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Control of DC-DC Buck Boost Converter Output Voltage Using Fuzzy Logic Controller

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Abstract: Today DC-DC converter is inseparable part of any power electronics applications especially in the field of renewable energy technology. The converter is used as switching-mode regulator to convert a dc voltage (unregulated) to a regulated dc output voltage by pulse-width modulation (PWM) technique and the switching device being used is normally the MOSFET. The PWM can be generated using PID or by Fuzzy Logic Controller (FLC) but FLC is much superior than that of PID controller. In this paper, the Mamdani based Fuzzy Logic Controllers (FLC) is applied for DC-DC buck boost converter for regulating output voltage. The model of DC-DC buck boost converter with FLC are designed on Matlab simulink environment using SimPowerSystem and Fuzzy Tool Box respectively. The simulation studies show that the Fuzzy Logic Controller technique gives better performance than that of Conventional PID Controller. The response with FLC is relatively faster and is more stable than the conventional PID Controller. From the results of FLC it is observed that there is less overshoot, less ripples and fewer oscillations which will be very useful for PV based constant voltage battery charging applications.

Keywords: Fuzzy Logic Controllers (FLC), pulse-width modulation (PWM), Photovoltaic Cell (PV), Proportional-Integral-Derivatives (PID).

1. INTRODUCTION

With an appropriate control techniques, dc-dc converter is used as switching-mode regulator to convert a dc unregulated input voltage into a regulated desired dc output voltage by PWM technique and the switching device is normally MOSFET(M) or IGBT. It steps down (buck) or steps up (boost) the output voltage or generic (buck-boost) voltage by changing the duty ratio of the MOSFET/IGBT. If the duty ratio D is less than 0.5, the output voltage is step down. If D is greater than 0.5, the output voltage is step up. D is the ratio of time for which the MOSFET is ON to the total switching time [1,2]. DC-DC buck boost converter with feed backing the measuring output in closed loop produces the output more efficiently as compared to the converter when used in open loop. Control systems are designed and implemented to accomplish the requirements by providing specified voltage level irrespective of uncertainties and disturbances occurred in power semiconductors and therefore more efficient technique is necessary to design control system. When nonlinear phenomenon characteristics occur in DC-DC

converters, they make their control and analysis very difficult [3]. There are many control techniques used to control these DC-DC converters. These techniques include PI, PID controller and Fuzzy Logic Controller. The PID controllers are linear controllers and it is difficult to control the nonlinear phenomena occurring in converters with the help of linear controllers due to limited operating points [4]. Fuzzy Logic Controller is a nonlinear controller which is one of the most widely used for non-linear applications such as solar PV based DC-DC Converter. FLC does not need exact information about the system and works with approximate mathematical model. New rules can be added into it and it is very robust in nature. And hence FLC provides better output with lower rise time, peak time, settling time and is more robust than several control methods [5-7].

In this paper, the fuzzy Logic Controller have been used to control or track the output voltage of converter for a given reference Voltage and compared the results with that of PID controller. In the FLC algorithms, five membership functions and a rule table are used, the details of which are explained in section IV, Mathematical model of the buck- boost converter is given in [8-10] is revisited. For the ease of understanding the paper is arranged into different sections. Section I explains the introduction, sections II deals with the buck boost converter overall structure. Section III explains a brief outline of PID Controller, Section IV deals Fuzzy Logic Controller based DC-DC converters, Section V Simulation results and the section VI being the conclusion.

2. DC-DC BUCK BOOST CONVERTER

The converter model was developed in SimPowerSystem tool box in the MATLAB. The converter consists of a dc input voltage source V_{in} , a controlled switch M, inductor L, Diode D_1 a filter capacitor C and a load resistance R_o . When the M turns on, the input voltage source V_d gets connected to the inductor L, the diode being reverse-biased is not conducting. So the voltage across the inductor during ON stage is given as,

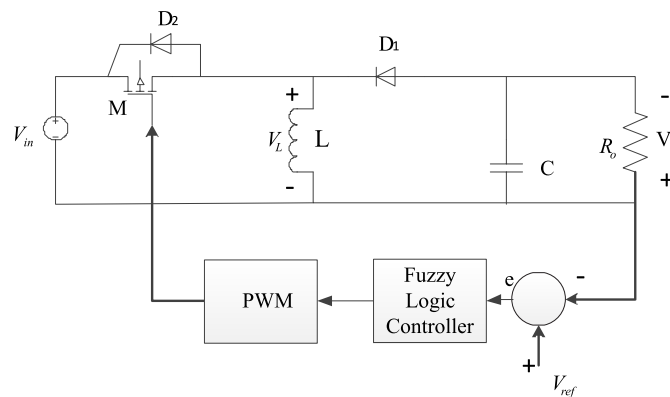


Figure 1: Fuzzy logic control with buck-boost converter

$$V_{in} = V_L \tag{1.1}$$

Then the inductor current is increased and therefore capacitor produces output V_0 at the load. When the M is turned off, the diode gets forward biased and the diode being conducting provides a path for the inductor current. So the voltage across the inductor during OFF stage is given as,

$$V_L = V_o \tag{1.2}$$

Inductor L is connected to the load R_o and the capacitor C.

For steady-state operation, the net change in the inductor current must be zero over one switching cycle. By applying volt-second balance we get:

$$V_{in}D + V_o(1 - D) = 0 \tag{1.3}$$

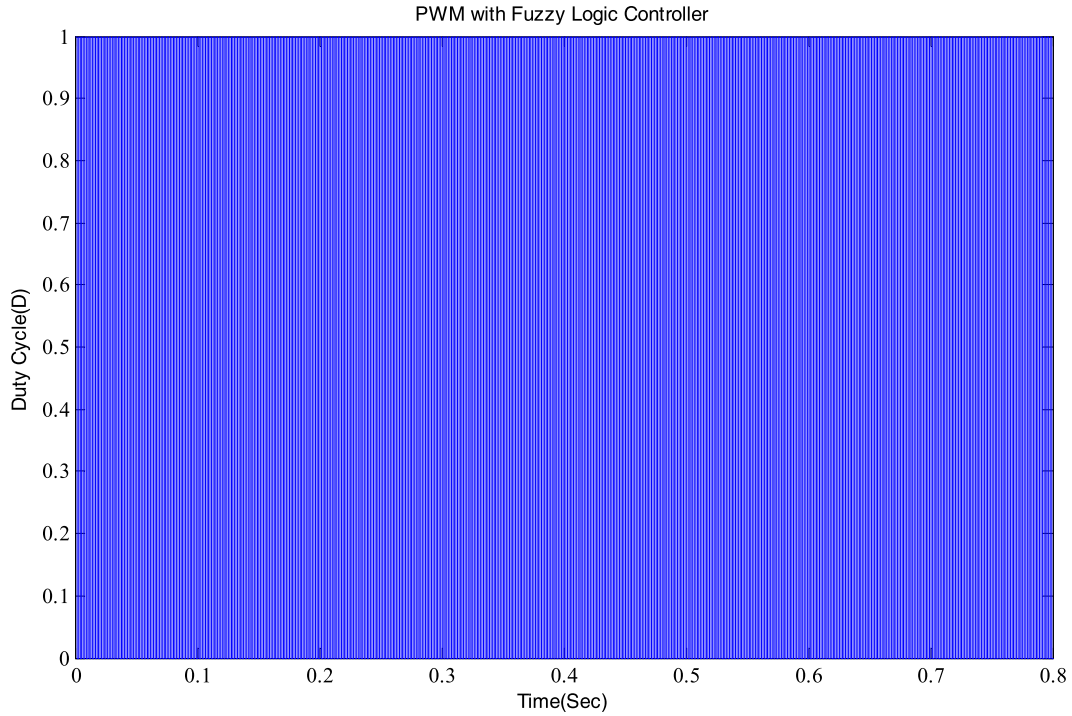


Figure 2: PWM Output with Fuzzy Logic Controller

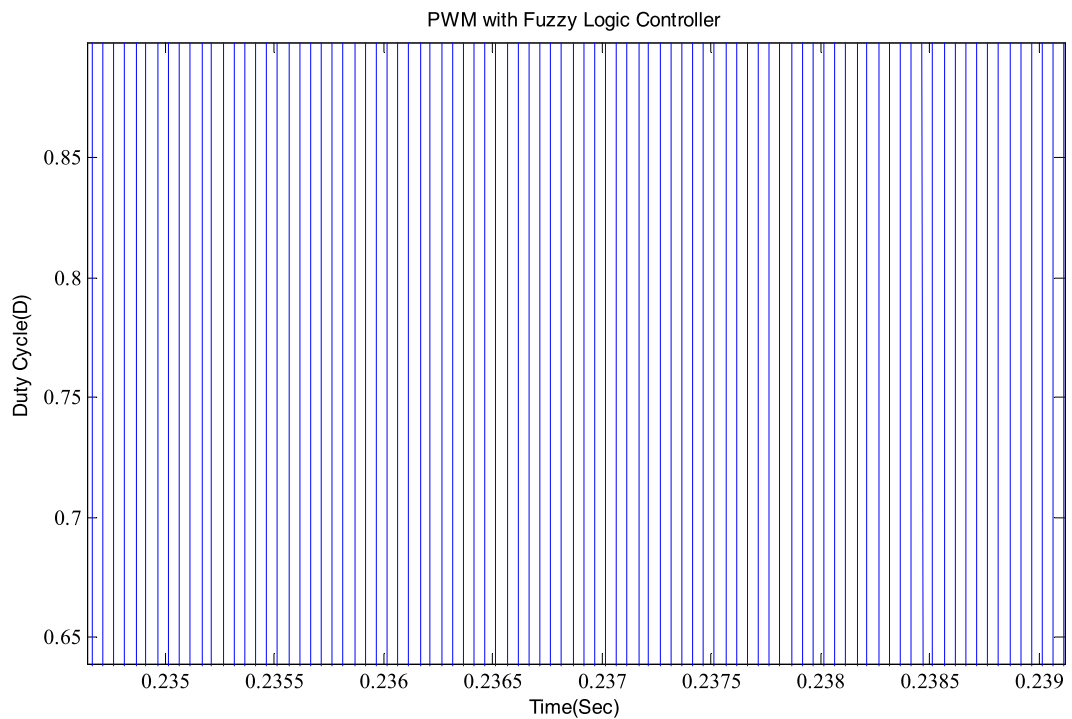


Figure 3: PWM Output with Fuzzy Logic Controller

Where D is the duty cycle of converter is given by $D = \frac{T_{on}}{T_s}$ and T_{on} is the on-state time of the MOSFET and T_s is the switching time period.

From Eq (1.3), we got

$$V_o = -\frac{D}{1-D} V_{in} \quad (1.4)$$

Therefore from (1.1) and (1.2) energy transferred from inductor to the capacitor and then to the load. Figure 1 shows the buck-boost converter system with the FLC controller. The actual output voltage V_o is compared to the reference voltage V_{ref} to produce an error signal. This error signal is used to determine the switching signal duty cycle with the help of fuzzy logic Controller. The switching signal generated from the controller are compared with a reference saw tooth signal so as to generate the require PWM. The PWM generated by FLC is given in Figure 2 and Figure 3 respectively. This PWM is applied on the MOSFET (M) to reduce or enlarge the output voltage of the converting circuit. The buck converter system is analyzed for switch on time and off time which is called duty cycle ratio D . For calculating the minimum value of Converting circuit parameters, the input power to Buck-Boost Converter is taken as 55W which may taken obtained from 55W PV Module.

The circuit parameters with the input power P_{in} is

$$P_{in} = 55 \text{ Watt} \quad (1.5)$$

Assuming the efficiency η to be 95 %

$$P_o = 52.25 \text{ Watt} \quad (1.6)$$

The output current,

$$I_o = \frac{P_o}{V_o} = \frac{52.25}{12} = 4.35 \text{ A} \quad (1.7)$$

The output resistance is

$$R = \frac{V_o}{I_o} = \frac{12}{4.35} = 2.75 \Omega \quad (1.8)$$

The inductor minimum value ($D = 0.5$) is

$$L = L = \frac{R(1-D)^2}{2f} = \frac{2.75 \times 0.25}{2 \times 10 \times 10^3} = 34.5 \mu\text{H} \quad (1.9)$$

Minimum capacitor value is

$$\frac{\Delta V_o}{V_o} = \frac{DT_s}{RC} \quad (1.10)$$

Or

$$\Rightarrow C = \frac{DT_s V_o}{\Delta V_o R} \quad (1.11)$$

$$\text{Hence, } C = \frac{0.5 \times 10^{-4}}{1.5 \times 2.75} \times 12 = 145 \mu\text{F} \quad (1.12)$$

3. PID CONTROLLER

The Term PID refers to Proportional plus Integral plus Derivatives. For reducing the tracking error in a system to get the desired step response, the proportional, derivative and integral action of PID controller are applied.

During such operations the control action is controlled by the value of the gains parameter of PID. Here in this work, PID controller is used to control the output voltage of DC-DC buck/boost converter. But normally, the gain parameters are usually fixed during the operation.

Therefore, the PID controller is insufficient for controlling a system while the surrounding environment of the systems is changing [11].

The governing equation of PID Controller is given by

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau) d\tau + K_d \frac{d}{dt} e(t) \tag{1.13}$$

where, K_p is proportional constant, K_i is Integral constant and K_d is derivative constant. The block diagram of PID controller for Buck-Boost converter is shown in Figure 4.

With the varying of PID parameters, the corresponding responses whose nature are given in Table 1. [11,12].

Table 1
Effect of parameters variation

Parameters	Speed of Response	Stability	Accuracy of output
Increasing K_p	Increase	Deteriorates	Improves
Increasing K_i	Decrease	Deteriorates	Improves
Increasing K_d	Increase	Improves	No Effect

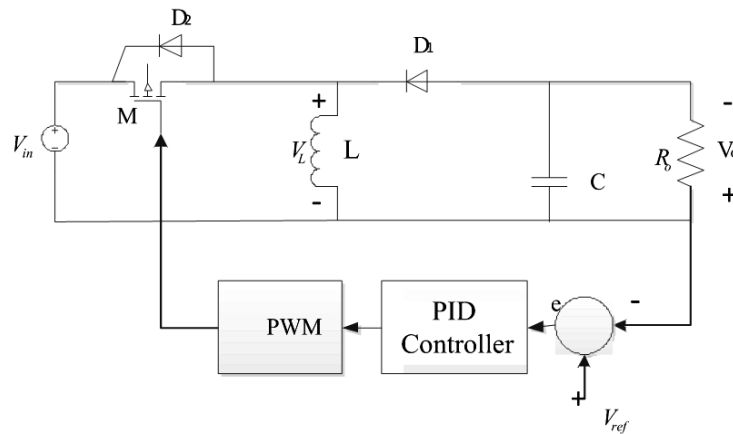


Figure 4: PID Controller with Buck-Boost Converter

4. FUZZY LOGIC CONTROLLER

The fuzzy Logic Controller have been used to control or track the output voltage of converter for a given reference Voltage. The block diagram of Fuzzy logic Controller with the DC-DC buck boost Converter is shown in Figure 1 above. The general block diagram of FLC (Fuzzification and defuzzification) for the closed loop system as in [13] with replacing by buck boost converter is shown in Figure 5.

The buck boost converter output voltage is controlled by changing the switching duty cycle. The system error is defined as a difference between the reference voltage and measured output voltage value from the load. For the system; $r(k)$ is the reference voltage and $y(k)$ is the measured output voltage values then the error voltage signal is calculated by

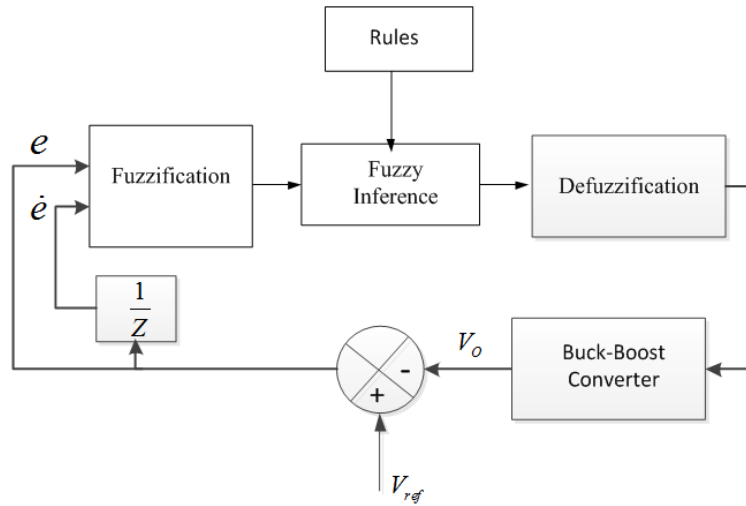


Figure 5: The Block Diagram of FLC with dc-dc Converter

$$e = \varepsilon(k) = r(k) - y(k) \quad (1.14)$$

The change in the error voltage (Δe) is also calculated as;

$$\Delta e = e(k) - e(k - 1) \quad (1.15)$$

The error and change in error to the FLC are converted to generate fuzzy sets in fuzzifier. The signals are used in a rule table to determine the fuzzy number of the compensated output signal. Finally, the resultant united fuzzy subsets representing the controller output are converted into the crisp values, the values which have maximum membership degree of 1.0 in the corresponding fuzzy subsets. The details of block diagram of converter with Matlab/Simulink is given in Figure 9. The output voltage is compared with the reference voltage and generated error signal. The output of FLC is compared with a saw tooth reference signal to generate a PWM signal which drives the switching MOSFET and compare with that PID controller.

The Membership Functions for each of error, change in error and output of the fuzzy variables are shown in Figure 6, Figure 7 and Figure 8 respectively

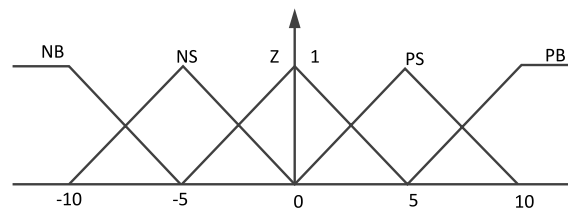


Figure 6: Membership Function of error

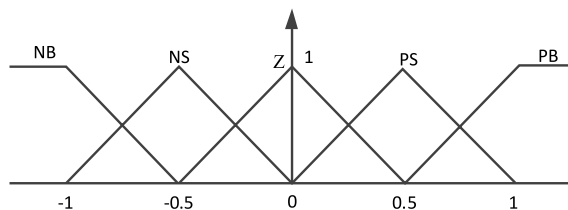


Figure 7: Membership Function of change in error

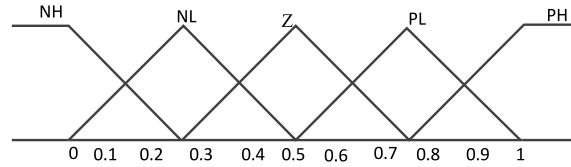


Figure 8: Membership Function of Output

Table 2
Fuzzy Control Rules

Δe \ e	PB	PS	Z	NS	NB
NB	Z	NL	NL	NH	NH
NS	PL	Z	NL	NL	NH
Z	PL	PL	Z	NL	NL
PS	PH	PL	PL	Z	NL
PN	PH	PH	PL	PL	Z

The fuzzy control rules as given in Table 2 was done with Mamdani Methods and the defuzzification was done with the centre of gravity method to calculate the out of FLC (duty cycle).

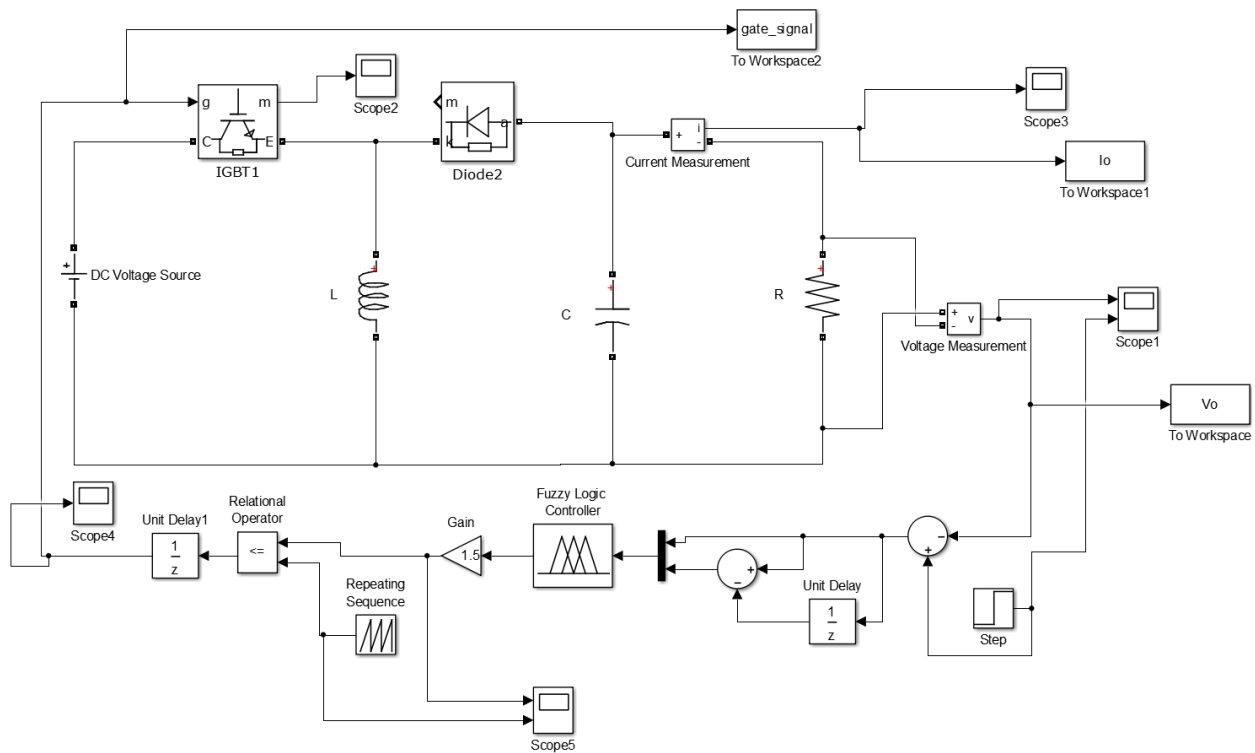


Figure 9: Simulink Model of FLC with B/Boost Converter

5. ANALYSIS OF SIMULATION RESULTS

The simulation results of buck-boost Converter based on Fuzzy logic controller and PID controller on its MATLAB simulink model for both buck mode and boost mode are studied. The parameters used for simulation are in Table 3.

Table 3
Simulation Parameters

Parameters	Value
DC Input Voltage	15V
Reference output Voltage	13V(Buck), 30V(Boost)
Switching Frequency	10KHz
Inductor	34.5 μ H
Capacitance	145 μ F
Output Resistance	2.75 Ω

- (a) *Buck mode*: Output voltage is calculated for $V_{ref} = 13V$ and $V_{input} = 15V$. Rise time (T_r), peak time (T_p) peak overshoot (M_p) and settling time (τ_s) are analyzed for $V_{ref} = 13V$. The simulation results of output voltage of buck-boost converter with FLC, PID and Combination of both are shown in Figure 10, 11 & 12 respectively. The simulation results for both FLC and PID are given below.

FLC results: $T_r = 0.0011sec$, $T_p = 0.00175 sec$, $M_p = 0.1V$, $\tau_s = 0.005 sec$

PID results: $T_r = 0.00117sec$, $T_p = 0.0151 sec$, $M_p = 15V$, $\tau_s = 0.385 sec$

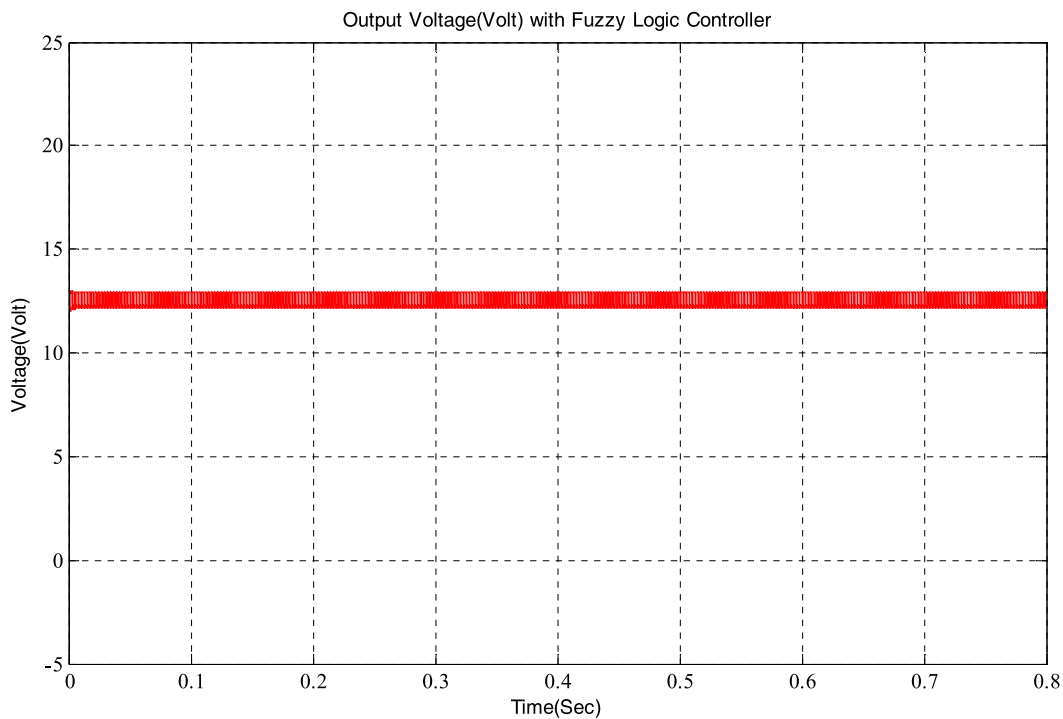


Figure 10: Output Voltage with FLC reference Voltage = 13V_s

- (b) *Boost Mode*: Output voltage is calculated for $V_{ref} = 30V$ and $V_{input} = 15V$. The simulation results of output voltage of buck-boost converter with FLC, PID and Combination of both are shown in Figure 13, 14, and 15 respectively.

The simulation results for both FLC & PID in boost mode are given below.

FLC results: $T_r = 0.0018sec$, $T_p = 0.00205sec$, $M_p = 10.5V$, $\tau_s = 0.0032 sec$.

PID results: $T_r = 0.00185sec$, $T_p = 0.0445 sec$, $M_p = 40V$, $\tau_s = 0.635 sec$

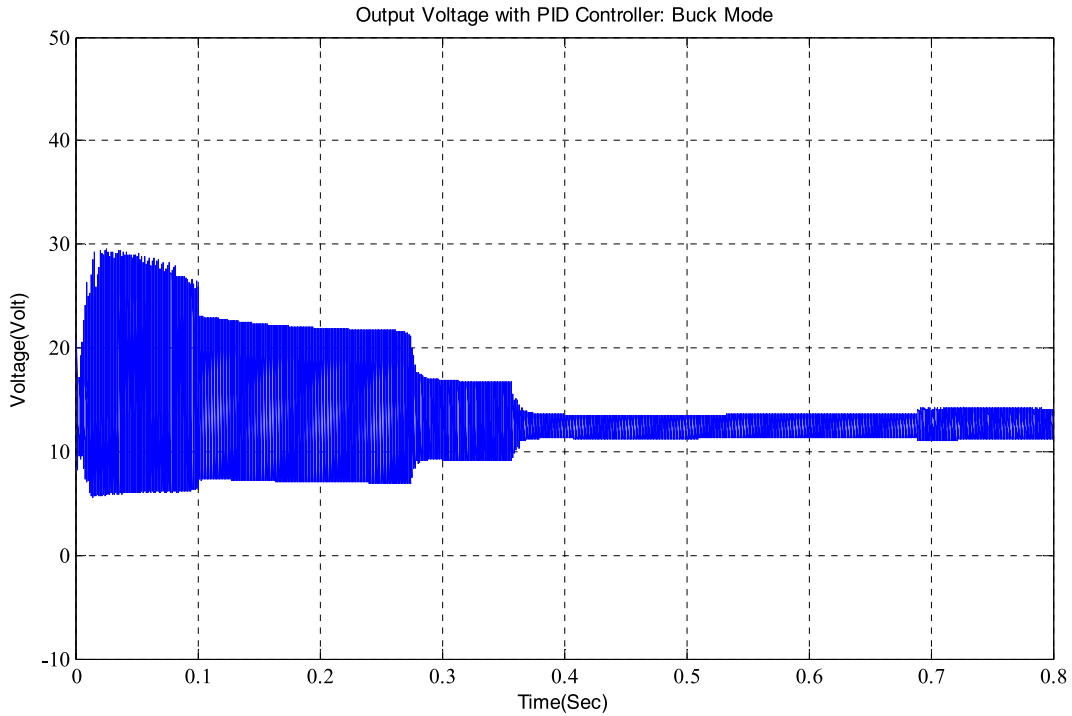


Figure 11: Output Voltage with PID reference voltage = 13V

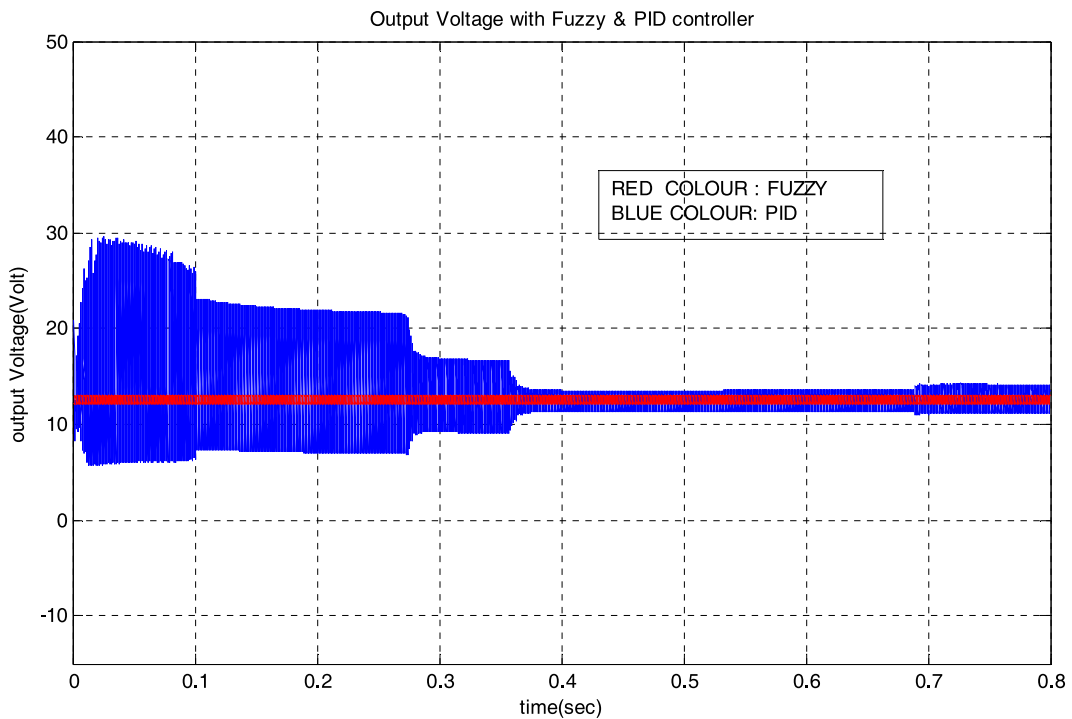


Figure 12: Results with both Fuzzy & PID Controller

6. CONCLUSION

In this paper, a Fuzzy Logic Controlled (FLC) based buck-boost DC-DC converter for resistive load of 2.75Ω has been presented. Converters model were done on SimPowerSystem and FLC were done on Fuzzy tool box with

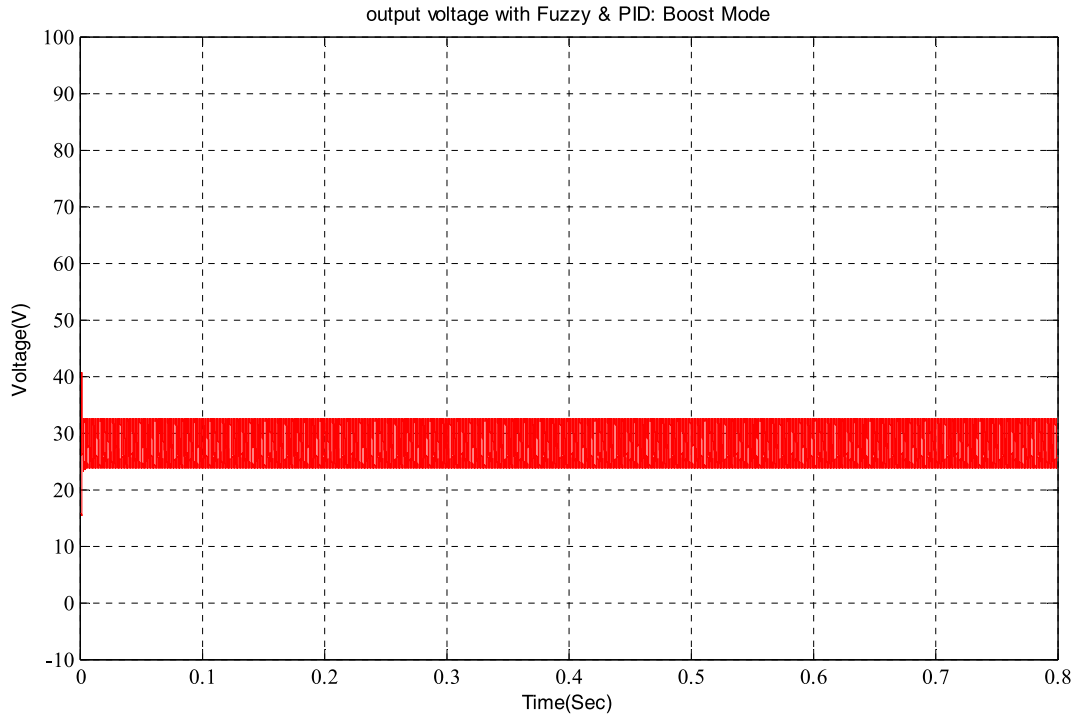


Figure 13: Output voltage with FLC for reference voltage = 30V

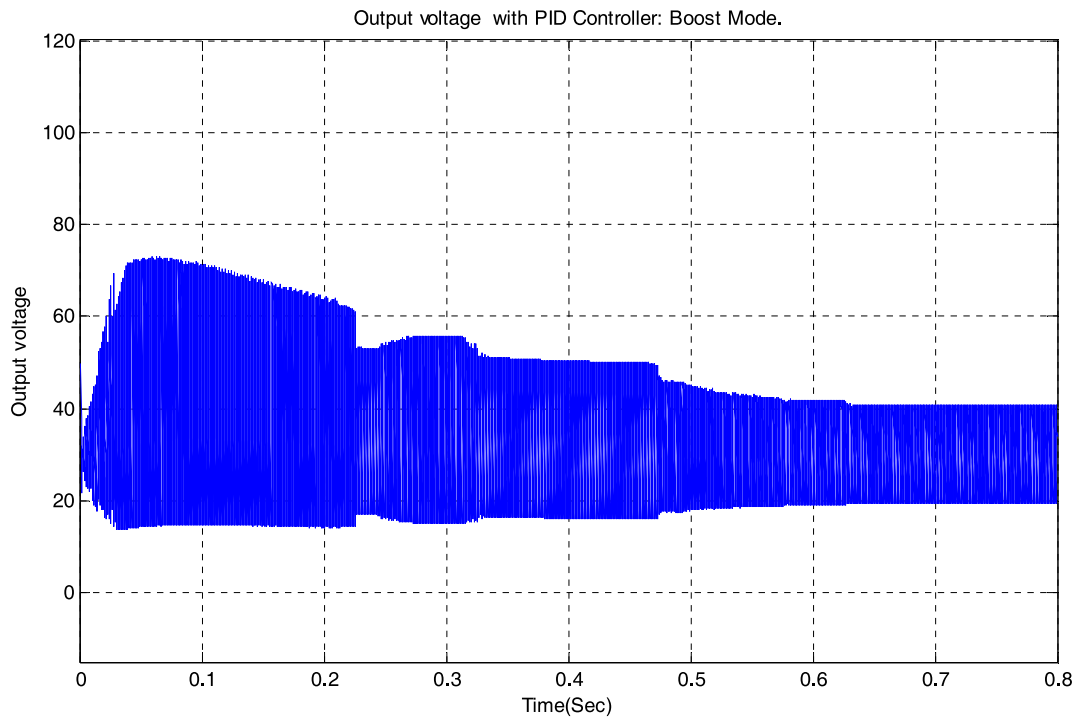


Figure 14: Output voltage with PID for reference voltage = 30V

Matlab/Simulink environment. The model have been successfully designed and implemented with the Mamdani type Fuzzy logic controller for comparing the results with PID controller. From the simulation results, it is found that the Fuzzy Logic Controller technique gives better performance than that of Conventional PID Contoller. The response with FLC is relatively faster and is more stable than the conventional PID Controller. From the

results it is observed that there is less overshoot, less ripples and fewer oscillations, less settling time of output voltage with Fuzzy Logic Controller than that of PID Controller. The output voltage of the converter with FLC is control, regulated and more stable which will be suitable for PV based battery charging applications.

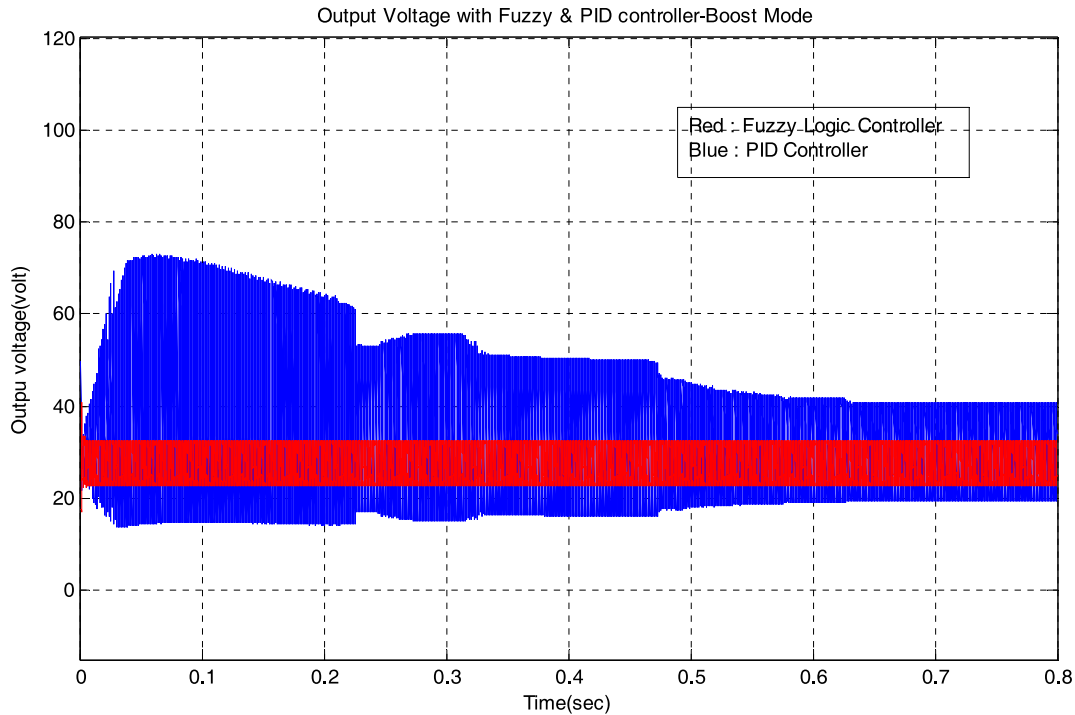


Figure 15: Results with both Fuzzy & PID Controller

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