An Analytical Comparison between Open Loop, PID and Fuzzy Logic Based DC-DC Boost Convertor

Muhammad Mujtaba Asad, Razali Bin Hassan, Fahad Sherwani

***Abstract*—**This paper explains about the voltage output for DC to DC boost converter between open loop, PID controller and fuzzy logic controller through Matlab Simulink. Simulink input voltage was set at 12V and the voltage reference was set at 24V. The analysis on the deviation of voltage resulted that the difference between reference voltage setting and the output voltage is always lower. Comparison between open loop, PID and FLC shows that, the open loop circuit having a bit higher on the deviation of voltage. The PID circuit boosts for FLC has a lesser deviation of voltage and proved that it is such a better performance on control the deviation of voltage during the boost mode.

***Keywords*—**Boost Convertors, Power Electronics, PID, Fuzzy logic, Open loop.

I. Introduction

DC to DC boost converters are important in portable electronic devices such as cellular phones and laptop computers, which are supplied with power from batteries primarily. Such electronic devices often contain several sub-circuits, each with its own voltage level requirement different from that supplied by the battery or an external supply (sometimes higher or lower than the supply voltage) and boost converter (step-up converter) is a DC-DC power converter with an output voltage greater than its input voltage. They provide smooth acceleration control, high efficiency, and fast dynamic response [1]. DC converter can be used in regenerative braking of DC motor to return energy back into the supply, and this feature results in energy saving for transportation system with frequent stop; and also are used, in DC voltage regulation [1]. In many ways, a DC-DC converter is the DC equivalent of a transformer. There are four main types of converter usually called the buck, boost, buck-boost and Boost converters.

The main feature of a fuzzy controller is that it can convert the linguistic control rules based on expert knowledge into automatic control strategy. So it can be applied to control systems with unknown or un modeled dynamics [3]. Mostly, the DC-DC converter consists of the power semiconductor devices which are operated as electronic switches and classified as switched-mode DC-DC converters.

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Operation of the switching devices causes the inherently nonlinear characteristic of the DC-DC converters. Due to this unwanted nonlinear characteristics, the converters requires a controller with a high degree of dynamic response. Pulse Width Modulation (PWM) is the most frequently consider method among the various switching control method [2]. In DC-DC voltage regulators, it is important to supply a constant output voltage, regardless of disturbances on the input voltage [2].

Currently, the control systems for many power electronic appliances have been increasing widely. Crucial with these demands, many researchers or designers have been struggling to find the most economic and reliable controller to meet these demands. The idea to have a control system in dc-dc converter is to ensure desired voltage output can be produced efficiently as compared to open loop system.

II. Statement of Problem

Developing the fuzzy controller is cheaper than developing a model based or other controllers for the same purpose. Proportional-Integral- Differential (PID) controllers have been usually applied to the converters because of their simplicity. However, the main drawback of PID controller is unable to adapt and approach the best performance when applied to nonlinear system. It will suffer from dynamic response, produces overshoot, longer rise time and settling time which in turn will influence the output voltage regulation of the Boost converter [5].

The implementation of practical Fuzzy Logic controller that will deal to the issue must be investigated. The Fuzzy control is a practical alternative for a variety of challenging control applications because Fuzzy logic control is nonlinear and adaptive in nature that gives it a robust performance under parameter variation and load disturbances. Fuzzy controllers are more robust than PID controllers because they can cover wider range of operating conditions than PID, and can also operate with noise and disturbance of different natures. Fuzzy logic is suited to low-cost implementations and systems of fuzzy can be easily upgraded by adding new rules to improve performance or add new features [3].

III. Literature Review

A. DC-DC Converters

The DC/DC converter is a device for converting the DC voltage to step-up or step-down depending on the load voltage required. If the requirement of voltage is step-up then it is necessary to use a boost converter. It the requirement of voltage is step-down, and then it necessary to use a buck converter. Sometimes, both step-up and step-down is required to cover the load, but at different times then it is necessary to use a buck-boost converter. Therefore, different types of DC-DC converters are used for different voltage levels in load [9].

Fig. 1 shows the basic circuit configuration used in the buck converter. There are only four main components namely switching power MOSFET Q1, flywheel diode D1, inductor L and output filter capacitor C1. In this circuit the transistor that is switched ON will put voltage V_{in} on one end of the inductor. This voltage causes the current of the inductor to rise. When the transistor is switched OFF, the current continue to flow through the inductor. At the same time, it flows through the diode. Initially it is assumed that the current flowing through the inductor does not reach zero; thus the voltage will only go across the conducting diode during the full OFF time. The average voltage depends on the average ON time of the transistor on the condition that the current of the inductor is continuous [11].

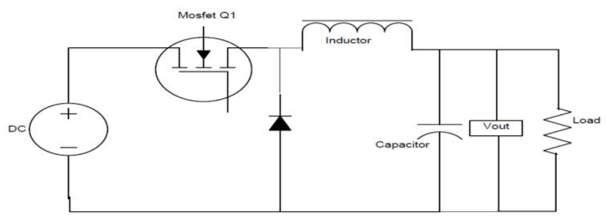

Fig. 1 The Basic Circuit Configuration of the Buck Converter

B. Boost Converter

A boost converter or a step up converter is a non-isolated converter. It the most commonly used DC/DC converter, especially used in UPS and PV. This is because battery charge requires high DC voltage to be fully charged. Fig. 2 shows the basic boost converter. The theory of a boost converter is not complicated as other converters rather. It is simple and straight forward. If the switch, S is ON, the current flows only through the inductor, which has stored energy. When the switch, S is OFF, the energy in the conductor is translated to a capacitor, which usually has a large capacity to store a bigger amount of energy. Finally, this energy converts to load with a high DC voltage [8].

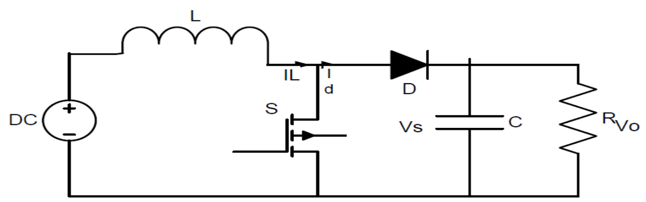

Fig. 2 Basic Circuit of Boost Converter

C. Buck-Boost Converter

The main components in a buck-boost converter are the same as in the buck and boost converter types, but they are configured in a different way. Fig. 3 in buck-boost converter, a step-up or step-down voltage can change the value of duty cycle. Nevertheless, in a similar process, once the switch is ON, the inductor begins charging and, the converter is stored with energy. However, once the switch is OFF, the circuit changes into inductor and capacitor simultaneously hence all the stored energy in the inductor is converted to capacitor. One thing that controls the voltage is the duty cycle. If the duty cycle is big, voltage is high in the load. On the other hand, when the duty cycle is small, voltage in the load is low [4].

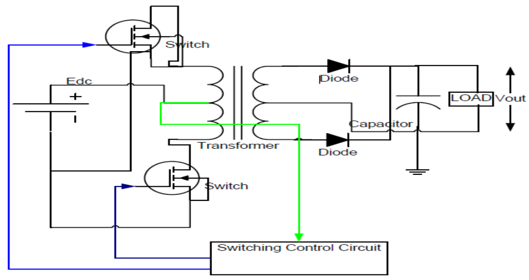

Fig. 3 Basic Circuit of Buck-Boost Converter

D. Fuzzification

Fuzzification is a process of making a crisp quantity fuzzy. Before this process is taken in action, the definition of the linguistic variables and terms is needed. Linguistic variables are the input or output variables of the system whose values are words or sentences from a natural language, instead of numerical values. A linguistic variable is generally decomposed into asset of linguistic terms. Next, to map the non-fuzzy input or crisp input data to fuzzy linguistic terms, membership functions is used. In other words, a membership function is used to quantify a linguistic term. Note that, an important characteristic of fuzzy logic is that a numerical value does not have to be fuzzi field using only one membership function meaning, a value can belong to multiple sets at the same time. There are different forms or shapes of membership functions such as Triangular, Gaussian, Trapezoidal, Generalized Bell and Sigmoidal. Figs. 4-8 show the different types of membership function shape.

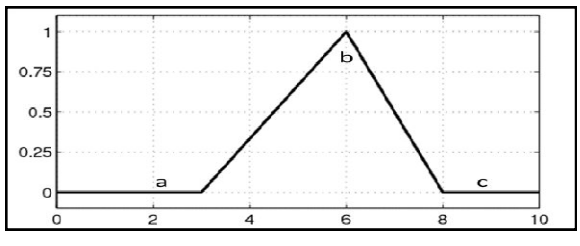

Fig. 4 Triangular Membership Function Shape

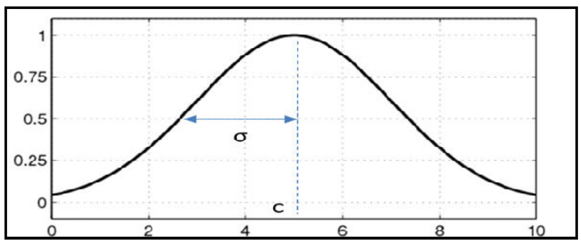

Fig. 5 Gaussian Membership Function Shape

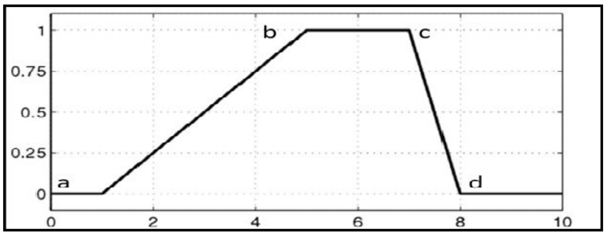

Fig. 6 Trapezoidal Membership Function Shape

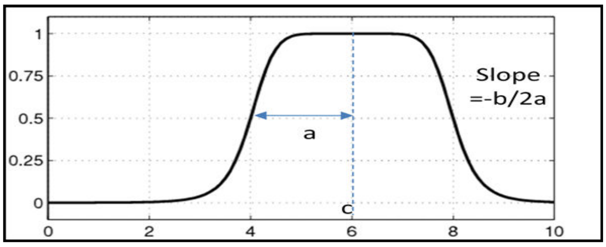

Fig. 7 Generalized Bell Membership Function Shape

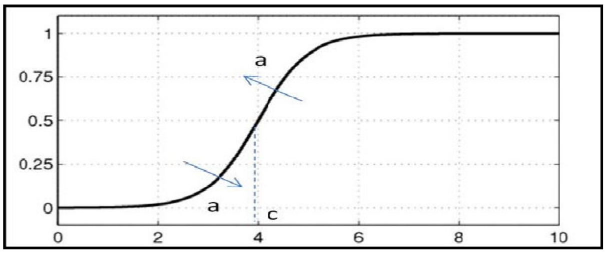

Fig. 8 Sigmoidal Membership Function Shape

In a fuzzy logic control system, a rule base is constructed to control the output variable. A fuzzy rule is a simple IF-THEN rule with a condition and conclusion. It can be represented by the matrix table. The premise variables error and change in error are laid out along the axes, and the conclusions are inside the table [7]. The most prominent connective is the 'and' connective, often implemented as multiplication instead of minimum. For examples 'If error is Neg and change in error is Pos then control is Zero [8].

In general, inference is a process of obtaining new knowledge through existing knowledge. In the context of fuzzy logic control system, it can be defined as a process to obtain the final result of combination of the result of each rule in fuzzy value [6].

After the aggregation process, there is a fuzzy set for each output variable that needs defuzzification. It is possible and in many cases much more efficient, to use a single spike as the output membership functions rather than a distributed fuzzy set. This is sometimes known as a singleton output membership function. It enhances the efficiency of defuzzification process because it greatly simplifies the computation required by the more general Mamdani method, which finds the centroid of two dimensional functions.

Meanwhile, Takagi-Sugeno-Kang method is similar to the Mamdani method in many aspects. The first two parts of fuzzy inference processes which are fuzzifying the inputs and applying the fuzzy operator are exactly the same. But, the main difference is that the Takagi-Sugeno-Kang output membership function is either linear or constant [7]

IV. Methodology

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 24V, switching frequency that is used is about 27 kHz and the load resistor is fixed at 10Ω.

TABLE I
Parameters and Values for Boost Converter

Parameter	Value
Voltage Input, Vs (V)	12
Voltage Output, Vo (V)	24
Output Power, P (W)	57.6
Duty Cycle, D	0.5
Switching Frequency, f (kHz)	27.7
Resistance, R (Ω)	10
Inductor, L (mH)	25
Capacitor, C (μF)	250
Output Voltage Ripple (%)	0.173
Input Current, Is (A)	9.132
Output Current, I0 (A)	2.4
Diode forward voltage Vf (v)	1.05

Fuzzy control is an artificial intelligence technique that is widely used in control systems. It provides a convenient method for constructing nonlinear controllers from heuristic information.

Conventional controllers are designed based on a mathematical model. Closed loop control specifications include disturbance rejection properties, in sensitivity to plant parameter variations, stability, rise time, overshoot and settling time and steady-state error. Based on these specifications, conventional controllers are designed. Major conventional control methods include classical control methods (frequency response and root locus techniques), state-space methods, optimal control, robust control, adaptive control, sliding mode control and other nonlinear control methods such as feedback linearization and back stepping. These conventional control methods provide a variety of ways to utilize information from mathematical models on how to obtain good control.

Different from conventional control, fuzzy control is based on the expert knowledge of the system. Fuzzy control provides a formal methodology to represent and implement a human's heuristic knowledge about how to control the system.

A fuzzy controller contains four main components: (1) the fuzzification interface that converts its inputs into information that the inference mechanism can use to activate and apply rules, (2) the rule base which contains the expert's linguistic description of how to achieve good control, (3) the inference mechanism that evaluates which control rules are relevant in the current situation, and (4) the defuzzification interface which converts the conclusion from the inference mechanism into the control input to the plant.

The performance objectives and design constraints are the same as those for conventional control. Design of fuzzy controllers involves the following procedures: (1) choose the fuzzy controller's inputs and outputs, (2) choose the preprocessing for the controller inputs and post processing for the controller outputs, and (3) design each of the four components of the fuzzy controller.

There is a tradeoff between the size of the rule base and the performance of the controller. A 5*5 rule base was also designed and implemented for the boost converter. Experimental results indicate that the fuzzy controller with a 5*5 rule base exhibited less oscillation during steady state, and faster transient response was achieved by increasing the output gain h. For the same universe of discourse, more membership functions resulted in finer control. The output of the controller had less variation when either of the inputs had small changes, and a more accurate control was achieved; chattering or oscillation were reduced [10].

V. Finding and Results

Voltage output for DC-DC Boost converter between open loop, PID controller and fuzzy logic controller through Matlab simulink package. Simulinks input voltage was set at 12V and the voltage reference was set at 24V.

A. Analysis for Open Loop Boost Converter

From the simulation, the waveform of output voltage and capacitor voltage have same characteristic of waveform. The value of output voltage is about 24.05V. Then the mean values of input current or inductance current, IL is about 10.24A and it has high overshoot compare the output current that has more stable. The value of output current is about 2.4A. The result from the simulation is nearest with the mathematical calculation. It is because of the losses at the components. The simulation result can see at Figs. 9-12.

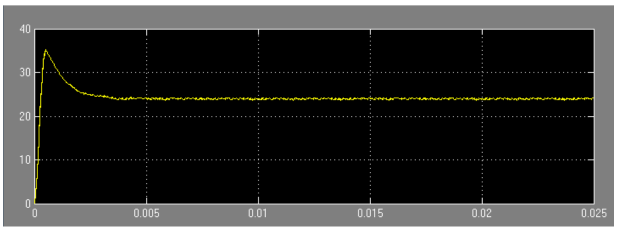

Fig. 9 Results on output voltage for open loop circuit DC to DC boost converter

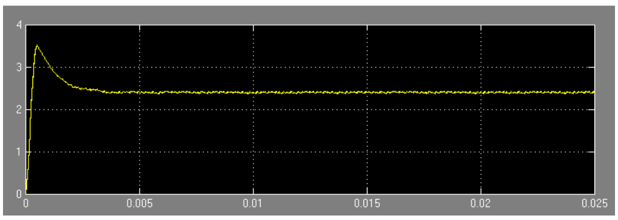

Fig. 10 Results on output current for open loop circuit dc to dc boost converter

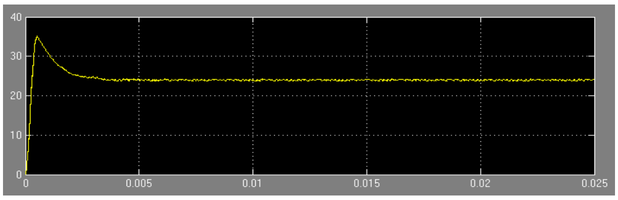

Fig. 11 Results on capacitor voltage for open loop circuit dc to dc boost converter

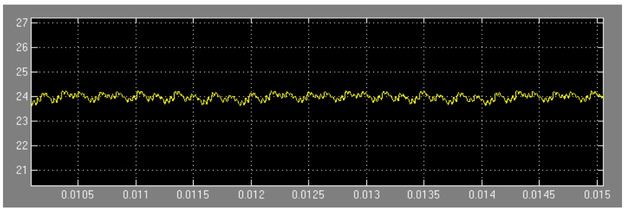

Fig. 12 Results on ripple output voltage for open loop circuit dc to dc boost converter

B. Analysis for Boost Converter with PID Controller

The simulation results of output voltage for boost converter with PID controller have shown at Figs. 13-15 from the simulation result, the value of output voltage is getting about 24V.

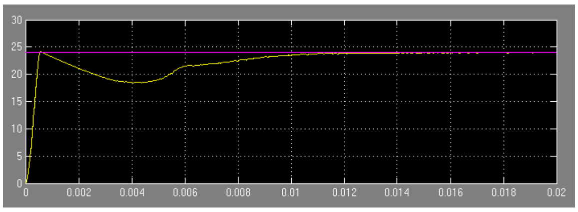

Fig. 13 Results on output voltage for PID controller closed loop circuit DC to DC boost converter

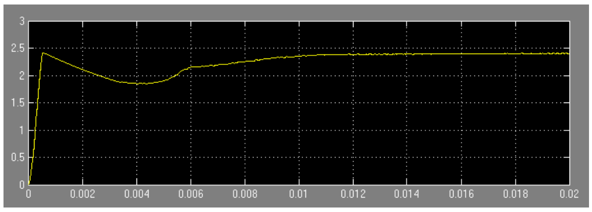

Fig. 14 Results on output current for PID controller closed loop circuit DC to DC boost converter.

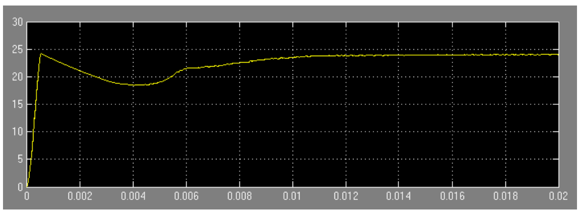

Fig. 15 Results on Capacitor voltage for PID controller closed loop circuit DC to DC boost converter

C. Analysis for Boost Converter with Fuzzy Logic Controller

The simulation results of output voltage for boost converter with fuzzy logic controller have shown at Figs. 16-18 from the simulation result, the value of output voltage is getting about 23.74 V and the duty cycle value was display at rules viewer is about 0.44. Fig. 16 shows the output current. The value of output current is about 2.38 A.

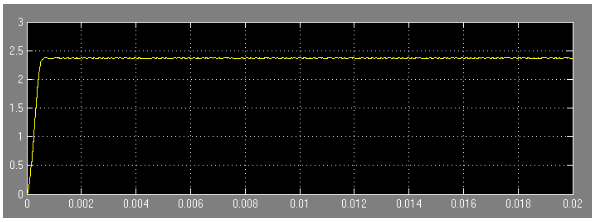

Fig. 16 Output current for FLC controller closed loop circuit DC to DC boost converter

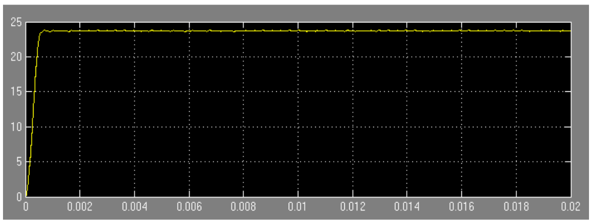

Fig. 17 Results on Capacitor voltage for FLC controller closed loop circuit DC to DC boost converter

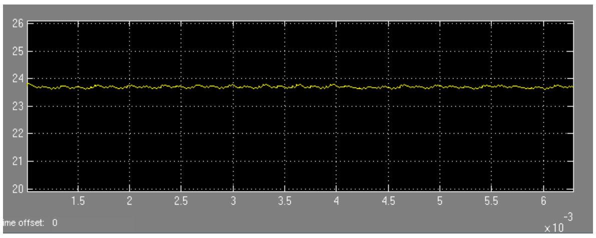

Fig. 18 Results on ripple output voltage for FLC closed loop circuit DC to DC boost converter

The comparison analysis between open loop and closed loop were continue on the simulation result based on the output voltage deviation, voltage overshoot percentage, rise time, peak time and settling time. These comparisons based on the 2nd order Step Response System.

TABLE II
PEAK OVERSHOOT RATIO, RISE TIME, PEAK TIME AND SETTLING TIME OF OPEN LOOP , PID AND FLC

	Voltage Input (V)	Voltage Reference (V)	Peak Overshoot Ratio (%)	Rise Time (mS)	Peak Time (mS)	Settling Time (mS)
Open Loop	20	24	46.7	0.29	0.512	4
PID	20	24	0.833	0.545	0.577	12
FLC	20	24	0.0	0.525	0.575	0.6

Based on the Matlab simulink results, obtained and shown in Table II, it is shown that both are having a different rise time, peak time and also have a different settling time. However, the analysis shows that the closed loop circuit with fuzzy controller is having the faster settling time.

TABLE III
THE DEVIATIONS OF VOLTAGE RESULTED FROM OPEN LOOP AND CLOSED LOOP CIRCUIT FOR PID AND FLC BOOST CONVERTER

	Voltage Input (V)	Voltage Reference (V)	Voltage Output (V)	Deviation (V)	Deviation (%)
OPEN LOOP	12	24	23.79	0.21	0.875
PID	12	24	23.88	0.12	0.5
FLC	12	24	23.89	0.11	0.458

The analysis on the deviation of voltage resulted that the difference between reference voltage setting and the output voltage is always lower. Comparison between open loop, PID and FLC in Table III show that, the open loop circuit having a bit higher on the deviation of voltage. The PID circuit boosts for FLC has a lesser deviation of voltage and proved that it is such a better performance on control the deviation of voltage during the boost mode.

VI. CONCLUSION

In conclusion of this paper is the comparison between Voltage output for DC-DC Boost converter between open loop, PID controller and fuzzy logic controller through Matlab simulink package. Simulinks input voltage was set at 12V and the voltage reference was set at 24V. The analysis on the deviation of voltage resulted that the difference between reference voltage setting and the output voltage is always lower. Comparison between open loop, PID and FLC shows that, the open loop circuit having a bit higher on the deviation of voltage. The PID circuit boosts for FLC has a lesser deviation of voltage and proved that it is such a better performance on control the deviation of voltage during the boost mode.

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