A Standalone PV System with a Hybrid P&O MPPT Optimization Technique

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Abstract—**In this paper a maximum power point tracking (MPPT) design for a photovoltaic (PV) system using a hybrid optimization technique is proposed. For maximum power transfer, maximum harvestable power from a PV cell in a dynamically changing surrounding should be known. The proposed technique is compared with the conventional Perturb and Observe (P&O) technique. A comparative analysis of power-voltage and current-voltage characteristics of a PV cell with and without the MPPT module when connected to the grid was performed in SIMULINK, to demonstrate the increment in the efficiency of the PV module after using the MPPT module.**

Keywords-maximum power point tracking; mppt; photo voltaic; perturb and observe; p&o; optimizaton

I. Introduction

A solar photo voltaic (PV) cell converts solar energy directly into electrical energy. The solar cell is fabricated with the use of semiconductor devices that produce voltage from solar irradiance. The efficiency of a solar cell is small as it converts 30%-40% of solar irradiance into electrical energy but the nature of the application provides obvious advantages. To overcome the efficiency problem, the Maximum Power Point Tracking (MPPT) technique is used, which increases the efficiency about 20% - 30%. A MPPT system is defined as an electronics device which guides the PV cell in a manner that all the power produced by the PV cell will be delivered to the load. Generally MPPT is used to transfer maximum power either with higher voltage & lower current or with lower voltage & higher current and MPPT is installed between the PV cell and the load. An appropriate MPPT algorithm is required to reach the MPP, as the MPP varies with the solar irradiance and cell temperature. MPPT algorithm gives the point where the actual power output of the PV cell reaches to its maximum value when the source impedance is equal to the load impedance. A boost converter is employed to the PV system which increases the output voltage. The boost converter matches the impedance by changing its duty cycle. A boost converter is connected between the PV cell and the load [1-2]. There are a number of MPPT techniques used for maximum power point tracking [3-4]. This paper considers the P&O (perturb and observe) algorithm and provides comparison with and without MPPT that demonstrates the improvement in efficiency. The block diagram of the proposed model is shown in Figure 1. It consists of a PV cell, the MPPT, the boost converter and the load. First the voltage and current are fed to the MPPT controller, and then the MPPT generates the required gate pulse to the boost converter, so as to maintain the output voltage across the load irrespective of temperature and solar irradiance.

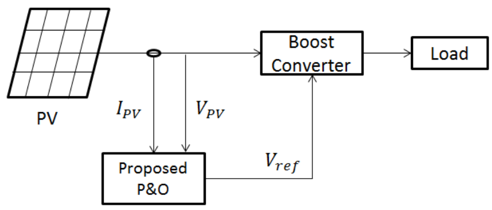

Fig. 1. Block diagram of the P&O method.

II. Characterstics of a PV System

A. Basic Characteristics of a PV Cell

A solar cell is based on the photoelectric effect i.e., the ability of a matter to emit electrons when light falls on it. A solar PV cell is a PN junction diode. When the photo current (I_{ph}) falls on the solar cell, the valance band electron (free electron) in the N-type semiconductor get energized and moves to the P-side to fill up the holes. So the holes moves opposite to the electron and treated as direction of current. If there is no load i.e. R_{se}=0, then a short circuit condition occurs that means the short circuit current $I_{ph}=I_{sc}=I_{max}$. So that net current I_{ph} = 0. If a load is connected, then a voltage produces across the load i.e. (V_{rse}), which is the diode voltage and this voltage(V_{rse}), forwards bias the PN diode. So a diode current (I_d) flows opposite to the photon current (I_{ph}). So the net current is given as $I=I_{ph}=I_d$ (always $I_d<I_{ph}$). If R_{se}=0, then I_{ph}=0, and at this condition, the diode voltage is given as $V_D=V_{max}=V_{oc}$.

B. Equivalent Circuit of a PV Cell

Photo voltaic cells have non-linear characteristics as the output power changes directly with the temperature of the PV cell and solar irradiance [6]. The equivalent circuit of a PV cell is a single diode model. Here Gallium arsenide is taken as the semiconductor material, which have the band gap energy=1.12. The equivalent circuit of a PV cell is shown in Figure 2.

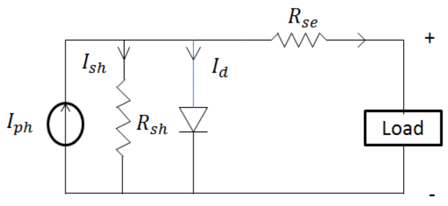

Fig. 2. Equivalent circuit of a PV cell.

The equivalent circuit consists of a diode, the photo current, the shunt field resistance and the series diode resistance. The net current is given as:

$$I = I_{ph} - I_d - I_{sh} \tag{1}$$

The photo current is given as:

$$I_{ph} = I_{ro}\left[I_{sc} + K_1\left(T_{op} - T_{ref}\right)\right] \tag{2}$$

where, I_{ro}=references irradiations=1000, I_{sc}=short circuit current=3.8 amp, K_1= current coefficient=22.2·10^{-3}, T_{op}=operating temperature=25+273.15°C, T_{ref}=reference temperature=25+273.15°C.

Diode current can be written as:

$$I_d = I_s\left[\exp\left(\frac{V_D}{\eta V_T}\right) - 1\right] = I_s\left[\exp\left(\frac{V_D}{\eta \frac{kT_{op}}{q}}\right) - 1\right]$$

$$= I_s\left[\exp\left(\frac{qV_D}{\eta kT_{op}}\right) - 1\right]$$

$$= I_s\left[\exp\left(\frac{q\left(V + IR_{se}\right)}{\eta kT_{op}}\right) - 1\right]$$

$$= I_s\left[\exp\left(\frac{q\left(V + IR_{se}\right)}{\eta V_T}\right) - 1\right] \Rightarrow$$

$$I_d = I_s N_P\left[\exp\left(\frac{\left(V + IR_{se}\right)}{\eta . V_T . C . N_S}\right) - 1\right]$$

So,

$$I_d = I_s N_P\left[\exp\left(\frac{\left(\frac{V}{N_S} + \frac{IR_{se}}{N_S}\right)}{\eta . V_T . C}\right) - 1\right] \tag{3}$$

where: η=ideality factor=1.36, k=Boltzmann's constant, q=charge in electron, C=number of cells=36, N_S=N_P=1, number of series and parallel paths.

Reverse saturation current is given as

$$I_S = I_{rs} * \left(\frac{T_{OP}}{T_{ref}}\right)^3 * \exp\left[\left(\frac{1}{T_{OP}} - \frac{1}{T_{ref}}\right) * \left(\frac{qE_g}{\eta k}\right)\right] \tag{4}$$

Where, reverse saturation current at operating temperature is given as

$$I_{rs} = \frac{I_{SC}}{\exp\left(\frac{qV_{OC}}{\eta kCT_{OP}}\right) - 1} \tag{5}$$

where: V_{OC}=open circuit voltage=21.1 V and I_{SC}=short circuit current=3.8 A.

Now the shunt field current is given as

$$I_{sh} = \frac{V + IR_{se}}{R_{sh}} \tag{6}$$

where V the output voltage, R_{se} the series field resistance, R_{sh} the shunt field resistance. Now putting the values of (2), (3) and (6) in (1), the net current of the PV cell can be obtained. Figures 3 and 4 show the I-V and P-V curve of PV cell with the temperature variation and change in solar irradiance.

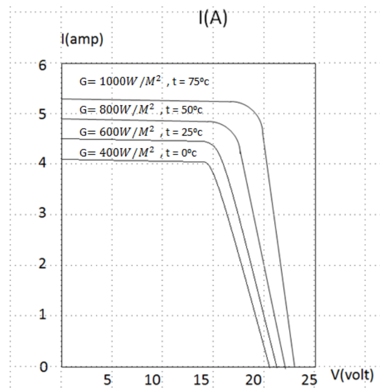

Fig. 3. I-V curve of a PV cell without MPPT.

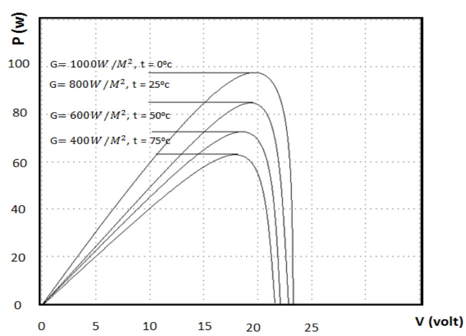

Fig. 4. P-V curve of PV cell without MPPT.

III. CHARACTERISTICS OF A BOOST CONVERTER

A boost converter has an important role for MPPT. It maintains the output voltage of PV cell by changing its duty cycle [3, 7]. So voltage at which maximum power obtained is determined. The duty cycle of the boost converter is given as $D = \frac{t_{ON}}{T}$ and the output voltage is given as $V_{out} = \frac{V_{in}}{1-D}$.

If D=0 then $V_{out}=V_{in}$ and if D=1 then $V_{out}=\infty$. So the value of duty cycle varies from 0 to 1. By adjusting the duty cycle, the output voltage as well as the output power can be adjusted. Figure 5 shows the basic boost converter circuit. The circuit contains an inductor, a capacitor, a diode, a switch (MOSFET/ IGBT) and the load. When the switch is ON, the MOSFET/IGBT is short circuited and the entire current goes through the path as shown in Figure 6. At this time the inductor is charging and the diode act as reverse biased, so the output circuit cut from the input circuit. When the switch is OFF, the MOSFET/IGBT is open circuited and the diode D1 is forward biased. Now the inductor discharges and the capacitor stores the charge. So a higher voltage ($V_{IN}+V_L$), minus a small voltage drop across the diode, appears across the load. After the initial start-up when the switch is OFF, capacitor discharges each time and the current across the load maintains as the same current. So the output voltage across the load is almost maintaining the steady voltage. Figure 7 shows the current path when the switch is OFF.

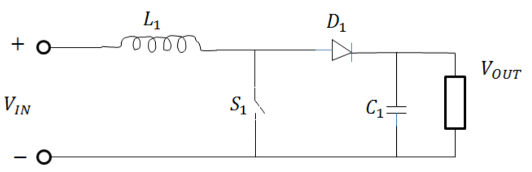

Fig. 5. Basic Boost Converter Circuit.

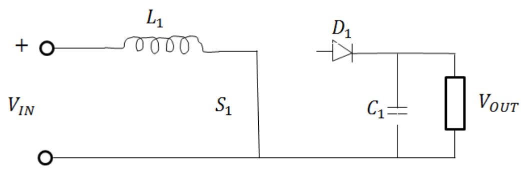

Fig. 6. Boost Converter Operation at Switch ON.

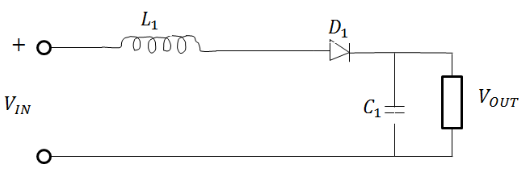

Fig. 7. Boost Converter Operation at Switch OFF.

IV. P&O AND ITS APPLICATION IN MPPT DESIGN

Due to the simple structure and convenience of the P&O method, it is generally used to track the maximum power [8-9]. It finds the maximum power point of PV cell by iteratively comparing and observing the generated power of the PV cell. In this algorithm, the maximum power point is obtained by changing the terminal voltage and output power of the PV cells. The terminal voltage and output power can change by adjusting the load. By comparing and observing the previous and current value of voltage and power, we can conclude on the maximum power point (Figure 8).

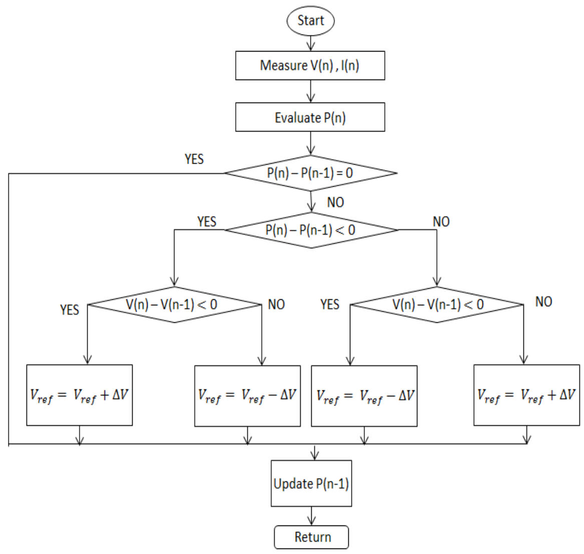

Fig. 8. The flow diagram of the P&O method.

One disadvantage is that oscillation occurs near the maximum operating point [10]. The magnitude of oscillation determined from variation of the output voltage. From the Figure 9, starting point is point A, and a +ΔV voltage perturbation moves the operating point A to B, causing a power drop with steady weather condition. According to the P&O method the voltage will change -ΔV in the opposite direction to maintain the output power. If the sun irradiance increases, power curve moves from P_1 to P_2 and operating point moves from A to C.

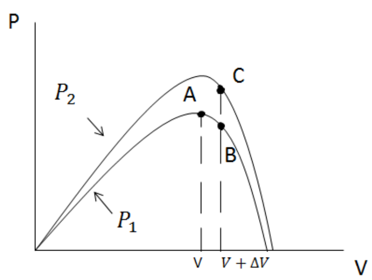

Fig. 9. Separation diagram of MPP for P&O.

V. SIMULATION RESULT

In this paper, soft switching boost converter for PV system interface has been implemented to reduce ripples at input current and switching losses in the converter. Figure 10 represents power vs voltage characteristics. As shown with an open circuit voltage of 1000 V and short circuit current of 47 A maximum power that can be tracked is 30 kW. From the I-V characteristic (Figure 11), it is clear that with an increase in voltage, initially current decreases gradually but there is a drastic decrease in current just after maximum power point. Results are shown in Table I.

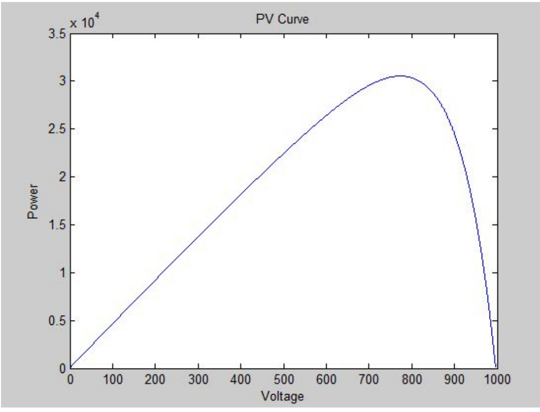

Fig. 10. PV curve of P&O MPPT.

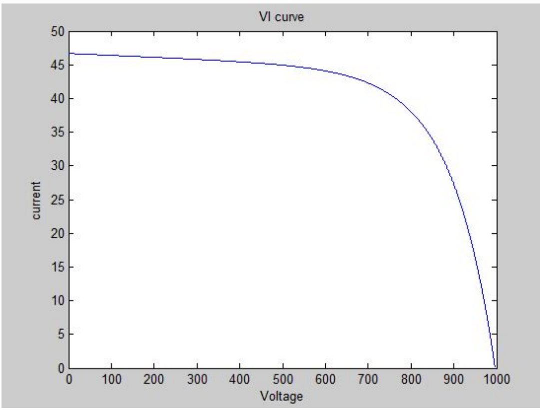

Fig. 11. I-V curve of P&O MPPT.

TABLE I. PERFOMANCE COMPARISON OF THE PROPOSED P&O MPPT METHOD FOR 1S1P CONFIGURATION

Shading Pattern	Maximum Power From PV Module (kW)	Tracking Techniques	Maximum Power (kW)	Tracking Efficiency
1S1P	32	Without MPPT	14	43.75
1S1P	32	P&O	30	93.75

VI. CONCLUSION

The classical MPPT tracking method has been simulated showing the increased tracking ability of a stand-alone PV system with the P&O MPPT technique. The PV simulation system used in this paper is simulated in MATLAB/SIMULINK. The model of PV modules used in the simulation is established according to the electrical specifications of industrial PV modules. After accomplishing the model of PV modules, the models of DC-DC boost converter and MPPT systems are combined with it to complete the PV simulation system with the MPPT function. The accuracy and execution efficiency for the MPPT algorithm can then be simulated under different weather conditions. Under normal environmental condition maximum achievable power is 30 kW.

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