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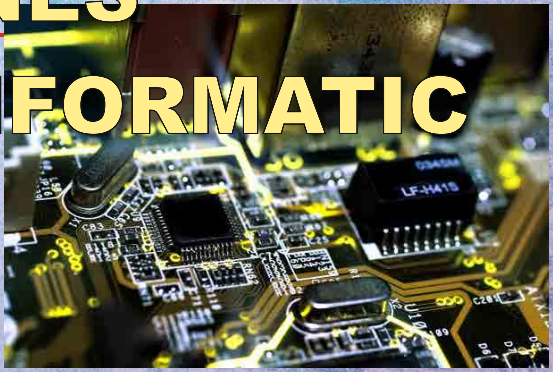

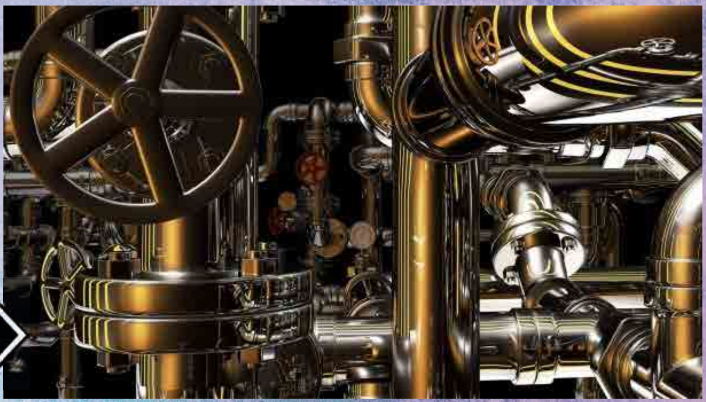

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C O N T E N T S

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ANALYSIS AND PERFORMANCE OF TWO PV CELLS UNDER VARIOUS WEATHER CONDITIONS

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Abstract: This paper presents performances of two different types of PV cells under various temperature clime of Stip, R. Macedonia. Stip with geographical position 41 .742N, 22.1 94E has 2260 sun hours yearly with average temperature 25 °C during spring.
The types of cells examined in this study are: crystalline silicone (c-Si) and polycrystalline silicon (p-Si). The calculations are made for various operating conditions and a comparation of I-V and P-V characteristics are represented here. Also, the efficiency and fill factor for photovoltaic (PV) cells is calculated based on simulation results.

Keywords: SOLAR CELL, EFFICIENCY, MAXIMUM POWER, CRYSTALLINE SILICON, POLYCRISTALLINE SILICON

1. Introduction

Photovoltaics use semiconductor materials to generate electricity from solar energy. Photovoltaic cells (PV) present a prime source of clean energy that utilizes energy from sunlight. Solar cells are used to convert solar energy directly into power. PV cells are manufactured from fine films or wafers made from silicon [1], [2].

PV cells are semiconductor devices and they are capable to convert solar light into DC current. Efficiency of produced power is changing in the interval from 3% to 17%, and that depends of different factors, such as kind of technology used, ambient temperature, the light spectrum, system design, semiconductor characteristics and material of solar cell[1],[2]. Solar cells can be connected serial or parallel depending on what we want to get high currents or high voltages. Different modules produce different amount of electricity according to required amount ranging from few watts to megawatts.

Photovoltaic energy conversion in solar cells consists of two basic steps: First, absorption of light generates an electron-hole pair. The electron and hole are then separated by the structure of the device; electrons go to the negative terminal and holes to the positive terminal, in effect generating electrical power. Solar energy has emerged as a renewable, clean and a free source of energy encapsulated in photovoltaic (PV) cells. In this paper, are analyzed two different types of solar cells and make the real comparison between their performances at different weather temperatures and solar irradiance of Stip, R. Macedonia. This study investigated theoretically and experimentally the effects of ambient air temperature on performance on PV panel under real outdoor conditions. The experimental results are obtained in PSIM software.

2. Technology of solar cells

Almost 95% of available solar cells are made from silicon. The advantage of using silicon is its mature processing technology. It is a semiconductor material suitable for PV applications, with energy gap of 1.1eV. This type of solar cell is in mass production and individual companies will soon be producing it at the rate of several hundred MW a year and even at the GW-scale. The silicon is used in PV cells for monocrystalline (m-Si) and polycrystalline (p-Si) wafer production of thin film silicon modules. Thus, silicon-based technology is very important for the production of the PV cells at present time. The manufacturing process of wafer-based silicon PV modules comprises four steps [3]:

1. Polysilicon production
2. Ingot/wafer production
3. Cell production
4. Module assembly

Crystalline silicon cells are classified into three main types depending on how the Si wafers are made. They are:

- Monocrystalline (Mono c-Si) sometimes called single crystalline (sc-Si)
- Polycrystalline (Poly c-Si), sometimes referred to as multi-crystalline (mc-Si)
- Ribbon silicon and silicon sheet – defined film growth

Commercial production of c-Si modules began in 1963 when Sharp Corporation of Japan started producing commercial PV modules and installed a 242 Watt (W) PV module on a lighthouse, the world's largest commercial PV installation at the time (Green, 2001). Crystalline silicon technologies accounted for about 87% of global sales in 2010 (Shott Solar, 2011). The efficiency of crystalline silicon modules ranges from 14% to 19%[4].

The development of Si-PV technology materials is driven by cost reduction. The large growth in PV market and need for lower cost material than monocrystalline make polycrystalline silicon a good alternative. Performance of monocrystalline silicon is more expensive but better in performance than the polycrystalline silicon wafers. In single crystal silicon, the crystal lattice of the entire sample is continuous and unbroken with no grain boundaries. Polycrystalline are composed of smaller crystals or multiple small silicon crystals. Polycrystalline can be recognized by a visible grain (metal flake effect) and are more sensitive to thermal processing. Polycrystalline silicon wafers are usually characterized by their grain sizes, orientations, and content of defects and impurities. Conversion efficiencies of commercial types of polycrystalline silicon cells are in range from 12% to 15% and could reach 17% using more sophisticated solar cell designs[5]. The efficiency of polycrystalline solar cells is mainly limited by minority carrier recombination. Depending on the crystallization process, materials develop different defect structure, which limit their efficiency. In order to improve polycrystalline cell efficiency, reduction of thermal load is required. Polycrystalline silicon is either grown by an ingot or ribbon technique. The microstructures of polycrystalline silicon materials differ considerably depending on whether the material is grown by an ingot or a sheet growth technique. Dislocations in ingot silicon are formed during crystal growth by plastic deformation to reduce the thermal stresses. These dislocations shows high recombination rates and are thus very detrimental to the lifetime of minority charge carriers. To modify the performance of polycrystalline silicon wafers, it is necessary to minimize the level of transition metals in the raw silicon material.

3. Singe- diode model

The equivalent model of PV cell (Fig.1) is consisted of a current source in parallel with diode and series and shunt resistances. The current source represents the light generated electric current I_{pv} and depends on solar irradiation. The output current is defined as:

$$I = I_{pv} - I_o\left[\exp\left(\frac{V + IR_s}{nV_T}\right) - 1\right] - \left(\frac{V + IR_s}{R_{sh}}\right) \quad (1)$$

Where, I_o is diode reverse bias saturation current of the diode, $V_T=kT/q$ is thermal voltage, q is electron charge, k is Boltzmann constant, T is temperature of the p-n junction and n is diode ideality factor. The series resistor takes into account losses in cell, interconnection and junction, while the shunt resistor takes into account the current leakage through the high conductivity shunts across the p-n junction.

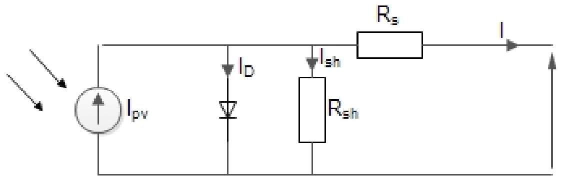

Fig. 1 *Single diode model of PV cell*

The characteristics of the most important parameters of PV cell can be determined by I-V curve. From this curve parameters such as the short circuit current, open circuit voltage, the maximum voltage and current can be read. Short circuit current I_{sc} is defined as:

$$I_{sc} = I = I_{pv} - I_o\left[\exp\left(\frac{IR_s}{nV_T}\right) - 1\right] - \left(\frac{IR_s}{R_{sh}}\right) \quad (2)$$

The open circuit voltage for same radiance and temperature of the p-n junction is the greatest value of the voltage at the cell terminals and can be calculated as:

$$V_{oc} = nV_T \ln\left(1 + \frac{I_{sc}}{I_o}\right) \quad (3)$$

I-V characteristics of ideal solar cell have a rectangle shape with sides I_{sc} and U_{oc}. But, in practice the maximum power of real solar cell is smaller than the maximum power of ideal solar cell. The maximum output power is the point (I_{mp}, U_{mp}) at which the power dissipated in the load is maximum and is defined as:

$$P_{mp} = U_{mp}\left(I_{pv} - I_o\left[\exp\left(\frac{U_{mp} + I_{mp}R_s}{nV_T}\right) - 1\right] - \frac{U_{mp} + I_{mp}R_s}{R_{sh}}\right) \quad (4)$$

The efficiency of the PV cell is ratio between the maximum power and the incident light power:

$$\eta = \frac{P_{mp}}{P_{in}} = \frac{I_{mp}U_{mp}}{AG} \quad (5)$$

where G is the ambient irradiation and A is cell area. The fill factor is a measure of squareness of I-V characteristic and can be calculated as ratio between the maximum power that can be delivered to the load and multiplication of I_{sc} and V_{oc}.

$$FF = \frac{P_{mp}}{V_{oc}I_{sc}} = \frac{I_{mp}U_{mp}}{V_{oc}I_{sc}} \quad (6)$$

4. Simulations scenario and results

The mathematical model for PV cell with single- diode model was implemented in PSIM simulator [6] using the physical model of solar cell shown in Fig. 2. I-V characteristics of monocrystalline solar cell and polycrystalline solar cell were obtained. The simulations were performed under Standard Test Conditions STC (1000W/m^2 irradiance, 25^{o}C cell temperature and AM1.5) and Nominal Operating Cell Temperature (800W/m^2 irradiation, 1m/s wind and 20^{o}C cell temperature). The characteristics points of SPR-327 NE-WTH-D (SunPower Coorpotation) and JKM350P (Jinko Solar) modules are given in manufacture datasheets [7] and [8] are represented in Table 1 and Table 2, respectively. The ideality factor depends only on cell temperature not on irradiance. In [9] is proposed that ideality factor for monocrystalline has value 1.2 whereas for polycrystalline is 1.3. The value of ideality factor can be adjusted in order to improve the model fitting to the experimental data.

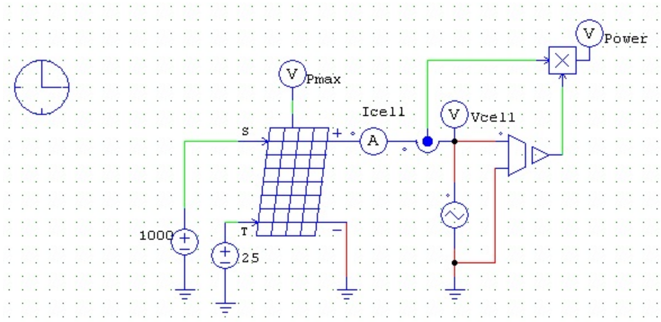

Fig. 2 *Test circuit for solar cell (physical model)*

Table 1: *Parameters of model SunPower SPR-327NE-WHT-D*

	STC	NOCT
Nominal power	327W	243W
Number of cells	96 monocrystalline silicon cells	
Voltage at P_{mp}	54.7V	50.4V
Current at P_{mp}	5.98A	4.82A
Open circuit voltage	64.9V	60.8V
Short circuit current	6.46A	5.22A
Temperature power coefficient	-0.38%/K	
Temperature voltage coefficient	-176.6mV/K	
Temperature current coefficient	3.5mA/K	

Table 2: *Characteristics of Jinco Solar model JKM350P*

	STC	NOCT
Nominal power	305W	225W
Number of cells	96 polycrystalline cells	
Voltage at P_{mp}	36.8V	34.0V
Current at P_{mp}	8.30A	6.62A
Open circuit voltage	45.6V	42.4V
Short circuit current	8.91A	7.21A
Temperature power coefficient	-0.41%/K	
Temperature voltage coefficient	-0.31%/^{o}C	
Temperature current coefficient	0.06%/^{o}C	

When temperature raises, the current increases while the voltage decreases and as a result the maximum point of I-V and P-V characteristics a decrease. I-V characteristics obtained through simulations of monocrystalline and polycrystalline solar module are represented in Fig 3 and Fig.4, respectively. In Fig.5 and Fig. 6 are represented the P-V characteristics of monocrystalline and polycrystalline module, respectively. Short circuit current is a linear function of the irradiation since photocurrent depends on the radiation, and thus higher the irradiation leads to higher current. Also, if the irradiation is reduced, the output voltage of the module decreases.

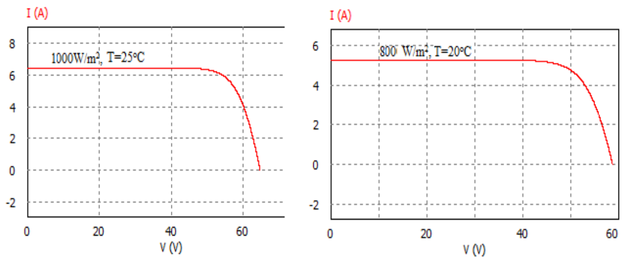

***Fig. 3** I-V Characteristics of monocrystalline module SPR-327NE-WHT-D*

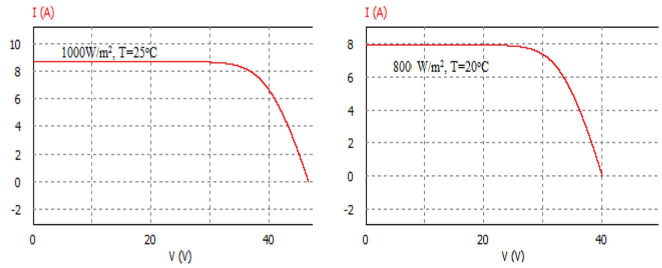

***Fig. 4** I-V Characteristics of polycrystalline module JKM350P*

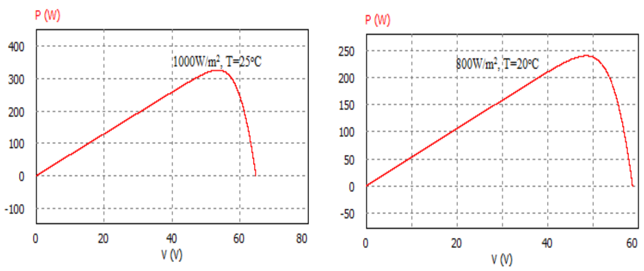

***Fig. 5** P-V Characteristics of monocrystalline module SPR-327NE-WHT-D*

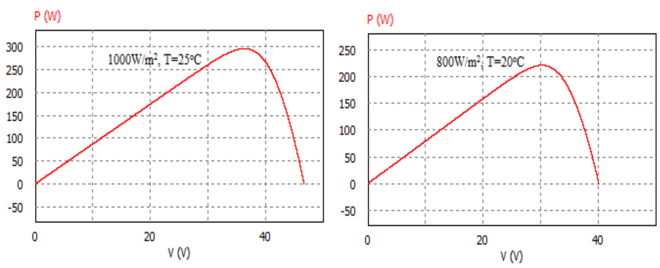

***Fig. 6** P-V Characteristics of polycrystalline module JKM350P*

PSIM simulator through its utility Solar Module (physical model) calculates the maximum power, maximum current and maximal voltage. These results are summarized in Table 3 and are used to calculate the efficiency and fill factor for both modules.

***Table 3:** Calculated maximum power at STC and NOCT conditions*

	STC	NOCT
SPR-327NE-WHT-D	P_{mp}=326,67W I_{mp}=6.10A U_{mp}=53.52V	P_{mp}=241.19W I_{mp}=4.97A U_{mp}=48.55V
JKM350P	P_{mp}=296,90W I_{mp}=8.14A U_{mp}=36.37V	P_{mp}=221,90W I_{mp}=7.33A U_{mp}=30.26V

Using equation (5) and results obtained through simulation for standard test simulation the monocrystalline module has efficiency 20% while efficiency of polycrystalline is 15.25%. Also, using equation (6) and results obtained through simulations it is calculated that monocrystalline module has fill factor 77.91%, while the polycrystalline has fill factor 75.56%. 1000W/m^2, T=25^{o}C

5. *Conclusion*

In this paper, PSIM simulations of equivalent single- diode model of solar cell for two commercial solar modules were performed to generate I-V and P-V characteristics. The simulations were performed under standard normal conditions and nominal operating cell temperature. The obtained results followed the expected values given in manufactures specifications.

Using the obtained numerical and graphical results, and data from manufactures this paper shows that the monocrystalline module has better performances in term of output voltage and power, efficiency and fill factor. This is due to higher silicone purity of monocrystalline cell because is consisted of a single ingot, whereas a polycrystalline cell is consisted of a multiple structures. It term of cost, monocrystaline solar modules are more expensive than polycrystalline modules.

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