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# A Novel high step up three-port DC-DC Flyback Forward Converter

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***Abstract* - A three port DC-DC Converter integrating photovoltaic (PV) and battery power for high step-up applications is proposed in this paper. The topology includes four MOSFETs, two coupled inductors, and two active clamp circuits. System efficiency and cost effectiveness are of critical importance for photovoltaic (PV) systems. This work addresses the two issues by developing a novel three-port dc–dc converter for stand-alone PV systems, based on an improved Flyback-Forward topology. Therefore to achieve flexible power flow, and high power capability while still making the system simple and cheap. The converter can provide a high step-up capability for power conversion systems including the PV array, the battery storage, and the isolated load consumption. Three operating modes are analyzed and have shown the effective operation of the proposed topology for PV applications. Simulations can be done by using MATLAB/Simulink.**

***Keywords*—DC–DC power conversion, phase shift, photovoltaic power system, voltage control.**

## 1. INTRODUCTION

As the world population is increasing rapidly, the power demand and the load demand is also increasing rapidly. Renewable energy sources hold a vital role in generating the power and meeting with the load demands. With surplus advantages like low or almost nil harmful emissions, reliability, durability and low maintenance, renewable energy sources are now playing a major role in satisfying the future energy demand. However, owing to few disadvantages like fluctuation in output due to climatic conditions, irradiance, and temperature and so on, renewable energy sources are still under the research area. To cope up with the drawbacks batteries are used as storage mechanism for smoothing output power, improving start up transitions and dynamic characteristics, and enhancing the peak power capacity.

For this purpose hybrid power system combining PV, battery, etc are being proposed. These hybrid power systems have the potential to provide high quality, more reliable and efficient power. Many hybrid power systems with various power electronic converters have been proposed in the literature up to now. However, the main shortcomings of these integrating methods are complex system topology, high count of devices, high power losses, expensive cost, and large size. Integrated multi port converters are used to interface power sources with storage devices. They have the advantages like less components, lower cost, more compact size, and better dynamic performance. In many cases, at least one energy storage device should be incorporated.

Solar power is the cleanest energy in the world. Usages of solar energy are widespread in industry, commercial, and military applications. It will gradually become one of the primary energy supply resources in the future. The solar power is not an ideal energy source. The solar cell panels can only generate power at certain times of the day. So the most important consideration for using the solar power is to maximize the utility of the solar power while it is available. Solar cells can only generate power at certain times of the day, a storage element is required in all solar power systems. The most common form of the energy storage for the stand alone solar power system is battery technology. The basic functions of the battery management are to control the charge/discharge of the battery, to protect the battery from damage, to prolong the life of the battery, and to maintain the battery in a state to fulfill the functional requirements.

There are two main system configurations – stand-alone and grid connected. As its name implies, the stand-alone PV system operates independently of any other power supply and it usually supplies electricity to a dedicated load or loads. It may include a storage facility (e.g. battery bank) to allow electricity to be provided during the night or at times of poor sunlight levels. Stand-alone systems are also often referred to as autonomous systems since their operation is independent of other power sources. By contrast, the grid-connected PV system operates in parallel with the conventional electricity distribution system. It can be used to feed electricity into the grid distribution system or to power loads which can also be fed from the grid. Hybrid systems can be used in both stand-alone and grid connected applications but are more common in the former because, provided the power supplies have been chosen to be complementary, they allow reduction of the storage requirement without increased loss of load probability.

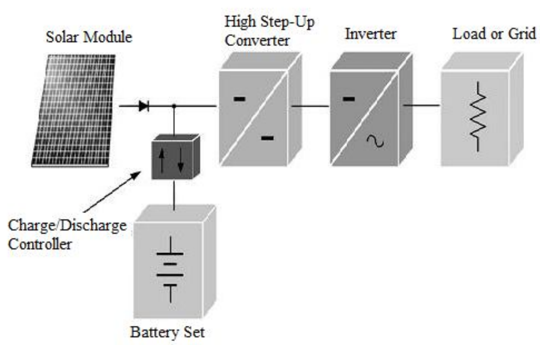


Figure.1 Typical photovoltaic system

A grid connected system is connected to a larger independent grid (typically the public electricity grid) and feeds energy directly into the grid. This energy may be shared by a residential or commercial building before or after the revenue measurement point. The difference being whether the credited energy production is calculated independently of the customer's energy consumption or only on the difference of energy. A stand-alone, or off-grid system is not connected to the electrical grid. Standalone systems vary widely in size and application from wristwatches or calculators to remote buildings or spacecraft. If the load is to be supplied independently of solar insolation, the generated power is stored and buffered with a battery. In non-portable applications where weight is not an issue, such as in buildings, lead acid batteries are most commonly used for their low cost and tolerance for abuse.ie, The stand-alone system is termed a “separate system” by the electric utility.

Basically, there are two structures that can be used in hybrid power source systems, i.e., the conventional structure and the multiport structure [4], [15].

In the conventional structure, there usually exists a common high-voltage or low-voltage dc bus interconnecting multiple sources. Separate dc-dc conversion stages are often used for individual sources. Those converters are electrically linked together at the dc bus and are usually controlled separately. The main structural concern of a hybrid power source is the position of the storage (e.g., batteries). As illustrated in Fig. 2(a), storage can be connected in parallel with the main source. With this configuration, the main source is effectively a charger for the storage. The current of the main source, however, is not controlled directly. The mismatch between source and storage impedance also presents a problem [15].

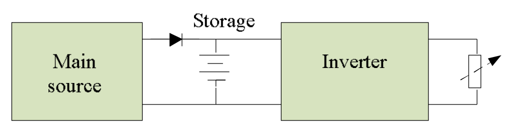


Figure.2(a)

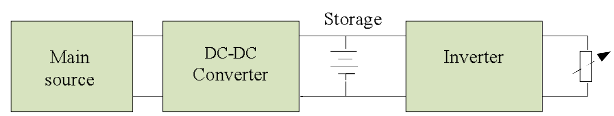


Figure.2(b)

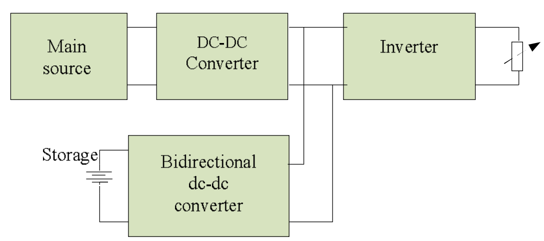


Figure.2(c)

Figure.2 Different storage positions in a hybrid power source, showing (a) in parallel with the main source, (b) on the main power flow path, and (c) connected to the dc bus through a bidirectional dc-dc converter.

As shown in Fig.2(b), energy storage can also be on the main power flow path to define a bus voltage. A dc-dc converter (e.g., boost converter) can be placed between the main source and the storage. The converter controls the current taken from the main source.

In the scheme shown in Fig.2(c), energy storage is placed outside the main power flow path and connected to the dc bus through a bidirectional dc-dc converter. The converter acts as an active filter to improve the dynamic response and to level the power difference between the generator and the load [16]. An advantage of this configuration is that it is possible to choose an optimal voltage for the storage.

Traditionally, multiple converters are used to provide interfaces for power inputs of the system. In principle, any basic power electronics topology can be used to design a power converter for a hybrid power system. For diverse applications, different system configurations were reported.

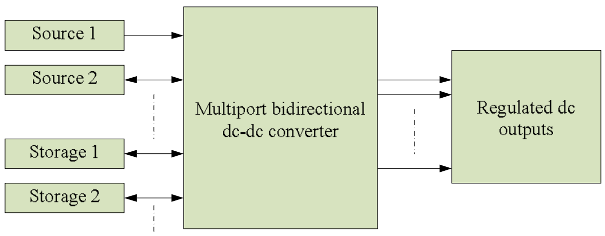


Figure.3 Multiport structure

The multiport structure is emerging as an alternative for hybrid power sources. It is different from the conventional one. The whole system is viewed as a single power processing stage that has multiple interfacing ports (Fig. 3). A multiport dc-dc converter can be used to interface multiple power sources and storage devices. It regulates the system voltages and manages the power flow between the sources and the storage elements. For small hybrid power systems, the multiport concept can provide a reduced parts-count solution compared with the conventional structure that uses multiple converters. A multiport converter may best satisfy integrated power conversion, efficient thermal management, compact packaging, and centralized control requirements. The multiport topology has an advantage over the conventional approach. It is shown that the number of stages in the conventional structure can be reduced by recognizing redundancy in the power processing.

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## 2.PROPOSED CONVERTER STRUCTURE

### A. Circuit Design

The proposed converter topology is shown in Fig.4.It consists of main switches $S_1$ and $S_2$ transfer the energy from the PV to the battery or load, and can work in either interleaved or synchronous mode. The switches $S_3$ and $S_4$ are operated in the interleaved mode to transfer energy from source to load. $L_1$ and $L_2$ are two coupled inductors whose primary winding ($n_1$) is employed as a filter and the secondary windings ($n_2$ ) are connected in series to achieve a high-output voltage gain. $L_{LK}$ is the leakage inductance of the two coupled inductors and N is the turns ratio from $n_2/n_1$ . $C_{S1}$ , $C_{S2}$ , $C_{S3}$ , and $C_{S4}$ are the parasitic capacitors of the main switches $S_1$ ,$S_2$ , $S_3$ , and $S_4$ , respectively.

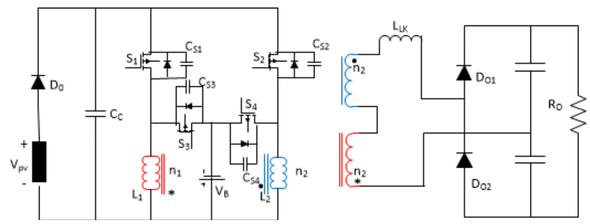


Figure.4 Proposed converter topology.

In proposed converter structure, there are three operational modes for the converter, as illustrated in Fig.3.2. In mode 1, the PV array supplies power to load and possibly also to the battery, corresponding to the daytime operation of the PV system. Two 180° out-of-phase gate signals with the same duty ratio (D) are applied to $S_1$ and $S_2$ , while $S_3$ and $S_4$ remain in a synchronous rectification state.

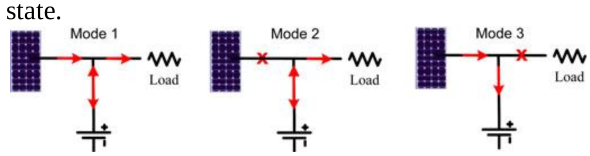
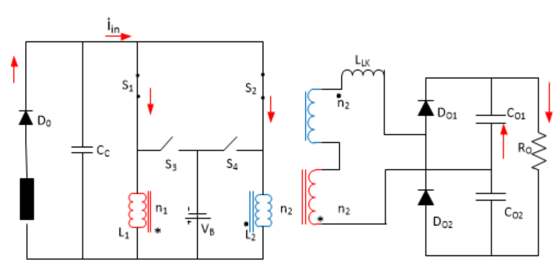



Figure.5 Three operating modes of the proposed converter.

When in the steady-state operation, there are four states in one switching period, of which the equivalent circuits are shown in Fig.5. The steady-state waveforms of the four states are depicted in Fig.7, where $V_{GS1}$, $V_{GS2}$, $V_{GS3}$, and $V_{GS4}$ are the gate drive signals; $V_{ds1}$ and $V_{ds2}$ are the voltage stresses of $S_1$ and $S_2$ ; $iL_{1a}$ and $iL_{2a}$ are the currents through $L_{1a}$ and $L_{2a}$ , respectively. $i_B$ is the current through the battery, is1 is the current through $S_1$ , $v_{Do1}$ is the voltage stress of the output diode $D_{o1}$ , and $iD_{o1}$ is the current through $D_{o1}$ .



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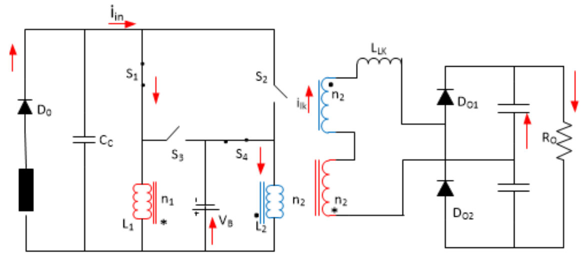


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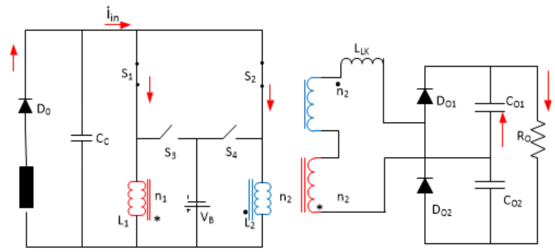


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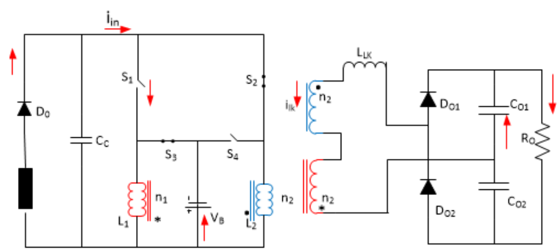



(d)

Figure.6 Four operating states of the proposed converter in mode 1

State 1 [$t_0$ –$t_1$ ]: The main switches $S_1$ and $S_2$ are both in turnon state before $t_0$ . The two coupled inductorswork in the flyback state to store energy from the PV array. The output rectifier diodes $D_{o1}$ and $D_{o2}$ are both reverse-biased. The energy stored in the secondary output capacitors $C_{o1}$ and $C_{o2}$ transfers to the load.

State 2 [$t_1$ –$t_2$ ]: At $t_1$ , $S_2$ turns OFF, $S_4$ turns ON, while the diodes $D_{o1}$ is ON. The primary side of the coupled inductor $L_2$ charges the battery through $S_4$ . During this state, $L_1$ operates in the forward mode and $L_2$ operates in the flyback mode to transfer energy to the load. When $S_1$ turns ON and $S_2$ turns OFF, the primary voltage of the coupled inductor $L_1$ is $V_{pv}$ and the voltage on $L_2$ is $-V_B$ .

State 3 [$t_2$ –$t_3$ ]: At $t_2$ , $S_2$ turns ON, which forces the two coupled inductors work in the flyback state to store energy and $D_{o2}$ is reverse-biased. The energy stored in $C_{o1}$ and $C_{o2}$ transfers to the load. At $t_3$ , the leakage inductor current decreases to zero and the diode $D_{o1}$ turns OFF.

State 4 [$t_3$ –$t_4$ ]: At $t_3$ , $S_1$ turns OFF and $S_3$ turns ON, which turns $D_{o2}$ ON. The primary side of coupled inductor $L_1$ charges the battery through $S_3$ . During this state, $L_2$ operates in the forward mode and $L_1$ operates in the flyback mode to transfer energy to the load. When $S_1$ turns ON and $D_{o2}$ turns OFF, a new switching period is started.

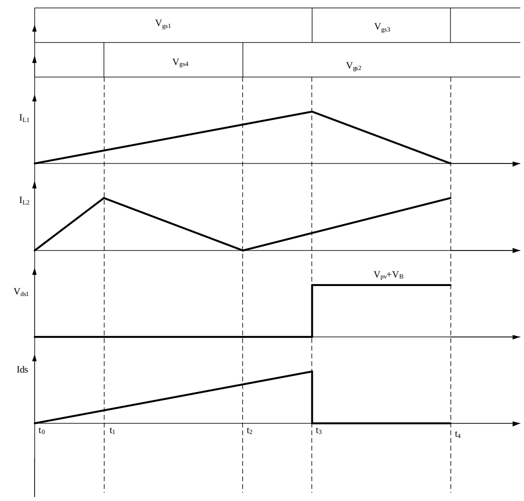
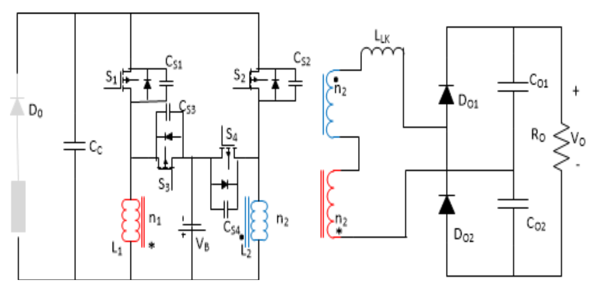
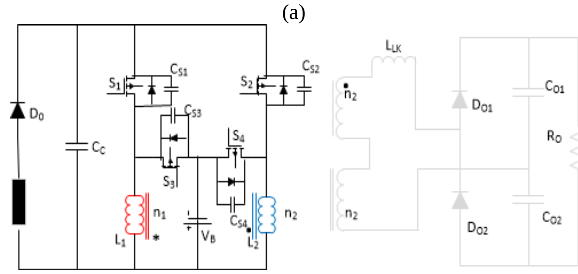


Figure.7 Waveforms of the proposed converter under mode 1

In mode 2, the battery supplies power to the load, as shown in Fig.8, indicating the nighttime operation of the stand-alone system. The circuit works as the Flyback-Forward converter, where $S_3$ and $S_4$ are the main switches, $C_c$ , $S_1$ , and $S_2$ form an active clamp circuit.




(a)




(b)

Figure.8 Converter operating modes 2 and 3. (a) Mode 2, (b) mode 3.

When the load is disconnected, the standalone system enters into mode 3. The PV array charges battery without energy transferred to the load due to the opposite series connected structure of the coupled inductor Fig.8(b). $S_1$ and $S_2$ work simultaneously and the topology is equivalent to two paralleled Buck-Boost converters.

## 3. SIMULATION RESULTS AND DISCUSSION

In this stage, the simulation of proposed system done with MATLAB/SimPowerSystems. The interfaces and controllers are done using Simulink toolbox. The studied system is modeled in continuous-time mode.
The values of the circuit parameters are given below:

Table 1 Simulation Parameters

| Simulation Parameters | Proposed Converter Value |
|---|---|
| Input Voltage | 25V |
| Output Voltage | 45V |
| Inductor | 150 µH |
| Capacitor | 500 µF |
| Resistor | 600Ω |
| Switching Frequency | 10KHz |

### A. Overall MATLAB-Simulink Model

**By using PI controller**

The simulation model of a novel three-port dc-dc converter for stand-alone photovoltaic systems is shown in Fig.9. Here we can see that in mode 1, $S_1$ and $S_3$ are complementarily conduct, and the ON/OFF operation of $S_2$ and $S_4$ is complementary. When the output power of the PV array is lower than the load power, the battery should supply the difference. The primary side of the proposed converter is equivalent to a bidirectional Buck–Boost converter.

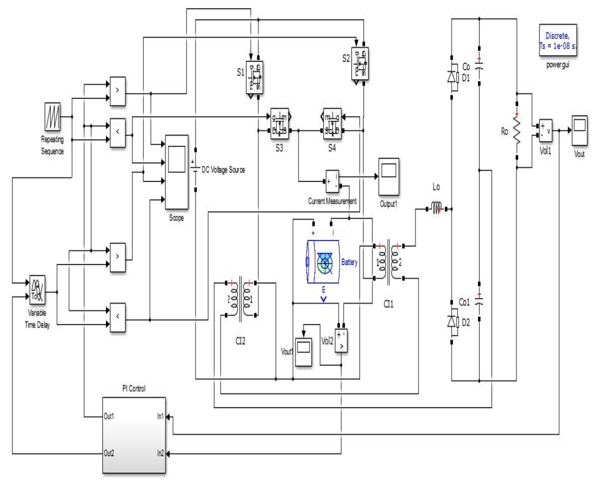



Figure.9 Simulation model of the proposed converter structure in closed loop system with PI controller

Here we can use two control,first control is used for delay purpose. ie, to set the delay. First, to generate a PWM ,that is given to the input. And then a phase shifted version is given to the next one. And this phase shifting is decided by using PI controller. A proportional-integral-derivative controller (PID controller) is a control loop feedback mechanism (controller) widely used in industrial control systems. A PID controller calculates an error value as the difference between a measured process variable and a desired set point. The controller attempts to minimize the error by adjusting the process through use of a manipulated variable.

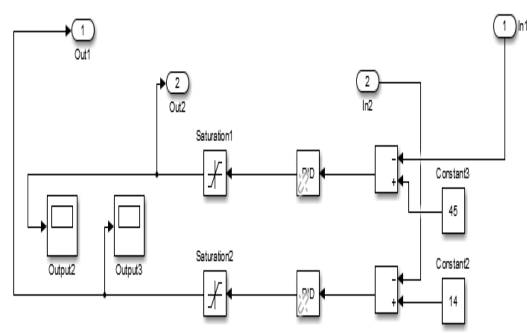



Figure.10 Subsystem for generating firing signal for the switches

The output of the PID controller is given to the saturation block. The Saturation block imposes upper and lower bounds on a signal. This controlled voltage is given to variable time delay. In this mode, the block has a data input, a time delay input, and a data output. The output at the current time step equals the value of its data input at a previous time step. This time step is the current simulation time minus a delay time specified by the time delay input. After setting time delay, to generating firing pulses of four switches. Firing signal for the switches is given by means of PWM method. Here two signals are compared, a reference signal and a carrier signal. When the reference value is more than the carrier waveform the output PWM signal is HIGH, ie $S_1$ is ON. The switching turn ON points is determined by the carrier waveform used. Otherwise the signal is low.ie $S_3$ is ON.

Second PI controller is used to control the battery voltage. Here we can use 12V battery. So battery voltage doesnot exceed the limit (reference voltage=14V) during its charging period. Otherwise the battery will damaged.

### B.Simulation Results

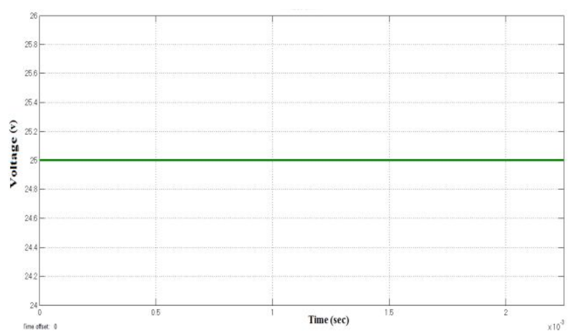



Fig.11 Input voltage of proposed converter structure is 25V.

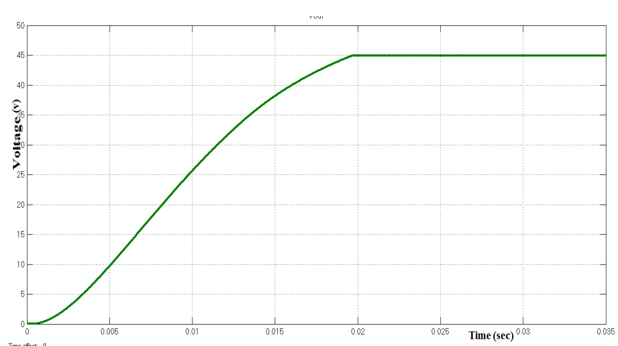



Figure.12 Output voltage across the load in the proposed converter is almost 45V

Figure 11 shows the input voltage of proposed converter structure is 25V. The output voltage across the load in the proposed converter is almost 45V is shown in figure 12.

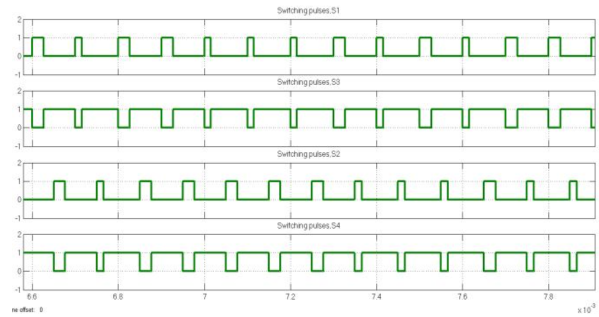



Figure.13 Gate signals of four switches in the proposed converter circuit.

Figure13 shows the gate signals of four switches in the proposed converter circuit. Here, $S_1$ and $S_3$ are complementarily conduct, and the ON/OFF operation of $S_2$ and $S_4$ is complementary.

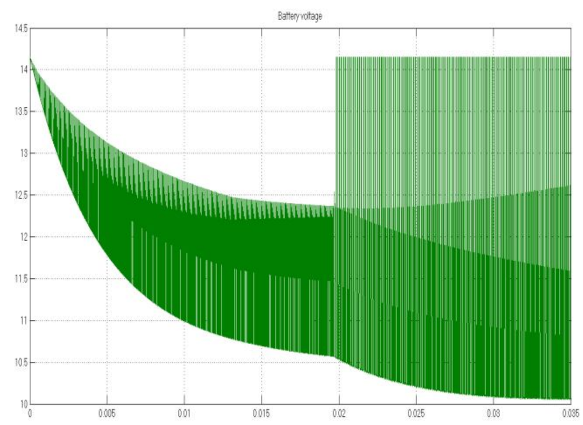



Figure. 14 Voltage across the battery in the proposed converter structure.

Figure 14 shows the voltage across the battery in the proposed converter structure. The output voltage will be stable when it reach at the time .02s.That particular time battery voltage will be stable. When the output power of the PV array is lower than the load power, the battery should supply the difference.

### C. By using Fuzzy Logic Controller

Fuzzy logic is widely used in machine control. The term "fuzzy" refers to the fact that the logic involved can deal with concepts that cannot be expressed as the "true" or "false" but rather as "partially true".

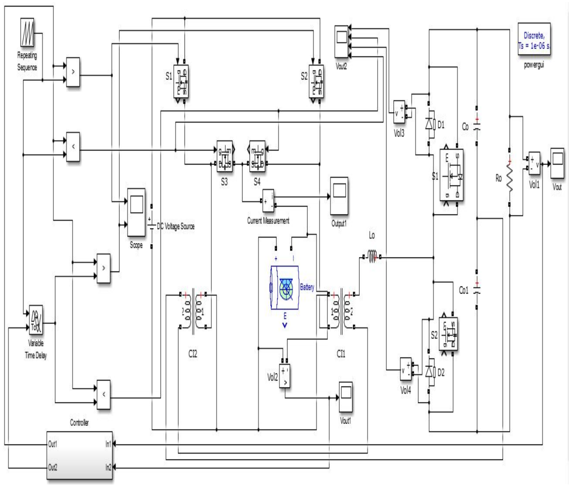



Figure.15 Simulation model of the proposed converter structure in closed loop system with Fuzzy controller.

Fuzzy controllers are very simple conceptually. They consist of an input stage, a processing stage, and an output stage. The input stage maps sensor or other inputs, such as switches, thumbwheels, and so on, to the appropriate membership functions and truth values. The processing stage invokes each appropriate rule and generates a result for each, then combines the results of the rules. Finally, the output stage converts the combined result back into a specific control output value.

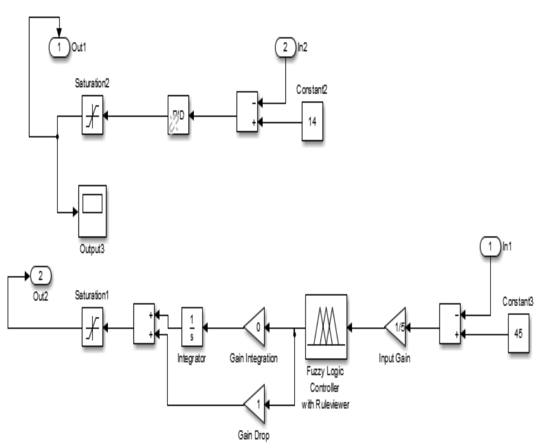



Figure.16 Subsystem for generating firing signal for the switches

Fuzzy consists of two inputs. One input is the error. That is the difference between the output and reference. That is multiplied with a gain factor. That is given as the input to the fuzzy. Other input is the derivative of error. There is one output. The inputs and output is related by several rules.

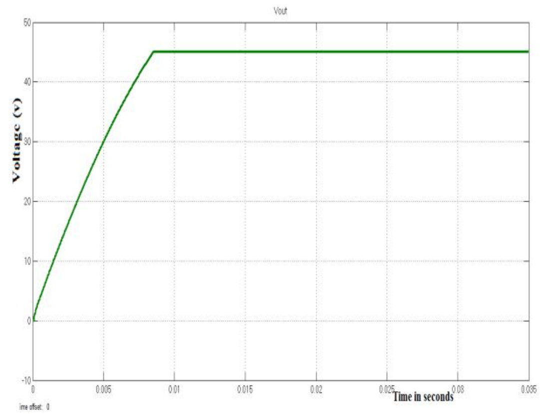



Figure.17 Output voltage across the load in the proposed converter is 45V

The output voltage across the load in the proposed converter is almost 45V is shown in figure 17. The output voltage will be stable when it reach at the time .008s

## 4.EXPERIMENTAL RESULTS

The experimental setup is given in Figure.18. It consists on a Stratix DSPIC 30F2010 microcontroller . The switches are MOSFETs IRF Z44n.

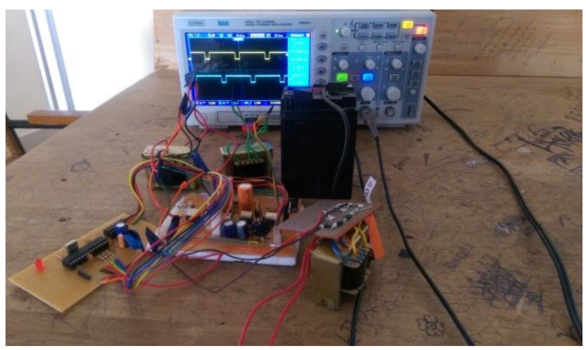
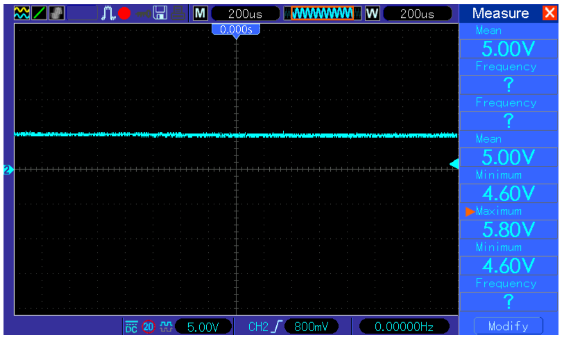


Figure. 18 Hardware Implementation of proposed converter structure

LED Indicators are provided to indicate power supply in the converter. A regulator IC LM7805 is provided to get regulated 5V supply to the converter and also 5V input supply is boosted upto 12V by using this particular converter.

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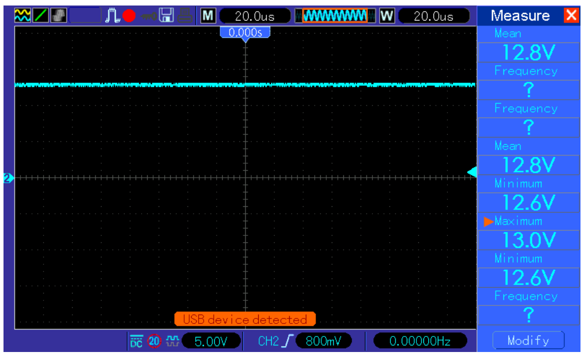


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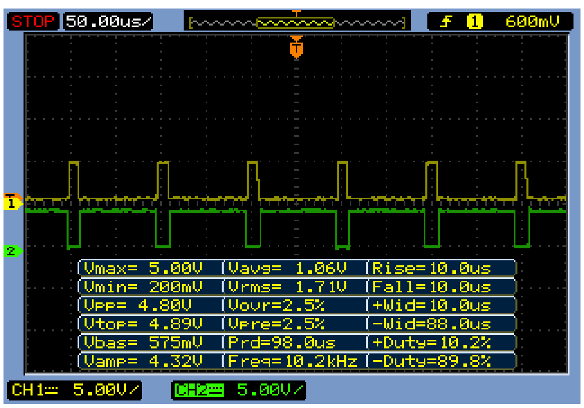


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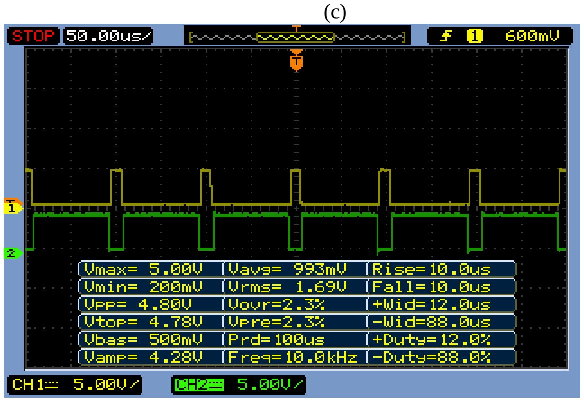


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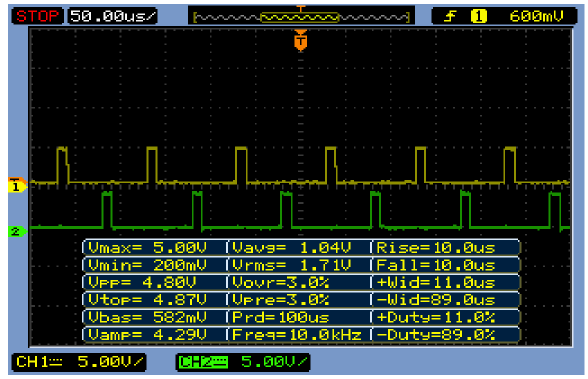


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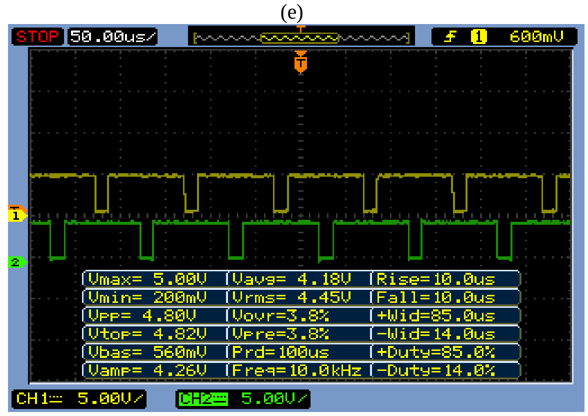


(f)

Figure. 19.(a) Input signal = 5V (b) Output voltage of about 12V (c) Switching pulses of $S_1$ & $S_3$ (d) Switching pulses of $S_2$ & $S_4$ (e) Phase shifted version of switching pulses for $S_1$ & $S_2$ & (f) Switching pulses of $S_3$ & $S_4$

## 5. SUMMARY AND CONCLUSION

An isolated three-port dc–dc converter for stand-alone PV systems, based on an improved Flyback-Forward topology. The converter can provide a high step-up capability for power conversion systems including the PV array, the battery storage, and the isolated load consumption. According to these topologies, a new three-port dc–dc converter is developed in this work to combine a new ITPC topology with an improved control strategy, and to achieve decoupled port control, flexible power flow, and high power capability while still making the system simple and cheap. Three operating modes are analyzed and have shown the effective operation of the proposed topology for PV applications.

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