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Dynamic Characteristics of PV System in Shaded/Un-shaded Portions Using MPPT Algorithm

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Abstract-In this paper, a combined low cost high efficiency converter and maximum peak power tracker has been presented. The maximum power point tracker system consists of DC-DC boost converter and PWM. PWM generates high quality sinusoidal line current. The suitable duty ratio for the boost converter will force the PV to work around the optimum voltage. The power generated by a PV cell depends on the operating voltage of the array, its voltage-current and voltage-power characteristic curves specify a unique operating point at which maximum possible power is delivered and the array is operated at its highest efficiency. One of the problems in designing efficient PV systems is to track the maximum power operating point for varying solar irradiance levels and ambient conditions. The output power produced by the PV panel is non-linear and changes with the solar irradiation and the ambient temperature. Therefore, a maximum power point tracking controller is needed to optimize the photovoltaic output power. A dc-dc converter is used to match the PV system to the load and to operate solar array at maximum power point .The perturbation and observation algorithm which is often employed to track the maximum power point This algorithm is selected due to its ability to withstand against any parameter variation and having a very high efficiency. As a result, by variation of the temperature and the insolation, the algorithm still managed to track the MPP successfully.

Index Terms- *Boost converter, Photovoltaic, high efficiency, MPPT*

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I. INTRODUCTION

Partial shading is one of the main causes for reduced energy yield of many PV systems [1]. Hence research activities have mainly focused on the influences of array configuration on the energy yield while in contrast very little attention has been drawn on the performance of the MPPT under shaded array conditions. So far hardly any information is available on the performance of MPPTs under such conditions, a fact which can be explained by the complexity and extensive measurement equipment required for this purpose Against this background, the aim of the work presented in this paper was to fill this gap by determining the actual impact of non-ideal, irregular conditions on MPPTs of state-of-the-art PV system and recommend solutions for improved MPPT performance For the MPPT algorithm, which aims at maximizing the power output of the array, it is obvious that non-ideal conditions resulting from partial shading can create considerable difficulties. P-V curves often exhibit multiple local maxima at different locations, which may also result in quite odd ratios between global MPP voltage and open-circuit voltage. These factors, can present a considerable hindrance to the accurate operation of a MPPT. Among the large number of MPPT techniques described in literature [3], most work on the principle of driving either d_P/d_I or d_P/d_V to zero. Accordingly the MPPT will exhibit a "local maximum tracking behaviour". That means once the MPPT has found a local maximum, it will track this maximum, irrespective of other maxima which might eventually be present at other positions of the V curve. In particular, this applies to the generic implementation of the most common methods Perturb and Observe (P&O), Incremental Conductance and Ripple Correlation Control. It is clear that considerable yield loss may occur if such a local maximum is tracked over time instead of the global MPPT.

II. MODELING THE SOLAR CELL

Thus the simplest equivalent circuit of a solar cell is a current source in parallel with a diode. The output of the current source is directly proportional to the light falling on the cell (photocurrent I_{ph}). During darkness, the solar cell is not an active device; it works as a diode, i.e. a p-n junction. It produces neither a current nor a voltage. However, if it is connected to an external supply (large voltage) it generates a current *ID*, called diode (*D*) current or dark current. The diode determines the I-V characteristics of the cell.

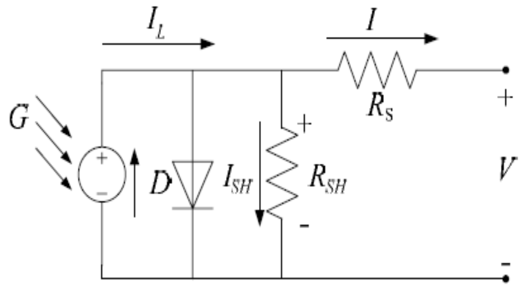

Fig. 1. Equivalent circuit diagram of the PV model

Increasing sophistication, accuracy and complexity can be introduced to the model by adding in turn [4]:

- Temperature dependence of the diode saturation current I_0.
- Temperature dependence of the photo current I_L.
- Series resistance *Rs*, which gives a more accurate shape between the maximum power point and the open circuit

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voltage. This represents the internal losses due to the current flow.

- • Shunt resistance R_{sh}, in parallel with the diode, this corresponds to the leakage current to the ground and it is commonly neglected
- Either allowing the diode quality factor n to become a variable parameter (instead of being fixed at either 1 or 2) or introducing two parallel diodes with independently set saturation currents

III. THEORETICAL EQUATION

The equation for the single-diode model, including series and shunt resistances, is given, where I_q is the light generated current, I_o is the reverse saturation current, q is the electronic charge, A is a dimensionless factor, K is the Boltzmann constant, T is the temperature in °K, R_s is the series resistance of the cell and equation for output voltage (V_o) is:

$$I = Iph - I_d\,[\exp(qV / K_b TA) - 1] \quad (1)$$

$$I_{ph} = S\,[I_{scr} + K_i\,(T - Tr)] \quad (2)$$

$$I_d = Irr\,[T / T_r]^3 \exp(qE_g / KQA\,[1/T_r - 1/T]) \quad (3)$$

Where

I, V output current, voltage (A, V).
T cell temperature (K).
S solar irradiance (W/m^2).
I_{ph} light-generated current.
I_d PV saturation current.
Irr saturation current at Tr.
I_{scr} short-circuit current at reference condition.
T_r reference temperature.
K_i short-circuit temperature coefficient
E_g band-gap energy of the material

For an ideal PV module, Rs is zero and Rsh is infinitely large. Interval shunt resistance is neglected. Output power produce by solar array are depend on solar irradiation and temperature. It influences the I-V and P-V characteristics

IV. PV MODULE CHARACTERISTICS

The Effect of the Temperature on the P–V Characteristic Curve Figure 2 and Figure 3 give the current–voltage (I–V) and power–voltage characteristics of a PV module for different values of solar radiation and temperature.

Figure 2 shows that the short circuit current is clearly proportional to the solar radiation which is more radiation, more current, and also more maximum output power. On Figure 3, the temperature is inversely proportional to the open-circuit voltage. An increasing in temperature causes a reduction of the open-circuit voltage (when sufficiently high) and hence also of the maximum output power. Hence, these opposite effects of the variations of solar radiation and temperature on the maximum output power make it important to track the maximum power point efficiently [4].

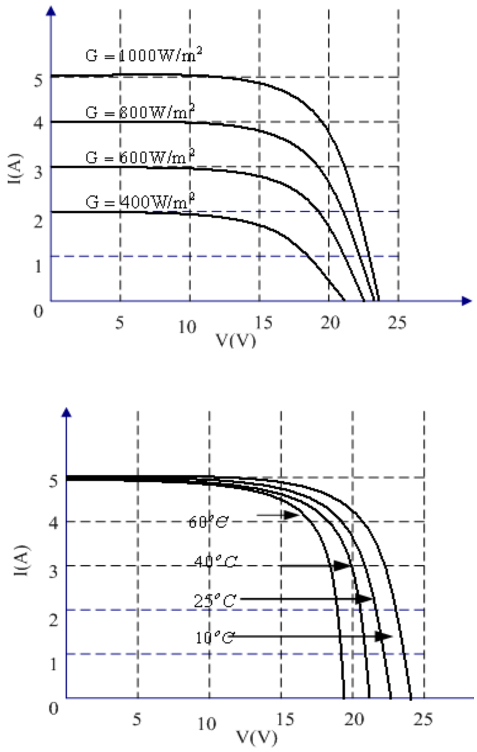

Fig.2.The Effect of the Temperature & Radiation on the I–V Characteristic Curve

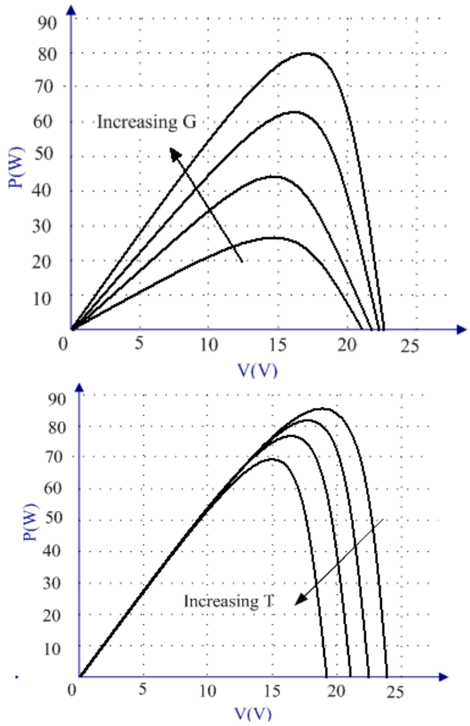

Fig.3.The Effect of the Solar Radiation on P–V Characteristic Curve

V. IRRADIANCE AND TEMPERATURE CHANGES.

Since the band gap energy decreases with rising temperature, more photons have enough energy to create electron-hole pairs. As a consequence of increasing minority carrier diffusion lengths the photocurrent, that is to say: the short-circuit current.

There are two possibilities to operate PV arrays at the maximum power point:

- Open-loop control.
- Closed-loop control.

The open-loop control scheme based on an assumption that the maximum-power-point voltage (*V*mp) is a linear function of *V*oc. For example, *V*mp = 0.75* *V*oc. This assumption is reasonably accurate even for large variations in *I*sc and temperature. This type of MPPT is probably the most common type. A variation in this scheme involves periodically measuring *V*oc. With the Closed-loop control scheme, more accurate maximum power point can be tracked. It involves in varying the input voltage around the optimal value by giving it a slightly increment or decrement alternately. As the consequences, the output power is then assessed and a small correction is made to both input voltage and input current. This method is also called a "hill-climbing algorithm". The power output of PV array is which depends on the irradiance and temperature conditions, so the result is sampled at a proper sampling period and compared with the previous value. In the event where the power is increasing, the solar array voltage is increased while the array current is slightly decreased. On the contrary, if the power is decreasing, the array voltage is decreased while the array current is slightly increased. The output power is finally tracked around the maximum power point. Note that, the array current also can be sampled and monitored as the system variable instead of monitoring the array voltage. The output power of the PV array can be expressed as

$$Ppv \square Vpv*Ipv \qquad (4)$$

The conventional MPPT algorithm used $dP/dV = 0$ to obtain the maximum output power point, hence the maximum output power of the PV array is also determined by

$$\frac{dP_{pv}}{dV_{pv}} = I_{pv} + \frac{dI_{pv}}{dV_{pv}} * V_{pv} \qquad (5)$$

Therefore, the MPPT algorithm can be developed [8].

VI. BOOST CONVERTER

Filters made of capacitors in combination with inductors are normally added to the output of the converter to reduce output voltage ripple [4]. By implementing the pulse width modulations technology (PWM) techniques on the boost converter, a stable output voltage from a non stable input voltage can be obtained by changing the duty cycle of the switched input pulse. The Boost converter is a simple power electronic converter and basically consists of a voltage source, an inductor, a power electronic switch (usually a MOS-FET or an IGBT) and a diode. It usually also has a filter capacitor to smoothen the output. Its function is to step up DC voltage to bring it to a desired level and is shown in Figure 4.

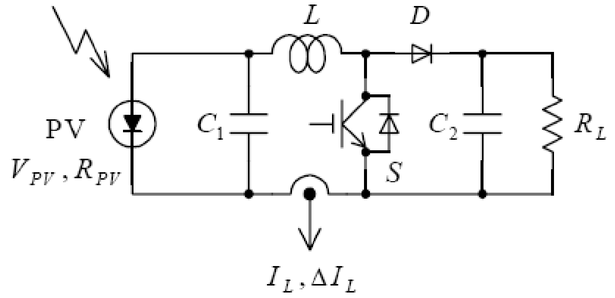

Fig .4. Equivalent diagram of boost converter

If the switch is turned on and off repeatedly at very high frequencies and assuming that in the steady state the output will basically be DC (large capacitor):

$$(i_c) = I_c = 0 \qquad (6)$$

$$(I_L) = I_L = I_R - I_{switch}$$
$$= I_R - DI_L \qquad (7)$$

$$I_L = V_O / R(1\text{-}D) \qquad (8)$$

The DC component of voltage across the inductor has to be zero if losses are neglected. The average voltage across the inductor is given by:

$$\begin{aligned}\langle v_L \rangle = 0 &= \frac{1}{T}\left(\int_{DT} v_{on} dt + \int_{(1-D)T} v_{off} dt\right) \\ &= \frac{1}{T}[V_s DT + (V_s - V_o)(1-D)T] \\ &= V_s - (1-D)V_o = 0 \end{aligned} \qquad (9)$$

After solving we get:

$$\frac{V_o}{V_s} = \frac{1}{1-D} \qquad (10)$$

The fraction to the right is always greater than one since the duty is always less than one thus the voltage is stepped up. The filter inductor that determines the boundary is given by

$$L_{boundary} = \frac{(1-D)^2 DR}{2f}$$

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For any inductance larger than this value the boost converter will operate in the continuous conduction mode. A much larger filter capacitance C is required as the current supplied to the output RC circuit is discontinuous. The limiting value is given by

$$C_{min} = \frac{DV_o}{V_r R f}$$

If the energy generated at the MPP is not enough to supply the load, the power system operates as a boost converter, transferring energy from the battery to the load. In this case, while the switch is turned on, the inductor L stores energy from the battery, as shown in Fig.5 When the switch is turned off, the energy stored in the inductor is transferred to the load. Fig. shows the command signal of the power switches

VII. MAXIMUM POWER POINT TRACKING CONTROL

Maximum power point tracking (MPPT) is a form of an electronic arrangement to sense the array output and provides the input impedance required to maintain operation at the maximum power point irrespective of the insolation level [7]. It is able to track or trace the input power from the solar array and the voltage from the battery bank. It then re-adjusts the voltage for the highest ampere output to the battery bank. MPPT is capable of taking a higher voltage and down converting to a lower voltage. One other use of MPPT is capable of adjusting with cloud cover or edge of cloud brightness. MPPT controllers use pulse width modulation (PWM) as well. PWM charging allows the battery to reach full charge by pulse charging, The PWM pulses slower, gradually tapering off the charge as the battery fills with amps. Pulsing is good for the batteries because it mixes the electrolyte cleaning the lead plates. This technology is used in most all charge controllers. There are many MPPT methods available and the most widely-used are constant voltage method, open voltage method, perturb and observe method and etc.

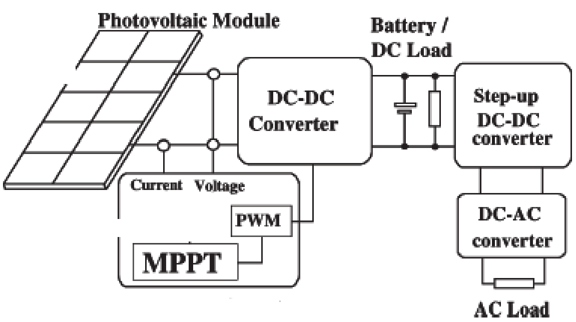

Fig .5.MPPT system block diagram.

The classical implementation of the MPPT is the connection of a dc–dc converter between the source and load, which is as shown in Fig. 2 and which presents both functions of battery charger and MPPT. In order to obtain a good dynamic performance from the MPPT, different control algorithms were developed [4]–[8]. With data for the actual power extracted from the PV array, which are obtained by measuring the voltage and current in the PV array, the task of these algorithms is to change the converter duty cycle in order to reach the MPP.

VIII. PERTURB-AND-OBSERVE (P&O) METHOD

The perturb-and-observe method, also known as perturbation method, is the most commonly used MPPT algorithm in temperature variations. This is essentially a "trial and error" method. The PV controller increases the output power by a small amount, and then detects the actual output power. If the output power is indeed increased, it will increase again until the output power starts to decrease, at which the controller decreases the reference to avoid collapse of the PV output due to the highly non-linear PV characteristic. Although the P&O algorithm is easy to implement, it has a number of problems, (1) the PV system cannot always operate at the maximum power point due to the slow trial and error process, and thus the solar energy from the PV arrays are not fully utilized; (2) the PV system may always operate in an oscillating mode even with a steady-state sunshine condition, leading to fluctuating inverter output; and(3) the operation of the PV system may fail to track the maximum power point due to the sudden changes in sunshine. When the irradiance decreases, the P&O method tracks the maximum power point well and the tracking error is nearly zero. However, when the irradiance increases, the P&O control does not track the maximum power point well, and the maximum tracking error is nearly 100W that is around 8% of the full.

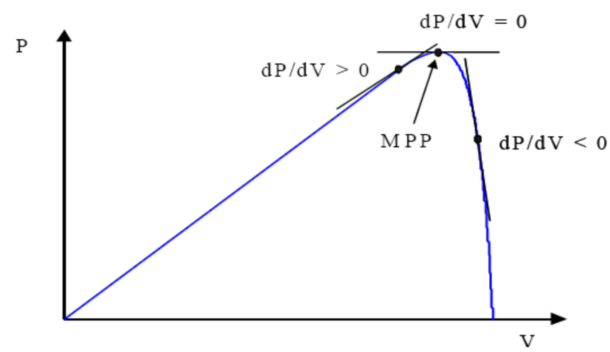

Fig .6.Perturb & Observe (P&O) control action

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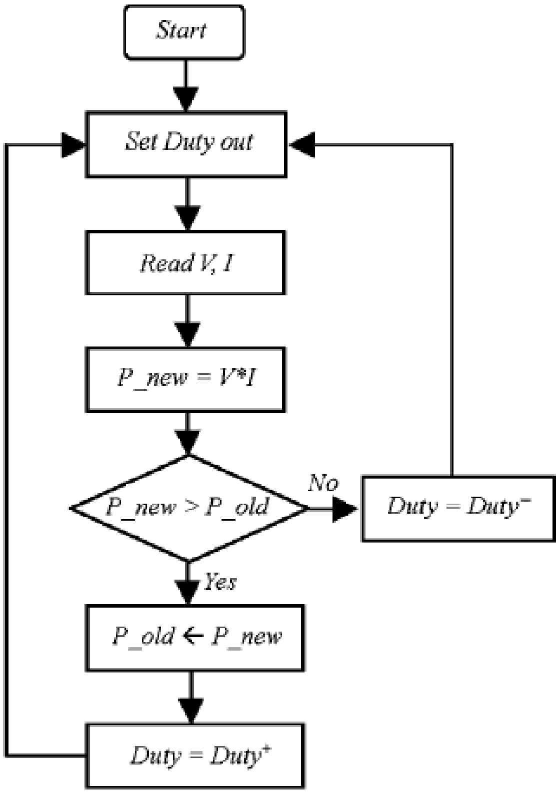
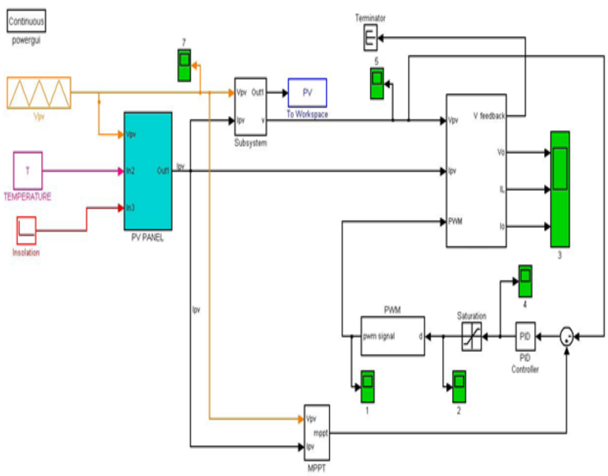


Fig .7.Perturb and Observe Method Flowchart

Figure.7 shows the flowchart of P&O algorithm method. The P&O algorithm would then continue to perturb the PV array voltage in the same direction. If $d_P/d_V < 0$, then the change in operating point moved the PV array away from the MPP, and the P&O algorithm reverses the direction of the perturbation [9]. The advantage of the P&O method is that it is easy to implement. However, it has some limitations, like oscillations around the MPP in steady state operation, slow response speed, and even tracking in wrong way under rapidly changing atmospheric conditions [9][11].

IX. EXPERIMENTAL RESULTS



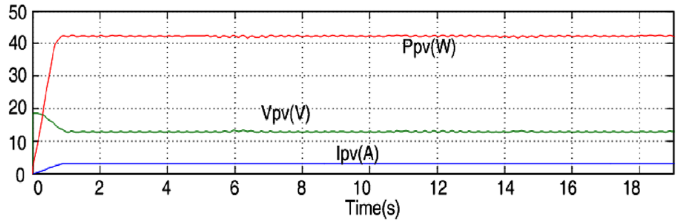


Fig.8. Output voltage, current, power waveforms

Duty-Cycle control

The output voltage is measured and then compared to the reference. The error signal is used as input in the compensator, which will calculate it from the duty-cycle reference for the pulse-width modulator.

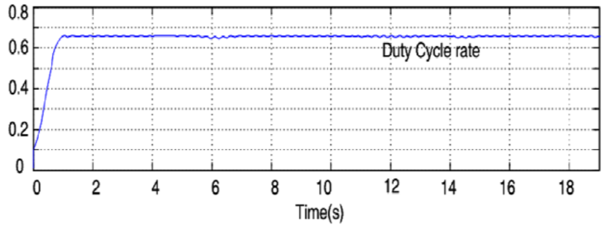


Fig.9. Duty-Ratio cycle

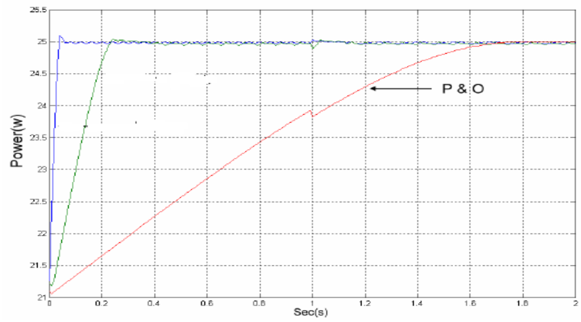


Fig.10. Output power in P & O Algorithm

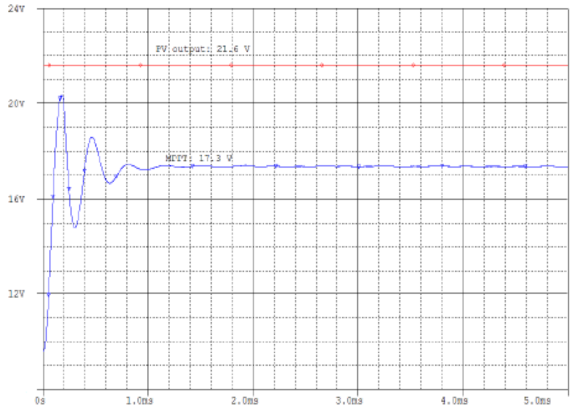


Fig.10.Boost converter output and P& O Algorithm Waveforms

Boost converter output and mppt Fig. 9 shows the PV output power, voltage and current for the P & O control proposed in this paper. This figure shows the waveforms that are similar to those of Fig. 10.

XI. CONCLUSION

An improved performance MPPT algorithm with accurate power tracking ability has been proposed in this paper for PV systems. In additional to the fast tracking feature, because the responding speed and tracking accuracy are considered separately in the proposed P & O method, the perturbation steps can be set to be very small. As a result the tracking accuracy of the proposed method is much improved Moreover, the output power losses caused by the dynamic tracking errors can be significantly reduced, which is particularly important under dramatic weather changing conditions. The PV array output power delivered to the load can be maximized using MPPT control method. The adaptive algorithm was implemented to satisfy the good dynamic response and steady-state performances .Improved tracking performance of this proposed method was verified through experiment.

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