Multi-Port DC-DC Converter for PV-Battery System

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Abstract – In this paper, three port DC to DC converter (TPC), that interfaces with solar panel, a rechargeable battery, and a load. This three-port converter is suitable for standalone applications. Each port is employed for specific input or output. This converter is used to connect the Solar Array with battery part and the affect of re-newable energy irregularities and non-consistent demand can be minimized. Given converter is re-configurable and can be operated as a standard boost converter, in various operations to different power flow and get the power situation among the Photovoltaic module, battery, load port at the same time. Using coupl-ed inductor, connecting the PV module and battery in series high voltage conversion ratio can be achieved.

***Key Words*:** Battery, intermittency, maximum power point tracking (MPPT), photovoltaic, renewable energy, Single-input single-output (SISO), three-port converter (TPC)..

1.INTRODUCTION

Renewable energy's inconsistency has a negative impact on the power system's reliability. To address this issue, use of converter connects battery to recyclable energy source, renewable energy sources maximum power point (MPPT) and regulate output loads.

Traditionally, single energy source is connected to out-put via one DC to DC power converter with only 2 ports [1]. Multiple power converters were required to join to many inputs and outputs. Number of multi-port converters (MPC) have been designed in recent years to link numerous recyclable energy source with various I-V properties to output.

A three-port converter (TPC) multi-port converter that have 3 ports. Bi-directional port on TPC is frequently connected to a power storage system, which is a supplementary input supply [1]. Partially, non-isolated, isolated converters are three types of MPC converters.

To obtain large regulation of voltage, galvanic isolation, an isolated converter employs a large frequency transformer. By maintaining phase shift to all Mosfets in a half or full bridge rectifier, it can achieve zero voltage switching (ZVS). A large number of switches and linked gate driver circuit are required for the isolated converter. Furthermore, transformer-based topologies would necessitate a large amount of work which deals with leakage power, as well as more complex maintain technique for non-interrupting power flow between any of the three types of ports.

In few applications, partly isolated converter is a superior choice when a high-voltage regulation ratio is necessary but galvanic isolation between all ports are not needed [2].

Three port non-isolated converters have been proposed by the authors of [2], [3], and [5]. voltage gain is constrained despite reduced number of switches. By use of coupled inductor with non-similar turns ratio, author of [4] suggests a high-voltage non-seperated converter. The circuit consist of 3 power mosfets and 5 diode, yet the number of component is still quite large.

2. PROPOSED METHODOLOGY

2.1 Circuit Diagram

The suggested three-port converter contains four ports:

two one directional in-put port, a bidirectional battery port, and an output port, as illustrated in Fig. 2.1. Sa and Sb are two switches. Sb is a bi directional switch made up of two MOSFETs connected back-to-back with each other. The flyback output is formed by diode D1 and coupled coil L1. C2 and C3 are used as filter capacitors at Va and Vb respectively. For energy transfer between all the ports, coupled inductor L1 & L2 is used like an intermediary storage system. A solar module connected to main in-put-port. Bi-directional battery-port connects to battery storage part and connected in series with input-port and hence this can be used to do two things such as provide high-voltage gain or it can help in regulation of out-put in reaction to inconsistency of Photo-Voltaic power. BC547 transistors were used in MOSFET driver circuit to provide additional input voltage to drive MOSFET. This suggested circuit is capable of achieving maximum power point, battery charging/discharging, and output voltage regulation.

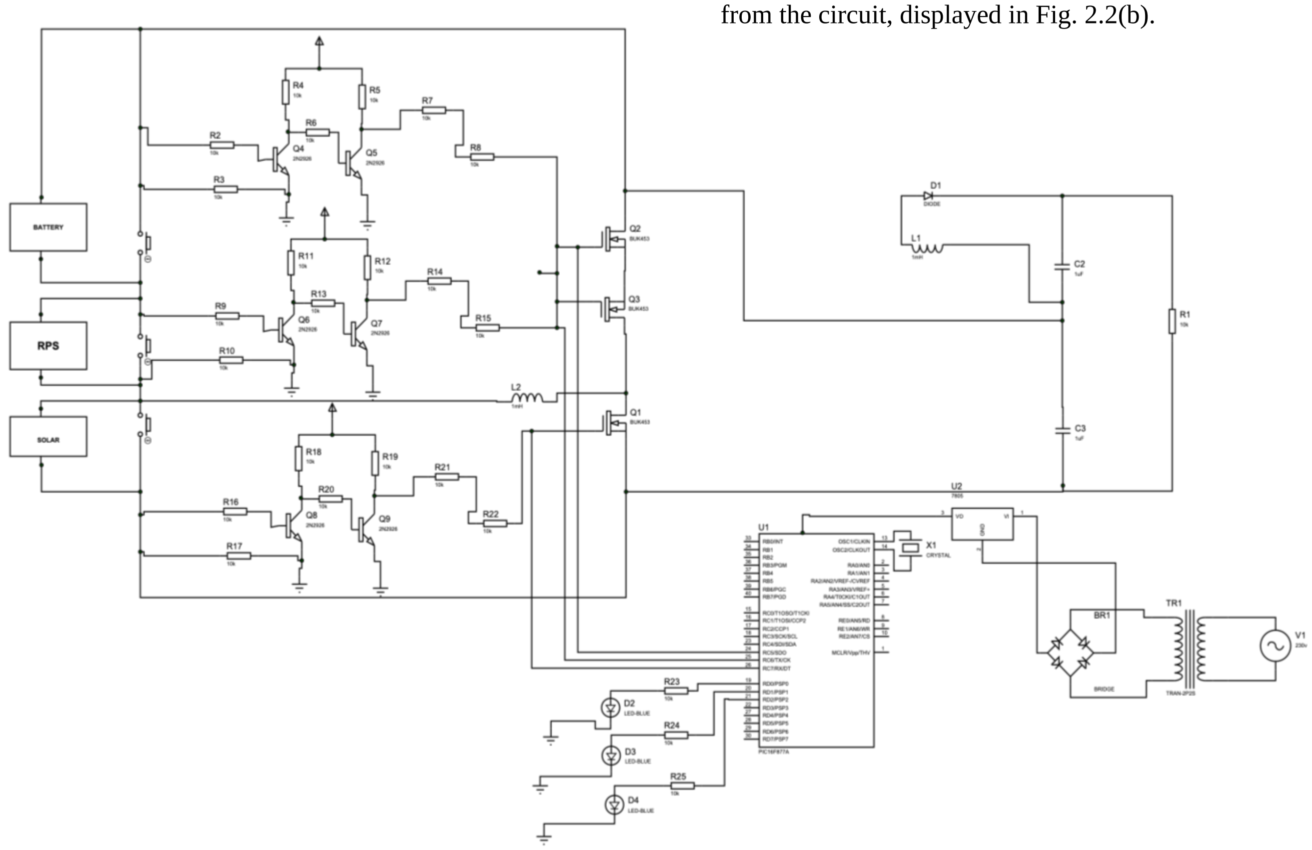

Fig-2.1: Proposed Circuit Diagram

2.2 Modes of Operation

The input solar energy is equal to the power given to battery and energy which goes to the out-put, according to the circuit diagram depicted in Fig. 2.1,

$$P_{pv} = P_b + P_o$$

and the solar current is equal to the sum of primary inductor charge and battery charge,

$$I_{pv} = I_{L2} + I_b$$

Also, out-put voltage is equal to sum of voltages across C2 and C3 capacitors,

$$V_0 = V_1 + V_2$$

The suggested triple port converter features 6 modes of operation. The following are the modes:

• PV/Battery Mode(Single Input Single Output): This operation is operational when solar module is charging battery at no load constraint, displayed in Fig. 2.2(a).

• Photo Voltaic/Load Operation (Single In-put Single Out-put): In this operation solar module supplying power directly to out-put considering that battery is disconnected from the circuit, displayed in Fig. 2.2(b).

• Battery/Load operation(Single Input Single Output):

This case arises when solar module have shade or not delivering electrical power specially during night . In this mode battery delivers power to out-put, displayed in Fig. 2.2(c).

• Dual Input Single Out-put Mode: Solar module together with battery both deliver power to output at the same time but battery is not charging, this mode is active, as presented in Figure 2.2(d),

• Single In-put Dual Out-put Mode: Here solar module delivers power to out-put and extra non-utilised power which we get from solar module is used to charge battery simultaneously, presented in Figure 2.2(e).

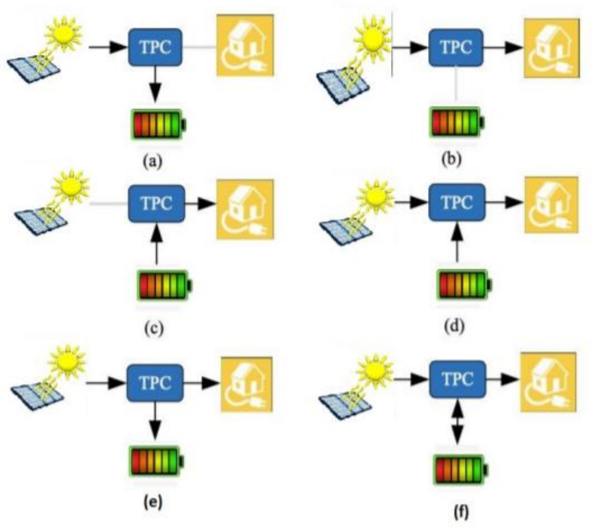

Fig. 2.2 Modes of operation

2.3 Working Modes Analysis

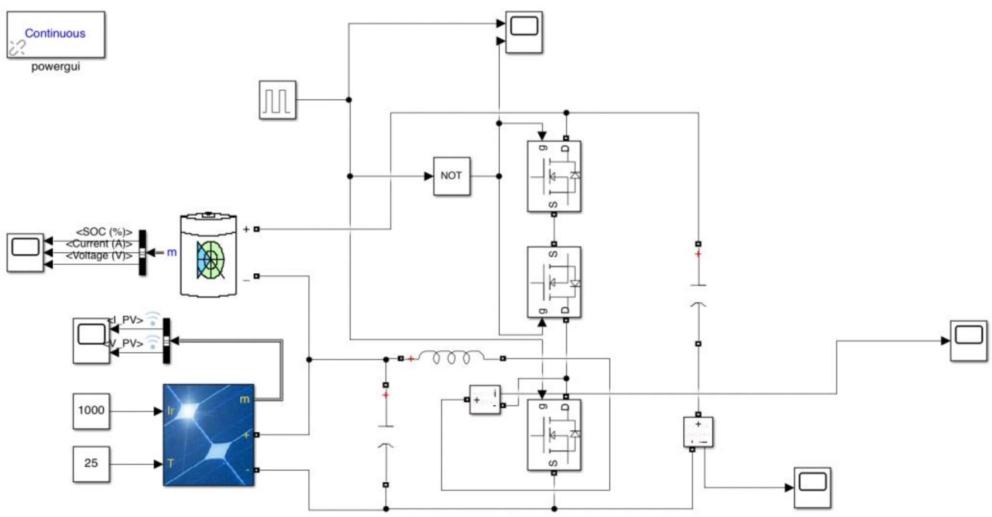

Fig. 2.3 PV Battery Mode Simulation

2.3.1. PV Battery Mode:-

The input and battery ports are the only ports that are active in this mode. Switches Sa and Sb are in complimentary mode of operation.

Switching mode 1: This mode starts when switch S_a is turned 'ON' but switch S_b is turned 'OFF'. input solar power and battery, first inductor, L_2 begins charging . Electrical Polarity of coupled inductor's secondary winding causes D_1 to be reversed biased, so secondary inductor loop is open hence no current flows through L_1.

Switching mode 2: This mode starts when S_b is switched 'ON' and S_a is switched 'OFF'. First inductor, L_2, begins discharging, increasing the battery current.

From %SOC waveform and I_b waveform as shown in figure 2.4, it can be seen that state of charge of battery is gradually decreasing over time and battery current is positive. HENCE battery is discharging.

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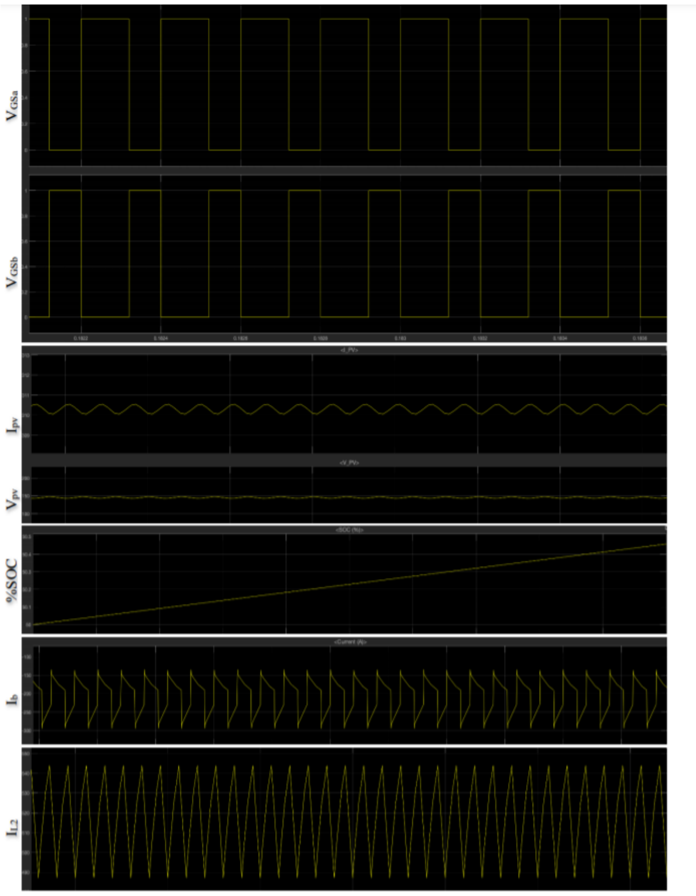

Fig. 2.4 Waveforms

Switching mode 1: This mode starts when switch S_a is turned ‘ON’. Switch S_b is in ‘OFF’ position. L_2, the primary inductor begins to charge. The polarity of the coupled inductor's secondary winding causes D_1 to be reverse-biased.

Switching mode 2: Switch Sb is switched ‘ON’ while S_a remains ‘OFF’. L_2, the primary inductor begins to discharge. Electrical power stored in linked inductor is delivered to out-put via the diode D_1 as D_1 becomes forward biased.

Switching mode 3: The switching status does not change in this switching mode. They remain same as mode 2. The only change that can be viewed in this mode is that direction of current on first inductor L_2 is reversed.

2.3.2 PV Load Operation: -

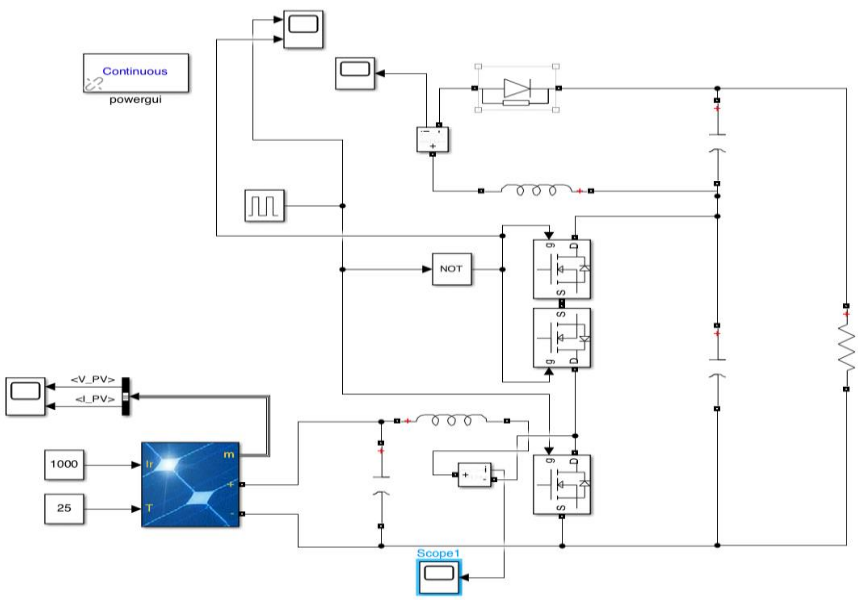

Fig. 2.5 PV Load Mode Simulation

Just 2 ports are active in this mode which are solar in-put port and out-put port. The battery port is unplugged.

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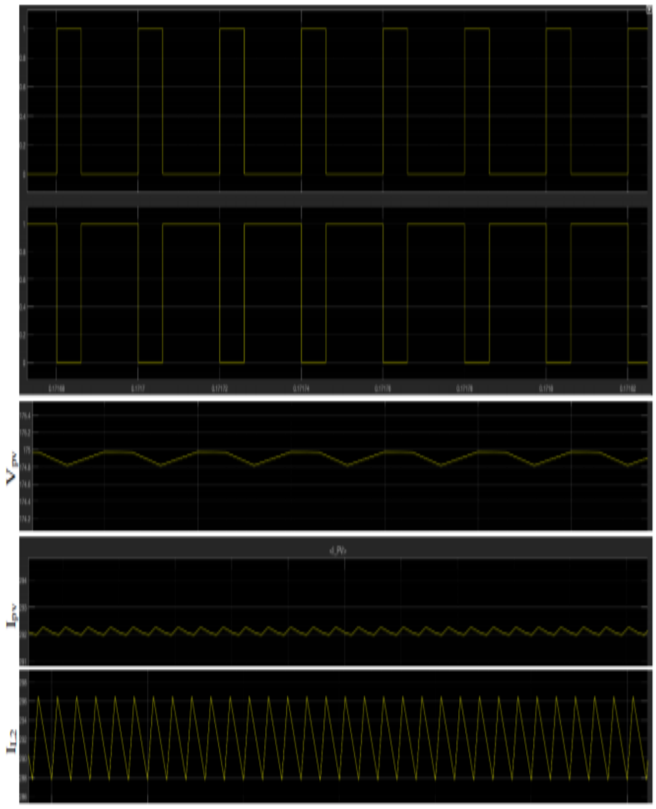

Fig. 2.6 Waveforms

2.3.3. Battery - Load Operation: -

Just 2 port is active in this mode: battery and out-put terminal. Solar input port is unplugged.

Switching mode 1: In this mode switch Sa is always 'OFF' but switch Sb is switched 'ON'. L2 (first inductor) begins to charge. Electrical Polarity of coupled inductor's secondary winding causes D1 to be forward biased. And hence secondary inductor loop starts conducting and current flows to load via D1. To deliver more current to the load, the battery current begins to rise.

Switching mode 2: Switch Sb is switched 'OFF' while Sa remains 'OFF' in this switching mode. When the primary inductor, L2, begins to lose its electrical power, battery charge decreases. Now current is directed towards switch Sa's anti-parallel diode.

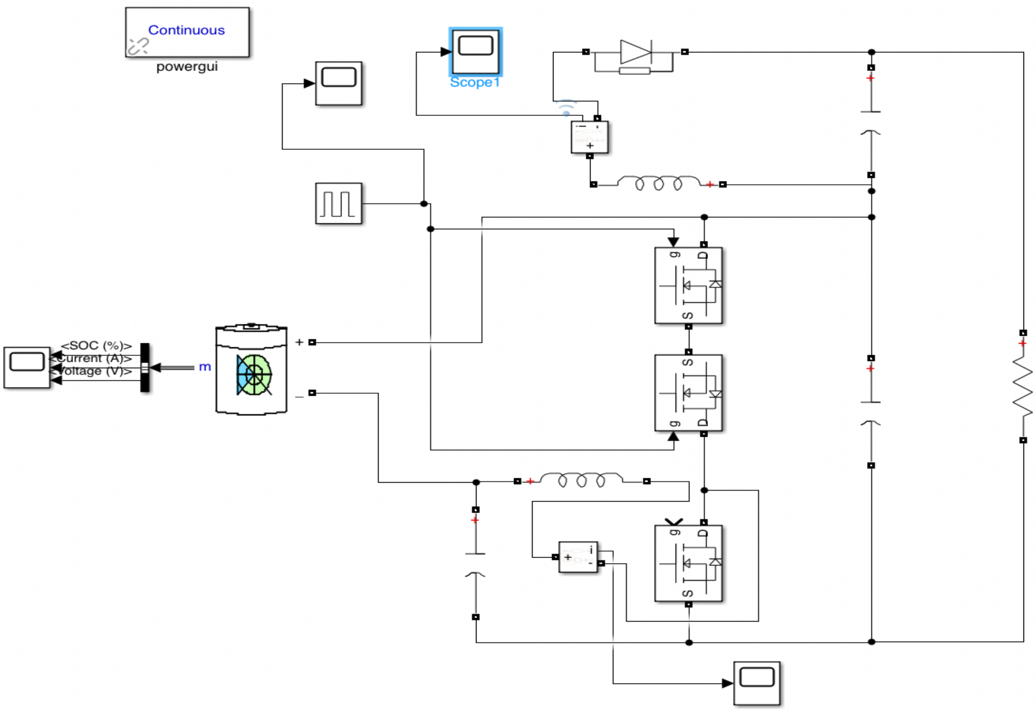

Fig. 2.7 Battery Load Mode Simulation

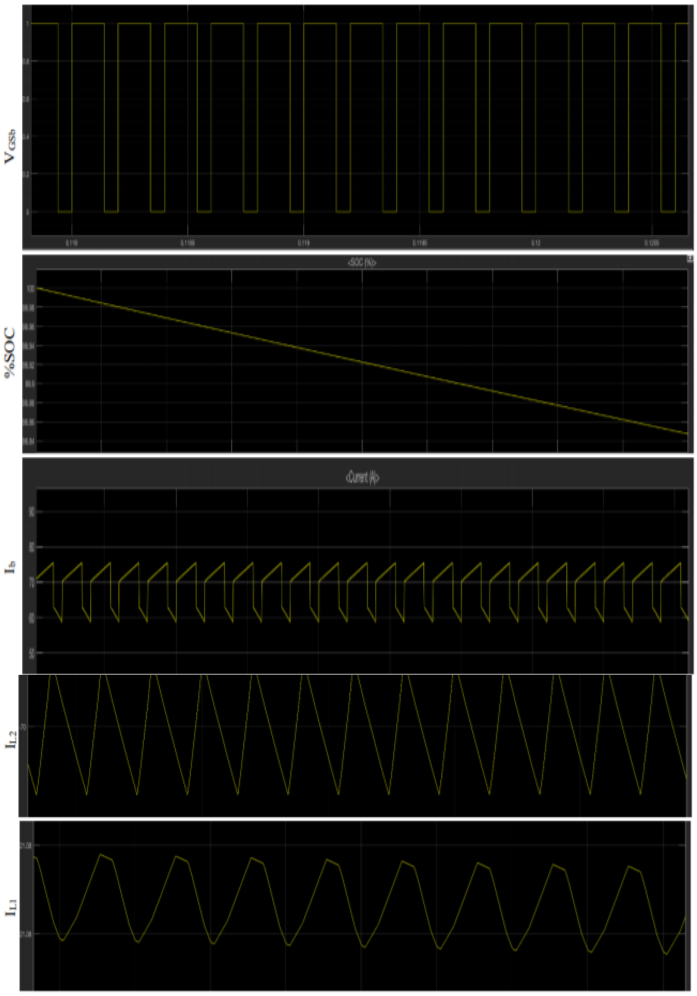

Fig. 2.8 Waveforms

From %SOC waveform and Ib waveform it can be seen that state of charge of battery is gradually decreasing over time and battery current is positive. HENCE battery is discharging. From IL1(current across secondary inductor) waveform it is clear that power is supplied to load from battery.

3 Components Design

Following design is based on the following parameters:

$$V_0 = 40 \text{ volt}$$

$$V_{pv} = 12 \text{ volt}$$

$$V_b = 12 \text{ volt}$$

Duty Cycle:

$$d_1 = V_b / (V_b + V_{pv}) = 12 / (12 + 12)$$

$$d_1 = 0.5$$

Coupled Inductor:

$$V_1 = V_{pv} / (1 - d_1) = 12 / (1 - 0.5)$$

$$V_1 = 24V$$

$$V_2 = V_0 - V_1 = 40 - 24$$

$$V_2 = 16V$$

Coupled inductor turns ratio can be calculated by

$$Ns / Np = (d_2 * V_2) / (d1 * V_{pv})$$

$$= (0.5 * 16) / (0.5 * 12) = 1.33$$

$$L_p / L_s = (N_p / N_s)^2$$

By using above equation and substituting the inductor turns ratio, the primary inductor should be half times the value of the secondary inductor.

3.1 Components

Component	Model/Value
Digital Controller	PIC16F73
MOSFET	IRFZ44
Transistor	BC547
N_p/N_s	3/4
L_p	1mH
L_s	1mH
C_1	10µF
C_2	10µF
C_{pv}	10µF
Resistors	10KΩ

4.0 Result

Initially, to verify the viability of the suggested converter, it was first simulated using MATLAB Simulink software.
To check the functioning and evaluate the performance, a 50-Watt hardware prototype is made and tested. Two modes namely Solar Load Mode and Battery Load Mode have been implemented in hardware prototype. Primary input source is a 12V solar module. A 12V battery is used to store unused

power which is connected to the bi directional port. A low power LED is connected to output port. The value of output voltage measured across output port in Solar Load Mode and Battery Load Mode was around 32 volts.

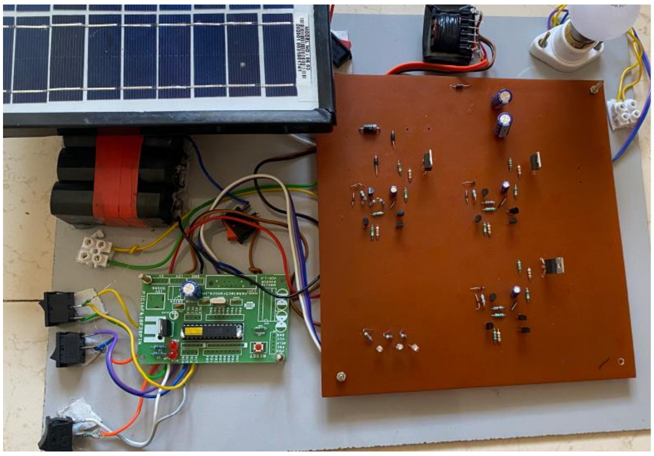

Fig. 4.1 Hardware Prototype

5.0 Conclusion

For free-standing power applications like direct current motor & Light Emitting Diode driver, a new multi-port converter is suggested and it's working is confirmed experimentally through above shown hardware implementation.

This multi-port converter can be used to combine a battery with a solar module. This suggested converter is very simple to control. The efficiency of this converter varies in range of 75 to 85 %.

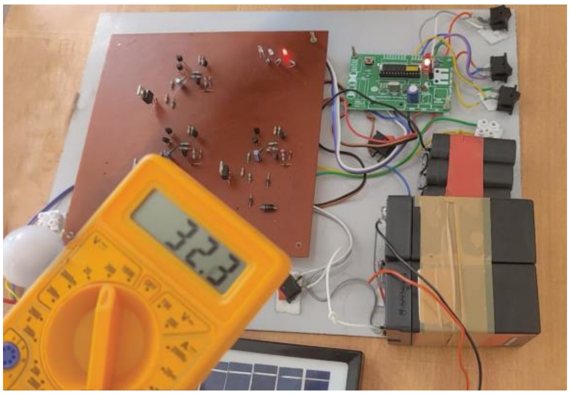

Fig. 4.2 Hardware Prototype with output voltage

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