A Study of DC-DC Buck-Boost Converter Using Fuzzy Logic Controller

Mohd Ruzaimi Bin Mohd Nor
Faculty of Electrical Engineering
Universiti Teknologi MARA Malaysia
40450, Shah Alam
e-mail: mart_emink@yahoo.com

Abstract - **This paper presents a study of Fuzzy Logic Controller (FLC) on Buck-Boost Converter (BBC) by using MATLAB-SIMULINK to improve the dynamic performance of the converter. The circuit model of Buck-Boost converter with FLC has been derived to evaluate the effectiveness of the control methodology. This paper also focuses on producing the output voltage at the converter. It also can improve the performance in term of shortest rise time, settling time, reducing the percentage of overshoot and minimize voltage deviations. By selecting the best rules of FLC, it can produce a good performance of DC-DC Buck-boost Converter.**

Keywords- Fuzzy Logic Controller, Buck- Boost Converter.

I. INTRODUCTION

Nowaday, the control systems for many power electronics appliance are increasing widely. Crucial with these demands many researcher or designer have been struggle to find most economic and reliable controller. The idea to have control system in dc-dc converter is to ensure desire output voltage can be produce efficiently to meet the demand need. Basically, feedback controller compares the output of the power processor unit with a reference value, and the error between the two is minimized by the controller.

Therefore, the main objective is to developed good converter, and achieved an output voltage regulation, under large load variations, as fast as possible without having any stability problem.

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 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 [3].

In this paper, a fuzzy logic controlled on DC-DC buck boost converter is proposed. A Fuzzy Logic Controller (FLC) is used to control the converter output voltage. The buck-boost converter is designed and simulated by using MATLAB-SIMULINK software.

II. BUCK-BOOST CONVERTER

A. Converter

The dc-dc converters can be operated in two distinct modes either in Continuous Conduction mode (CCM) or Discontinuous Conduction mode (DCM). In practice, a converter may operate in both modes. Therefore, a converter and its control should be designed based on both modes of operation [5].

However, for this research, buck-boost in Continuous Conduction Mode (CCM) can only choose to operate the circuit dc-dc buck-boost converter. The dc-dc buck-boost converter circuit is shown in figure 1.

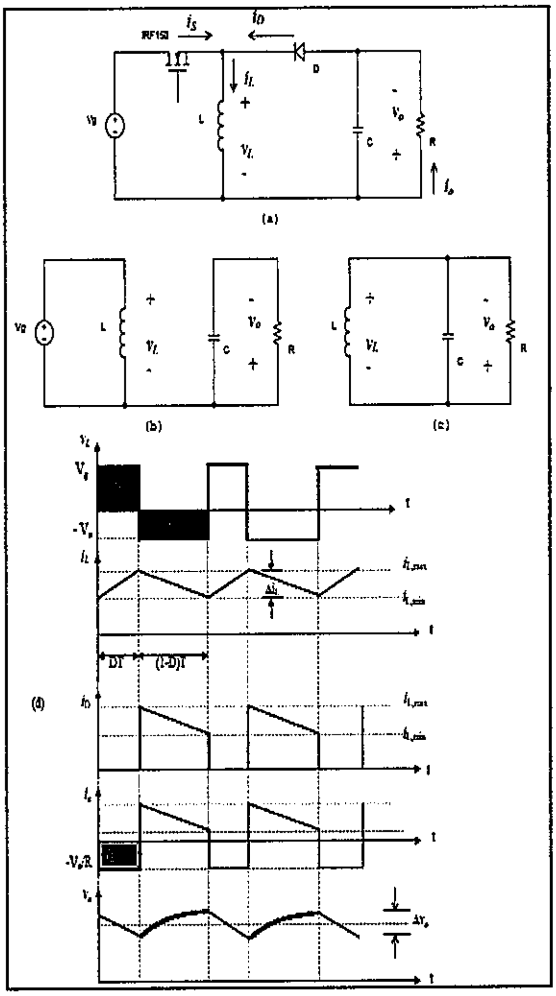

Figure 1: (a) Buck- Boost Converter (b) Switch on for time DT (c) Switch off for time (1- DT) T (d) Key wave forms [5]

B. Circuit Operation

Referring to Figure 1, when the switch is on for a time duration DT, the switch conducts the inductor current and the diode becomes reverse biased. This results in a positive voltage $V_L = V_g$ across the inductor. This voltage causes a linear increase in the inductor current i_L. When the switch is turned off, because of the inductive energy storage, i_L continues to flow. This current now flows through the diode, and $V_L = -V_o$ for a time duration (1-D) T until the switch is turned on again [5].

C. Analytical Expression of Vo, ΔiL and ΔV_o.

Assuming that no power loss in the converter whereas power absorbed by the load must equal power supplied by the source;

$$P_o = Ps \qquad (1)$$

$$\frac{Vo^2}{R} = V_g i_s \qquad (2)$$

But average source current related with average inductor current as:

$$i_s = i_L D \qquad (3)$$

Therefore,

$$\frac{Vo^2}{R} = V_g i_L D \qquad (4)$$

Substituting for average inductor current, i_L,

$$i_L = \frac{Vo^2}{VgRD} = \frac{Po}{VgD} = \frac{VgD}{R(1-D)^2} \qquad (5)$$

For a buck-boost converter, it is obvious that

$$i_L = i_s + i_o$$

$$\Delta i_L = \frac{1}{L}\int_0^{DT} VL\,dt$$

$$= \frac{1}{L}[\textit{shaded area under waveform } V_L]$$

$$= \frac{1}{L} V_g \, X\, DT \qquad (6)$$

Substitution equation (4) and (5) to get V_o

Therefore,

$$V_o = -V_g\left[\frac{D}{(1-D)}\right] \qquad (7)$$

Where, Vo is output voltage, Vg is voltage supply and D is duty ratio.

Note that the output voltage Vg is always negative and by varying the Duty cycle, D the output voltage can be increased and decreased. If D > 0.5 the output voltage is higher than input voltage and if D< 0.5 the output voltage is lower than input voltage [5].

From the information of the capacitor current, i_c, the peak-peak output voltage ripple, Δv_o can obtain.

$$\Delta V_o = \Delta V_c = \frac{1}{C}\int i_c\,dt$$
$$= \frac{1}{L}[\textit{shaded area}, i_c\,]$$

Therefore

$$\Delta V_o = \frac{1}{C} X \frac{V_o}{R} X DT \qquad (8)$$

The proposed Buck- Boost circuit is operated in CCM condition. Therefore,

$$L_{min} = \frac{(1-D)^2 X R}{2 X fs}$$

Where D is duty ratio and fs is switching frequency and R is load resistor.

D. Designing The Converter

When designing converter, 3 main elements must be consider capacitor, inductor and resistor. The value of it elements can affect the results of simulation. So, to get the best value of its element, the value is set by table below:

TABLE I. PARAMETER AND VALUE OF BUCK BOOST CONVERTER

Parameter name	Fuzzy Logic Controller	Open Loop System
Input Voltage	20V	20V
Inductor	2.5mH	2.5mH
Capacitor	250 μF	250 μF
Resistor	50 Ω	50 Ω
Frequency	20KHz	20KHz
Switching	MOSFET	MOSFET

III. IMPLEMENTATION OF FUZZY LOGIC CONTROLLER

Fuzzy rules are expressed in MATLAB-SIMULINK environment in terms of implications of if . . . then . . . rules. In the FLC for the BBC, there are two input variables involved the error (eV) and the change of error(ceV). In this section, a FLC is used to regulate and stabilise the output voltage of a BBC. This controller is determined from the fuzzified input parameters, the inference rules and the deffuzzified output parameters [1-3-4-7]. There are few steps flows involved in modelling Fuzzy Logic Toolbox in the Matlab as illustrate in Figure 2.

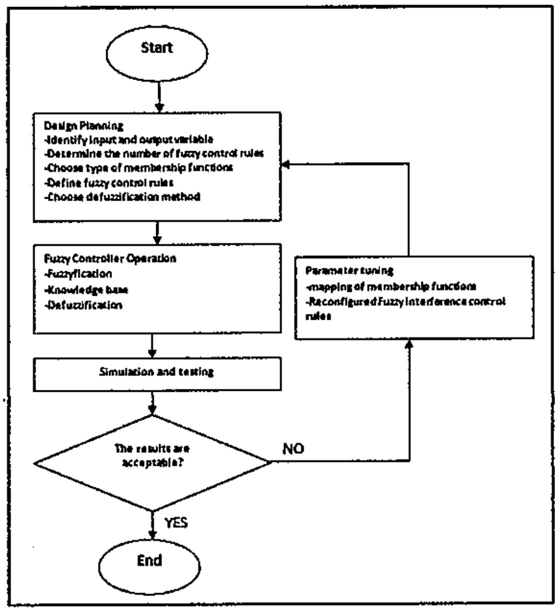

Figure 2: Illustrate Mat lab Fuzzy Logic Toolbox steps flow.

The first step is to identify and configure number of input and output in the Fuzzy Inference System editor (FIS). The model type of FIS is set to Mamdani. The second step is to configure the input and output characteristics in the Membership Function editor. Third step to configure the rule based editor in the Rule editor. The proposed FLC is used 5 fuzzy levels negative small (NS), negative big (NB), zero (ZO), positive small (PS), and positive big (PB) from two input error (eV) and change of error (ceV) and denoted 5^2= 25 number of fuzzy control rules.

The inference engine used is minmax method and defuzzify method change of duty cycle used in this fuzzy is centroid. The Membership function plots input and output for FLC as shown at Figure 4.The most important part is to determine the control rules which are based on human knowledge and experience. For instance, the controller accepts the inputs and maps them into their membership functions and truth values. These mappings are then feed into the rules. The rule specifies an AND relationship between the mappings of the two input variables, as shown in the examples Figure 5, the minimum of the two is used as the combined truth value. The appropriate output states are selected and then defuzzify output changed in duty cycle feed to PWM generator as illustrated in Figure 3 to 5.

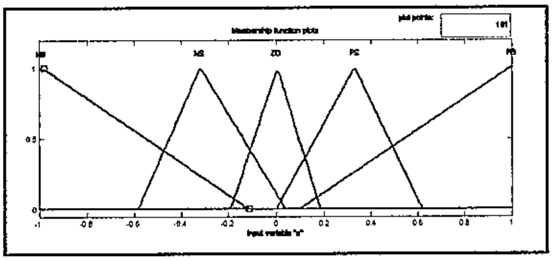

Figure 3: The membership function plots input error (eV) for FLC voltage loop

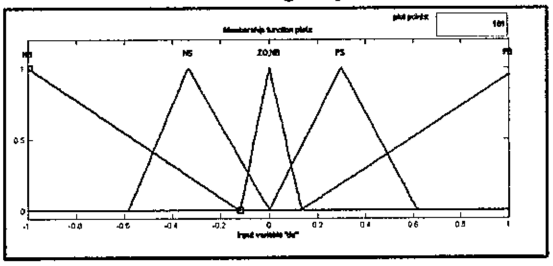

Figure 4: The membership function plots input change of error (ceV) for FLC voltage loop

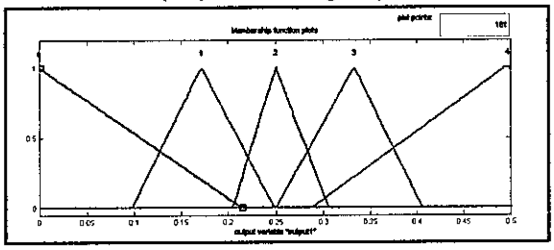

Figure 5: The membership function plots output for FLC voltage loop

TABLE II. THE FUZZY CONTROL RULES TABLE

		ERROR (eV)				
		NB	NS	ZO	PS	PB
CHANGE ERROR (ceV)	NB	PB	PS	ZO	NS	NB
	NS	NB	PB	PS	ZO	NS
	ZO	NS	NB	PB	PS	ZO
	PS	ZO	NS	NB	PB	PS
	PB	PS	ZO	NS	NB	PB

The configurations of fuzzy control rules in Table I are simplified from Rule Editor as illustrated in Figure 6.

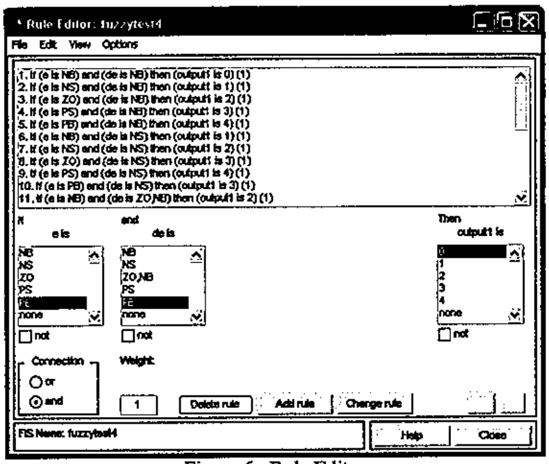

Figure 6: Rule Editor

IV. RESULTS AND DISCUSSION

The simulation results are based on output voltage deviation, voltage overshoot percentage, rise time, peak time and settling time for closed loop (fuzzy logic controller) comparison with open loop system. The simulation for this close loop and open loop had been tested in two condition mode buck (step down) and boost (step up) with variations of reference voltage. The result also touches about the rules of fuzzy logic controller.

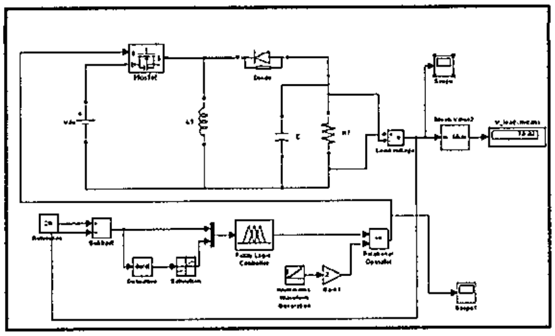

Figure 7: Circuit diagram of Fuzzy Logic controller for Buck-Boost converter

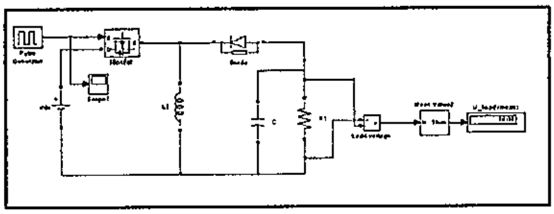

Figure 8: Circuit diagram of open loop system for Buck-Boost converter

A. *Comparison Between Fuzzy Logic Controller and Open Loop System*

a) Open loop system

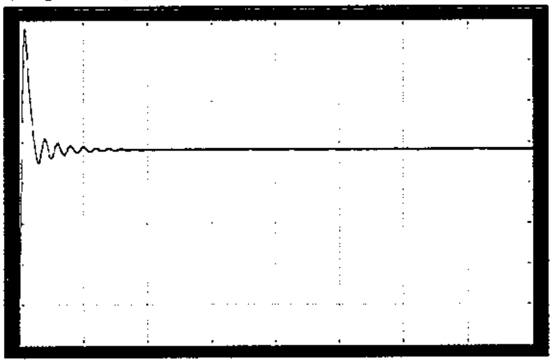

Figure 9: Output voltage from Buck- Boost Converter using open loop system

b) Fuzzy Logic Controller

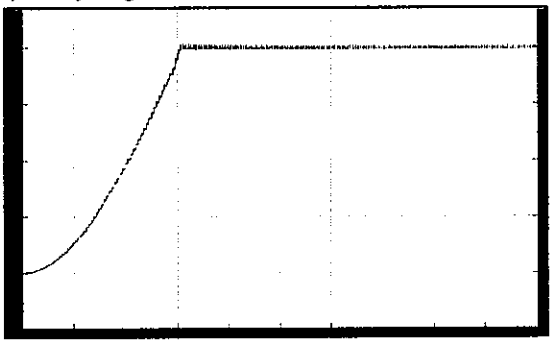

Figure 10: Output Voltage from Buck- Boost Converter using Fuzzy Logic Controller

From figure 9 and 10 the fuzzy logic controller produced better output voltage than the open loop system. It means that the fuzzy logic controller system is better than the open loop system. The peak voltage and overshoot is high compare to the fuzzy logic controller. Thus, for comparison of this system, the fuzzy logic controller system is more efficient and can improve the performance of DC-DC converter.

TABLE III. PERCENTAGE OF OVERSHOOT, RISE TIME, PEAK TIME AND SETTLING TIME FROM FLC BUCK-BOOST CONVERTER

Vin (V)	Vref (V)	Overshoot (%)	Rise Time (sec)	Peak Time (sec)	Settling Time (sec)
20	10	2.50	0.0020	10.25	0.0020
20	15	1.67	0.0026	15.25	0.0026
20	20	1.50	0.0034	20.30	0.0034
20	25	1.20	0.0036	25.30	0.0036
20	30	1.13	0.0042	30.34	0.0042
20	35	0.80	0.0045	35.28	0.0045
20	40	0.75	0.0051	40.3	0.0051

TABLE IV. PERCENTAGE OF OVERSHOOT, RISE TIME, PEAK TIME AND SETTLING TIME FROM OPEN LOOP BUCK-BOOST CONVERTER

Vin (V)	Vref (V)	Overshoot (%)	Rise Time (sec)	Peak Time (sec)	Settling Time (sec)
20	10	77.30	0.0081	17.73	0.130
20	15	53.47	0.0059	23.02	0.080
20	20	75.50	0.0061	35.10	0.078
20	25	70.80	0.0062	42.7	0.092
20	30	72.93	0.0063	51.88	0.130
20	35	80.06	0.0062	63.02	0.132
20	40	88.30	0.0064	75.32	0.133

TABLE V. THE DEVIATION OF VOLTAGE RESULTED FROM FLC AND OPEN LOOP BUCK-BOOST CONVERTER

Vin (V)	Vref (V)	Vo(FLC) (V)	Vo(OP) (V)	Diff Vo(FLC) with Vref (V)	Diff Vo(OP) with Vref (V)
20	10	9.973	8.749	0.027	1.251
20	15	14.960	13.480	0.040	1.520
20	20	19.950	18.560	0.050	1.440
20	25	24.940	23.460	0.060	1.540
20	30	29.910	28.800	0.090	1.200
20	35	34.920	33.530	0.080	1.470
20	40	39.900	38.720	0.100	1.280

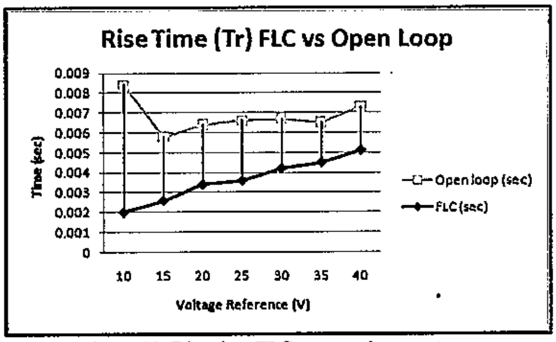

Figure 11: Rise time FLC vs open loop system

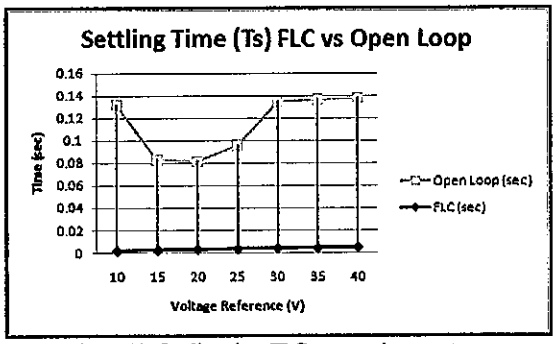

Figure 12: Settling time FLC vs open loop system

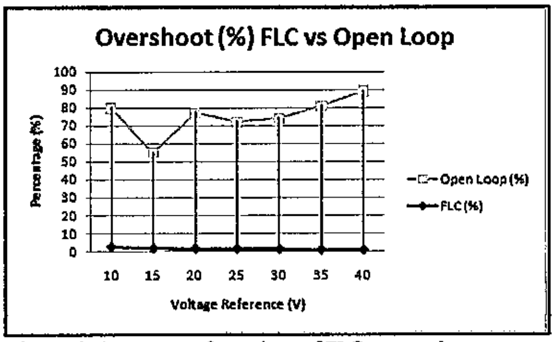

Figure 13: Percentage of overshoot of FLC vs open loop system

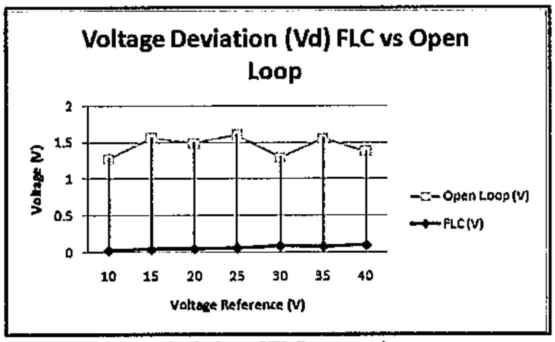

Figure 14: Voltage deviation of FLC vs open loop system

The graphs above are the comparison between open loop and closed loop test held in MAT-LAB SIMULINK. The results had shown that FLC faster rise time than open loop as illustrated at figure 11. The closed loop took a shortest settling time to reach and stable at the desired output voltage as compared to open loop as illustrated at figure 12. At figure 13, percentage of overshoot shown that open loop contributed the highest percentage of overshoot and for FLC the percentage of overshoot is very small at closed to zero and can be neglected. The deviation of voltage as illustrated in table 14 shown that the close loop is at closed zero, where the open loop is more than 1V. The result shown the controller can improve the performance of buck boost converter compare normal operation without controller.

B. Comparison rules of Fuzzy Logic Controller

This simulation is between the rules of fuzzy logic controller to compare the best result can be made in this experiment. The table below is the rules of fuzzy logic which is test in the MAT-LAB SIMULINK.

TABLE VI. TEST 1 FOR FUZZY LOGIC RULES

CHANGE ERROR (ceV)		ERROR (eV)				
		NB	NS	ZO	PS	PB
	ZO	NB	NB	NB	NS	ZO
	PB	NB	NB	NS	ZO	PS
	PS	NB	NS	NB	PS	PB
	NS	NS	ZO	PS	PB	PB
	NB	ZO	PS	PB	PB	PB

TABLE VII. TEST 2 FOR FUZZY LOGIC RULES

CHANGE ERROR (ceV)		ERROR (eV)				
		NB	NS	ZO	PS	PB
	NB	PB	PS	ZO	NS	NB
	NS	NB	PB	PS	ZO	NS
	ZO	NS	NB	PB	PS	ZO
	PS	ZO	NS	NB	PB	PS
	PB	PS	ZO	NS	NB	PB

TABLE VIII. TEST 3 FOR FUZZY LOGIC RULES

CHANGE OF ERROR (ceV)		ERROR (eV)				
		NB	NS	ZO	PS	PB
	NB	NB	NS	ZO	PS	PB
	NS	NS	NB	PS	PB	PS
	ZO	ZO	PS	NB	PS	ZO
	PS	PS	PB	PS	NB	NS
	PB	PB	PS	ZO	NS	NB

TABLE VI. COMPARISON RULES TEST OF OUTPUT VOLTAGE (VO), RISE TIME (TR), AND SETTLING TIME (TS) FOR FUZZLY LOGIC RULES

Test	Vin(V)	Vref(V)	Vo(V)	Tr(sec)	Ts(sec)
1	20	10	8.706	0.0022	0.0024
2	20	10	9.973	0.0064	0.0130
3	20	10	8.735	0.0024	0.0026

From this comparison, the test 1 and 2 is not suitable for this simulation because the value of output voltage (Vo) is not closed to the reference voltage. The test 2 is suitable because value of output voltage (Vo) is very closed to the reference voltage compare to test 1 and 3. It means, by adjusting the rules of Fuzzy Logic Controller can made the difference value of output voltage

V. CONCLUSION

In this project, the main objective is to improve performance of Dc-Dc buck boost converter. From this result, the fuzzy logic controller is better than open loop system without controller. The fuzzy logic controller is very good controller in produced good output voltage. The results confirmed that the fuzzy logic controller achieved much better in term of fasters in rise time, peak time and settling time as compared to open loop. The fuzzy logic controller also produced less output voltage deviations from variations of voltage reference setting. The rules of fuzzy logic controller also can be adjusted to get better performance in output voltage. By use 25 fuzzy logic rules, the value of output voltage can reduced until closed to the reference voltage.

RECOMENDATION

For future work, several improvements could be taken such as to improving the output of current and reduce the current stress on inductor, it can be resolved by tapped inductor in buck boost converter circuit. This will reduce the losses in the rectifier circuit and increase the efficiency of the converter.

ACKNOWLEDGMENT

A special thank to Associate Professor Wan Norainin Bt Wan Abdullah for her guidance, support, commitment, and opinion in completing this research. Her contribution is really appreciated and grateful.

REFERENCES

[1] Guang Feng, Wanfeng Zhang, Yan-Fei Liu. "An adaptive current mode fuzzy logic controller for dc-to-dc converters", IEEE 2003, page. 983-989;

[2] Rashid, M.H., Power Electronics (Circuits, Devices and applications). 2004. Third edition (principle of step-up operation): p. 176-180

[3] Mattavelli, P., Rossetto, L., Spiazzi, G., Tenti, "P. General-purpose fuzzy controller for dc/dc converters", APEC, 1995.

[4] [4]. Kevin M. Passino, Stephen Yurkovich. "Fuzzy Control". Page 23

[5] Ned Mohan, Tore M. Undeland, William P. Robbins. "Power Electronics: Converter, Applications and Design". Chapter 7, Page 178

[6] R.Kayalvizhi, S. P. Natarajan, S.Anbumalar. "Development of Fuzzy Logic Control for Paralleled Positive output Elementary Luo Converters". IEEE 2006

[7] Johnson A. Asmadu, Vaidyanathan Jagannathan. "Synthesis of Nonlinear Control of Switching Topologies of Buck- Boost Converter Using Fuzzy Logic". IEEE,2000, pp.