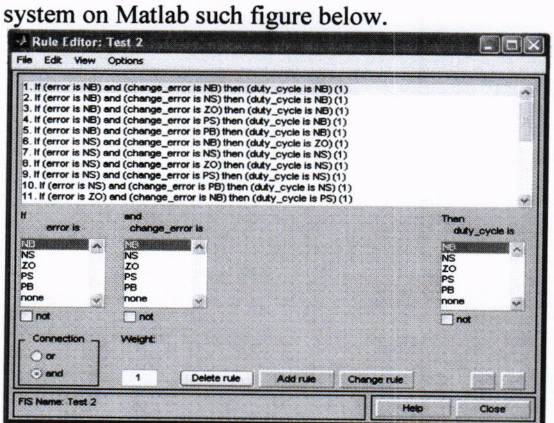


Figure 2.5. Mamdani section in FIS system

By setting all these parameters boost converter with fuzzy logic controller is ready for the test and simulation.

D. SIMULATION OF BOOST CONVERTER WITH FUZZY LOGIC CONTROL

Figure 2.4 illustrate the complete boost converter with the fuzzy logic controller embedded to the circuit topology.

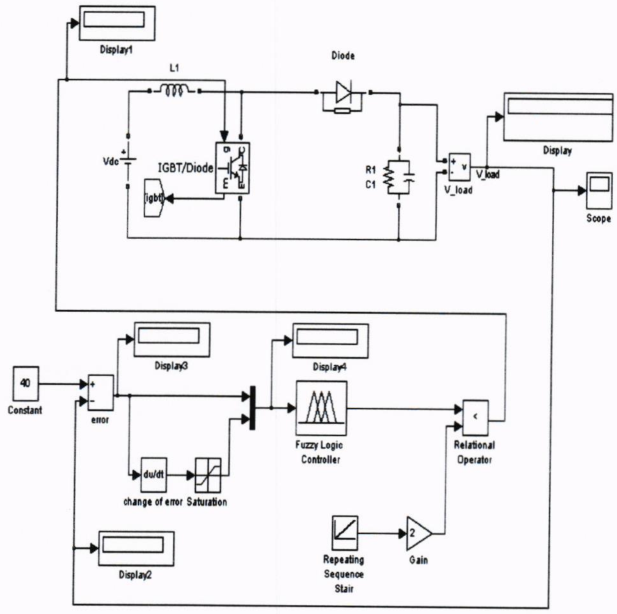


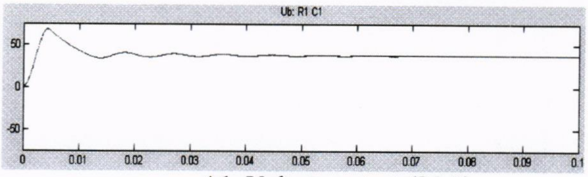
Figure 2.6
Boost Converter with Fuzzy Logic Controller Simulation in Matlab

The output of the circuit will be input of fuzzy control which is feedback to the circuit in order to control of duty ratio of pulse generator. This controller will taken all the output and will compared with constant voltage which is desired in this experiment and it will adjusting pulse generator until the value of converter produce is near to the value needed.

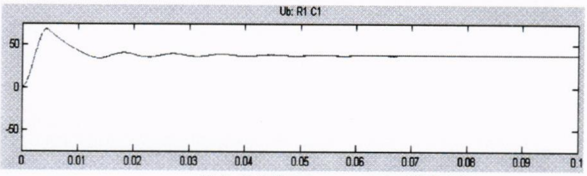
3.0 RESULT AND DISCUSSION

The results of the observed of both simulation circuits are presented in this section. On the open loop section, all the parameter is set as in table 2.1. For $V_{in} = 24V$, $22V$, $20V$ and duty cycle was set to 40%, 45% and 50% base on equation *1* to produce 40V constant voltage.

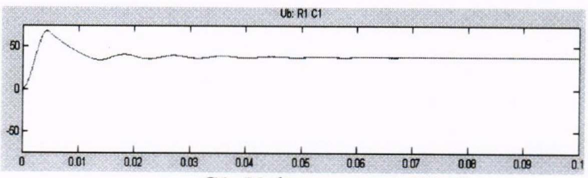
Figure below shows all the simulation result according to the open loop system.



A1. Voltage output (24 *V*)



B1. Voltage output (22 *V*)

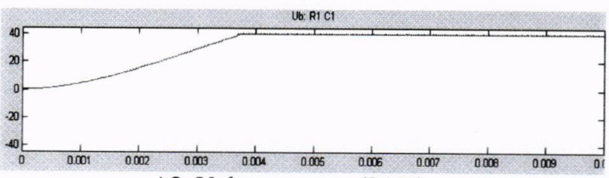


C1. Voltage output (22 *V*)

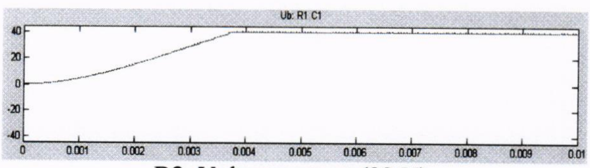
Figure 3.1
Simulation result of open loop circuit

At the closed loop section, all parameter in boost topology remain same. FLC which embedded to the converter will control the output converter in order to produce the required voltage.

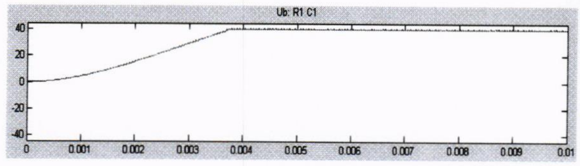
Figure below shows the Simulation result of closed loop system with V_{in} = *24V*, 22*V*, 20*V*



A2. Voltage output (24 V)



B2. Voltage output (22 V)



C2. Voltage output (20V)
Figure 3.2
Simulation result of closed loop circuit with V_{in}= 24 V

3.1 ANALYSIS BETWEEN OPEN LOOP AND CLOSE LOOP CIRCUIT

V_{in}	Required Voltage V_r	$V_o(OL)$	$V_o(CL)$	Diff V_r with $V_o(OL)$	Diff V_r with $V_o(CL)$
24	40	38.252	39.947	1.748	0.053
22	40	38.106	39.997	1.894	0.003
20	40	37.931	39.993	2.069	0.007

Table 3.1
Accuracy of output voltage

V_{in}	Required Voltage V_r	Peak Voltage $V_p(OL)$	Peak Voltage $V_p(CL)$	Overshoot *(OL)%*	Overshoot *(CL)%*
24	40	69.936	40.376	74.84	0.94
22	40	69.167	40.365	72.92	0.9125
20	40	68.230	40.268	70.58	0.067

Table 3.2
Percentages overshoot of output voltage

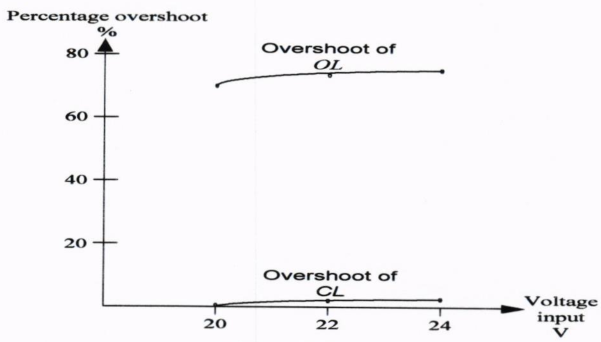


Figure 3.3
Graph overshoot versus voltage input for both system

For the output voltage results, open loop circuit produced 37.931V such figure 3.1 (A1) with overshoot a waveform, meanwhile the closed loop circuit produced 39.993V figure 3.2 (A2). It shows that the FLC control the output value better than system that without controller with the same input voltage 20V.

Then looking at the overshoot for both output waveforms, converter with FLC control can reduce the transient response almost 99% with respect to the overshoot which produce by the converter without controller.

Hence, the converter with digital control (FLC) will taken short amount of time to raising until achieve the steady state condition in around 3.8mS while the open loop circuit acquire around 80mS. As a result, it proves that the converter with digital control will have the better achievement and can produce tremendous outcome compared to the analog circuit *(OL)*.

4. CONCLUSION

Design of simulation dc-dc boost converter controlled by fuzzy logic controller to control output voltage has been successful achieved. The 20V, 22V and 24 V voltage input is applied to the simulation circuit and the output parameters for open and closed loop circuit was tested and measured.

Simulation results have been compared for both system *(OL)* and *(CL)* and them show there are significant differences of the output results. The closed loop circuit achieved the desired output voltage compared to the open loop circuit with difference of 0.007V while open loop circuit require almost 2.069V to attain 40V with V_{in} = 20V. For the same input 20V the output voltage for the closed loop circuit (fuzzy logic controller) with 0.067% overshoot and rise time 3.8ms shows the better performance compared to the open loop circuit (without controller) whereby it has 70.58% overshoot and rise time is 80ms. Despite the increase of voltage due to higher duty cycle, the FLC managed to control the output current so that the efficiency will remain the same or slightly improving

5. RECOMMENDATION

For future research and work, it's recommended that several improvements or alternatives to be taken:

a. Research could be done in area of improving the output of current and reduce the current stress on Inductor current while having high duty ratio in order to increase the amount of output voltage. This could be resolve by having mutual or tapped inductor in boost converter circuit.
b. Further work can be carried out to reduce the losses in the rectifier circuit and increase the efficiency of the converter.
c. This project could be enhance by implementing hardware base on simulation result.

6. ACKNOWLEDGMENT

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6. REFFERENCES

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