Design and data comparison of the photovoltaic power plants in the southern and northern hemispheres

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Abstract. We have recently developed a unique monitoring system for photovoltaic power plants and have gradually improved it in recent years. The system is installed at about 80 power plants in several European countries and at one power plant in Chile. We collect and evaluate all data in our laboratory. In this paper we describe the unique design of a photovoltaic power plant in the southern hemisphere in Chile with photovoltaic panels installed on tracking stands. We present the evaluated data and we discuss their comparison with photovoltaic power plants installed in Europe. We also discuss different solar conditions of these locations.

Key words: photovoltaics, PV power plant, data monitoring.

INTRODUCTION

The amount of electricity generated is significantly influenced by the design of the photovoltaic (PV) power plant and its location. Monitoring data from PV systems is important for the operator. For example, the works (Ayompe et al., 2011, Madeti & Singh, 2017) talk about monitoring data from PV power plants. We have also developed our own monitoring system Solarmon-2.0 (Beránek et al., 2018), which is already installed on about 80 PV power plants in the Czech Republic and abroad (Romania, Slovakia, Hungary, Chile). Data are continuously collected and evaluated and some results have already been reported e.g. in previous works (Libra et al., 2016, Šafránková et al., 2019). We compare our data with predicted values according to the internationally used internet application Photovoltaic Geographical Information System (https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html). This application predicts the expected values of electricity generated according to the location and the basic design of the PV power plant.

Fig. 1 shows the world map with iso-areas of average solar energy incident per unit area and of the respective amount of produced electric energy (kWh m^{-2} year^{-1}). It is evident that the best areas for PV systems installation are in Tibet and in the half-desert mountains of Chile. There is enough of solar radiation, cold weather and high altitudes. Sahara is a good locality but not a top one. The climate is very hot and PV panels overheat so that the efficiency of PV energy conversion decreases.

If the electricity generated does not meet the expected values, this indicates a failure of the PV power plant and the most common failure is faulty PV panels. Our Solarmon-2.0 monitoring system is intelligent and can predict the location and type of failure. We have investigated methods of defects monitoring in PV panels, see for example works (Olšan et al., 2017, Libra et al., 2019). Similar investigation is also in works (Rösch et al., 2012, Spertino et al., 2015, Bilčík et al., 2019). It is sometimes advisable to store surplus electricity for later use. For example, works (Papež & Papežová, 2016, Papež & Papežová, 2019) deal with the accumulation of electric energy into electrochemical accumulators.

In this paper, we compare advanced PV system with tracking stands of PV panels installed in Chile in the southern hemisphere in a location with excellent solar conditions with two PV systems of conventional construction with fixed PV panels installed in Central Europe with temperate solar conditions (see below). We compare the amount of electricity produced.
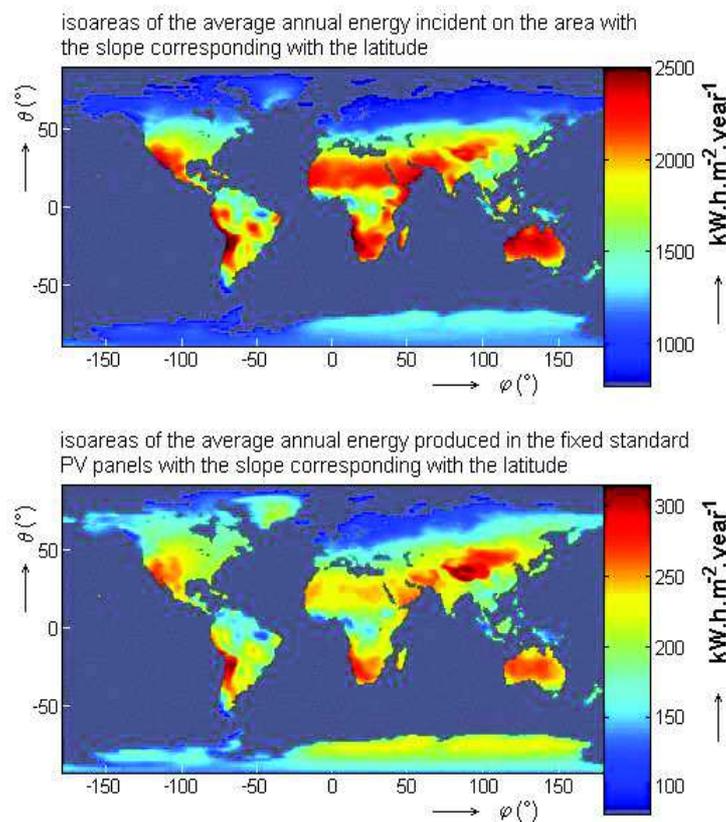
Figure 1. World map with iso-areas of the average solar energy incident per unit area and of the respective amount of produced electric energy.

MATERIALS AND METHODS

The PV system in Cuz Cuz in Chile (see Fig. 2) is installed in a subtropical half-desert area in a location with excellent solar conditions (see Fig. 1). Its coordinates are 31.665° S, 71.222° W, altitude 275 m. Chinese BYD PV panels based on polycrystalline silicon with a nominal output power of 305 W_p, type P6C-36, were used. The nominal output power of the whole PV system is about 3000 kW_p. The tracking axes are oriented horizontally in the north-south direction.

Two comparative PV systems of different constructions are installed in Prague (Czech Republic) in a locality with solar conditions common in Central Europe. One comparative PV system in Prague-Suchdol (see Fig. 3) is installed on the roof of our Faculty of Engineering. Its coordinates are 50,129° N, 14,374° E, altitude 280 m. PV panels Renesola, GmbH of German production based on polycrystalline silicon with a nominal output of 260 W_p, type JC 260M-24/Bb were used. The PV system has a standard construction with fixed PV panels inclined to the south at an angle of 35°. The nominal output power of the whole PV system is about 10 kW_p.

Figure 2. PV system in Cuz Cuz (Chile), advanced construction with tracking stands of PV panels with horizontal tracking axis.

The second comparative PV system in Prague-Vršovice (see Fig. 4) is located approximately 10 km from the first, so it is in a location with similar solar conditions. Flexible waterproof PV foils VAEPLAN V Solar 432 with a nominal power of 432 W_p were used for the construction. They lie nearly horizontally on the roof of a football stadium without supporting stands. A total of 1,040 foils are connected to eight independent sections and these are connected to eight merge switchboards. 26 strings are connected into each switchboard and each string consists of 5 PV foils. The total nominal output power of the PV power plant is therefore approximately 449 kW_p.

Figure 3. PV system in Prague (Czech Republic) with standard construction with fixed stand of PV panels inclined to the south at an angle of 35°.

Figure 4. PV system in Prague (Czech Republic) with standard construction with PV panels laid horizontally without supporting stands.

All PV these systems are connected to the AC grid via DC/AC converters. PV systems are connected to our above-mentioned Solarmon-2.0 monitoring system. Data collection and evaluation takes place in our laboratory. For better comparison, the values of generated electricity are converted to 1 kW_p of installed nominal power.

RESULTS AND DISCUSSION

Fig. 5 shows the amount of electricity produced in said PV systems during one year. The values are given by months and for the whole year. In the southern hemisphere of Cuz Cuz, the seasons of the summer and winter are opposite to that of Europe, so there are the highest values of electricity produced in December and January and the lowest values are in May and June. It can be also seen that the total annual value of the generated electricity (2,043 kWh kWp^{-1} $year^{-1}$) in Cuz Cuz is almost double compared to the PV system in Prague-Suchdol with fixed PV panels inclined to the south at an optimal angle. And the value is nearly triple compared to the PV system in Prague-Vršovice with fixed PV panels placed horizontally.
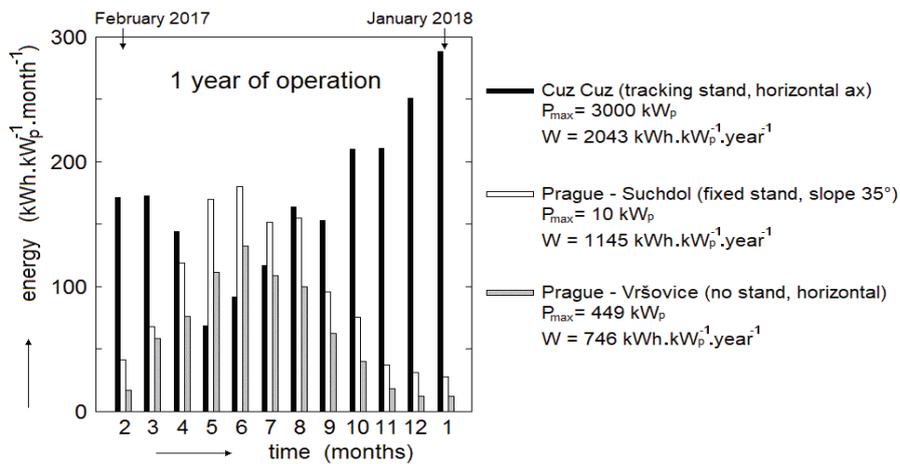
Figure 5. The amount of electricity produced in the said PV systems during one year.

The high value of electricity generated in Cuz Cuz is certainly related to the location with excellent solar conditions as well as to the advanced design of the PV system with tracking stands of PV panels. In the half-desert region, PV panels are often dusty with desert dust, but still the value of the electricity generated is high. It can also be seen that in subtropical locations the percentage differences between these values between summer and winter months are smaller than in Central Europe. Sun tracking racks of PV panels can increase the annual value of generated electricity by up to 30% (Poulek & Libra, 1998). Thus, in the case of fixed racks, an annual value of generated electricity of about 1,570 kWh.kWp^{-1} $year^{-1}$ could be expected at Cuz Cuz, which corresponds to the values in Fig. 1. 1 kWp of nominal output power corresponds approximately to the area of PV panels 5 m^2.

In the case of PV systems installed in Prague, the values of electricity generated correspond to the values according to the above-mentioned and internationally used internet application Photovoltaic Geographical Information System (https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html). In the case of a PV system in Prague-Suchdol, the actual annual value is slightly higher than expected (1,145 kWh kWp^{-1} year^{-1} versus 1,015 kWh kWp^{-1} year^{-1}), which can be explained by high-quality PV panels with high efficiency of energy conversion. In the case of the PV system in Prague-Vršovice, the actual annual value is slightly lower than expected (746 kWh kWp^{-1} year^{-1} as opposed to 850 kWh kWp^{-1} year^{-1}). This we have seen in the previous work (Libra et al., 2016) and it was explained by the dusty environment near the railway track and by a slight rounding of the roof, where all PV panels are not completely horizontal.
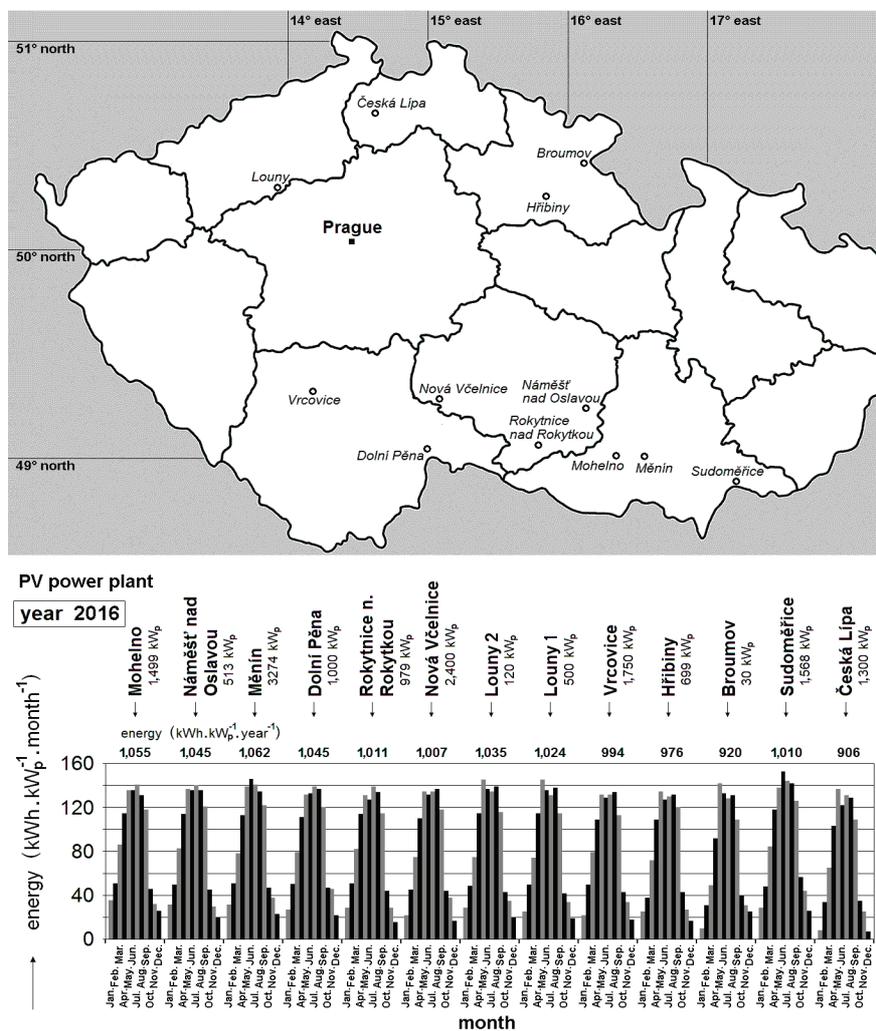
Figure 6. The amount of electricity produced in selected thirteen PV power plants located in the Czech Republic during one year.

We consider the roofs and facades of buildings to be suitable places for the installation of photovoltaic systems in high population density areas of Central Europe. We do not consider occupation of agricultural land a good solution here. On the other hand, in desert and half-desert areas the price of land is low and the population density is low as well. Therefore, we consider the installation of PV systems suitable also in open areas. Therefore, all three photovoltaic systems mentioned in this article were chosen in this way.

For a better comparison of the PV power plants located in Central Europe, Fig. 6 shows the amount of electricity generated during one year in the other selected thirteen PV power plants located in the Czech Republic. All these power plants are connected to our above mentioned monitoring system Solarmon-2.0 and the data are evaluated in our laboratory. The graph was created by evaluating a large data set. It can be seen that the annual values of electricity generated are around the expected values ($1,000 \div 1,100$ kWh kWp^{-1} year^{-1}), only in the north of the Czech Republic the values are slightly lower. We have been evaluating this data for many years and the annual values of the electricity generated from individual years differ only slightly in terms of the year-on-year fluctuation in meteorological conditions.

CONCLUSIONS

Our monitoring system Solarmon-2.0 monitors about 80 PV power plants in different parts of the world and works without significant defects. It is well proven and significantly helps operators of PV power plants with management and troubleshooting. In this paper, we compared and discussed the evaluated data from power plants in locations with very different solar conditions. The location in the half-desert area in northern Chile is, according to all forecasts, one of the places with excellent solar conditions, as confirmed by our data.

Sun tracking stands slightly increase the amount of electrical energy produced, but at higher latitudes they must have an inclined polar axis. The individual racks must be set apart from each other so that they do not shield each other. In this way, however, the use of the area of the PV power plant is reduced and the price of the area is high in Central Europe. Conversely, in subtropical half-desert regions, the rotational axis can be oriented horizontally, thereby minimizing shielding. In addition, the price of the power plant area is lower.

In densely populated areas of Central Europe, we recommend installing PV systems on roofs and facades of buildings and not on farmland. In the desert and half-desert areas, installation on open areas is also suitable with regard to the lower price of the PV power plant area.

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