ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 4, April 2014

Efficient Utilization of Solar Energy under Partial Shading Conditions Using a Novel MPPT Technique

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ABSTRACT: Vastly growing concerns on energy sustainability and security have introduced significant research efforts on the penetration of Renewable Energy Sources (RES) into present electric power system. Photovoltaic (PV) energy is the most important RES since it is clean, pollution free, and inexhaustible. The efficiency of a photovoltaic (PV) array is greatly influenced by shading conditions. The PV arrays get shadowed, completely or partially, by the passing clouds, neighboring buildings and towers, trees, and utility and telephone poles. Under partially shaded conditions, the PV exhibits non convex characteristics with multiple peaks. Extraction of maximum power from PV array under partial shading condition is possible using Maximum Power Point Tracking (MPPT).The technique of MPPT can be achieved either by distributed MPPT (DMPPT) which acts on the voltages of PV modules or by centralized MPPT (CMPPT) which acts on the input voltage of inverter. But both DMPPT as well as CMPPT has its own advantages and disadvantages. This paper details the study of a novel MPPT which is a combination of both C&D MPPTs and can overcome the disadvantages of DMPPT as well as CMPPT enhanced PV system. In this paper, DMPPT is achieved with the use of sub-module integrated converters(subMIC) which gives an efficiency of 98% for a mismatch of not less than 25%.And CMPPT is achieved using 2 conventional MPPT techniques-perturb & observe and incremental conductance MPPT. A 3-module PV series string with novel MPPT was simulated under mismatched solar irradiation conditions using MATLAB Simulink.

INDEX TERMS - PV Module, Partial shading, CMPPT, DMPPT, subMIC.

I.INTRODUCTION

Generally solar panels are divided into number of substrings and are connected in series. And in most PV systems, the presence of shade or mismatch have a greater impact on the system's power output. This is due to the serial nature of PV modules in strings, which creates a "Christmas tree effect" in which current reduction in one series-connected module causes mismatch losses in the rest of the string. In order to overcome these adverse effect of partial shading on solar array, use of MPPT in photovoltaic system is very necessary[1]. There is a unique point on the VI or VP curve called the maximum power point (MPP), at which the entire PV system operates with maximum efficiency and produces maximum output power. MPPT is an electronic system that operates the PV modules in a manner that allows the modules to produce all the power they are capable off. That is, it varies the electrical operating point so that the modules are able to deliver maximum available power.

There are mainly two types of MPPT-Centralized Maximum power point tracking(CMPPT) and Distributed Maximum power point tracking(DMPPT). In case of mismatch (due to clouds, shadows, dirtiness, manufacturing tolerances, aging, different orientation of parts of the PV field, thermal gradients etc.), the Power versus Voltage (P–V) characteristic of a PhotoVoltaic (PV) field may exhibit more than one peak, because of the presence of bypass diodes, and therefore Centralized Maximum Power Point Tracking (CMPPT) algorithms can fail[3]. Moreover, the maximum power of a string of PV modules operating in mismatching conditions is lower than the sum of the powers which could be extracted by the PV modules if, each one of them, could operate in its MPP.

Distributed Maximum Power Point Tracking (DMPPT) architectures allow to overcome the drawbacks associated to mismatching phenomena. They are based on the use of module dedicated DC/DC converters (microconverters)realizing the

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MPPT for each module[1]. DMPPT enhanced PV module providing higher powers cancause potentially dangerous voltage stresses across switches.In order to get full profit from DMPPT, it is necessary that the bulk inverter voltage belongs to an optimal range whose position and amplitude are functions of the following factors: the number of PV modules and dedicated DC/DC converters in a string, the atmospheric operating conditions characterizingeach PV module (irradiance and temperature values), the voltage and current ratings of the physical devices theDC/DC converters are made of, and the adopted DC/DC converter topology[2]. Therefore the optimal range for theinverter input voltage continuously changes in time. In conclusion, the joint adoption of both a DMPPTtechnique, acting on the voltages of the PV modules, and a CMPPT technique, acting on the input voltage of theinverter, is mandatory.

A good number of publications report on different MPPT techniques for a PV system together with implementation. But, confusion lies while selecting a MPPT as every technique has its own merits and demerits. Since, MPPT is an essential part of a PV system, extensive research has been revealed in recent years in this field and many new techniques have been reported to the list since then. A detailed analysis of different MPPT techniques is deliberated by Subudhi.B, Pradhan.R in their work on “A Comparative Study on Maximum Power Point Tracking Techniques for Photovoltaic Power Systems”.

Most commercial systems utilizes the perturb& observe (P&O) MPPT technique because of its simple algorithm, low cost and ease of implementation. Astudy of problematic behavior of P&O technique and a novel MPPT hybrid technique that is combination of two basic techniques i.e. P&O and Fractional Open Circuit Voltage (FOCV) technique is carried out by Murtaza.A.F,Sher.H.A, in their work on “A novel hybrid MPPT technique for solar PV applications using perturb & observe and Fractional Open Circuit Voltage techniques”.

This paper is organized in to five parts as (i) The photovoltaic module models under partial shading conditions (ii) Effect of partial shading on photovoltaic module (iii)CMPPT enhanced PV module under partial shading condition(iv) DMPPT enhanced PV module under partial shading condition(v) Novel MPPT enhanced PV module under partial shading condition.

II.THE PHOTOVOLTAIC MODULE MODELS UNDER PARTIAL SHADING CONDITIONS

Many models of varying complexity describing the behavior of a PV cell are available. The simplest model is insufficient in most application, therefore we need a more complex model if we are going to be able to deal with realities such as the shading problem. Figure 1shows the single-diode equivalent circuit model of PV cell which is commonly used in many studies and provides sufficient accuracy for most application.

Many models of varying complexity describing the behavior of a PV cell are available. The simplest model is insufficient in most application, therefore a more complex model is needed if it is going to be able to deal with realities such as the shading problem. In this paper photo voltaic module is modeled in MATLAB according to the equations,

$$I = I_{LG} - I\left[\exp\left[\frac{q}{AKT}(V + I_A R_S)\right] - 1\right]$$

Where,

$$I0 = I_{0R}\left[\frac{T}{TR}\right] \wedge 3\exp\left[\frac{qE_{G0}}{BK}\left(\frac{1}{T_r} - \frac{1}{T}\right)\right]$$

$$I_{LG} = \left[I_{SCR} + K_1(TC - 28)\right]\lambda / 100$$

Where I is cell output current, V is cell output voltage, Io is cell saturation current T is cell temperature in K,K/q is Boltzmann’s constant divided by electronic charge 8.62*10^-5 eV/K, Tc is cell temperature in degree Celsius, Ki is short circuit current temperature coefficient at Iscr 0.0017 A/degreeCelsius, lamda is Cell irradiance(mW/cm^2), Iscr is cell short

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circuit current at 28 degree Celsius and 100mW/cm2=4.57A, Ilg is light generated current,Ego is band gap for silicon=1.11eV,B= A ideality factors=1.92, Tr is reference temperature =301.18K,Ior is saturation current at Tr=19.963*10^6,Rs is series resistance=0.001 ohms.

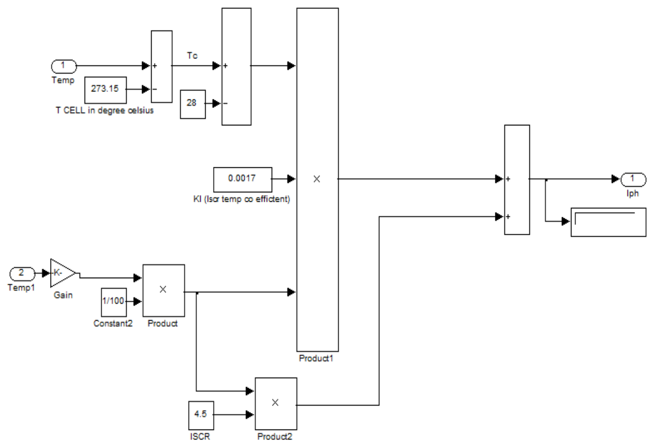

Fig 1: MATLAB modeling of light generated current

For light generated current Simulink is as shown in figure 1.Similarly modeling of both cell saturation current and output current according to the equations is possible

III.EFFECT OF PARTIAL SHADING ON PHOTOVOLTAIC MODULE

Mismatch conditions can occur due to the non-homogeneous external characteristics of the cells, due to dissymmetric manufacturing, the degradation of the cell blooming layer, the manufacturing defects, the possible breaking of the cells, the dirt on the anterior part of the cells, the degradation of the materials used for the cells encapsulating and the unequally radiation of the cells. All these factors lead to a reduction of the module performances implying that the generated power of a module is less than the sum of the generated power of the single cells.

Figure 2 shows the simulation diagram of solar panel under partial shading conditions. Here three PV modules are connected in series among which two of them produce sixty watts which are assumed to be non-shaded modules. And the third module is producing a power output of thirty watts only since it is assumed as a shaded module. Simulation of the arrangement shown in the figure 2 produces a power of about 15W only. From simulated output, it is inferred that under partial shading conditions the maximum extraction of power from solar panel is not possible. Even if two PV modules are producing an output of sixty watts each it is unable to use that under partial shading conditions. Figure below shows the simulation output.

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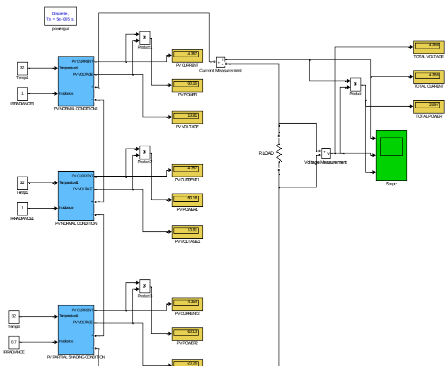

Fig 2: Simulation diagram of solar panel under partial shading conditions

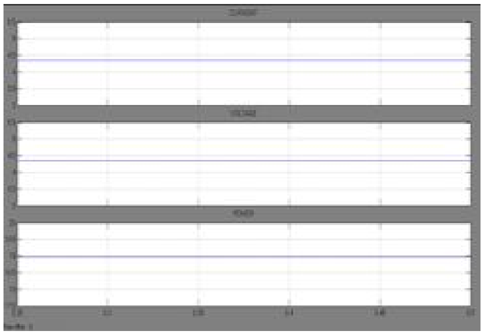

Fig 3: Simulated output of solar panel under partial shading conditions

IV.CMPPT ENHANCED PV MODULE UNDER PARTIAL SHADING CONDITION

In centralized MPPT, number of PV modules are connected in series with its output connected to a single inverter which is controlled by any conventional MPPT techniques like P&O algorithm, incremental conductance algorithm, constant voltage algorithm etc. This thesis is based on the conventional P&O MPPT technique since it is the simplest MPPT technique both in hardware and in software basis.

a)*Perturb & observe MPPT*

In Perturb and Observe method, the controller adjusts the voltage by a small amount from the array and measures power, if the power increases, further adjustments in that direction are tried until power no longer increases. It is referred to as a *hill climbing* method, because it depends on the rise of the curve of power against voltage below the maximum power point, and the fall above that point. Perturb and observe is the most commonly used MPPT method due to its ease of implementation. Figure 6 & 7 shows the MATLAB Simulink of P&O algorithm and P&O MPPT enhanced PV module.

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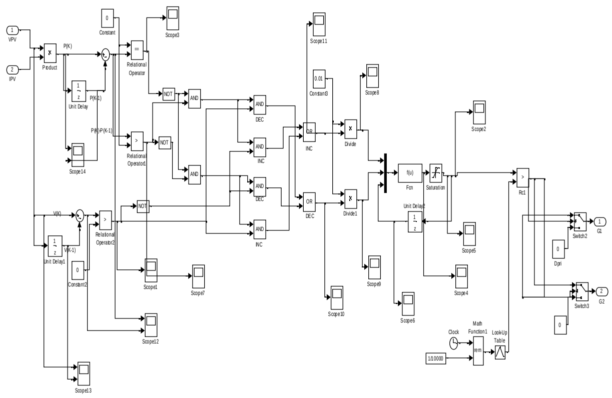

Fig 4: MATLAB Simulink model of P&O algorithm

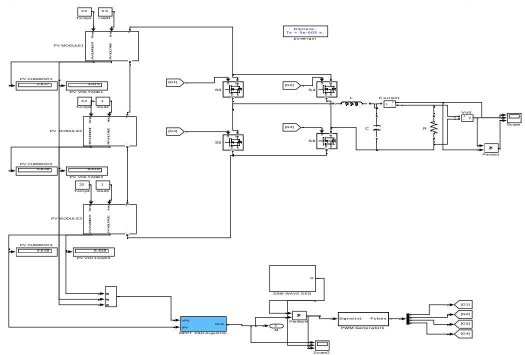

Fig 5:Simulink model of P&O enhanced PV module.

Gate pulses to inverter is provided by the P&O MPPT which leads to the maximum extraction of power from the solar module even under partial shading conditions. Figure 6&8 shows the output waveforms of P&O MPPT enhanced PV module under normal & partial shading conditions respectively and figure 7 shows the Output waveforms of PV module under partial shading condition without MPPT. From the output waveforms in figure 8&7 it is inferred that under partail shading condition the output from the PV module increases with the presence of P&O MPPT .

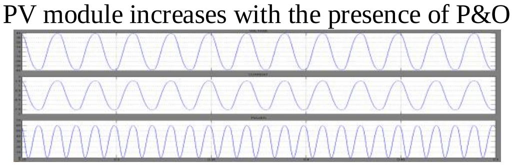

Fig 6: Output waveforms of P&O MPPT enhanced PV module under normal condition

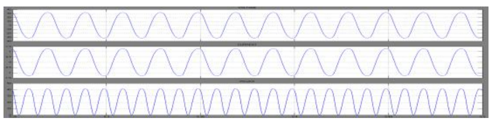

Fig 7: Output waveforms of PV module under partial shading condition without MPPT

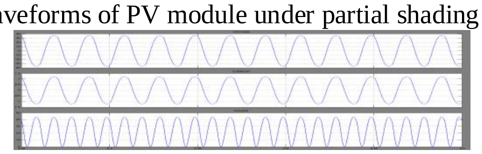

Fig 8: Output waveforms of P&O MPPT enhanced PV module under partial shading condition

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ISSN (Online): 2278 – 8875

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V.DMPPT ENHANCED PV MODULE UNDER PARTIAL SHADING CONDITION

In DMPPT enhanced PV module number of dc-dc converter is connected across each PV module. In order to extract maximum amount of power from a PV module under partial shading conditions, use of sub-module integrated converters is very necessary. Basic working principle of a subMIC is "Voltage or Power equalization". In VEP, voltage across each substring is made equal, or power delivered by each substring is made equal. This is possible by the injection or extraction of current in PV module by the operation of subMIC.

A sub-module integrated converter (subMIC) is nothing but a bidirectional dc-dc converter use of which in parallel with each PV module gives maximum extraction of power. Dc-dc converter topology used here is a bidirectional flyback converter. The Output of each flyback converter is connected in parallel and are isolated from the solar module. Isolated topology permits the independent choice of rating of parameters on the secondary of the converter. The operation of solar panel under partial shading condition with subMIC is explained with help of diagram shown in figure 14.

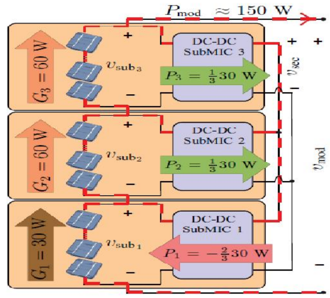

Fig 11: operation of solar panel with subMIC under partial shading conditions

The subMIC connected across the PV module which is under partial shading condition is handling a power of -20W. This -20W is extracted from the solar module under normal condition (10W each). Thus a total power output of 150W (50+50+50) is obtained. Unlike the use of bypass diode, subMIC gives convex characteristics. That is, the use of subMIC in solar panel gives only one peak in voltage power characteristics. Therefore the use of MPPT in sub-module integrated converter is very easy.

(a)*Converter topology-bidirectional flyback converter*

The dc-dc converter topology uses two MOSFET switches for bidirectional power flow. It can operate in two different modes. During mode-1 the duty cycle of switch-1 is set greater than duty cycle of switch-2 and voltage across the PV module is greater than converter voltage. Therefore the power flows from PV Module to converter output.During mode-2 the duty cycle of switch-2 is set greater than duty cycle of switch-1 and voltage across the PV module become less than (under partial shading condition) converter voltage. Therefore the power flows from PV Module to converter output. The converter topology uses a special controller which is a sensor less current controller.

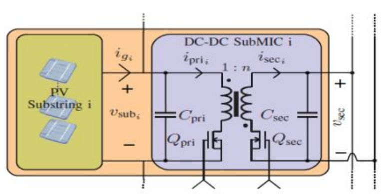

Fig 12: Bidirectional flyback dc-dc converter

(b)*Controller design in matlab*

For the control of bidirectional power flow a controller (sensor less current controller) is designed in MATLAB. The gating pulses to two MOSFET in bidirectional flyback converter is provided by this controller.

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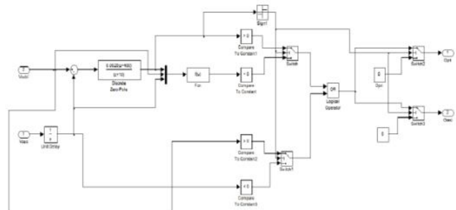

Fig 13: Model of sensor less current controller in MATLAB

The controller compares two voltages (voltage across the subMIC and PV module voltage).Then the difference is multiplied with a transfer function to convert the secondary value to primary value. After the comparison (taking account of sign of output) two gate pulses are produced. Simulation result shows that, the use of subMIC in solar panel under partial shading conditions

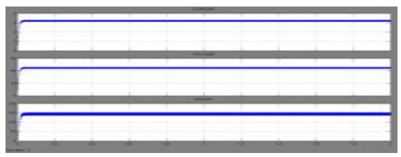

Fig 14: Simulation result for solar panel with subMIC under partial shading condition

gives extraction of maximum amount of power(60+60+30)In DMMPT, the output voltage of the shaded PV modules is reduced and the DC current is kept the same as in the non-shaded PV module. Therefore, the input voltage to the inverter is varied, and the total current is kept constant. The permanent D-MPPT is performed at each PV module. The voltage and current of the DC-DC stage of the shaded PV modules are reduced. The DC voltage at the inverter input is kept constant by increasing the DC voltage of the each DC-DC stage.

VI.PROPOSED METHOD- NOVEL MPPT ENHANCED PV MODULE

Combined centralized and distributed MPPT is the proposed method in this paper. Disadvantages of CMPPT is eliminated with the use of DMPPT and disadvantages of DMPPT is eliminated with the use of CMPPT. Figure 17 shows the combined C& D MPPT enhanced PV module.Main disadvantage of CMPPT includes, even with the use of IC MPPT maximum power cannot be extracted under partial shading conditions and the operation of MPPT is not stable under fast rate of variation of atmospheric conditions. But this problem of CMPPT can be eliminated by the use of DMPPT in the PV module which can extract maximum power even at high degree of irradiance variation.

Main disadvantage of DMPPT includes, inverter input voltage keeps on varying with varying atmospheric conditions. So the inverter cannot work properly with varying atmospheric conditions or with varying input voltage. This disadvantage of DMPPT is eliminated by the use of CMPPT which provides constant inverter input voltage.

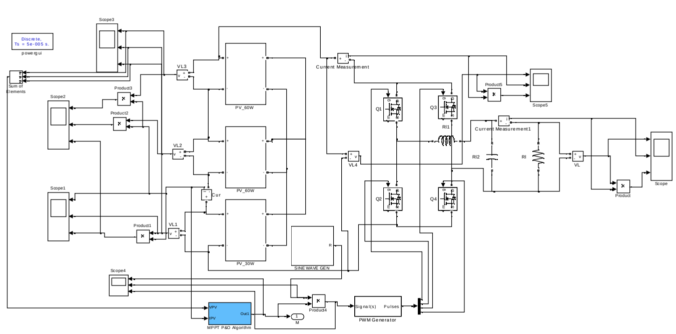

Fig 15: Novel MPPT enhanced PV module

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VII. RESULTS& DISCUSSIONS

Use of novel MPPT enhanced PV module causes extraction of maximum power under rapidly varying atmospheric conditions. Figure 16 shows the output waveform under partial shading condition. Even with high degree of partial shading condition the novel MPPT enhanced PV module gives maximum output.

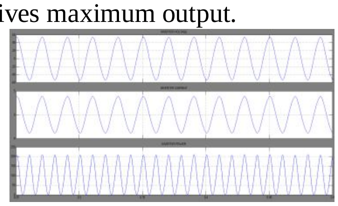

Fig 16: Output waveform of novel MPPT enhanced PV module under partial shading condition

Table 1: Table of Comparison

Sl.No	CIRCUIT	MAXIMUM AC OUTPUT IN WATTS UNDER PARTIAL SHADING CONDITION	
		WITHOUT MPPT	WITH MPPT
1	PV with centralized inverter	2.7	2.7
2	Series connected PV modules	41	43
3	Series connected PV modules with distributed Inverter	27	28
4	PV with DMPPT & centralized inverter(Proposed method)	200	210

Table 1 shows the comparison of various circuits of PV system under partial shading condition with and without MPPT based on simulation results. Use of MPPT in the PV module gives more output than the circuit with no MPPT under partial shading conditions. Novel MPPT enhanced PV module gives maximum efficiency compared to all other circuits discussed.

VIII.CONCLUSION

Inverter gets constant input voltage even under rapidly varying irradiance conditions with the use of CMPPT. And maximum output is extracted from PV module under partial shading condition with the use of CMPPT. Thus a combined C& D MPPT technique is very adequate for proper working of PV system. Novel MPPT enhanced PV module works with highest efficiency and overcomes the disadvantages of distinct CMPPT or distinct DMPPT enhanced PV module.

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