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Modelling and simulation of PV module for different irradiation levels

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ABSTRACT

This paper proposes a review of the main uniqueness and parameters of photovoltaic (PV) cell. A photovoltaic (PV) cell converts the solar energy into the electrical energy by the photovoltaic effect. The heat does not participate constructively in this process. Heat actually limits the performance of p-n layers, and the presence of excess heat is a sign of deterioration in a PV cell. Most solar cells are built from silicon, and the presence of impurities influences their performance. The losses occurring in the field operation of a PV cell have to be considered in order to calculate precisely its real electric power output. The PV module model is simulated using Matlab. The reviewed model is based on previous studies and previous models. Finally, the model has been compared with experimental data of a commercial PV module USP5-6V.

Introduction

Today, new advances in power generation technologies and new environmental regulations encourage a significant increase of distributed generation resources around the country. Distributed generation systems have mainly been used as a standby power source for critical situations. For example, most hospitals and office buildings have stand-by diesel generators as an emergency power source for use. However, the diesel generators are not inherently cost-effective, and produce noise and exhaust that would be objectionable on anything except for an emergency basis.

On the other hand, environmental-friendly distributed generation systems such as fuel cells, micro turbines, biomass, wind turbines, hydro turbines or photovoltaic arrays can be a solution to meet both the increasing demand of electric power and environmental regulations due to green house gas emission. PV cells are motionless, noiseless, vibration less and there is no need of intermediate circuits.

Photovoltaic cell

The solar cell is the basic unit of photovoltaic module and it is the element in charge of transforming the sun rays or light into electrical power. A PV generator is a whole assembly of solar cells, connections, protective parts and etc.

The use of photovoltaic cells is emerged as an alternate measure of renewable energy conservation and demand side management. The materials used in PV cells have different spectral responses to incident light, and exhibit a varying sensitivity with respect to the absorption of photons at given wavelengths. Figure.1 shows the cross section view of PV cell.

The photovoltaic systems have become increasingly popular and are ideally suited for distributed systems. A PV panel is constructed from a number of PV cells. A PV cell is constructed from a p-n junction material. A p-n junction is fabricated in a thin wafer of silicon. Semiconductor materials have an equal band width and different doping, which there is a built in electric field.

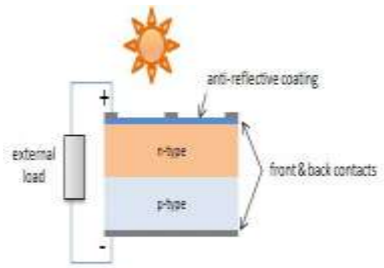

Figure:1 Cross section view of PV cell

In the dark, the volt-ampere output characteristics of a solar cell similar to that of a diode. When the solar energy hits the cell, with energy greater than band width of the semiconductor material, electrons are knocked loose from the atoms in the material, creating electron hole pairs (EHP).

These carriers are swept apart under influence of the internal electric field of p-n junction and create a current proportional to the incident radiation.

When the cell is short circuited the, circuit current flows in external circuit. When open circuited, this current is shunted internally by the p-n junction diode.

Solar arrays are used in many commercial applications. For best result the PV cells must be operated at their maximum power point (MPPT). However, the MPPT varies with illumination, temperature, radiation and aging factors.

The major advantage of PV cells are short lead time for designing and installing new system, output power matching with peak load demands.

PV Arrays

PV cells can be arranged in a series configuration to form a module, and modules can then be connected in parallel-series configurations to form arrays (figure.2).

When connecting cells or modules in series, they must have the same current rating to produce an additive voltage output, and similarly, modules must have the same voltage rating when connected in parallel to produce larger currents.

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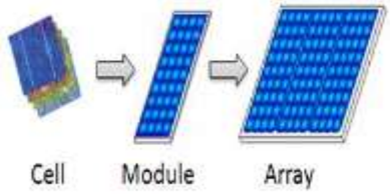

Figure.2: PV Array

USP5-6V Module

USP5-6V Solar provides cost-effective photovoltaic power for general use, for operating DC directly or inverter system and AC loads.

The 18/36 cells in series provides 5 watts of maximum power. It is used in telecommunications, medium sized hospitals and remote villages.

Figure 3: USP5-6V PV Module

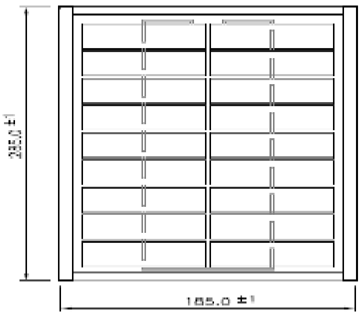

Figure 4: USP5-6V Module

The *USP5-6V* module (figure.3 and 4) delivers maximum performance and it is extremely powerful and reliable. Anodized aluminum frame offers required strength and allows for quick and easy installation on standard array structures. 18 Crystalline silicon solar cells in series in 6V. Modules are laminated in toughened low iron content PV grade glass – Ethyl Vinyl Acetate films – PV module back sheet. Optimized lamination process parameters ensure a stable laminate. Junction Box is standard in all modules. Each module is flash tested in a Sun Simulator to ensure conformity to specification. The electrical and mechanical data applies to standard test condition.

*Note: The data are based on Standard Test Condition with Irradiance 1,000W/Sq.m and Temperature 25°C. Under most climatic conditions, the cells in a module operate hotter than the ambient temperature. Nominal Operating Cell Temperature (NOCT) an indicator of this temperature differential, and is the cell temperature under standard operating conditions.

Modelling of the PV cells

Modelling is a basic tool of the real time system simulation. For Modelling, it is necessary to analyze the influence of various factors on the PV cells and to take in consideration the characteristics given by the manufacturers. The solar cell is a basic unit of photovoltaic module and it is the element in charge of transforming the sun light or photons directly into electric power. The solar cell used is the PN section, whose all electrical uniqueness differ very little from a diode. The mathematical models for PV cells are based on the theoretical equations that explain the operation of PV cells and can be developed using the equivalent circuit of the PV cells.

There are many models for a photovoltaic cell. The use of equivalent circuits makes it possible to model electrical characteristics of a PV cell. The final objective is to develop a general model to simulate the electrical behavior of the PV systems cell. The technique used here is implemented in MATLAB for simulations.

The 1-Diode-Model for Photovoltaic cell

The 1-Diode-Model (figure.5) is the most vital and the most used model for PV cells. The basic equivalent circuit of PV cell refers a current source in parallel to a diode. The current source generates the photo current I_{pho} [Amps], which is directly proportional to the light falling (irradiance F_s in W/m^2) on the cell, temperature T [°C], output voltage V_{out} [Volts] and output current I_{out} [Amps]. During darkness, the solar cell is not an active cell. It produces neither current nor voltage. However, if it is connected to a supply it generates a current I_d called dark current or diode current. The p-n junction transition area of the solar cell is equivalent to a diode.

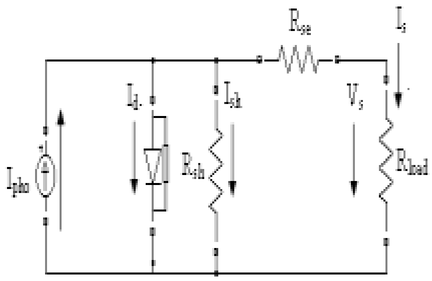

Figure 5: 1-Diode-Model for Photovoltaic cell

The characteristics equation of the one-diode-model is derived from Kirchhoff's current law:

$$\mathrm{Is} = \mathrm{Ipho} - \mathrm{Id} - \mathrm{Ish} \qquad (1)$$

Where,

Is - Load current

I_{pho} - Photo current

I_d - Diode or Dark current

I_{sh} - Diode saturation current (reverse)

The photo current I_{pho} is,

$$\mathrm{Ipho} = \mathrm{P1.FS.}[1 + \mathrm{P2.}(\mathrm{FS} - \mathrm{FO}) + \mathrm{P3.}(\mathrm{TJ} - \mathrm{T0})] \quad (2)$$

$$\mathrm{Id} = \mathrm{Isat}\left[\exp\left(\left(\frac{\mathrm{eo}}{\mathrm{af.Ns.k}}\right)\left(\frac{\mathrm{Vs+Rs.Is}}{\mathrm{Tj}}\right)\right) - 1\right] \qquad (3)$$

$$\mathrm{Isat} = \mathrm{P4.Tj3.exp}\left(-\frac{\mathrm{Eg}}{\mathrm{k.Tj}}\right) \qquad (4)$$

The diode reverse saturation current is,

$$\mathrm{Ish} = \left[\frac{\mathrm{Vs+RS.Is}}{\mathrm{Rsh}}\right] \qquad (5)$$

Where: F_o= 1000W/m2, T_o=298.15k, P_2 and P_3 are constants given by the manufacturers, T_j is junction temperature, e_0=charge of the electron (1.60217733.10^{-19} C), a_f = ideally factor (usually 1), Ns =Number of cells in series, K=Boltzmanns'constant (1380658.10^{-23} J/K), Rs= Series resistance (in Ω), Eg=Band gap (in eV), P_4=Correction factor (in A/K^3).

The data P_4, R_s, R_{sh} can be obtained from PV panel data sheet.

The 2-diode-Model for PV cell

An accurate modelling could be achieved by the 2-diode-model (figure.6). In this model 2 different diodes with different diode ideally factors (a_f) are connected in parallel. This gives more precision and need to more parameters to implement.

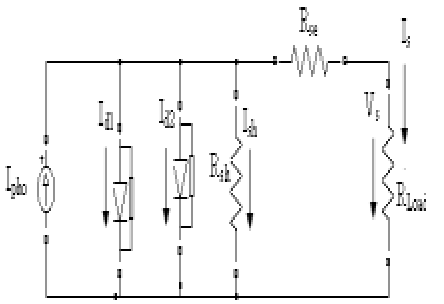

Figure.6: 2-diode-Model for PV cell

The equations are derived from Kirchhoff's current- law:

$$I_s = I_{pho} - I_{d1} - I_{d2} - I_{sh} \quad (6)$$

$$I_{pho} = (P_1 + P_2.T_j).F_s \quad (7)$$

$$I_{sat\ 1,2} = P_{01,2}.T_j^3.\ \exp((E_g)/(k.T_j)) \quad (8)$$

Where: $I_{sat\ 1,2}$ is a saturation current and the set of parameters P_1, P_2, P_{01}, P_{02} can be obtained from the solar data sheet

Volt-Ampere Curve for a solar cell

A typical VI curve of the solar cell for a certain irradiation G and fixed cell temperature T is shown in figure 7. for a resistive load. The load characteristics is a straight line I/V = 1/R.

It refers to the power delivered to the load depends upon the value of the load resistance only.

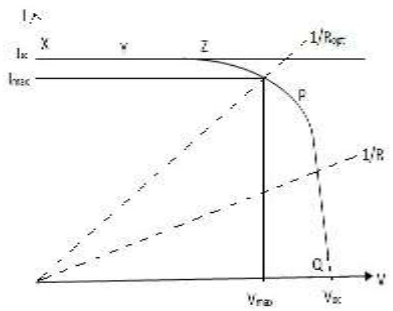

Figure 7: Volt-ampere curve for a solar cell

If the load resistance R is small, Solar cell operates as a constant current source (point X-Y) and it equals to short circuit current I_{sc}, if the load resistance R is large it behave as a constant voltage source (point P-Q) and it equals to open circuit voltage $V_{oc.}$

Performance for the cell can be determined from the following values.

Short Circuit Current (I_{SC})

The short circuit current I_{SC} corresponds to the short circuit condition when the impedance is low and is calculated when the voltage equals 0.

$$I\ (\text{at } V=0) = I_{SC} \quad (9)$$

I_{SC} occurs at the beginning of the forward-bias sweep and is the maximum current value in the power quadrant.

For an ideal cell, this maximum current value is the total current produced in the solar cell by photon excitation.

$$I_{SC} = I_{MAX} = I_\ell \quad (10)$$

Open Circuit Voltage (V_{OC})

The open circuit voltage (V_{OC}) occurs when there is no current passing through the cell.

$$V\ (\text{at } I=0) = V_{OC} \quad (11)$$

V_{OC} is also the maximum voltage difference across the cell for a forward-bias.

$$V_{OC} = V_{MAX} \quad (12)$$

Maximum power point (MPPT)

It is the operating point V_{max}, I_{max} (point Z). Power dissipated in the resistive load is maximum:

$$P_{max} = V_{max}\ .\ I_{max} \quad (13)$$

Fill factor

Fill factor is the ratio of maximum power that can be delivered to the load and the product of V_{oc} and $I_{sc.}$ The fill factor valued is greater than 0.7 for good cells.

$$\text{Fill factor} = P_{max} / (V_{oc}\ .I_{sc}) \quad (14)$$

Efficiency (η)

Efficiency is the ratio of the electrical power output P_{out}, compared to the solar power input, P_{in}, into the PV cell. P_{out} can be taken to be P_{MAX} since the solar cell can be operated up to its maximum power output to get the maximum efficiency.

$$\eta = \frac{P_{out}}{P_{in}} \Rightarrow \eta_{MAX} = \frac{P_{MAX}}{P_{in}} \quad (15)$$

Shunt (R_{Sh}) and Series (R_S) Resistance

During operation, the efficiency of solar cells is reduced by the dissipation of power across internal resistances.

These parasitic resistances can be modeled as a parallel shunt resistance (R_{sh}) and series resistance (R_s).

Decreasing R_{sh} and increasing R_s will decrease the fill factor (FF) and $P_{max.}$ If R_{SH} is decreased too much, V_{oc} will drop, while increasing R_S excessively can cause I_{sc} to drop instead.

Temperature Measurement

The crystals used to make PV cells, like all semiconductors, are sensitive to temperature. Figure.8 depicts the effect of temperature on a Volt-ampere curve. When a PV cell is exposed to higher temperatures, I_{SC} increases slightly, while V_{OC} decreases more significantly.

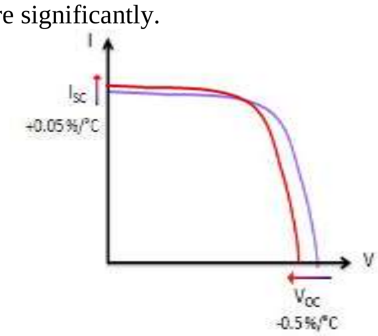

Figure.8: Temperature effect in Volt-ampere curve

For a specified set of ambient conditions, higher temperatures result in a decrease in the maximum power output P_{MAX}. Since the I-V curve will vary according to temperature, it is beneficial to record the conditions under which the I-V sweep was conducted. Temperature can be measured using sensors such as thermistors or thermocouples, etc.

Sources of Losses in a Photovoltaic Cell

Reflection Losses: When the incidence angle of the solar radiation differs from the perpendicular direction on the surface of a PV generator, reflection losses occur which will cause an overestimation of the PV yield under field conditions. These losses are reduced by coating the surface with antireflection layer.

Spectral Losses: The solar radiation is characterized by a wide spectral distribution because the Air Mass (AM) value changes during the day. The solar radiation contains photons with extremely different energies. Photons with smaller energy than the band gap energy are not absorbed and thus are unused. In case of photons with larger energy than the band gap energy, only an amount of energy equals to the band gap energy is useful, regardless of the value of a photon's energy. The excess energy is simply dissipated as heat into the crystal lattice.

Mismatch Losses: The volt-ampere characteristic of PV modules from the same type and the same manufacturer can vary from one module to another. According to the information of the suppliers, the MPP of a module under STC can deviate up to 10% from the data sheet characteristics. By series and parallel connection of the modules in a PV generator, the different volt-ampere characteristics will produce power losses which are called mismatch losses.

External losses: In a real system, the PV generator output power is not exactly equal to the input power to the connected power conditioning unit. In order to calculate this input power, the losses caused by the voltage drop due to cable resistances and the blocking diodes have to be considered. The losses caused by resistance of the connecting cables (ohmic losses) form the PV generator have to be calculated based on cables length and diameter. This resistance is considered as a series resistance of the PV model. In each string that forms the PV generator, blocking diodes are connected in series with these strings. If a short circuit occurs in one or more of these strings, the blocking diodes will prevent the currents to flow from the perfect strings to the faulty strings. During operation there is a voltage drop through each diode of approximately 0.7V. This value has to be subtracted from the output voltage of the PV generator.

Simulation result

The parameters that determine the operation of a PV panel is reflected in their volt-ampere characteristics curves. A typical volt-ampere curve of the solar cell for a certain irradiation G and fixed cell temperature T is shown in figure 7.

During the selection of the panel, also the effect of the panel can also be calculated. Module output power reduces as module temperature increases.

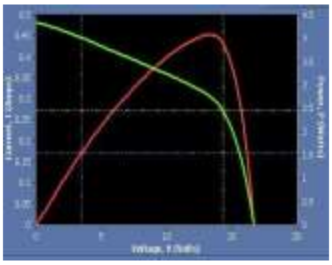

Figure.9: Volt-ampere and Volt-power curve for under condition G=250 W/m^2

The output of the Matlab function is shown in figure.9. for irradiation G=250 W/m^2 and obtained parameters are I_{sc}=0.48541 Amps, V_{oc}=16.66678 Volts, Fill factor=0.50753, R_s=5.129Ω, R_{sh}=100.08586Ω and P_{max}=4.07228 Watts.

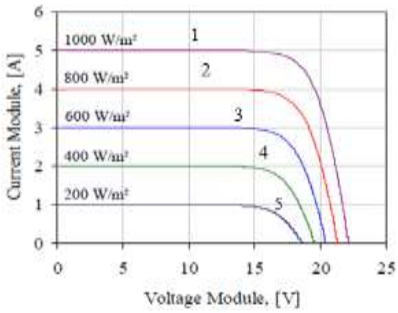

Figure.10: Volt-ampere characteristics of different irradiation levels

The output of the Matlab function is shown (figure.10) for various irradiation levels and then for various temperatures. Curve: 1 for G=1 Sun, 2 for G=0.8 Sun, 3 for G=0.6 Sun, 4 for G=0.4 Sun and 5 for G=0.2 Sun (G [Suns] = Irradiance, 1 Suns = 1000 W/m2).

Conclusion

In this paper the behavior of PV cell model was reviewed. The review includes temperature dependence, solar radiation change, diode ideality factor and losses. It also adds the simulation of each components of the module. The results of volt-ampere characteristics of different irradiation levels are based on 1-diode-model and 2-diode-model. Simulation results are compared with commercial PV module USP5-6V.

References

[1] Adel el shahat, "PV Cell Modelling and ANN simulation for smart grid applications", Journal of Theoretical and applied information technology, 2005-2010 JATIT, 9-20.

[2] Ramos Hernanz, " Modelling of Photovoltaic Module", International conference on Renewable energies and power Quality, March'2010

[3] Dorin Petreus, " Modelling and simulation of PV Cells", ACTA Technica Napocensis, Volume 49, Number 1, 2008

[4] Kashif Ishaque, " Accurate MATLAB Simulink PV system simulator based on two diode model", Journal of power electronics, Volume 11, No.2, March'2011

[5] Francisco M. Gonzalez-Longatt, " Model of photovoltaic module in matlab", Congreso electrica, 2009.

Table 1: Electrical and Mechanical Data

Model	*USP5 (6V)
Maximum power (P_{max})	$5W_p$
Open Circuit Voltage (V_{oc})	10.75 V
Maximum power point voltage (V_{mpp})	8.55 V
Short circuit current (I_{sc})	0.66 A
Maximum power point current (I_{mpp})	0.58 A
Tolerance	±10%
Cell Size (mm)	26 x 78
No. of cells	18
Dimensions (mm) ± 1	285 x 185 x 22
Maximum system voltage	600
Temperature co-efficient	NOCT (OC)45
V_{oc} (mV/ OC)	-105
I_{sc} (mA/ OC)	-0.32
P_{max} (%/ OC)	-0.45
Weight (Kgs)	0.6