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A Photovoltaic System With Rapid Focusing MPPT Mechanism Based on Boost Converter Topology for Rapidly Varying Solar Irradiation and Resistance Connected to Load Side

Mohana Sudha.P, Ramesh Kumar.R.

P.G Scholar, Dept. of Power Electronics and Drives, AVS Engineering College, Salem, Tamilnadu, India

Assistant Professor, Dept. of Power Electronics and Drives, AVS Engineering College, Salem, Tamilnadu, India

ABSTRACT: For fast-varying solar irradiation and load resistance, a fast-converging maximum power point tracking (MPPT) system is essential to ensure the photovoltaic (PV) system response rapidly with minimum power losses, multiple peaks are observed through the power–voltage (P–V) characteristic curve of a photovoltaic (PV) array, and the conventional maximum power point tracking (MPPT) algorithms may lag to track the global maximum power point (GMPP). Therefore, this paper proposes an improved incremental conductance (Inc Cond) algorithm that is able to track the GMPP under partial shading conditions and varying load conditions. A modified algorithm is introduced to modulate the duty cycle of the dc–dc converter in order to ensure the MPPT process faster. Simulation and hardware implementation are carried out to evaluate the correctness of the proposed algorithm under partial shading and load variation. The results shows that the proposed algorithm is able to track the GMPP accurately under various types of partial shading conditions, and the response during various load and solar irradiation are faster than the conventional Inc Cond algorithm. Hence, the effectiveness of the proposed algorithm when partial shading condition and load variation is validated in this paper.

KEYWORDS: DC–DC converter, incremental MPPT, photovoltaic (PV) system.

I. INTRODUCTION

1.1 General

SOLAR ENERGY is important renewable source of electricity generation. The high expense for the photovoltaic (PV) module has limited the implementation of PV system in electricity generation. Furthermore, the power generated by PV modules is not stable and dependent on solar irradiation and load capacity. Hence, the maximum power point tracking (MPPT) controller is introduced to assure the PV system always provide high efficiency. The Boost converter is connected to achieve the PV system always operates at the maximum power point (MPP).

1.2 Existing System

A dc–dc boost converter is connected in between the PV module and the load, the switching duty cycle of the dc–dc converter is regulated to ensure the PV system always operates at the maximum power point (MPP) . For P&O, the power of the PV module is determined, and then the duty cycle of the converter is either increased or decreased to achieve the MPP. Generally, the perturbation keeps going in both directions near the MPP, and thus, oscillations occur in the power of PV module. Unlike P&O, the slope of the power-against-voltage (P–V) curve of PV module is used by the incremental conductance algorithm to vary the duty cycle of the converter. By varying the duty cycle of the converter, the voltage of the PV module is able to be increased or decreased and thus the PV system is able to operate at the peak of the P–V curve.

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1.3 Existing Systems Technique

A few modified algorithms have been introduced to improve the converging speed during the variation in solar irradiation level and load. The relationship between the load line and the MPP locus is used. To present a fast-converging algorithm. The MPP locus is a line which approximately connects all the MPP for all levels of solar irradiation. In a control loop is introduced to ensure the PV system operates in accordance with the MPP locus and thus the MPP searching time is reduced. However, tuning is required in the control loop, and it further complicates the MPPT system. In the control loop is eliminated, but the short circuit current and open circuit voltage are required. Thus, disconnection of PV module is required to collect the data and the power is wasted during disconnection.

Photovoltaic (PV) systems have generated immense market and research interests recently due to the abundance of raw materials and their noiseless and environment friendly power-generating process [1]–[3]. Since the power generated by PV modules depends on solar irradiation level, a maximum power point tracking (MPPT) controller is required to ensure that the highest possible power is generated. In order to achieve the optimum performance, several MPPT algorithms have been introduced, including fractional open-circuit voltage
[4], fractional short-circuit voltage [4], incremental conductance (Inc Cond) algorithm [4], [5], fuzzy logic [6], perturbation and observation (P&O) [7]–[10], and neural network [11]. These algorithms have been successfully demonstrated in tracking the maximum power under uniform insolation where only one maximum power point (MPP) exists in the power against- voltage (P–V) curve. However, in partially shaded condition where there are multiple MPPs in the P–V curve, the conventional algorithms are unsuccessful in identifying the global MPP (GMPP) among the local MPPs (LMPPs), therefore reducing the overall efficiency of the PV system [12]–[14]. Concerning the multiple-peak issue during partial shading, several solutions have been proposed by modifying the conventional algorithms. As reported in [15], Inc Cond algorithm is altered to realize a simple linear equation to track the GMPP.

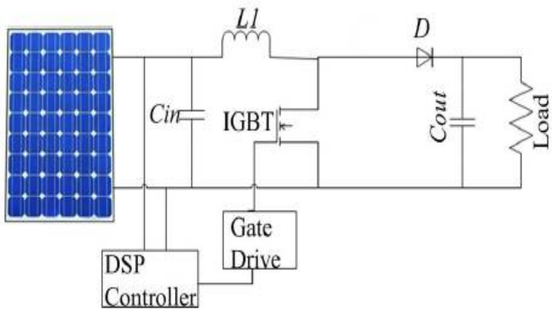

Fig.1 Circuit Diagram Of The Proposed Converter

Yet, additional measurement circuits are required at the output of the converter, adding hardware complexity. Moreover, tracking of the GMPP for the P–V curve, which has more than two peaks, is not ensured. Using the P&O algorithm, the authors in [16] proposed tuning the duty cycle of dc–dc converter between the highest and lowest to identify all the possible MPPs. In this method, all peaks can be successfully identified but the time consumption increases. Dividing Rectangles (DIRECT) algorithm is introduced in [17], which begins by selecting an exploration range for the dividing process. The exploration range is then reduced through successive divisions, and the process continues on the section where there is a high potential of finding the GMPP. Even so, this method may overlook the GMPP if an inaccurate section is chosen for further division. Fuzzy logic-based hill-climbing algorithm is introduced in [18] where all the MPP's values are periodically stored in an advanced microcontroller and fuzzy logic is later implemented to track the GMPP based on the records. Yet, in addition to the long processing time in perturbing and storing all the possible MPPs, the use of fuzzy logic also involves complicated fuzzification and defuzzification. Particle swarm optimization is introduced and implemented in [19]–[21] where a velocity equation is used to ensure that the exploration process converges toward the GMPP accurately. However, the method relies heavily on precise settings of a few parameters in the governing equation in order to propel the exploration process rapidly and accurately.

A comprehensive study on the P–V curves under partial shading conditions was reported in [22], which shows that the
Peaks in the P–V curve occur approximately at the multiples of 80% of open-circuit voltage Voc (0.8□Voc). Additionally, the magnitudes of the peaks display the trend of increasing before the GMPP and decreasing after the

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GMPP. Based on these characteristics, P&O algorithm is widely used to track the MPPs and GMPP [22]. However, under rapid-varying solar irradiation, the P&O algorithm may fail to track the MPPs accurately [23].

II. PROPOSED ALGORITHM

Under fast-varying solar irradiation and load resistance, a fast-converging maximum power point tracking (MPPT) system is required to ensure the photovoltaic (PV) system response rapidly with minimum power losses. Traditionally, maximum Power point (MPP) locus was used to provide such a fast response. However, the algorithm requires extra control loop or intermittent disconnection of the PV module. Hence, this paper proposes a simpler fast-converging MPPT technique, which excludes the extra control loop and intermittent disconnection. In the proposed algorithm, the relationship between the load line and the I–V curve is used with trigonometry rule to obtain the fast response. Results of the simulation and experiment using single ended primary-inductor converter showed that the response of the proposed algorithm is four times faster than the conventional incremental conductance algorithm during the load and solar irradiation variation. Consequently, the proposed algorithm has higher efficiency**.**

2.1 Proposed System Technique

A PV module consists of numbers of solar cell connected in series or parallel and the total power generated is the sum of the power contributed by all of the individual solar cells. A few methods exist in modeling the PV cell , and the model is used to model the PV cell in his paper. Under different levels of solar irradiation, the PV module produces different levels of power. The I–V curve of PV module under different levels of solar irradiation and also the MPPs which can be connected approximately by a straight line (MPP line) . A load line is generated and it can be imposed on the I–V curve when the PV module supplies power to the load. The power generated by the PV module is the product of the voltage and current of PV module at the intersection point between the load line and the I–V curve. Therefore, the output power of PV module varies according to the solar irradiation (I–V curve) and the resistance of the load (load line). Generally, a dc–dc converter is connected in between the PV module and the load. Then, the MPPT controller is used to regulate the duty cycle of the dc–dc converter to ensure the load line always cuts through the I–V curve at MPP than is customary. This measurement and others are deliberate, using specifications that anticipate your paper as one part of the entire proceedings, and not as an independent document. Please do not revise any of the current designations

TABLE I
VARIATION OF VOLTAGE AND CURRENT OF THE PV MODULE DURING THE VARIATION OF SOLAR IRRADIATION AND LOAD RESISTANCE

		Variation of Voltage (dV)	Variation of Current (dI)
Solar Irradiation	Increase	Increase	
	Decrease	Decrease	
Load Resistance	Increase	Increase	Decrease
	Decrease	Decrease	Increase

III. DUTY CYCLE COMPUTATION FOR DC–DC CONVERTER

In the proposed algorithm, the MPPs (Pmpp1, Pmpp2, and Pmpp3) are tracked according to the desired voltage or reference voltage (Vmpp1, Vmpp2, Vmpp3). The voltages are approximately to be in the multiple of 0.8□Voc. Hence, the duty cycle of the converter is modulated in both directions to obtain the desired voltage from the PV array. Conventionally, the duty cycle of the converter is modulated step by step to reach the desired voltage, and it is time consuming or slow for large PV array. Therefore, a faster algorithm to obtain the desired voltage is introduced in the following section. In the proposed PV system, a dc–dc converter is connected in between the PV array and the load. Equations (2) and (3) show the relationships between the input and output voltages (currents) of the dc–dc converter

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$$V_{\text{in}} = \frac{1-D}{D} V_{\text{out}} \qquad (2)$$

$$I_{\text{in}} = \frac{D}{1-D} I_{\text{out}}. \qquad (3)$$

Divide (2) by (3) to obtain (4)

$$Z_{\text{in}} = \frac{(1-D)^2}{D^2} Z_{\text{out}} \qquad (4)$$

Where D is the duty cycle of the dc–dc converter; Vin is the input voltage of the converter or the voltage of the PV array Vpv; Iin is the input current of the converter or the current of the PV array Ipv; Zin is the input impedance of the converter or the impedance seen by the PV array; and Zout is the output impedance of the converter or is the load impedance Zload.

In the PV system, (4) can be rewritten to obtain (5) and (6)

$$\frac{V_{\text{pv}}}{I_{\text{pv}}} = \frac{(1-D)^2}{D^2} Z_{\text{load}} \qquad (5)$$

$$Z_{\text{load}} = \frac{D^2}{(1-D)^2} \frac{V_{\text{pv}}}{I_{\text{pv}}}. \qquad (6)$$

Under any operating point (Vpv, Ipv) of the PV array and the duty cycle D is known, the load impedance Zload at the output of the converter can be calculated by using (6). After obtained the load impedance, (6) can be rewritten into (7). With the desired voltage and current of the PV array, the duty cycle can be calculated by using (8). When this duty cycle is applied on the converter, the PV system can be modulated to operate at the desired voltage and current

$$\frac{D^2}{(1-D)^2} = \frac{I_{\text{pv}}}{V_{\text{pv}}} Z_{\text{load}} \qquad (7)$$

$$D = \frac{\sqrt{a}}{1+\sqrt{a}} \qquad (8)$$

where $a = (I_{\text{pv}}/V_{\text{pv}})Z_{\text{load}}$.

In the proposed algorithm, the load of the PV system is calculated by using (6). Then, the desired value of voltage and current are substituted into (8) to obtain the duty cycle. Hence, the duty cycle can be obtained and modulated rapidly.

As shown in Fig. 5, when MPP1 is tracked by using conventional Inc Cond algorithm, the proposed algorithm goes to the right of MPP1 to search for other MPPs. As aforementioned, the voltages of MPPs are approximately 0.8□Voc away from each other. Therefore, the voltage of MPP2 Vmpp2 is obtained by adding 0.8□Voc to Vmpp1. Then, the current of MPP2 is also required in order to obtain the duty cycle by using (8), but the current at MPP2 is unknown. Therefore, the current at MPP1 and Vmpp2 are substituted into (8), and the operating point of the PV array is converged to point A rapidly. After this, the current at point A and Vmpp2 are substituted into (8) again to obtain the next duty cycle. This process continues until at a point where the difference in current d I is smaller than a minimum value dI min. Then, the conventional Inc Cond algorithm is used to track the MPP2. This is because the conventional Inc Cond algorithm can only be used when the operating point is near MPP2 or else the same MPP (MPP1) will be tracked. Therefore, dI min is set to be 0.03 in this proposed system based on try and error observation from the simulation. Finally, the same method is used in the searching of MPP3 at the left of MPP1. Current at MPP1 and Vmpp3 (obtained by deducting 0.8□Voc from Vmpp1) are substituted into (8) to obtain the duty cycle. Then, the operating point of the PV array is converged to point B rapidly. This process continues until d I is smaller than dI min and then the conventional Inc Cond algorithm is used to track MPP3. Fig. 6 shows the simulation results of the MPPs searching by the conventional and the proposed modified Inc Cond algorithms. The proposed algorithm is able to reach the desired voltage at t = 0.6 s, but the conventional algorithm Fig. 6. Tuning of the voltage of the PV array with the

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conventional algorithm and the proposed algorithm needs 1.6 s. With the fast tuning in the voltage of the PV array, the MPPs can be reached rapidly

TABLE II
PARAMETERS OF KC85T PV MODULES
AT STANDARD TEST CONDITIONS (STC) TEMPERATURE = 25 °C AND INSOLATION = 1000 W/m^2

Maximum Power (P_{max})	87W
Voltage at MPP (V_{mpp})	17.4V
Current at MPP (I_{mpp})	5.02A
Open Circuit Voltage (V_{oc})	21.7V
Short Circuit Current (I_{sc})	5.34A
No of Series Cells	36
No of Series Cells with Bypass diode	18

IV. MODULES DESCRIPTION

4.1 Maximum Power Point Tracking (MPPT)

MPPT stands for maximum power point tracker, which is an electronic system designed for optimizing the varying power output from a solar panel module such that the connected battery exploits the maximum available power from the solar panel. We know that the output from a solar panel is directly proportional to the degree of the incident sunlight, and also the ambient temperature. When the sun rays are perpendicular to the solar panel, it generates the maximum amount of voltage, and deteriorates as the angle shifts away from 90 degrees.

4.2 Incremental Conductance (IC)

The disadvantage of the perturb and observe method to track the peak power under fast varying atmospheric condition is overcome by IC method [7, 18]. The IC 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 dl/dV and –I/V [7] 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 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 accuracy than perturb and observe [7]. One disadvantage of this algorithm is the increased complexity when compared to P&O [7].

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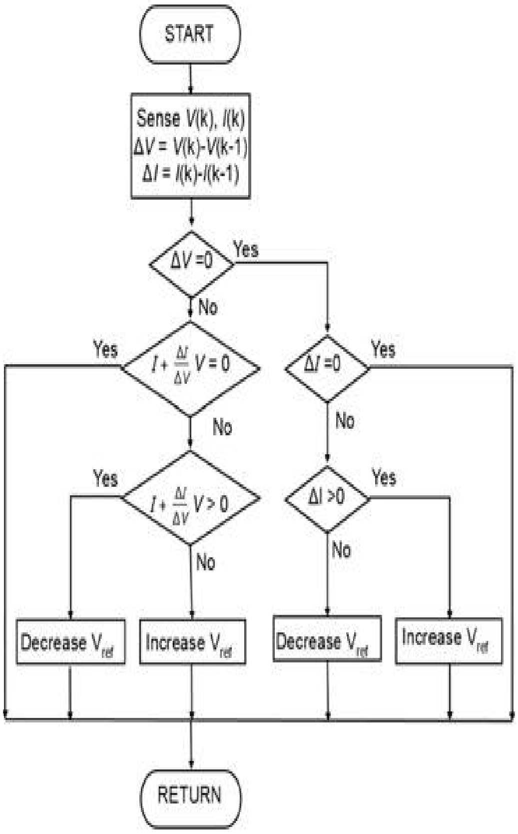

Fig.2 IC Algorithm

Following the above steps, now the current may be further reduced toC/10 rate which makes sure the charging rate and the pace does Finally when the battery voltage reaches around 14.3V, the process may be reduced to a C/50 rate which almost stops The charging process yet restricts the charge from falling to lower levels.

The entire process charges a deep discharged battery within a span of 6 hours without affecting the life of the battery .An MPPT is employed exactly for ensuring that the above procedure is extracted optimally from a particular solar panel. A solar panel may be unable to provide high current outputs but it definitely is able to provide with higher voltages.

4.3 Photo Voltaic System

A photovoltaic system, also solar PV power system, or PV system, is a power system designed to supply usable solar power by means of photo voltaics. It consists of an arrangement of several components, including solar panels to absorb and convert sunlight into electricity ,Photovoltaic's (PV) is the name of a method of converting solar energy into direct current electricity using semiconducting materials that exhibit the photovoltaic effect, a phenomenon commonly studied in physics, photochemistry and electrochemistry. The direct conversion of sunlight to electricity occurs without any moving parts or environmental emissions during operation.

Cells require protection from the environment and are usually packaged tightly behind a glass sheet. When more power is required than a single cell can deliver, cells are electrically connected together to form photovoltaic modules, or solar panels. A single module is enough to power an emergency telephone, but for a house or a power plant the modules must be arranged in multiples as arrays.

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4.4 Circuit Explanation Operation

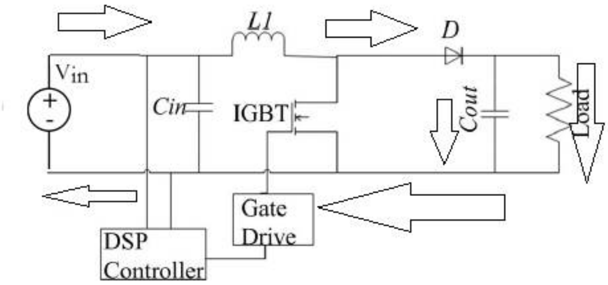

Fig.3 Circuit Diagram

A few modified algorithms have been introduced to improve the converging speed during the variation in solar irradiation level and load. The relationship between the load line and the MPP locus is used to present a fast-converging algorithm. The MPP locus is a line which approximately connects all the MPP for all levels of solar irradiation. In, a control loop is introduced to ensure the PV system operates in accordance with the MPP locus and thus the MPP searching time is reduced. However, tuning is required in the control loop, and it further complicates the MPPT system. In the control loop is eliminated, but the short circuit current and open circuit voltage are required. Thus, disconnection of PV module is required to collect the data and the power is wasted during disconnection. Although the aforementioned algorithms can provide fast response, the complexity of the systems is greatly increased. Therefore, this paper proposes a modified MPPT algorithm, i.e., able to provide fast response without the requirement of an extra control loop. Other than that, the proposed system also does not require the intermittent disconnection. The proposed PV system simply consists of a dc–dc converter which connected in between the PV module and load. Then, the current and voltage of the PV module are sensed by a PIC controller, which is also used to execute the modified MPPT algorithm. An inverter and a rectifier are connected at the output of the dc–dc converter to validate the proficiency of the proposed algorithm under a nonlinear load.

V. SIMULATION AND RESULTS

5.1 Expected Input And Expected Output

Here the Input given to the circuit is Solar irradiation = 1000w/m^2Cand the output got is VDC = 38DC output voltage can be vary based on duty cycle For solar irradiation=700W/m^2 the output voltage VDC= 12V.

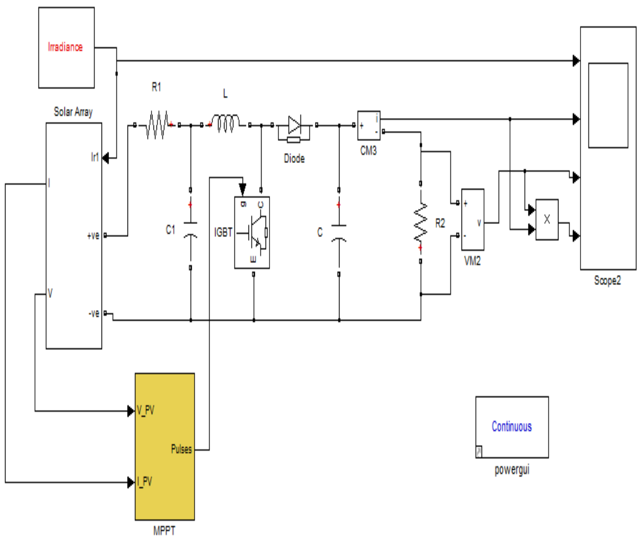

Fig.4 Simulation Diagram of the Proposed System

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5.2 Output Waveforms

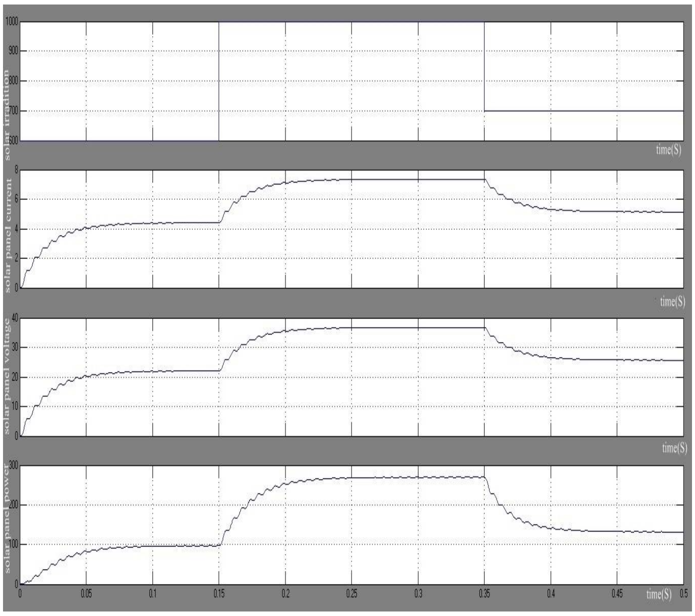

Fig.5 Simulation Output Waveforms of Proposed System

VI. HARDWARE DETAILS

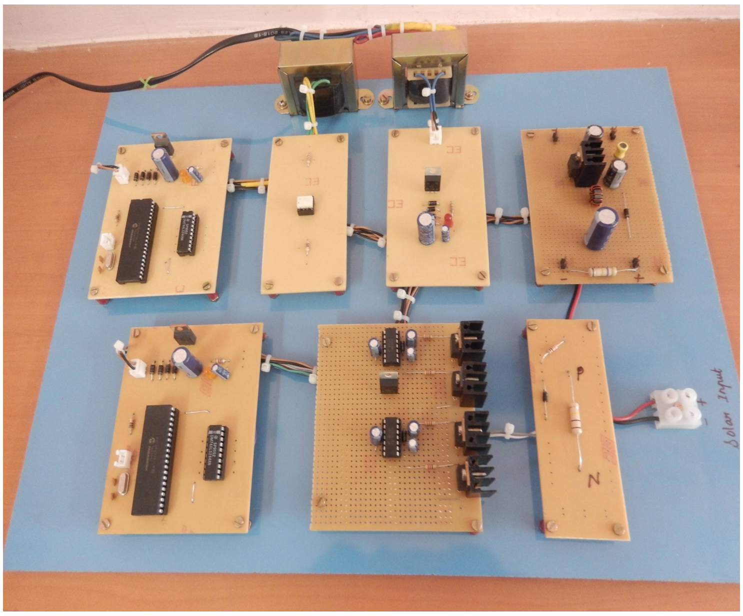

Fig.6 Fabricated Prototype Model

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TABLE III SPECIFICATIONS

S.no	Parameters	Specifications
1	Switching frequency	20KHz
2	Capacitors	10µF
3	Inductance	5mH
4	Solar panel voltage	12V
5	Solar panel Current	1.5A
6	Solar panel Power	18W

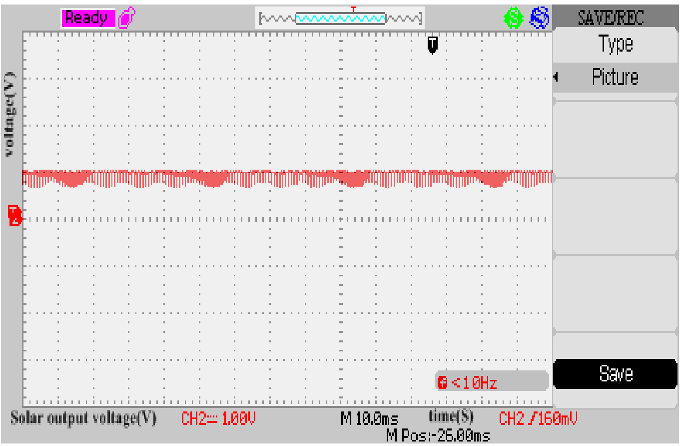

Fig.7 Solar Pv Panel Output Voltage

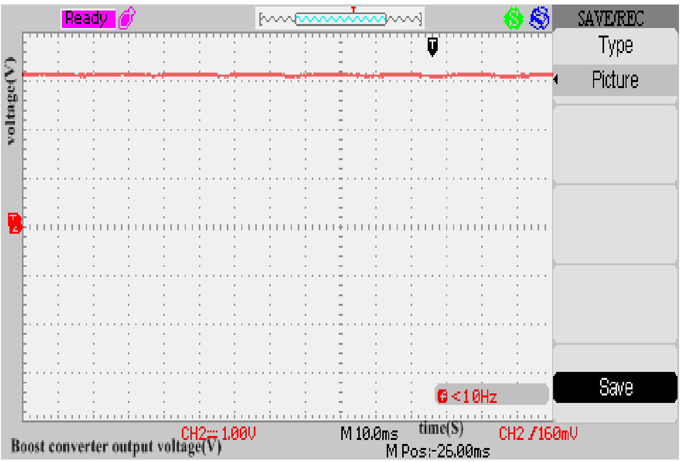

Fig.8 Boost Converter Output Voltage

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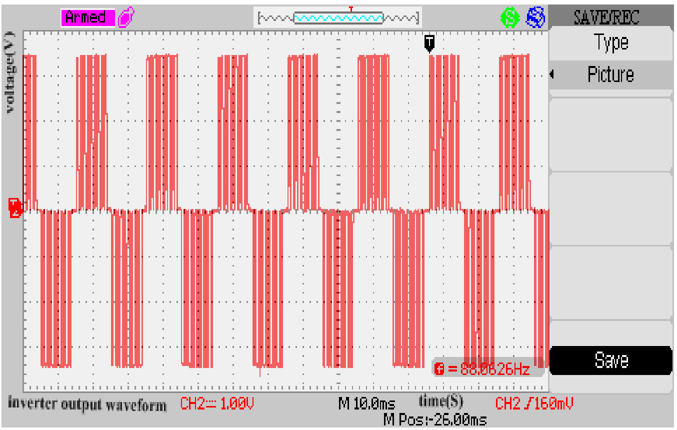

Fig.9 Inverter Output Voltage

6.1 Advantages

- The proposed algorithm responds to the variation in solar irradiation and load faster than the conventional algorithm
- Highly efficient
- The maximum power point tracking tracks the maximum power according to solar irradiation.

6.2 Applications

The maximum power point tacking technique can able to track the maximum power output in renewable energy sources like solar and wind.

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