A Typical Assessment Of Photovoltaic Array: Modelling, Simulation and Application Aspects

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***Abstract*—The paper provides a deep insight into PV array behaviour. The paper provides the information regarding modelling techniques and its simulations. It also presents different installation aspects and power handling of PV array. Some issues and solution related to the PV array are also reviewed in the paper.**

***Keywords*—Photovoltaic, PV array, MPPT, Array Grounding, Grid Connected Array**

I. Introduction

PV cell are basically semiconductor diode. This semiconductor diode has got a p-n junction which is exposed to light. When illuminated by sunlight it generates electric power .Though many materials might be used but mono-crystalline silicon and poly-crystalline silicon are mainly used for commercial use. The power produced by a single PV cell is not enough for general use. So by connecting many single PV cell in series and in parallel can get us the desired power. The series connection is used for high voltage requirement and the parallel is used for high current requirement .Generally a series connection is chosen this set of arrangement is known as a module. Generally commercial modules consist of 36 or 72 cells. The modules consist of transparent front side, encapsulated PV cell and back side. The front side material is usually made up of low-iron and tempered glass. The efficiency of a PV module is less than a PV cell. This is due to the fact that some radiation is reflected by the glass cover and frame shadowing etc.

A photovoltaic array (PV system) is a interconnection of modules which in turn is made up of many PV cells in series or parallel. The power produced by a single module is seldom enough for commercial use, so modules are connected to form array to supply the load. The connection of the modules in an array is same as that of cells in a module. Modules can also be connected in series to get an increased voltage or in parallel to get an increased current.

II. PV Module and Array Model

A. Single Diode Model

The equivalent circuit of the general model is composed of photo current source, diode, and parallel resistor expressing the leakage current, and series resistor describing the internal resistance to the current flow. The *I-V* characteristic equation of a PV cell is given as:

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

Eq. (1)

where I_{ph} is a light-generated current or photocurrent, mainly depends on the solar cell working temperature, I_s is the cell saturation of dark current, varies with the cell temperature , q (= 1.6 × 10-19 C) is the electron charge, k (= 1.38 × 10-23 J/K) is Boltzmann constant, T is the cell working temperature, A is the ideal factor, R_{sh} is the shunt resistance, and R_s is the series resistance.

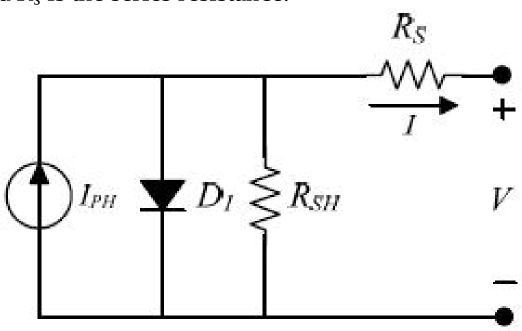

Fig. 1 Equivalent circuit of PV cell

The approximate model of a PV cell with suitable complexity can be derived from Eq. (1) via neglecting the effect of the shunt resistance and be rewritten as:

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

For an ideal PV cell (no series loss and no leakage to ground, i.e., *RS* = 0 and *RSH* = ∞, respectively), the equivalent circuit of PV cell can be further simplified where Eq. (1) can be rewritten as:

$$I = I_{ph} - I_s\left(\exp\left[\frac{qV}{kTA}\right]-1\right)$$

The power that one module can produce is seldom enough to meet requirements of a home or a business, so the modules are linked together to form an *array*. The cells should be arranged in series-parallel configuration on a module to produce enough power.

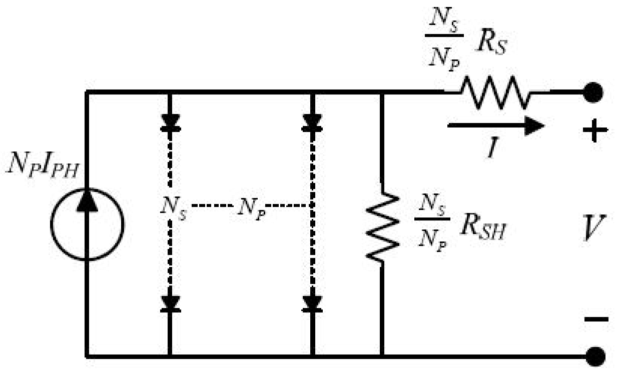

Fig. 2 Generalized array model

The equivalent circuit for a PV module arranged in N_P parallel and N_S series cells is shown in Fig. The terminal equation for the current and voltage of the array becomes as follows:

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

B. Double Diode Model

In this model an extra diode attached in parallel to the circuit of single diode model. This diode is included to provide an even more accurate I-V characteristic curve that considers for the difference in flow of current at low current values due to charge recombination in the semiconductor's depletion region.

The accuracy of this model is more than the single diode model but because of the difficulty to solve the equation, single diode model is preferred.

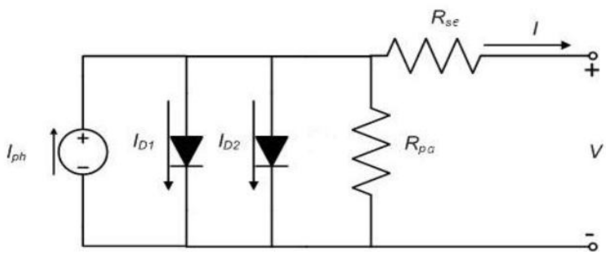

Fig. 3 Equivalent circuit of PV cell using two diodes

The characteristic equation for double diode model for a PV cell is given by:

$$I = I_{ph} - I_{01}\left(\exp\left[\frac{q(V + IR_s)}{kTA} \right] - 1 \right) - I_{02}\left(\exp\left[\frac{q(V + IR_s)}{kTA} \right] - 1 \right) - \frac{(V + IR_s)}{R_{sh}}$$

Where,
I_{01}- Saturation current due to diffusion
I_{02}- Saturation current due to recombination in the space charge layer

As discussed preciously in single diode method it may also be implemented for PV array for more accurate analysis.

C. Methods for desired parameters

If a datasheet of different solar panels is used e.g. 1-STH-235(235W), 1-STH-235(235W), 1-STH-235(235W), AB-1 (65W), AB-225MK (225W), then mainly 5 parameters are found unknown I_{ph}, I_0, A, R_s, Rsh. Two methods may be used for this.

1) Newton's Method: Since, it assumes the value of diode ideality factor beforehand, only two parameters remain unknown. These can be easily determined using Newton method to solve a non-linear equation. No experimental data is required. A big compromise is done by assuming diode ideality factor beforehand. The parameters obtained can be less accurate. Though the computational time is less with respect to other method the number of iterations is large.

2) *Newton Raphson Method to solve system of Non-linear equation:* No compromise with any parameter is done. Accuracy is more than the previous method. Though computational time is more, the equations converge in 4 to 10 iterations. Initial values should be properly determined otherwise there is greater number of chances for divergence to take place. Therefore, proper experimental values are required.

D. I-V and P-V Characteristics

The I-V and P-V Characteristics for the photovoltaic array are shown in the figure. The equations are simulated using MATLAB.

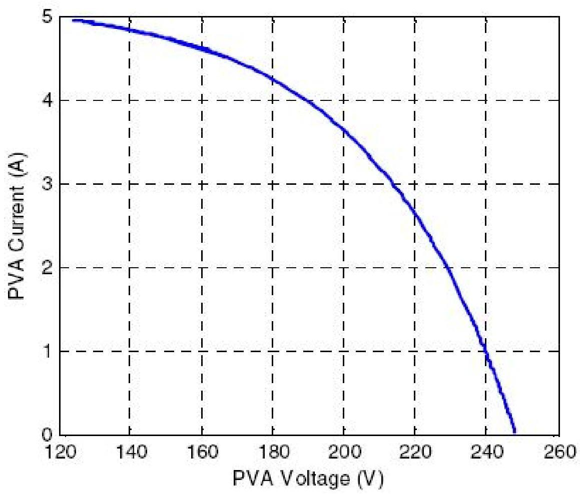

Fig. 4 I-V Characteristics of PV array

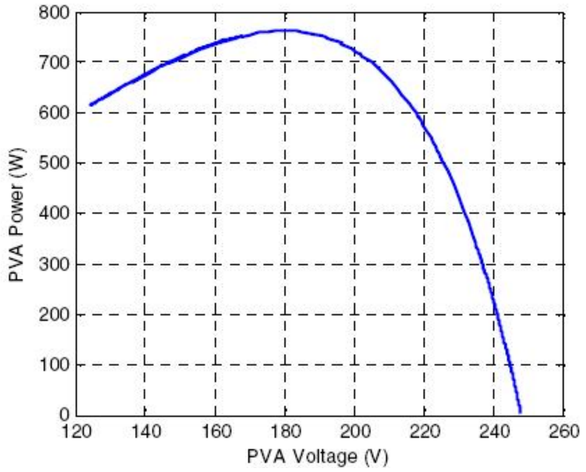

Fig. 5 P-V Characteristics of PV array

III. MPPT (MAXIMUM POWER POINT TRACKING)

A. P&O Algorithm

The “perturb and observe” or P & O algorithm searches for the MPP on a P-I or P-V curve by comparing its sampled power and voltage with its previous power and voltage respectively. The operating point of a PV array is thus always shifted towards the MPP. The P & O has some advantages including its ease of operation, its previous implementation with some modifications to improve its operation, and its fast convergence speed. On the other hand, this algorithm can oscillate around the MPP and in case of natural perturbations in the circuit due to the switching converter, the oscillations would increase due to the perturbations of the converter and the perturbations of the array voltage. Also, the “perturb and observe” algorithm could diverge from the MPP under rapidly changing climate conditions.

B. RCC Algorithm

Ripple correlation control (RCC), is a recently proposed and attractive MPPT technique that is currently under research to track the maximum power of a single array. The main advantages of RCC include the asymptotic convergence to the MPP and the utilization of the ripple available in the power electronic converter instead of using external perturbation. The main operation concept of the RCC is that it correlates the time varying PV array power with the time varying PV array current or voltage.

IV. GRID CONNECTED ARRAY

A grid connected array is connected to a larger independent and feeds energy directly into the grid. This energy may be shared by a residential or commercial building before or after the revenue measurement point. The analysis for grid array involves collecting data on temperature, solar radiation, and the performance of different photovoltaic arrays. These different arrays used include single crystal, multicrystal and amorphous silicon arrays, which are the most common installed types. By creating a model which predicts the power output as a function of solar radiation and temperature, a side-by-side comparison of different arrays can be made. Current predictive models are not useful for a grid connected system, which is limited to operate at the maximum power point, thus adaptations to previous models have been made.

The focus of this analysis has been on measuring the impact of solar radiation on the power output of grid connected arrays. The solar spectrum is constantly changing throughout the day and year. This is caused by absorption and re-radiation in the atmosphere. A power output versus time result is shown in the figure for a particular day. This may vary in accordance with the climate of the day.

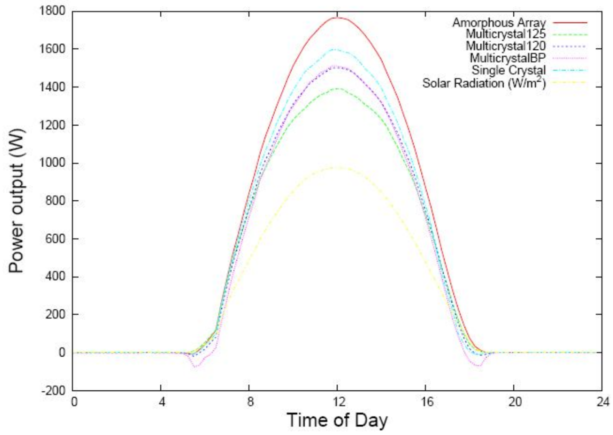

Fig. 6 I-V Power Output versus clock time at a particular day

V. PV ARRAY GROUNDING

PV systems need to be grounded just like other electrical systems. PV arrays are usually mounted away from tall objects that could shade the array. PV systems are grounded to limit and stabilize the voltage to ground during normal operation, and to prevent excessive voltages due to lightning, line surges, or unintentional contact with higher voltage lines.

With the increasing numbers of utility-interactive PV installations in urban environments, PV systems are being located in close proximity to high voltage transmission lines. In the event of high winds, earthquakes, or accidents, there is a remote possibility that high voltage lines may come into contact with PV arrays. In dry climates, high winds can build up high static electric voltages on large PV arrays. Grounding PV modules to reduce or eliminate shock and fire hazards is necessary, but can be difficult. Systems typically use copper conductors for electrical connections, and the module frames are generally aluminum. Copper and aluminum don’t mix. The installer of a PV system is required to ground each module frame. The module frame must be grounded at the point where a designated grounding provision has been made. The connection must be made with the hardware provided.

VI. CONCLUSIONS

The paper has discussed about the importance of PV array, its issues, modeling and simulation. It also dealt with power management aspect of the PV array along with some installation challenges. The I-V and P-V characteristics are plotted using MATLAB. The paper provides a good awareness regarding renewable resources especially solar resources.

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