DOI: 10.24427/978-83-67185-12-7_3

# Chapter 3
# Analysis of the efficiency of a solar station for charging personal electric vehicles

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**Abstract:** Popularizing ecological life, reducing human impact on the environment, and ultimately striving for zero emissivity is significantly visible in the media. In recent years, the significant development of the automotive industry in the field of electric cars and programs popularizing renewable energy sources, have contributed to the growing interest of the public in personal electric vehicles, e.g. scooters, bicycles, skateboards. The exploitation of such a vehicle requires charging. The research results presented in the article will allow estimating the practical potential of solar stations for charging personal electric vehicles in urban space. Analysis of the efficiency of a solar station for charging personal electric vehicles.

**Keywords:** renewable energy sources, energy efficiency, electric vehicles, charging.

## Introduction

Nowadays, there is a significant increase in the interest in electric vehicles. Last years resulted in popularization of cars, bicycles, scooters, skateboards and other vehicle variations. In urban space we can observe more often people using such solutions, and electronic scooters offered by rental companies have already become a common feature of city landscapes. Each year more and more emphasis is placed on reducing pollution and striving for zero emissions, not only in terms of transport but also industry and energy. The European Union aims to exclude combustion cars from production by 2035 [1].

Combining the above mentioned facts with the better availability of these technologies and changes in the habits of society in last years lead to a new market trend related to the provision of electricity for personal electric vehicle. People using such a vehicles for transport e.g. to work, school, university, must store these vehicles somewhere and sometimes charge their battery packs. It is highly complicated in public places or office spaces, where several such vehicles significantly take up free space. Therefore, a concept was created based on bicycle shelters combined with electrical infrastructure powered by photovoltaic panels in order to charge parked vehicles.

This article presents the results of the performed analysis. It shows the efficiency results of such a charging station, taking into account practical factors. Finally, it aims to develop conclusions to improve the solution.

## Environmental conditions

The basic aspect that must be taken into account during the creation of any project that uses a photovoltaic system is its location. It is mainly the geographical location that is the most important as in some areas such an installation may not be economically and practically justified. If the initial classification is successful, it is important to make an on-site visit to verify the concept of such an installation e.g. whether it will not be overshadowed by another building. The success of this phase should guide to the design phase during which the physical position of the panels will be specified [2].

The described project assumes a structure in the form of a canopy where the roof would be replaced with photovoltaic panels. Its location was established on the northern side of the campus of Bialystok University of Technology, near the building of the Faculty of Electrical Engineering (Fig. 3.1). Such a location – due to the openness of the space to the east, south-west and south – allows to minimize the risk of shading the area in which the station is located. By these means it is possible to maximize the time of using solar energy while staying close to the building.

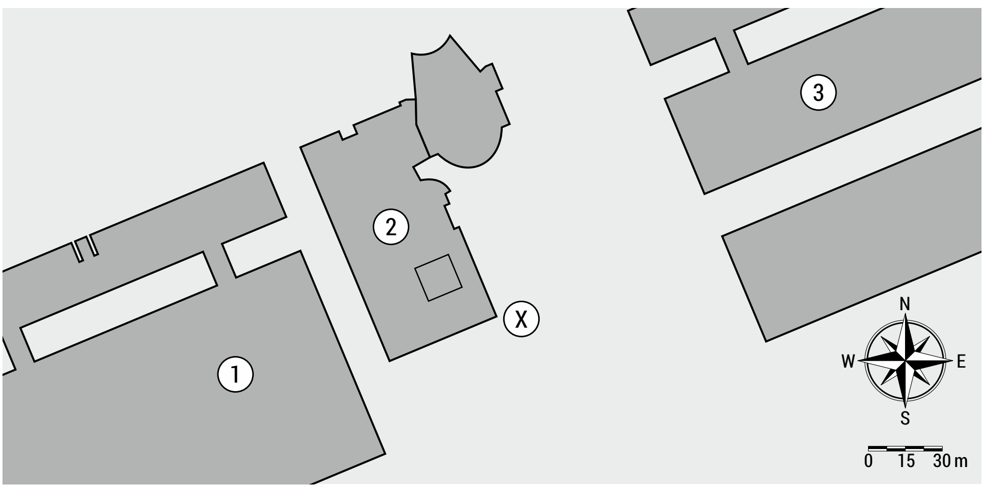


FIGURE 3.1. Fragment of the campus map; 1 – Faculty of Mechanical Engineering, 2 – Faculty of Electrical Engineering, 3 – Faculty of Civil Engineering and Environmental Sciences, X – proposed location of charging station

In order to reduce the area of environmental data analysis, the period was taken into account in which there is an increased number in road users using personal electric vehicles. This period was defined between April and October.

TABLE 3.1. Long-term average (1991–2014) of solar radiation power in Bialystok [3]

| Month | Average power [W/m$^2$] |
|---|---|
| April | 170 |
| May | 190 |
| June | 240 |
| July | 220 |
| August | 200 |
| September | 120 |
| October | 80 |

The data of the Institute of Meteorology and Water Management [3] show the average long-term solar radiation power in the given months in Poland. Table 3.1 shows the read (approximated) data for the Bialystok region. In the analysis, for the sake of simplicity, long-term monthly average data were adopted. This allows ignoring the position of the sun during the day or changing weather conditions, while maintaining an accepted accuracy in long-term calculations.

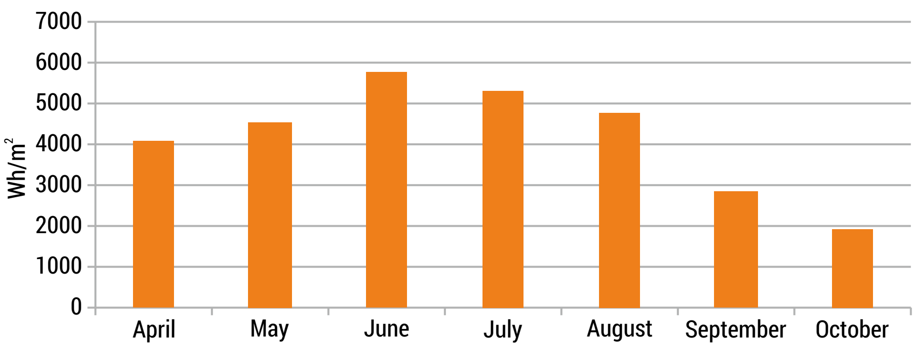


FIGURE 3.2. Diagram of energy supplied daily (average) in a given period to the station in a given month per m$^2$ of surface

Mean values were converted into watt hours according to the formula:

$$P\ [W/m^2] \cdot t\ [h] = Wh/m^2. \qquad (3.1)$$

This procedure allowed to adjust the value of energy supplied to the station per m$^2$ of the photovoltaic panel area (Fig. 3.2).

## Construction

The construction of the station was designed in such a way to provide not only support for the photovoltaic panels, but also to act as a parking shelter to store personal electric vehicles. This way it is possible to optimize the use of the available space. It is desirable in the construction of modern urban infrastructure and private properties, where every square meter counts.

The frame of the shelter consists of closed steel profiles of various sections. The four main supports are made of a profile with dimensions of 60 × 60 × 3 mm and respectively a height of 2200 and 3180 mm. The construction underneath photovoltaic panels is made of profiles with dimensions of 30 x 30 x 2 mm. The entire station measures 4 x 1,4 x 3.18m. The lean angle of the photovoltaic panels (Fig. 3.3) called α, was selected according to the geographical position of Poland, based on the average values of the solar inclination during the year. The α angle measures 35°, although a wide range is allowed, from 20° in the south of Poland to 40° in the north [4, 5].

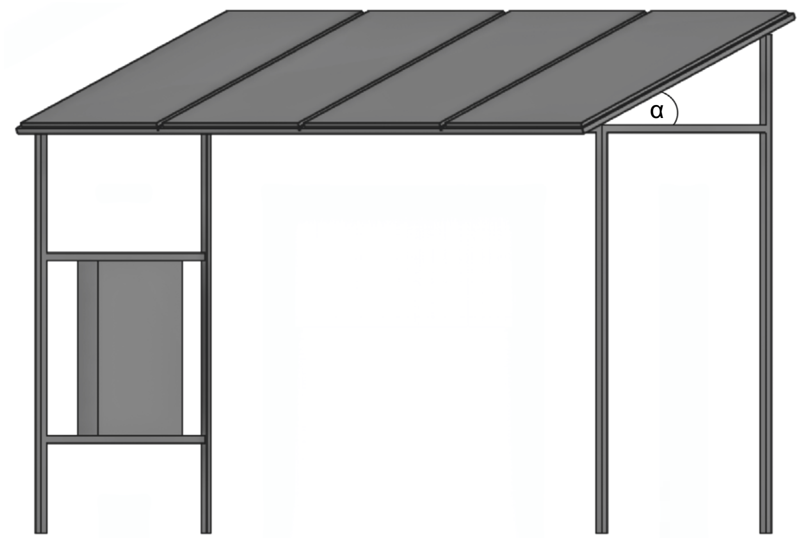


FIGURE. 3.3. Visualization of the station structure from the CAD program

All electronic and power electronic components (Fig. 3.4) were placed in a hermetic box dedicated for the assembly of electrical equipment. The box is locked with a key, which prevents access by unauthorized persons. On the front there are 230 V mains sockets for connecting vehicles.

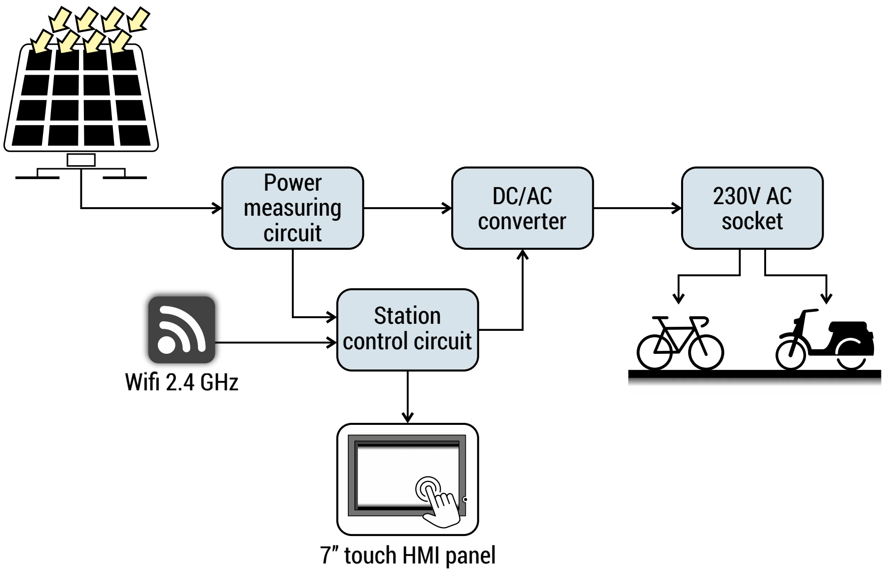


FIGURE. 3.4. Block diagram of the solar station

The control system of the station is based on the ESP8266 microcontroller with 2.4 GHz Wi-Fi wireless connectivity and will ultimately work in the network as an IoT device [6]. Network functions allow for remote control of electrical parameters including power consumed by vehicles and the amount of generated energy for a given period (e.g. day or month). The station will be operated by a 7-inch touch display from Nextion, which functions as an HMI panel.

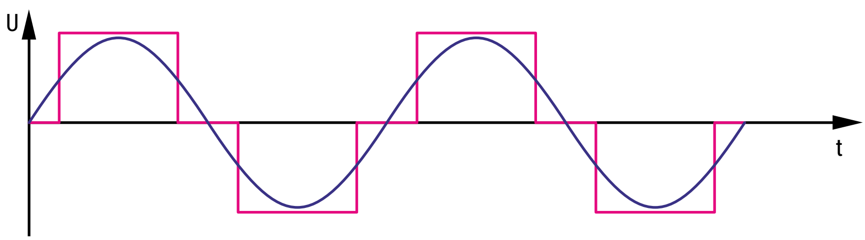


FIGURE. 3.5. Waveforms, blue line – sine wave, pink line – modified sine wave

The used DC/AC converter has a continuous power of 1000 W and a momentary power of 2000 W. The inverter generates an output voltage in the form of the modified sine wave (Fig. 3.5). This choice was motivated by the fact that the energy receiver is also a pulse converter (AC/DC), which acts as a vehicle charger. Therefore, it is not necessary to use an inverter at the station providing a sine wave at its output. Also this would be associated with higher costs. The declared efficiency of the applied converter is 85%. This value was taken into account in further calculations of the station's efficiency.

## Results

Four photovoltaic panels with a rated power of 280 Wp each generate electricity. The entire station has a rated power of 1.12 kWp. According to the manufacturer's data, one photovoltaic panel consists of 60 cells with dimensions of 156 × 156 mm. It follows that the effective area of all four panels is:

$$S = 4 \cdot 60 \cdot 0{,}156\ \mathrm{m} \cdot 0{,}156\ \mathrm{m} \approx 5{,}84\ \mathrm{m}^2. \tag{3.2}$$

The efficiency of photovoltaic panels declared by the manufacturer is 17.21%.

TABLE 3.2. Values of the average power falling on the surface of the panels, power at the output of the panels and monthly energy at the output of the station, taking into account the efficiency of the converter

| Month | Delivered power [W/5,84m$^2$] | Output power [W] | Gross energy [kWh] |
|---|---|---|---|
| April | 992.8 | 145.23 | 104.57 |
| May | 1109.6 | 162.32 | 116.87 |
| June | 1401.6 | 205.03 | 147.62 |
| July | 1284.8 | 187.95 | 135.32 |
| August | 1168.0 | 170.86 | 123.02 |
| September | 700.8 | 102.52 | 73.81 |
| October | 467.2 | 68.34 | 49.21 |

Based on all the data presented so far, it is possible to estimate the amount of energy produced by the station. The results of the calculations are shown in Fig. 3.6.

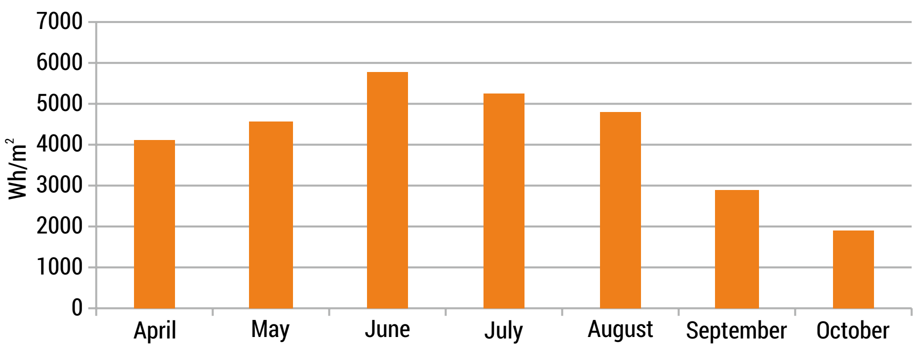


FIGURE 3.6. Graph of the energy produced (gross) by the station in the given months based on the data in Table 2

It is assumed that the station can produce about 0.75 MWh of energy during the entire season.

## Results analysis

In order to draw the practical use of the obtained results, an analysis of the personal electric vehicles available on the market was carried out. On the basis of the data declared by selected manufacturers and own experience, an approximate summary of energy consumption expressed in Wh per kilometer of the vehicle has been developed.

The presented data (Table 3.3) are mean values expected under optimal conditions. They do not take into account weather, terrain conditions, load and other factors that may significantly affect the range of the vehicle. On their basis, it can be seen that average energy use for different personal electric vehicles is similar. The mentioned fast electric bikes and motorcycles are characterized higher energy demands. Vehicle range can be estimated based on the average battery capacity and energy obtained from the sun. For analytical purposes, it was assumed that the efficiency of the charger is 80%.

TABLE 3.3. Electricity consumption per distance travelled by selected groups of vehicles.

| Type of electric vehicle | Energy usage [Wh/km] | Average energy usage [Wh/km] |
|---|---|---|
| Bike | 10–20 | 15 |
| Scooter | 9–20 | 14.5 |
| Skateboard | 8–20 | 14 |
| Sports bike or light electric motorcycle [7]* | 20–50 | 35 |

* – Vehicles with curb weight above 50 kg

TABLE 3.4. Estimated vehicle range for a given battery capacity

| Type of electric vehicle | Battery capacity [Wh] | Estimated vehicle range [km] |
|---|---|---|
| Bike | 816 | 54.4 |
| Scooter | 460 | 31.7 |
| Skateboard | 192 | 13.7 |
| Sports bike or light electric motorcycle ** | 4000 | 114.3 |

** In the case of this type of vehicles, the capacity discrepancy is large, from 1 kWh to even 8 kWh

On the basis of the collected data, it is possible to estimate the efficiency of the station in terms of the number of fully charged electric vehicles per month, taking into account the influence of the charger efficiency.

TABLE 3.5. Number of fully charged vehicles from the station per month

| Month | Bike | Scooter | Skateboard | Sports bike or light electric motorcycle |
|---|---|---|---|---|
| April | 103 | 182 | 436 | 21 |
| May | 115 | 203 | 487 | 23 |
| June | 145 | 257 | 615 | 30 |

| Month | Bike | Scooter | Skateboard | Sports bike or light electric motorcycle |
|---|---|---|---|---|
| July | 133 | 235 | 564 | 27 |
| August | 121 | 214 | 513 | 25 |
| September | 72 | 128 | 308 | 15 |
| October | 48 | 86 | 205 | 10 |

The table above shows the number of complete charging cycles for a given vehicle. The analysis assumed that only one type of vehicle would be loaded at the station, for example only bicycles or only scooters. Based on the data, it is possible to calculate the possible distance to be travelled by the vehicle, provided that it is charged only with energy from the station.

TABLE 3.6. Estimated distance travelled by a vehicle that uses energy only from the station (km)

| Month | Bike | Scooter | Skateboard | Sports bike or light electric motorcycle |
|---|---|---|---|---|
| April | 5577 | 5765 | 5969 | 2390 |
| May | 6233 | 6443 | 6671 | 2672 |
| June | 7873 | 8139 | 8427 | 3375 |
| July | 7217 | 7460 | 7725 | 3093 |
| August | 6561 | 6782 | 7022 | 2812 |
| September | 3937 | 4069 | 4213 | 1687 |
| October | 2624 | 2713 | 2809 | 1125 |

The above analysis shows that the most efficient means of transport in terms of energy consumption is the electric skateboard. Unfortunately, this vehicle has the shortest range. A light city bike or an electric scooter can cover a similar distance in a given period. At the end of the list are sports bikes and light electric bikes. They have the greatest range and maximum speed, but also the highest energy consumption.

## Summary and conclusions

The article presents the results of the analysis of the efficiency of the solar station project for charging personal electric vehicles. The purpose of this analysis was to determine the practical utility of the presented solution, to identify its disadvantages and to select potential solutions in order to improve functionality.

The obtained results represent the actual values of energy that can be obtained from the solar station. With the assumed parameters, these values can be used in a practical way for charging. This would enable users to improve the comfort of using personal electric vehicles.

This analysis looks at efficiency in the general energy bill. The presented project assumes the construction as an independent unit. Not loading the station results in not using energy. Attempts to use the station outside the sunny hours, during unfavorable weather conditions or its excessive load will result in poor results.

In order to improve the real practical aspects, it is possible to connect the station to the power grid. Thanks to this solution, the continuity of the station's operation will be ensured, regardless of sunny or weather conditions. Such a solution, however, is associated with the deterioration of the economic aspects by increasing technical requirements [8] and increasing legal requirements in order to make it available for public use.

An alternative solution is to expand the station with energy storage. This approach allows for an autonomous form of the station. Moreover, with the correct estimation of the storage capacity, it is possible to maximize the use of the energy produced at the same time, allowing the station to be used 24 hours a day, regardless of weather conditions and also increasing its load capacity (within the warehouse capacity). However, this solution is associated with an increase in project implementation costs and the need for additional research in order to correctly estimate storage capacity so that its size is economically justified.

The research will be continued as the project develops, taking into account actual use, location and design improvements.

**Streszczenie:** Popularyzacja ekologicznego życia, redukowanie wpływu człowieka na środowisko, a finalnie dążenie do zero emisyjności znacząco się odznacza w przestrzeni medialnej. W ostatnich latach znaczący rozwój przemysłu motoryzacyjnego w gałęzi aut elektrycznych oraz programy popularyzujące odnawialne źródła energii, przyczyniły się do wzrostu zainteresowania społeczeństwa osobistymi pojazdami elektrycznymi, np. hulajnogami, rowerami, deskorolkami. Eksploatacja takiego pojazdu wiąże się z koniecznością jego ładowania. Przedstawione w artykule wyniki badań pozwolą na oszacowanie praktycznego potencjału solarnych stacji ładowania osobistych pojazdów elektrycznych w przestrzeni miejskiej. Analiza sprawności stacji solarnej do ładowania osobistych pojazdów elektrycznych.

**Słowa kluczowe:** odnawialne źródła energii, efektywność energetyczna, pojazdy elektryczne, ładowanie.

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Many thanks to the Diamond Discoverers Association for financial support in the scientific development of students.

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