Simulation & Implementation Of Stand-Alone Photovoltaic Generation System

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Abstract

This paper proposes an implementation of single ended primary inductor converter (SEPIC) converter and an inverter using photovoltaic energy. This system is a two stage system where it has a DC-DC converter and an inverter as interface circuits. In order to match up with the load to the photovoltaic modules, the DC-DC converter with maximum power point tracking (MPPT) system is necessary. The MPPT system tracks the maximum power obtained in the PV panel, so that power output increases. The MPPT system used is the Perturb and Observe algorithm. The boosted output voltage is converted to AC voltage by using the inverter. The simulation works of the SEPIC converter and the inverter have been carried out using the MATLAB software. The AC voltage is obtained using a single phase full bridge inverter is implemented on it to attain sufficient voltage to drive the load.

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1. Introduction

The ever increasing demand for power and cost of energy, persistent climatic changes, global warming etc. are necessitating satisfactory power quality to save energy and reduce carbon emission.

In order to meet the increasing demand for energy, the trend is to shift to distributed generating system for encouraging greater use of renewable sources, like Solar and Wind Energy. According to different irradiations, the output power of a PV module is substantially changed. In general, PV modules have nonlinear voltage-current characteristics, and there is only one unique operating point for a PV generation system with a maximum output power under a particular environmental condition. However, the P&O method, which measures the variations of power and voltage to judge the momentary region and change the reference voltage for operating close to the maximum power point, is often used because of its simple structure and fewer measured parameters point varies with irradiation and temperature, so that the maximum power point tracking (MPPT) at all atmospheric situations is a challenging problem. In general, an earth parasitic capacitance will be generated between solar modules and their ground. This capacitance is about 50-150nF/KW for a glass- faced solar cell array. This capacitance is increased to 1 µF/KW, if a thin film cell array is used. Thus serious leakage current occurs if a high frequency pulsating voltage is applied between the modules and the ground. This project investigates in detail the concept of Maximum Power Point Tracking (MPPT) which significantly increases the efficiency of the solar photovoltaic system.

2. System Configuration

The proposed photovoltaic generation system consists of a Solar Panel, DC-DC power converter, battery, inverter and the resistive load. The system is tested under standard test conditions of 25ºC and average insolation of 1000Watt/m².The PV module parameters considered are open circuit voltage(Voc),short circuit current (Isc) and rated voltage.

2.1. PV Module Characteristics

In a single diode model, there is a current source parallel to a diode. The current source represents light-generated current, which varies linearly with solar irradiation. This is the simplest and most widely used model as it offers a good compromise between simplicity and accuracy.

The characteristic equation for the solar cell is given by,

$$I = Iph - Is\exp\left[q\left(\frac{V+IRs}{KToA}\right)-1\right]-\frac{V+IRs}{Rsh}$$

Where, Iph = light-generated current or photo current, Is = cell saturation of dark current, q = 1.6 x10-9C is an electron charge, k = 1.38x10-23J/K is a Boltzmann's constant, Tc= cell's working temperature, A = ideal factor, Rsh = shunt resistance, and Rs = series resistance

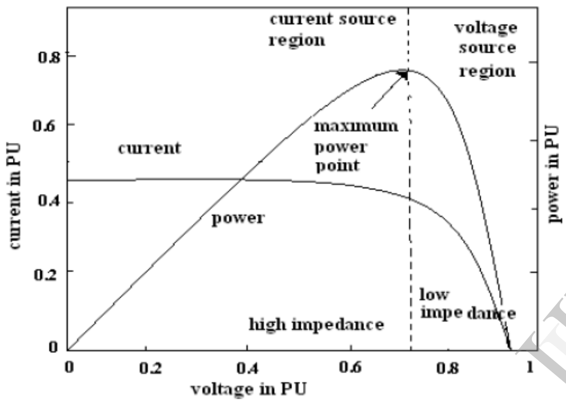

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Figure 1. PV Module IV and PV Characteristics

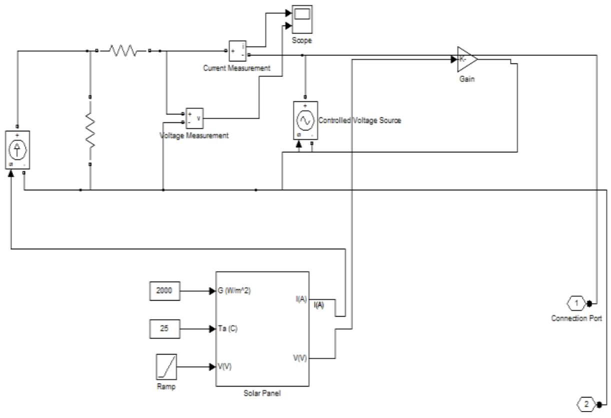

Figure 2. PV Panel Subsystem Model

As seen in the power versus voltage curve of the module there is a single maximum of power. That is there exists a peak power corresponding to a particular voltage and current. Since the module efficiency is low it is desirable to operate the module at the peak power point so that the maximum power can be delivered to the load under varying temperature and insolation conditions. Hence maximization of power improves the utilization of the solar PV module. A maximum power point tracker (MPPT) is used for extracting the maximum power from the solar PV module and transfers it to the load.

2.2. DC-DC converter with MPPT Technique

The important requirement of any DC–DC converter used in the MPPT scheme is that it should have a low input-current ripple. Buck converters will produce ripples on the PV module side currents and thus require a larger value of input capacitance on the module side. On the other hand, boost converters will present low ripple on the PV module side, but the load current exhibits more ripple and gives a voltage higher than the array voltage to the loads. The buck– boost converters can be used where the requirement of load voltage, either low or higher than the array voltage. However, with this converter the input and load currents are pulsating in nature. Furthermore, the load voltage will be inverted with buck–boost or CUK converters. Under these conditions, the SEPIC converter, provide the buck–boost conversion function without polarity reversal, in addition to the low ripple current on the source and load sides.

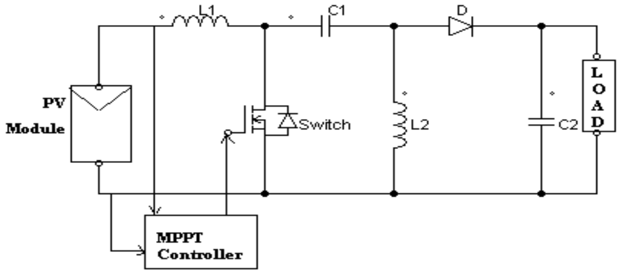

Figure 3. Sepic converter topology with PV and MPPT

L1 is the input inductance, L2 is the output inductance, C1 is the energy transfer capacitor, C2 is the output capacitor, Vin is the input voltage, Vo is the output voltage, VC1 is the voltage across capacitor C1, IL1 is the current though L1 and IL2 is the current through L2.The operation of Sepic can be described as,

1) When the switch is turned on, the input inductor is charged from the source, and the second inductor is charged from the first capacitor. No energy is supplied to the load capacitor during this time.

2) When the switch is turned off, the first inductor charges the capacitor C1 and also provides current to the load. The second inductor is also connected to the load during this time.

2.3. MPPT Control Algorithm

Maximum Power Point Tracking, frequently referred to as MPPT, is an electronic system that operates the Photovoltaic (PV) modules in a manner that allows the modules to produce all the power they are capable of. MPPT is not a mechanical tracking system that “physically moves” the modules to make them point more directly at the sun. MPPT is a fully electronic system that varies the electrical operating point of the modules so that the modules are able to deliver maximum available power. Additional power harvested from the modules is then made available as increased battery charge current. The MPPT algorithm used in this proposed system is the Perturb and Observe method. The most commonly used MPPT algorithm is the P&O due to its simplicity of implementation. Fig. 5 shows the algorithm of P&O.

P&O algorithm is based on the calculation of the PV array output power and the power change by sensing both the PV current and voltage. The controller operates periodically by comparing the present value of the power output with the previous value to determine the change on the solar array voltage or current. The algorithm reads the value of current and voltage at the output solar PV module. Power is calculated from the measured voltage and current. The magnitude of voltage and power at kth instant are stored. Then the magnitude of power and voltage at (k+1)th instant are measured again and power is calculated from the measured values.

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If the magnitude of power is increasing, the perturbation will continue in the same direction in the next cycle, otherwise the perturbation direction is reversed. When the MPP is reached, the system then oscillates around the MPP. In order to minimize the oscillation, the perturbation step size should be reduced such that when the operating point is away from the MPP, the step change in duty cycle should be large, when it nears the MPP, the step change in‘α’ should reduce.

2.3. H-Bridge Inverter

Single-phase converters are used where transformation between dc and ac voltage is required; more precisely where converters transfer power back and forth between dc and ac. The single-phase full-bridge converter shows the basic circuit topology. AC output voltage is created by switching the full-bridge in an appropriate sequence. The output voltage of the bridge, Vac, can be either +Vdc, -Vdc or 0 depending on how the switches are controlled. For switching of the switches in the simulation SPWM pulses are used. SPWM or sinusoidal pulse width modulation is widely used in power electronics to digitize the power so that a sequence of voltage pulses can be generated by the on and off of the power switches. Sinusoidal pulse width modulation or SPWM is the most common method in motor control and inverter application. Conventionally, to generate the signal, triangle wave as a carrier signal is compared with the sinusoidal wave, whose frequency is the desired frequency. The PWM signal is high when the magnitude of sinusoidal wave is higher than the triangular wave otherwise it is low.

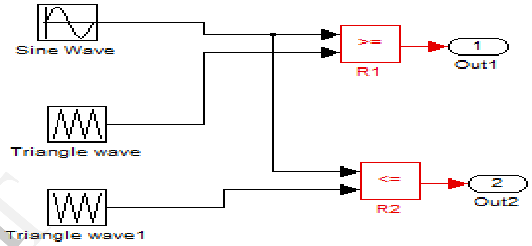

Figure 4. SPWM Generation

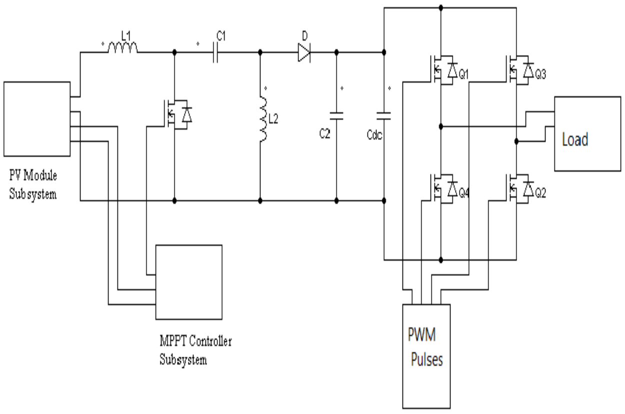

Figure .5. Simulation Model of Sepic Converter and Inverter

3. Hardware Description

The control experiment has been performed using a solar panel with a rated output power of 5W.The solar panel is given as a power supply unit. In both the SEPIC converter and the inverter circuits the selected switch is MOSFET.

The control circuit which has the PIC microcontroller unit and driver circuit unit necessitates the power supply circuit module. The PIC microcontroller is given 5V dc as its supply and the driver circuit requires both 5V and 12V dc supply. So it is necessary to construct a power supply circuit module which produces both 5V and 12V dc output. The circuit uses two ICs 7812(IC1) and 7805 (IC2) for obtaining the required voltages.

The main device of controller circuit is a PIC 16F887A microcontroller and the coding for pulse generation is programmed and flash into the microcontroller. The microcontroller is operated at 4MHz clock frequency. The pin diagram of PIC 16F887A microcontroller and the various features of this microcontroller are referred in PIC16F88XA datasheet. Port B of this controller is assigned as output port. Pin no 13 and 14 are connected with the crystal oscillator of 4 MHZ frequency. Pin 1 is connected with the reset switch through the 1K resistor. Pin 32 is given with 5V dc supply and 31 is connected with the ground.

Power circuit of the hardware prototype consists of two circuits such as SEPIC converter and voltage source inverter. Here it is designed to boost the input dc voltage of 12-15V into 24V. The voltage source inverter converts the boosted DC voltage from the SEPIC converter into AC voltage.

The driver circuit used to drive the MOSFET switch of the SEPIC and inverter is constructed with the IR2110 driver IC. The IR2110 IC is a 14 pin IC. The pins 1 and 7 are the output pins and pins 10 and 12 are receiving the pulses from the microcontroller of amplitude 5V.

The switch used in the SEPIC converter circuit is IRF840 MOSFET. The inductor L1 and L2 are having the values of 200mH and is constructed as coupled inductor. Capacitor values are C_1=1000 μF and C_2 = 470 μF. The boosted DC voltage of the SEPIC converter is fed to the single phase voltage source inverter through the DC link capacitor. The DC link capacitor is used to maintain the constant DC voltage in the input side of the inverter.

Table 1. Sepic converter design specification

Parameter	Value
Input Voltage	12V
Output Voltage	24V
Switching Frequency	20KHz

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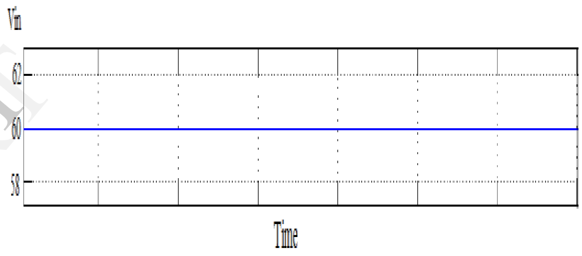
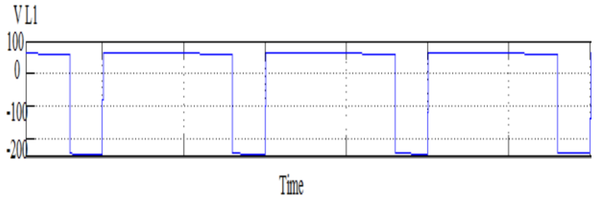
4. Results And Discussion

4.1. Simulation Results

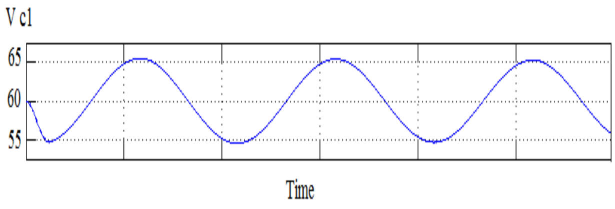
The simulation of SEPIC converter and single phase full bridge inverter is done in MATLAB/SIMULINK software. For the purpose of the simulation, constant irradiance and temperature is considered for the PV module. Figure 6 shows the SEPIC converter output waveforms from the simulation model. It has the boosted DC voltage of PV module. When the pulses of Q1 switch are in on period (high) the pulses for lower leg switch Q4 are in the off period (low). When Q1 pulses are high we can get the output voltage in the positive half cycle and when the Q4 pulses are high the output voltage will have negative half cycle. Figure 7 and 8 shows the simulation results of SPWM technique pulses, the inverter output voltage waveforms before and after filtering.



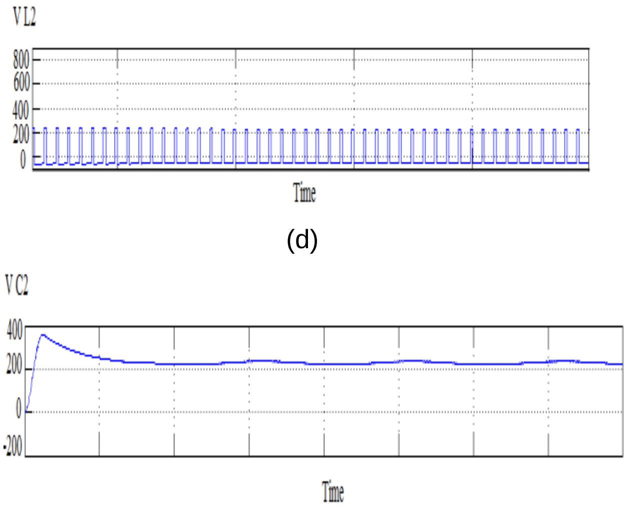
(a)



(b)



(c)



(d)

(e)

Figure . 6. Simulation Results of Sepic Converter. (a) voltage across input, (b) voltage across the inductor l1 , (c) voltage across the capacitor c1,(d) voltage across the inductor l2, (e) voltage across the capacitor c2

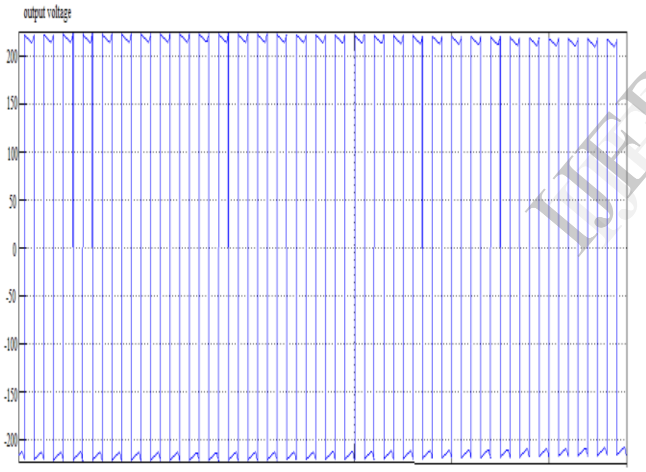


Figure .7. Simulation Result of Inverter Before Filtering

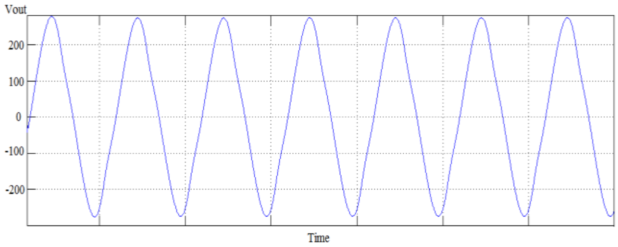


Figure .8. Simulation Result of Inverter After Filtering

4.2. Hardware Results

The input voltage of the hardware prototype is the 12V DC input of the SEPIC converter. This 12V DC is boosted up to 24V DC using the SEPIC converter is shown in figure 9 and 10. The controller output pulse waveform is shown in the figure 11. The boosted DC output voltage is converted to AC voltage using the inverter is shown in figure 13.The load on the output of the inverter is the resistive load.

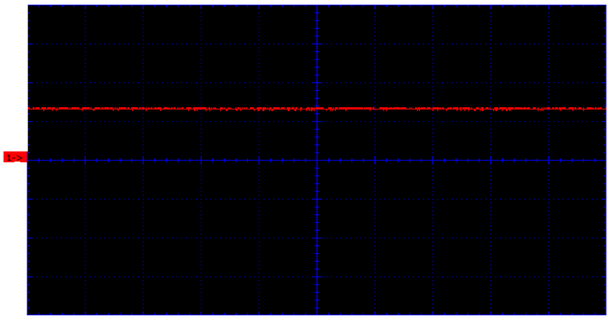


Figure . 9. Input Voltage Waveform

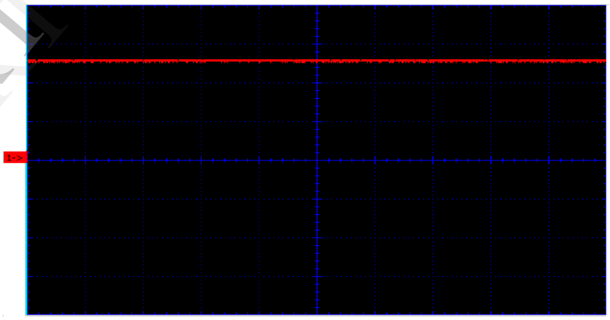


Figure . 10. SEPIC converter output Voltage Waveform

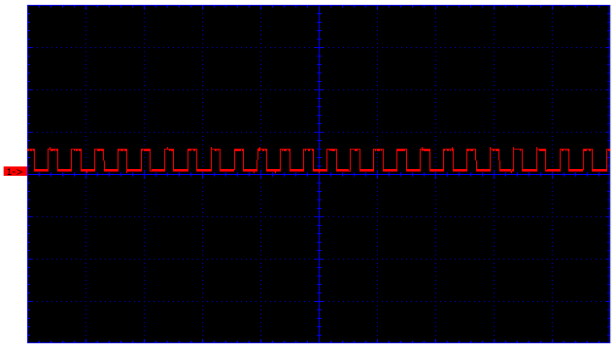


Figure . 11. Pulse output from the controller circuit

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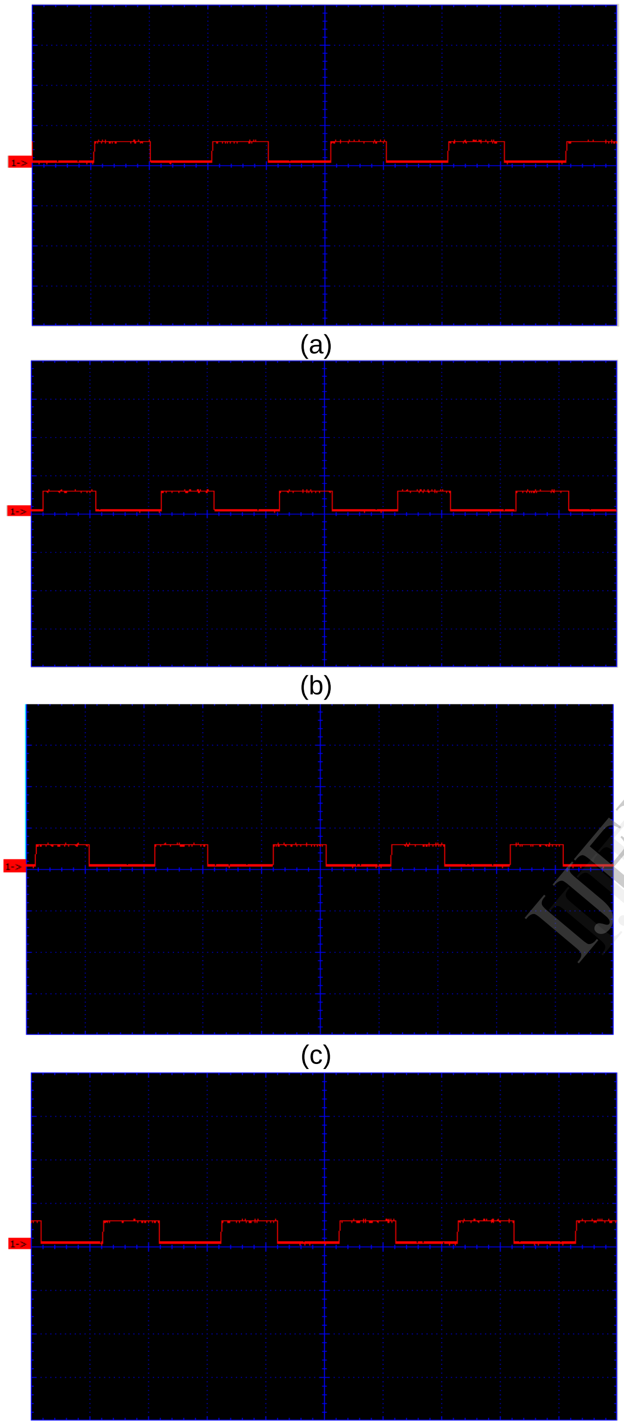

(a)

(b)

(c)

(d)

Figure. 12. Driver circuit output waveforms
(a) Pulses of switch Q1, (b) Pulses of switch Q2 , (c) Pulses of switch Q3 , (d) Pulses of switch Q4.

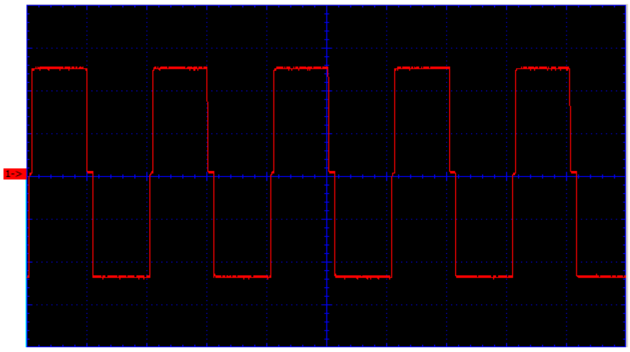

Figure. 13. Inverter Output Voltage Waveform

5. Conclusion

The paper proposes the stand-alone photovoltaic generation system in which the boost converter is replaced with the SEPIC converter for which the DC voltage from the solar panel can be buck or boosted up to the voltage which is then inverted and are connected to a resistive load. This uses the MPPT technique for the maximum tracking of power. This system can be developed for the future in ordered to improve the overall system efficiency.

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6. References

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