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ANALYSIS OF PV POWER GENERATION IN THE CZECH ELECTRICITY TRANSMISSION SYSTEM ČEPS

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ABSTRACT: We analyse basic power generation characteristics of solar PV capacities in the Transmission System of the Czech Republic ČEPS. The PV power is simulated using satellite-based solar radiation and air temperature with 15-minute time step, as available in the SolarGIS database. In the simulation we assume a scenario of 1000 MWp capacity so that the results can be easily scaled up. The statistics relates to the period 2004 to 2010. It was found that variability of PV power in the ČEPS transmission system is relatively low and predictable. The shape of power curves at the level of ČEPS transmission system is relatively smooth, regardless of weather. The unpredictable component of photovoltaic power generation contributes to the overall uncertainty in the ČEPS transmission system by the amplitude of approx. ±7% relative to the nominal PV power. These results cannot be mechanically transposed, as they are country specific.
Keywords: PV power simulation, solar radiation, transmission system, ČEPS, SolarGIS

1 INTRODUCTION

By April 2011, 1950 MW of PV power has been cumulatively installed in the Czech Republic, representing mostly larger power plants. We simulate an impact of PV power in the Electricity Transmission System (TS) of the Czech Republic ČEPS. This includes expected PV power generation statistics, short-term variability. The developed knowledge contributes to the complex assessment of the needs for forecasting and ancillary services in TS.

2 APPROACH

The impact of PV production on the TS was studied for a scenario of 1000 MWp of the grid-connected nominal capacity, and it is assumed that 90% of this capacity includes solar parks (installations larger than 500 kWp) and 10% are roof installations – all distributed evenly across the Czech Republic. Such a scenario can be scaled to any installed nominal capacity in the future.

In this work, 15-minute solar irradiance and air temperature data (representing years 2004 to 2010, source SolarGIS) are used, together with in-house PV simulation tools operated by GeoModel Solar [1, 2, 3].

The sensitivity of calculations was analysed in respect to all major factors influencing PV power simulation at the level of TS. The following aspects of PV power generation in the ČEPS transmission system are studied:

- Space and time correlations, and their effect on daily PV power generation profiles at the level of TS. Special attention was given to the impact of the stochastic component determined by clouds and the state of the atmosphere.
- Analysis of the daily power generation profiles in TS in individual months with a focus on critical weather types (cloudless day, cloudy day, intermittent weather, sudden change of weather). Monthly probability statistics has been calculated for daily profiles with 15-minute time step.
- Statistical analysis of absolute and relative short-term changes of power production from the PV capacity installed in ČEPS, and their typical patterns during each month, considering above mentioned weather types.

Understanding the approximate portfolio of PV power in the Czech Republic, but in the absence of accurate information about the position of PV power plants, we worked with a scenario of evenly distributed PV capacity in the country, with slight stronger weighting in more sunny regions (Tab. 1, Fig. 1).

Table 1: Scenario for simulations: 1000 MWp PV power evenly distributed in the Czech Republic, excluding forest and water areas.

Type of PV power plant	Installed power [MW]	% of solar parks	% of roof systems
Solar parks-fixed c-SI 35°	365	40,6	-
Solar parks-fixed c-SI 30°	365	40,6	-
Solar parks-fixed a-SI 30°	45	5,0	-
Solar parks-fixed CdTe 30°	45	5,0	-
Solar parks – 1-axis tracker c-Si	80	8,8	-
Roof systems – residential and commercial	100	-	100
Total	**1000**	**100**	**100**

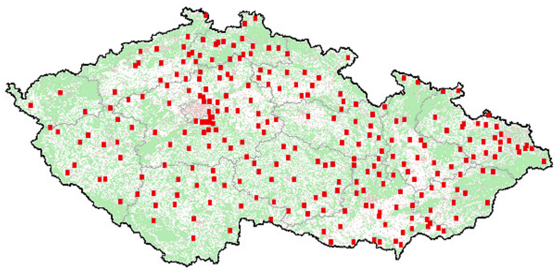


Figure 1: Scenario assuming the geographical distribution of PV installations.

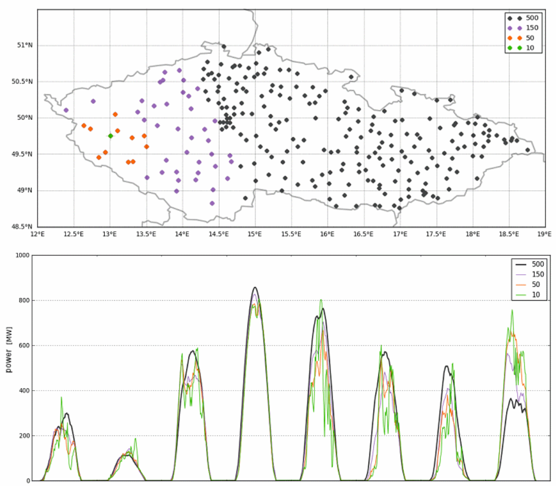
3 RESULTS

Daily profile and variability of solar electricity generation depends on: (i) *deterministic component* (sunpath), which is given by the astronomic characteristics, site position and geographic conditions, and (ii) *stochastic component*, which is determined by variability of cloud fields and atmospheric conditions (mainly aerosol load and water vapour). For the management and prediction of PV power, the stochastic component is to be analyzed.

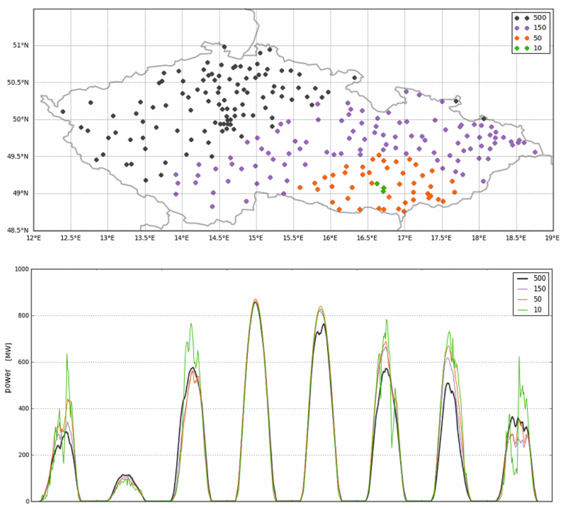
3.1 Space and time correlations

It is of no surprise that the highest correlation in PV power production is between the closest power plants. With increasing distance the correlation decreases, and for power plants far from each other it is low. The correlation between PV power plants is higher for stable weather (assuming the country level) – for situations when it is either completely cloudy of sunny. For intermittent weather conditions (dynamically changing cloud patterns) the spatial-time correlation between PV systems does not exist.

Fig. 2 demonstrates that geographic distribution of PV power plants within the country has an effect on PV daily generation profiles as could be seen in ČEPS TS.



Daily profiles if capacity is concentrated in regions of varying size centred in Western Bohemia



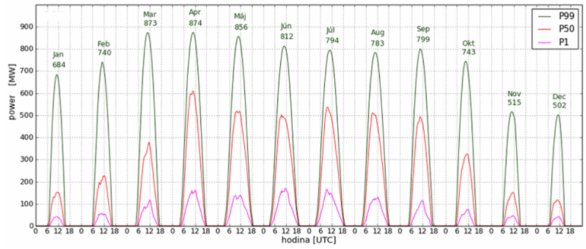
Daily profiles if capacity is concentrated in regions of varying size centred in Southern Moravia

Figure 2: Power generation from 1000 MWp capacity at the level of ČEPS TS, which is concentrated in the territories with radius of 10, 50, 150 and 500 km (green to violet colour), centred in the opposite regions of the Czech Republic (simulation shows eight days, from 17 to 24 May 2005). For comparison, the black curve shows the power production profile assuming that the PV capacity is evenly distributed over the whole country.

It is known that PV power capacities are relatively evenly distributed within the Czech Republic; therefore uncertainty from not knowing exact position in this scenario is low (estimated to about 0.5% of the total simulated power).

3.2 Daily power generation profiles

For a portfolio of 1000 MWp, the maximum instant power generation reaches 850 MW/MWp, and this occurs mainly in spring months (March, April and May). The minimum PV power production drops during the winter period (from November to January) to the level of 50 MW/MWp, however this does not consider the situation of snow-covered modules. Snow will reduce power generation even more and without forecast of snowfall, the uncertainty of PV performance in winter may be high.



Percentile*	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
P99	684	740	873	874	856	812	794	783	799	743	515	502
P97	601	693	832	859	829	800	783	778	785	721	482	464
P50	153	226	378	608	518	501	536	510	493	326	151	116
P3	49	85	133	202	190	185	177	166	141	91	56	46
P1	42	56	116	160	138	170	165	129	115	77	46	41

* power in MW

Figure 3: Probability analysis calculated form 15-minute simulation, showing, for each month, daily profiles of power generation [MW] from 1000 MWp portfolio of PV power plants in ČEPS TS.

3.3 Short-term changes of PV power generation

Fluctuation of the power generation at the level of an individual PV power plant is high, especially for the intermittent short-term cloud changes (Fig. 4).

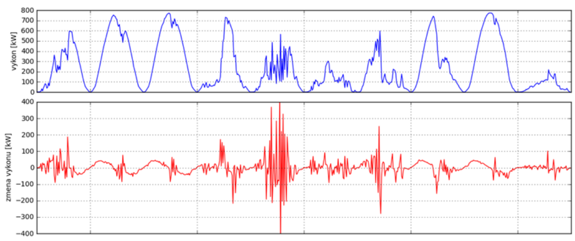


Figure 4: Generation profile of a single 1 MWp PV power plant (blue) and the corresponding absolute variability (red), assuming 15-minute time step.

However, at the national level, when assuming a complete portfolio of PV power plants, the fluctuations are compensated (balanced out), which results in a relatively smooth power production profiles without occurrence of major extremes.

The magnitude of short-term variability in PV power production at the level of ČEPS electricity transmission systems, assuming 15-minute time step, rarely exceeds ±60 MW per 1000 MWp of PV capacity (Fig. 5 and 6). This indicates a range of uncertainty from short-term fluctuating PV power, for the PV grid integration at the level of ČEPS TS. This high magnitude of PV power generation variability was observed in two seasons - from February to March and from October to November. Smaller short-term variability occurs in summer, both in absolute and relative terms, and 15-minute fluctuation was lower than ±50 MW per 1000 MWp, which represents approx. ±5% of the nominal capacity.

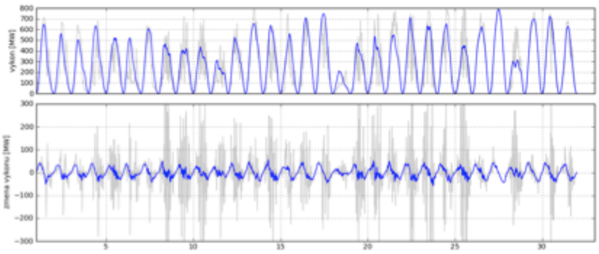


Figure 5: Daily PV power generation profiles (above) and the related variability (below) assuming complete portfolio of PV power at the level of the Transmission System (blue colour), and assuming 10 randomly selected 1 MWp PV plants in the country (grey colour).

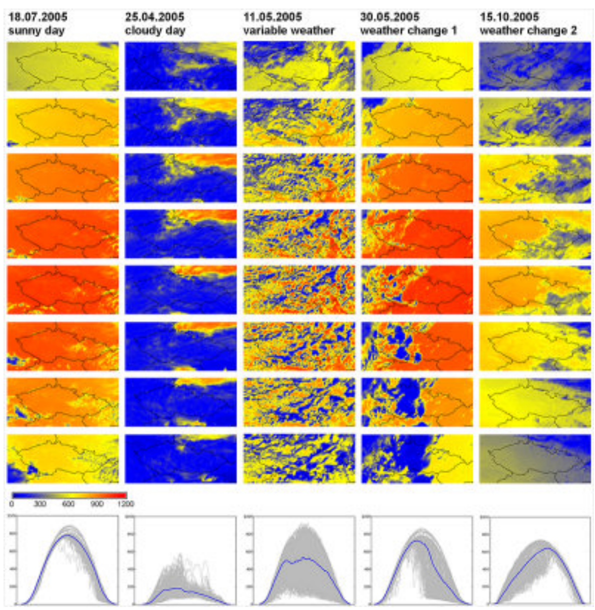


Figure 6: Maps showing variability of solar radiation in the Czech Republic, and graphs of the respective daily profiles of PV power generation at the level of ČEPS Transmission System (blue line) and also daily profiles of randomly selected 1 MWp PV power plants.

PV power production during the typical synoptic situations, selected over the period of 2004 to 2010, is simulated in Fig. 6. The hourly solar radiation maps (from 9:00 to 16:00), and the related PV power daily diagrams below show the type and magnitude of variability of power generation - at the level of (i) individual PV power plants, and (ii) at the level of ČEPS transmission systems. Fig. 6 shows, that short-term variability of PV power generation at the level of ČEPS TS is low, and the shape of power curves is relatively smooth, regardless of the synoptic (weather) situation.

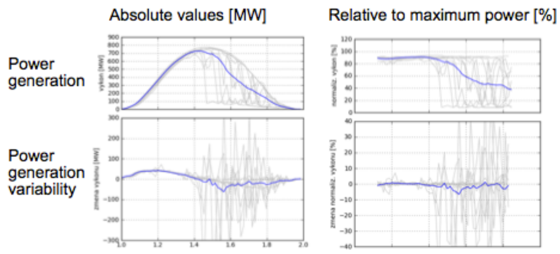


Figure 7: PV power generation and variability during sudden change of weather (daily profile in 30 May 2005). Blue profile: ČEPS TS, grey profiles: randomly selected 1 MWp PV power plants. Refer to the maps in Fig. 6.

Fig. 7 provides a detailed insight to absolute and relative 15-minute variability of PV power in ČEPS TS on 30 May 2005, when a sudden change of weather (from cloudless to cloudy) was recorded. The respective synoptic situation for the given day can be consulted in the maps shown in Fig. 6.

4 CONCLUSIONS

Statistical analysis of PV power generation based on the use of 15-minute solar radiation and air temperature data (source SolarGIS) show that the unpredictable component of solar power generation fluctuates within about ±7% of the nominal PV power installed in the ČEPS TS. This uncertainty is one of many, which have to be considered in the maintaining balance between power supply and demand in the electricity transmission system.

The results presented for Czech Republic cannot be mechanically transposed to other region, as they are country-specific. In other words, the key determining factors influencing the PV power generation at the level of transmission or distribution grid are: (i) regional weather patterns (daily and seasonal dynamics) and (ii) technical parameters and geographic distribution of PV power systems.

The results of this study are considered as a first step in the analysis of power generation and consumption patterns of the future, and understanding the impact of solar electricity in the transmission and distribution electricity networks.

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