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Autonomous photovoltaic system for night-time lighting in the stable

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Abstract: Autonomous photovoltaic (PV) systems are suitable, for example, for powering various appliances or scientific instruments in the field, for automatic data collection, for signaling, etc. At the Czech University of Life Sciences Prague, we have designed an experimental autonomous PV system designed for night-time lighting for orientating in a stable for horses. The article describes the construction of a PV system with a PV panel rated at 170 Wp, with a lead-acid accumulator and a 1.5 W LED light source. The data collection was automated. The data evaluation shows that during the whole year, the PV system has been recharged and there was no lighting failure. The paper also presents important measured characteristics.

Key words: photovoltaics, off-grid PV system, LED.

INTRODUCTION

Autonomous photovoltaic (PV) systems are typically built in places where they are far away from the grid and the cost of networking would be higher than the cost of energy storage. Autonomous PV systems can also be designed because we require their independence from the grid. They are suitable, for example, for powering various appliances or scientific instruments in the field, for automatic data collection, signaling, etc. (see Bakos & Soursos, 2002; Axaopoulos & Theodoridis, 2009; Ghafoor & Munir, 2015; Wang et al., 2017). Their use is extended in settlements or camps without an electrical grid connection. We have dealt with the construction of autonomous PV systems and their inclusion in the automation structure earlier, see eg Kouřím et al., 2015.

Previously, it was used to power a classic light bulb. However, these have little energy conversion efficiency to visible radiation (about n = 3%), and therefore the batteries have been discharged very quickly. Halogen lamps or discharge lamps have been more efficient, but today the most economical and therefore the most commonly used are light emitting diode (LED) semiconductor sources. They work on the principle of the radiative electron passage between energy levels in the band pattern of energy levels in the semiconductor. For yellow LEDs, the efficiency reaches up to n = 40%. For white light emitting diodes, the efficiency is no more than n = 30%, because the white light is achieved by the fact that the semiconductor chip gives light in the blue area of the spectrum, and by means of the luminophores, part of the photons are convertedinto photons with less energy in other areas of the visible spectrum. The resulting radiation color is then white. In addition, the LED light source has a lifetime of about 50,000 hours, but the classic bulb has a lifetime of only about 1,000 hours. The serial production of LED light sources has also lowered their cost, which has also been positively influenced by their expansion, see, for example (Sastry et al., 2010; Das et al., 2015).

Lately, we have seen more and more autonomous PV systems designed for illumination. E.g. Fig. 1 shows an autonomous PV system designed for street illumination in Shanghai. As a light sources, low-pressure sodium discharge lamps were used there. In this article we will describe the design and results of testing our experimental autonomous PV system for night-time illumination in a horse stable. A larger PV system for street lighting has been described, for example, in the work (Liu, 2014). A comparison of European sites in terms of the amount of energy produced in PV panels was given, for example, in works (Libra et al., 2016; Olšan et al., 2018) and data monitoring from PV systems was concerned with work (Beránek et al., 2018).

Figure 1. Autonomous PV system for street illumination in Shanghai.

MATERIALS AND METHODS

At the Czech University of life Sciences in Prague, we designed an experimental autonomous PV system designed for night-time lighting in the horse stable. This PV system was then installed in a stable in Panenske Brezany near Prague. The position is approximately 50.2° north latitude and 14.4° east longitude. The outside of the PV system consists of a monocrystalline silicon PV panel with nominal power Pmax = 170 W, see Fig. 2. Inside the building there is s a lead-acid battery Tesla (12 V, 45 Ah) and MPPT solar charge controller) (see Fig. 3). The Solar charge controller itself controls the lighting of the light source at dusk and at dawn. When the battery is fully charged, it gives the open circui voltage about Ue = 14 V and can accumulate about Wmax = 0.5 kWh of energy. The LED light source is shown in Fig. 4, it takes power of about P = 1.5 W (12 V, 165 lm, 120°) and is located in a waterproof housing. Automatic data storage is provided by microcontroller ARDUINO UNO programmable platform, data is stored on the SD card. The block diagram of the PV system is in Fig. 5.

Figure 2. Outer part of the PV system - PV panel.

Figure 3. Lead acid accumulator with charge regulator with MPPT.

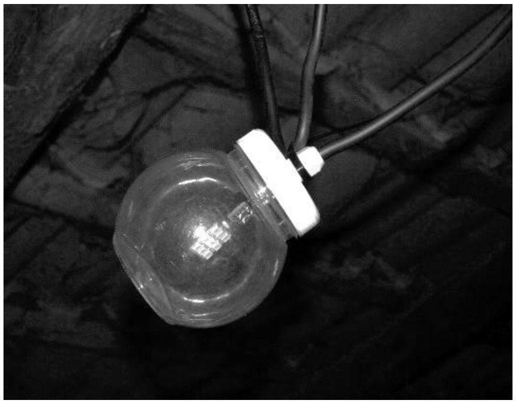

Figure 4. LED light source in the watertight case.

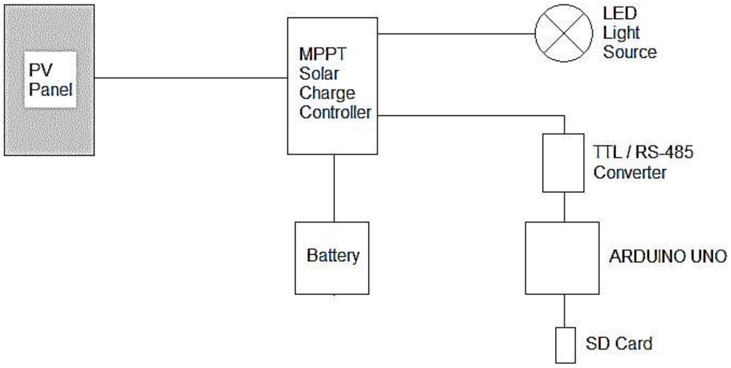

Figure 5. Block diagram of the PV system.

RESULTS AND DISCUSSION

Our PV system was put into operation in the spring of 2017 and the data storage was started too. Based on our previous measurements and the internationally-used software of the expected amount of produced electricity in a specific PVGIS site (http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php#), we made the following estimation. Throughout the year, the PV panel is able to deliver more than $W_d > 160$ kWh of electricity. If the light is switched on for 10 hours per day, it consumes an energy of about $W_s \approx 6.5$ kWh per year. Theoretically, the PV system should be self-sufficient even if some energy losses are accounted for, mainly due to lower lead acid efficiency (efficiency about 0.4). However, it is to be expected that the winter days will be much shorter, the sun will be below the horizon, and therefore the PV panel will deliver less energy than in the summer. If the battery is fully charged, the extra energy cannot accumulate, and the charging unit further charges the battery only with a maintenance current which compensates self-discharge. Therefore, it has to be verified whether the PV system is sufficient to recharge the battery during the entire winter time. The system is optimised for good performance in December. During December the electric energy production is approximately 5 kWh (PVGIS 2018) and the system's energy consumption is approximately 0.8 kWh (efficiency about 0.4). Long-term data monitoring has shown that our autonomous PV system is truly self-sufficient throughout the year.

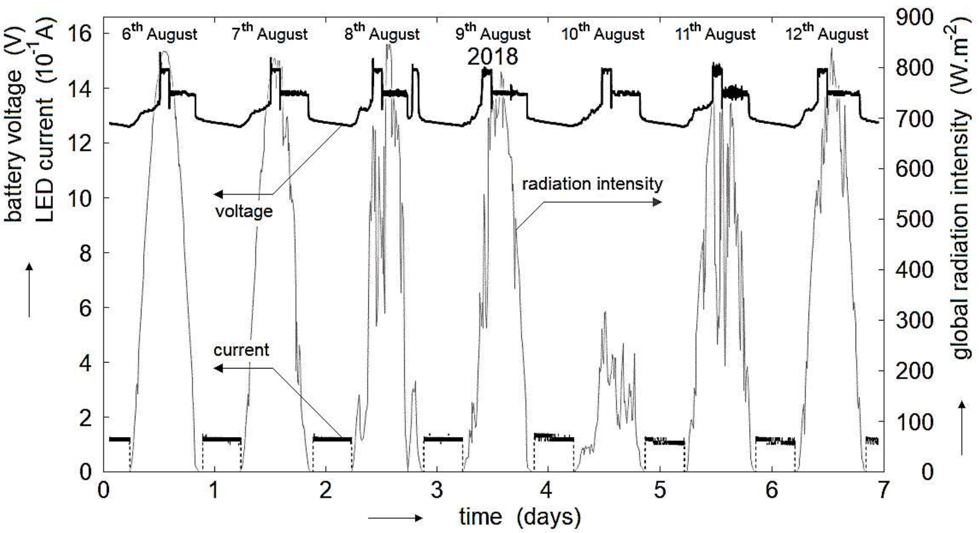

Figure 6. Time dependence of the battery voltage, LED current and global radiation intensity during the selected summer days.

In Fig. 6, battery voltage, light source current, and global radiation intensity (on a horizontal surface) over time are selected over several selected summer sunny days. It can be seen that every day in the afternoon, the battery is fully recharged and recharged only by the maintenance current, which corresponds to a constant value of the open circuit voltage of approx. U = 14 V. In the evening when the light source is switched on, the voltage dropped slightly, according to Kirchhoff laws and slowly discharge during lightning.

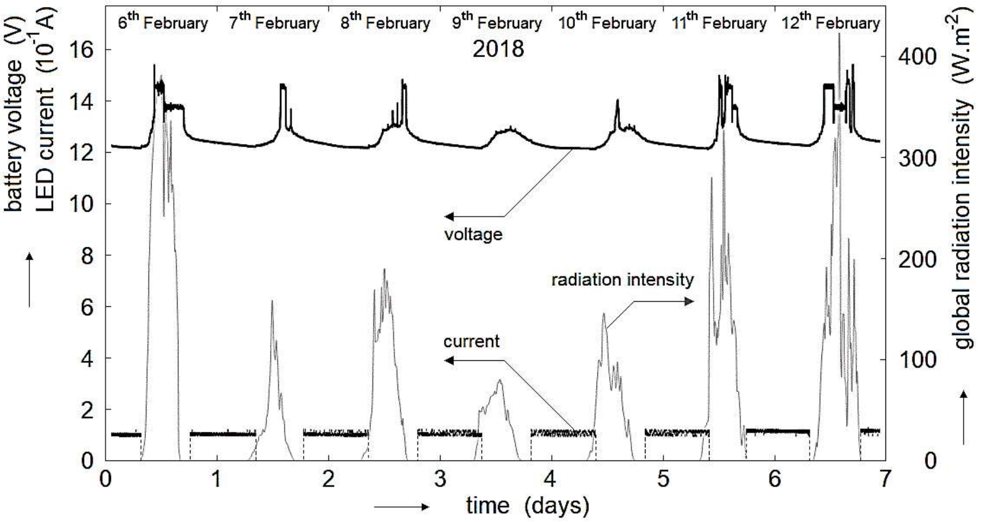

Figure 7. Time dependence of the battery voltage, LED current and global radiation intensity during the selected winter days.

Fig. 7 shows similar dependence for several selected winter days. Days with cloudy weather were selected. It can be seen that even if there were shorter days in winter and low radiation intensity, there was no failure in the function of the device. Even though the battery was not fully charged in some days, it still worked reliably.

CONCLUSION

We have designed the autonomous PV system for lighting. The installation was completed in the summer of 2017 and immediately began its testing and data collection. The evaluation of the annual traffic data showed that the PV system was self-sufficient all year round. It was even able to recharge the battery in the winter at the shortest days and several consecutive days with low global radiation intensity.

Our PV system has proven itself well for night-time lighting in the stable. The low light intensity of the light source does not interfere with the night's peace, but it allows orientation of people in the stable.

We will collect and evaluate the data further and we will monitor whether the parameters will change over a longer period of operation. We assume that due to the aging of the lead-acid battery, it may show a decrease in its capacity over several years.

The system is not very economical if it is very close to the electric grid (less than 100 m). The main advantage is the independence on the electric grid. On the other hand, the system is economical when it is located more than 1000 m from the electric grid.

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