Micromorph and polymorphous solar panel in a warm temperature transitional climate - comparison of outdoor performance and simulations

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Abstract. The publication contains polymorphic and micromorphic photovoltaic module outdoor tests performed during autumn, winter, spring and summer day. Simulations of an installation consisting of panels both types have been made. Both performances were compared for the location in the Kraków-Częstochowa Upland, continental climate.

Key words. photovoltaic, power losses, outdoor performance, polycrystalline silicon module, micromorphous module

1. Introduction

Photovoltaics, as the fastest growing type of renewable energy, is continuously developed. Photovoltaics achievements are promising and new performance limits are constantly being crossed [1,2]. The first generation of photovoltaics is based on crystalline silicon. Silicon is the most popular material on the photovoltaic cell market (about 90% of commercialized cells are silicon). There are four types photovoltaic solar cells based on silicon: monocrystalline, polycrystalline, amorphous and hybrid silicon cells. More and more silicon based photovoltaic solar cells types are being developed [3–8]. The paper will present a comparison of the work of polycrystalline and micromorphic cells in the field conditions.

Polycrystalline silicon cells [9–11] are obtained by the controlled melting and re-coagulation of silicon in a quartz crucible. The wafer is cut from the block thus obtained, after which a number of processes are carried out, leading to the formation of the functional solar cell. The production of polycrystalline material for solar cells is cheaper than monocrystalline, because it needs less electrical energy and time. Micromorphic [12–14] cells are examples of tandem cells. They are a combination of microcrystalline silicon ($\mu\text{c-Si}$) and thin film amorphous technology (a-Si).

Photovoltaics needs increasingly precise methods of characterisation and measurement. Basic tests of the photovoltaic panels are usually carried out in the laboratories using Standard Test Conditions (STC)[15,16]. Measurement according to STC is a test at 1000 W/m² exposure at a cell temperature of 25°C and Air Mass radiation spectrum parameter - AM 1.5. The panel parameters may also be quoted using Normal Operating Cell Temperature (NOCT) [17,18]. These are the cell parameters obtained when temperature reached by open circuited cells in a module assuming 800 W/m² irradiance, 20°C ambient temperature and wind speed of 1m/s with the module at a tilt angle of 45°.

Both STC and NOCT conditions will never occur in practice. With practically insolation 1000 W/m² it is not possible to maintain the temperature of the cell at 25°C (with no external cooling [19,20]). Parameter AM 1.5 specifies that the sun's rays fall at an angle of 48,2° to the position of the sun in the zenith. The intensity of sunlight and temperature are almost always different from those assumed in STC, as well as the tilt angle.

In order to confirm the long-term and actual behaviour of the cells and parameters, tests in the external environment are required. The different temperatures and weather conditions are able to give an idea of the actual performance and benefits of silicon photovoltaics. Therefore, it is interesting and research on real parameters in different climates is being conducted [21–26].

2. Location and technical conditions

A. Location and climatic condition

The measurements were carried out in the Education and Research Centre for Renewable Energy Sources and Energy Conservation at the AGH University of Science and Technology in Miękinia, Małopolskie Voivodship, Poland (50°09'37.7"N 19°36'04.0"E). It is situated on the Kraków-Częstochowa Upland, within the

Silesian-Cracowian monocline, and in the southern part in the area of the pre-Carpathian sinkhole.

The most appropriate feature for determining the climate of Poland is the transience of the climate, which is conditioned by the abrasion of air masses with different characteristics from several barium centres. The formation of air temperature clearly shows oceanic and continental influences. In January, the isotherms are arranged in a longitudinal direction, and in July - in a parallel direction. The weather shows variability and significant fluctuations of the seasons in successive years. This is caused by the borderline between a warm and rainy temperate climate and a boreal, snow-forest climate running through Poland. The annual isoamplitudes are about 20°C and 23°C, which define the conventional boundaries between the oceanic and continental climate, also pass through. Intensity even on a sunny summer day rarely exceeds 900 W/m² in Poland.

B. Modules technical description

The photovoltaic installation consisting of photovoltaic modules of different generations placed on a metal rack structure (Figure 1). Two modules were selected for comparison in the work: the polymorphic module from German Solar (GSP6-S160 model) and micromorph module from Sontor (silicon tandem thin film solar module SN2-130).

Figure 1. Location of panels on the frame (1) micromorphous (2) polymorphous

The basic solar cell parameters provided by the manufacturer are shown in Table 1. The following are listed: P_{max} (maximum power point designated as MPP) maximum voltage (V_m) and a current (I_m), short circuit current (I_{sc}) and the open-circuit voltage (V_{oc}). Temperature coefficients given by the manufacturer were also taken into account. Both panels operate at a typical operating temperature range -40~85°C.

Table 1. Basic panel parameters measured in STC

panel	SN2-130.0, Sontor,	GSP6-240- SI60, German Solar
P _{max} [W]	130	240
I _m [A]	1.64	8.05
U _m [V]	97.2	29.80
I _{sc} [A]	1.62	8.56
V _{oc} [V]	127.1	37.4
temperature coefficient of P _{max} [%/°C]	-0.44	-0.40
temperature coefficient of I _{sc} [%/°C]	-0.334	-0.39
temperature coefficient of V _{oc} [%/°C]	0.069	0.07

3. Results

A. Measurements

The measurements were taken during the day during the four seasons - autumn, winter and spring, summer. The measurements were taken from 2019 to 2020 (8th November - autumn, 20th February - winter, 21st April - spring and 18th July - summer). The ideal course of the characteristics during the day is a symmetrical parabola, half-width and maximum depending on the season. Temperature and humidity variations over the investigation days were presented in the Figure 2. The results are based on the data from publicly available meteorological stations [27]. The Figure 3. shows dependence of power generated by investigated panels during the day.

Figure 2. Temperature and humidity variations over the investigation days

Figure 3. Daily characteristics of the panel power during the day
a) autumn, b) winter c) spring d) summer The time colour means the waveforms for the polymorphic panel, red - micromorph

The most similar to the standard daily power output, are the spring and summer spectra. In winter and autumn, significant power fluctuations are observed. On the autumn day, during the highest temperature, the power was 150 W, at 5.72°C average daily temperature. In winter the maximum power was 130 W, with an average daily temperature of 1.56°C. The spring day with an average temperature of 9.73°C showed a power of about 200 W for both modules. On summer day (average temperature 13.8°C) the only difference between the panels appeared. Changes in input power are not correlated with either temperature or humidity. The daytime temperatures vary in a range that strongly depends on the season stable, similarly there is no humidity dependence, also. However, we may hypothesize that the power output is strongly influenced by varying clouds.

Definitely higher power values are obtained in the summer day analysis. The power output signal on both cells is similar for both cells. Large changes in the drop in performance of the micromorphic panel are observed only on the spring day. These changes can only come from selective shading of the micromorphic panel. Around noon, you can see the increased power output - the shading has almost disappeared. The average values of the power output in both cases do not generally fluctuate - despite the higher power point, the polymorphic cell in principle.

Figure 4. Efficiency comparison for panels during a daytime

B. Simulations

The Vela Solaris Polysun [28] is a popular software for the simulation of both photovoltaic and hybrid (e.g. thermovoltaic) installations. The inverter Sunrise Midi Plus was used. Using Polysun software simulation for a panel arrangement (consisting of ten panels of a selected type located in the location as reported) was carried out. The Figure 5 (micromorphous panels SN2-130.0, Sontor). and Figure 6 (polymorphous panel, GSP6-240-SI60, German Solar) show the power generated by the installations with the average efficiency of the panel, with the weather conditions of the programme database shown in the Figure 7.

Figure 5. Daily characteristics of the panel power (black line) and efficiency (blue line) during the day a) autumn, b) winter c) spring d) summer for micromorph panels SN2-130.0, Sontor

The obtained curves have similar shape to the recorded results, however, significant differences can be seen in the continuity of the real performance. The comparison of the maximum performance received is shown in Table 2.

Figure 6. Daily characteristics of the panel power (black line) and efficiency (blue line) during the day a) autumn, b) winter c) spring d) summer for polymorphous panel, German Solar

Table 2. Maximum power generated. For the installation simulation it has been converted to 1 panel

Power [W]	outdoor performance		simulations	
	Micro-morphous	Poly-morphous	Micro-morphous	Poly-morphous
autumn	150	150	100	130
winter	150	150	75	80
spring	200	200	100	140
summer	100	200	100	180

Figure 7. Daily characteristics of the temperature (red line) and global irradiation (blue line), diffuse irradiation (purple line) normal direct irradiation (grey line) during the day a) autumn, b) winter c) spring d) summer

The maximum power obtained in both ways of registration is strongly differentiated. This is particularly observed the winter. Maximum values higher than expected for the recorded outdoor performance values appear, which may be due to additional factors such as temporary cooling due to the atmospheric factors. The simulation values are based on catalogues so they are more stable data, however, their inadequacy must be considered.

4. Conclusion

The paper presents executive tests of panels in real conditions. The performance of photovoltaic installation was also simulated. The aim of the study was to determine the changes in efficiency during the year under sunshine conditions at different seasons of the year during the day. The waveforms and temperature profiles in the cells will be presented and compared with the simulations performed.

For the micromorphic cell, the actual (outdoor) values turned out to be more favourable than the values

obtained by simulation with the Polysun program. The increase in maximum power achieved was twice as high in winter and spring, while in autumn the actual values were 50% higher. In summer, simulation and measurements showed the same value. In the case of the polymorphic panel also the maximum powers are higher for outdoor performance. In this case, the significant change is only in the spring season (about 30%). In the other cases, the difference is 5-20%. The powers measured for the panels have a very jumpy power delivery, their characteristics are jagged due to environmental influences. However, the disadvantages of outdoor operation are apparently compensated for. Both panels perform better than expected, confirming that photovoltaics is a promising and efficient renewable energy source for the future. The results also point to the need for intensified outdoor research, as well as the importance of obtaining better and better simulations models.

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