Research of material and power of photovoltaic panels of various types of degradation in operating conditions

Peter Tauš[*], *Jana* Tomčejová, *Marcela* Taušová, *Ľubomíra* Gabániová , *Dušan* Kudelas, *Matúš* Jeňo and *Daniel* Šlosár[1]

[1] Institute of Earth Resources, Faculty of Mining, Ecology, Process Control and Geotechnologies, Technical university of Kosice, 04001, Kosice, Slovakia

Abstract. The paper deals with the results of research on the influence of material and operating parameters on the performance characteristics and efficiency of photovoltaic panels. The disadvantage of PV panels is that their performance depends on a number of factors such as the intensity of the sun's radiation, the outside air temperature, the surface temperature of the photovoltaic panel, its pollution, shielding, etc. In the paper is analyzed the model photovoltaic power plant, from which data were obtained during the monitored period and subsequently the progress of individually measured parameters was evaluated.

1 Description of the analyzed PV power station

PVE is located on an area of 30,000 m2, 75% of which was used to install the facility. The construction of the PV power plant was carried out in 2010 from September to November, at the end of November of the same year it was put into the testing operation. In December it acquired a license from URSO and a license to join the distribution system ZSE Distribúcia, a.s. They launched regular operation of the facility in March 2011. The PV system was designed using PC software PVsyst, weather data was used from Meteonorm software. The optimal inclination at the site was set at 35˚. Additional parameters are shown in Table 1.

Table 1 Parameters of PVPP

Total incident radiation over the year on a horizontal plane	1360 kWh.m^{-2}
Total installed PVPP power	828 kWp
Specific amount of electricity produced	1124 kWh.kWp^{-1}.rok^{-1}
Total estimated minimum amount of electricity produced (annually)	931 MWh
Total available land area	30 000 m^2

1.1 Photovoltaic panels

[*] Corresponding author: peter.taus@tuke.sk

We used 3600 polycrystalline PV panels from the REC Solar manufacturer, specifically the REC 230AE type with a maximum power of 230 Wp, which the company acquired directly from the manufacturer. It provides the quarantee of 90% of power production for photovoltaic panels after 10 years and 80% production after 25 years. The relative spacing of the individual rows with the PV panels is 8.61 m with fixation on fixed structures of the MSP-AL type with orientation 0˚ to the south [3] [4].

1.2 Other PVE components

Three Vacon (RS-IYZ-0460-3-250 kWp) inverters are installed to connect to the distribution network and are located in the LN substation next to the transformer station. In connection with the construction of a photovoltaic power plant, it was necessary to build a new 22 kV cable connection and a transformer station for power output from PVP. To supply electricity to the ZSE, a.s. a 1000 kVA transformer was used. The measurement of the consumed and supplied energy is carried out in the switchgear of the transformer station.

2 Analysis of the operating parameters of the PV power station

At the PV power plant measurements of selected quantities related to the power and material properties of PV panels and cells were realized. These are the following parameters:

• power of global radiation P_{GZ} (W), operating temperature of panel T_{PVP} (°C) air temperature T_{vzd} (°C), produced electricity EP_{PVPP} (kWh), power of P_{PVP} PV panels (kW) and efficiency of panels f_{PPP} (%).

The data gathered for the years 2012 to 2015 with blackouts in 2014 due to a power plant failure. Blackouts are included as unavailable data in statistical analyzes, or as extremes - by data type. For the statistical evaluation, the 12th hour data was used with the highest average global radiation value during the year. The measured values of the inverter power outputs and the theoretical efficiency of the PV panels were calculated.

2.1 The course of operating parameters for the period under review

The average monthly maximum of 0.91 kW.m^{-2} was reached for the reference period in April 2015, the average monthly minimum was 0.22 kW.m^{-2} was in January 2012. The following graph (Figure 3) presents a comparison of the average monthly GZ in of the years examined.

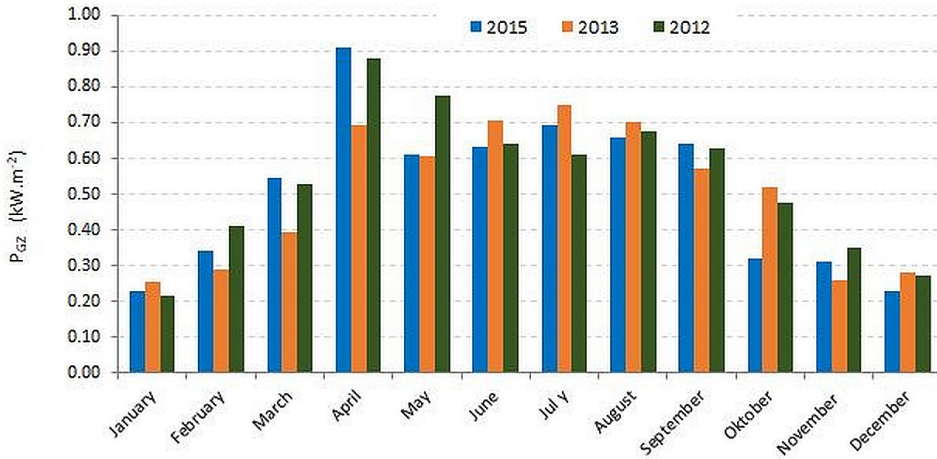**Fig. 1** Comparison of P_{GZ} in individual years.

The highest temperature of the entire monitored period of 35.8 °C was reached on 01.07.2012 and the lowest temperature was -4.92°C on 13.01.2013. The following graph (Fig. 2) presents a comparison of the average monthly temperatures of the PV panels in the individual years under review.
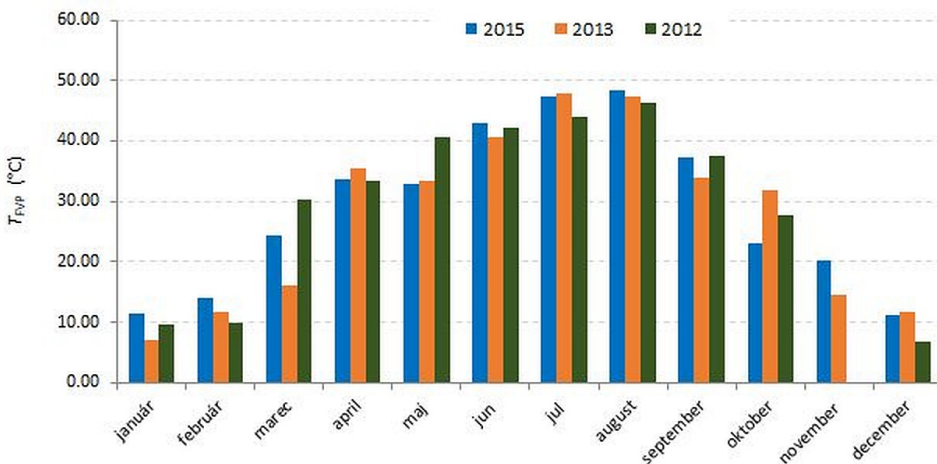

Fig.2 Comparison of the average monthly temperature of PV panels in individual years.

The highest average monthly P_{PVP} is in the range of 624 to 403 kW between April and September. The lowest average monthly P_{PVP} was recorded from 259 to 159 kW between November and January (PVE was out of service in November 2012). The average monthly maximum of 624 kW was reached for the reference period in April 2015, with an average monthly minimum of 164 kW in January 2012. Fig. 3 shows the comparison of the average monthly PV power outputs in the years under review.
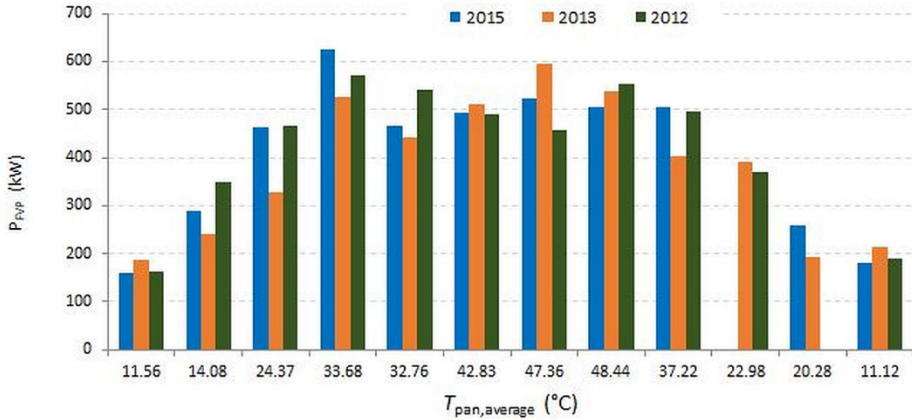
Fig. 3 Comparison of average monthly PV power over the reference period

2. 2 Evaluation of the interdependencies of the operating parameters of the PV power plant

The individual dependencies were evaluated on the analyzed PVP for a given reference period using correlation and regression analyzes of the measured values.

2.3 Dependence of the amount of energy produced on the output of global radiation

Fig. 4 shows the relationship between the values of the PV energy produced and the power of the incident GR. As can be seen, there is a high direct correlation between these variables ($r = 0.8734$). The power variation of the incident GR(GR=GZ) explains the variability of the produced PV energy from 76.21 % ($r^2 = 0.7621$).
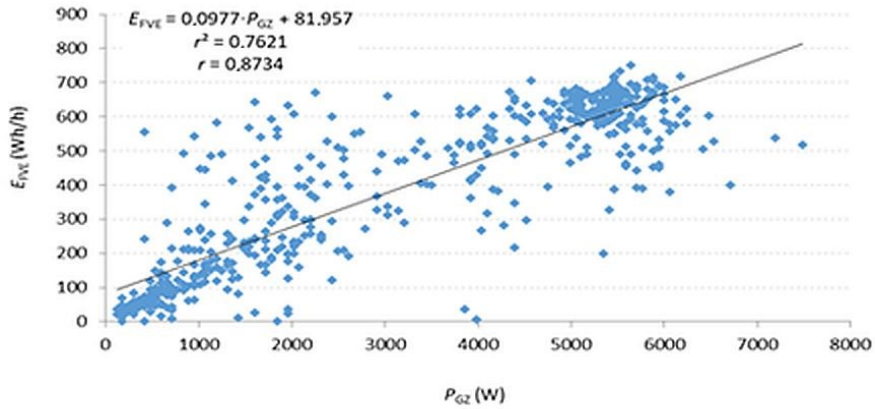
Fig. 4 Dependence of the generated PV power on GZ power over the period under review

As can be seen from the analysis, the dependence of the electricity production from the PV panels on the incident GZ is confirmed. However, a considerable scatter of dependence is confirmed, which indirectly affirms the influence of temperature on the efficiency of PV panels. Most of the deviations from the average value are due to the temperature of the PV panels associated with the air temperature. Spatial values above the average line at low GZ values are recorded in the winter period, while values below the line GR at high GR show PV panels with elevated temperature during the summer period.

It follows from the above that, in the correct configuration of the PV field, we can maximize the power plant production for the different conditions of use or location of the installation.

2.4 Air temperature dependence on global radiation

As can be seen in Fig. 5, there is a direct correlation relationship between the Tvzd air temperature and the daily totals of the GZ-incidence but significantly lower than in the previous case (r = 0.5674). The scattering of the correlation field points suggests that Tvzd is also dependent on atmospheric conditions such as wind velocity or hydrometeorologal conditions, in addition to incident GZ radiation, over the year. The variability of incident radiation GZ explains the variability of T_{vzd} from 32.19% ($r^2 = 0.3219$). The confidence value is $r^2 = 0.3219$, that is, the 32.19% increase in the operating air temperature is dependent on the increase in the power of the incident GZ.

This is, of course, the one-year period to consider when planning a PV plant or plant. Especially for seasonal PV plants that are currently on the rise.
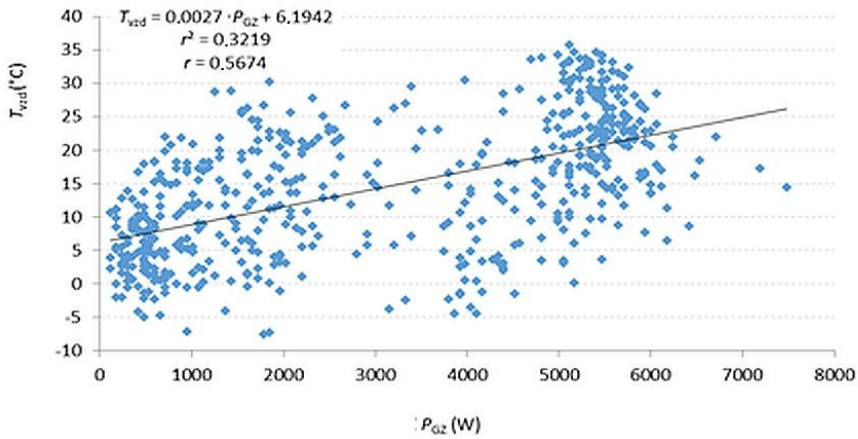
Fig. 5 Air temperature dependence on GZ performance over the period under review

2.5 Temperature dependence of photovoltaic panels on the output of incident global radiation

There is a relatively high correlation between the temperature of the T_{PVP} photovoltaic panels and the output of the GZ incident, as evidenced by r = 0.7750. The variability of incident radiation GZ explains the variability of T_{PVP} from 60.06 % (r^2 = 0.6006).
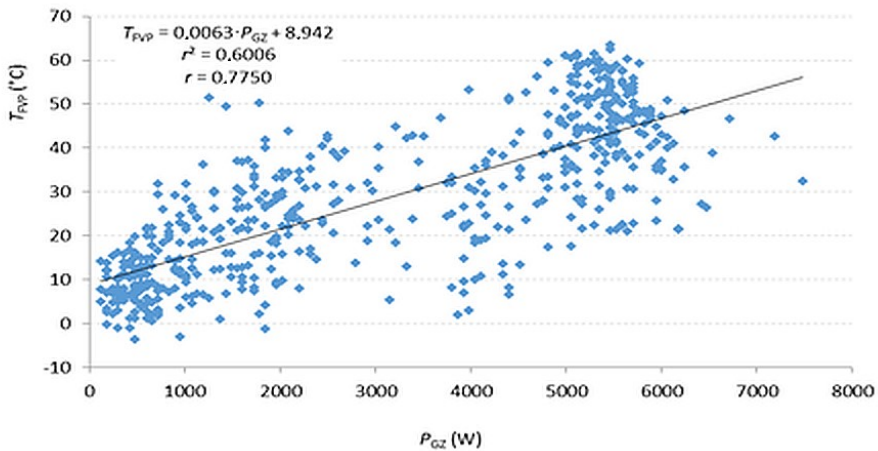

Fig. 6 The dependence of the PV panel temperature on the GZ output over the period under review

All of the aforementioned dependencies show a relatively wide dispersion despite confirmed correlation dependence. This confirms the influence of the weather, respectively. of the annual period to the power parameters of the PV panels.

2.6 Temperature dependence of photovoltaic panels on air temperature

As can be seen in Fig. 7, there is a high direct correlation dependence (r = 0.9185) between the T_{vzd} air operating temperature and the temperature of the T_{PVP} panel. The scattering of the correlation field points suggests that T_{PVP} is also dependent on other atmospheric conditions such as GZ intensity and wind velocity. The T_{vzd} air temperature variability explains the T_{PVP} variability from 84.37 % ($r^2 = 0.8437$).
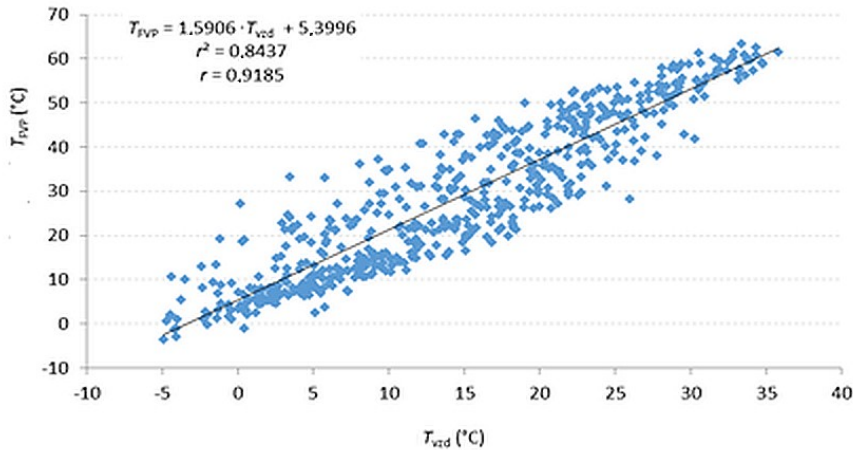

Fig. 7 Dependence of the PV panel temperature on air temperature over the period under review

Unlike Fig. 4, the FV panel temperature dependence on air temperature is more pronounced, which implies inter alia that there are no faulty PV panels in the power plant. Furthermore, this dependence is confirmed by the fact that neither the influence of GZ nor the temperature difference of PV panels and ambient air is affected.

2.7 Dependence of power of PV panels on performance of GZ

Graphic dependence on Fig. 8 shows the relationship between PV panel power outputs and GZ output power. From the correlation coefficient value, there is a relatively high correlation coefficient r = 0.9620 between these parameters. The confidence value is $r^2 = 0.9255$, that is, 92.55% of the PV power output is dependent on the increase in the power of the incident GZ. Similarly, this is also true for the next analysis, where the PV power performance of the PV panels is clearly confirmed. For most of the extremes shown in the graph in Fig. 8 occurred during the summer period, which confirms material wear / fatigue due to increased temperature.
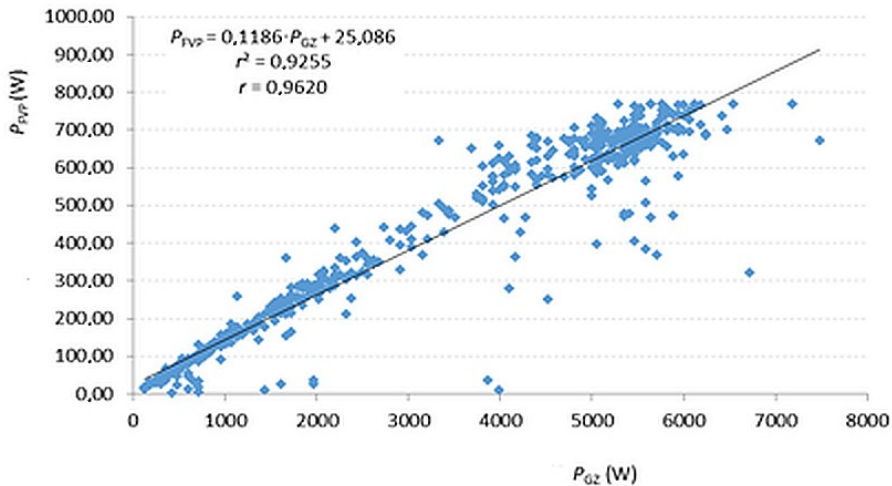
Fig. 8 Dependence of the power of the PV panels and the performance of the incidental GZ for the period under review

Conclusion

Many photovoltaic power producers often do not address the type of PV panels that are more advantageous for them in terms of quality, as well as the realization of their future power generation. The primary criterion for decision-making at the time of the largest PV boom was clearly the price of these panels, as there were large volumes of supply. In addressing this issue, the FVE investor has leaned to acquire quality panels from REC SOLAR. This manufacturer of PV Panels has a lot to do with the quality of its products from both material and power point of view. from the point of view of lifespan, as evidenced by the analysis of the measured data in PVP. Within the measurements, the dependencies between the temperature of the PV panels, the ambient air temperature, the efficiency of electricity generation and the incident solar radiation were evaluated by correlation analysis.

The results of the research show that the material used in the manufacture of the studied PV panels does not show the expected degradation. Positive is that the degradation of the PV panels is significantly slower than expected. Also, the direct dependence of the influence of temperature on the efficiency of PV panels was proven to be lower than the theoretical. This is a positive phenomenon from the point of view of the plant operator, because the efficiency of the panels, depending on their temperature, has fallen more slowly than the value mentioned. The results of the analyzes showed that in the winter the temperature influence on the efficiency of the PV panel is not relevant. The average efficiency of PV panels may be up to 1% higher than the efficiency declared by the manufacturer during this period. On the contrary, in the summer, the average efficiency is 1.5% lower than the declared efficiency.

This research has proven that RECOLAR PV panels of the REC230AE type are an appropriate choice for installation in our climatic conditions in terms of their tolerance to temperature and optimum performance. The manufacturer shall declare a temperature coefficient of 0,0046 $°C^{-1}$ for these panels. The calculated value for the reference period is about 0.0026 $°C^{-1}$ lower.

As a result, these panels are also designed for areas with higher hot summer days. As well as in terms of temperature, it is important to choose the correct type of PV panel also from the viewpoint of other climatic conditions, relative air humidity, pollution factor, etc. After careful consideration of these factors, it is possible to choose the correct PV panel or a situation where the power and material degradation of this component is minimized (taking into account the correct techniques and installation procedures). The recommendation for the photovoltaic electricity producer is to consider the possibilities and choose the right PV panels with the relevant characteristics for the given climatic conditions and location based on existing analyzes in similar locations.

References

1. J.Tomčejová, *Výskum materiálovej a výkonovej degradácie fotovoltaických panelov rôznych typov v prevádzkových podmienkach*, Písomná časť dizertačnej skúšky. s. 26. (2013)

2. J. Tomčejová, *Analýza vplyvu zmeny vstupných podmienok FVE na jej prevádzkové parametre na základe dopytu prevádzkovateľa*, Diplomová práca. s. 99. (2011)

3. P. Inn Inneichen, Th. Lejeune, PC software PVsyst Version 5.4. University of Geneva. (2009)

4. E. Skoplaki, J.A. Palyvos, On the temperature dependence of photovoltaic module electrical performance: A review of efficiency/power correlations. *Solar Energy*, **83**, s. 614 – 624. (2009)

5. V. Leitman, Identifikace a detekce poruch FV system. [online]. Bakalárska práca. VUT v Brně. [cit. 2018-02-18]. Dostupné na internete: <https://www.vutbr.cz/www_base/zav_prace_soubor_verejne.php?file_id=84404> (2013)

6. J. Hofierka, J. Kaňuk,. Assessment of photovoltaic potential in urban areas using open source solar radiation tools. *Renewable Energy*. **34**, s. 2206–2214. (2009)

7. J. Hofierka, M. Šúri,. The solar radiation model for Open source GIS: Implementation and applications. *Proceedings of the Open source GIS - GRASS users conference 2002*. 19 s. (2002)

8. M. Libra, V. Poulek, Fotovoltaika: teorie i praxe využití solární energie. 165 s. (2010)

9. M. Malcho,J. Jandačka, R. Lenhard, S. Gavlas, T. Ochodek, Numerical simulation of heat transport from the electric arc furnace to the heat recovery system, *Communications : scientific letters of the University of Žilina.***18**, s. 115-121.(2016)

10. A. Klenovčanová, T. Brestovič, Možnosti využitia fotovoltických článkov na výrobu elektrickej energie v oblasti Košíc. *Acta Mechanica Slovaca*., **4** s. 511-516.(2007)

11. P. Bača, Posibilities of electric power storage from renewable sources. *Acta Montanistica Slovaca*, **15**, s. 100-104. (2011)