IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)
e-ISSN: 2278-1676,p-ISSN: 2320-3331, Volume 11, Issue 3 Ver. IV (May. – Jun. 2016), PP 85-93
www.iosrjournals.org

Dual Input Single Stage Sine –Wave Inverter Based Stand Alone Solar Supply Scheme for Rural Development

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Abstract: *This paper proposes a high performance dual input single stage inverter topology for the autonomous operation of a solar photovoltaic system. In remote areas mainly in hill stations, the electric pole cannot be inserted which makes the electrification too difficult. In order to rectify the problem of electrification in such areas, we have to implement solar power plant. The main aim of this paper is to evolve the promising solution to provide electricity where grid is not available. The proposed configuration which can boost the low voltage of photovoltaic (PV) array, can also convert the solar dc power into high quality ac power for driving autonomous loads without any filter and protection of over charge and discharge of battery. An MPPT circuit with parallel connection is implemented so that the part of the energy generated is processed by the dc–dc converter to supply dc loads. This topology has several desirable features such as low cost and compact size as number of switches used, are limited to four compared to classical two-stage inverters without transformer . In this paper analysis, simulation and experimental results are presented.*
Keywords: *Maximum power point tracking (MPPT), photo voltaic, Renewable energy sources(RESs)*

I. Introduction

In recent years the solar photovoltaic (PV) has become one of the most promising method among the available RESs.300 million Indians reside in rural areas they do not have electricity. To change this in availability of electricity in rural areas many initiatives have been taken and majority of them are focused towards renewable energy source(RESs).PV based stand-alone systems need an energy storage element which is generally realized by utilizing a battery bank.

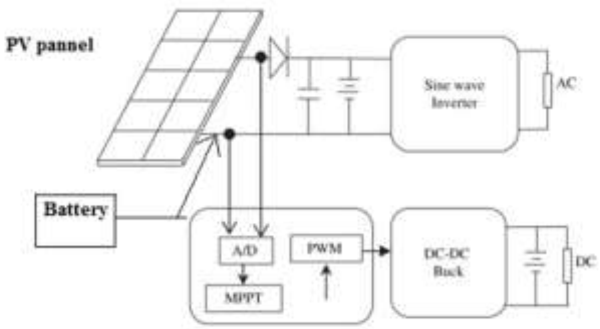

Fig.1 Solar PV system with MPPT connection

All these pv system require power electronic converters to form an interface between the pv array ,the battery and the load. In General, PV connected solar system power circuit mainly consists of a boost DC/DC converter unit and DC/AC buck inverter unit as shown in Figure.1. But the rms output voltage of buck converter is lower than the input dc voltage. This leads to increase in size of output transformer [6]. As a consequence, when an output voltage larger than the input is needed, a boost dc–dc converter must be used between the dc source and inverter as shown in Figure 2.

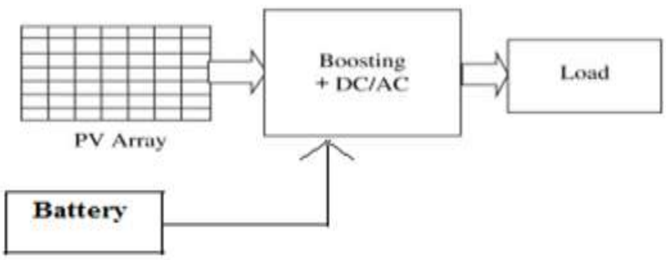

Fig.2 Proposed PV system with boost inverter

In view of the ongoing discussion, it is reasonable to conclude that the best option is to have only a dual power electronic stage between the PV array and the load to achieve all the functions namely the boosting and inversion leading to a compact system [7]. This paper proposes a new dual input and single stage boost convert using Sinusoidal Pulse Width Modulation (SPWM) technique and MPPT algorithm, suitable for PV fed stand alone applications in remote areas where the electrification is not possible . The proposed voltage source boost inverter naturally generates rms output ac voltage lower or higher than the input dc voltage with reduced number of components, depending on the duty cycle produced by Sinusoidal Pulse Width Modulation (SPWM).

II. Proposed Topology and Operational Principle

2.1. Introduction

The proposed boost dc-dc converter gives an output voltage that is always higher than the input voltage. The output voltage level of the PV pannel is very low ,that voltage is further enhanced by this proposed boost converter [18].In this paper boost voltage source inverter generates an ac output voltage which can be made lower or higher than given input voltage from solar array and battery ,by varying the duty cycle based on MPPT and SPWM. In this proposed boost inverter the load is connected different manner between two dc-dc converter and modulating the dc-dc converter output voltage sinusoidal. The two converters P and Q produce a dc biased sine-wave output, although each source produce only a unidirectional voltage .Modulation technology produce 180° out of phase with the other which only boost the voltage across the load as shown in Figure 3.The dc bias appears at each end of the load with respect to ground the differential dc voltage appear across is zero. The push pull arrangement gives a bipolar voltage at output.

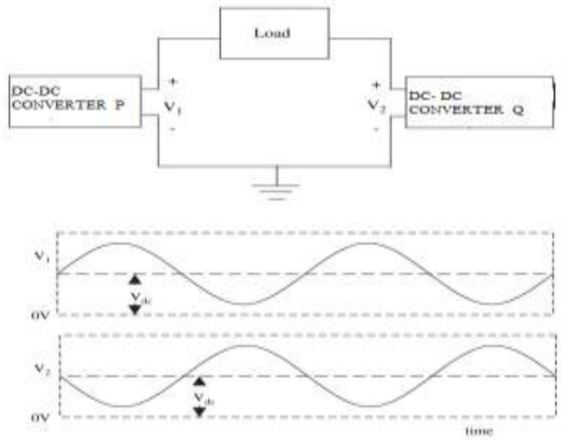

Fig.3 DC-DC convention with boost characteristics

2.2. Principle of operation of DC-DC boost converter

Boost DC-DC converter output is designed to 350V dc to generate an ac voltage of 230V .A stand alone system is designed with low voltage levels for the PV array and the battery in the range of 24-36V.

Mode1: S1 OFF, S2 ON

Figure 4 shows the operative circuit during the period ‘ D T_S’ of a Switching period. The inductor current flows from the input source to energize the inductor.

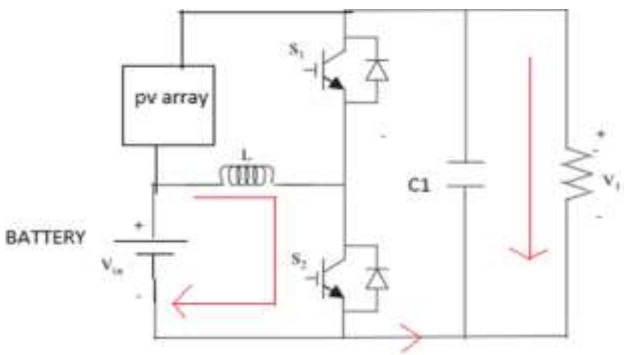

Fig.4 Converter Mode of Operation1

Mode2: S1 ON, S2 OFF

Figure 5 shows the operative circuit during the period$(1-D)T_S$ of the switching period. The inductor current cannot change instantaneously, inductor current starts to decreases. This negative inductor current develops sufficient voltage L*di/dt with a polarity such as to drive the inductor current through S_1 to charge the output capacitorC_1.

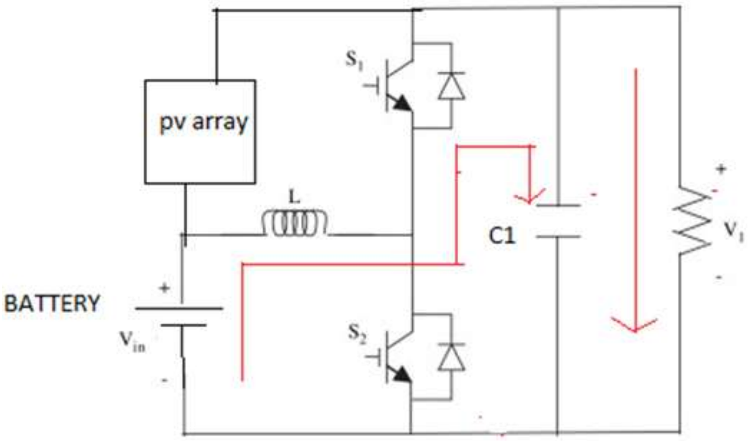

Fig.5 converter mode of operation2

Boost Inverter:

When switch S_2 is closed and S_1 is open, current i_L rises quite linearly, diode D_1 is reverse polarized, capacitor C supplies energy to the output stage, and voltage V_1 decreases. Once the switch S_2 is open and S_1 is closed, the current i_L flows through capacitor C and the output stage. The current i_L decreases while capacitor C recharges. This is repeated for the consecutive switching periods to generate a capacitor voltage shown in Fig. 6. The 180° phase shift can be achieved by triggering the diametrical switches simultaneously.

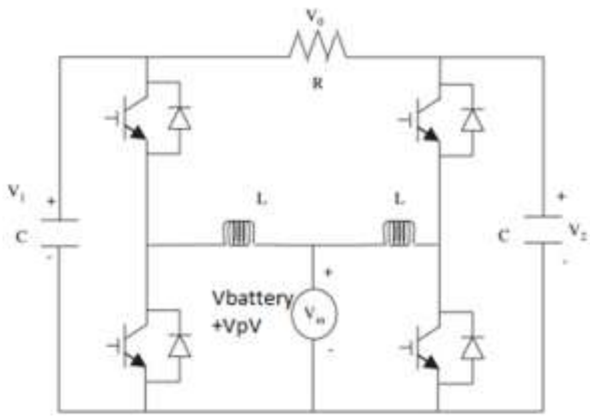

Fig.6. Boost inverter used in the proposed scheme

2.3. Expressions

From Figure 4 the voltage across the inductor "L" can be expressed as $V_L=V_{PV}$ when S_1 is ON

$V_L=-V_{BATTERY}$ when S_2 is ON (1)

Consider average voltage drop across the inductor is $V_L=D*V_{PV}-(1-D)*V_{BATTERY}$ (2)

Where "D " is the duty ratio of the switch S_1 .Equating the average voltage drop across the inductor to zero.

$0=DV_{PV}-(1-D)*V_{BATTERY}$

$D*V_{PV}=(1-D)*V_{BATTERY}$

$V_{PV}=((1-D)/D)*V_{BATTERY}$ (3)

From (3) it can be concluded that PV voltage V_{PV} can be controlled by changing "D" as battery voltage assumed to be a constant. Using MPPT operation change in "D" can be carried out.

2.4. Design of Passive Components

Inductor value

The value of inductor L is calculated on the basis of the amount of current ripple(Δi_L)

$L=Vi*D/(\Delta I_L*F_S)$.In this prototype "L" used is of 3mH.

Capacitor value

In boost converter the capacitor has to handle a large swing in the current through it.
$C=I_O*D/(\Delta V_O*Fs)$.In this prototype "C" used is 1000µF.

III. Control Structure

The fundamental principle behind the stand alone system required to perform the following works. 1,maximum power extraction from pv panel using MPPT algorithm 2, To have control over the battery usage by limiting charge 3,DC-DC Boost convention .In order to achieve the three tasks MPPT control loop is required to operate in four modes.

1. Control Action 1(Mode1):

When the availability of PV power is more at that time MPPT mode of operation is selected.In this case MPPT algorithm block generate reference voltage V_{refpv} of 350-460Vdc.However to achieve this voltage the two conditions must be satisfied in MPPT mode. They are 1,$P_{maxpv}>P_{load}$ and battery should have the capacity to consume surplus power without being overcharged. 2,$P_{maxpv}< P_{load}$ and batter should supply $P_{load} - P_{maxpv}$ without being over discharge. Where P_{maxpv} is the addition of battery power and load power.

2. Control Action2 (Mode2):

This mode depends on the state of charge(SOC) level of battery. In order to operate in this mode the maximum permissible limit of battery $I_{batterymax}$ should be maintained to prevent damage due to overcharge. The maximum battery power can be calculated as $P_{batterymax}=I_{batterymax}*V_{battery}$.The condition in which this mode cannot be operated is $P_{max\ pv}> P_{load}$ that is excess power from solar panel is more than battery capacity in this stage. The main task of this mode is to reduce the power extraction from PV a value given by $P_{maxpv}=P_{battery}+P_{load}$. This mode of operation is called as NON-MPPT mode .From control action 1 V_{pvref} is generated the error between V_{pvref} and V_{pv} which is passed through a PI controller to generate inductor current reference. The upper limit and lower limit of current to prevent overcharging and over discharging the battery are as follows. $I_{lmax}=I_{batterymax}+I_{pv}$ and $I_{lmin}=I_{batterymin}+I_{pv}$.

3. Control Action3 (Mode3):

If there is no sunlight (rain ,cloud) the system operates in battery operating mode.The current reference generated from control block2.When this reference current I_{LREF} lies within the derived limit ,the system will operates in MPPT mode $I_{PV}>0$ or in battery operating mode $I_{PV}< 0$.

4. Control Action4 (MODE4):

The situation when maximum power extracted from PV array less than load demand the system will operate in this mode. $P_{maxpv}< P_{load}$ and in such situation battery does not have the capacity to supply $P_{load} - P_{maxpv}$, so system need to be shutdown to prevent damage of battery. When the inductor current reaches minimum limit, thereby indicating over discharge limit is reached control block3 remove all the gate pulses from IGBT switches through control algorithm and shutdown the system[1],[9],12].

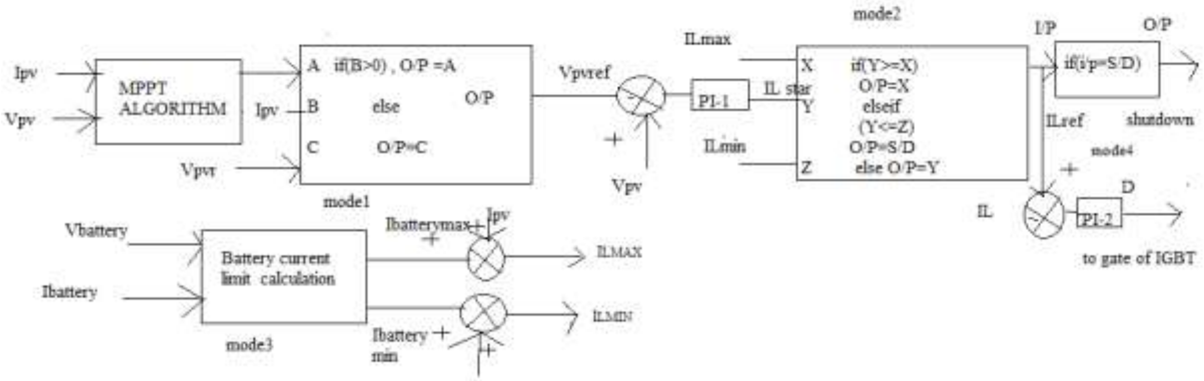

Fig.7 control structure for the proposed system

IV. Simulation

4.1. Basic Simulation Block Diagram.

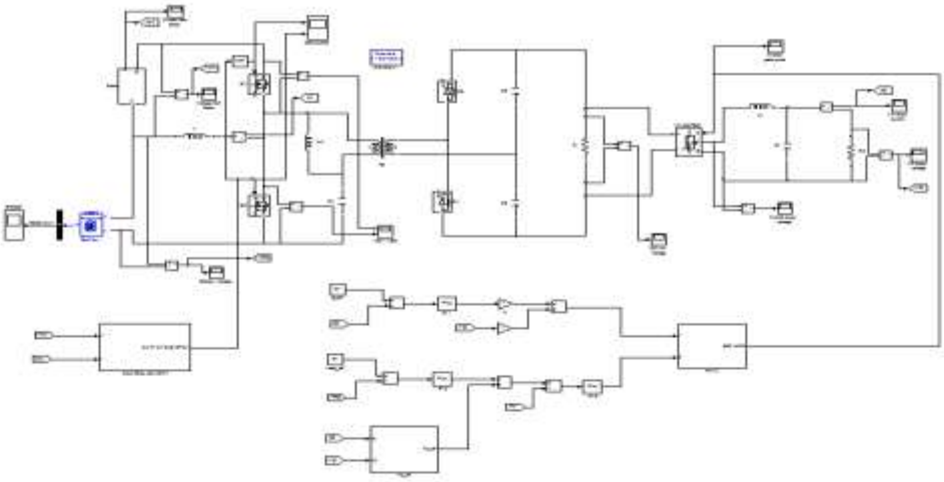

Fig.8 simulation diagram

Fig.8 shows the simulation diagram of our project. Both solar array and battery will provide power to the load. Solar array consists of five solar panels connected in series. Input from both the sources is DC. Conveter (S1 and S2) converts input DC into AC. Boost converter enhances the voltage level. In order to correct the frequency it is again converted into DC by the voltage doubler. Diodes D3, D4 and Capacitors C2, C3 constitutes as a voltage doubler. The ouput of the converter is given to the inverter which converts DC into single phase, 50Hz Ac. The harmonics in the inverter output voltage can be reduced by passing into LC filter. Then the harmonic free voltage is supplied to the load.

4.2. Proposed Algorithm

Fig.9 shows the simulation diagram for MPPT algorithm using Incremental Condutance method. The Incremental conductance method can determine that the MPPT has reached the Maximum Power Point and stop perturbing at the operating point. If this condition is not met, the direction in which the MPPT operating point must be perturbed can be calculated using the relationship between Di/Dv and –I/V. This relationship is derived from the fact that Dp/Dv is negative when the MPPT is to the right of the MPP and positive when it is to the left of the MPP. This algorithm has advantages over P&O such that it can determine when the MPPT has reached the Maximum Power Point, where P&O oscillates around the MPP. Also, Incremental Conductance Method can track the rapidly increasing and decreasing irradiance conditions with higher accuracy[12].

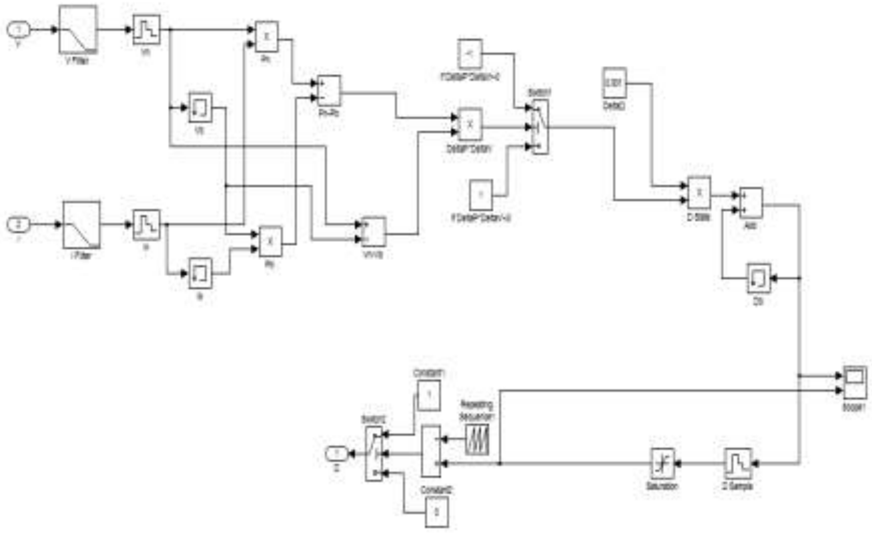

Fig.9 Simulation Diagram of MPPT

4.3. Simulation Results

4.3.1. Voltage from Solar Array

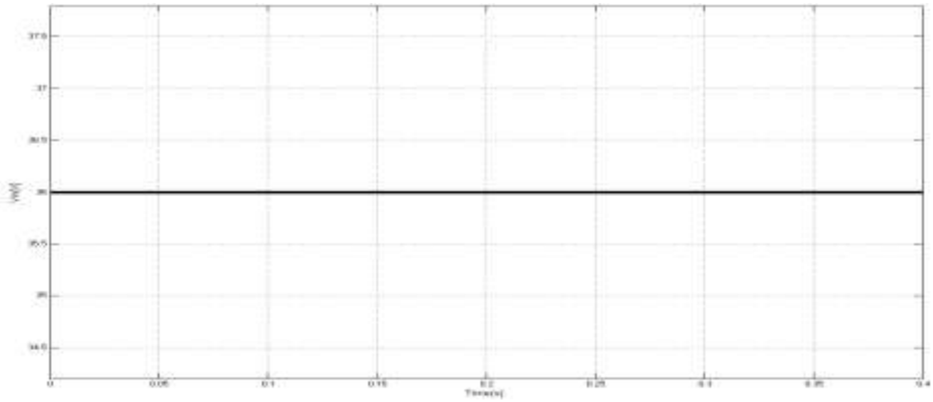

Fig.10 voltage from Solar Array

Fig.10 shows the input voltage waveform from the solar array. Input voltage from the solar array is DC. In this simulation input voltage level is 36V.

4.3.2Current from Solar Array

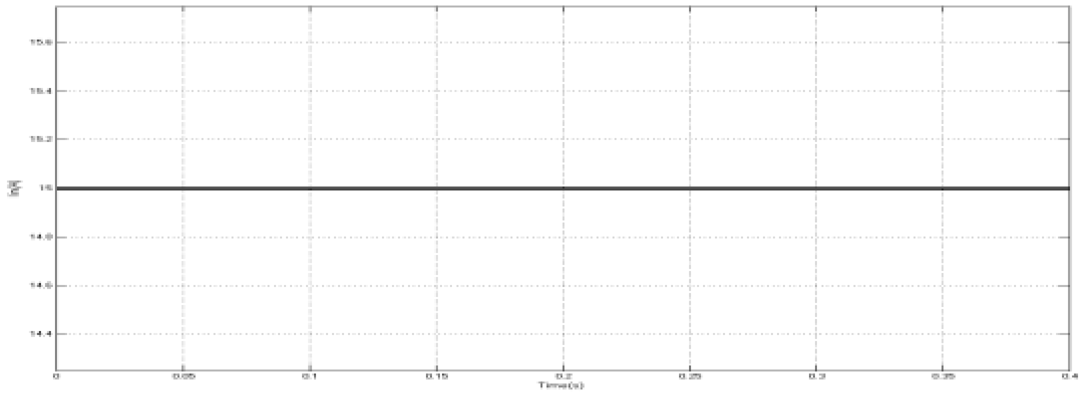

Fig.11 Current from Solar Array

Fig.11 shows the input current from the solar array. The generated current depends on the insulation level, irradiation, age of solar cell, characteristic of material. In this simulation the input current is 15 A.

4.3.3 Voltage from Battery

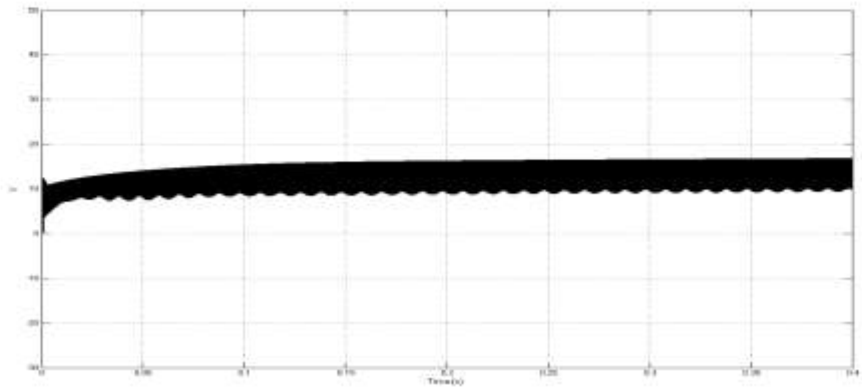

Fig.12 Voltage from Battery

Fig.12 shows the voltage stored in the battery. When generated solar power is more than the load demand, the surplus power is stored in the battery.

4.3.4 DC Link Voltage

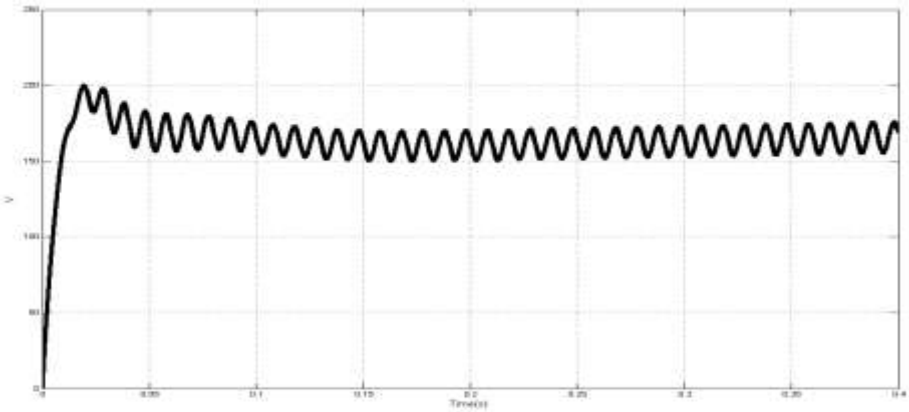

Fig.13 DC link voltage

Fig.13 shows the waveform of DC link voltage which is measured across the capacitor. The Dc link voltage should be maintained within the desired range of 350-460V.

4.3.5 Inverter Gate Pulses

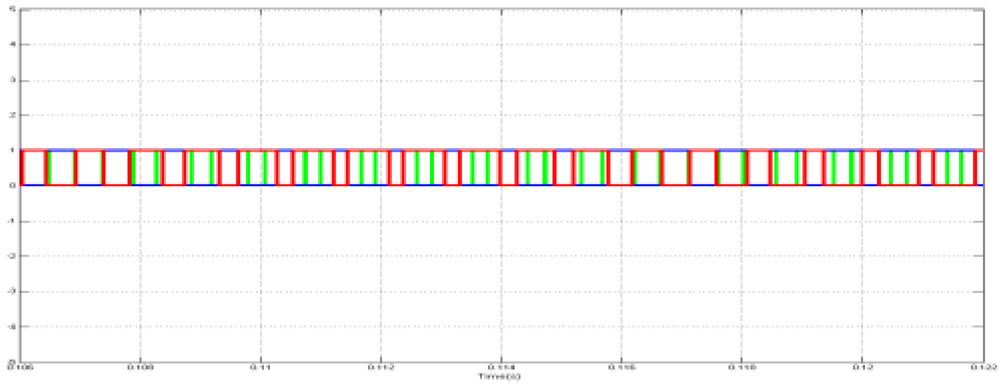

Fig.14 Inverter gate pulses

Fig.14 shows the gate pulses given to the switches in the inverter. As Inverter is kept as a single block, the gate pulses are also shown in single graph.

4.3.6 Inverter Output Voltage

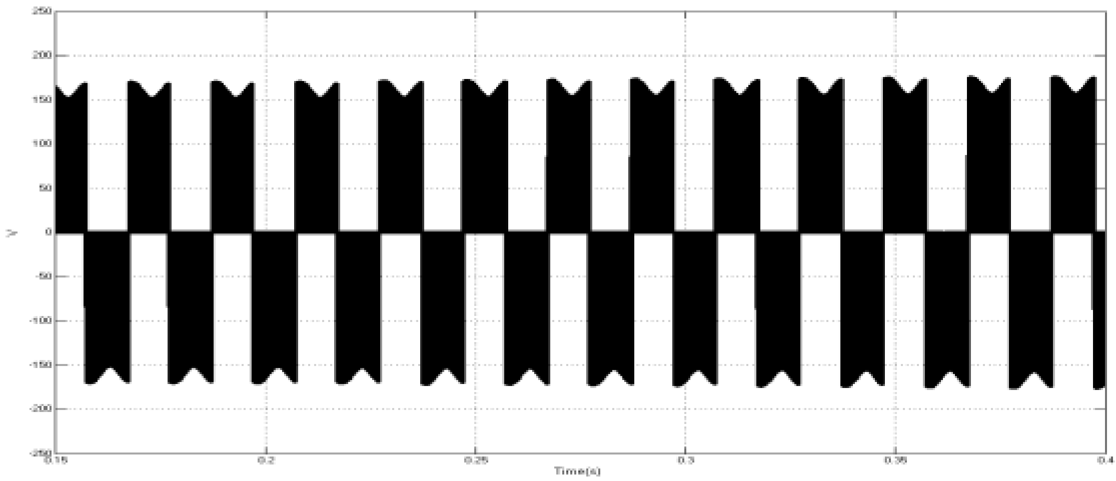

Fig.15 Inverter Output Voltage

The DC link voltage which is measured across the capacitor is given to the inverter circuit is shown in Fig.15 Inverter converts DC voltage into AC voltage.

4.3.7 Output voltage

Fig.16 shows the output voltage waveform which is measured across the load. Inverter output voltage contains some harmonics. To eliminate this harmonics, inverter output voltage is sent through the LC filter, and then output voltage is measured. The output voltage level is 230V.

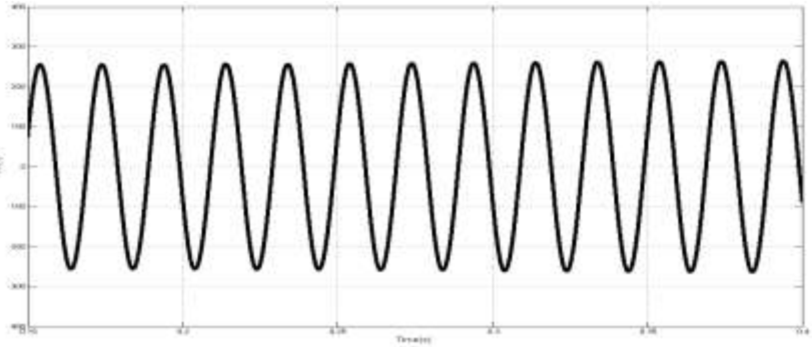

Fig.16 Output voltage

4.3.8 Output current

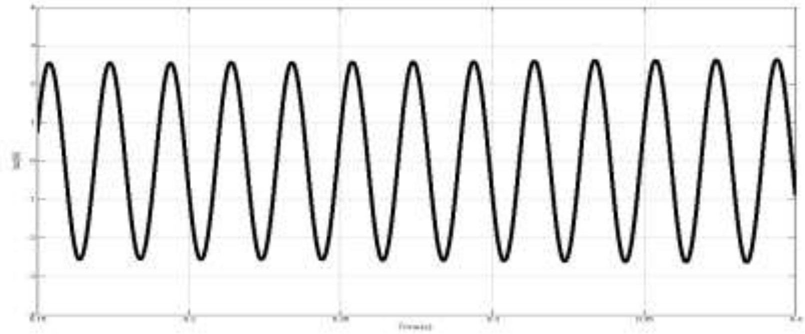

Fig.17 Output current

Fig.17 shows the output current waveform measured at the load.

V. Experimental Verification

The behavior of dual input single stage boost converter based stand alone power supply system described in this paper has been validated using a prototype. The controller of the prototype is implemented using the MICOCONTROLLER PIC16F876A.For an input voltage of 36Vdc output of 94Vdc as well as 64V(ac) rms have been obtained for a duty cycle of 0.4 and modulation index of 0.5 in sinusoidal pulse width modulation**.** Figure 18. shows the photograph of the experimental setup. Table 5.1gives experimental result.

Fig.18 Photograph of the experimental setup

These are the readings taken from the hardware circuit.It shows how the output voltage changes as the insolation level changes.

Table5.1 Output voltage at different time

Sl.no.	Time	Output Voltage (V)
1	10:00 am	64
2	12:00 pm	65
3	1:00 pm	69
4	2:00 pm	70
5	4:00 pm	65

VI. Conclusion

A dual input single stage solar PV-based stand-alone scheme for application in rural areas is proposed in this paper. It is realized by involving a new single stage boost converter. The salient features of the proposed scheme include the following: 1) boosting of the dc voltage are accomplished in a single converter; 2) requirement of dedicated converter for ensuring MPP operation of the PV array is eliminated leading to enhanced utilization of power converters; 3) enhancement in battery charging efficiency as a single converter is present in the battery charging path; 4) lesser component count as only two power conversion stages are required. The efficacy of the scheme is verified by performing detailed simulation studies. The viability of the scheme is confirmed through detailed experimental studies for different time.

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