DESIGN OF BATTERY LESS HYBRID PV SYSTEM FOR DC DISTRIBUTION SYSTEM IN BUILDING APPLICATIONS WITH IMPROVED TRANSIENT RESPONSE

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Abstract: *In this paper, the maximisation of energy transfer from a low voltage source to dc grid is investigated for building power supplies fed from photovoltaic (PV) array without battery backup system. The energy extracted from the PV array can be maximized via the energy transfer from a low voltage to high voltage or vice versa depending on the requirement by using parallel connected dc-dc converters. The concept of parallel connected dc-dc converter with properly sized PV array to feed the dc bus is demonstrated in this paper. The comparative performance analysis of proportional plus integral (PI) control with fuzzy logic control (FLC) in terms of percentage ripple and transient response has been presented. The improved performance has been obtained with fuzzy logic controller.*

Keywords:*Ripple reduction, PI control, fuzzy logic control, Matlab software*

1. Introduction

The trend in increasing the global warming insisted the usage of renewable energy sources. Electricity produced from the renewable energy sources yield better health benefits when compared with that generated out of fossil fuels[1, 2]. The pollution resulting out of coal and other natural gas plants create many health issues like breathing problems, neurological issues, heart attacks, cancer, etc. The electricity generated out of wind, solar and hydroelectric systems are not generating any pollution. Biomass and geothermal energy systems release quite a lot air pollutants, total emission is very less when compared with fossil fuel plant emission [3]. The maintenance and operating costs of renewable energy resources are low in comparison with conventional fuels [4]. The usage of modern dc-dc converters are extensively popular for the implementations, like hybrid electric vehicle systems, uninterrupted power supplies, fuel-cell power systems, PV hybrid power systems, and battery chargers [5, 6]. Some literatures research the solitary DC-DC converters, which include the half-bridge types and full-bridge types [7-9]. These converters can provide high step-up and step-down voltage gain by modifying the turn’s ratio of the transformer [10]. Fuel cells, batteries and PV cells generate and store dc power[11]. Around 1million residential homes and business organizations in Northern America uses dc power system. There is a set of home appliances and other recreational vehicle items that are manufactured to work either on 12/24 V. Conversion of dc power to ac power causes waste of energy. In dc configuration wind turbines are cheap and effective. Research and development is going on to build an energy router which is capable of connecting appliances to dc distribution system without effort conversion [12, 13].

One of the noteworthy issue in renewable power generation is the amalgamation of photovoltaic(PV) power systems with energy PV installations due to considerably enhancing economies, fundamental environmental benefits and encouraging energy policies require enhancement in power supply stability, which in turn demand energy storage systems [14].The uplift in the number of storage system for the PV generation [15, 16]. Many focus on system configurations and control strategies while many others concentrate only on system topologies or on control algorithms. In the traditional PV system design, the power generated is transported to load through unidirectional and bidirectional converters, where significant loss in power arises in every conversion stages.

In this paper, the dc supply obtained from the PV system has been utilized for powering the dc loads during day time and from processed ac supply during night time. Both modes, the controller performance is analysed to get proper dc.

2. Physical model of hybrid PV system for DC distribution

The block diagram representation of the proposed s ystem is shown in Fig. 1.

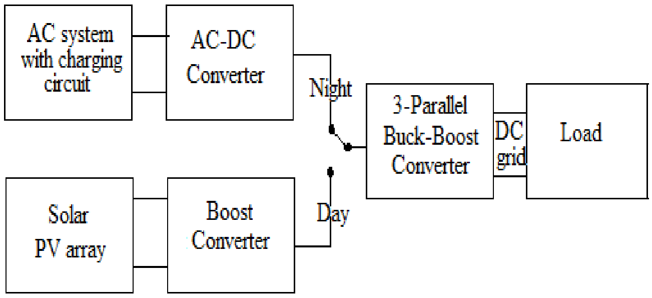

Fig. 1. Physical model of hybrid PV system.

There are two modes of operation, namely day time and night time. During the day time, the solar PV array supplies power to the boost converter. Then, it is given to the three parallel buck-boost converters through which it is contributed to the load. Throughout night time, power is transferred from the normal ac grid through charging circuit. Then it is given to ac-dc converter, from which it is transferred to the three parallel buck-boost converters and to the load. The energy conversion efficiency is the main factor of increase of energy capture from wind, PV or grid connection [17, 18].

In order to design the suitable buck-boost converter and to investigate the stability limits for this converter an integrated state-space model is necessary which is true for the complete switching period, and a state-space averaging method is suggested [19]. The efficiency and simplicity of this method when executed for PWM dc-dc converter is analyzed in this paper. The minute variations around the operating point can be understood, if in the circuit, state variables have been changed. At this point, if a Fourier series derivation is applied to a state variable, then the dc term will be the predominant term throughout a certain period. However this theory is not practical when shaping converters whose characteristics having oscillations, namely large ripple PWM converters or resonant converters.

In sequence to have a more accurate state-space average model, which is able to represent circuit state variable waveforms the specific state-space averaging method [19, 20] is suggested. In the above mentioned method, time-based coefficients are applied to satisfy the state variables, which produce in a synthesized sequence of differential equations with time-invariant coefficients.

In order to enhance the execution of dc-dc boost converter, a fuzzy logic controller (FLC) is applied. FLC is a process which suggests output to modify the input to get the aspired output. The outcome of load disparities at the response could be scrutinized for situations which uses FLC and PI controller. In order to plan for FLC, some researchers concentrated on maintaining the aspired output voltage by changing the duty cycle, but in this effort the reference voltage is changed to obtain the aspired output voltage. The transient as well as steady state behavior and the closed loop characteristics of the network with FLC controller for resistive load can be found out by applying MATLAB software.

The design and selection of different components of Fig. 1 are explained in the forthcoming sections.

3. AC and DC supply at the input side

The day time and night time operations are supported by PV array and ac.

3.1 Sizing of PV array

The PV array is sized depending on the load. Here maximum dc bus voltage is taken as 600 V. The dc bus feeding 1 kW is considered. Solar PV panel rated 37 W_p, and 16.64 V_{mp} (maximum power point voltage) is used in this work. To get the required voltage and power rating, 37 panels are connected in series and hence the array size become 37×1. PV array is simulated by using MatLab-Simulink [21]. The characteristics indicating the operating point voltage is shown in Fig. 2.

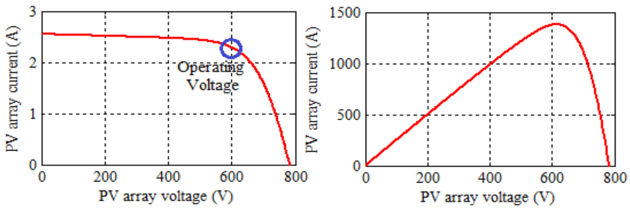

Fig. 2. Operating voltage in PV array characteristics

3.2 AC system with charging circuit

Three phase ac supply is provided to the three phase transformer which is attached to a charging circuit and a LCL filter (Fig. 3). Since the inrush current of dc-dc converter is high, capacitor of dc-dc converter is fully discharged. So a charging circuit is used with LCL filter which prevents high inrush current. In order to reduce harmonics, input current ripple, reduce inrush current, to obtain high frequency operation this filter is used.

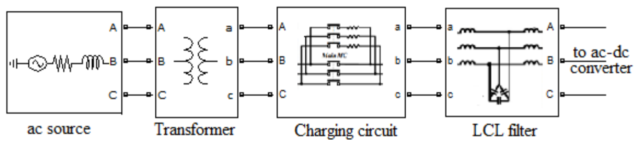

Fig. 3. AC system with charging circuit and LCL filter

3.3 Power converters

The schematic of power converter configuration is shown in Fig. 4. When supply is fed from the grid, ac-dc converter is used through charging circuit and filters. Three phase 415 V ac is converted into 100 V dc. When the circuit is powered by PV array, boost converter is used. MOSFET is effectively used because of its high frequency, lower voltage stress, high impedance and it consumes less dc power.

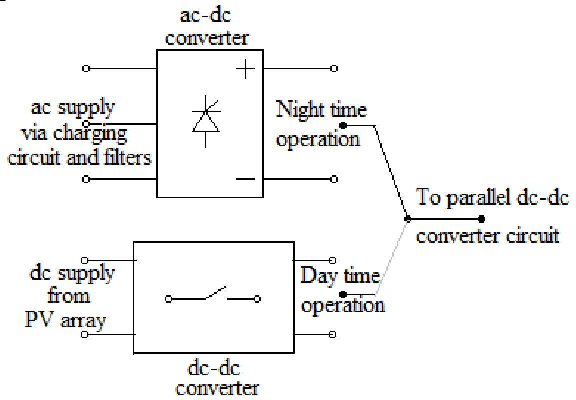

Fig. 4. Power converter selection for day and night time operation

Dc bus voltage is converted to different voltage levels in order to supply the load devices. Dc-dc converters are having high power density, reduced voltage ripple, high voltage gain and high efficiency and is found applied in dc motor drives, office appliances and telecommunication system.

3.4 Parallel buck boost converter

Whenever only one dc-dc converter delivers power to loads connected to dc grid, diminished life span of the system and reduced expansion capacity along with high temperature occurs. For building applications with the use of dc distribution, which demand high power, the steady state stability and output response of the dc grid are crucial. For revamping the switching frequency in dc-dc converters, bidirectional dc-dc converter with parallel operation is suggested [17]. The parallel operation of dc-dc converters ensures reduced current in each parallel output stages and the efficiency increases considerably. The input ripple in current is equally distributed in each stage. Apart from this, the frequency rises with shared the number of stages. Bidirectional converter ensures two operations namely, bidirectional power flow and buck/boost. Connecting the outputs of three separate dc-dc converter in parallel is not recommended because it does not have the possibility of balancing the output current. Hence if loading is asymmetrical, one of the dc converters will be overloaded while the others have to deliver fewer loads. This over loading can cause power supply oscillations. This can be avoided by the use of this parallel dc-dc converter. In this work, three parallel bidirectional buck-boost converters have been used and shown in Fig. 5.

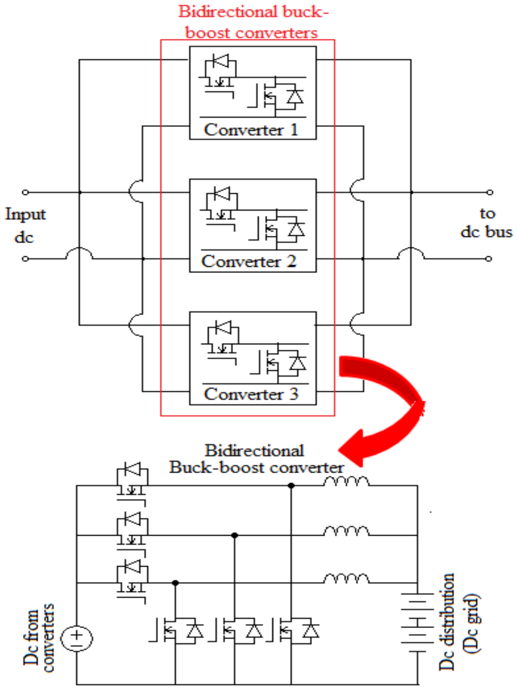

Fig. 5. Parallel buck boost converter

4. Control techniques

For stabilizing the output voltage, in the proposed system, PI and fuzzy logic controllers are used. The controllers minimize the ripple in the output voltage and enhance the transient response of the system. The comparative analysis of controller performances is carried out in buck and boost mode. Fig. 6 shows the block diagram of the controller structure.

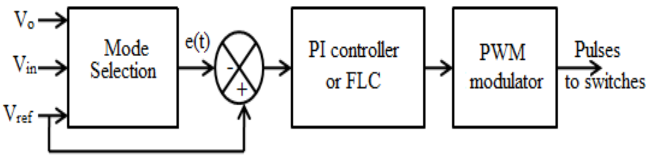

Fig. 6. Control block for proposed system

The mode selection switch decides the mode of operation, namely buck mode and boost mode. V_o is the bus voltage, V_{in} is the input voltage given to the dc-dc converter and V_{ref} is the reference voltage. When the reference voltage is 300V and the input voltage is 415V, mode selector switch selects buck mode. When the reference voltage is 600V and input voltage is 100V, it selects boost mode. The error function e(t) is given to PI controller or FLC. The processed error is then given to PWM modulator and afterwards pulses are given accordingly to switches.

4.1 PI controller

A heuristic method to tuning the PI controller gain value is Ziegler-Nichols method [25]. The proportional gain K_p is improved till it reaches the gain Ku at which the response of the control loop is stable.

$$K_p = 0.45K_u \quad (1)$$

$$K_I = \frac{T_u}{1.2} \quad (2)$$

where K_u and T_u are the oscillation period to set PI gain values.

Though this controller is most widely used and easy to implement it has certain drawbacks such as performance of these controller is affected by the variation of the system parameter and external factor. The transient response of the converter with fixed gain controller cannot be sufficiently fast. Hence adaptive controller must be implemented.

4.2 Fuzzy logic controller

In this control technique two inputs are given to the fuzzy logic block and the single output is obtained depending on the membership function. The two inputs are error (e) and change in error (ce) and the output obtained is the duty cycle D.

The input voltage to the buck –boost converter can be resolved by fuzzy inference system. For example, when the output voltage rises slowly, at the same time the current is moderate throughout the charging period, the fuzzy controller will balance the expansion of voltage to arrive the set point. A decrease in the output voltage activates the fuzzy controller to elevate the output voltage of the converter by revamping the input voltage to the fuzzy converter. The resolution of the fuzzy controller relay on the fuzziness of the control variables whereas the fuzziness relay on their membership functions. The different stages of fuzzy controller are: fuzzification, knowledge base, Inference or rule evaluation and defuzzification. The main advantage of fuzzy logic controller compared with conventional PI controller is that is fast settling time and low transient response. The rule base of the FLC for the output variable 'D' is shown in Table 1. The membership functions for error and change in error are shown in Fig. 7(a) & 7(b).

Table 1 Rule base for 'D' output variables

		Change in error				
		NB	NM	Z	PM	PB
Error	NB	NB	NB	NB	NM	NB
	NM	NB	Z	NB	NM	NM
	Z	NB	PM	PM	PB	PM
	PM	Z	PB	PB	PM	PB
	PB	PB	Z	PB	PB	PB

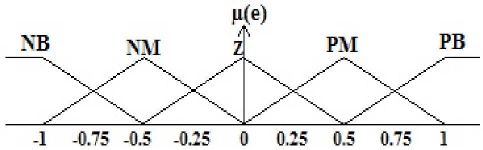

Fig. 7(a) Membership functions of error

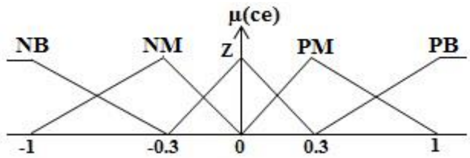

Fig. 7 (b) Membership functions of change in error

5. Simulation results

The schematic shown in Fig. 1 has been simulated with designed parameters and procedures discussed through Section 3 and Section 4. The proposed system is operated in both buck and boost mode by varying the input voltage values and having the set reference voltage to be 300 V and 600V for buck and boost mode respectively.

The simulation results of both buck and boost mode using PI controller is shown below. The output voltage of buck converter using PI controller is shown in Fig.8. The output voltage ripple is shown in Fig.9.

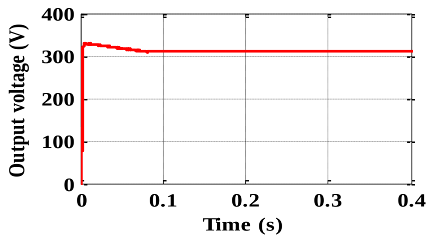

Fig. 8. Output voltage of buck converter using PI controller

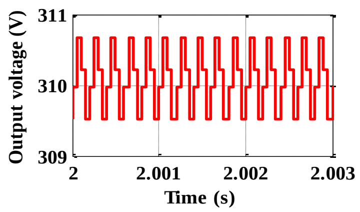

Fig.9. Output voltage ripple of buck converter using PI controller

The output voltage of boost converter using PI controller is shown in Fig.10. The output voltage ripple is shown in Fig.11.

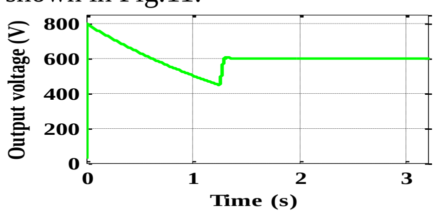

Fig. 10. Output voltage of boost converter using PI

controller

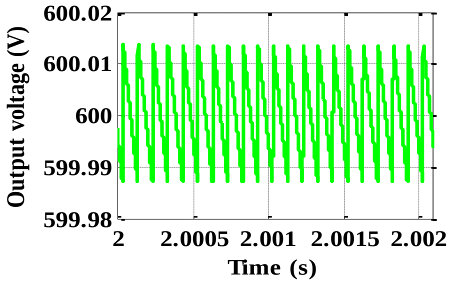

Fig.11. Output voltage ripple of boost converter using PI controller

The results of simulation of both buck and boost mode using fuzzy logic controller is shown below. The output voltage of buck converter using FLC is shown in Fig.12.The output voltage ripple is shown in Fig.13.

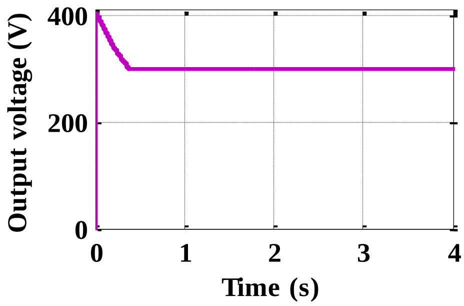

Fig.12. Output voltage of buck converter using FLC controller

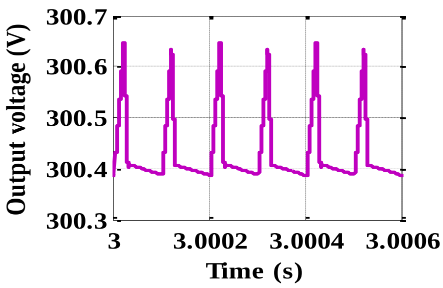

Fig.13. Output voltage ripple of buck converter using FLC controller

The output voltage of boost converter using FLC is shown in Fig.14. The output voltage ripple is shown in Fig.15.

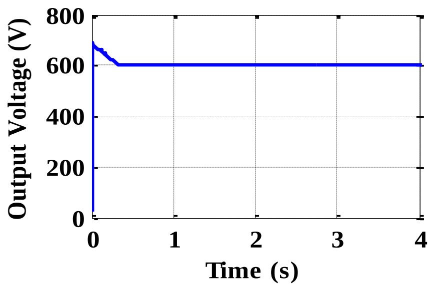

Fig. 14. Output voltage of boost converter using FLC controller

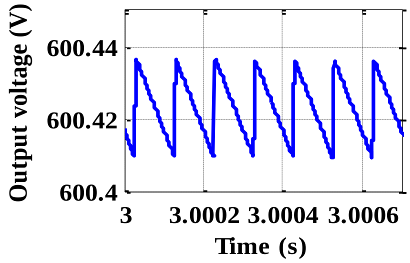

Fig. 15. Output voltage ripple of boost converter using FLC controller

The comparative analysis is carried out based on the rise time, settling time, peak overshoot and voltage ripple for both the controller in buck and boost mode. The analysis is shown in Table 2.

Table 2 Comparison analysis of PI and FLC controller

Parameters	**BUCK**		**BOOST**	
	V_{ref}-300 V, V_{in}- 415 V		**V_{ref}-600 V, V_{in}- 100 V**	
	PI	**FLC**	**PI**	**FLC**
Rise time	0.0014 s	0.00055s	0.0021s	0.0008s
Settling time	0.8s	0.3s	1.2s	0.2s
Peak overshoot	310V	300V	800V	700V
Ripple voltage	0.42%	0.10%	0.33%	0.16%

From Table 2 it is known that the FLC controller has short settling time, low rise time and low overshoot when compared with the conventional PI controller. And also the voltage ripple reduced in case of fuzzy logic controller with improved transient response. The comparative analysis of each parameter is represented graphically as shown in Fig.16.

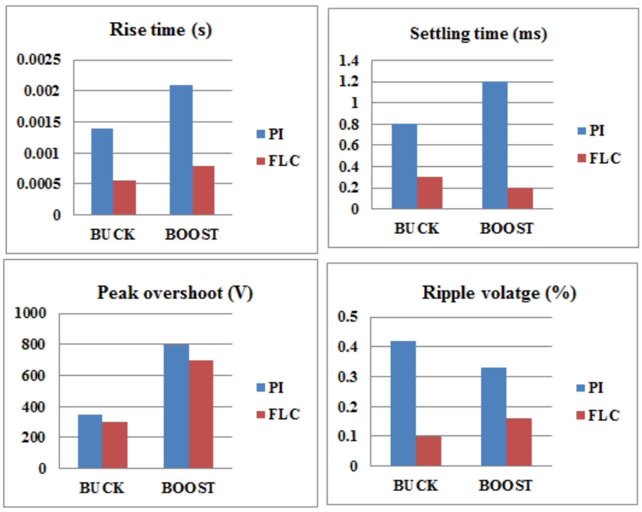

Fig.16. Graphical representation of analysis of the **proposed system**

6. Hardware Implementation

The hardware implementation of the proposed converter is shown in Fig.17. The gating signals to each power switches are given through PIC microcontroller. The pulses generated from the microcontroller are given to the opto-coupler circuit. Opto-coupler has been supplied from a developed power supply board consists of step down transformer, bridge rectifier with 7812 voltage regulator. Gating pulses from the processor is given to switches via the opto-coupler.

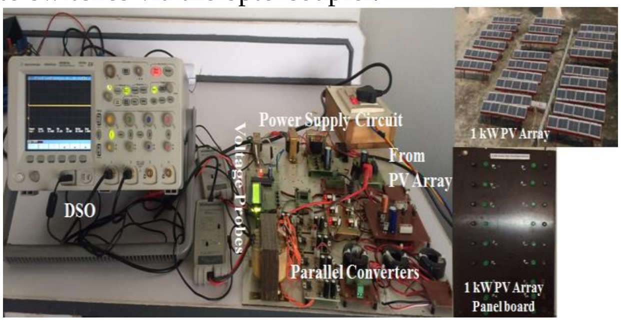

Fig. 17. Hardware setup of the proposed system

In the buck mode the input voltage is 415 V and the output voltage is about 300 V which is shown in Fig.18.

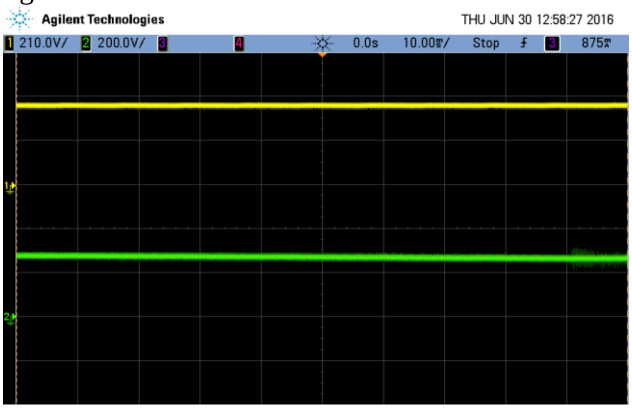

Fig. 18. Input and output voltage of the buck converter

The transient response of the buck converter in buck mode using PI controller and the fuzzy logic controller is shown in Fig.19.

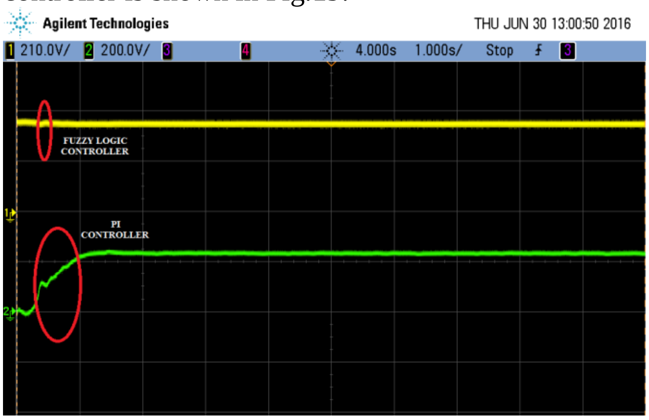

Fig.19. Transient Response of buck converter using PI and FLC controller

In the boost mode the input voltage is 100 V and the output voltage is about 600 V which is shown in Fig. 20.

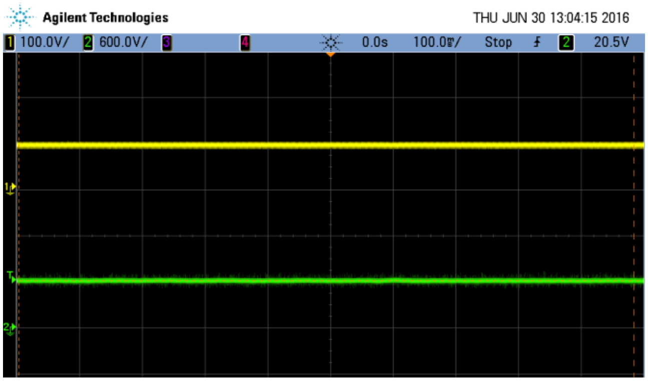

Fig.20. Input and output voltage of the boost converter

The transient response of the boost converter in boost mode using PI controller and the fuzzy logic controller is shown in Fig.21.

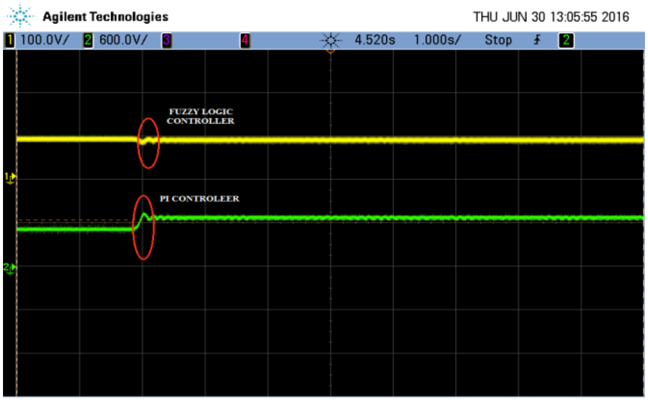

Fig. 21. Transient Response of boost converter using PI and FLC controller

The percentage of ripple for both buck and boost modes with PI controller and FLC is measured using single phase clamp on Fluke meter and presented in Fig. 22.

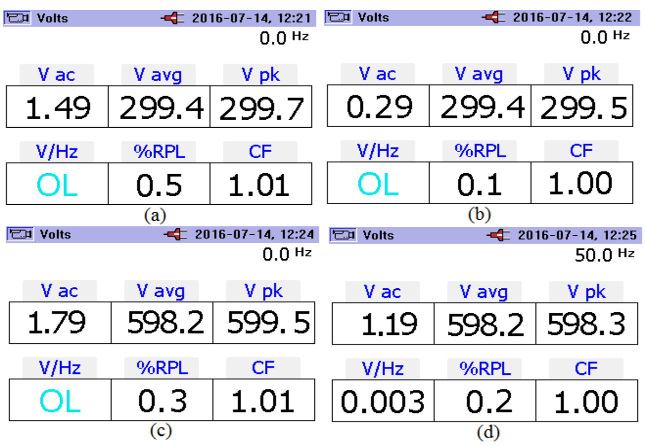

Fig. 22. Measured ripple: (a) Buck mode with PI controller; (b) Buck mode with FLC; (c) Boost mode with PI controller; (d) Boost mode with FLC

The % ripple presented in Fig. 16 is in good agreement with the measured %ripple shown in Fig. 22.

7. Conclusion

In this paper, the application of parallel connected buck-boost converter is investigated for building power supplies fed from photovoltaic (PV) array without battery backup system. The conventional PI controller and FLC controller are implemented in the proposed parallel dc-dc converter. From the results obtained it is observed that the FLC controller has better system performance compared with conventional PI controller. The FLC controller is able to achieve faster transient response, less overshoot and short settling time with minimum ripple voltage. Hence the fuzzy logic controller proven to be the appropriate controller for improved transient response of the system compared with conventional PI controller. The proposed system is also validated experimentally.

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