PHOTOVOLTAIC POWER PLANTS, EXTREME CHANGE OF POWER DIFFERENCE

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ABSTRACT

Photovoltaic power plants are sources of electrical energy that are dependent on weather conditions. Consequences include their stochastic change of the production power. The survey focus on assess the impact of photovoltaic power plants operation on the daily load diagram with regard to output change difference of active power. Statistical methods have been employed to process a methodology in order establish extreme conditions of production power for photovoltaic power plant. The already evaluated minimum and maximum extreme conditions are applied to the daily load diagram. Evaluation is based on real-time synchronous data measuring both on-site photovoltaic power plant operation and on-site electric power line output from the substation, where the power plant is connected. This paper describes the methodology for determining the difference in the change of active power at the power line output from the substation to ensure loads in this location.

Keywords: *photovoltaic power plant, stochastics, extreme production conditions, difference of active power, statistics, methodology, daily load diagram*

1. INTRODUCTION

The aim of this survey is to evaluate the impact of operation of the photovoltaic power plant (PVP) with respect to the daily load diagram (OBD). The data available has been obtained by measurement at the PVP operation site and the point of electric power output from substation plant. Both measurements were conducted on synchronised basis.

The main purpose of this survey is to assess the differential changes of active power at the place of measurement within substation plant. The facts considered include power changes caused by both production output from PVP as well as the nature of consumption within the specific area.

The evaluation is conducted by means of several individual tasks that can be split into two stages. The first stage determines methodology for set-up of extreme thresholds for production generated by the PVP and the second stage concerns analysis of impact of these extreme threshold values on the magnitude of active power flows at the place of measurement within substation plant. The conclusion reached herein will refer to the versatile methodology to define differential change of active power. These changes to power flowing from the substation plant have adverse effect on supporting services provided by operators of distribution networks.

The data was processed and evaluated using the Excel Microsoft office 2003 chart processor and Statgraphic XV statistical software.

2. DATABASE FILE OF MEASURED DATA

The data was obtained by measurement at PVP in the municipality of Starojická Lhota on the relevant power line output of the substation plant in Nový Jičín, where this PVP is connected. The data has been obtained from source [3].

2.1. FVE Starojická Lhota

The peak output of this PVP is 1.1 MWp. The measurement was conducted on the low voltage side on continuous basis for one year; that was from 30.6.2010 till 29.6.2011. The time increment was set to one minute. The measured value (observed in this survey) was represented by active power P in the course of time. The data file contains 511,993 entries in total.

2.2. Substation Plant in Nový Jičín

The data was obtained at substation plant in Nový Jičín at the power line output, where the PVP is connected. This measurement was conducted on the high voltage end. The line has a loop system, yet it is operated in radial system. When this measurement was conducted, the PVP Starojická Lhota was the only electric power source with significant output on the given power line. The measurement ran within various time periods from 26.7.2010 till 23.6.2011. The data was recorded with time step set at one-minute increments. The values measured included the active power P, once again. The data file contains total of 336,539 entries. Source [1] shows all database file, where it is present. Further steps described in this article analyse data in April 2011 [3].

3. DETERMINATION OF EXTREME PRODUCTION CONDITIONS OF PVP

The consistency and comprehensibility of this article is supported by the results from survey to define methodology for determination of extreme production conditions. The methodology is described in [1]. The purpose is the set maximum and minimum threshold of extreme production conditions for PVP. The methodology was used to define polynomial equations to describe such extreme thresholds in production. The evaluation is based on statistical methods with 95% probability level. Two extremes are laid out:

a) maximum extreme conditions of active power P_{PVPmax}

$$P_{PVP\max} = -5700{,}51 + 63525{,}7 \cdot Time - 246642 \cdot Time^2 + 400745 \cdot Time^3 - 279206 \cdot Time^4 + 66861{,}7 \cdot Time^5 \quad (1)$$

b) minimum extreme conditions of active power P_{PVPmin}

$$P_{PVP\min} = 4554{,}05 - 68932{,}4 \cdot Time + 414328 \cdot Time^2 - 1{,}25591 \cdot 10^6 \cdot Time^3 + 2{,}0145 \cdot 10^6 \cdot Time^4 - 1{,}62904 \cdot 10^6 \cdot Time^5 + 523013 \cdot Time^6 \quad (2)$$

where: P – active power (kW), *Time* – time (hh:mm:ss).

Fig. 1 shows extreme areas of PVP production. The thresholds of these extreme conditions are defined by two regression polynomial equations (1) and (2), which form the top and bottom envelope curves of stochastic changes in the produced output. Determination of these extreme conditions was conducted with division of data from the period monitored into relevant frequency categories using the so called Sturges rule. This is a rule for optimal determination of frequency categories. Further procedure then involved selection of frequency categories bordering envelope curves, i.e. extreme values. Both areas of values were then subject to regressive analysis with convenient determination index R^2 [2].

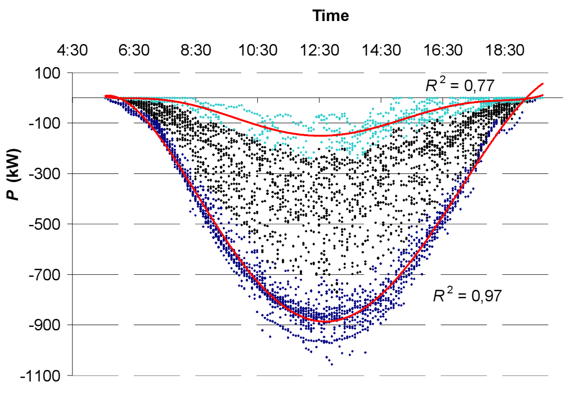

Fig. 1 Regression of both extreme production conditions [1]

4. DAILY LOAD DIAGRAM

4.1. Correction and synchronising of data obtained by measurement

For the month of April 2011 data record contain 41 % of substation plant and 99 % of PVP. Further step requires determination of common synchronous percentage of record, which determines the percentage record of data measured with values available from both the PVP and the substation plant. The common synchronous percentage corresponds with 41 % level in this case.

Fig. 2 shows three graphic illustrations. The one marked FVE represents power generated by the photovoltaic plant, the ROZ refers to data measured at the outlet from substation plant, and the OBD shows load diagram within the specific location, where the PVP is situated. As the network is operated in radial mode and the PVP was the only source with significant output within the network at the time of measurement, the following applies:

$$OBD = FVE + ROZ \quad (MW). \quad (3)$$

The relation (3) was used to determine the course of daily load diagram (OBD) at the specific location.

The measurement instruments were not always set to identical actual time during synchronous measurement between PVP and substation plant. That resulted in occurrence of the so called measurement synchronisation errors. Their duration and occurrence types were assessed to place them into several categories. Most errors were removed pursuant to visual and statistical methods. However, certain errors could be eliminated only. This elimination comprised smoothing the data out by means of moving average with parameter 2 with subsequent conversion of output measure in minute increments into average five-minute output values [4]. Such corrected data is shown in Fig. 2.

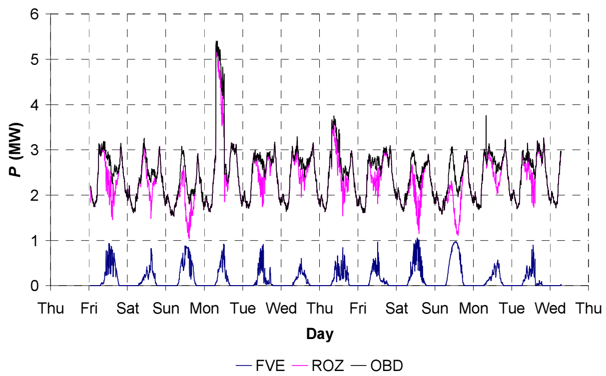

Fig. 2 Input data file after corrections, synchronisation and elimination of errors

4.2. Daily load diagram correlation field

Based on synchronisation can be used to determine the scatter plot over the observed period (Fig. 3) for the data measured at PVP (FVE), the output line from substation plant (ROZ) and for the data from daily load diagram for the specific location (OBD).

Morning hours between 4:00 till 9:00 a.m. (Fig. 3) show the load diagram with apparent two different courses. It has been revealed that these courses are dependent on individual days of the week. Should the range of data considered be limited to working days only, the load diagram will show its course identical to Fig. 4 (black scatter plot).

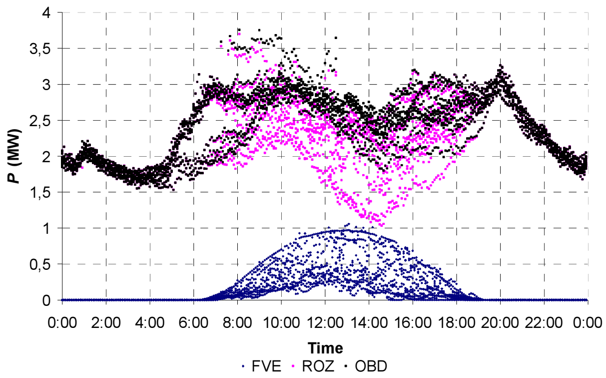

Fig. 3 Scatter plot of five-minute output intervals of FVE, ROZ and OBD

where: FVE – data from PVP operation,
ROZ – data measured as the substation plant,
OBD – daily load diagram calculated.

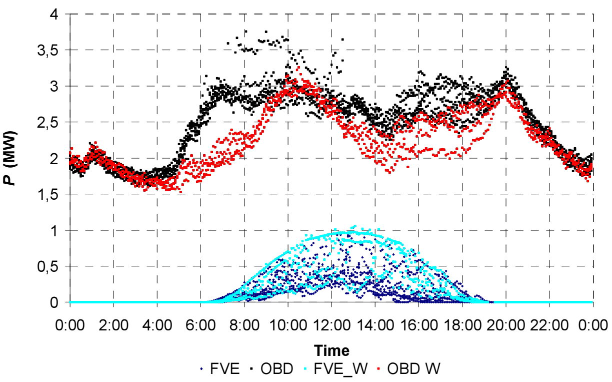

Fig. 4 Daily load diagram for FVE, ROZ and OBD during working days and weekends

where: FVE_W – output from operation of PVP during weekends,
OBD_W– daily load diagram for weekends.

Fig. 4 shows graphic comparison of the daytime course of the diagram during workings days and weekends respectively too. It can be stated that the nature of the power loads changes depending on working days or weekends. The purpose of analysis and assessment require examination of these two periods separately. Further surveys have analysed the daily load diagram during working days so far. Evaluation of weekend periods requires a larger data file to be assessed within further surveys.

4.3. Regression analysis of the daily load diagram

Correlation fields (scatter plot in Fig. 4) of daily load diagram can be subject to regression analysis applied to enable determination of differential thresholds of changes in output produced with certain reliability. Differential thresholds are determined using 95% prediction reliability levels. These prediction levels generally define the probability and range for output daily load diagram for ever individual value within specific time intervals. These thresholds are shown in Fig. 5. Regression and relevant prediction levels have been determined using the Statgraphic XV computing software.

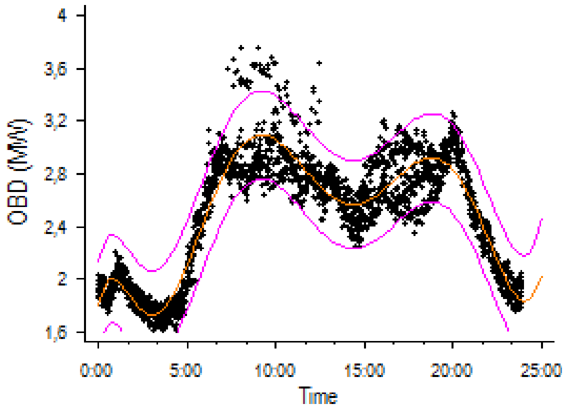

Fig. 5 Regression analysis of the daily load diagram

where: purple – 95% prediction level,
red – polynomial regression curve of 8th degree.

The regression was matched by determination index $R^2 > 86$ %, which corresponds with strongly dependent regression [2]. The regression curve of daily load diagram is defined by the polynomial equation of 8th degree:

$$P_{\mathrm{OBD}}\,(MW) = 1{,}79528 + 0{,}0105233 \cdot Time - 0{,}000169499 \cdot Time^2 + 9{,}37263 \cdot 10^{-7} \cdot Time^3 - 2{,}32474 \cdot 10^{-9} \cdot Time^4 + 3{,}00525 \cdot 10^{-12} \cdot Time^5 - 2{,}10558 \cdot 10^{-15} \cdot Time^6 + 7{,}56915 \cdot 10^{-19} \cdot Time^7 - 1{,}09185 \cdot 10^{-22} \cdot Time^8, \quad (4)$$

where: P – active power (MW),
$Time$ – time (hh:mm:ss).

Prediction levels of the daily load diagram have been expressed by the regression equations below. Both cases involve polynomial equations of 8th degree again:

a) top threshold of prediction level

$$P_{\mathrm{OBDmax}}\,(MW) = 2{,}13445 + 0{,}000174187 \cdot Time - 4{,}6908 \cdot 10^{-8} \cdot Time^2 + 4{,}32657 \cdot 10^{-12} \cdot Time^3 - 1{,}78877 \cdot 10^{-16} \cdot Time^4 + 3{,}85326 \cdot 10^{-21} \cdot Time^5 - 4{,}49778 \cdot 10^{-26} \cdot Time^6 + 2{,}69318 \cdot 10^{-31} \cdot Time^7 - 6{,}46948 \cdot 10^{-37} \cdot Time^8, \quad (5)$$

b) bottom threshold of prediction level

$$P_{\mathrm{OBDmin}}\,(MW) = 1{,}45615 + 0{,}000176551 \cdot Time - 4{,}72509 \cdot 10^{-8} \cdot Time^2 + 4{,}35116 \cdot 10^{-12} \cdot Time^3 - 1{,}79852 \cdot 10^{-16} \cdot Time^4 + 3{,}87564 \cdot 10^{-21} \cdot Time^5 - 4{,}52732 \cdot 10^{-26} \cdot Time^6 + 2{,}71398 \cdot 10^{-31} \cdot Time^7 - 6{,}52996 \cdot 10^{-37} \cdot Time^8. \quad (6)$$

4.4. Determination of difference thresholds

Previous analyses have produced the difference of output generated by PVP (determination of the minimum and maximum extreme conditions of production) and determination of thresholds for daily load diagram. Extreme conditions that might occur at the substation plant outlet correspond with the sum of extreme conditions of PVP and the daily load diagram.

Grey and black curves (P_OBD_MAX a P_OBD_MIN) in Fig. 6 correspond with 95% prediction levels in the daily load diagram. These are defined by equations (7) and (8). The light blue curve represents such condition, when the daily load diagram has reached its maximum level, whereas the contribution from PVP is at its minimum level; that represents the top threshold of power flowing from the substation plant. The curve is therefore defined by the difference between the curve of top threshold of prediction level for daily load diagram (5) and the minimum extreme condition of production at PVP (2). That actually refers to the maximum extreme power at the substation plant output (P_ROZ_max):

$$P_{\mathrm{ROZmax}} = P_{\mathrm{OBDmax}} - P_{\mathrm{FVEmin}} \quad (MW). \tag{7}$$

The dark blue curve represents such condition, when the daily load diagram has reached its minimum level, whereas the contribution from PVP is at its maximum level; that represents the bottom threshold of power flowing from the substation plant. The curve is therefore defined by the difference between the curve of bottom threshold of prediction level for daily load diagram (6) and the maximum extreme condition of production at PVP (1). That actually refers to the minimum extreme power at the substation plant output (P_ROZ_min):

$$P_{\mathrm{ROZmin}} = P_{\mathrm{OBDmin}} - P_{\mathrm{FVEmax}} \quad (MW). \tag{8}$$

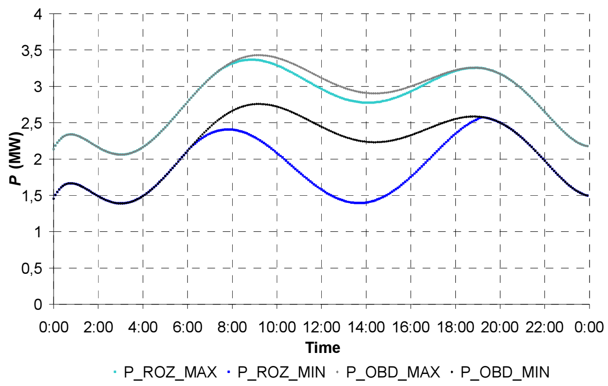

Fig. 6 Determination of power output difference

4.5. Check and adjustment of power output difference thresholds

In order to control of developed methodology, the values of the average five-minute power at the measurement point on the substation plant (pink and red scatter plot) are plotted in competent thresholds of curves describing the minimum and maximum extreme power at the substation plant. It shows Fig. 7.

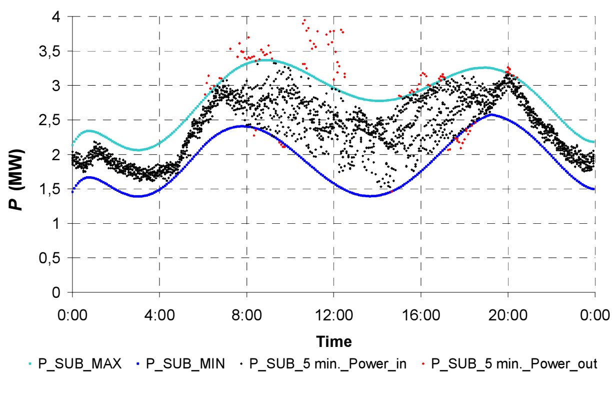

Fig. 7 Control of adjustment of power output difference thresholds

All the data and evaluation methodology were considered with reliability level of 95 %. This particular case concerns 95.54 % of values (average five-minute output intervals) situated within the defined output difference (thresholds), which is determined by curves P_ROZ_MAX and P_ROZ_MIN (see Fig. 7). It can be therefore concluded that output difference curves in this model respect more than 95 % of values. Another adjustment of thresholds is not desirable, as the resulting evaluation meets expectations.

4.6. Quadral output difference

The outcome of entire methodology is to determine the assumed difference of change in active power at substation plant outlet for a particular time interval. The time interval in this survey comprises fifteen minutes. That is the so called "quadral difference of output" illustrated in Fig. 8. Pursuant to this graph is possible for a given period of time to determine the necessary power reserve for the appropriate outlet from the substation independently of the operating PVP with more than 95% probability.

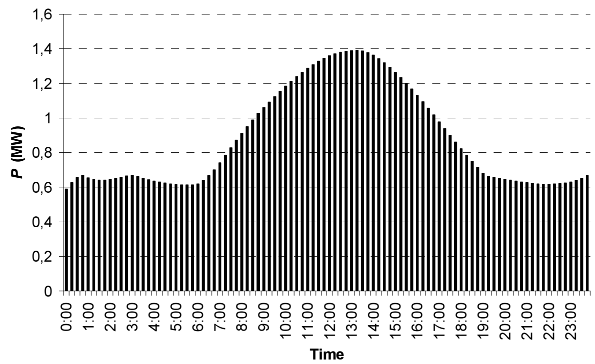

Fig. 8 Quadral output difference

5. CONCLUSIONS

This part of the survey describes a new methodology for statistical evaluation of the measured data on PVP to determine the difference of active power. Previous study [1] defines methodology for describing the extreme conditions of production PVP. This study develops the previous study. It focuses on the analysis of the daily load diagram, where PVP is located. Next Steps of this study consist in the application of this methodology on a full database file and the potential defining discovered mutual states.

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BIOGRAPHIES

Martin SMOČEK was born on 24.8.1986. In 2011 he graduated (Ing) with distinction at the department of Power Electrical Engineering of the Faculty of Electrical ngineering and Computer Science at VŠB – Technical university of Ostrava. Today he is Ph.D. student in the Department of Electrical Power Engineering, Technical University of Ostrava. His scientific research is focusing on photovoltaic power plants and their influences to the distribution system.

Zděnek HRADÍLEK was born on 17.6.1940. After graduation of college education at Faculty of Electrical Engineering and Computer Science Brno University of Technology in 1962 he worked as a technician in company Southern Moravian power plants in Brno, than he worked as a major power-supply director in Heat-supply Ostrava and from 1966 until now he is at the VSB-Technical University Ostrava. His scientific preparation graduated by his candidate dissertation defending at the Brno University of Technology, power supply field, in 1972. He defended his doctoral thesis at the Czech Technical University in Prague in 1988. His pedagogical and scientific work is focused in power engineering field. He was appointed associate professor in 1977 and at the time of electricity department inception in 1978 he became its leader. He undertook this function, without pause, until2009. He was appointed professor in 1988.