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Brief Note

Roof photovoltaic power plant operation during the solar eclipse

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ABSTRACT

The article describes the construction of the photovoltaic (PV) system and shows the unique data measured during the solar eclipse on the 20th of March 2015. The data are discussed. The PV power plant was installed on the roof of the football stadium in the year 2010. Considering the location on the atypical roof and integration into the architectural style of the surroundings, flexible photovoltaic foils based on thin semiconducting layers of amorphous silicon oriented horizontally were used at this location. Some data obtained during five-year operation and testing of the PV power plant are also presented.

1. Introduction

The PV power plant was installed on the roof of the football stadium "Slavia Praha" in the district Prague 10 - Vršovice of the capital city Prague in the year 2010. The especially flat roofs of the large buildings were deemed by the authors of this article suitable for such utilisation. Smaller similar photovoltaic systems had been tested by our team previously in the district Prague 1 and the results have been published (Libra et al., 2013). We have also summarized more detailed theoretical and practical experiences in the photovoltaics, for example in the work mentioned below (Poulek and Libra, 2010).

Unique results are presented in this article regarding behaviour of the aforementioned roof PV power plant during partial solar eclipse. The data that were collected during this natural phenomenon on the 20th of March 2015 were obtained under ideal weather conditions. Important data obtained during the five-year operation of the power plant are also discussed.

The roof is atypical a little rounded and it is integrated into the architectural style of the surroundings. For that reason, flexible PV foils based on thin semiconducting layers of amorphous silicon oriented horizontally were used for the construction of the PV power plant. The above construction is not visible from the streets and so it does not disrupt the architectural conception of its surroundings. Using the classic construction of the PV power plant utilising PV panels based on crystalline silicon inclined to the south, would have disrupted the architectural style of the area.

The use of PV cells based on thin layers of amorphous silicon is analysed for example in the reference (Foti et al., 2014). Thin solid films based on other semiconductors are discussed for example in references (Mathews, 2012) (SnSe), (Mathew et al., 2004) (CdTe/CdS), (Khrypunov et al., 2006) (CdTe). References (Peng et al., 2011; Fung and Yang, 2008; Didoné and Wagner, 2013; Ng et al., 2013) show the other possibilities of the building integrated photovoltaic systems from the architectural point of view.

1.1. Construction of the building integrated PV power plant

The bird's eye view of the above mentioned PV power plant is shown in the Fig. 1. The power plant was constructed using flexible water-resistant PV foils VAEPLAN V Solar 432 with nominal output power 432 W_p. 1040 foils in total are connected into eight independent sections and these sections are connected into eight merge switchboards. 26 strings are connected into each switchboard and each string consists of 5 PV foils. Switchboards are equipped with fuse disconnecters and with DC disconnecters ABB OT160E4 with protection against overvoltage. The DC power is then led out to the inputs of electronic inverters. The nominal power of the PV power plant is therefore 449 kW_p in total. Fig. 2 shows a more detailed view of the PV foils and surrounding architecture.

Two inverters produced by Power-One Aurora (type PVI-CENTRAL-220.0-CZ) with a three-phase AC output are used to connect the PV power plant to the three phase AC power grid. Each inverter consists of four sections and each section has maximum

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Fig. 1. The birds eye view of the building integrated PV power plant on the roof of the football stadium.

Fig. 2. The view of photovoltaic foils and surrounding roof architecture.

power of 55 kW. Each section has output to the central busbar. The power is then carried out to the transformer. The eight sections are thus connected to the two inverters and the maximum power on the side of AC power grid is 440 kW_p.

2. Results and discussion

We had a unique opportunity to observe the behaviour of the PV power plant described above during the partial solar eclipse on 20th March 2015. The maximum coverage of the sun disc was 68%. Important parameters of the eclipse are presented in Table 1. The radiation intensity on the plane perpendicular to the direction of radiation was calculated as the projection of a horizontal plane on the plane perpendicular to the direction of radiation. The weather condition was perfect from 19th to 20th of March 2015. The sky was clear and bright and so we were able to measure, evaluate and compare the data from both these days including the day of the solar eclipse. The Fig. 3 shows dependence of the instantaneous power relative to time and amount of electric energy produced during those days. We can see that the power decrease at the height of the eclipse corresponds with the proportional coverage of the sun disc and the amount of electric energy produced during the day of the eclipse is lower by about 11 % (energy corresponds with the area under the graph).

The Fig. 4 shows dependence of the radiation intensity absorbed by a horizontal surface relative to time and the total incoming solar energy during both days. It is also clear, that the decrease of the radiation intensity at the height of the eclipse corresponds with the proportional cover of the sun disc and the total incoming solar energy is lower by about 12%. The small difference in the ratio of the incoming solar energy and of the produced electric energy amount during both days could be caused by the fact that the roof of the football stadium is a little rounded, as seen in Fig. 1. For this reason, all PV foils are not oriented exactly horizontally. Let's consider two facts. First, the amount of produced electric energy is given by the least illuminated PV foil in each string. Secondly, the projection of PV panel area to the plane perpendicular to the direction of solar radiation is given by the cosine of the angle of incidence ($S' = S_0 \cos \alpha$, where S_0 is the PV panel area and α is the angle of incidence of the direct solar radiation) (Poulek and Libra, 2010; Reda, 2015). The angle of inclination of the tangent is approx.±3° at the edges of the curved roof.

We also monitored the temperature of the photovoltaic foils because the efficiency of the photovoltaic energy conversion decreases with the increasing temperature (Poulek and Libra, 2010). The manufacturer determines the 0.21%/°C decrease in the case of the used photovoltaic foils. Photovoltaic foils are glued directly on the water-resistant surface of the roof which makes the cooling from the bottom side limited. Therefore, the temperature reached up to 60 °C during the hottest summer days. Fig. 5 describes dependence of the temperature of the photovoltaic foils relative to time during selected March days at the turn of winter to spring of the year 2015 including the solar eclipse on the 20th of March 2015. Dependence of the air temperature relative to time is presented as well in the figure. However, the air temperature was measured near the photovoltaic foils and therefore it is not objective meteorological data. We can clearly see the alternation of morning minimum temperatures and afternoon maximum temperatures. The differences between temperatures is much higher during sunny days. The temperature decrease in the case of the solar eclipse is also evident. At night, the temperature of PV foils is usually lower than the air temperature due to heat radiation. On the contrary, the temperature of PV foils is higher than the air temperature during the day as a result of absorption of solar radiation.

The results of monitoring the electric energy production during the five-year operation of the PV power plant described above are shown in Fig. 6. For better comparison, the data are converted per 1 kW_p of the installed power. In the years 2011 and 2014, there was almost no snow in Prague. So winter values are influenced only negligibly by the lying snow. Low values of the electric energy produced in October and November 2014 are influenced by the failure of the PV power plant caused by a whirlwind. If we add

Table 1
Parameters of the solar eclipse in Prague on 20.3.2015.

Eclipse phase	Time (h)	Cover of the sun (%)	Height of the sun (°)	Azimuth of the sun (°)	Angle of incidence on the horizontal surface (°)	Radiation intensity on the horizontal surface ($W\,m^{-2}$)	Radiation intensity on the plane perpendicular to the direction of radiation ($W\,m^{-2}$)
Start	9:37	0	30	134	60	437	874
Maximum	10:46	68	37	154	53	155	258
End	11:58	0	40	176	50	612	952