

# Comparative Study of Fuzzy Logic Controller and Proportional Integral Derivative Controller on DC-DC Boost Converter

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**Abstract** –This paper shows the comparison between Fuzzy Logic Controller and Proportional Integral Derivative Controller (PID) in improving the performance of DC-DC Boost Converter. The evaluation of the result has been compared by using MATLAB Simulink. Comparison of simulation results indicates that the Fuzzy Logic Controller have much higher performance than the PID Controller. Fuzzy Controller can achieve faster transient response, steady state was more stable reaction and robust under different operating points.

**Index Terms** – Fuzzy Logic Controller, PID Controller, DC-DC Boost Converter, MATLAB Simulink

## I. INTRODUCTION

DC-DC converters have been dominated and controlled by analog integrated circuit technology and linear system design techniques. Lately, with the development of advanced high-speed digital circuits, digital control will regularly replace the current used of analog controller in high frequency switching converters [1].

The DC-DC Boost Converter, also known as step up converter is another switching converter that has the same components as the buck chopper, but the name ‘Boost Converter’ most probably evolves from the fact that the output voltage produces is greater than the source.

The DC-DC converters can operate in two distinct modes, which are either in Continuous Conduction Mode (CCM) or Discontinuous Conduction Mode (DCM). The term continuous and discontinuous is referred to inductor current. Continuous means the inductor does not reach the zero value at the end of OFF period. Whereas, the current goes to zero when works in discontinuous mode [2].

## A. Circuit Operation

Figure 1.1 shows the DC-DC Boost Converter circuit topology. The circuit operation can be divided into two modes. First mode (mode 1) begins when transistor (e.g. IGBT) is switched on at  $t = 0$ . The input current, which rises, flows through inductor L1 and transistor. Second mode (mode 2) begins when transistor is switched off at  $t = t1$ . The current that was flowing through the transistor would flow through inductor L1, capacitor C1, load R1 and diode. The inductor current falls until transistor is turned on again in the next cycle [3].

The circuit topologies for the converter during both modes are shown in Figure 1.2 and the waveforms for voltages and currents are shown in Figure 1.3 for continuous load current, assuming that the current rises or falls linearly.

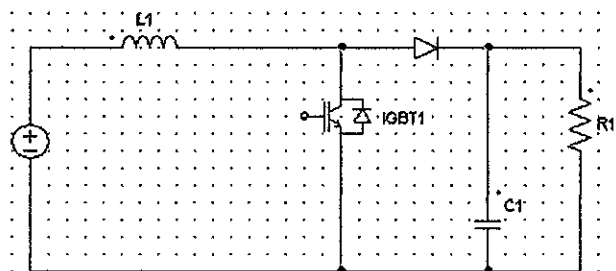


Figure 1.1: DC-DC Boost Converter

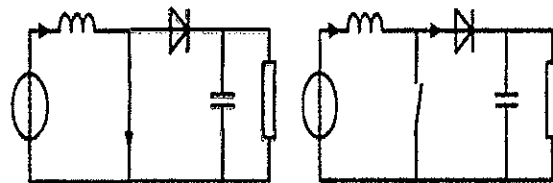


Figure 1.2: (a) Mode 1 (b) Mode 2

Figure 1.2: The Converter's circuit topology during switch is closed (mode 1) and during switch is opened (mode 2)

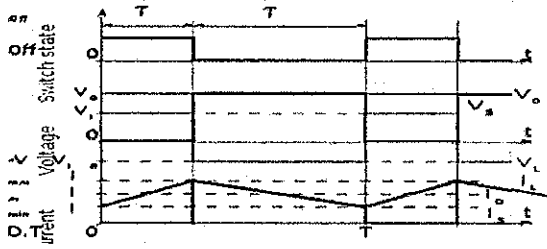


Figure 1.3: Waveform for voltages and currents

### B. Circuit Parameters

For designing a Boost Converter, certain parameters need to consider making sure the circuit operate in the best performance. From equation 1.1, the value of duty ratio,  $D$  is defined as:

$$D = 1 - \left( \frac{V_{in}}{V_o} \right) \quad (1.1)$$

The selection for the value of capacitor,  $C$  and inductor,  $L$  can be done based on equation 1.2 and equation 1.3 respectively.

$$C = \frac{V_o D}{f R \Delta V_o} \quad (1.2)$$

Where:

$V_o$  = output voltage

$D$  = duty ratio

$f$  = frequency (Hz)

$R$  = Resistance ( $\Omega$ )

$\Delta V_o$  = the change in the output voltage (V)

$$L = \frac{V_o (1-D)^2 D}{2 f I_{in}} \quad (1.3)$$

Where:

$I_{in}$  = Input current

DC-DC Boost Converter is simulated in MATLAB Simulink and the parameters as shown in Table 1.1.

Table 1.1: Parameters of DC-DC Boost Converter

Parameters	Values
Input Voltage	1.5V
Output Voltage	3.6V
Switching Frequency	7500Hz
Duty Ratio	0.58
Inductance, L	570 $\mu$ H
Capacitance, C	38.57 $\mu$ F

## II. CONTROLLER DESIGN

### A. Proportional Integral Derivative (PID) Controller

PID control is a traditional linear control method used commonly in industrial applications. PID letter is stand for the calculation (algorithm) that involves three separate parameter, the proportional, the integral and derivatives. A PID and a PI controller are designed for boost converter for operation during a startup transient and steady state, respectively. The derivative term in a PID controller is liable to noise and measurement error of the system, which could result in oscillation of the duty cycle during steady state [4].

Proportional term (sometimes called *gain*) makes a change to the output that is proportional to the current error value. The contribution from integral term (sometimes called *reset*) is proportional to both the magnitude of error and duration of error. The rate of change of the process error is calculated by determining the slope of the error over time and multiplying this rate of change by derivative gain  $K_d$  (sometimes called *rate*) [2].

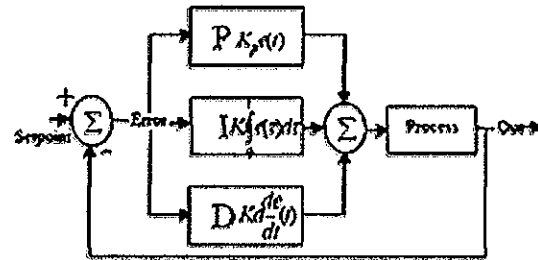


Figure 2.1: A block diagram of PID controller

The PID control scheme is named after its three correcting terms, whose sum constitutes the manipulated variable (MV) as shown in equation 2.1. Hence:

$$MV(t) = P_{out} + I_{out} + D_{out} \quad (2.1)$$

where  $P_{out}$ ,  $I_{out}$ , and  $D_{out}$  are the contributions to the output from the PID controller from each of the three terms. By tuning the three constant in PID controller algorithm, the controller can provide control action designed for specific process requirement [5]. Figure 2.1 shows a block diagram of PID controller.

A heuristic tuning method is formally known as the Ziegler-Nichols method, introduced by John G. Ziegler and Nathaniel B. Nichols in the 1940s. As in

the method above, the  $K_i$  and  $K_d$  gains are first set to zero. The  $P$  gain is increased until it reaches the ultimate gain,  $K_u$ , at which the output of the loop starts to oscillate.  $K_u$  and the oscillation period  $P_u$  are used to set the gains as shown in Table 2.1:

Table 2.1: Ziegler–Nichols tuning method

Control Type	$K_p$	$K_i$	$K_d$
$P$	$0.50K_u$	-	-
$PI$	$0.45K_u$	$1.2K_p / P_u$	-
$PID$	$0.60K_u$	$2K_p / P_u$	$K_p P_u / 8$

These gains apply to the ideal, parallel form of the PID controller. When applied to the standard PID form, the integral and derivative time parameters  $T_i$  and  $T_d$  are only dependent on the oscillation period  $P_u$  [5].

### B. Fuzzy Logic Controller

Unlike Boolean logic which the state value of any variable is either 0 or 1, fuzzy logic allows states between them. More specifically, that's call membership value. The grade of membership value of fuzzy variable can be described in linguistic term [6].

Fuzzy use Linguistic variables and defined as the variables whose values are define in a usual language (e.g. small and big) that may be represented by fuzzy set. The general structure of Fuzzy Logic controller is shows in Figure 2.2. That comprises four principal components [7]:

#### 1) Fuzzifier

A fuzzyfication interface which converts input data into suitable linguistic values.

#### 2) Rule Base and Data Base

Both are known as knowledge base which consists of data base with necessary linguistic definition and control rule set.

#### 3) Decision Making

A decision making logic which is simulating a human decision process, infers the fuzzy control action from the knowledge of the control rules and the linguistic variable definition.

#### 4) Defuzzifier

A defuzzification interface which yields a non-fuzzy control action from an inferred fuzzy control action.

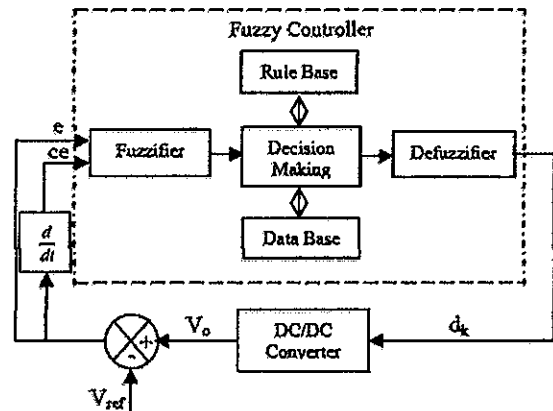


Figure 2.2: Basic Configuration of Fuzzy Logic

The Fuzzy Logic control is made from 2 inputs and 1 output variable, as shown in Figure 2.3, which the input variables are error and change of error and the duty cycle is the output variable. Each variables control has been divided into five partitions and has named into five fuzzy subsets: PB (Positive Big), PS (Positive Small), ZO (Zero), NB (Negative Big) and NS (negative Small). The partition of fuzzy subsets and the shape of the membership function are shown in Figure 2.4 (error variable), Figure 2.5 (change of error variable) and Figure 2.6 (output variable).

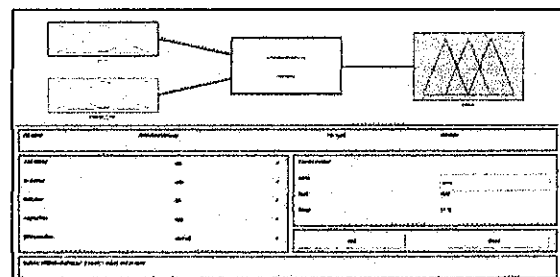


Figure 2.3: The editor of Fuzzy Inference System

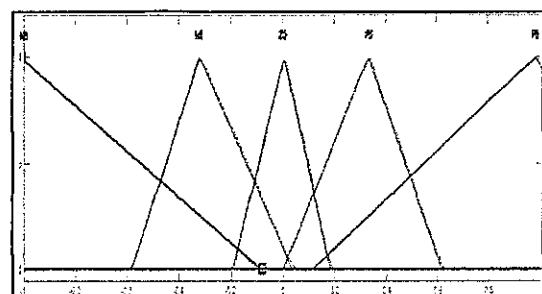


Figure 2.4: Membership function of input variable 'error'

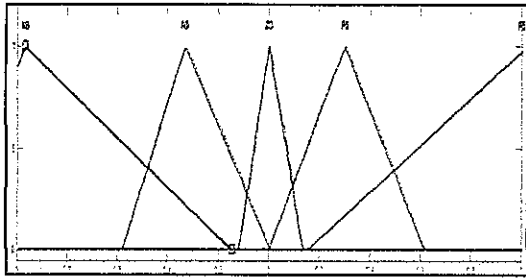


Figure 2.5: Membership function of input variable 'change of error'

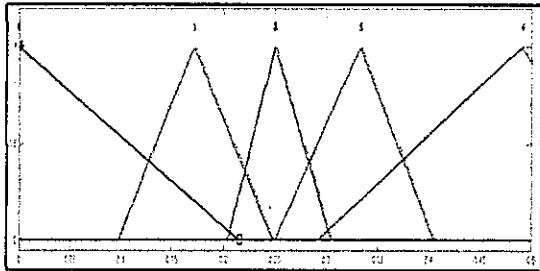


Figure 2.6: Membership function of output variable

The triangular shapes of the membership function of this arrangement presume that for any particular input there is only one dominant fuzzy subset. From the combination of error and change of error, a maximum of five rules are applied. The rules for the Fuzzy Logic control is formulated into 25 rules and tabulated in Table 2.2 [2].

Table 2.2: The rule base with 25 rules

		ERROR				
		NB	NS	ZO	PS	PB
CHANGE ERROR	NB	NB	NS	ZO	PS	PB
	NS	NS	ZO	PS	PB	PS
	ZO	ZO	PS	PB	PS	ZO
	PS	PS	PB	PS	ZO	NS
	PB	PB	PS	ZO	NS	NB

### III. RESULTS AND DISCUSSION

The simulation has been constructed in Matlab Simulink. The results are obtained by using 1.5V input and the output produced up to 3.6V. There are three condition of simulations that have been conducted which are:

- i. Open loop for Boost Converter
- ii. PID Controller for Boost Converter
- iii. Fuzzy Logic Controller for Boost Converter

The waveform obtains from the open loop control Boost Converter simulation test is shown in Figure 3.1.

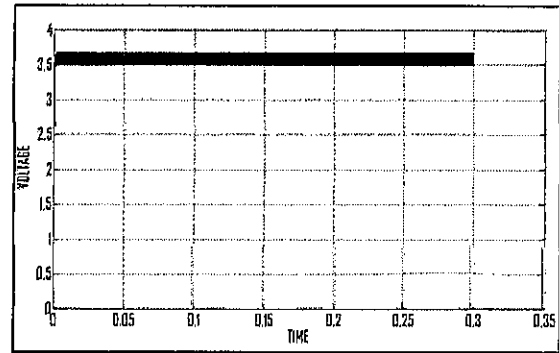


Figure 3.1: Output waveform of open loop control Boost Converter for 3.6Vref

From the results, it shows that the conditions for the Boost converter in open loop for the rise time to reach reference voltage ( $V_{ref}$ ) 3.6V and settling time to be in steady state condition takes a very short time. However, in a real world the system might be not stable if running for a long time because of no compensation or correction for the error. Furthermore, the gain is uncontrollable because of no feedback path. Therefore in order to eliminate these problems, the closed loop controllers are needed for the converter.

Table 3.1 and Table 3.2 show the results from simulation test on PID control and Fuzzy Logic control respectively. The comparison of waveforms obtained from both control topologies are shown in Figure 3.2 with a reference voltage ( $V_{ref}$ ) 3.6V respectively.

Table 3.1: PID Controller for Boost Converter's Parameter

$V_{in}$ (V)	$V_{ref}$ (V)	$V_{peak}$ (V)	OS (%)	$T_r$ (ms)	$T_s$ (ms)
1.5	3.6	3.602	0.056	56.3	56.5
1.5	3.7	3.702	0.054	58.2	59.3
1.5	3.8	3.802	0.053	62.1	63.4
1.5	3.9	3.902	0.051	62.7	63.1
1.5	4.0	4.002	0.05	68.4	69.1

Table 3.2: FL Controller for Boost Converter's Parameter

$V_{in}$ (V)	$V_{ref}$ (V)	$V_{peak}$ (V)	OS (%)	$T_r$ (ms)	$T_s$ (ms)
1.5	3.6	3.63	0.83	0.36	0.43
1.5	3.7	3.73	0.81	0.38	0.46
1.5	3.8	3.83	0.79	0.42	0.51
1.5	3.9	3.93	0.77	0.45	0.53
1.5	4.0	4.03	0.75	0.51	0.57

Although the results produced from simulation claimed that the targeted output voltage for PID control is much accurate than Fuzzy Logic Control, the waveforms obtained from Figure 3.2 observed that with Fuzzy Logic Controller, the rise time and settling time for Boost Converter is much faster than PID Controller. Therefore, by comparing these results it can be conclude that Fuzzy Logic Controller gives a better performance in regulating the output of Boost Converter. Furthermore, Boost Converter with Fuzzy Logic Controller is more efficient by offering better performance compared to PID Controller.

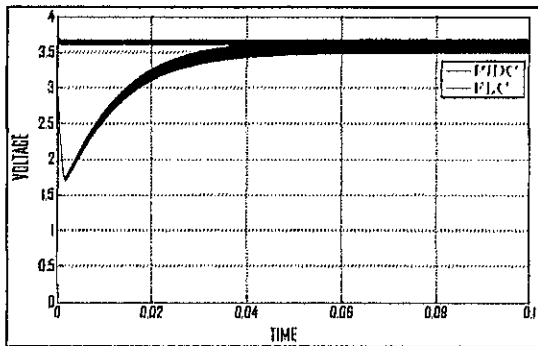


Figure 3.2: Comparison of FL control and PID control for 3.6Vref

*A. Test on Performance of PID Controller and Fuzzy Logic Controller with varying load*

Further test has been measured to observe how well the controllers contribute to a better performance for DC-DC Boost Converter. A varying load is a test that using additional load in simulation test. The value of additional load is calculated by increase the output current by 20 percent. With setting 0.05s for the additional load start to operate during simulate, the performance of the controller have been tested and compared.

The waveform obtained in Figure 3.3 is the comparison for PID control and Fuzzy Logic control with 3.6V reference voltage during applying the varying load test.

From the waveform obtained, it shows that the both controllers are almost achieving back to the desired output after the varying load test is applied.

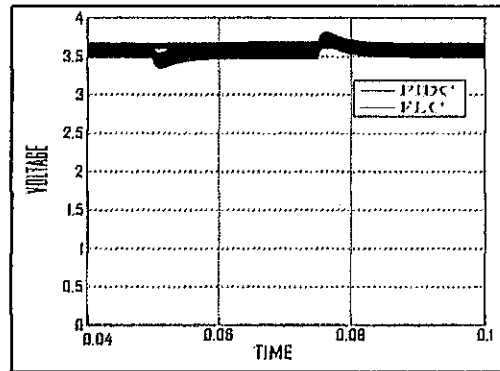


Figure 3.3: Comparison of FL control and PID control with varying load test applied

Although the PID Controller successful in achieving back to the value of targeted output after 0.05s, there is still has disadvantages compared to Fuzzy Logic control. After 0.05s, the voltage for PID control has been drop because of the effect of additional load and start to achieve back to 3.6V during 0.08s. Furthermore, the time for PID controller to be in steady state condition is much slower compared to Fuzzy Logic Controller. In contrast, additional load seems like does not effected to the performance of Fuzzy Logic Controller because no voltage drop occurred even though after 0.05s. From the results, Fuzzy Logic Controller still gives the better performance and more precise output parameters even the varying load test is applied.

*B. Test on Performance of PID Controller and Fuzzy Logic Controller with varying references voltage*

Another test has been applied to both controllers for observing which controller have the better performance instead of varying references voltage. Two references voltage are used, 3.6V and 4.0V. The performance of the controller have been tested and compared during 0.06s to 0.12s. The waveform obtained in Figure 3.4 is the comparison for PID control and Fuzzy Logic control during applying the varying references voltage test.

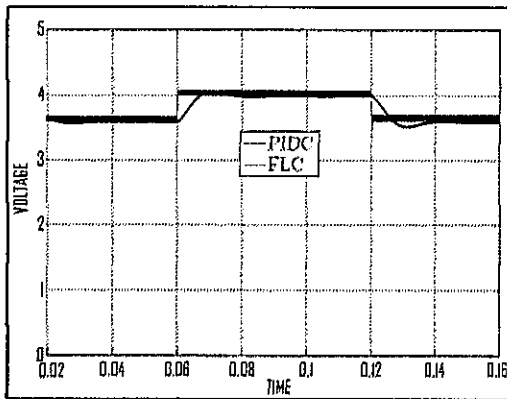


Figure 3.4: Comparison of FL control and PID control with varying references voltage test applied

From the waveforms obtained, it shows that Fuzzy Logic Controller have the better performance compared to PID Controller. After 0.06s, Fuzzy Logic Controller does not require much time to be in steady state condition and achieve 4.0V but different to PID controller that need much longer time to achieve 4.0V.

After 0.012s, Fuzzy Logic Controller remain the best performance by achieving 3.6V in a short time and PID Controller still need much longer time to stabilize and achieve 3.6V with a steady state condition. From the results, it proves that Fuzzy Logic is the best controller compared to PID even the varying references voltage test is applied.

#### IV. CONCLUSION

In conclusion, Fuzzy Logic Controller is much better in overall performance compared to PID Controller. By using Fuzzy Logic Controller, the rise time and settling time for Boost Converter is much faster than PID Controller. Furthermore, Fuzzy Logic Controller only need a short time to reach a steady state condition and much more efficient with a better dynamic performance. Not only Boost Converter, Fuzzy Logic Controller also can be applied to many converter topologies and has a potential to improve robustness of DC-DC converters.

Further work can be performed with the existing design to improve the performance of the converter. Hardware implementation can be applied to prove that hardware application gives same performance as software simulation.

#### V. ACKNOWLEDGEMENT

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