

LONG-TERM TEST OF AN ELECTRIC VEHICLE CHARGED FROM A PHOTOVOLTAIC CARPORT

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Abstract

The article includes experimental investigations of electricity consumption over a distance of 30,000 km by a small city electric vehicle. During that time period, the vehicle was charged in most cases from a photovoltaic carport with a peak power of 3 kWp. The analyses include vehicle mileage and the number of times the battery has been charged during 5 years of operation. In addition, the amount of energy generated by the photovoltaic carport was also measured. During the entire research period, the small electric vehicle was charged with State of Charge (SoC) 50% almost 900 times. Then, an analysis was performed to determine the adequacy of the carport peak power selection for the energy needs of the electric vehicle.

Keywords: electric vehicle; photovoltaic carport; battery charging

1. Introduction

Electric vehicles are characterized by zero emissions of harmful substances to the atmosphere at the place of use. Also, hybrid electric-powered vehicles emit far less pollution than vehicles powered only by a traditional internal combustion engine [20]. In relation to electric vehicles, people often complain that they are not as ecologically as they appear because very often the electricity used to charge them originates from the burning of fossil fuels such as coal or natural gas [15], [16]. In this case, exhaust emissions are merely relocated from the place of use of the vehicle to the location of electricity production [4]. However, this relocation of emissions is also very beneficial due to the reduction of the smog effect in the centres of large and small cities both within and outside Europe [1]. The optimal way to counteract smog is to use zero-emission electric vehicles charged with electricity from Renewable Energy Sources [5], [7], [21].

Since 2012, a trend called electromobility has been observed both in Europe and around the world [23]. In some countries, a real revolution has taken place whereby more than 10% of new vehicles sold are battery electric vehicles (BEVs) or hybrids with the option of charging batteries from external sources - hybrid electric vehicles (HEVs) [10]. Increasing

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numbers of BEV and HEV vehicles have also been recorded in Poland. The properties of electric vehicles are convincing customers to choose this type of propulsion, including:

- quiet driving, resulting from the lack of an internal combustion engine in BEV or, in the case of HEV, from a restriction on the rotational speed of the internal combustion engine,
- favourable driving dynamics, resulting from the availability of torque at low speeds in BEV or the simultaneous operation of two power sources in HEV,
- the increasing range of BEVs,
- constantly evolving infrastructure for charging both BEV and HEV [3],
- very low or zero costs for charging traction batteries in many public places [8].

The higher costs of buying BEV and HEV vehicles are being offset by government subsidies in some countries. This type of support may contribute to a large increase in the number of green vehicles sold.

The attractive appearance and properties of electric vehicles are the result of the work of engineers working in large automotive concerns and scientists working in universities and research institutes [13]. It is due to the development of material engineering that green vehicles have a lightweight, durable body with low air resistance. Significant discoveries and research and development work have led to the availability of new types of traction batteries capable of accumulating larger amounts of electricity in a smaller mass and volume. Due to the reduction in vehicle weight and the greater capacity of the traction batteries, the range of electric vehicles currently exceeds over 400 km on a single charge [18].

The infrastructure for charging electric vehicles is another element supporting electromobility [6]. Typically, every electric vehicle user has the ability to charge the battery overnight. Almost all electric vehicles have on-board chargers of up to 7 kW supplied with single-phase AC 230 V or up to 22 kW, powered with three-phase AC 400 V. However, the owners of such vehicles expect to be able to charge their vehicles at public charging points. This is of great importance, especially for long-distance journeys and during long international journeys. These expectations relate to the possibility of rapidly charging traction batteries with external DC chargers with powers of up to 150 kW [9]. The number of public points for both the slow and fast charging of electric vehicles is constantly increasing. In some countries, it is sufficiently developed and allows motorists to move around the country without any inconvenience. The development of software for mobile devices allows motorists to use one of many applications to enable them to locate a charging point and pay for the charging service [17]. Many entities such as hotels, banks and shopping centres offer free battery charging for their customers. This is due to another current trend related to promoting the pro-ecological image of the institution or company as a result of supporting electric vehicles [8].

If current trends continue then an inevitable issue will arise: Where is all of the electricity required to charge the new electric vehicles going to come from [2]? This issue concerns both the origin of the electricity produced and the infrastructure required for its distribution [1]. In some countries, the existing electricity production and distribution infrastructure is not sufficient to support many high-power chargers and must be significantly expanded. The electricity required for charging electric vehicles in different countries

originates from different sources. Western European countries have been investing in the production of electricity from renewable energy sources for many years. In Poland, since 2016, a large increase in the number of photovoltaic installations has been observed [11]. This includes both small household installations with a capacity of up to 5 kWp, industrial micro-installations with a capacity of up to 40 kWp and large photovoltaic farms with a capacity exceeding 1 MWp [22]. The attractiveness of such investments is due to significant funding from both government and European funds. Many people and institutions have decided to invest in a photovoltaic system due to the short payback period and large profits resulting from the production of energy for own needs.

Taking into account the technical and financial possibilities currently available, the best solution for ecological and economical city traffic is to buy an electric vehicle and build a photovoltaic system to charge it [17]. The system should be able to release excess energy produced to a nearby building. Before making such investments, it is worth reviewing the literature in this regard. It is also worth becoming familiar with the state of the market in the area of both electric city vehicles and photovoltaic systems. In this case, the key challenge would be the selection of the appropriate peak power of the photovoltaic system to match the energy capacity of the traction batteries of the vehicles.

2. Research object – Renault Twizy

The test object is a small electric vehicle - Renault Twizy. It has been produced since 2012 by the Renault group. It was designed as a typical urban vehicle capable of moving two people over short distances. The vehicle is very manoeuvrable due to its small dimensions and small turning radius resulting from the rear-wheel drive used. The small width of the vehicle, amounting to less than 1.2 m, allows for easy parking. The vehicle, with a curb weight of 405 kg and a gross vehicle weight (GVW) of 600 kg, is capable of reaching a maximum speed of 85 km/h. It uses an asynchronous 13 kW AC motor generating 57 Nm of torque. The vehicle is equipped with a lithium-ion battery pack with a rated voltage of 57 V and an energy capacity of 6.1 kWh. The traction battery is charged from the 230 V AC network. The full charging time is approximately 3.5 hours.

The vehicle has an open body as standard and can be optionally retrofitted with doors. It has no internal ventilation, heating and air conditioning. It only has electric windscreen heating. It is therefore a vehicle designed for markets with a warm climate.

Currently in Poland, owners of electric cars can depend on the following concessions and privileges related to the ownership and use of such cars:

- exemption from parking fees in Paid Parking Zones in designated cities,
- the possibility of using BUS lanes.

The vehicle was purchased in 2015 when the only option available at that time was to rent a traction battery. The minimum lease period of a new vehicle purchased was 3 years with a limit of 25,000 km. After this time, the lease contracts were renewed twice a year with the extension of the mileage limit to 40,000 km.

Figure 1 shows the Renault Twizy during the process of charging its batteries from a photovoltaic carport.



Fig. 1. Charging a vehicle from a photovoltaic carport

The basic technical data of the Renault Twizy vehicle, which has an influence over the use of the vehicle and the conduct of the tests, are presented in Table 1.

Tab. 1. Renault Twizy technical data [24]

Parameter	Value
Curb weight of the vehicle	405 kg
Permissible gross weight	690 kg
Maximum speed	85 km/h
Motor type	Electric - asynchronous
Motor power	13 kW (17 HP)
Type of traction batteries	Lithium-ion
Traction battery capacity	6.1 kWh
Range in the New European Driving Cycle (NEDC)	100 km
CO ₂ emissions	0 g/km
Normalized power consumption (from socket to wheel)	63 Wh/km
On-board charger supply	Socket 230 V

The test period covers 4 years and 6 months of using the vehicle in urban conditions. Due to the cold winters in Poland, the vehicle was not used all year round. Usually the vehicle

was used from the beginning of April to the end of September. Thus, the test period covers five seasons of use of the vehicle in which it covered 30.000 km. During the remaining 6 months of the year in the autumn-winter period the vehicle was not normally used with just a few exceptions.

The first column in Table 2 lists the subsequent years of use of the vehicle. The second column lists the actual mileage of the vehicle in a given year. The third column shows a calculation of the average monthly mileage per 6 months of actual use of the vehicle. The fourth column shows the maximum annual coverage resulting from the battery lease agreement. The fifth column contains the % of battery usage resulting from the subtraction of columns 4 and 2. The number of monthly charges with the assumed value of 50% State of Charge (SoC) is listed in the sixth column. It was calculated on the basis of the average monthly mileage divided by the average range on one charge, 65 km, and multiplied by 2. Column seven lists the amount of electricity consumed per year.

Tab. 2. Data from vehicle use

1	2	3	4	5	6	7
Year	Annual mileage [km]	Monthly mileage [km]	Maximum mileage resulting from the lease contract [km]	Battery usage [%]	Number of monthly charges 50% SoC	Amount of energy consumed per year [kWh]
1	7100	1183	8333	85.2	36	666
2	6800	1133	8333	81.6	35	638
3	8100	1350	8333	97.2	42	760
4	3700	617	7500	49.3	19	347
5	3300	550	7500	44.0	17	310

The analysis of the data shows that during the first 3 years of operation the vehicle was covered at a level of 81.6% to 97.2%. There was no incident of exceeding the maximum annual coverage resulting from the battery lease agreement. If this were to happen, it would be necessary to pay for every additional 100 km. The next two years of operation (years 4 and 5) were periods of a lower intensity of vehicle use. Monthly mileage was about 2 times shorter, which also resulted in less battery load. It is worthwhile focusing on column six. During the entire research period, the car was charged with SoC 50% almost 900 times.

After calculating the total amount of energy consumed during the five seasons of use and covering 30.000 km, it amounted to 2,721 kWh. This value was confirmed by reading the total energy balance value from the Electronic Control Unit of Vehicle using a Bosch KTS diagnostic device. This value was 2.707 kWh. Thus, the assumed average vehicle range on a fully charged battery of 65 km was confirmed. Thus, Renault Twizy requires 9.4 kWh of energy to travel 100 km on average. This value could be used as the basis for further economic analysis.

At any one time, the battery was charged with low power and this manner of charging prevented a significant decrease in the energy capacity of the battery. As stated above,

charging takes place in a slow-charge mode using a 2 kW on-board charger. In the first three years of operation, the vehicle was charged approximately once a day. During the next two years, about once every two days.

3. Research object – 3 kWp photovoltaic carport

A photovoltaic carport was specially designed and made to the purchased Renault Twizy electric vehicle. The photovoltaic carport consists of 12 monocrystalline photovoltaic panels made with glass-glass technology, with each unit having an individual optimizer. The carport has a Schuko electricity socket and is connected to the Sector 4 of Lublin Science and Technology Park (LSTP). This means that when the electric vehicle is not being charged from the carport, it provides energy to the LSTP building. This on-grid approach used to connect the carport to the power grid ensures that the vehicle will be charged in all solar conditions [14]. If the power generated by the carport is not able to supply the power required to charge the electric vehicle, the shortfall will be taken from the power grid. However, if the power generated by the carport is greater than the power consumed by the vehicle, its excess will be transferred to the power grid [19].

The carport research covers the period from the beginning of June 2016 to the end of September 2019. The carport is capable of producing over 3 MWh of electricity annually. Most of the production falls in the spring and summer months, as shown in Figure 2.

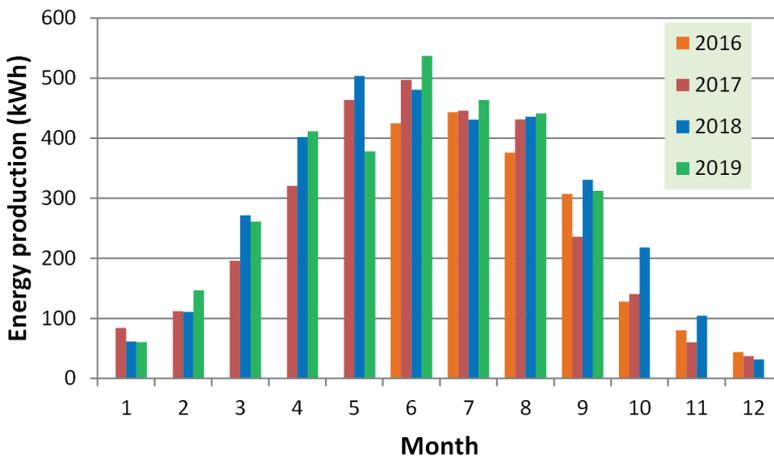


Fig. 2. Energy produced by carport in individual months

Table 3 presents the monthly and daily average values of electricity produced by the carport. The last column lists the number of complete charging cycles for a small electric vehicle. Based on this data, it may be concluded that the average electricity production

in the selected period is approximately 2 times higher than that required to fully charge the electric vehicle (100% SoC). When designing the carport, the power required to charge the electric vehicle was taken into account. Therefore, it may be concluded that by charging the vehicle during the period of the most intense sunshine (between 10.00 and 15.00) it was guaranteed that the full requirements of the photovoltaic carport were met. Since December 2019, two 40 kWp photovoltaic micro-installations have also been operating in the Lublin Science and Technology Park. Therefore, in the absence of full coverage of the power required for charging from the carport, it is supplemented by one of the micro-installations [12]. This is possible because both the carport and micro-installation are connected to one LSTP sector. Since its commissioning in early June 2016 to the end of September 2019, the carport produced about 10.600 kWh of energy. At that time, the vehicle consumed approximately 2.055 kWh, which is 19.4% of the energy produced.

Tab. 3. Average values of energy produced by the carport

	Month energy production [kWh]	Day energy production [kWh]	Day number of full charges
April	378.08	12.60	2.07
May	448.48	14.95	2.45
June	484.73	16.16	2.65
July	445.60	14.85	2.43
August	420.91	14.03	2.30
September	296.77	9.89	1.62

4. Conclusions

The combination of electric vehicle technology with the option of charging them from Renewable Energy Sources is the most ecological way to power vehicles. A photovoltaic carport with a peak power of 3 kWp was used to charge a small electric vehicle. The tests cover 5 spring and summer seasons during which the car was driven a total of 30.000 km.

Long-term testing of the electric vehicle showed that it covered only 3,300 km to 8,100 km annually in urban traffic. This necessitated the recharging of the vehicle by 50% SoC once every two days in the first three years and once a day in the final two years of the test period. An analysis of the data shows that during the first 3 seasons of operation the vehicle was used at a level of 81.6% to 97.2% of the total mileage allowed by the lease agreement. The next two seasons of operation (year 4 and 5) were periods of lower vehicle use intensity with a use rate of 49.3% and 44%. During the entire research period, the car was charged with SoC 50% almost 900 times. Based on an analysis of the amount of electricity produced by the carport during the season of use of the electric vehicle, it may be concluded that the average production of electricity in the selected period is about 2 times higher than that required to fully charge the electric vehicle (100% of SoC). Therefore, when designing the carport, the power required to charge the electric vehicle was correctly forecast.

Since its commissioning in early June 2016 to the end of September 2019, the carport produced about 10.600 kWh of energy. At that time, the vehicle consumed approximately 2.055 kWh, which is 19.4% of the energy produced. The remaining part of energy was completely consumed by the building of the Lublin Science and Technology Park.

5. Nomenclature

EV	Electric Vehicle
BEV	Battery Electric Vehicle
GVW	Gross Vehicle Weight
HEV	Hybrid Electric Vehicle
LSTP	Lublin Science and Technology Park
SoC	State of Charge

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