Carports as an element of energy security for electric vehicles

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Abstract. Energy security with regard to electric vehicles consists in providing an appropriate infrastructure in the form of charging points for electric vehicles, which are able to generate and supply the traction batteries of vehicles with an appropriate amount of electricity. This role is played very well by photovoltaic carports, which are the structures designed to generate electricity and generate a shadow. The vehicle parked under the carport structure is protected against excessive heating. The shade for the parked vehicle is provided by a photovoltaic system mounted on the roof of the carport. Carports are, therefore, an ideal solution for charging electric vehicles. The article analyzes the problem that is related to the selection of peak power of the carport for the electric vehicle (or vehicles) that will be parked under it. An economic and energy analysis is carried out to ensure the fastest and cheapest charging of an electric vehicle. The authors present a study of two cases of carports of different sizes, which were used to charge electric vehicles of various brands with different sizes of traction batteries and different powers of on-board chargers. The results obtained from the conducted research and analysis can be generalized to a larger number of carports and vehicles available on the market.

Keywords – electric vehicle, traffic monitoring, carport

1. Introduction

Energy security in relation to electric vehicles consists in providing an appropriate number of charging points for electric vehicles that are able to generate and supply the vehicle's traction batteries with an appropriate amount of electricity. At present, i.e. in Europe and in the world, in the 21st century, almost all areas of our life have been mechatronized. At the beginning of the 20th century, they were electrified in order to obtain greater reliability and safety in relation to the previously present mechanical solutions. Electric drives turned out to be more reliable, more efficient (efficient) and more ecological than steam drives based on direct combustion of coal in a boiler [1]. Moreover, the electrification of towns and villages allowed for the transfer of emissions of carbon dioxide and other exhaust components generated during the combustion of coal, outside the clusters of people [2]. Alternating current makes it possible to transmit electricity over long distances with little losses. At the same time, mankind has started to use alternative [3] and renewable energy sources [4]. At the beginning, they were used in stationary mode, but with time, they were developed to such a degree
that they could find widespread mobile use [5]. For centuries, it has been a huge problem to store large amounts of non-fossil energy. However, the development of technology ensured the appearance on the market of traction batteries capable of storing the amount of energy necessary for a vehicle to travel several hundred kilometers [6]. Importantly, each year such battery packs are becoming cheaper and more reliable [7]. Due to the possibility of charging with high currents, the electric drive of vehicles is becoming more and more popular [8]. Some countries have already (2022) been declaring the complete withdrawal of diesel and even gasoline engines from production in a very short term (by 2028). Obviously, humanity faces many challenges, which are studies of risk, reliability and the impact of a given technology on human life [9].

The multitude of energy generating sources and their electrical receivers requires monitoring and supervision to ensure safe and reliable operation [10]. It would have been impossible on such a large scale if it had not been for the global Internet network introduced in the last three decades. In the 20s of the 21st century, most power generation sources and receivers are already Internet of Things devices and have Industry 4.0 functions [11]. Their monitoring, diagnostics and even servicing are carried out by means of sending and selected parameters to the data cloud and their on-line or off-line analysis [12]. Advanced internet platforms allow you to manage electricity over large areas. The types and interconnection of electricity generation and consumption infrastructure are shown in Figure 1 in the form of infographics [13][14].

![Figure 1. Power supply and power take-off infrastructure [own source]](image)

Photovoltaic carports are a very effective way of obtaining electricity from RES and charging electric cars with it [15]. Photovoltaic carports are structures that generate electricity and shade. The vehicle parked under the carport structure is protected against excessive heating. The shade for the parked vehicle is provided by a photovoltaic system mounted on the roof of the carport. Carports are therefore an ideal solution for charging electric vehicles [16]. The article analyzes the problem related to the selection of peak power of the carport for the electric vehicle (or vehicles) that will be parked under it. Large parking spaces located in front of shopping centers or office complexes can be developed with carports. The vehicles will be protected from excessive sunlight and charged with electricity at the same time while their owners are shopping or working.

The safety of an electric vehicle can be considered in many ways:

- Safety of the driver and passengers traveling by electric vehicle. It involves, among others, safe reaching the destination, which is related to the range of the electric vehicle.
- Thermal safety when charging high power DC traction batteries. It can damage the batteries as a result of overheating and in extreme cases ignite them.
- The safety of an electric vehicle involved in a road collision or accident.
- Safety during diagnostics and repairs of selected components of the electric vehicle. Authorized persons should have appropriate qualifications and permits.
- Ecological safety resulting from zero emissions to the atmosphere at the place of use of the vehicle.

Safety in each of the above areas affects the road safety of this vehicle. If the vehicle has a battery charged with electricity, it will have good driving properties and will be able to move safely on the roads. If the battery is fully discharged, the electric vehicle will not be roadworthy and will present a
traffic hazard, especially if it occurs on the motorway. Topping up a traction battery is not as simple as adding gasoline to an empty fuel tank. Thus, one of the main goals in the operation of an electric vehicle is to provide an adequate amount of electricity needed to cover the planned route. The infrastructure for charging electric vehicles, developing every year, reduces the risk of an electric vehicle being stopped in an undesirable place. Carports are part of such an energy security infrastructure.

2. Case 1: PV carport with a peak power of 1 kWp and a small electric vehicle
At the very beginning, the photovoltaic minicarport with a peak power of 1 kWp located at the University of Economics and Innovation in Lublin is analyzed. The supporting structure of the carport consists of two legs made of welded steel profiles. The steel elements have been protected against corrosion by galvanizing. Another part of the carport is the supporting structure of photovoltaic panels. The roof structure is made of anodized aluminium profiles. The structure was subjected to strength calculations due to its own weight, additional load of snow remaining in the winter and gusts of wind. Four photovoltaic panels in polycrystalline technology with a peak power of 250 Wp each were installed on the roof structure.

The design assumption was to make a compact structure of utility importance. The minicarport is to generate electricity needed to charge electric cars. If the vehicle does not receive energy, it is transferred to the power grid. An additional function of the minicarport is to be the exhibition capacity to promote the idea of electromobility, as well as the university itself, at various seminars, exhibitions, demonstrations and fairs. To fulfill this function, the minicarport must be easily and quickly assembled and disassembled. The appearance of the final version of the carport with the connected electric vehicle is shown in Figure 2. The photovoltaic system of the carport was connected to the power grid by means of an inverter. Additionally, 3 230 V sockets were installed on the supporting structure of the minicarport in order to power external receivers, including the electric vehicle. The author has the Renault Twizy electric vehicle, which is a small city vehicle with a traction battery with a nominal capacity of 6.1 kWh. The vehicle is designed to carry two people and has a range of 60 to 100 km on a single charge.

![Figure 2. Charging a Renault Twizy vehicle from the WSEI photovoltaic minicarport [own source]](image-url)

The time course of the current parameters during the process of full charging of the Renault Twizy vehicle from the WSEI PV minicarport is shown in Figure 3. The process of a fully discharged battery starts with a power level of 1200 W. After a few minutes, the power consumed by the on-board charger was about 1800 W (Pev). The power consumed by the vehicle slowly increases to around 2,000 W. After the battery has reached a level of approx. 95%, the charging current and, therefore, the power consumed have been reduced. The entire charging process took 210 minutes (3.5 hours). The charging process took place during the sunny noon between 11:45 a.m. and 3:15 p.m. At that time, the
WSEI photovoltaic minicarport generated instantaneous power ranging from 600 to 800 W (P$_{pv}$). This power is lower than the power consumed by the vehicle during charging. For this reason, the photovoltaic minicarport has been connected to the power grid, which is an energy buffer for the vehicle being charged. This connection is called on-grid. In contrast to the off-grid connection, when the photovoltaic system is not connected to the power grid and the generated energy is stored in stationary or mobile energy storage [17].

*Figure 3.* Mileage of the power generated by the carport and the power consumed during vehicle charging [own source]

The vehicle consumed almost 6 kWh of electricity to be fully charged. At that time, the photovoltaic minicarport generated 2.75 kWh of electricity, which is 46% of the demand. The graphs in Figure 3 show that the WSEI minicarport is not able to cover the instantaneous power needed to charge the Renault Twizy vehicle. It has to get the missing power from the utility grid. It is worth noting that the charging process shown in Figure 4 took place in very good sunlight conditions which are rare. Usually, over the course of a year, the minicarport generates less instantaneous power and for a shorter period of time. The high uniqueness of the power generated by each photovoltaic system depends on weather conditions and is characterized by seasonality (seasons). Thus, the peak power of a carport cannot be a parameter on the basis of which its size can be selected for a specific electric vehicle.

In addition to the charging power, an important parameter of traction batteries in vehicles is their energy capacity. It is the amount of electricity stored in the battery and is expressed in kWh. The range of each electric vehicle depends on the amount of energy stored in the battery and the energy consumption. Renault Twizy has a nominal battery capacity of 6.1 kWh. This is the amount that corresponds to the daily electricity requirement of a single-family house. A fully charged battery provides the vehicle with a range of 50 to 100 km, depending on the speed and characteristics of the vehicle. Previous long-term studies conducted by the author show that the average range on a single full charge is 65 km [24].

Now let's analyze the daily amount of energy produced by the minicarport WSEI on individual days of the month of June in 2021. The amount of energy produced varies greatly from 1.5 to over 6 kWh. The maximum amount of energy produced in the sunniest month of the year is similar to the energy capacity of an electric vehicle battery.
However, the amount of energy produced in particular months of the year varies significantly [18]. In the winter months (December and January), in Polish climatic conditions, the amount of energy produced is 10 to 20 times lower than in the most sunny months (May, June and July). In the winter months, the amount of energy produced during the day is sufficient to drive a vehicle from several to several kilometers. However, the monthly amount of produced energy is an important parameter characterizing photovoltaic systems [19]. This is due to the fact that the customer's settlements with the electricity supplier and seller are usually monthly. Thus, the amount of monthly energy produced by the WSEI carport in the winter months corresponds to the need for one or more full charges of a Renault Twizy battery.

From the amount of energy produced in the summer months, you can fully charge the vehicle about 20 times. According to the author, the minimum size of the photovoltaic carport should be selected to ensure the desired range of the electric vehicle on summer days. With 20 fully charged batteries, Renault Twizy will travel about 1300 km. This is the real value of the monthly mileage of this small city vehicle. This monthly mileage has been achieved many times by the author who owns such a vehicle. The research results were also analyzed and published in a peer-reviewed article.

The amounts of electricity produced in the spring and winter months are smaller and ensure a monthly vehicle mileage of less than 1,000 km. Due to the semi-open structure of the Renault Twizy body, its use in the winter months in Poland is not possible. The size of the WSEI carport was selected in a proper way to the real electricity demand of the Renault Twizy vehicle. The basis for such selection is the monthly amount of energy produced by the minicarport needed to cover the actual demand of the vehicle.
3. Case 2: PV carport with 3 kWp peak power and electric city vehicle

Another carport designed and made by the author is the carport in the Lublin Science and Technology Park (LSTP). Carport LSTP consists of 12 monocrystalline photovoltaic panels made in the glass-glass technology, with an individual optimizer. Carport LSTP has a single-phase Schuko electricity receiving socket and is connected to Segment 4 LSTP. This means that when an electric vehicle is not charged from the carport, it transfers energy to the LSTP building. The on-grid approach used to connect the carport to the power grid ensures that the vehicle is charged in all sunlight conditions. If the power generated by the carport is not able to cover the power needed to charge the electric vehicle, the shortage will be taken from the power grid. On the other hand, if the power generated by the carport is greater than the power consumed by the vehicle, its excess will be returned to the power grid. The appearance of the LSTP carport as well as the charging socket and plug is shown in Figure 6.

![Figure 6. Charging a Nissan Leaf vehicle from a photovoltaic carport in LSTP [own source]](image)

The study used a Nissan Leaf vehicle manufactured in 2016, which had a traction battery with a capacity of 30 kWh. The vehicle is equipped with two battery charging sockets. The slow-charging socket is Type 1 and is connected to the 3 kW on-board charger. If the charging socket in the Type 1 vehicle is powered from a single-phase socket with a Schuko plug, the charging power is 2 kW. It is easy to calculate that the time to fully charge the battery will be approx. 15 hours. In the case of slow charging using the Type 2 socket, the charger can achieve a maximum charging power of 3 kW. Then the time to fully charge the battery will be approx. 10 hours. The fastest possible battery charging is via a Chademo socket and a 50 kW DC external charger. The charging time is then approx. 40 minutes.

Figure 7 shows depicts the course of the instantaneous power generated by the LSTP carport on several days in June 2020. The presented data shows that on a sunny summer day (June 21), the photovoltaic carport is able to cover the real power demand needed to slowly charge the Nissan Leaf vehicle with a capacity of 2 kW. The graph clearly shows that the instantaneous power generated by the LSTP carport is higher than 2 kW (2,000 W) for a period of approx. 6 hours (between 10.00 and 16.00). However, the size of the LSTP carport is not able to charge the Nissan Leaf in the off-grid mode, even in the process of slow charging with the lowest power.
Figure 7. Course as a function of time of the power generated by the LSTP carport on 9, 12 and 15 June 2020

Figure 8 shows the daily production of electricity by carport LSTP in June 2020. The average daily amount of energy produced by carport LSTP in the sunniest month of the year is enough to charge half the battery of a Nissan Leaf vehicle. The actual mileage of this vehicle with a full battery is approx. 200 km. Thus, the amount of energy produced by the LSTP carport in the summer months ensures a daily vehicle mileage of about 100 km. This distance is traveled daily by people living in rural areas and commuting to a large city for work [20].

Figure 9 shows the monthly production of electricity by carport LSTP in 2020. The monthly amount of energy produced in the months from April to August is over 400 kWh [21]. This amount of energy gives the electric vehicle a monthly range of over 2,600 km. The amount of energy produced by carport LSTP in 2017-2021 was over 3 MWh per year. This amount of produced energy ensures that the vehicle's battery is fully charged 100 times. This in turn corresponds to the annual mileage of a Nissan Leaf vehicle of 20,000 km [22].
4. Conclusions

The analysis presented above show that it is possible to rationally select the size of a photovoltaic carport for an electric vehicle. According to the author, the minimum size of the photovoltaic carport should be selected to ensure the desired range of the electric vehicle on summer days. The nominal size of the carport should be selected to cover the annual electricity demand of the vehicle. The author proved that it is very difficult or impossible to charge an electric vehicle battery from a carport in off-grid mode. In each of the analyzed cases it was necessary to connect the carport to the power grid and take the missing power for charging from it.

The author intends to continue research on solar carports in the future. An interesting direction is adding a stationary energy storage and a hybrid inverter to the carport. The selection of the size of the energy storage is an interesting challenge due to the high purchase costs of the energy storage.

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