PHOTOVOLTAIC MODULES PERFORMANCE – COMPARATIVE STUDY

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Abstract

This paper describes different types of photovoltaic cells in order to improve the electrical performance of photovoltaic modules and choose the best solution for industry. It is presented the characteristics of photovoltaic cells (conventional and high- efficiency) and the photovoltaic modules. The performance of photovoltaic cells and modules are measured complying with the standard reporting conditions, which are presented as a reference temperature, total irradiance and spectral irradiance distribution. This study compares the structure, function, advantages and disadvantages photovoltaic cells.

Keywords: Performance, monitoring, photovoltaic cells, energy

1. INTRODUCTION

In the last years, the renewable energy market experienced a fast increase. In our days are several types of renewable energy and the most important of them are the below: biomass, geothermal energy, wind, solar (e.g. thermal and photovoltaic), hydro and wave energy. The one who directly converts solar energy into electricity is photovoltaic energy. In solar energy production the main component is represented by photovoltaic cells [1] ,[2]. The structure of photovoltaic cell is in dependence with manufactured material and during last years a lot of materials have been tested. From them, only a few were found to have the properties required to manufacture the photovoltaic cells. The most frequently used material for photovoltaic cells production at industrial level is silicon. For photovoltaic cells there are several classifications. If we take into account the material thickness there are thick cells and thin cells. In terms of evolution of manufacturing technology are defined: first generation of photovoltaic cells (egg. Si), second generation (thin cells) and third generation (organic cells). The classification by cell type defines semiconductor material cells (Ge, Si, Cd Te, Ga As, Ga Al As, Ga In As P, INAS, In Sb or In P) or organic cells made using organic pigments. The classification by base structures are crystalline cells (monocrystalline, polycrystalline) and amorphous cells. In therm of the type of junction there is single junction, multi-junction or tandem cells [2], [3].

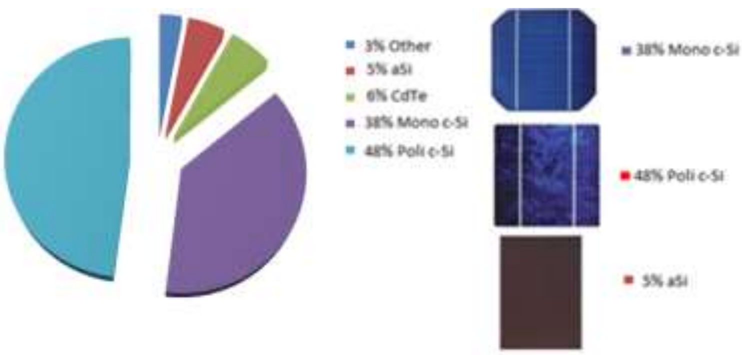


Fig.1. Market shares of different photovoltaic technologies in 2014, [2], [3]

The four general types of silicon photovoltaic cells are: single-crystal silicon; polycrystalline silicon (or multi-crystal silicon); ribbon silicon and amorphous silicon (abbreviated as "aSi", also named „thin film silicon"). The percentage and the situation of these types of photovoltaic cells on the market in 2014 is presented in Fig.1. Monocrystalline silicon cells are considered to be the first generation of solar cells. From this family of silicon solar cells, these cells are robust and efficient, but also are the most expensive because of high energy consumption for producing silicon with a purity of 99.99% [4]. Polycrystalline silicon cells were developed by the need to reduce the cost of photovoltaic cells. The solutions which decreased costs using cheaper materials, and the cells were made by processes with consuming low energy consumption. Ribbon silicon cells are made using a growing of ribbon from the molten silicon instead of an ingot. The ribbon silicon cells have the same functionality as the single and polycrystalline cells. Amorphous silicon cells are made by depositing an extremely thin film of silicon on a glass surface or a cheap substrate using deposition techniques on large areas of 1m^2. The cells are connected together in series to increase the voltage. Several of these series strings of cells may be connected together in parallel to increase the current as well. These interconnected cells and their electrical connections are then sandwiched between a top layer of glass or clear plastic and a lower level of plastic or plastic and metal. An outer frame is attached to increase mechanical strength, and to provide a way to mount the unit. This package is called a "module" or "panel" and the module is the basic building block of photovoltaic systems [5].

2. EXPERIMENTAL PROCEDURE

A cell is essentially a low - voltage, high - current device with a typical open -circuit voltage of around 0.5V, lower than the operating voltage of most electrical loads and systems. So it is normal for a PV module to contain many series - connected cells, raising the voltage to a more useful level. For example, many manufacturers offer modules with 36 crystalline silicon cells connected in series, suitable for charging 12 V batteries. These modules have an open - circuit voltage Voc of around 20V and a voltage at the maximum power point Vmp of about 17V, giving a good margin for battery charging, even in weak sunlight [2], [5]. Cells are connected together in series to increase the voltage, and in parallel to increase the current. These cells are connected in parallel or/and serial. It is called a "module" or "panel" and is the basic building block of photovoltaic systems [2],[5]. In figure 2 is represented an equivalent circuit which explain the performance of photovoltaic panels.

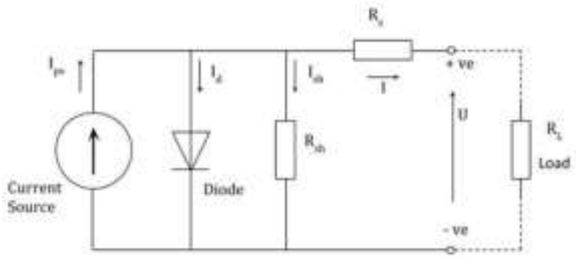


Fig.2. Photovoltaic module equivalent circuit

This equivalent circuit has below basic equation of load current:

$$I = I_{pv} - I_d - I_{sh} \quad (1)$$

Where: I - current through load, [A];
I_d - current through diode, [A];
I_{pv} - current generated by PV, [A];
I_{sh} - current through the shunt resistor, [A].

The voltage across the shunt branches is presented in equation (2).

$$U_{sh} = U + I * R_s \quad (2)$$

Where: U_{sh} – shunt voltage, [V];
U - voltage applied to the load, [V];
R_s - equivalent circuit series resistance, [Ω].
The current through the shunt resistor is related in equation (3).

$$I_{sh} = \frac{U_{sh}}{R_{sh}} = \frac{U + I * R_s}{R_{sh}} \qquad (3)$$

Where: I_{sh} - current through the shunt resistor, [A];
R_{sh} - equivalent circuit shunt resistance, [Ω].
The current through the diode is given by Shockley's equation and is related in equation (4).

$$I_d = I_0 \left[e^{\frac{U_{sh}}{n*V_T}} - 1 \right] \qquad (4)$$

$$V_T = \frac{k * T}{q} \qquad (5)$$

Where: I_0 - reverse saturation current, [V];
k - Boltzmann's constant, k=(1.3806488×10−23), [J.K-1];
n - Linearity factor (1 for ideal diode);
q - Elementary charge, n=(1.602176565×10−19), [C];
T – p-n junction absolute temperature, [K];
V_T - thermal voltage, [V]

The photovoltaic cell (panel) characteristic equation represented in equation (6) is the combination of above equations.

$$I = I_{pv} - I_0 \left[e^{\frac{U + I*R_S}{n*V_T} - 1} \right] - \frac{U + I * R_S}{R_{sh}} \qquad (6)$$

Below we will determine the short circuit current and the open circuit voltage. In both cases, I=0 and the equation are reduced to:

$$0 = I_{pv} - I_0 \left[e^{\frac{U_{0C}}{n*V_T}} - 1 \right] - \frac{U_{OC}}{R_{sh}} \qquad (7)$$

R_{sh} is highest compared to the open circuit voltage and the last term can be ignored. If we rearrange the equation results:

$$U_{OC} \approx n * V_T * \ln \left[\frac{I_{pv}}{I_o} + 1 \right] \qquad (8)$$

Where: U_{oc} - open circuit voltage, [V]

If the output voltage is set to zero (the case of short circuit current), it results:

$$I_{sc} = I_{pv} - I_0 \left[e^{\frac{I_{sc} * R_S}{n*V_T} - 1} \right] - \frac{I_{sc} * R_S}{R_{sh}} \qquad (9)$$

Where: I_{sc} - short circuit current, [A]

R_{sh} is highest compared to the open circuit voltage and the last term can be ignored. If we rearrange the equation results:

$$I_{sc} \approx I_{pv} \qquad (10)$$

To calculate the photovoltaic panel performance are taken into account the solar radiation, temperature and the performance of photovoltaic panel. The temperature is calculated with equation (11).

$$\eta_t = 1 - [\gamma * (T_c - T_{stc})] \qquad (11)$$

Where: η - efficiency of system;
Y - Power temperature coefficient

The performance of photovoltaic cells could be also measured with the fill factor. The fill factor is the ratio of the maximum power to the product of the open circuit voltage and short circuit voltage. The equation is:

$$FillFactor = \frac{P_{\max}}{V_{oc} * I_{sc}} = \frac{U_{mpp} * I_{mpp}}{V_{oc} * I_{sc}} \tag{12}$$

Where: I_{mpp} - current at maximum power, [A];

U_{mpp} - voltage at maximum power, [V]

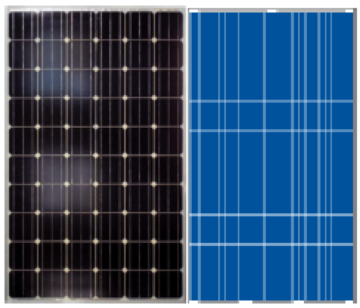
The photovoltaic panel is more productive if the fill factor is higher. This photovoltaic cells factor is greater than 0.7 in industry.

In this paper is presented the situation of types of photovoltaic panels installed on the roof of a building. These photovoltaic panels have in structure monocrystalline Si cells and polycrystalline Si cells. First photovoltaic panel has the nominal power of 250W, it contains 60 cells interconnected serial and the matrix panel is the structure of 6x10 cells. The cells have dimensions of 156mm x 156mm. Second photovoltaic panel has the same nominal (250W); the same structure and the cells have the same dimensions like the first panel, but polycrystalline cells.

3. RESULTS AND DISCUSSIONS

Two types of photovoltaic panels installed on the roof of a building situated in Timisoara are presented in this paper. These photovoltaic panels have in structure mono crystalline Si cells and polycrystalline Si cells. First photovoltaic panel has the nominal power of 250W, it contains 60 cells interconnected serial and the matrix panel is the structure of 6x10 cells. The cells have dimensions of 156mm x 156mm. If we take into account the photovoltaic cells from its structure, first panel is appointed “Mono c-Si Panel”. Second photovoltaic panel has a slightly lower nominal power (240 W), also it has the same structure and the cells have the same dimensions that the first panel, but polycrystalline cells. This panel is appointed “Poly c-Si Panel”.

Electrical Specifications at (STC* = 25 ºC, 1000W/m2 Irradiance, and AM=1.5)		
Characteristics	Mono c-Si Panel	Poly c-Si Panel
Max System Voltage (IEC/UL)	1000V / 600V	1000 V/600 V
Maximum Power Pmax	250 W (-2%, +2%)	240 W (-2%, +2%)
Voltage at Maximum Power Point Vmpp	30.7 V	30.5 V
Current at Maximum Power Point Impp	8.15 A	7.87 A
Open Circuit Voltage Voc	37.7 V	37.3 V
Short Circuit Current Isc	8.72 A	8.46 A
Temperature Coefficient of Voc	-0.128 V/ºC (-0.34% /ºC)	-0.127 V/ºC (-0.34% /ºC)
Temperature Coefficient of Isc	3.49x10-3 A/ºC (0.04% /ºC)	1.69x10-3 A/ºC (0.02% /ºC)
Temperature Coefficient of Pmax	-1.20 W/ºC (-0.48% /ºC)	-1.15 W/ºC (-0.48% /ºC)



Mono c-Si Panel   Poly c-Si Panel

Mechanical Specifications		
Characteristics	Mono c-Si Panel	Poly c-Si Panel
Cell Size	156mm x 156mm (6.14” x 6.14”)	156mm x 156mm (6.14” x 6.14”)
Module Dimension (L x W x T)	1640mm x 990mm x 40mm (64.6” x 39.0” x 1.6”)	1650mm x 990mm x 40mm (64.9” x 38.9” x 1.6”)
No. of Cells	6 x 10 = 60	6 x 10 = 60
Weight	18.6 kg (41.0 lbs)	19.5 kg (43.3 lbs)
Cable Length	900mm (43.3”) for positive (+) and negative (-)	≥ 900mm (35.4”) for positive (+) and negative (-)
Type of Connector	MC-IV	MC-IV
Junction Box	IP65 or IP67 Rated	IP65 Rated
No. of Holes in Frame	4 draining holes, 8 installation holes, 2 grounding holes, 16 air outlet holes.	

Fig.3. The characteristics of photovoltaic panels

The scope of this paper is to monitor the performance for two photovoltaic panels mounted in the same climatic conditions, the same tilt and the same characteristics, but with different photovoltaic cells. The measurements were realized during year 2014, period January- September. The main factors that influence the function of these panels are the temperature, the total solar irradiance and the angle. The optimum situation for these panels is realized when these panels are mounted on a surface with 45 deg angle faced toward South. The characteristics mechanical and electrical are presented in below picture comparatively. It is seen that these panels have almost the same characteristics.

In figure 4 is presented the photovoltaic electricity [kWh/kWp] for these photovoltaic systems, in order to compare the cells' productivity during of a short period of time.

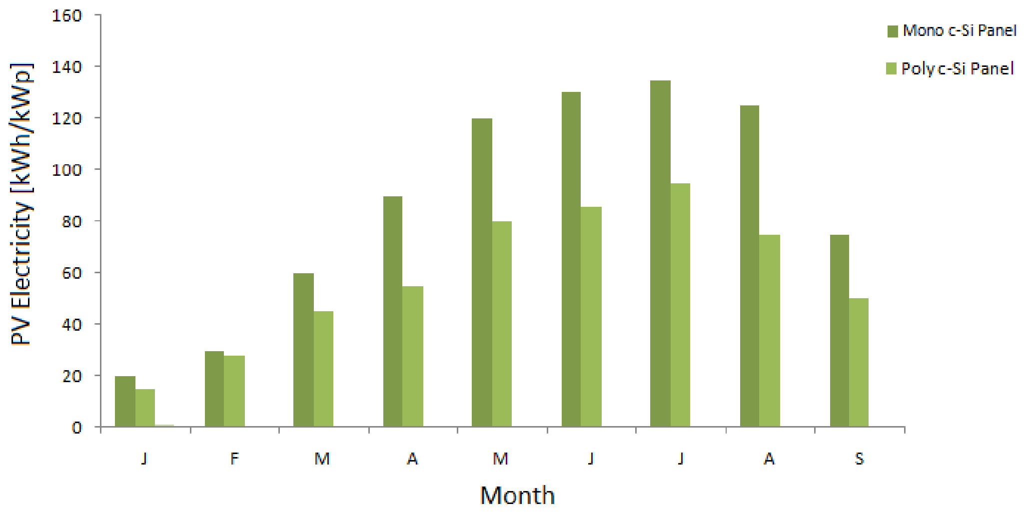


Fig.4. Monthly Photovoltaic Electricity collected comparatively for photovoltaic panels

To monitor the solar radiation has an important role in analyzing both the efficiency of the cells and evaluating the optimal locations for the systems. It is seen that mono crystalline photovoltaic panel provide a highest quantity on electricity than polycrystalline photovoltaic panel.

4. CONCLUSIONS

The photovoltaic panels with monocrystalline silicon cells are able to convert a greater amount of solar energy into electricity compared to panels that have the same power, but were constructed with polycrystalline silicon cells. It was also observed that monocrystalline silicon photovoltaic cells have a good functionality and collective power is higher than the polycrystalline photovoltaic panel. It is advisable to use photovoltaic systems because they offer advantages like: simple operation mode, low cost maintenance and low impact on the environment.

LITERATURE

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