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Comparative Analysis of Electricity Production from Different Technologies of PV Modules

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Abstract Distributed generation of electricity from renewable energy sources has drastically grown in recent times. One of the most common types of distributed generation is photovoltaic (PV) systems. Like any other system of distributed generation, PV systems have a lot of various pros and cons. Paper deals with the comparison of electricity production for three different technologies of crystalline silicon PV modules. Comparative analysis of electricity production includes measurements on monocrystalline silicon, polycrystalline silicon and high-efficient monocrystalline silicon PV modules. At the very beginning, different technologies are compared in theory supported by measurements. Anyhow, focus is placed on measurements of several parameters of different PV module technologies under the same conditions that describe electricity production. A comparison of electricity production of PV modules based on the measurements is carried out and important conclusions were adopted.

Keywords:• photovoltaic module • monocrystalline silicon • polycrystalline silicon • high-efficient monocrystalline silicon • electricity production •

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1 Introduction

Today, electricity is globally available to approximately 4.8 billion people but 1.8 billion people are still without, or have very limited, access to electric power [1]. In recent times exploitation of solar energy is growing rapidly and it could be solution to improve the situation mentioned above. By implementation of distributed generation (DG) of electricity from photovoltaic systems, electric power can be provided to more people all around the world. Photovoltaic (PV) system market had powerful growth so far and will be continued in the upcoming years [2]. Because of that, electricity will be available even in areas with poor accessibility. An extenuating circumstance in implementation of distribution generation from solar energy is legislative framework which encourages development of such systems [3].

According to Smart Grid Technology Roadmap published by International Energy Agency, operators will require real-time system information to manage generation from renewables, balance intermittent supply with flexible demand, handle multidirectional power flows and maintain power quality. Leaders in renewables deployment are China and Europe with leadership in deployment of smart grid technologies that are trigger for expanding the use of distributed generation of electricity in reliable way [1]. The International Energy Agency forecasts that solar power could deliver between 20 % and 25 % of global electricity by 2050, reducing CO_2 emissions by approximately 6 billion tons per year [4]. A smart grid will make possible these high level penetrations of clean renewable energy by [1]:

- balancing of supply interruption with demand side resources and storage
- forecasting and monitoring for better prediction of intermittent generation and regulation of power supply
- managing reverse power flows from distributed generation to protect the grid
- using advanced communication and control technologies to reduce power system maintenance, management and operation costs.

Very important role in sustainability of DGs have efficiency of PV modules. Production of PV modules is broadly divided on crystalline and thin-film approaches [5]. In following chapter three different technologies that are subject of conducted measurements are compared.

2 Comparison of Different PV Module Technologies

Crystalline PV modules are divided between monocrystalline (MC) and polycrystalline (PC) solar cells depending on PV cell production approach (single crystal or multiple crystal cells), Figure 1. In comparison to polycrystalline, monocrystalline cells are more efficient but at the same time they are more difficult to produce which results with higher costs per unit of surface area [5].

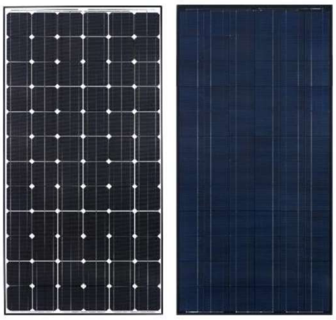

Figure 1. MC and PC PV modules [6]

Manufacturing process of thin-film (TF) PV modules is completely different than crystalline. Thin layer of photovoltaic effect capable materials (amorphous silicon or some nonsilicon combination of metals) lies on a backing material, Figure 2. They are cheaper to produce than crystalline cells due to production process which is easier to scale up than the growing and cutting of crystals. There is also PV module made of a thin monocrystalline silicon wafer surrounded by ultra-thin amorphous silicon layers (TF-MC) also known as high-efficient monocrystalline silicone module, which is included in measurements of electricity production. It is more efficient than previously described crystalline modules [5].

Figure 2. TF-MC PV module [7]

Comparison of characteristics of these three PV module technologies is shown in Table 1. Observed modules were BISOL BMO 250 as MC module, BISOL BMU 250 as PC module and Panasonic N240 as TF-MC module [6, 7].

Table 1. Characteristics of PV modules [6, 7]

Module types	Units of measu re	MC	PC	TF-MC
Peak power [W]	P_{max}	250	250	240
Nominal voltage [V]	U_{mpp}	8.20	8.25	43.70
Nominal current [A]	I_{mpp}	30.50	30.30	5.51
Short circuit current [A]	I_{sc}	8.80	8.75	5.85
Open circuit voltage [V]	U_{oc}	37.90	38.40	52.40
Module efficiency [%]	η_m	15.60	15.30	19.00
Cell efficiency [%]	η_c	17.40	17.10	21.60
NOCT [°C]		44	44	44
Temperature coefficient I_{sc} [mA/°C]	α	+4.50	+4.90	+1.76
Temperature coefficient U_{oc} [mV/°C]	β	-132	-121	-131
Temperature coefficient P_{mpp} [%/°C]	γ	-0.35	-0.40	-0.30
Maximum system voltage [V]		1,000	1,000	1,000
Current value String fuse [A]		13	13	15
Length [mm]		1,649	1,649	1,580
Width [mm]		991	991	798
Height [mm]		40	40	35
Weight [kg]		18.50	18.50	15.00

I-V characteristics in different conditions of irradiance for crystalline and thin-film monocrystalline modules are shown in continuation, Figure 3 and Figure 4.

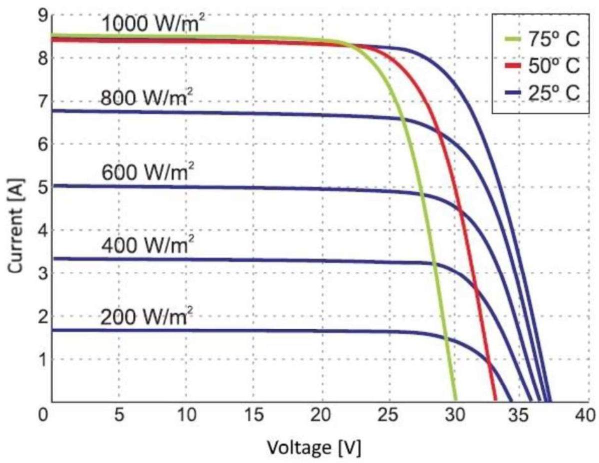

Figure 3. Crystalline *I-V* characteristics [6]

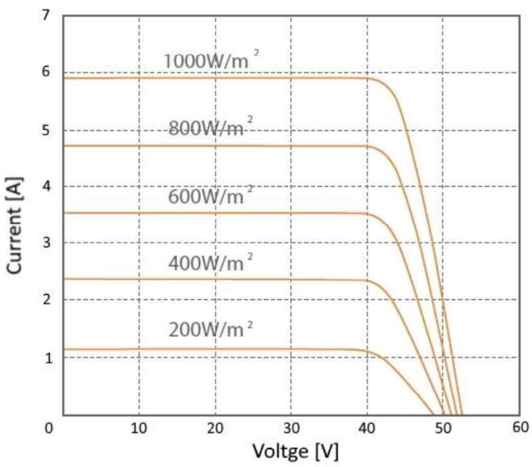

Figure 4. TF-MC *I-V* characteristics [7]

A photovoltaic module has two types of warranties: power output and equipment guarantee. Product warranty and output power warranty are very important because they protect customer against failures due to manufacturing defects, environmental issues, premature wear and tear etc. It can help you assure that your service and support needs will be covered if a PV module problem ever occurs.

Most common performance warranty will guarantee 90 % of output power after 10 years and 80 % after 20 years as TF-MC module manufacturer assures, Figure 5 [7].

Likewise, some of the producers offer linear warranty for output power as MC and PC manufacturer assures, Figure 6 [6].

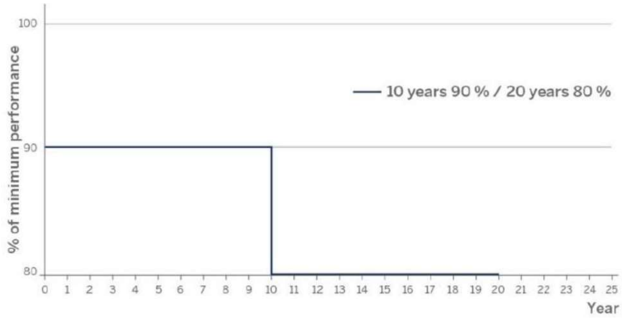

Figure 5. Power output and product warranty – TF-MC module [7]

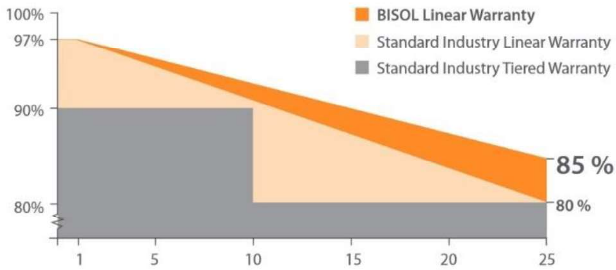

Figure 6. Power output and product warranty – MC and PC modules [6]

3 Materials and Method

3.1 Equipment and measuring instruments

Measurements were conducted on PV modules made from three different photovoltaic technologies. Measuring instruments used for measurements are Metrix PX110 Digital Wattmeter and Seaward Solar Survey 200R. Metrix PX110 Digital Wattmeter is used for output voltage, output current and PV module output power in maximum power point. Solar irradiance is measured with Seaward Solar Survey 200R irradiance meter.

3.2 Measuring methodology

Measurements of electrical characteristics of the PV modules are conducted from 7 a.m. to 6 p.m. for two days, with different weather conditions. Frequency of the measurement is one hour. Firstly, solar irradiation is measured. After that, maximum power point of a PV module is tracked for each module and output power with digital wattmeter is measured. Electrical circuit used for the maximum power point tracking is given in Figure 7 [8].

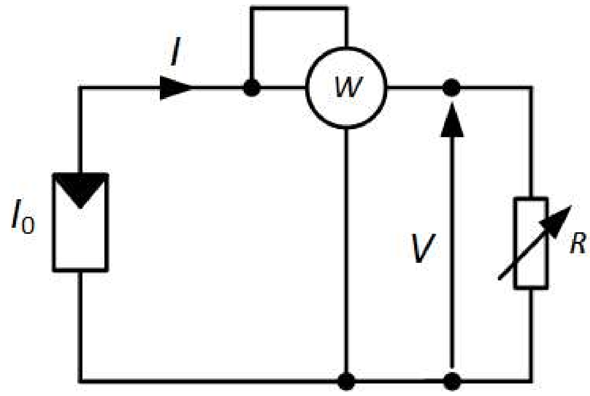

Figure 7. Maximum power point tracking electrical circuit

4 Results and Discussion

Figures 6-7 show output power of three different PV module technologies in the same weather condition. Two different weather conditions in a day were considered, sunny day and partly cloudy day. First type, given in Figure 8 and Figure 10, is a sunny day. Measurements for sunny day are taken on April 3rd, 2014. Second case of weather conditions, given in Figure 9 and Figure 11, is partly cloudy day. Measurements for partly cloudy day are taken on April 24th, 2014. Horizontal axis of the Figure 8 and Figure 9 shows time while vertical axis gives relation of output power of a PV modules P and output power in standard test conditions (STC) P_{MPP}.

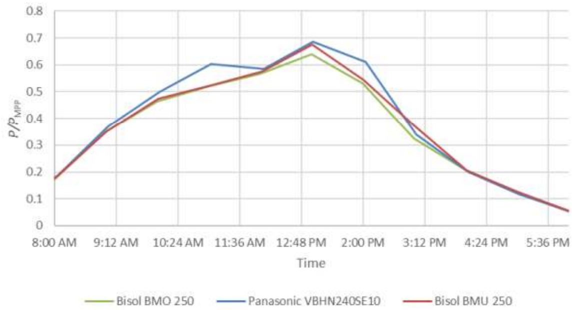

Figure 8. Output power of three different PV module technologies for a sunny day

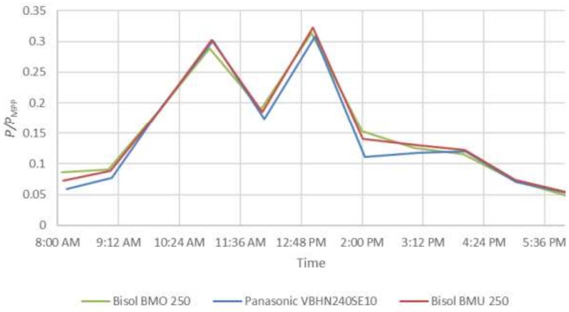

Figure 9. Output power of three different PV module technologies for partly cloudy day

Efficiency of three different PV module technologies for different weather conditions is given in Figure 10 and Figure 11. Figure 10 shows efficiency of PV modules for a sunny day while Figure 11 shows efficiency for partly cloudy day.

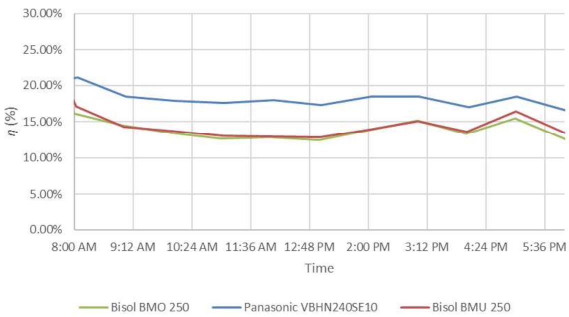

Figure 10. Efficiency of three different PV module technologies for a sunny day

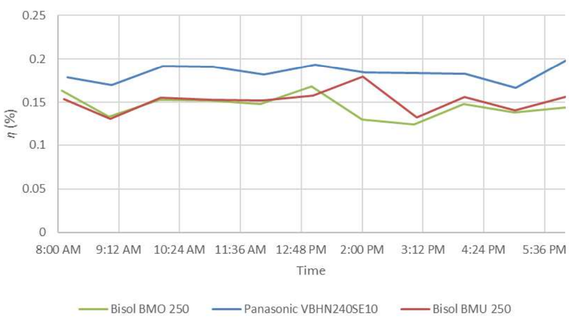

Figure 11. Efficiency of three different PV module technologies for partly cloudy day

Total daily electricity production per surface area of three different PV module technologies for different weather conditions is given in Table 5.

Table 5. Total daily electricity production per surface area

PV module	Sunny day [Wh/m^2]	Partly cloudy day [Wh/m^2]
Bisol BMO (MC)	799.62	367.85
Panasonic VBHN240SE10 (TF-MC)	1,077.11	457.93
Bisol BMU (PC)	830.40	379.72

Results of output power for a sunny day given in Figure 8 show that the biggest output power gives MC-TF PV module i.e. Panasonic N240. For a partly cloudy day, the biggest output power gives PC PV module i.e. Bisol BMU 250 even though MC-TF PV panel gives slightly lower output power while its STC output power is 10 W lower than MC and PC STC output power. This difference in efficiency of solar energy conversion into electricity is visible in Figures 10 and Figure 11. MC-TF PV module has significantly greater efficiency of energy conversion. MC and PC PV modules have almost equal efficiency of energy conversion even though PC PV module has slightly greater efficiency than MC PV module. Deviations in output power and efficiency of energy conversions in relation to the time are results of rapid changes in solar irradiation in short time. Results given in Table 5 show that greatest energy production per surface area has MC-TF PV module. PC PV module has slightly greater production of electricity per surface area than MC PV module which confirms results analysed above.

5 Conclusion

Photovoltaic systems come in a wide range of sizes, from those sized to meet the needs of a single-family house to huge commercial systems [5]. Analysis of electricity production showed that high-efficient monocrystalline thin-film module has 20 % to 35 % greater electricity production per square meter in comparison with classical monocrystalline and polycrystalline PV modules. The measurements have confirmed details from the PV modules datasheets. TF-MC module achieves the best performance per square meter and by that, it is particularly suited for small roof areas. This module has glass with anti-reflective coating that ensures high power output even in poor weather conditions which is showed by measurements for partly cloudy day. Polycrystalline module has little bit better performance per square meter in comparison with monocrystalline module.

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