Design of Fuzzy PI Controller for Voltage Regulation in DC Micro-Grid

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ABSTRACT

Efficiency, standard and security of a micro-grid can be tested by measuring the voltage regulation in the DC bus. Photovoltaic micro-grid are prone to time invariant and non-linearity due to variation in solar irradiance. Energy storage device is incorporated to overcome such variations. Traditionally using PI controllers, we can control the charging and dis-charging of battery which only regulates voltage in the bus but it fails to control the fluctuations in the DC bus. Therefore, Fuzzy PI controller is proposed in this paper where it employs the intelligent controlling method thereby reducing the fluctuations in the DC bus.

Keywords— Fuzzy, PI, Fuzzy-PI, DC-Micro-Grid, Closed Loop Control, Voltage Regulation

I. INTRODUCTION

The voltage instability may lead to inefficiency which in turn leads to losses, leading to wastage of available energy sources and also causes usage of extra power for compensation. The voltage instability may lead to inefficiency which in turn leads to losses, leading to wastage of available energy sources and also causes usage of extra power for compensation. As a result, a fuzzy-PI controller is developed here, which combines the benefits of both fuzzy and PI controllers, with the fuzzy providing strong transient performance and the PI controller providing good steady-state response. In the outer loop, fuzzy logic-based control is implemented in such a way that it only activates when the bus voltage deviates owing to transients. Fuzzy logic controllers outperform conventional controllers in terms of bus voltage deviation and recovery time when the load changes. When the battery is in the charging state, it only responds if there are any transients [1]. To get the best dynamic reaction and handle power quality issues, a fuzzy PID controller is used in conjunction with D-STATCOM. [2] There is more robust stability and improved dynamic reactivity. The author discusses a fuzzy logic-based control strategy for reducing power sharing mismatches caused by changes in available power. The controller is straightforward to construct and does not necessitate any mathematical modelling. The multi-bus achieves effective power management and source power consumption [3]. When compared to PI and Fuzzy PI controllers, [4] study proposes Fuzzy PI controller based model reference adaptive control for voltage regulation in two isolated micro-grids, which delivers good dynamic performance. [5] The voltage changes caused by a solar DC micro-grid are also discussed in this work. To increase the system's dynamic response, a Fuzzy-PI dual mode controller is presented. By managing the bi-direction with batteries for voltage compensation in the micro-grid, Fuzzy controller can give better transient performance and PI can provide better steady state performance by taking into account the outer ring.

[6] A frequency and voltage stabilization method based on fuzzy logic is developed to govern the battery energy storage system. The fuzzy controller is utilized as a supervisory controller in this case, assisting in system control owing to load shedding. [7] Shows how to create a fuzzy PID controller for voltage regulation in a DC micro-grid to show that it has a lower maximum overshoot and settling time than a PID controller. The Fuzzy PID controller is faster than the PID controller due to its short settling period, and the response of the Fuzzy PID controller is reached at maximum overshoot faster than the response recorded in the PID controller. The author presents a fuzzy based control for ultra-capacitor power regulation in [8]. When the output voltage deviates from the reference value, a fuzzy logic controller is employed in the outer voltage loop to send a high pulse current command. It eliminates transients and delivers excellent steady-state performance.

A voltage controller based on PI and fuzzy PI has been built for DC micro-grid in this work. The fuzzy PI controller makes use of PI knowledge and fuzzy experiences. This paper presents a comparative study between conventional closed dual loop control and Fuzzy PI controller.

II. PROPOSED DC MICRO-GRID SYSTEM

SPV unit, boost converter, battery, bi-directional converter, and fuzzy-PI dual mode controller are all part of the proposed system. The SPV unit converts solar energy into electricity. The SPV unit produces a voltage of 48 volts. This voltage is raised with the help of a boost converter, which transforms 48V to 110V. The converter's output is changeable, which could cause problems with the micro-grid stability. The grid's Energy storage devices with bi-directional converters are used to

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adjust for variations in the micro-grid. The battery is charged and discharged using a bi-directional converter. Traditionally PI controllers are used for controlling the battery thereby providing voltage regulation in the grid. But the output obtained is still varying. Fig.1. gives the generalized block diagram of the dc-micro-grid with fuzzy PI control for energy storage system in order to compensate the voltage fluctuations in the system. In section III, there is a description of design of PI controller. In section IV, the design of fuzzy – PI controller is discussed. Section V gives simulation results and comparison of the proposed and conventional system. Finally Section VI concludes the paper.

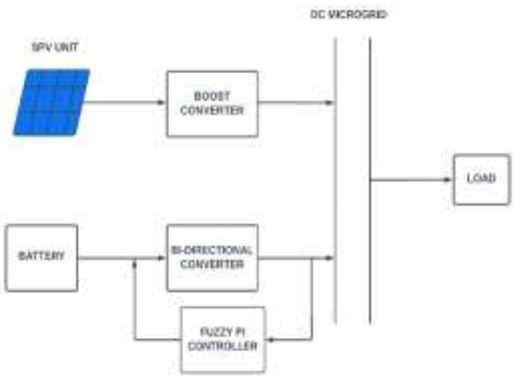

Figure 1: Generalized block diagram

III. DESIGN OF THE CONTROLLER

A. Conventional Control Method

Two factors can be used to evaluate the performance of a proportional integral (PI) controller: propositional gain (K_p), integral gain (K_i). The voltage regulation of a DC micro-grid is presented using a unit feedback closed loop control system with a PI controller. The controller amplifies the error signal (e) signal, which is the difference between the measured voltage (V_o) and the intended voltage (V_d). By adjusting the PU power sharing via AC-DC converter with DC microgrid, the controller output makes the appropriate changes to the PWM signal to reduce the error. The size and polarity of the ensuing error signal are proportional to the difference between the micro-grid's V_o and V_d.

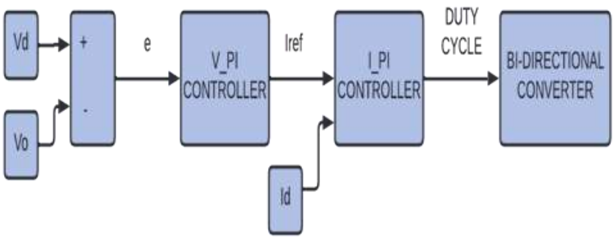

Figure 2: Conventional control method

The above diagram gives the conventional control method using PI controllers.

Where I_{ref} is the reference current and I_d- desired current.

Two loop control is used here, outer voltage and inner current control. The outer voltage control can be determined by

The output from the controller can be given as:

$$u(S) = K_p\, e(S) + K_i \frac{1}{S} e(S)$$

And the transfer function for the PI controller will be

$$G(S) = \frac{u(S)}{e(S)} = K_p + K_i \frac{1}{S}$$

Where e(S) = $|V_d - V_0|$

The Kp will shorten the rising time but never completely eliminate the steady-state inaccuracy. The Ki will remove the steady-state error from the system. Here U(S) is the reference current and this current is again compared with the required battery current and the PWM is generated for the bi-directional converter's switches.

The Transfer function for the PI controller for inner current loop is

$$G(S) = \frac{u(S)}{d(S)} = K_p + K_i \frac{1}{S}$$

Where d(S) is the duty cycle for bi-directional converter

B. Proposed Controller-Design

The only difference from the conventional method is that the outer voltage ring controller is replaced by the fuzzy controller and the inner ring current control remains the same. Fuzzy controller mainly consists of fuzzification, interface and the De-fuzzification. The input to the fuzzy controller is the difference between the required voltage and the obtained voltage and the change in that deviation whereas the output is the reference current which will be compared with required battery current and this deviation is given as input to the Current PI controller where the duty cycle is obtained as output from the controller to the bi-directional converter.

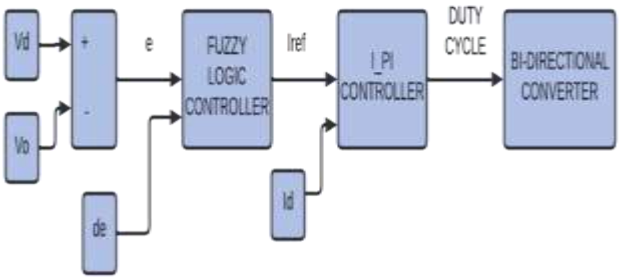

Figure 3: Fuzzy-PI control for voltage regulation in micro-grid

Where I_{ref} is the reference current and I_d- desired current. e- Error signal and de is the rate of change in the error signal.

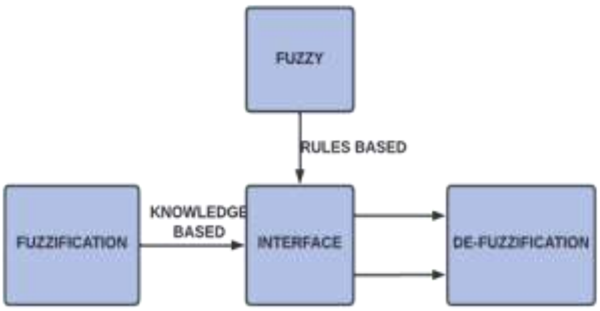

Figure 4: Fuzzy logic controller

The above diagram gives the proposed controller and the Fuzzy components. The member functions for the inputs of fuzzy controller are 7 which are negative big (NB), negative medium (NM), negative small (NS), zero (Z), and positive small (PS), positive medium (PM) and positive big (PB). The fuzzy table has 49 rules. The output also has 7 member functions same as the input.

Table I: Fuzzy Set Rule Table

E,EC	NB	NM	NS	ZO	PS	PM	PB
NB	NB	NB	NB	NM	NM	NS	ZO
NM	NB	NB	NM	NM	NS	ZO	PS
NS	NB	NM	NM	NS	ZO	PS	PM
ZO	NM	NM	NS	ZO	PS	PM	PM
PS	NM	NS	ZO	PS	PM	PM	PS
PM	NS	ZO	PS	PM	PM	PS	PS
PB	ZO	PS	PM	PM	PS	PS	PS

The above table gives the fuzzy set rules for the fuzzy logic controller used in the system.

The Transfer function for the PI controller for inner current loop is

$$G(S) = \frac{u(S)}{d(S)} = K_p + K_i \frac{1}{S}$$

Where d(S) is the duty cycle for bi-directional converter.

$$G_{id_B} = \frac{57.29 + (709.91 \times 10^{-3})S}{1 + S(4.66 \times 10^{-3}) + S^2(115.39 \times 10^{-6})}$$

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The above expression gives the transfer function of inner ring current control.

IV. SIMULATION RESULTS

The proposed system is designed and simulated in the MATLAB software and the results are obtained.

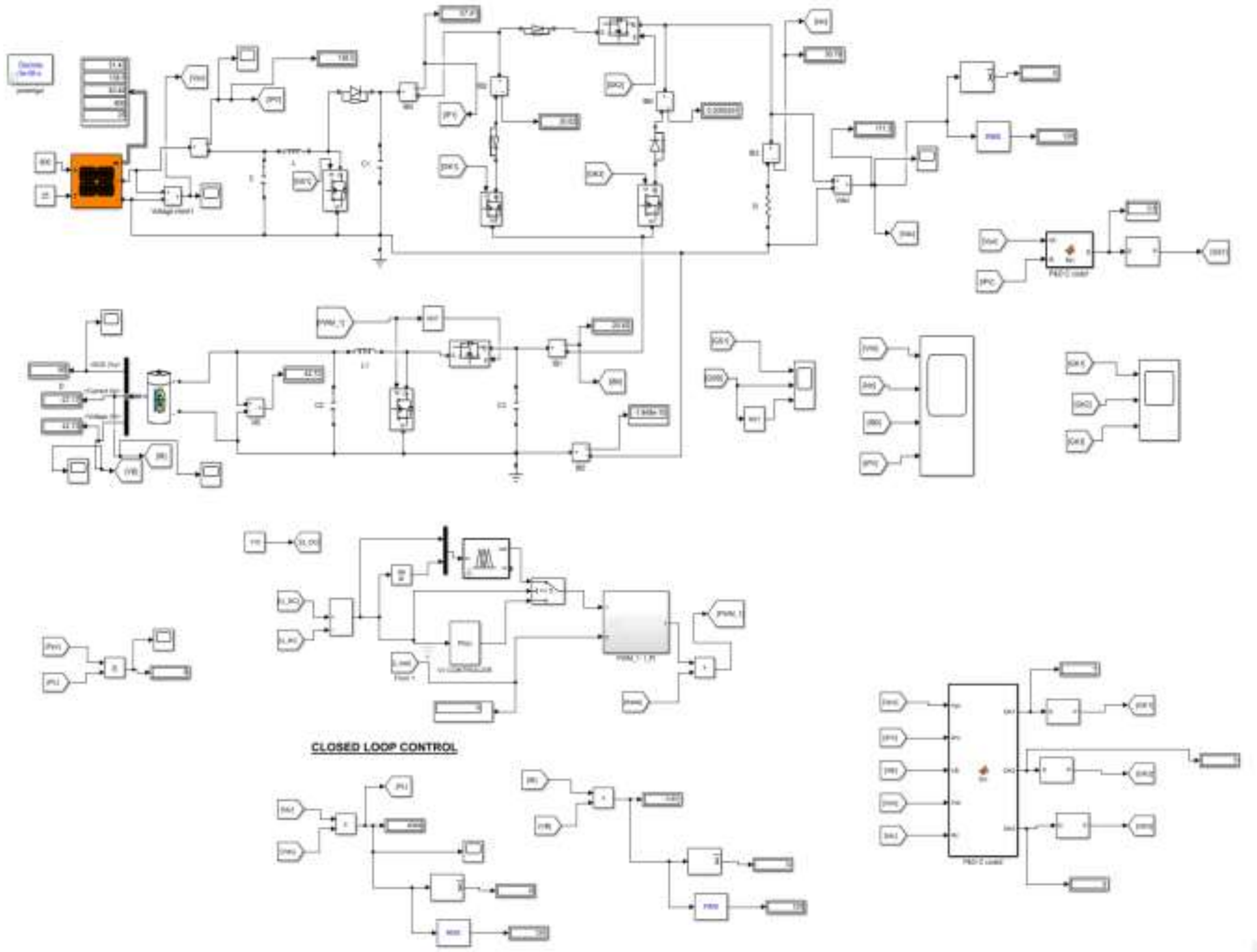
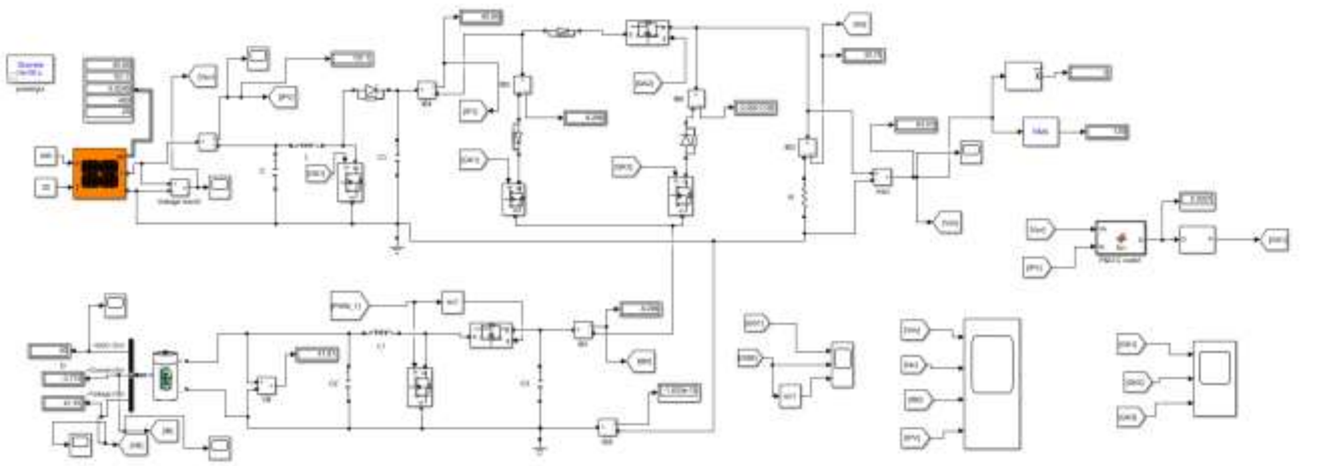


Figure 5: For irradiation 800 W/m^2



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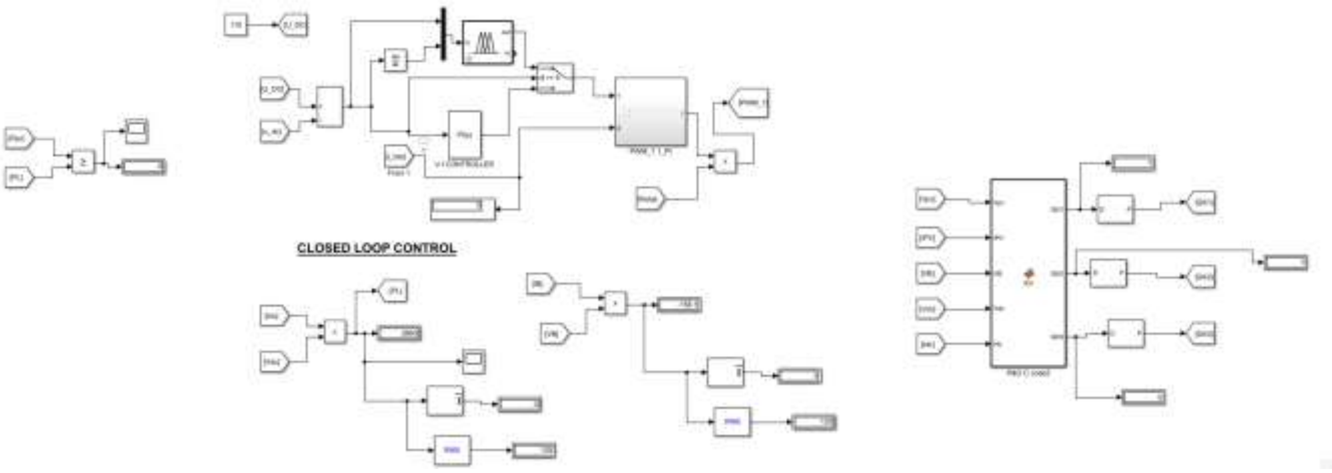

Figure 6: For irradiation 400 W/m^2

A. Solar PV Unit with Boost Converter

The specifications are given in the table III. The boost converter designed with solar PV unit as source and with a load of 24.2Ω.

Table II: System Parameters

S.No.	PARAMETERS	VALUES
1.	V_O	110V
2.	V_{in}	48V
3.	I_{in}	10A
4.	L	18.03mh
5.	C	1.024mf

The above table gives the design parameters of boost converter.

Table III: SPV Unit Parameters

S.No.	PARAMETERS	VALUES
1.	V_{oc}	21.7V
2.	I_{sc}	8.14A
3.	Maximum power point	125W_p
5.	AM	1.5AM
6.	Standard irradiation	1000W/m^2
7.	Temperature	25℃
8.	V_O	48V
9.	Rated power	10Kw

The above table given the design specifications of SPV unit.

B. Energy Storage Device with Bi-Directional Converter

The energy storage device is used for compensating the voltage variations in the system and helps in maintain the voltage in the grid.

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Table IV: Battery Parameters

S.NO.	PARAMETERS	VALUES
1.	$V_{battery}$	48V
2.	$I_{battery}$	10A
3.	Ah	50Ah
4.	WAh	2400Wah

Table V: Bi-Directional Converter Parameters

S.NO.	PARAMETERS	VALUES
1.	BUCK OPERATION: L_{min} D	 18.03mH 43.63
2.	BOOST OPERATION L_{min} D	 18.03mH 56.36
3.	C	$46.5\mu F$

C. Results

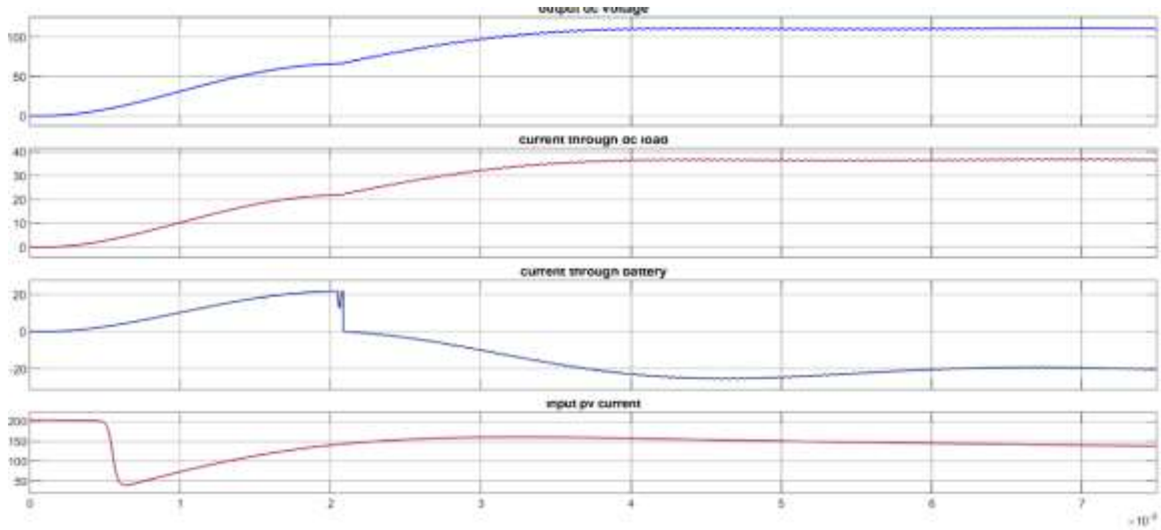

Figure 7: Output graph for 800W/m^2

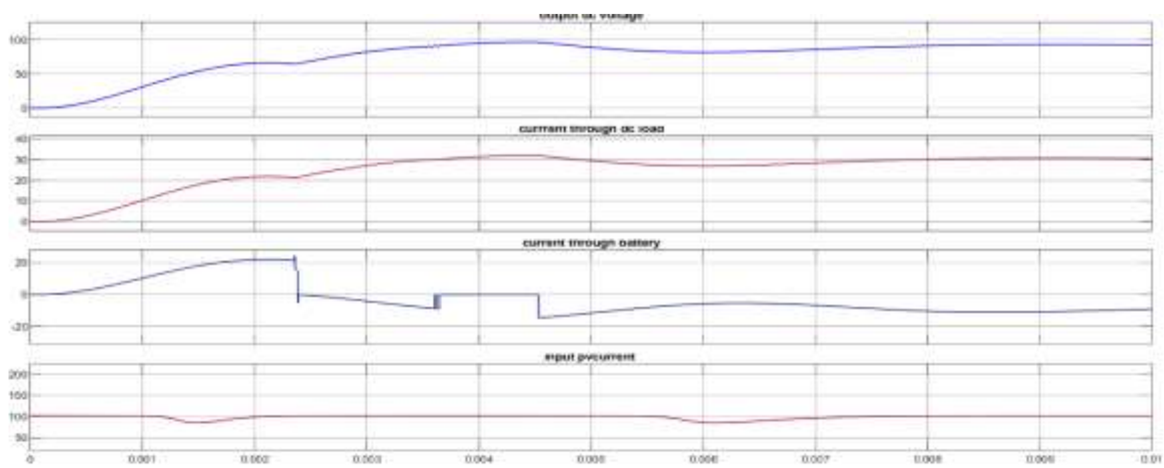

Figure 8: Output graph for 400W/m^2

From the Fig.7. shows the solar PV unit output voltage which is 47.98V but the required voltage is 48V. Fig.7. displays the DC bus voltage and bi-directional converter output without the closed loop controller where the output is 93.83V but the required voltage is 110V. Fig.8. gives the output of both DC bus and bi-directional converter which varies from 99 to 118V but the required voltage is 110V which is DC micro-grid's voltage and it is clear that it voltage regulation in the DC micro-grid system. Finally Fig. 9. Shows the battery voltage and battery current. The battery voltage obtained is 48.17 but the required voltage is 48V which is more than the required voltage. The battery current obtained is 9.96A but the required battery current is 10A. It is observed from the above experiment that the fuzzy PI controller can be used for voltage regulation in the micro-grid which reduces the mathematical calculations invloved in the conventional control method.

V. CONCLUSION

A closed loop control for DC micro-grid is proposed in this paper. The design and simulation of the proposed closed loop control is done in MATLAB software. The Fuzzy PI controller satisfies in regulating the voltage but there are some fluctuations in the system. This controller gives both the advantages of Fuzzy controller and PI controller. It helps in maintaining the solar PV unit output and also in maintain battery current and voltage.

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