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# COMPARISON OF SPECIFIC PRODUCTION PERFORMANCES BY TWO CRYSTALLINE SILICON PV SYSTEMS

Martin Fajman, Josef Vacuška

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## Abstract

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A comparison of two independent photovoltaic (PV) systems located close to each other on the south of the Czech Moravian Highland was accomplished. Due to differences in installation parameters; reference quantities were used to calculate transformed data sets for specific production performances comparison. Differences in monthly and annually daily production were performed by t-test. According to obtained results, it was concluded that annually mean daily productions per 1 $kW_p$ of installed capacity and per 1 $m^2$ of active area of the panels are significantly better by single crystal silicon installation in tracking system than by stable installation of a different technology of single crystal silicon. However, comparing this performance per 1 $m^2$ of occupied land by studied power-plants the stable installation performed higher production rates on daily mean basis in majority of months of the year 2010 as well as by annually mean daily production.

specific production performance, comparison, crystalline silicon, PV systems, PV technology

Solar energy is a dominant energy source on the planet Earth giving a chance of life here. Since very ancient times till today, energy of the Sun had been transformed into a variety of energy resources mankind got used to utilize. Throughout ages of natural transformations, so called fossil fuels, had developed into a form of primary energy resources that constitute a majority of energy resources consumed worldwide today. According to the BP (2012) study, the share of fossil fuels in the worldwide consumption of energies is 92.2 % within last years.

Main advantage of fossil fuels is a relatively high amount of chemical energy bound in a specific amount of these primary energy sources that can be slightly increased by their further processing into secondary energy sources. High specific amount of energy, expressed by net calorific value, is quite important namely by mobile means; because, the higher the energy content the lower the ballast of the fuel in a tank; what, increases the overall efficiency of the original chemical energy transformation into mobility. That is why, crude oil products are crucial ones for the transportation sector, specifically road transportation, nowadays. The same seems to be position of coal in electricity production so far.

On the contrary, the principal disadvantages of fossil fuels in general are their limited reserves due to the fact that transformations of originally solar energy into them took much longer time than is the episode of their utilization by mankind.

Further, there is very high probability of a significant $CO_2$ concentration increase in the atmosphere in connection with the fossil energy resources utilization, namely by combustion. This connection is very clear to explain by chemical composition of these hydrocarbon fuels; where, except the natural gas, carbon constitutes the main part of a flammable content of these fuels.

That's why; there is a noteworthy effort to find other energy sources, or at least their forms, to be used in the future for reaching sustainability in all of its aspects. The necessity of bringing environmentally friendly and renewable energy resources into efficient operation is even higher in terms of expected energy demands growth. These facts are documented by many official studies, published historically yet (e.g. Global Energy Perspectives to 2050 and Beyond by World Energy Council, 1995); and further analyzed in different scenarios of future development in scientific papers and variety of books. According to analysis of above mentioned study, NAKICENOVIC *et al.* (1998) assumed the primary energy demand would be 14 Gtoe and 21 Gtoe in 2050 and 2100 respectively; under the conditions of the environmental development scenario. However, the EIA (2011) already estimated the actual primary world energy consumption at the level of 13.3 Gtoe in 2011.

Further, SMALLEY (2005) turned a focus on energy flux demand on a daily basis. Summarizing data for year 2004, he estimated the required power worldwide reached 14.5 TW; and for a population of 10 billion people (what represents the era beyond 2050) he estimated the prospect demand to 60 TW; nevertheless, he also evaluated future contributions of different ways of solar energy conversions for covering a growing demand; concluding the solar flux of 165 000 TW would play a key role in the future.

Furthermore, the idea of the "terawatt challenge" was developed by ZWEIBEL (2005); by studying and quoting distinct references, he reduced the power demand around 2050 to the level of 30 TW; yet, he reminds the 20 TW from that amount should be covered from non-$CO_2$ sources. The same, in his study, ZWEIBEL (2005) reduced the available solar flux potential to 120 000 TW. Nevertheless, photovoltaic technologies are presented by him as almost the only solution for covering prospect power demand from solar energy in the future.

Even if we can agree the direct solar energy utilization is probably the most important future energy technology thanks to its enormous potential worldwide; one has to take into account the conditions in different regions of our planet vary significantly. Thus, it can be expected the potential of other renewable energy sources, suitable in individual regions will be realized primarily in a short and medium term scenarios. On the other hand, a direct transformation of solar energy into electricity is quite important due to a fact that electricity consumption rise all over the world; and an additional increase might be expected in connection with electricity applications into a road transportation sector in the future.

Actually, the photovoltaic technologies are still in a research and development stage in general. Although, it is not a short era since members of the Becquerel family unveiled the photovoltaic effect in 1839 and Albert Einstein explained the phenomenon from a physical point of view in 1905; practical applications still reach relatively low overall efficiency today that varies in the most common installations of crystalline silicon about 12–17% in comparison with much higher efficiency levels by other renewable technologies (e.g. water power plants).

Thus, the efficiency of these low levels contributes to need of relatively large areas of photovoltaic panels (PV-panels) to reach significant amounts of electricity produced. Annually average gain able amount of solar irradiation is about 1,000 $W.m^{-2}$ under the conditions of the middle Europe; even if in total it represents enormous potential, the "density" of reachable energy per specific area is small; what is emphasized by low transformation efficiency.

In some installations, there are trackers used to potentially increase the amount of energy gained by positioning a PV-panel towards the Sun during the day. Multiple types of trackers and algorithms for a proper setup are available. Then, potential user can choose either a stable installation or choose among tracking systems. There are also software means for optimizing the installation to the conditions of specific location. However, the final decision can be checked by operational conditions only.

That's why this contribution deals with an analysis of two independent PV-systems that are already in a full operation as grid-on power plants under the conditions of the south of the Czech Moravian Highland.

## MATERIAL AND METHODS

### Description of the Locality and Power Plants

Both power plants are in a commercial operation since 2009. The owner of both plants is the same; and, according to his permission of using operational data; there are not specified tangible locations or names of power plants. Thus, a notation "Plant1" and "Plant2" will be used in the text.

Both power plants are situated in the south of the Czech Moravian Highland, approximate location is 49° latitude and 16° longitude, average altitude is about 420 m. The distance between them is about 3 km only; thus, it is assumed the operational conditions are fully comparable. That is why, there will not be tested the operational performance difference between the locations in the text; differences in installed technologies' performances are tested only.

The photovoltaic system notated as "Plant1" consists of 216 PV-panels installed in 3 rows in stable position with 35° inclination. Each row is then formed by 72 panels connected to an independent invertor for each individual row. The effective area of panels is 275.6 $m^2$ and the land covered by this system is 945 $m^2$. Material used as an active part of the panel is formed out single crystal silicon, the producer is the Solar Swiss AG (SSM-180/24M 180 W type). Rated power of single PV-panel is 180 W; thus, the system reaches in total 38.88 $kW_p$. The invertors used are the Fronius (IG Plus 150 type) and their operation is fully automatic by grid connecting and disconnecting according to the actual production as well as an optimal setup of the MPP – maximum power point; thus, no manual settings were accomplished during the testing period to affect production performance. The operational data are monitored by the DATCOM device that is connected directly to inventors by RS-485 and enables user friendly web communication on the other side; operational data are saved on 1 hour bases.

The "Plant2" PV-system consists of 1,296 PV-panels that are mounted into groups of 12 panels to 108 independent stands. Producer of the panels is the Sunpower (225 type), material of these PV-panels is single crystal silicon; rated power of each panel reaches 225 W; thus, the installed capacity is 291.6 $kW_p$. Design of the stands was developed by the owner of the PV plant in a form of tripod that enables positioning the 12-panel groups towards the Sun by the SGA tracker based on timing principle produced by the Green Source Technology. The inclination of the axis of the tracker stand is 30°. Land taken by the Plant2 is cca 11,000 $m^2$; while, the effective area of panels is 1,612 $m^2$. In total, there are 36 invertors mounted in the plant installation produced by the SMA company, type SMC 7000HV. The operational data are monitored by the Sunny WebBox device that is connected directly to inventors by RS-485 and enables user friendly web communication as a feed-back; operational data are saved continuously. Again, no affection of the original setup was made in connection with this monitoring.

Parameters of both systems are summarized in Tab. I.

## Data Acquisition and Methods of Analysis

The data were collected from above mentioned monitoring systems of both plants. The monitored quantity was electricity production that was summarized for every single day of the year 2010; thus, the data originally represent 365 samples for each monitored plant.

The hypothesis was; there is a significant difference in the production performance between these two power plants due to potentially different technologies of the panels used and different types of installations. However, it is obvious the basic data can not be processed due to a high difference in installed capacities; that is why, the data were transformed to reference quantities to accomplish further analyses.

Generally, for each reference quantity the original data were divided by a specific characteristic of each plant to get transformed data. Further, the mean daily production performances for each individual month were calculated for transformed data as well as annually mean of daily productions; and the contrasts between studied plants were tested by a pair t-test on monthly basis and finally by the annual mean for each reference quantity transformed data sets.

First, the reference quantity was chosen to be 1 $kW_p$ of installed capacity to reach the production performance per installed kW; thus, the installed capacity was taken as a measure. Therefore, the mean production per 1 $kW_p$ per day was calculated for each individual month as well as a yearly mean production per 1 $kW_p$ from all transformed samples to test the contrast in mean performances between these two plants. Even if, the daily mean productions per installed capacity for a particular month vary significantly with each other during the year; these mean productions describe the performance for financial and economical analyses, namely in terms of potential cash-flow prospects. On the other hand, the daily mean production for a whole year (annual mean) represents important characteristic of the production potentials, particularly in project stages and global projections. Moreover, in case, there is a significant difference in the production per installed capacity found only for some months, but not for every month within the year; the difference tested between the daily mean productions for a whole year contributes to formulation of a conclusion about contrasts between the plants' productions. Similarly, the above mentioned methodology for the production per 1 $kW_p$ of installed capacity differences evaluation was then used to express further reference quantities.

Then, the production per 1 $m^2$ of effective area of panels was calculated. This transformation should express the best the difference in technologies used; because, the magnitude of panels in general influences the amount of gain able energy; however, by the specific performance per 1 $m^2$ of the effective area of panels then it fully corresponds to the efficiency of panels used and the difference between stable and tracking installations.

I: *Selected parameters of tested PV-plants*

| Plant | Plant1 | Plant2 |
|---|---|---|
| Installed capacity [$kW_p$] | 38.88 | 291.6 |
| Technology of panels [-] | Single crystal Si | Single crystal Si |
| Number of panels [-] | 72 | 1,296 |
| Rated power of one panel [W] | 180 | 225 |
| Installation type [-] | Stable | Tracking (timing type) |
| Effective area of plant [$m^2$] | 275.6 | 1,612 |
| Land taken by plant – horizontal projection [$m^2$] | 945 | 11,000 |

Finally, speaking about reference area, the land taken (horizontal projection) by the both systems is very different as well (see Table I). Thus, the question, whether a specific electricity production performance per the area of land taken is influenced by a specific installation type and the contrasts in technologies of PV systems installed, can be unveiled. Thus, the original data were divided by the area taken by each power-plant to receive transformed data of a production performance by 1 $m^2$ of occupied land. Then, the difference between such specific performances of the two studied PV-systems was tested the same way as by previous reference quantities.

## RESULTS

There are presented the calculated results of analyses of transformed data only in the text; nevertheless, the original data are available by authors. In accordance with methods explained above, the contrasts in production performances of both plants were tested by pair t-test for the transformed data for each described reference quantity. Presented charts and partly the calculations were performed in the MS Excel with a strict application of $df = n - 1$ for variances and standard deviations calculations and partly in the Statistica 9.0 software. The Statistica 9.0 CZ was also used for verifying of calculations accomplished by MS Excel.

### Production performance per 1 $kW_p$

As described above, the original data were transformed by selected reference quantity by both of the described power plants. In this case, it was the installed capacity of each plant used as a reference quantity. Thus, each daily production recorded in the information system of a specific plant was divided by the installed capacity presented in Tab. I of this monitored plant. Further, the daily mean productions were calculated for particular months as well as the annual mean daily production per installed $kW_p$ was considered.

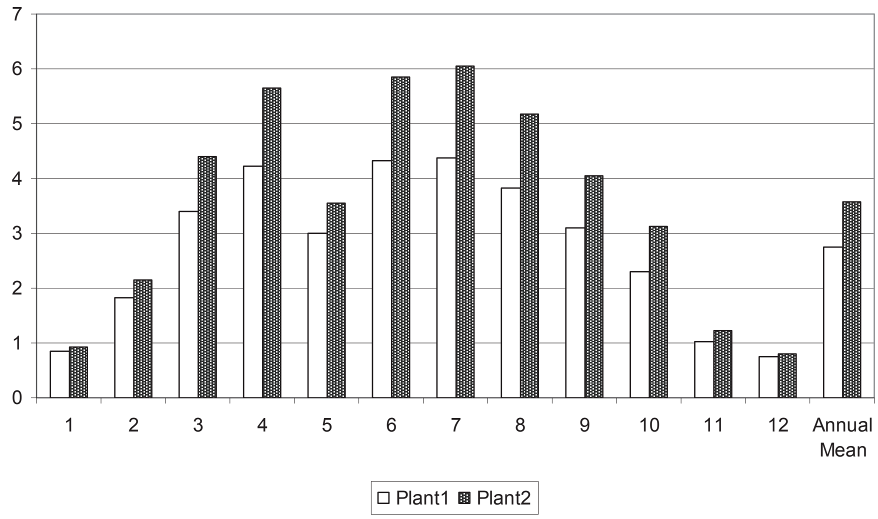
Monthly mean daily production performances per installed $kW_p$ in individual months as well as the annual mean daily production performance per installed $kW_p$ are presented in Fig. 1. Further, the contrasts testing is presented in Tab. II and graphically explained in Fig. 2.

Several statistical methods could be used for testing the contrasts of daily mean performances in general. The most common method would be the ANOVA method. However, assumptions for a specific method should be tested in advance to receive valid results of a specific method. Testing the transformed data by all studied reference quantities it was found the assumption of homogeneity of variances for ANOVA are violated in some months. Thus, the ANOVA could not be used in general for testing the contrasts between performances of studies plants. The t-test utilization also assumes the variation of scores in the two groups is not reliably different; nevertheless, this method can be used for relatively small sizes of samples. That is why; the pair t-test for evaluation of differences in means between the production performances was finally used. Moreover, the two-sample pair t-test was transformed to one sample t-test; thus, it is assumed the difference between the performances of both plants is 0 in the null-hypothesis. Differences in daily productions are in all cases of transformed data calculated as follows:

$$D = P_1 - P_2, \quad (1)$$

where:

*D* ... difference of transformed data [kWh] for daily productions;




1: *Monthly mean daily productions in kWh per day (and annual mean) expressed for 1 $kW_p$ of installed capacities of monitored power plants*

$P_1$... transformed daily production performance of the Plant1 [kWh];

$P_2$... transformed daily production performance of the Plant2 [kWh].

Then the mean differences for all studied cases were calculated for individual months as well as annual mean differences for transformed data cases and one-sample t-test characteristics were evaluated – see Tab. II.

## Production performance per 1 m² of effective area of the PV-panels

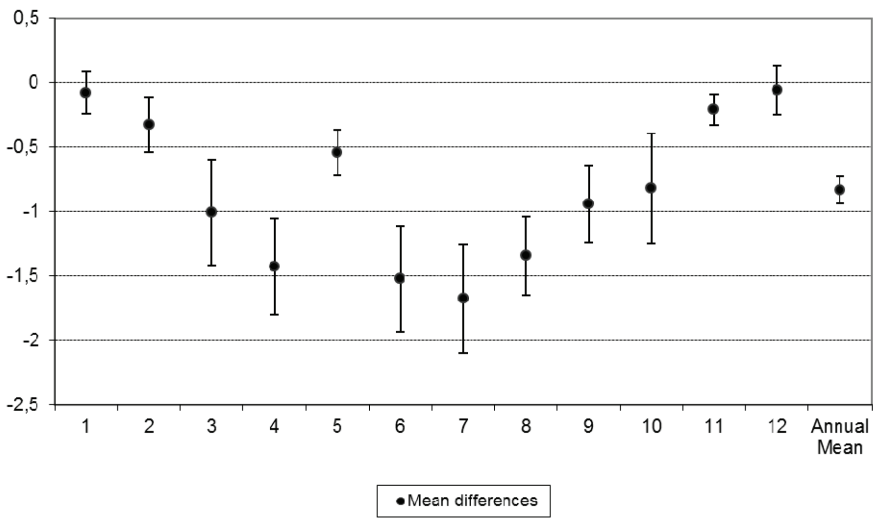
Monthly mean daily production performances per 1 m² of PV-panels in individual months as well as the annual mean daily production performance per 1 m² of PV-panels are presented in Fig. 3. Further, the contrast's testing calculated for these transformed data sets according to methods explained above is presented in Tab. III and graphically explained in Fig. 4.

## Production performance per 1 m² of horizontal projection area of the PV-Systems

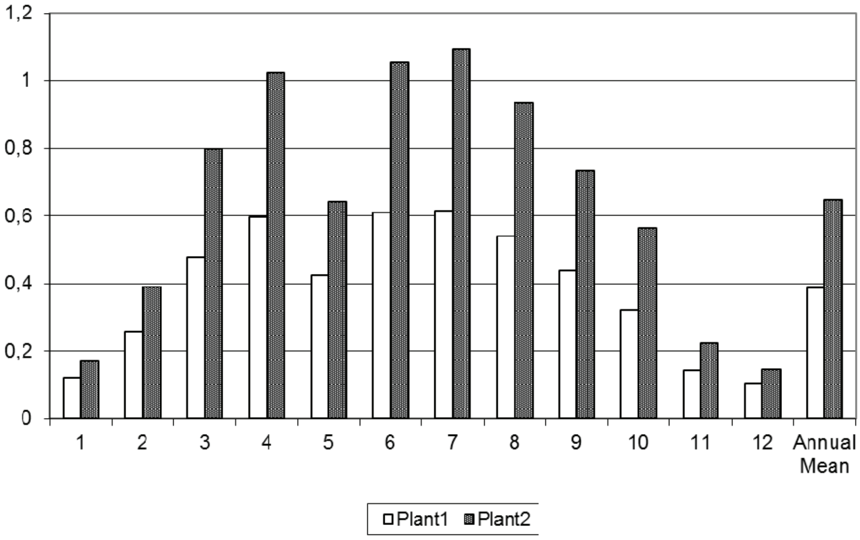
Monthly mean daily production performances by specific PV-system in individual months as well as the annual mean daily production performance per 1 m² of occupied land are presented in Fig. 5. Further, the contrasts testing calculated for these transformed data sets according to methods explained above is presented in Tab. IV and graphically explained in Fig. 6.

II: *Mean differences in daily production performances between the two studied plants per 1 $kW_p$ of installed capacity and appropriate t-test analyses*

| Month | Mean Differences in Daily Productions | Days per Month (n) | Standard Deviation | Standard Error | t-value | p |
|---|---|---|---|---|---|---|
| - | kWh | - | (kWh)² | (kWh)² | - | - |
| 2010_01 | –0.0810 | 31 | 0.4398 | 0.0803 | 1.0089 | 0.32082 |
| 2010_02 | –0.3262 | 28 | 0.5497 | 0.1039 | 3.1399 | 0.00396 ** |
| 2010_03 | –1.0046 | 31 | 1.1156 | 0.2004 | 5.0139 | 0.00002 ** |
| 2010_04 | –1.4265 | 30 | 0.9974 | 0.1821 | 7.8335 | 0.00000 ** |
| 2010_05 | –0.5434 | 31 | 0.4906 | 0.0881 | 6.1671 | 0.00000 ** |
| 2010_06 | –1.5193 | 30 | 1.0959 | 0.2001 | 7.5932 | 0.00000 ** |
| 2010_07 | –1.6768 | 31 | 1.1521 | 0.2069 | 8.1032 | 0.00000 ** |
| 2010_08 | –1.3434 | 31 | 0.8374 | 0.1504 | 8.9325 | 0.00000 ** |
| 2010_09 | –0.9412 | 30 | 0.8022 | 0.1465 | 6.4264 | 0.00000 ** |
| 2010_10 | –0.8199 | 31 | 1.1672 | 0.2096 | 3.9109 | 0.00047 ** |
| 2010_11 | –0.2104 | 30 | 0.3170 | 0.0579 | 3.6361 | 0.00103 ** |
| 2010_12 | –0.0537 | 31 | 0.5240 | 0.0941 | 0.5708 | 0.57225 |
| Annually | –0.8309 | 365 | 1.0050 | 0.0526 | 15.7950 | 0.00000 ** |




2: *Mean differences in daily production performances in particular months and the whole year in kWh per day expressed for 1 $kW_p$ of installed capacity and their confidence intervals (p = 0.05)*




3: *Monthly mean daily productions in kWh per day (and annual mean) expressed for 1 m² of the size of installed PV-panels of monitored power plants*

III: *Mean differences in daily production performances between the two studied plants per 1 m² of PV-panels and appropriate t-test analyses*

| Month | Mean Differences in Daily Production | Days per Month (n) | Standard Deviation | Standard Error | t-value | p |
|---|---|---|---|---|---|---|
| - | kWh | - | $(kWh)^2$ | $(kWh)^2$ | - | - |
| 2010_01 | –0.0487 | 31 | 0.0979 | 0.0179 | 2.7244 | 0.01049 * |
| 2010_02 | –0.1316 | 28 | 0.1499 | 0.0283 | 4.6479 | 0.00007 ** |
| 2010_03 | –0.3170 | 31 | 0.2388 | 0.0429 | 7.3894 | 0.00000 ** |
| 2010_04 | –0.4265 | 30 | 0.2279 | 0.0416 | 10.2505 | 0.00000 ** |
| 2010_05 | –0.2181 | 31 | 0.1269 | 0.0228 | 9.5657 | 0.00000 ** |
| 2010_06 | –0.4466 | 30 | 0.2609 | 0.0476 | 9.3762 | 0.00000 ** |
| 2010_07 | –0.4769 | 31 | 0.2665 | 0.0479 | 9.9632 | 0.00000 ** |
| 2010_08 | –0.3951 | 31 | 0.2083 | 0.0374 | 10.5587 | 0.00000 ** |
| 2010_09 | –0.2940 | 30 | 0.1885 | 0.0344 | 8.5446 | 0.00000 ** |
| 2010_10 | –0.2397 | 31 | 0.2455 | 0.0441 | 5.4372 | 0.00001 ** |
| 2010_11 | –0.0786 | 30 | 0.0964 | 0.0176 | 4.4667 | 0.00010 ** |
| 2010_12 | –0.0394 | 31 | 0.0954 | 0.0171 | 2.2984 | 0.02844 * |
| Annually | –0.2598 | 365 | 0.2449 | 0.0128 | 20.2713 | 0.00000 ** |

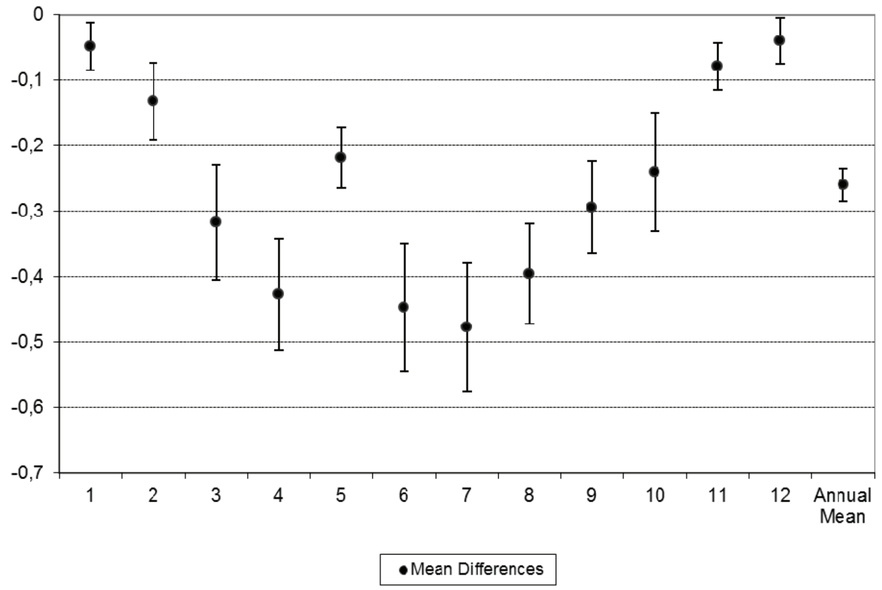
## DISCUSSION

Obtained results of monthly mean daily productions for monitored PV power plants for individual transformed data sets are suitable for decision making for potential prospects of newly prepared PV power plants. Namely, the contrasts unveiled can contribute to a proper decision of what type of technology to select for a potential owner of a new power plant.

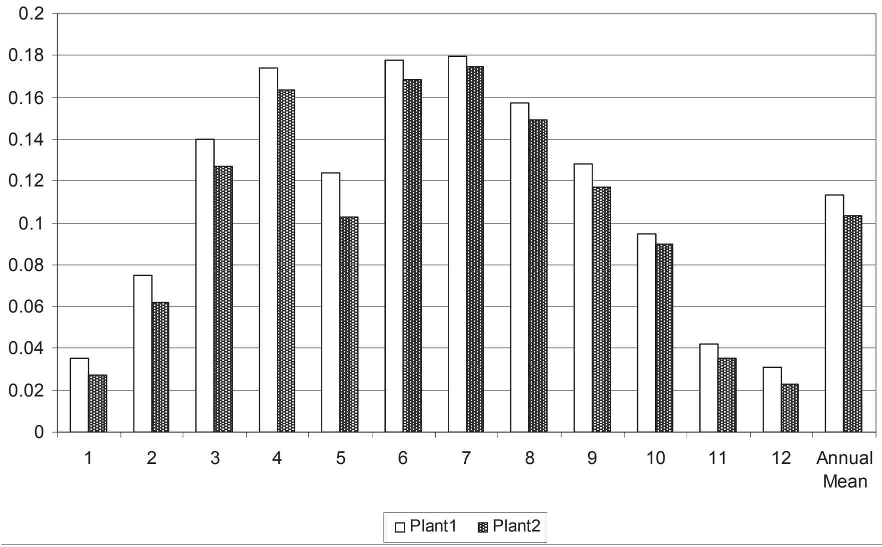
Transforming the original data to specific reference quantities the original differences in the sizes and installed capacities of both plants are eliminated and it was already mentioned the location of both plants is considered the same; thus, the contrasts in technologies used remain as main factors influencing the final production in transformed data by the specific studied plant.

Studying the annual results obtained for specific mean daily production per 1 $kW_p$ of installed capacity and 1 m² of active area of installed PV panels, it is obvious the performance of the Plant2 is significantly higher than by the Plant1. Such results are in a full accordance with theoretical assumptions, because the system of the Plant2 is equipped with tracking installation; and by the theoretical assumptions the performance of tracking system could be increased by 20–30% in contrast with stable installation (POULEK and LIBRA, 2005). Potentially, one can also assume that partly there is a difference in production performances in the technologies of single crystal silicon used by different producers of the panels.

Such a synergy interaction of potentially higher efficiency of used materials in connection with




4: *Mean differences in daily production performances in particular months and the whole year in kWh per day expressed for 1 m² of installed PV-panels and their confidence intervals (p = 0.05)*



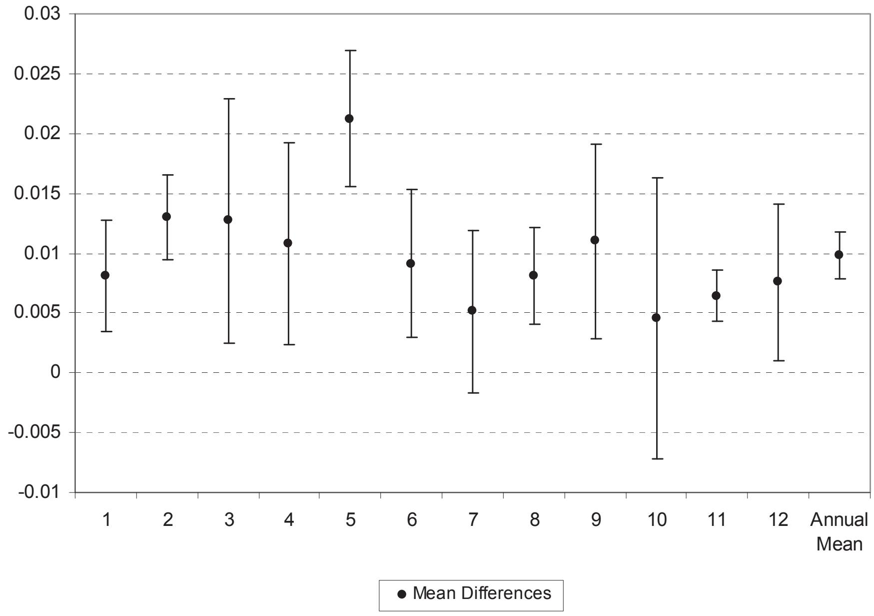

5: *Monthly mean daily productions in kWh per day (and annual mean) expressed for 1 m² of land occupied by monitored power plants*

tracking installation is presented namely by daily mean production per 1 m² of installed panels; where, annual mean daily production of the Plant1 comprised only 59.9% of the Plant2 performance. Whereas, the annual mean daily production per 1 $kW_p$ of installed capacity reached by the Plant1 76.8% of the Plant2 performance. Nevertheless, both contrasts in annual production parameters were statically highly significant.

This result can be probably obtained by much better utilization of an effective area of the panels by tracking system of the Plant2 in terms of direct solar radiation utilization; while, the stable installation partly relies on utilization of diffusion radiation portion. This explanation can be supported by studying differences in mean daily productions by individual months. While, by the transformed data sets for 1 m² of the installed panel's area the statistical significance of monthly mean daily productions was proven in all months of the year 2010; the differences in monthly mean daily productions transformed to 1 $kW_p$ of installed capacity weren't statistically significant in January and December 2010. Also, it is known the portion of diffusion radiation is higher in winter and autumn months in the middle Europe climate conditions. Thus, one can assume the technology of single crystal silicon by the Plant1 performs better under the conditions of majority of diffusion radiation even in stable installation; or the same, the interaction – technology of Plant2 and

IV: *Mean differences in daily production performances between the two studied plants per 1 m² of land occupied by PV-systems and appropriate t-test analyses*

| Month | Average Difference in Production | Days/Month (n) | Standard Deviation | Standard Error | t-value | p |
|---|---|---|---|---|---|---|
| - | kWh | - | (kWh)² | (kWh)² | - | - |
| 2010_01 | 0.0082 | 31 | 0.0125 | 0.0023 | 3.5778 | 0.00116 ** |
| 2010_02 | 0.0130 | 28 | 0.0090 | 0.0017 | 7.4937 | 0.00000 ** |
| 2010_03 | 0.0127 | 31 | 0.0274 | 0.0050 | 2.5428 | 0.01621 * |
| 2010_04 | 0.0108 | 30 | 0.0223 | 0.0041 | 2.6016 | 0.01427 * |
| 2010_05 | 0.0212 | 31 | 0.0152 | 0.0028 | 7.6328 | 0.00000 ** |
| 2010_06 | 0.0091 | 30 | 0.0163 | 0.0030 | 3.0059 | 0.00531 ** |
| 2010_07 | 0.0051 | 31 | 0.0182 | 0.0033 | 1.5460 | 0.13226 |
| 2010_08 | 0.0081 | 31 | 0.0108 | 0.0020 | 4.1081 | 0.00027 ** |
| 2010_09 | 0.0110 | 30 | 0.0213 | 0.0040 | 2.7726 | 0.00946 ** |
| 2010_10 | 0.0045 | 31 | 0.0315 | 0.0057 | 0.7854 | 0.43819 |
| 2010_11 | 0.0064 | 30 | 0.0056 | 0.0010 | 6.1536 | 0.00000 ** |
| 2010_12 | 0.0076 | 31 | 0.0176 | 0.0032 | 2.3606 | 0.02472 * |
| Annually | 0.0098 | 365 | 0.0190 | 0.0010 | 9.8109 | 0.00000 ** |




6: *Mean differences in daily production performances in particular months and the whole year in kWh per day expressed for 1 m² of land taken by PV-systems and their confidence intervals (p = 0.05)*

tracking system – is less profitable under such light conditions. Actually, trends within the year of lower differences in studied production performances are clearly visible in both Fig. 2 and Fig. 4; moreover, the variability of obtained data is lower in winter then in summer months.

On the contrary, it is clear from above reached results of data sets transformed for production performance per 1 m² of horizontal projection of studied systems; the annual mean daily production as well as a majority of monthly mean annual productions performances represent slightly better results by the Plant1. This trend is obvious from Fig. 5 and an opposite orientation of differences in Fig. 6 (compared to Fig. 2 or Fig. 4). While annual mean daily production per 1 m² of occupied land is significantly statistically different (the Plant2 performance was 91.4% of the Plant1); namely due to high *df* of annual samples; the differences in July and October were not found significantly different. It is also noticeable; the variability of studied differences is visibly higher than by previous reference quantities (compare Fig. 6 with Figs. 2 and 4) and individual differences are almost trend less within the year. One can conclude that due to larger area needed for the tracking system to avoid individual stands shading each other; neither the better material of panels for direct solar beams "catching" nor the benefits of tracking system itself cover the "consumption" of land taken by the tracking system. Nevertheless, the differences are an order of magnitude lower then by previous reference quantities; thus, a technology of trackers (probably a radiation intensity orientation principles) and a technology of panels (active material) can affect the magnitude of differences. And so, even if, the statistical significance of test data is proven in this monitoring, the strength of differences in production performances per 1 $m^2$ is the lowest from selected reference quantities.

One of the goals of this text was to constitute a document contributing to decision making for potential owners of PV power plants in terms of technology they tend to install. Software means and models of PV systems are also prepared to help these potential investors with their decisions. Published results were thus compared with the EU initiative the PV GIS (IET, 2012) and a high level of compliance with modeled data and real production performances of studied plants were found. By the Plant1 and Plant2 the estimated production was 96.1 % and 90.7% respectively of real production performance of studied plants (calculated on data presented by VACUŠKA, 2011). This relatively high compliance could be even better in a longer term of monitoring, because the PV GIS model is based on longer periods of all involved databases; and in addition by better setup of input parameters for the model calculation. On the contrary, MUÑOZ *et al.* (2009) dispute a precision of the PV GIS models in case of stand alone PV plants without maximum power point trackers (MPPT); moreover, SHAYANI and DE OLIVEIRA (2011) suggested absolute performance ratio (APR) to determine a potential energy production of a stand alone PV system rather than International Electrotechnical Commission (IEC) standard 61724. Similarly ESRAM and CHAPMAN (2007) discussed techniques for maximum power point tracking of photovoltaic (PV). The techniques taken from the literature dating back to the earliest methods altogether include at least 19 distinct methods. Finally, in connection with PV GIS, HULD *et al.* (2012) unveiled new approach from satellite databases joined into the data model for PV GIS in 2012; and so, higher precision of models can be expected in the future.

Nowadays, a fundamental research effort in terms of photovoltaic technologies is oriented to material engineering for higher efficiencies of used materials and their combinations; however, in practically oriented papers namely a precision of modeling of PV systems under specific climatological conditions and optimization methods for MPPT and tracking technologies are studied. Climatological approach was presented by MAVROMATAKIS *et al.* (2010), modeling of crystalline silicon behavior systems on the base of climatological data were published by FUENTES *et al.* (2007). The same a high level of compliance between their algebraic models of PV system was found by QUESADA et al. (2011) with practical data from 7.2 $kW_p$ system located in Spain. Further, ZHANG *et al.* (2011) developed a model of large arrays of PV panels for arbitrary conditions. Similarly, BEST *et al.* (2011) turned their focus on optimization of tracking systems under various tilt angles in comparison with above mentioned modeling of climatological data.

In contrast with previous studies BERINGER *et al.* (2011) tried to disputed necessity of an optimal setup of tilt angle of specific PV system, concluding that largest difference of the plant yield was less than 6% for tilt angles between 0° and 70° for both yearly sum and for the summer months by multicrystalline silicon under the conditions of Germany (Hannover).

## CONCLUSION

The goal of presented study was to demonstrate operational performance of typical installations of PV technology and their production parameters under the condition of the Czech Moravian Highland in the Czech Republic. Obtained results are in a high compliance level with expected results according to well known facts. Thus, theoretical hypothesis, there are significant differences in technologies used in a specific location were proven. Moreover, higher expectable production performance of single crystal silicon on tracking system was proven to be statistically significant by production performance per 1 $kW_p$ of installed capacities as well as per 1 $m^2$ of active area of the panels (where the relative differences were found to be the highest). On the contrary, as for production performance per 1 $m^2$ of horizontal projection, it was a bit unpredictably found the stable installation reaches slightly better production performance in the annual mean daily production as well as by majority of monthly mean daily productions.

Thus, the recommendation according to obtained results can be presented as a tracking PV system is suitable for panels with high efficiencies and for locations with higher portions of direct solar radiation. The same, an optimization of individual stands positions within a specific PV tracking system is desirable.

Speaking of PV technologies utilization in the Czech Republic, where the extent of agricultural land is reduced in average about 15 ha per day, the installations should be oriented to industrial zones or brown-fields instead of arable land; as it was accomplished in the past. Nevertheless, further increase of efficiency of the PV technology will be required to reach higher portions of electricity production mix. Thus, the ideas of ZWEIBEL (2005) about massive production of electricity from PV systems are under the conditions of the Czech Republic more or less close to a utopia so far.

## SUMMARY

Photovoltaic systems have become an integral part of the landscape of the Czech Republic; and generally, a great importance in the future structure of the production of electricity is indeed attributed to the photovoltaic technologies (Zweibel, 2005).

The subject of this paper is to compare tangible production parameters of two systems installed in the south of the Czech Moravian Highland as commercial applications in private ownership. With the permission of the owner, real data obtained from measuring and monitoring systems of the two installations were utilized. However, in accordance with the permission, both plants are labeled as "Plant1" and "Plant2" only. Due to their relative position - the linear distance of about 3 km, the climatic conditions of operation of both plants are considered identical. Thus, the object of production parameters comparison study is only in contrasts in the PV technology used in the installations.

Plant1 has an installed capacity of 38.8 kWp and is made up of 72 panels of monocrystalline silicon panels with an active area of 275.6 square meters that by stable south orientation installation angled 35° occupy 945 $m^2$; whereas, Plant2 consists of 1,296 panels of monocrystalline silicon with active area of 1612 square meters. By Plant2, groups of the panels are installed on the trackers regulated on a time basis, thus, total installed capacity of 291.6 kWp occupies an area of about 11,000 square meters.

As the individual parameters of the installed power significantly vary, the comparison of chosen production performance is accomplished based on appropriate reference values transforming the measured data by specific variables. Production per 1 kWp of installed capacity, production per 1 $m^2$ of active surface panels and production per 1 $m^2$ area of the plant were selected.

Due to violation of the homogeneity of variances assumptions by the analysis of variance, the method of contrasts testing between studied quantities was based on paired t-test. The analyzes confirm higher production capabilities of crystalline silicon in combination with the sun tracker if comparing specific daily mean production for the whole year and by all months of 2010 by the assessment of production per 1 $m^2$ of active surface panels. Similarly, the specific production per 1 kW of installed capacity is by the Plant2 higher by annual daily mean production; nevertheless, it was not statistically significantly different within the winter months in the monthly mean daily production basis. This is probably caused by a higher proportion of diffuse radiation portion within these months that the technology of monocrystalline silicon Plant2 modules manufacturer is not able so effectively utilize, neither in combination with the tracker.

Surprisingly, however, related to the specific production area of 1 $m^2$ plant, a better performance was found by stable installation, because the individual distances among module groups in the tracker system must be higher in order to avoid mutual shading. The difference is statistically significant only at the annual average of the daily production, while in July and October it is not possible to prove significant difference by monthly means of the daily production. Even if, values of differences are of order of magnitude lower than by the previous analyzes outputs, it is obvious that the advantage of high technology elected to specific power plant does not balance the drawback in connection with the need to occupy large territory. Therefore, there is a recommendation to future investors to carefully choose between stable and tracking installations in terms of final area of plant in contrast with specific production per this area.

The obtained results in general confirm the theoretical assumptions in the expected production parameters; the only exception represents characteristics related to the specific plant area; where, in practice, it will be a mutual balancing between production capacity and occupation of territory. Thus, the results obtained by one single comparison can not be fully generalized.

The current basic research in the field of PV technology is based on materials engineering with the aim to find a higher operating efficiency, while more practically oriented posts, like this one, are focused on the optimization of the decision-making phase of the construction of new power plants, which can be used in the practical conclusions.

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Address

Ing. Martin Fajman, Ph.D., Ing. Josef Vacuška, Department of Technology and Automobile Transport, Mendel University in Brno, Zemědělská 1, 613 00 Brno, Czech Republic, e-mail: fajman@mendelu.cz