Solar Based Constant Frequency Harmonic Free Power Generation without Battery Backup

Vinayak M P
Department of Electrical and Electronics, NSS College of Engineering, Palakkad, Kerala, India.

Dr. E G.Janardanan
Professor, Department of Electrical and Electronics, NSS College of Engineering, Palakkad, Kerala, India.

Abstract – In today`s world, energy is required for a variety of fields. The availability and acceptability of sufficient amount of energy accelerate individual's and nation's development. Energy supply should be secure and sustainable at the same time, it should be economical, environmental friendly and socially acceptable. With depletion in amount of non-renewable energy sources, renewable sources especially solar energy has increasing popularity.. Solar energy represents a promising alternative that will likely initially supplement fossil fuel based energy supply, and eventually replace them. This paper presents a solar based constant frequency harmonic free three phase generation technique without using a battery backup.

Index Terms – Photovoltaic Array Modelling, MPPT.

1. INTRODUCTION

Energy is the most fundamental part of our universe. It is required for a variety of fields such as transportation, industrial and agricultural sectors, in addition to household and office applications. It is available in many forms such as thermal energy, electrical energy, chemical energy, nuclear energy, light energy and so on. It is very much essential to ensure quality of life in our society. The relationship between social development and use of energy is very clear; nations with more use of energy are in more advanced state of development. The need for energy is increasing day by day, due to the increasing needs and growing technology. The current trends in energy consumption are neither secure nor sustainable. Energy sources may be renewable or non-renewable. The sources of non-renewable energy are fast depleting and cannot be replenished. In the current scenario, almost all the electricity generation takes place at central power station which utilizes coal, oil, gas, water or fissile nuclear material as the primary fuel source. Solar energy is the most popular among them. Solar panels are used to harness solar energy. Photovoltaic power control is one of the burning research fields nowadays. As a result, better solar cells and control mechanisms are developed. Solar energy represents a promising when compared to fossil fuels, solar energy is relatively an untapped source of energy, thus there still remains a lot of work to be done to make the PV system as efficient and reliable as possible and to make it always operating optimally at a given operating condition.

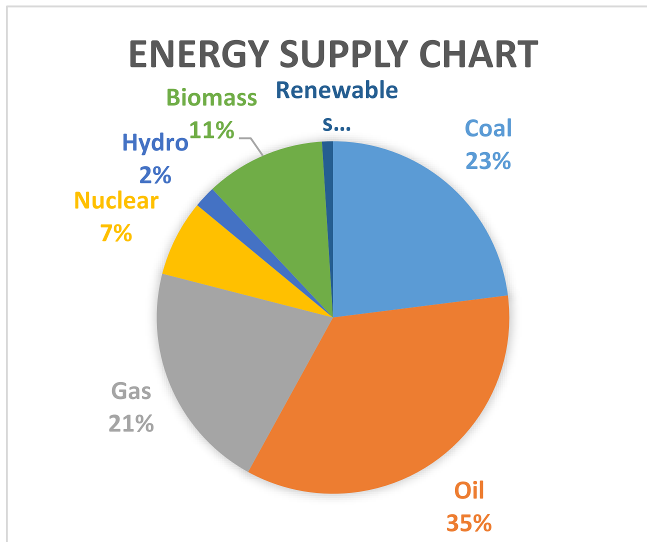


Fig 1. Share of primary sources in world's total energy supply

The popular way to generate electricity from solar energy is by making use of PV cells that converts the solar energy falling on them directly into electricity. Large scale applications of PV for power generation either on roof tops or in large fields connected to the utility grid are promising as well to provide clean, safe and sound alternatives to current methods of electricity generation.

2. PHOTO VOLTAIC SYSTEM

Solar energy is the free, readily available and has immense potential to generate energy. It doesn`t cause any pollution and is available to all at fairly equal manner. Through the photovoltaic effect the sunlight is converted directly into electricity. The use of solar photovoltaic energy is considered to be a primary energy source for countries located in tropical regions with solar radiation upto 1000W/m^2. Battery powered solar panel arrangement is widely used nowadays for street lighting. The usage of battery enables storing of energy, when it is available in surplus and using it at a later point of time, for instance at night time or during cloudy days. But the usage of battery will make entire system costly. Rather the solar energy can be utilized for operating motor loads. Here since the motors are used only during day time, usage of battery can be avoided. But there are several challenges associated with it.

This challenges of solar energy conversion are energy cost, energy fluctuations, location dependency and huge investment requirement. The solar energy is directly converted into electrical energy by solar photovoltaic module. The motor is chosen according to power requirement and the type of current output of the system. Battery less systems are considered to be more economical.

2.1. Solar Cell Characteristics

Solar cells are characterized and compared with each other with four parameters

- Short circuit current (Isc)
- Open circuit voltage(Voc)
- Fill factor (FF)
- Efficiency (η)

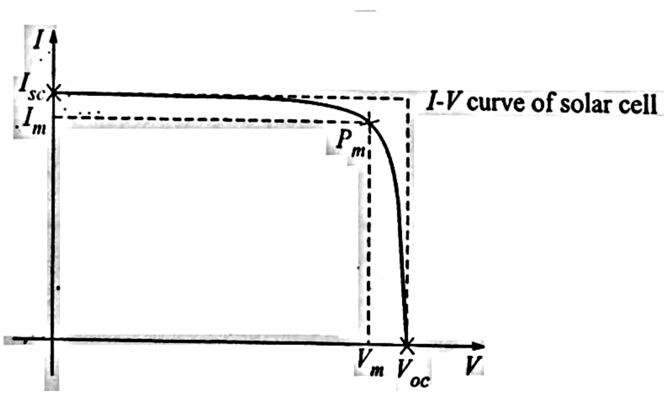


Fig 2. Typical I-V Curve of a Solar Cell

Short circuit current, Isc: This is the maximum current that flows in a solar cell when its terminals at P side and N side are shorted with each other, i.e., V=0.

Open circuit voltage Voc: As the name suggests, it is the maximum voltage generated across the terminals of a solar cell when they are kept open, i.e., I=0.

Fill factor, FF: it is the ratio of maximum power Pm= Vm*Im, that can be extracted from a solar cell to the ideal power PO = VOC * ISC.

Efficiency, η: It is defined as the ratio of the power output to power input.

a) Losses in solar cell

1. Fundamental Losses

- Losses due to low energy photons
- Losses due to excess energy in photons
- Voltage loss.
- Fill factor loss

2. Technical Losses

- Loss by reflection
- Loss due to incomplete absorption
- Loss due to metal coverage
- Recombination losses.

2.2. Solar Cell Model

Solar cells or PV cells are the basic components of PV module and it is the element in charge of transforming the sun rays or photons directly into electric power. An ideal PV is modelled by a current source in parallel with a diode [5]. However no solar cell is ideal and thereby shunt and series resistances are added to the model as shown in the PV cell diagram below. R_s is the intrinsic series resistance whose value is very small. R_p is the equivalent shunt resistance which has a very high value.

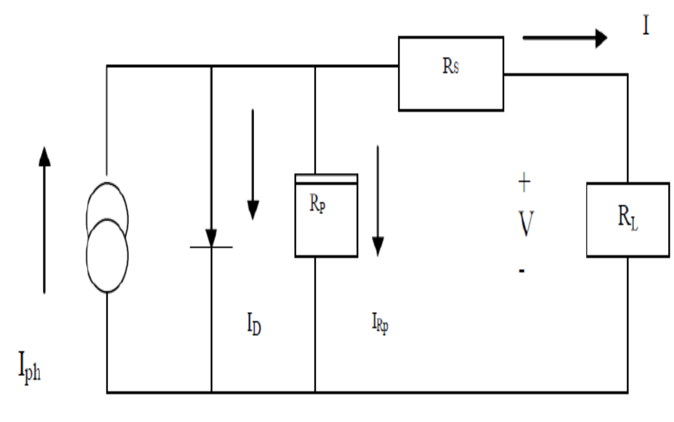


Fig 3. Equivalent circuit of a P-N junction solar cell

Applying Kirchhoff's current law to the node where I_{ph}, diode, R_p and R_s meet, we get

$$I_{ph} = I_D + I_{R_p} + I$$

We get the following equation for the photovoltaic current:

$$I = I_{ph} - I_D - I_{R_p}$$

Where, I_{ph} is the insolation current, I is the cell current, ID is the diode current and I_{RP} is the current through the parallel resistor.

PV cells are grouped in larger units called PV modules which are further interconnected in series-parallel configuration to form PV arrays or PV generators. The PV mathematical model used to simplify our PV array is represented by the equation

$$I = n_p I_{ph} - n_p I_{rs}\left[\exp\left(\frac{q}{KTA} * \frac{V}{n_s}\right) - 1\right]$$

where I is the PV array output current; V is the PV array output voltage; ns is the number of cells in series and np is the number

of cells in parallel; q is the charge of an electron; K is the Boltzmann's constant; A is the p-n junction ideality factor; T is the cell temperature (K); I_{rs} is the cell reverse saturation current. The factor A determines the cell deviation from the ideal p-n junction characteristics; it ranges from 1 to 5.
The cell reverse saturation current I_{rs} varies with temperature according to the following equation:

$$I_{rs} = I_{rr}\left(\frac{T}{T_r}\right)^3 \exp\left(\frac{qE_G}{KA}\left[\frac{1}{T_r}-\frac{1}{T}\right]\right)$$

Where T_r is the cell reference temperature, I_{rr} is the cell reverse saturation temperature at T_r and E_G is the band gap of the semiconductor used in the cell.

The photo current I_{ph} depends on the solar radiation and cell temperature as follows:

$$I_{ph} = \left[I_{scr} + K_i\left(T - T_r\right)\right]\frac{S}{100}$$

Where I_{scr} is the cell short-circuit current at reference temperature and radiation, K_i is the short circuit current temperature coefficient, and S is the solar radiation in mW/cm^2

2.3. PV Ratings

The solar PV modules are rated in terms of their peak power (Wp) output. It is the most important parameter from a user's point of view. The Wp is specified by the manufacturer under the so called Standard Test Conditions (STC). The module rating under STC is widely accepted by the manufacturers and the users [6][7]. The STC condition refers to the following conditions:

- Irradiation: 1000W/m^2, Am 1.5G global solar radiation
- Cell or module temperature: 250C
- Wind speed: 1 m/s

The conditions specified in the STC do not occur for most of the time and locations. Thus, in order to have a more realistic figure for the possible power output form a PV module, the performance of the module is described in two other test conditions: Standard operating conditions (SOC) and Nominal Operating Conditions (NOC). Both of these use a different concept of temperature, called Nominal Operating Cell Temperature (NOCT). The NOCT is defined as the temperature reached by the cell in an open circuited module under the following conditions:

- Irradiation: 800W/m^2
- Ambient temperature: 200C
- Wind speed: 1m/s
- Mounting: open back side

A PV array is constructed by many series or parallel connected solar cells. Each solar cell is formed by a junction semiconductor, which can produce currents by the photovoltaic effect.

3. MAXIMUM POWER POINT TRACKING

Maximum Power Point Tracking, frequently referred to as MPPT, is an electronic system that operates the PV modules in a manner that allows the modules to produce all 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. But, it 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.

3.1. Need for MPPT

When a solar PV module is used in a system, its operating point is decided by the load to which it is connected. Also, since solar radiation falling on a PV module varies throughout the day, the operating point of module also changes throughout the day. Ideally, under all operating conditions, we would like to transfer maximum power from the PV module to the load. Thus, Maximum power point tracking is a technique that is used to get the maximum possible power from solar panels. Solar cells have a complex relationship between solar irradiation, temperature and total resistance that produces a non-linear efficiency as shown in figure [8]. It is the purpose of the MPPT system to sample the output of the cells and apply the proper resistance (load) to obtain maximum power for any given environmental conditions.

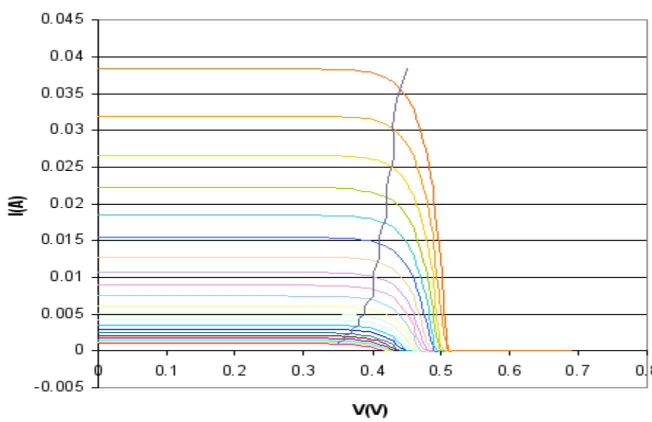


Fig.4 Solar cell I-V curve in varying sunlight

For any given set of operational conditions, cells have a single operating point where the values of the current (I) and Voltage (V) of the cell result in a maximum power output. These values correspond to a particular load resistance, which is equal to V / I as specified by Ohm's Law. The power P is given by P=V*I. A photovoltaic cell, for the majority of its useful curve, acts as a constant current source. However, at a photovoltaic cell's MPP region, its curve has an approximately inverse exponential relationship between current and voltage. From basic circuit theory, the power delivered from or to a device is optimized where the derivative (graphically, the slope) dI/dV of the I-V curve is equal and opposite the I/V ratio (where dP/dV=0). This is known as the maximum power point (MPP) and corresponds to the "knee" of the curve.

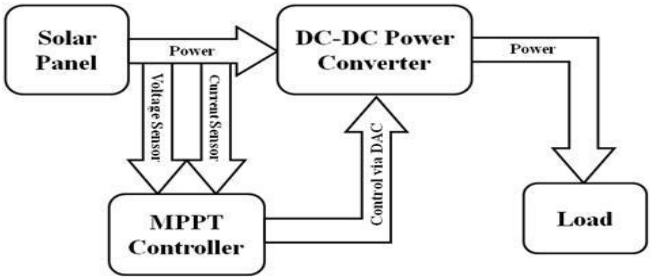


Fig.5 Block Diagram of Standalone PV system with MPPT

Maximum power point trackers utilize different types of control circuit or logic to search for this point and thus to allow the converter circuit to extract the maximum power available from a cell. The maximum power tracking mechanism makes use of an algorithm and electronic circuitry [9][10]. The mechanism is based on the principle of impedance matching between load and PV module, which is necessary for maximum power transfer. This impedance matching is done by using a DC-DC converter. Using a DC-DC converter, the impedance is matched by changing the duty cycle d of the switch. Figure shows a simple system using MPPT.

3.2. Algorithm for MPPT

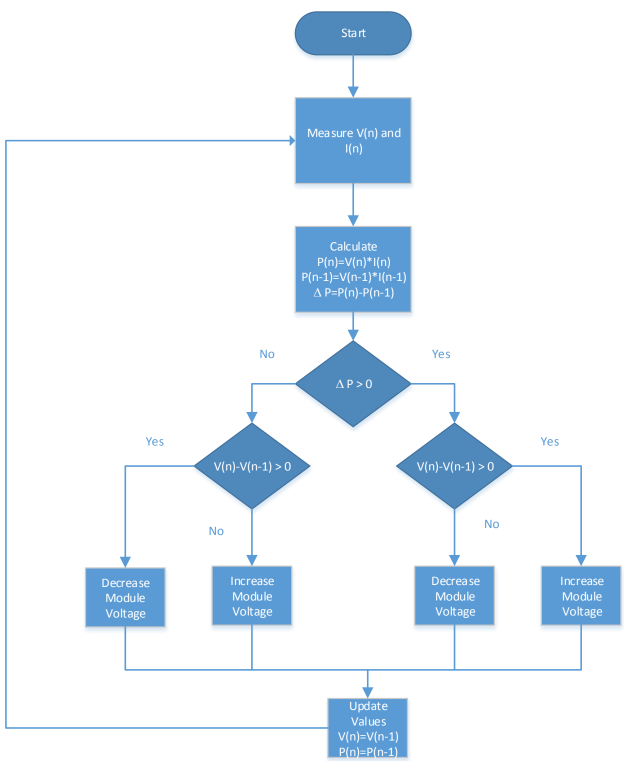


Fig.6 Flow Chart of Hill Climbing Method

Algorithms for MPPT are various types of schemes that are implemented for obtaining maximum power transfer. Some of the popular schemes are the hill climbing method, incremental conductance method, constant voltage method, modified hill climbing method, system oscillation method and the ripple correlation method. Controllers usually follow one of three types of strategies to optimize the power output of an array. Maximum power point trackers may implement different algorithms and switch between them based on the operating conditions of the array. The hill climbing method is used in here.

The hill climbing algorithm, uses the condition that P(n)[Power at present time] is greater than P(n－1)[Power at earlier instant] , the condition dP/dV to determine whether the MPP has been found or not. The hill climbing method uses the duty cycle (D) of these switching mode power interface devices, when the task of the maximum power point tracking is implemented. When the condition dP/dD = 0 is accomplished, it represents that the maximum power point has been tracked. The flow diagram of the hill climbing algorithm is shown in Figure. The duty cycle is determined by the comparison of the power at present time and previous time. If the incremental power $dP > 0$, the duty cycle should be increased in order to make $dD > 0$. If $dP < 0$, the duty cycle is then reduced to make $dD < 0$. The power interface device is DC-DC buck –boost converter. If the initial operating point of the PV system is located on the left side of the maximum power point, the duty cycle has to be continuously increased on the basis to track the maximum power point.

When the operating point of the PV system is located on the right side of the maximum power point, the duty cycle should be continuously reduced to return back to the maximum power point. If the operating point is moved toward the maximum power point ($dP > 0$) the incremental duty cycle should be greater than zero ($dD > 0$) .This will cause the operating point to move farther away from the maximum power point.

4. SEPIC CONVERTER

A converter is required in the PV application for matching between the PV output voltage and the load voltage requirements. In this work a buck-boost converter is used for matching the PV output with the load input voltage for maximum power point tracking. The SEPIC converter is used in certain applications where the current drawn from the input is required to be relatively ripple-free. In PV maximum power point tracking systems it must operate at certain point on the I-V curve without fluctuations around it to assure extraction of the maximum power from it. So that SEPIC converter topology is most appropriate in MPPT systems to operate at steady and ripple free current and voltage from the PV array.

4.1. SEPIC Converter Principles

The SEPIC converter works in two modes: mode 1 where the transistor (Q) is ON and mode 2 the transistor is OFF. The switching time period T is divided into two sub periods; DT where the transistor switch is in the ON state and $(1\text{-}D)T_S$ where the switch is in the OFF state. The basic circuit and the modes of operation of SEPIC converter are shown in Figure.

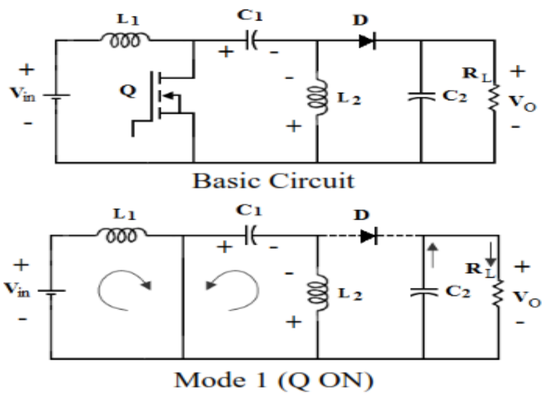
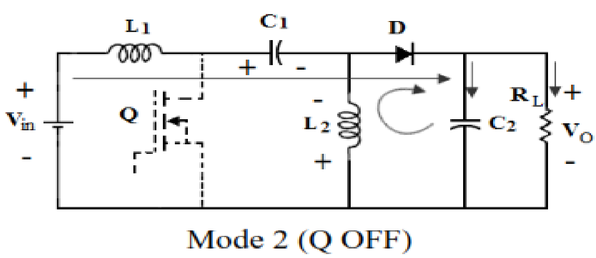


Fig. 7: The SEPIC DC/DC converter topology for buck-boost operation.



Taking into account that the average voltage across the inductor is zero, the capacitor C1 average voltage VC1 equals the input voltage Vin. The inductor L2 is parallel to C1 during ON interval, so its voltage equals VC1. During OFF interval the inductor L2 voltage equals (-VO). This leads to the equation:

$$DV_{in} = (1 - D)V_O$$

$$\frac{V_O}{V_{in}} = \frac{D}{(1 - D)} = k$$

$$\frac{I_O}{I_{in}} = \frac{1}{k}$$

4.2. SEPIC converter Design

In a SEPIC design, the output voltage can be higher or lower than the input voltage. The SEPIC converter shown in the above figure uses two inductors, L_1 and L_2. The two inductors can be wound on the same core since the same voltages are applied to them throughout the switching cycle. Using a coupled inductor takes up less space on the printed circuit board (PCB) and tends to be lower cost than two separate inductors. The capacitor C_1 isolates the input from the output and provides protection against a shorted load.

5. SIMULATION RESULTS

The proposed PV system is simulated using the scheme as shown in the following figures

PV Array Modelling

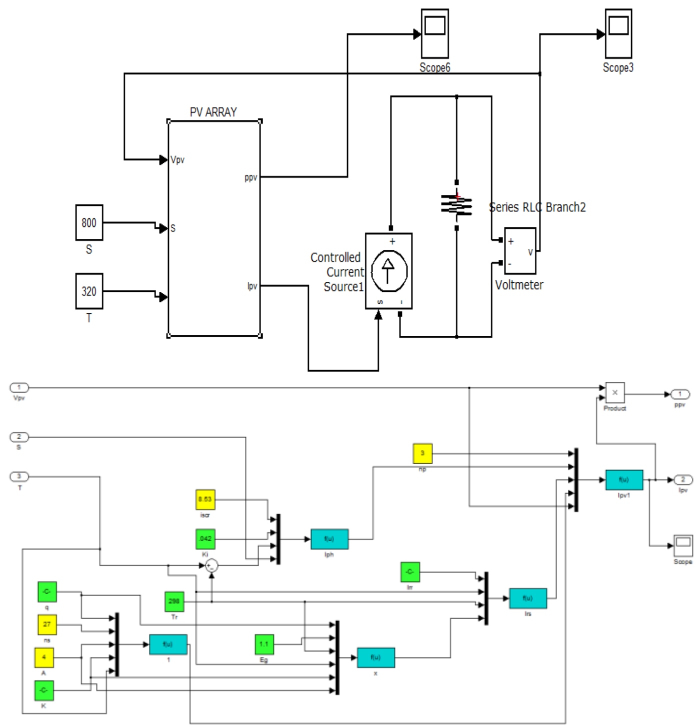


Fig. 8: PV Cell Modelling

PV System with MPPT

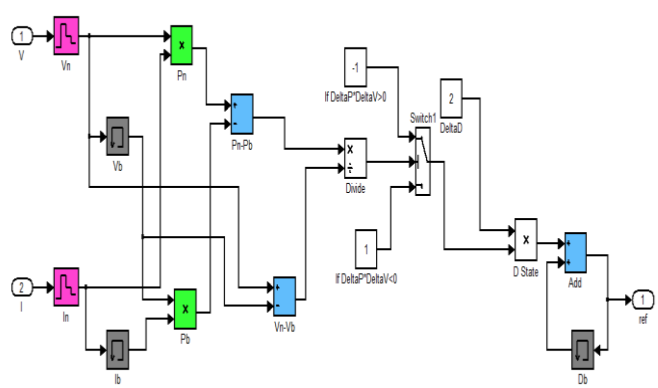


Fig. 9: Implementation of Hill Climbing Method

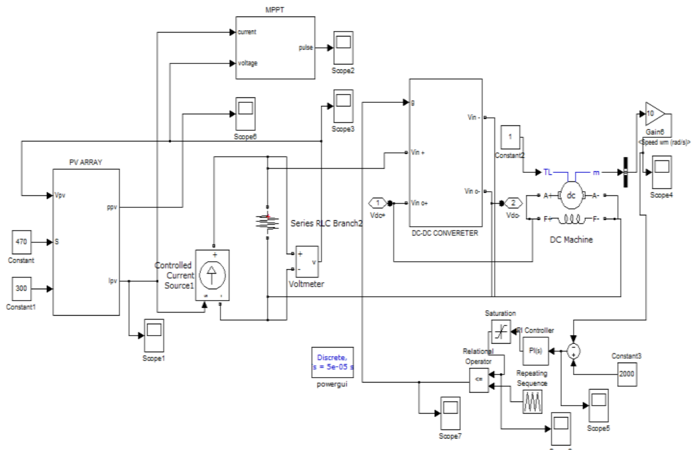


Fig. 10: PV System with MPPT

Results

1. Characteristics Of PV Panel

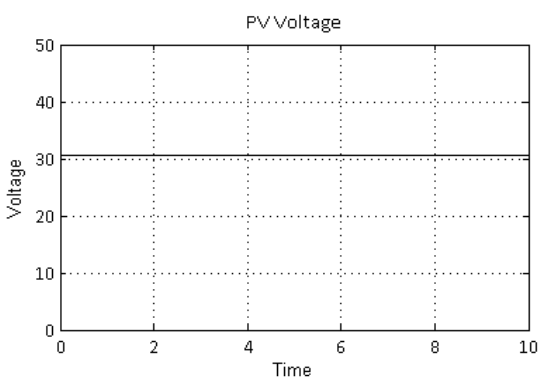


Fig. 11: Output of PV Panel

2. VI and PV Characteristics

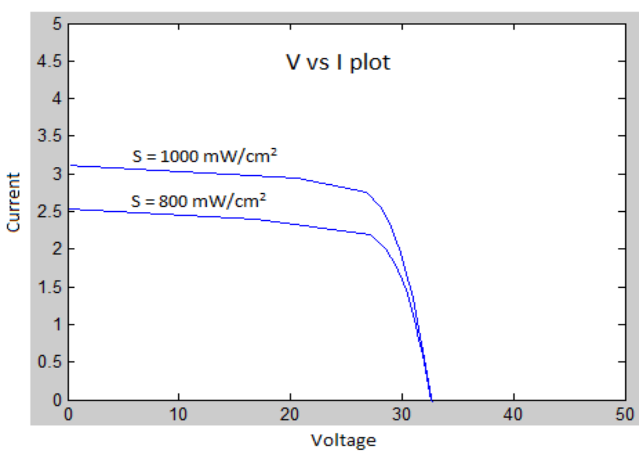


Fig. 12: VI Characteristics of PV Panel

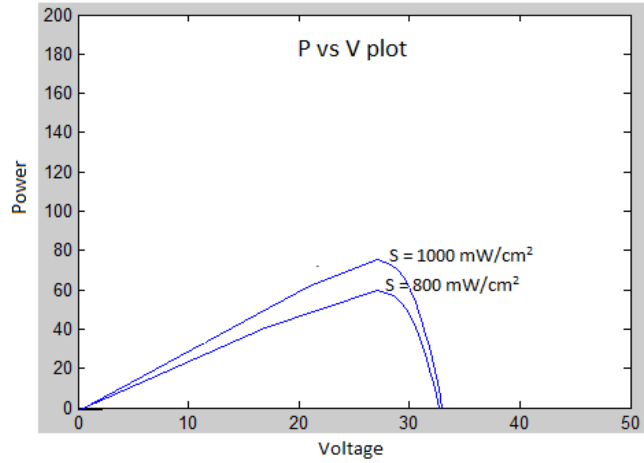


Fig. 13: PV Characteristics of PV Panel

3. MPPT Output

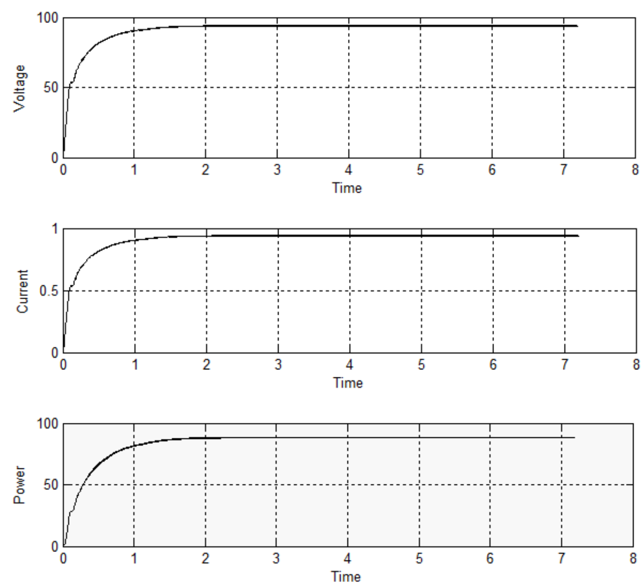


Fig. 14: Output of MPPT Algorithm

6. CONCLUSION

A novel MPPT for standalone PV system without battery backup is proposed and simulated in this work. The PV system model and characteristics is introduced and the MPPT technique based on Hill climbing algorithm is set up. The proposed control algorithm is simulated and applied to a SEPIC converter to extract the maximum power from the PV array regardless of the load or environmental conditions. The converter is designed according the load requirements. The resulting power is applied to a coupled DC-AC motor-generator set which in turn produces the desired AC supply without the presence of any harmonics at the output.

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