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Stochastic production of photovoltaic power plant

***Abstract**. Generating electricity from the sun is currently one of the most discussed topics, especially because of the huge increase in installed capacity. It is brings problems associated mainly with the instability of supply of electricity to the grid. Production of electricity from the sun greatly affects the stability of the network and has a great impact on dispatching reserve because it is necessary to back up each kW of solar power. Possession of such large reserves of power also brings economic impacts that affect all users in the form of increased electricity prices. Solar power is a soft source and affect short-circuit conditions in the network. Another disadvantage is the dependence of energy on a daily and annual time. In winter is power consumption higher than at the summer months because most of the electricity used for heating and lighting. The paper deals of the evaluation measurement operation of photovoltaic power with installed capacity 1MWp in the Czech Republic. It is confirmed by the stochastic production of electricity with large daily and annual changes of the installed capacity.*

***Streszczenie.** Generacja energii elektrycznej z energii słonecznej jest obecnie jednym z najbardziej dyskutowanych tematów, zwłaszcza w kontekście ogromnego przyrostu mocy zainstalowanej. Jest to przyczyną problemów, związanych głównie z niestabilnością dostaw energii elektrycznej do sieci. Produkcja energii elektrycznej z energii słońca w znacznym stopniu wpływa na stabilność pracy sieci i ma wielki wpływ na rezerwowanie dostaw, ponieważ konieczne jest rezerwowanie każdego kW energii słonecznej. Posiadanie tak dużych rezerw mocy powoduje skutki ekonomiczne, które obciążają wszystkich odbiorców wzrostem cen energii elektrycznej. Energia słoneczna należy do tzw. „miękkiej ścieżki energetycznej" i wpływa na warunki zwarciowe pracy sieci.Inną wadą jest uzależnienie możliwości produkcji energii od pory dnia i roku. W zimie konsumpcja energii jest wyższa niż w miesiącach letnich, ponieważ więcej energii elektrycznej zużywa się na ogrzewanie i oświetlenie. Artykuł dotyczy oceny metod pomiaru energii generowanej z 1MW mocy zainstalowanej w ogniwach fotowoltaicznych w Republice Czeskiej. W metodyce wykorzystano stochastyczny charakter produkcji energii elektrycznej, cechujący się dużą zmiennością dobową i roczną mocy zainstalowanej. (**Stochastyczny charakter produkcji elektrowni fotowoltaicznych**).*

Keywords: solar power plant, stochastic production.
Słowa kluczowe: elektrownia słoneczna, stochastyczna generacja.

Introduction

The Czech Republic has been currently experiencing a BOOM of solar power plants, especially thanks to the legislative support and the high feed-in tariffs per 1 kWh of electric power gained from the sun. In the year 2010, the installed capacity increased to the level of 1959,10 MWp. This value is close to the level of installed capacity of the largest nuclear power plant in Czech Republic.

This article deals with the methodology of prediction of electric power from solar power plants and the supply of electric power from the solar power plant with the installed capacity of 1MWp situated in the North-Eastern region of the Czech Republic. The article further deals with assessment of the utilization factor of the solar power plant within the period between July and November 2010.

Methods for Prediction of Electric Power Production from Photovoltaic Power Plants

There are several different approaches to the prediction of electric power production, same as for the prediction of electric power produced by wind power plants.

The most frequently used method is based on prediction of climatological and meteorological values with substantial effect (amount of clouds, temperature, wind speed, etc.) on the resultant amount of electric power produced. This data serves, together with the details from local devices used for measurement of current meteorological values and local solar databases, as the input data for the prediction system that uses the data to predict the expected amount of energy produced by a photovoltaic power plant, following performance of large number of various corrections.

Another option for prediction of the amount of electric power produced by photovoltaic plants is the utilisation of highly sophisticated mathematical methods based on time series, which are able to predict the volume of electric power with a certain accuracy using the database of real measurement results.

The current matters gaining in importance include the so called "neuron networks" to predict the electric power production. Those are networks that use a set of input and output data to establish logical links within to be further used for generation of output data for the relevant input details. For general example of prediction procedure using neuron network see the Fig. 1.

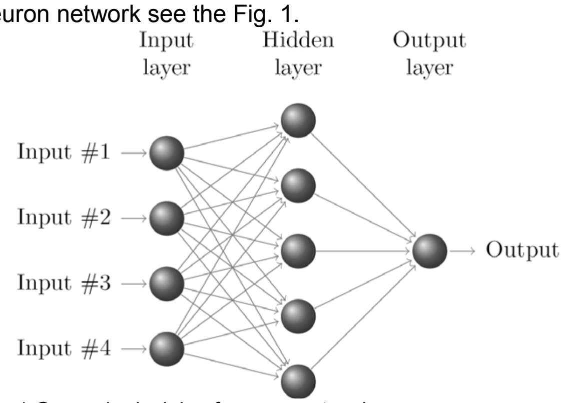


Fig. 1 General principle of neuron networks.

However, the modern prediction systems for photovoltaic power plants use mainly combinations of the above mentioned procedures to minimise the prediction errors [4],[5].

Solar Database

The territory of Europe is abundant with hundreds of meteorological stations used to measure the solar radiation by direct or indirect means, besides other various meteorological values.

To gain complex database of details on solar radiation within the entire territory of Europe, the measured values shall be used for mathematical derivation of solar radiation values for locations, where such meteorological measurements are not performed. The most frequent procedures include various interpolation methods as the function "spline", for example, weighted average methods or kriging (geo-statistical techniques serving for interpolation of values close to the known value of the parameter subject to monitoring).

Especially the levels of values related to particular regions can be obtained directly from photos from geostationary or orbital satellites. Such data obtained from satellites are compared with the data generated through terrestrial measurements.

New satellites, i.e. the Meteosat 8 and new models, i.e. Heliostat-3 provide data with high geographical (1 x 1 km grid) and time (1 photo per every 15 minutes) resolution.

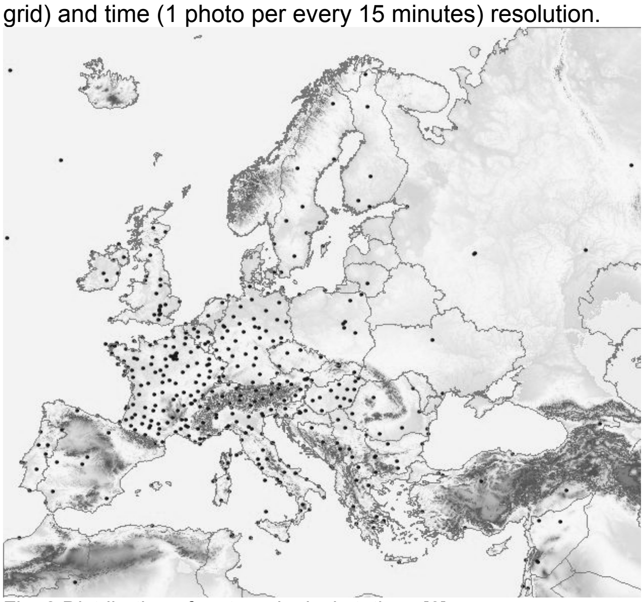


Fig. 2 Distribution of meteorological stations [6].

To ensure elimination of the effect produced by rugged topography, the models of solar radiation are often integrated with GIS systems.

Assessment of Impact on Particular Factors on Changes of the Predicted Capacity

Following the commission of a photovoltaic power plant, the return on investment depends on the annual volume of electric power produced by annual operation of the relevant photovoltaic power plant.

The amount of electric power obtained then depends on the availability of solar radiation within the specific region and the operability of the entire system of a photovoltaic power plant. For description of estimated volume of the electric power produced by a photovoltaic power plant, follow the most convenient method in terms of the flow chart shown in Fig. 3.

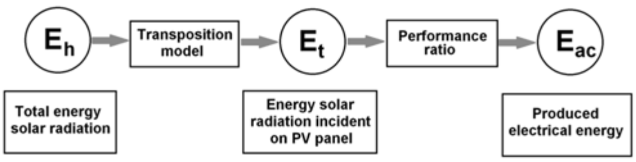


Fig. 3 Sequence of estimated volume of the electric power from a photovoltaic power plant connected to the grid.

The crucial problem here is the description of behaviour of the solar radiation source. The usual data include the amount of energy E_h (kWh/m^2/day) that impacts a horizontal surface in one day, converted per the unit of 1m^2. Photovoltaic panels are usually not positioned horizontally, yet most of them are oriented southwards at a certain angle defined by the position of the photovoltaic power plant.

The total amount of solar radiation that impacts a photovoltaic panel surface (E_t) is calculated using the so called “transposition model” using the total solar energy E_h that impacts a horizontal surface.

The next step includes conversion of amount of solar energy incident onto the surface of a photovoltaic panel into direct current voltage and electric current which are then changed into alternating current voltage and electric current via inverters. The efficiency levels of such conversions can be classified separately, yet these are mostly assessed together in terms of the power ratio.

(1) $$PR = \frac{\left(E_{AG} \cdot G^*\right)}{\left(E_t \cdot P^*\right)}$$

where:

$P^*(kW)$ is the system power under standard testing conditions

$G^*(kW/m^2)$ is the reference solar radiation corresponding with 1 kW/m^2

$E_{ac}(kWh)$ is the amount of electric power produced

$E_t(kWh/m^2)$ is the amount of solar energy incident onto a photovoltaic panel

Frankly speaking, the power ratio refers to the part of total solar energy incident onto a photovoltaic panel being converted into electric power.

The power ratio respects all the potential losses that follow the conversion of solar energy into electric power. These losses most often include the individual items listed below:

- losses caused due to the efficiency of inverters
- losses inherent to cabling
- losses caused due to panel temperature variation
- losses caused due to the failure to utilise complete spectrum of the solar radiation
- losses caused due to impurities on photovoltaic panels surface
- losses caused due to cover on the panel surface, e.g. snow
- losses caused due to output reduction at particular cells
- losses caused due to the system downtime
- losses caused due to defect of individual components

Using the procedure shown in Fig. 3, irregularities associated with estimates of electric energy produced can be divided into three categories:

- The irregularity in determination of the amount of solar energy incident onto a horizontal surface, which can be divided into the error of estimated volume of incident energy and the error related to the interim variability in amount of the incident solar radiation during particular months of the year.
- Irregularities associated with utilisation of the transposition model.
- Irregularities related to the output of the entire system itself defined using the power ratio.

Solar Power Plant Location

The region with the photovoltaic power plant subject to measurement experiences the average annual amount of solar radiation within the range of 1.054 – 1.082 kWh/m^2. The available energy ranges between 3.801 – 3.900 MJ/m^2 here, as shown in Fig. 4.

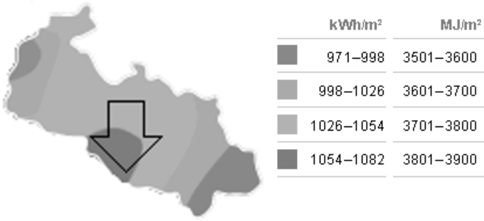
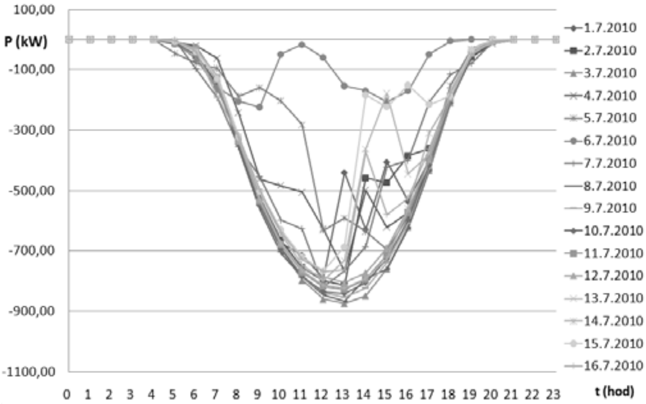


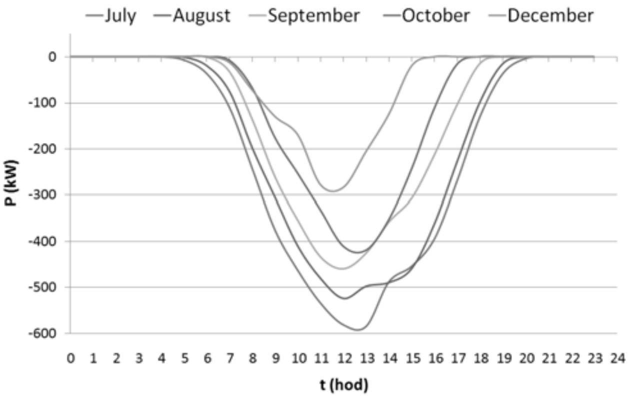
Fig. 4 Average annual total of global radiation within the solar power plant location area.

Analysis of Supply of Electric Power from the Solar Power Plant

Graph 1 shows the increase of power over time within the period from 1st July 2010 till 16th July 2010. Under favourable conditions, the power output achieved within the said period approached the level of 900kWp during the time between 11 a.m. and 2 p.m.. This curve is typical for all the solar power plants, where the top output is achieved during afternoon hours.



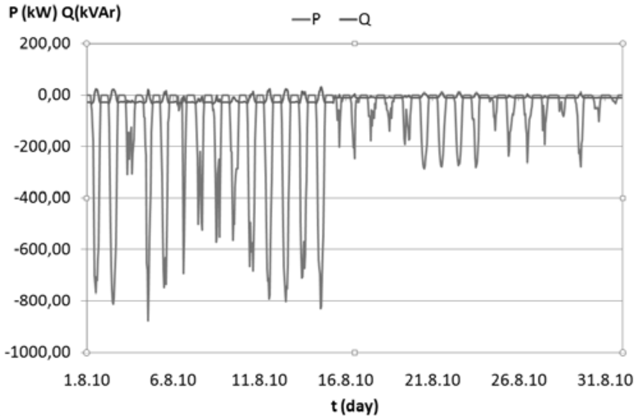
Graph 1 Power output increase.



Graph 2 Power output increase over 24 hours in selected months.

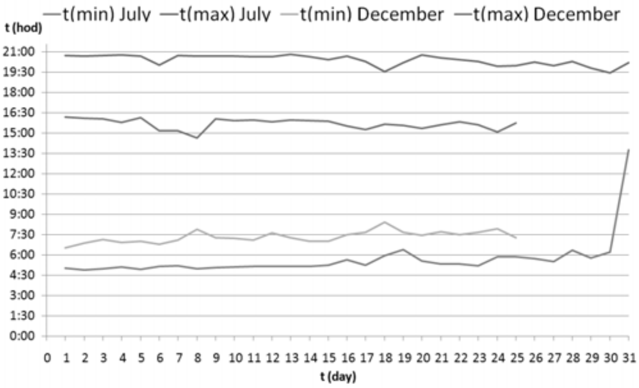
The Graph 3 shows the supply of active power in August. The values show that the first half of the month was sunny and the immediate values of active powers approached the installed capacity level. The active power values then did not exceed the level of 300kW during the second half of the month.

This is a typical demonstration of characteristics of solar power plants, which experience rapid drop in power supplied into the grid during periods of adverse weather conditions.



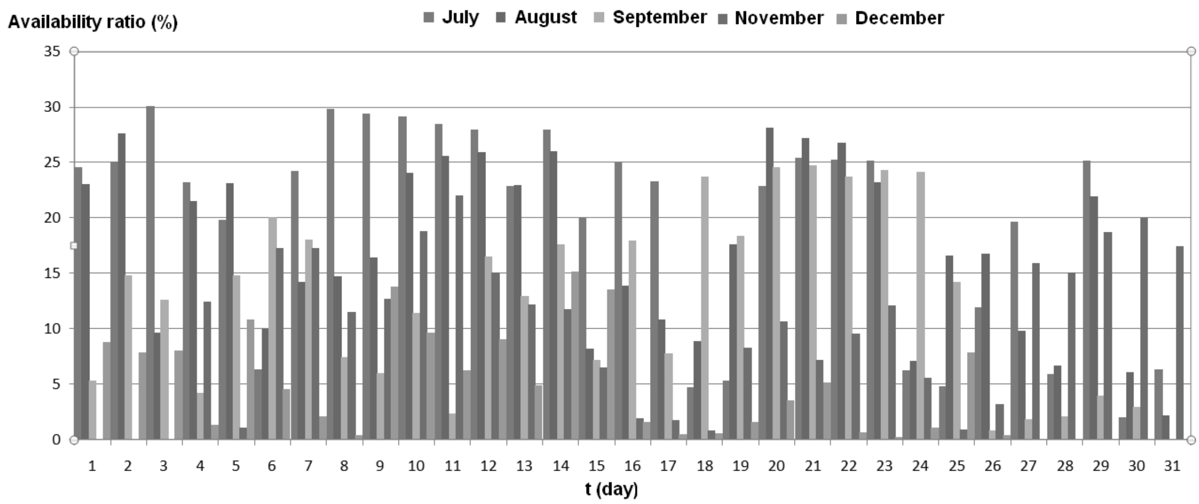
Graph 3 Active and blind power – August 2010

The great disadvantage of solar power plants, compared to other renewable resources, is their dependency on daytime and season. Summer season provides plenty of solar energy and the solar energy is then able to supply electric power throughout major part of the day, under favourable weather conditions, as shown in Graph 4.



Graph 4 Operation commission and termination time of photovoltaic plant – July, November 2010

On the contrary, winter months see reduced intensity of solar radiation both due to the amount of clouds as well as due to the greater between orbit of our planet and the Sun. the electric energy supply time then drops by about one half, compared to the situation during summer months.



Graph 5 Utilisation factor – July-November 2010

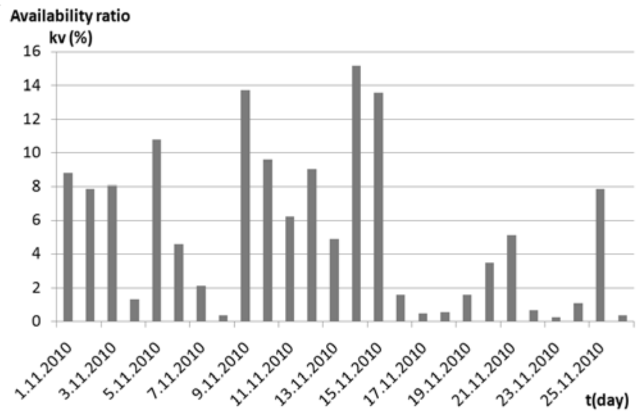
The effectiveness of a energy source can be best determined using the utilisation factor, which is defined by the following formula [1]:

$$k_v = \frac{W_T}{P_i \cdot h} \quad (2)$$

where W_T refers to the amount of energy produced (kWh), P_i refers to the installed capacity (kW), h refers to the number of hours

The utilisation factor then ranged about 19% in July. The total output supplied into the grid in July amounted to 145.9 MWh.

The average utilisation factor was approximately 5% in November, with the maximum value of the utilisation factor reaching 15.19% as shown in Graph 6. The total output supplied within the period from 1st November 2010 till 26th November 2010 was equal to 33.45 MWh.



Graph 6 Utilisation factor – November 2010

Conclusion

Obtaining electric power from the sun represents a great threat and substantial impact on the grid stability and the distributor´s backup as every kW of solar power plant shall be backed up. Holding of such great amount of power in backup also brings economic impacts which affect all the users in form of electric power price increases. Solar power plants are a soft source and they affect the short-circuit ration in the grid.

Another great advantage is the dependency of energy supply on daytime and season. Winter months are characteristic with greater consumption of electric power compared to summer months, as most of the electric power is used for heating and lighting. The supply of electric power from solar power plants range about 5% of the installed capacity.

Solar power plants are stochastic source of electric power, they would therefore represent a convenient additional source of electric power. An effective method of accumulation of electric power would be a convenient add-on for solar power plants.

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