Performance Improvement of Buck-Boost Converter Using Fuzzy Logic Controller

B. Sujanarko, I. Syafrizal, S. Bachri, R.B.M. Gozali, S. Prasetyo, T. Hardianto

Abstract— The Buck - boost converter is a system to step-down and step-up a DC source. But if the voltage of DC source and the load in the fluctuative condition, the output voltage of the Buck-boost converter is not stable. In this research, Fuzzy logic controller used to make Buck-Boost converter can adapt load and DC voltage variation to produce a stable DC output. Converter built using MOSFET, PWM signal in the frequency 4 kHz and voltage of DC source in the 30 V to 60 V. Fuzzy logic controller built using Matlab Simulink and connected to Converter by PCI 1710HG. This controller made PWM duty cycle in accordance with the changing of set point and input voltage. The experiment result shown that the converter output can produce voltage in the set point although in fluctuated input voltage.

Index Terms— Buck-boost Converter, Duty Cycle, Pulse Width Modulation, PCI 1710HG, Fuzzy Logic, Simulink Matlab

I. INTRODUCTION

In electric automobiles, trolley cars, marine hoists, forklift trucks, and renewable energy system need provide smooth acceleration control, high efficiency, and fast dynamic response. Usually they use dc-dc converter system to do it. They using step down, step-up, or step up- step-down the voltage of electric power. So, there are many types of DC-DC convertor, which is buck converter, boost converter, and buck-boost convertor [1-5]. Buck-boost converter is one type of converter circuit that the most used in power electronics appliances. The designers choose this converter because the output voltage is inverted from the input voltage, and the output voltage can be either higher or lower than the source voltage.

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The control point of view due to their intrinsic nonlinearity is an intriguing subject, because the presence of parasitic elements, time-varying loads, and supply voltages fluctuation [1-4]. There are many classical nonlinear controllers have been proposed, like sliding mode control strategies, nonlinear PI controllers, linear averaged controller, feedback linearizing controller, passivity-based controller and others. The major problem of the classical approach are the complexity of system, the difficult to make precise, and the difficult to make significant statements about its behavior [3-8].

Another controll that using human linguistic terms and common sense is Fuzzy Logic Controllers (FLC). Many FLC have been developed. The essential parts of the FLC are make a set of linguistic rules related by the fuzzy implication and the rule of inference. Each ways in the determining of these parts also produce the difference of Buck-Boost converter performance [5-8]. A method and some values are needed to determine the essensial parts, so the buck-boost converter has high performances.

In this research, the FLC implemented on Simulink atlab and connect to Buck-Boost converter using PCI 1710HG. Such this implementation will allow to make variation of the essential parts of FLC, so that the best performance can be achieved.

II. BUCK-BOOST CONVERTER MODELLING

The basic buck-boost converter circuit is shown in Fig. 1 [1-3]. When Switch S is on, energy is transferred to the inductor (L) and the load current (I_o) is provided solely from the output capacitor (C). When the transistor turns off, inductor current (i_L) is forced through the diode (Dx). Energy stored in L is transferred to C and the load R. This transfer action results in an output voltage of opposite polarity to that of the input.
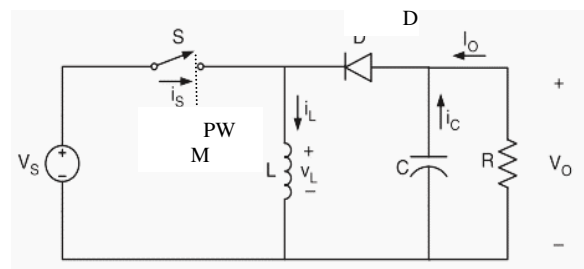

Fig.1 Basic Buck-Boost converter circuit

Assuming input and output voltage in a constant condition, dc voltage transfer function of the buck–boost converter is given by Eq. (1), where D is time of switch on divide by periode of time switching or Duty cycle. For D < ½,

the output magnitude is less than the input voltage magnitude, while for D > ½, the output voltage is greater in magnitude than the input voltage. While, the value of the inductor that determines the boundary between the Continuous Current Mode (CCM) and Discontinuous Current Mode (DCM) is given by Eq. (2) [1-8].

$$\frac{V_O}{V_S} = -\frac{D}{1-D} \qquad (1)$$

$$L_b = \frac{(1-D)^2 R}{2f} \qquad (2)$$

III. PULSE WIDTH MODULATION IN THE BUCK-BOOST CONVERTERS

As shown in Eq.(1) and Eq. (2), the output voltage is depend on duty cycle (D) of Pulse Witdh Modulation (PWM) cicuit, beside the inductor value, load, and parasitic value. Fig. 2 show an PWM principal [3-5] . A voltage level from a controller, as represents a desire output voltage, entered into the non inverting of comparator, and a sawtooth pulse, as carrier wave, entered into inverting of comparator. These system then generate pulse ouput in the certain duty cycle. This pulse then trigger power electronic device and produce average dc output voltage that comparable with a given desired level on non inverting.
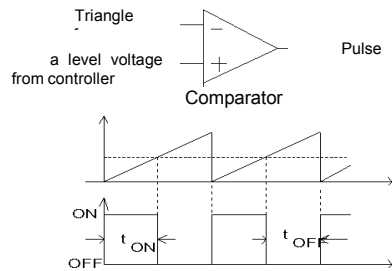

Fig.2 Pulse Width Modulation circuit

Usually, the input voltage (V_s) and output (V_0) may fluctuate. To determine a certain average output voltage in the constan value, the converter used a controller. This controller aims to regulate duty cycle. If the input or the ouput voltage is decrease the duty cycle then increase, and otherwise if the input or the output voltage increase the duty cycle then decrease.

Various control methods are available for buck boost converters. One method of control is to use sliding mode control. But its lack effective control [3-5]. Another alternative is a decoupled control scheme using PI controllers [9]. For high-performance applications, a PI controller cannot guarantee a perfect tracking in the case of a periodic reference, according to the internal model principle. So a non linear control method using fuzzy logic is proposed in this paper.

IV. FUZZY CONTROL IN BUCK-BOOST CONVERTER

The concept of Fuzzy Logic was introduced by Lotfi Zadeh in 1965. It is mathematical modeling which is deals with uncertainty and offers an important concept of soft computing with words [6-7]. The generic structure of fuzzy

logic controller is shown in Fig. 3. It has four main components, Fuzzifier, Rule Base, Inference Engine, and Defuzzifier [4-7].

Fuzzifier is a part of FLC that modifies the inputs so that they can be interpreted and compared to the rules in the rule-base. It convert crisp values to fuzzy values. Fuzzy values are linguistic variables. Error, load voltage, modulation index, etc is example of input. This input then convert to a set of linguistic values, like positive, zero, negative.

Intent of the linguistic values is quantified using membership functions. The membership function range input from 0 to 1. There are different types of membership functions, triangular, trapezoidal, gaussian, bell, sigmoidal, S, pi etc [4-8].
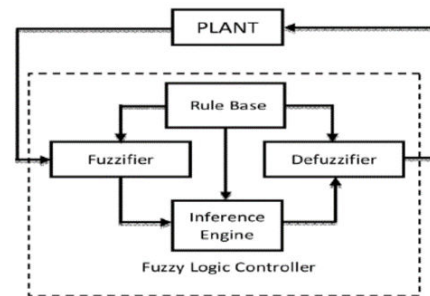

Fig.3 Generic structure of fuzzy logic controller

Rule Base is a part of FLC that holds the knowledge, in the form of a set of rules, in the IF-THEN statements. This part has function to achieve good control. Inference engine is a part of FLC that decision making mechanism. Based on the inputs, inference engine evaluates which control rules are relevant at the current time and then decides what the input to the plant should be. It has a goal is to find best control the plant.

There are two types of fuzzy inference engine, Mamdani and Sugeno method. Mamdani's method is widely accepted for capturing expert knowledge. But it has computational burden. Sugeno is computationally efficient. It is highly attractive in control problems particularly dynamic non linear systems. The Sugeno output membership functions are linear or constant.

Defuzzification is a part of FLC that converts the conclusions of the inference mechanism into the actual outputs. It converts the fuzzy value to crisp value. Centroid, max membership principle, mean-max membership, centre of sums, weighted average, centre of largest area various of defuzzification method.

V. MATERIAL AND METHOD

A. System Configuration

Fig. 4 show configuration system in the research. The system consists power supply with a voltage of 30 V - 60 V, voltage sensor that used to read the value of the power supply voltage and converter output, current sensor that used to read the converter current or that flow to the load, driver that used as control and separator between power signal and the real power, PWM circuit that produce signal to trigger converter, PCI 1710 HG and PCLD 8710 that used as a interfacing

between computer and external device, and Fuzzy logic controller that used to produce a voltage as control of the magnitude of the PWM duty cycle.

B. Buck-Boost Converter Circuit

Buck-boost converter circuit consists of MOSFET, diode, inductor and capacitor. This circuit shown at Fig. 5. Tipe and value of each component have been also shown in this figure. MOSFET used as electrical switches that controls by PWM. Changes in the average voltage at the output is due to differing value of the duty cycle. If the duty cycle (D) <50%, the value of the output voltage will be smaller than the input voltage and when D > 50%, then the value of the output voltage will be greater than the input voltage.
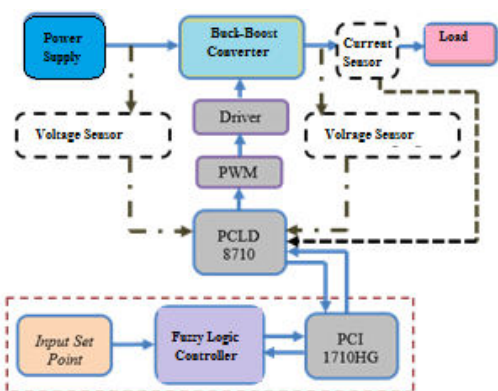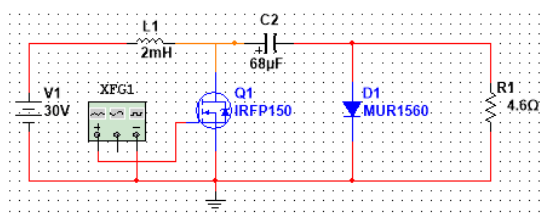

Fig.4 System configuration

Fig. 5 Buck-boost converter circuit

C. MOSFET Driver Circuit

MOSFETs with certain types will have specific specifications. Thus, the pulses entering the Gate of the MOSFET must also have certain shape, amplitude and frequency. The shape must primarily meet to dv/dt and di/dt. Suitable amplitude will make the MOSFET have a small R_{on} so the heat dissipation is small. While the corresponding frequency, will be able to work MOSFET at maximum current.

For that purpose, a MOSFET driver circuit is needed. This circuit will form the pulses of the PWM, so it has the shape and voltage corresponding to the MOSFET specification. For frequency it has been adjusted by using triangular wave with certain frequency in the PWM cicuit. The MOSFET driver circuit is shown in Fig. 6. MOSFET driver circuit also serves as a separator between power for control with power system.
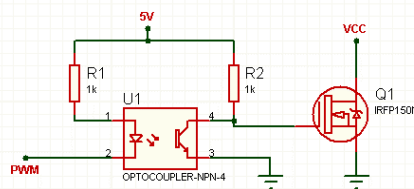

Fig. 6 MOSFET Driver circuit

D. PWM Circuit

PWM circuit shown in Fig. 7. It is consist of IC LM324 as comparator and NE 555 as triangular signal. The triangular signal that generated from the IC NE555 enter to inverting input and the output voltage from fuzzy logic control enter to non-inverting input. The result of the comparing then enter to MOSFET driver circuit.
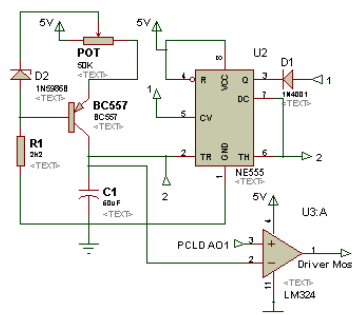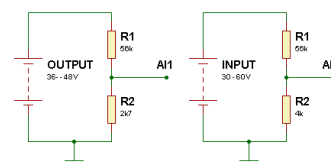

Fig. 7 PWM Circuit

E. Voltage and Current Sensor

The input and output voltage measure using voltage divider circuit. This voltage divider convert the input and output voltage of the converter in the 60 V (max) in to less than 5V. This sensor shown in Fig.8(a). Current sensor used in the system is ACS712-20A. It is a Hall Effect current sensors. Fig. 8(b) shown this sensor.

(a) Voltage Sensor
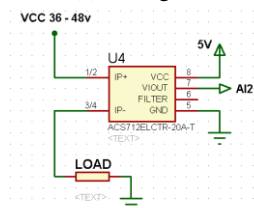
(b) Current Sensor

Fig. 8 Sensors

F. Fuzzy Logic Controller Design

Fuzzy logic controller modeled for buck boost converter is shown in Figure 9. It have two input, that is voltage output, and error of converter. The ouput of FLC is a voltage that enter to PWM circuit. In the FLC, three signals, then Fuzzyfier into some membership. Fig. 10 show the membership for these signals.
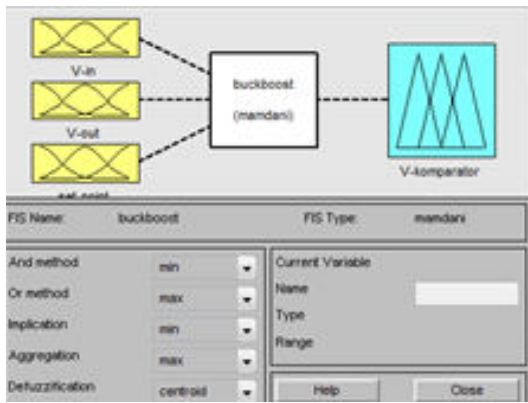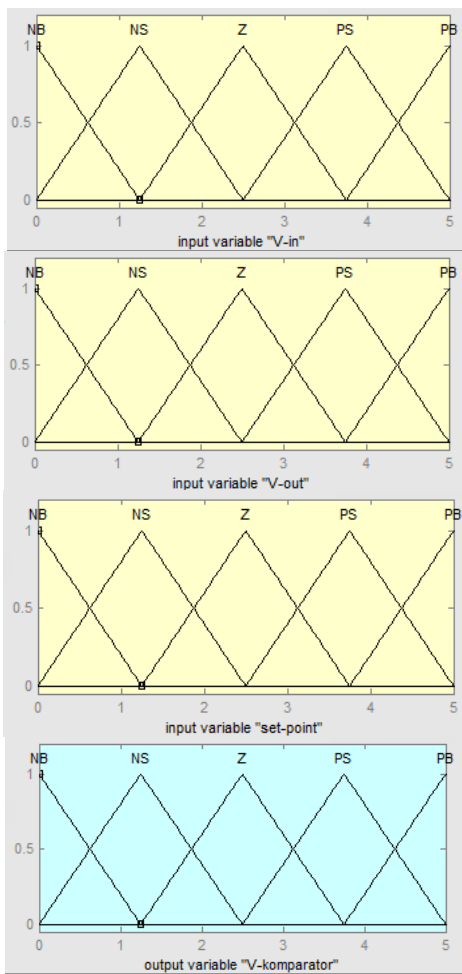
Fig. 9 Fuzzy Logic Controller Model

Fig. 10 Input and output membership of FLC

Based on these memberships, the next step is build the Fuzzy role decision that represent the correlation among the inputs and outputs signal, as shown in table 1. The next step is construct Rule base using IF-THEN logic. The rule base shown in Fig. 11. All process done using Fuzzy Logic toolbox of Matlab.

If set-point is NB and V-out is NB and V-in is NB
then V-komparator is Z
....
If set-point is NS and V-out is NB and V-in is NB
then V-komparator is PS

....
If set-point is Z and V-out is NB and V-in is NB
then V-komparator is PB
....
If set-point is PS and V-out is NB and V-in is NB
then V-komparator is PB
....
If set-point is PB and V-out is NB and V-in is NB
then V-komparator is PB
....
If set-point is PB and V-out is PB and V-in is PB
then V-komparator is Z

Fig. 11 Rule Base

Table 1 Fuzzy rules

Set-point =NB		V-in				
		NB	NS	Z	PS	PB
V-out	NB	Z	NB	NB	NB	NB
	NS	NS	NB	NB	NB	NB
	Z	NB	NB	NB	NB	NB
	PS	NB	NB	NB	NB	NB
	PB	NB	NB	NB	NB	NB

Set-point =NS		V-in				
		NB	NS	Z	PS	PB
V-out	NB	PS	PS	NB	NB	NB
	NS	PS	Z	NB	NB	NB
	Z	NS	NS	NB	NB	NB
	PS	NB	NB	NB	NB	NB
	PB	NB	NB	NB	NB	NB

Set-point =Z		V-in				
		NB	NS	Z	PS	PB
V-out	NB	PB	PB	PB	NS	NB
	NS	PB	PB	PS	NB	NB
	Z	PS	PS	Z	NB	NB
	PS	NS	NS	NS	NB	NB
	PB	NB	NB	NB	NB	NB

Set-point =PS		V-in				
		NB	NS	Z	PS	PB
V-out	NB	PB	PB	PB	PB	NS
	NS	PB	PB	PB	PS	NS
	Z	PB	PB	PB	PS	NS
	PS	PB	PB	PS	Z	NS
	PB	NS	NS	NS	NS	NS

Set-point =PB		V-in				
		NB	NS	Z	PS	PB
V-out	NB	PB	PB	PB	PS	PB
	NS	PB	PB	PB	PS	PB
	Z	PB	PB	PB	PS	PS
	PS	PB	PB	PB	PS	PS
	PB	PB	PB	PB	PS	Z

G. *Matlab Simulink*

After the Fuzzy logic built, the fuzzy logic then implemented using Simulink in the Personal Computer and connect to external system using PCI 1710HG and PCLD 8710 [10]. The system also added some blocks simulink. Fig. 12 shows the Simulink MATLAB of this system. It have three analog input to receive the value from input and output voltage sensor, and current sensor, and have one analog output to produce a voltage as input of PWM circuit.
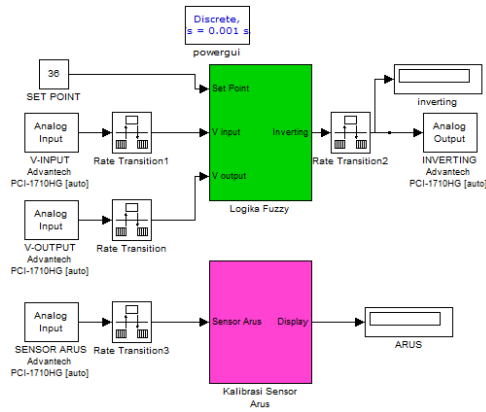
Fig. 12 Simulink block

H. *Experiment set-up*

In this research, the experiment set-up used a permanent magnet DC motor as load. The motor specifications are 36 V, 12 A current, power of 500 Watt and a speed of 500 rpm. This set-up shown in Figure 12. Fig. 13 shown buck-boost converter unit.
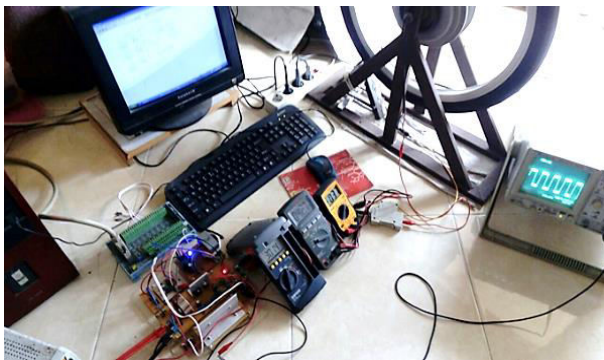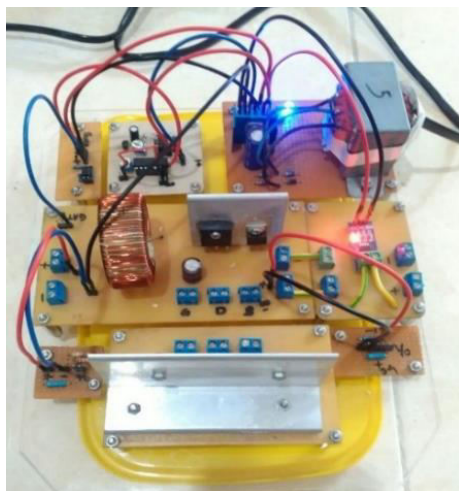

Fig. 12 Experiment set-up

Fig. 13 Buck-boost converter unit

VI. RESULT AND DISCUSSION

Table 2 show the experiment result of the system without Fuzzy Logic Controller. If the voltage input increase but duty cycle in the contant value (27.7%), the output voltage, the current, and the RPM motor increase too. As well as in the duty cycle of PWM in the 30.6%, the output of buck-boost converter also in the same result. Table 3 show the result of experiment result in this condition.

Table 2 Result experimen in the duty cycle 27.7%

No.	Vin (V)	Duty Cycle (%)	RPM	Vout (V)	Iout (A)
1	30	27.7	136	13.2	0.24
2	35	27.7	155	16.6	0.26
3	40	27.7	214	20.6	0.28
4	45	27.7	241	24.5	0.29
5	50	27.7	285	28.8	0.31
6	55	27.7	327	32.8	0.32
7	60	27.7	357	36.1	0.34

Table 3 Result experimen in the duty cycle 30.6%

No.	Vin (V)	Duty Cycle (%)	RPM	Vout (V)	Iout (A)
1	30	30.6	147	15.9	0.26
2	35	30.6	213	20.3	0.28
3	40	30.6	242	24.8	0.30
4	45	30.6	290	29.6	0.32
5	50	30.6	331	34.3	0.33
6	55	30.6	384	38.7	0.36
7	60	30.6	430	42.9	0.37

Table 4 show result experiment in the contan set point (36 V), but in the increase input voltage (30-60 V). The duty cycle is produce by FLC system. The output voltage (Vout) can maintain in the around of 36 V, as well as the current (0.34 A), and the RPM of motor. Maximum error in this experiment is 1,66% or about 0.6 V.

Table 4 Result experimen in the set point 36 V

No.	Vin (V)	Set Point	Duty Cycle (%)	RPM	Vout (V)	Iout (A)	Error (%)
1	30	36	47.3	353	36.2	0.34	0.55
2	35	36	41.6	352	36.0	0.35	0
3	40	36	37.4	352	36.1	0.34	0.27
4	45	36	33.9	320	35.5	0.34	1.38
5	50	36	31.9	344	36.6	0.34	1.66
6	55	36	29.3	353	36.1	0.34	0.27
7	60	36	27.3	323	35.7	0.34	0.83

Table 5 Result experimen in the set point 42 V

No.	Vin (V)	Set Point	Duty Cycle (%)	RPM	Vout (V)	Iout (A)	Error (%)
1	30	42	52.5	426	42.6	0.37	1.42
2	35	42	45.7	417	42.0	0.37	0
3	40	42	41.5	431	42.7	0.37	1.66
4	45	42	37.8	430	42.8	0.37	1.90
5	50	42	34.7	424	42.6	0.37	1.42
6	55	42	32.7	437	43.1	0.38	2.61
7	60	42	30.0	420	42.3	0.37	0.71

Same result also happened in the experiment result in the set point 42 V. In this experiment, the output voltage can maintain in the around 42 V and the output current in the 0.37 A. The maximum error in this experiment is 1.9% or about 0.8 V. This experiment result shown in Table 5.

The stability performance of the buck-boost converter tested using sudden changed of set-poit and input voltage. Fig. 14 show experiment result in the set-point changed and Fig. 15, in the input voltage change.

In the set point change, the putput of the system can follow the value of set point,but have error happen in the low and high voltage setting. In the Fig. 15 shown that in the set point 30 V, the result of output voltage is 31-32 V, so on in the set point 50 V, the output voltage is 51-52 V. In the set poit change from 30 V to 45 V, the system have overdamped and then toward to a value that over than set point (47 V). In the set point changed from 45 V to 35 V, also happeng an overdamped condition. However these condition have output voltage better than not controlled.
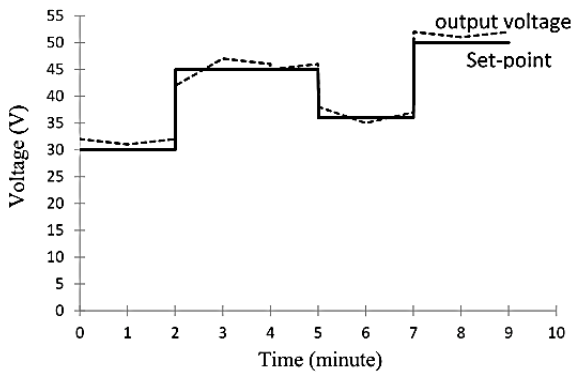

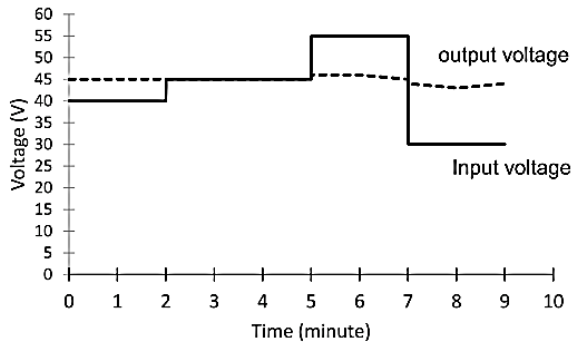Fig. 14 Experiment result in the set-point change

Fig. 15 Experiment result in the input voltage change

At the input voltage change, the system response is quite good, because of the experiment obtained quite small deviation. Fig. 15 shown the experiment result of input voltage changed in the set point 45 V.

VII. CONCLUSIONS

Fuzzy Logic Controller that implemented using Simulink Matlab and connect using PCI 1710 HG and PCLD 8710 can improve the performance of buck-boost converter. The converter is able to give a good response in set point and input voltage changed, although the errors that occur in the stability test still gives a considerable error. Better performance improvements can be made using improving of membership function and the rule base on the FLC system.

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