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Solar Powered Open Loop SVPWM Inverter with MPPT Control

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ABSTRACT: Due to the drastic increase of global energy demand and rapid consumption of conventional fossil fuel resource, solar energy has become one of the popular renewable energies. A solar powered open loop SVPWM inverter with MPPT control is proposed in this paper. The inverter which is fed by dc to dc converter model is programmed in Maximum Power Point Tracking (MPPT) mode using optimal duty ratio to achieve maximum output. Applying the concept of MPPT and properly controlling the duty cycle of the switches, the solar power powered DC-DC converter is successfully worked to extract maximum power from the solar panel.

KEYWORDS: Maximum Power Point Tracking (MPPT), Solar Photovoltaic (SPV), Space Vector Pulse Width Modulation (SVPWM), Incremental Conductance (IC)

I.INTRODUCTION

The rapid increase in the demand for electricity and the recent change in the environmental conditions such as global warming led to the introduction of a new source of energy that is cheaper and sustainable with less carbon emissions. Solar energy has offered promising results in the quest of finding the solution to the existing problem. The harnessing of solar energy using PV modules comes with its own problem that arises from the change in the atmospheric conditions.

Therefore maximum power point tracker methods are required to maintain the PV array's working at its maximum power point. Many MPPT methods have been available and the examples are the Perturb and Observe (P&O) methods, Incremental Conductance (IC) methods and constant voltage methods and so on. In this paper the most popular of MPPT technique Incremental Conductance (IC) method, Boost DC-DC converters and SVPWM inverter will involve in the implementation study. Some results such as current, voltage and output power for each various combination have been discussed. The MPPT technique will be implemented, by using Mat lab tool Simulink.

II.THE PROPOSED SYSTEM

The output voltage of the solar panel depends upon the insolation level and temperature and hence it varies with time during the day. It can be maintained constant with the help of proposed DC-DC converter, by properly controlling the duty cycle of the MOSFETs. The power obtained from the panel also varies with the insolation level and during early morning and late evening hours; the power obtained is very less. Applying the concept of MPPT and properly controlling the duty cycle of the MOSFETs, the solar powered DC-DC buck boost converter successfully worked to extract maximum power from the panel.

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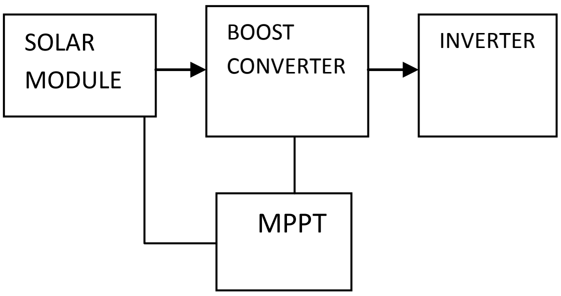

Fig 1: Basic Block Diagram

III.SOLAR CELL AND BOOST CONVERTER

A. Solar Cell

Solar cells are the basic components of photovoltaic panels. Most are made from silicon even though other materials are also used. Solar cells take advantage of the photoelectric effect: the ability of some semiconductors to convert electromagnetic radiation directly into electrical current. The charged particles generated by the incident radiation are separated conveniently to create an electrical current by an appropriate design of the structure of the solar cell, as will be explained in brief below. A solar cell is basically a p-n junction which is made from two different layers of silicon doped with a small quantity
of impurity atoms. Figure 2 shows the equivalent circuit of a PV cell. The equivalent circuit of the general model which consists of a photo current, a diode, a parallel resistor expressing a leakage current, and a series resistor describing an internal resistance to the current flow.

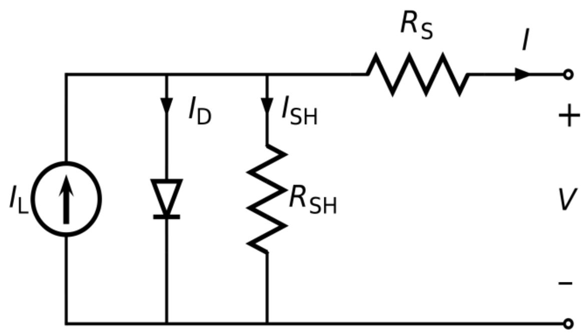

Fig 2: Equivalent Circuit

The voltage-current characteristic equation of a solar cell is given as

$$I = npIph - nsIrs\left[\exp(qV/kTAns) - 1\right] \quad (1)$$

Where I_{PH} is a light-generated current or photocurrent, I_S is the cell saturation of dark current, q (= 1.6 ×10−19C) is an electron charge, k (= 1.38 ×10−23J/K) is a Boltzmann's constant, T is the cell's working temperature, A is an ideal factor, RSH is a shunt resistance, and RS is a series resistance. The photocurrent mainly depends on the solar insolation and cell's working temperature, which is described as

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$$Iph = \left[Iscr + ki\left(T - Tr\right)\right]\frac{S}{100} \qquad (2)$$

Where I_{scr} is the cell's short-circuit current at a 25°C and 1kW/m2, K_i is the cell's short-circuit current temperature coefficient, T_R is the cell's reference temperature, and λ is the solar insolation in kW/m^2. On the other hand, the cell's saturation current varies with the cell temperature, which is described as

$$Irs = Irr\left[\frac{T}{Tr}\right]^3 \exp(\frac{qEG}{kA}\left[\frac{1}{Tr} - \frac{1}{T}\right]) \qquad (3)$$

Where I_{RR} is the cell's reverse saturation current at a reference temperature and a solar radiation, EG is the bang-gap energy of the semiconductor used in the cell.
In addition, the maximum power can be expressed as $P\max = V\max\ I\max = \gamma V_{OC} I_{SC}$

Where Vmax and Imax are terminal voltage and output current of PV module at maximum power point (MPP), and γ is the cell fill factor which is a measure of cell quality.

B. Boost Converter

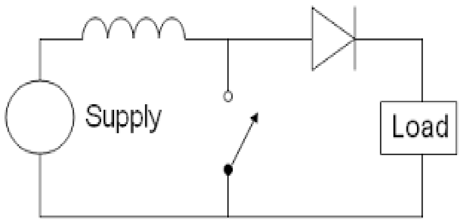

Fig 3: Boost Converter

It provides an output voltage that is greater than the input voltage –hence the name "***boost*".** The circuit diagram of a step up operation of DC-DC converter is shown in Figure 3. When the switch is closed for time duration T1, the inductor current rises and the energy is stored in the inductor. If the switch is opened for time duration T2, the energy stored in the inductor is transferred to the load via the diode and the inductor current falls. The waveform of the inductor current is shown in Fig: 4.

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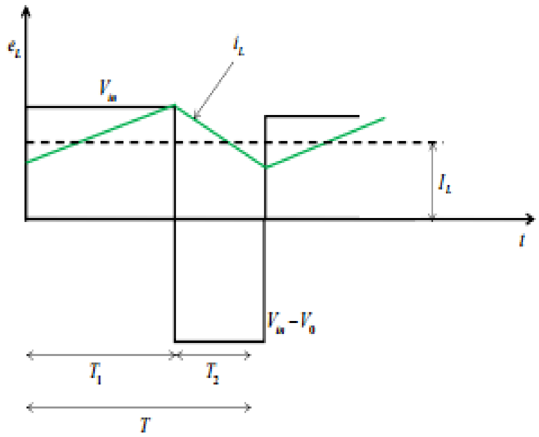

Fig 4: Inductor current waveform.

The average output voltage Vo is given by

$$Vo = Vs\left(\frac{1}{1-D}\right) \quad (4)$$

Where D is the duty ratio and Vs is the supply voltage.

From Equation 4 the following observations can be made:

- The voltage across the load can be stepped up by varying the duty ratio D
- The minimum output voltage is Vs and is obtained when D = 0
- The converter cannot be switched on continuously such that D =1. For values of D tending to unity, the output becomes very sensitive to changes in D.

IV.MPPT ALGORITHM

The weather and load changes cause the operation of a PV system to vary almost all the times. A dynamic tracking technique is important to ensure maximum power is obtained from the photovoltaic arrays. The MPPT algorithm operates based on the truth that the derivative of the output power (P) with respect to the panel voltage (V) is equal to zero at the maximum power point. In the literature, various MPP algorithms are available in order to improve the performance of photovoltaic system by effectively tracking the MPP.
However, most widely used MPPT algorithms are considered here, they are:

1. Perturb and Observe (P&O)
2. Incremental Conductance (InCond)
3. Constant Voltage Method.

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A frequently used class of MPT algorithms operates by continuously changing the operating point of the PV array and detecting the corresponding change in the array output power; therefore they are known as 'perturb and observe'(P&O) algorithms. The new IncCond algorithm is a software development of a previous MPT technique constructed using discrete circuit elements to overcome the drawbacks of the P&O algorithms. The perturb oscillation around peak power point of the perturb and observe method to track the peak power under fast varying atmospheric condition is overcome by IC method.

The Incremental Conductance can determine that the MPPT has reached the MPP and stop perturbing 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 truth that dP/dV is negative when the MPPT is to the right side curve of the MPP and positive when it is to the left side curve of the MPP. This algorithm has advantages over P&O in that it can determine when the MPPT has reached the MPP, where P&O oscillates around the MPP. Also, incremental conductance can track rapidly increasing and decreasing irradiance conditions with higher precision than perturb and observe. The disadvantage of this algorithm is the increased complexity.

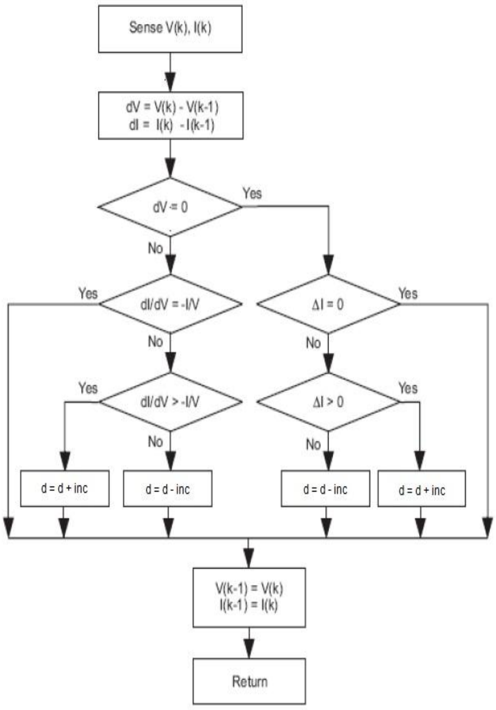

Fig 5: Incremental Conductance Algorithm

The MPPT regulates the PWM control signal of the dc – to – dc boost converter until the condition: $(\partial I/\partial V) + (I/V) = 0$ is satisfied. In this method the peak power of the module lies at above 98% of its incremental conductance.

V.SPACE VECTOR PWM

Figure 6 demonstrates the three phase three legs two level voltage source inverter. It has six power switches (S1 to S6) that are used to shape the output voltage. Switches S1, S3, S5 are upper switches and switches S2, S4, S6 are lower switches. In each leg, there must be two switches and these two switches are compliment to each other. If S1 and S4 are the switches in first leg of three phase VSI and when S1 is ON i.e. S1=1, S4 should be OFF i.e. S4=0 and vice versa.

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Therefore, Controlling of switches are in a way so that two switches should not be turned ON at a same time in a same leg otherwise leg may be short circuited and hence there will be zero output voltage at load side.

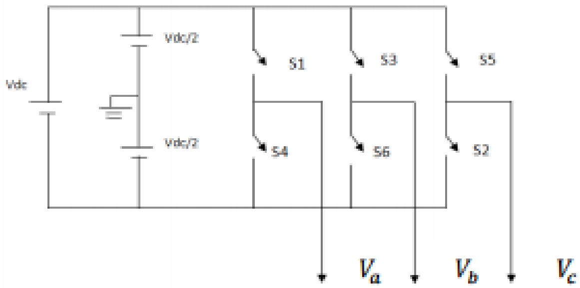

Fig 6: Two level VSI

The space vector concept is being derived from the rotating field of induction motor and it is used to modulate the inverter output voltage. In this modulation the three phase quantities can be transformed into their equivalent two phase quantity either in synchronously rotating frame or stationary frame. There are two possible vectors called zero vector and Active 58 vector. The objective of space vector PWM technique is to approximate the reference voltage vector Vref using the eight switching patterns. One simple method of approximation is to generate the average output of the inverter in a small period, T to be the same as that of Vref in the same period. Therefore, space vector PWM can be implemented by the following steps:

Step 1: Determine Vd, Vq, Vref, and angle (α)

Step 2: Determine time duration T1, T2, T0

Step 3: Determine the switching time of each transistor (S1 to S6)

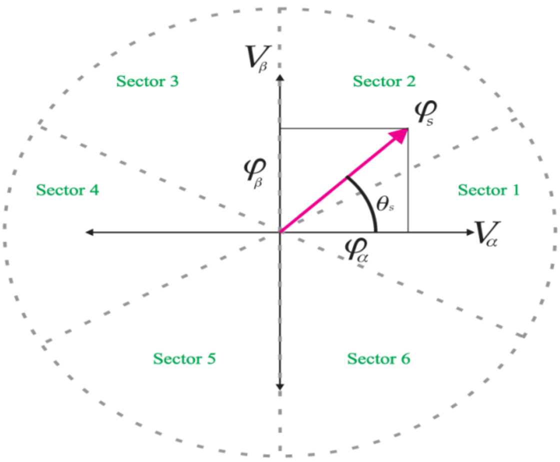

Fig 7: Space Vector Diagram with Sectors

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All sectors in SVPWM are shown in Figure 6.1. It uses a set of vectors that are defined as instantaneous space vectors of the voltages and currents at the input and output of the inverter. These vectors are created by various switching states that the inverter is capable of generating.

To implement the space vector PWM, the voltage equations in the ABC reference frame can be transformed into the stationary dq reference frame. Relating the three phase voltages and currents in terms of "ωt" is difficult to handle directly. It can be transformed into two reference frames by using Park's transform.

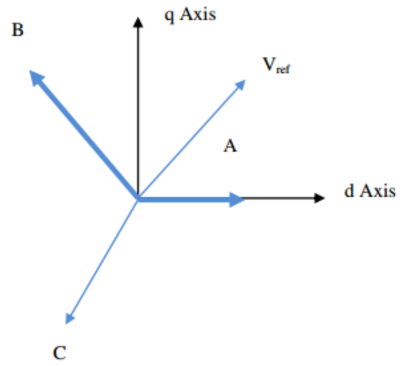

Fig 8: dq and ABC Reference Frame

$$F_{dq0} = K_S \, F_{abc} \qquad (5)$$

$$K_S = \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \\ 1/2 & 1/2 & 1/2 \end{bmatrix}$$

where F is voltage or current.

In dq reference frame, there are six sectors. Each sector is divided equally by sixty degrees. Basic Vectors are V_1, V_2, V_3, V_4, V_5 and V_6.

A. Calculation of time period for sector 1

At sector 1, V_1 and V_2 are voltage vectors. Assume V_{ref} makes 'α' ‟ phase angle difference with V_1. This Vref can be calculated using vector calculus. 'Tz' is switching time interval at which output voltage of inverter is constant. T1 and T2 are switching time duration of voltage space vectors V_1 and V_2.

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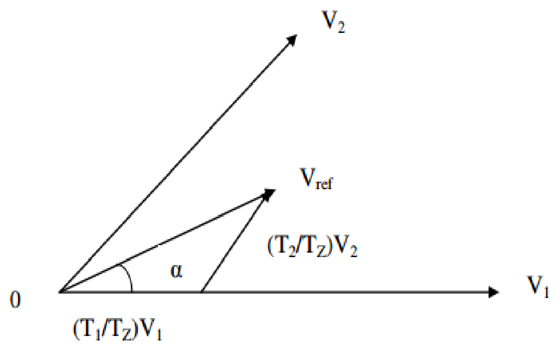

Fig 9: Reference Vector with respect to Sector 1

$$T1 = Tza \frac{\sin\left(\frac{\Pi}{3} - a\right)}{\sin\frac{\Pi}{3}} \qquad (6)$$

VI.SIMULATION MODELS AND RESULTS

Solar powered open loop SVPWM inverter has been done using MatLab Simulink. The model shown in Fig 10 represents a block diagram of a PV array connected to a RLC load through a dc/dc boost converter with MPPT controller.

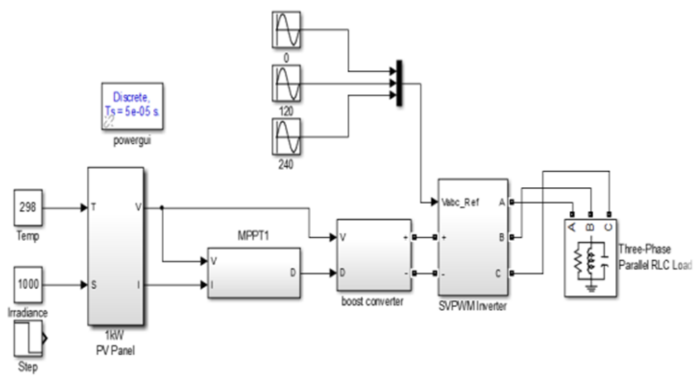

Fig 10: Overall system block diagram

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The model of PV panel as in Fig 11 shows a constant dc source created using the subsystem block from Simulink library browser, which included all functions of PV panel. The model has three inputs irradiance, temperature and voltage input that is coming as a feedback from the system and the output of the block gives the current. This model generates current and receives voltage back from the circuit.

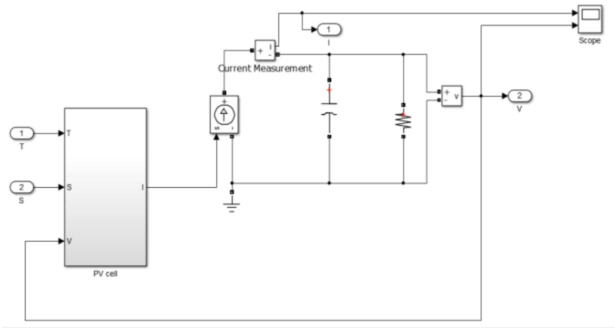

Fig 11: PV panel

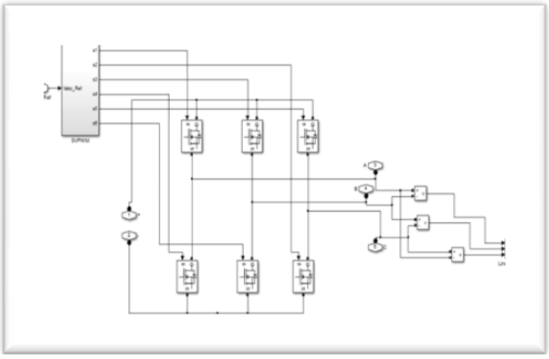

Fig 12: SVPWM Inverter

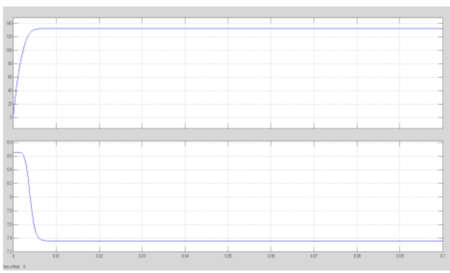

Fig 13:Voltage Vs Time and Current Vs Time at 1000W/m^2

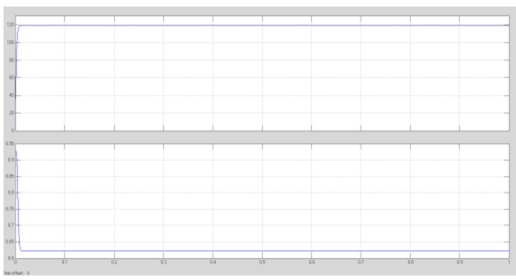

Fig 14:Voltage Vs Time and Current Vs Time at 800W/m^2

Fig: 12 shows open loop SVPWM inverter and the reference for SVPWM is three voltage sources phase shifted by 120^0. Fig:13 and fig 14 shows voltage and current for an irradiance of 1000W/m^2 and 800W/m^2.The voltage obtained

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for the former is 140V and the latter is130V. Fig:14 shows the duty ratios for space vector modulation and fig:15 gives the output voltage of the inverter which is unfiltered.

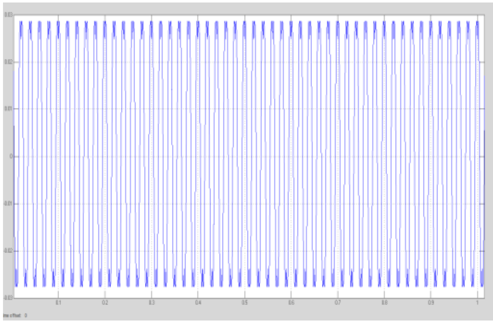

Fig 15: Duty ratios for space vector PWM

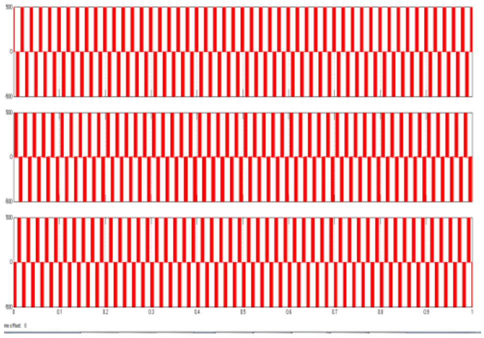

Fig 16: Output voltage of Inverter

VII.CONCLUSION

Solar powered open loop SVPWM inverter with MPPT control has been done using MatLab Simulink. Voltage and current waveform obtained for irradiance of 1000W/m^2 and 800W/m^2. The MPPT method simulated in this project is able to improve the dynamic and steady state performance of the PV system simultaneously. Through simulation it is observed that the system completes the maximum power point tracking successfully despite of fluctuations. When the external environment changes suddenly the system can track the maximum power point quickly.

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