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A Review on Photovoltaic Module and its Various Simulation Methods

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Abstract- The solar panel is a highly non-linear source and to select a right operating point on the I-V characteristics based on measured load current and voltage is very crucial in order to obtain maximum output. Several PV Simulation techniques for obtaining right operating point on the I-V characteristics of PV cell are available. In this paper mathematical model of a single diode PV module with different techniques for PV Simulation are briefly presented and compared.

Keywords- **Photovoltaic System, Maximum Power, PV Array**

I. INTRODUCTION

Non conventional sources are becoming popular for industrial and domestic application. There are many equipments which work on solar energy. With the ever increasing range of use of PV systems, it is imperative that better design methodologies, such as more accurate models and simulation techniques, be developed for PV applications[1-3]. The solar panel is a highly non-linear source. Existing methods for PV simulation face the problem of implementing an effective scheme for selecting the right operating point on the I-V characteristics based on measured load current and voltage.

This paper gives short summary and discussion about several PV Simulation techniques for obtaining right operating point on the I-V characteristics of PV cell.

II. CHARACTERISTIC AND MATHEMATICAL MODEL OF PV ARRAY

A. Equivalent Electric Circuit of Photovoltaic Cell

The most important component that affects the accuracy of the simulation is the PV cell model. Modeling of PV cell involves the estimation of the I-V and P-V characteristics curves to emulate the real cell under various environmental conditions. The most popular approach is to utilize the electrical equivalent circuit, which is primarily based on diode.

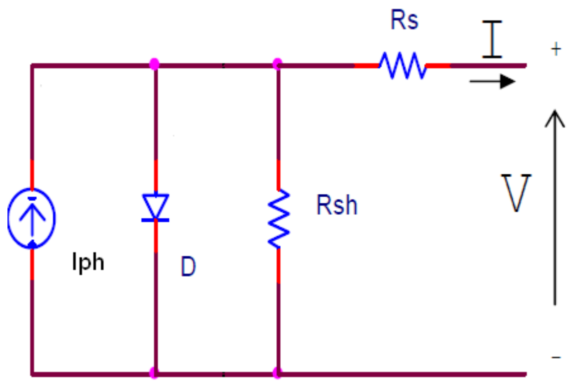


Fig1: Equivalent Circuit of the Solar cell

The output current I is:

$$I = I_{ph} - I_s\left[\exp\left(\frac{V + IR_s}{NV_T}\right) - 1\right] - \frac{V + IR_s}{R_{sh}}$$

where:

I_{ph} is the solar-induced current

I_r is the irradiance (light intensity) in W/m_2 falling on the cell.

I_{ph0} is the measured photo-generated current for the standard irradiance Ir0.

$I_s$is the diode reverse saturation current.

k is the Boltzmann constant.

T is the measurement temperature parameter value.

q is the elementary charge of an electron.

V is the voltage across the solar cell electrical ports.

I is the output current of PV cell.

N is the diode ideality factor.

The Ideality factor varies for amorphous cells, and is typically 1-2 for polycrystalline cells.

The above equation originates the I-V curve seen in Fig. 2, where three *remarkable points* are highlighted: short circuit (0, Isc), maximum power point (Vmp, Imp) and open-circuit (Voc, 0).

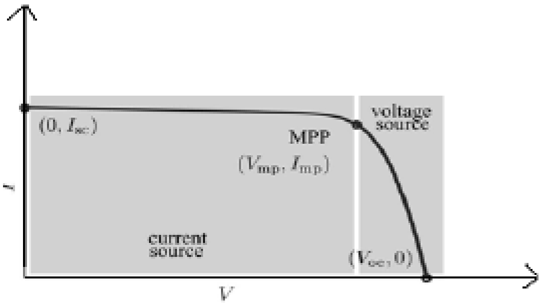
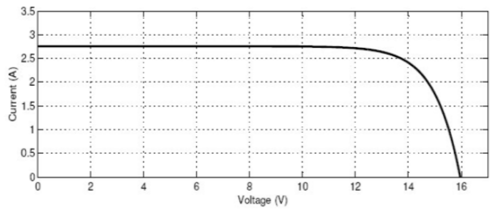


Fig. 2. Characteristic I–V curve of a practical PV device and the three remarkable points: short circuit
(0, Isc), MPP (Vmp, Imp), and open circuit (Voc , 0).

Also where,
Isc , short circuit current, flows with zero external resistance(v=0) and is the maximum current delivered by the solar cell at any illumination level.
Voc ,open circuit voltage, is the potential that develops across the terminals of the solar cell when the external load resistance is very large.
Power delivered to the load is zero at both extremes and reaches a maximum (Pmax) at a finite load resistance value.

III. SOLAR CELL V-I CHARACTERISTIC AND AFFECTING PARAMETERS

Each solar cell has its own voltage-current (V-I) characteristic. Figure 3 shows the V-I characteristic of a typical photovoltaic cell. The problem with extracting the most possible power from a solar panel is due to nonlinearity of the characteristic curve. The characteristic shows two curves, one shows the behavior of the current with respect to increasing voltage. The other curve is the power-voltage curve and is obtained by the equation (P=I*V).



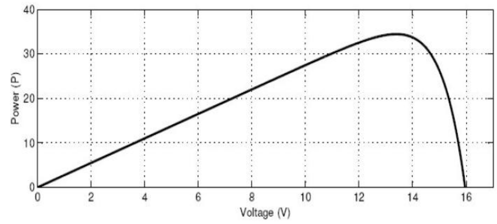


Figure 3: Solar panel V-I characteristic and Power curve

When the P-V curve of the module is observed, one can locate a single maxima of power where the solar panel operates at its optimum. In other words, there is a peak power that corresponds to a particular voltage and current. Obtaining this peak power requires that the solar panel operate at or very near the point where the P-V curve is at the maximum. However, the point where the panel will operate will change and deviate from the maxima constantly due to changing ambient conditions such as insolation or temperature levels, which we will discuss further[5]. The result is a need for a system to constantly track the P-V curve to keep the operating point as close to the maxima as much as possible while energy is extracted from the PV array.

1. Effect of Irradiance

Irradiance is an important changing factor for a solar array performance. It is a characteristic that describes the density of radiation incident on a given surface. In terms of PV modules, irradiance describes the amount of solar energy that is absorbed by the array over its area. Irradiance is expressed typically in watts per square meter (W/m2). Given ideal conditions, a solar panel should obtain an irradiance of 100mW/cm2, or 1000W/ m2)7. Unfortunately, this value that is obtained from a solar panel will vary greatly depending on geographic location, angle of the sun, or the amount of sun that is blocked from the panel because of any present clouds or haze. Although artificial lighting can be used to power a solar panel, PV modules derive most of their energy solely from the energy emitted from the sun. Therefore, changes of irradiance will greatly affect a PV module's performance.

2. Effect of Insolation Levels

Insolation is closely related to irradiance and refers to the flux of radiant energy from the sun. Taken as power per unit area, whose intensity and spectral content varies at the earth's surface due to time of day (position of the sun), season cloud cover, and moisture content of the air among other factors much like irradiance, insolation measures how much sunlight energy is delivered to a specific surface area over a single day. Insolation is typically measured as kilowatt-hours per square meter per day (kWh/(m2*day)) or in the case of photovoltaics, as kilowatt hours per year per kilowatt peak rating (kWh/kWp*y). In order to obtain the maximum amount of energy from a PV module, it should be set up perpendicular with the sun straight overhead, with no clouds or shade.

3. Effect of Temperature

A PV module's temperature has a great effect on its performance. Although the temperature is not as an important factor as the duration and intensity of sunlight it is very important to observe that at high temperatures, a PV module's power output is reduced. The temperature of a PV module also affects its efficiency. In general, a crystalline silicon PV module's efficiency will be reduced about 0.5 percent for every degree C increase in temperature. Figure demonstrates the effect of varying temperature on the output of a solar panel. One can easily see a voltage drop with increasing heat. The effect of varying temperature does not have a very large effect on the current developed.

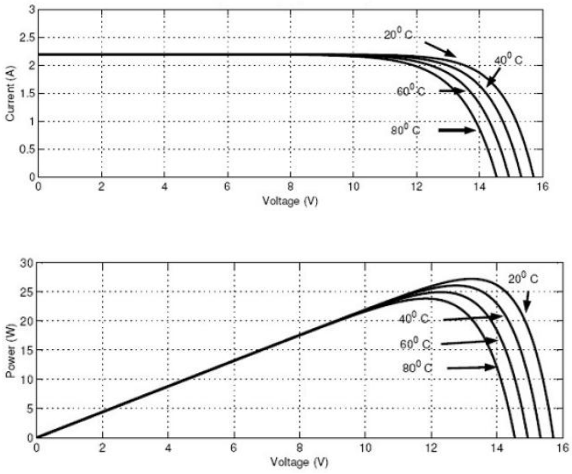


Figure .4 .:Temperature effect on solar panel power and I-V curves

4.Efficiency

Efficiency is most definitely one of the biggest issues when observing PV module performance. Different types of solar cells have varying efficiencies that vary depending on several factors. In order to ensure efficient absorption, the reflection from the surface of a solar cell must first be reduced. A semiconductor surface that has already been polished will still reflect a significant fraction of incident photons from the sun. Silicon, for example, will reflect 30% of such photons11. Texturing the surface of such cells helps mitigate reflection problems.

Also ,a solar panel's efficiency is limited by the bandgap energy of the semiconductor from which a cell is made. Low bandgap materials will allow the threshold energy to be exceeded by a large fraction of the photons in sunlight, allowing a potentially high current. On the other hand, a solar cell will extract from each photon only an amount of energy slightly smaller than the bandgap energy, with the rest being lost as heat. This is because the excess energy from the photon results in the electron energy being higher than the bandgap. This leads to the electron settling in the conduction band and releasing energy as heat. Unfortunately, a semiconductor is transparent to photons with energy less than that of its bandgap and thus cannot capture their energy. In other words, the photons do not contain enough energy to create an electron-hole pair, so the photon simply passes right through the semiconductor. These two factors, thermalization, and transparency, are two of the largest loss mechanisms in conventional cells. Thus there are still many problems that affect the overall performance of such an array. If a method is ensured such that the maximum power is constantly taken from a solar panel array, a solar panel's efficiency would increase and the overall usefulness of solar power as a renewable energy source will be invaluable.

IV METHODS FOR PV SIMULATION AND THEIR COMPARISON

A.Existing methods for PV Simulation

Existing methods for PV Simulation are 1)Trivial voltage control method 2)Current control method 3)Hybrid control strategy.The solar panel is a highly non-linear source, as seen in its typical I-V characteristics in Fig. 5 . All these Existing methods of PV simulation face the problem of implementing an effective scheme for selecting the right operating point on the I-V characteristics based on measured load current and voltage. A trivial voltage control technique that changes output voltage in the direction of the expected PV for the measured load current cannot be used since PV current is almost constant at low voltages, making the expected operating voltage hard to select in this region. Similarly, a current control technique will fail in the high output voltage region owing to the difficulty in selecting an accurate current reference.

One more method proposed is a hybrid control strategy [10] that divides the I-V characteristics into three segments, as shown in Fig. , employing different control methods for each segment. In the Current Source Segment in particular, a current controlled method selects the operating current and then uses a PI controller to converge to this current by varying simulator voltage. However, as will become clear later, this method has a number of drawbacks for simulating R-L loads that operate in this region. In addition, the use of a PI controller will increase convergence time and implementation complexity.

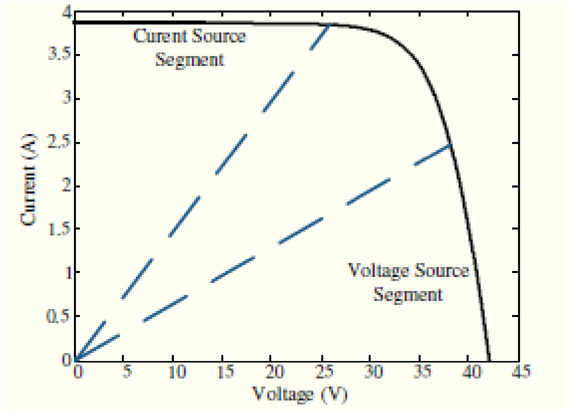


Fig.5. Hybrid control strategy for solar panel simulation

An alternative implementation in [4] selects the operating point using the intersection of the photovoltaic I-V curve and the predicted load I-V curve. The intersection is found using a look-up table, which inherently adds a degree of inaccuracy to the simulator. Importantly, this method, too, will fail to track R-L loads that operate at low voltages where the PV current remains almost constant.

B. Recent Method for PV Simulation

Adaptive Control Method for PV Simulation

In this method a novel adaptive control based strategy for accurate simulation of solar panels under any given physical condition and for any general static or dynamic load is developed .Thus it can simulate all types of solar panels for any given temperature and irradiance setting using only datasheet values, thus eliminating the need for purchasing and field-testing of solar panels[7][9].The method requires only PV datasheet values to set up the simulator for any given operating condition.Thus the contributions of this method are two-fold: (i) the development of a novel adaptive control based PV simulation methodology for dynamic tracking of any general load, and (ii) requires only PV datasheet values to set up the simulator for any given operating condition. Additionally, the developed simulation algorithm can choose gains and other constant parameters automatically prior to simulation, making the process of setting up the simulator from the PV datasheet very quick, and allowing multiple solar panels to be quickly tested on the simulator.

This method helps to resolve drawbacks of the existing methods while being fast, simple, and robust. A fast-converging algorithm for tracking of all static and dynamic loads is implemented using an adaptive control scheme, which automatically selects additional adaptive components for the tracking of certain special kinds of loads. The philosophy behind the controller is to change the simulator output voltage based on the difference between the circuit current and the expected photovoltaic module current for the present operating point.

Denoting by ILoad the circuit current, and by IPV (V) the current the solar panel would have provided at the present output voltage,

$$\Delta V = G_1 \times G_2 \times (I_{PV}(V) - I_{Load})$$

In other words, the controller adjusts simulator output voltage by using a proportional controller that acts on the error in the simulator current. The adaptive gain terms, G1 and G2, are elaborated on below, with G1 a general term for all loads to prevent undershoot, and G2 a specific gain term that automatically acts when highly inductive loads with small resistances are detected. The controller adjusts the output voltage so as to seek the operating point where the current through the load, ILoad, is the same as the PV module current, IPV , for that operating point.

Thus, the simulator voltage is updated as:

VLoad ← VLoad + V

The controller is adaptive in the sense that controller gains G1 and G2 change based on conditions observed in the circuit.

Thus by adjusting the values of G1 and G2,change in load current can be made equal to change in load voltage thus getting an appropriate operating point on the characteristic of Photovoltaic cell.

Also an algorithm is provided which senses current ILoad in the circuit to update VLoad every cycle.

Thus this method helps us to resolve drawbacks of the existing methods by selecing a right operating point on the I-V characteristics based on measured load current and voltage and giving maximum output while being fast, simple and robust.

V. CONCLUSION

A model is proposed based on the fundamental circuit equations of a solar PV cell taking into account the effects of physical and environmental parameters such as the solar radiation and cell temperature. The paper establishes the need for accurate PV simulation and thus explains several PV Simulation techniques for obtaining right operating point on the I-V characteristics of PV cell.It also discusses deficiencies of the existing PV simulation methods and thus bring forward recent Adaptive Control for PV Simulation which is fast, simple and robust.

The proposed method requires only PV datasheet values for simulation at any given temperature and irradiance setting. A controller-based strategy for PV simulation is proposed that uses two adaptive terms, with the first a general term for all loads, and the second a specific term that is automatically selected when an inductive load with low resistance is detected. The controller enables dynamic tracking of all kinds of loads, with no a priori information of the load needed. Thus it can be said that by using proper PV Simulation technique a solar panel's efficiency would increase and the overall usefulness of solar power as a renewable energy source will be invaluable.

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