U.P.B. Sci. Bull., Series C, Vol. 77, Iss. 1, 2015 ISSN 2286 – 3540

# SOLAR ENERGY EXPLOITATION FOR CHARGING VEHICLES

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*The increasing deployment of electrically powered vehicles needs to be supported by strong technological development in charging infrastructure. The aim of this research is to examine the possibilities and benefits that may be derived from the technological solution, in which a photovoltaic power generation system is integrated with traditional charging points. The analysis takes into consideration energy-related aspects linked to solar source production, modeled through suitable mathematical functions, and absorption by charging vehicles and evaluates the technical sustainability of the project. Different scenarios are analyzed in terms of production profiles and energy. Lastly, the results obtained enable a comparison to be drawn with other currently available technologies.*

**Keywords**: electric vehicles, charging infrastructure, photovoltaic energy

## 1. Introduction

Recently, EU countries have been trying to further assist the development of electric mobility, which has seen strong growth following the increase in fuel costs, more stringent standards in terms of exhaust emissions and new technological innovations in the field of batteries. However, the establishment of these cars is only possible with a strong development in the field of recharging infrastructure [1], which must be widespread and able to meet the different needs of users [2]. It is also true that the increase of PEVs will impact on the grid and on the need for electricity. However, the biggest environmental impact from the Modern Grid will be the ability to integrate renewable energy resources (RES) and electric vehicles into the grid with ease [3].

Some papers deals with the integration of renewable energy sources, like solar and wind [4], [5], in the charging system for electric vehicles. Moreover, other sources can be considered for charging electric vehicles. In the metropolitan

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areas, braking energy coming from the urban transportation systems can be exploited for the electric vehicles charge [6].

Therefore, in this paper we analyse the benefits of integrating a PV carport in the charging station. Furthermore, among the main problems for electric vehicles is to find a suitable time for charging. Since most cars used for work purposes remain parked during the day, a possible idea could be to charge PEVs during work hours. The following paper focuses on issues regarding charging infrastructure for commuters with access to parking garages at their workplace. The large availability of space, the excellent exposure to solar radiation and the reduced presence of shading [7] in the outdoor parking justifies the idea of development of a photovoltaic carport in replacement of the traditional shelter. However, the overall efficiency of renewable energy systems requires a high level of optimization of their components [8]. The efficient exploitation of non-programmable renewable sources is also related to the accuracy in the forecasting of their production [9]. Finally, the load profile depends on several variables that can be assumed to be stochastically distributed, including actual state-of-charge of the battery, parking duration, parking type, and vehicle powertrain [10]. A statistical approach based on measurements campaign is useful to improve the accuracy in load profile predictions [11].

In this work a PV charging system has been analysed. First, the estimation of the production from photovoltaic shelter based on a statistical approach is presented and is applied in the specific area (Milan). The production results

The results of the production have been used in order to evaluate the energy flows within a charging system for two electric vehicles consisting of a grid-connected photovoltaic carport.

## 2. Estimation of the production photovoltaic shelter

In this section, the amount of energy producible by PV shelter has been estimated. For the analysis of production, different scenarios are considered. It was taken as a reference the city of Milan and several orientations of the photovoltaic shelter (tilt angle [°] and the azimuth angle [°]) have been analyzed.

Table 1 shows the values used for the analysis.

*Table 1*

**Values utilized (tilt and azimuth) for analysis**

| Azimuth angle [°] | 0 | ±10 | ±20 | ±30 | ±40 | ±50 | ±60 | ±70 | ±80 | ±90 |
|---|---|---|---|---|---|---|---|---|---|---|
| Tilt angle [°] | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
| | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | | |

The data used to produce the estimates of production of the PV system were mined from the database of the software Photovoltaic Geographical

Information System (PVGIS), developed by the Joint Research Centre, a Directorate General of the European Commission [12], [13]. This data returned by the program are based on a climatic database consists of surveys conducted in ten years, between 2000 and 2009. The analysis of production is carried out initially on a monthly basis, and subsequently extended on an annual basis in order to determine the amount of energy available from the photovoltaic shelter.
The data required by the program are:

- The coordinates of the site (Milan): 45°27’ North, 9°11’ East;
- Peak PV power: 1 kWp. This choice is the base value that allows to easily extend the results to PV systems of any peak power.
- Mounting position: free-standing;
- Estimated system losses: 14%;
- Azimuth and Tilt angles are reported in table 1;
- PV technology: crystalline silicon, CIS, CdTe and thin film.

The outputs of the program are:

- *E*d: Average daily electricity production from the given system (kWh)
- *E*m: Average monthly electricity production from the given system (kWh)
- *H*d: Average daily sum of global irradiation per square meter received by the modules of the given system (kWh/m$^2$)
- *H*m: Average sum of global irradiation per square meter received by the modules of the given system (kWh/m$^2$)

Fig 1 shows the main effects plot of *E*d (kWh) for crystalline silicon technology. It can be noted that the maximum production occurs in the month of July, identified by the number 7. The pairs of tilt and azimuth that maximize the energy production are in the neighborhood of 30° and 0°, respectively.

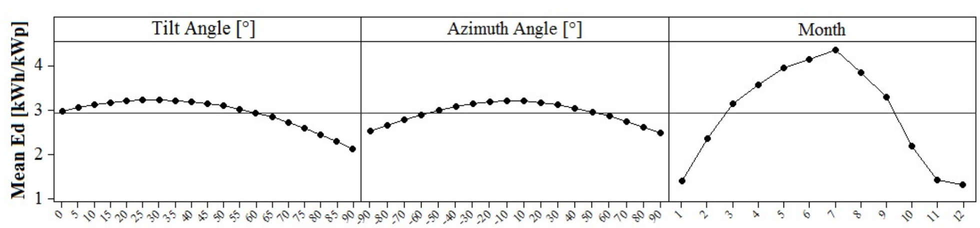


Fig. 1. Main effects Plot of Ed [kWh] for crystalline silicon cells

For each PV technology and for each month, a mathematical law (1) was obtained:

$$E_{(d,m)} = K_{(1,m)}T^2 + K_{(2,m)},A^2 + K_{(3,m)}T + K_{(4,m)} \qquad \forall m \qquad (1)$$

where $m$ is month, $T$ is the tilt in degrees, $A$ is the azimuth in degrees and $K_{1,m}$, $K_{2,m}$, $K_{3,m}$ and $K_{4,m}$ are the coefficients.

Fig. 2 reports the values of coefficients for each PV technology:

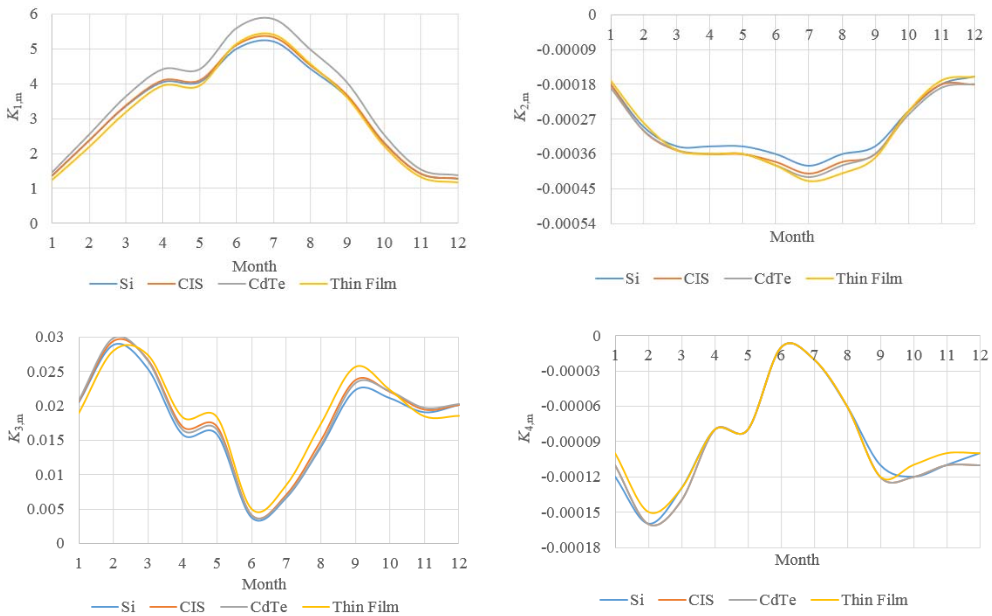


Fig. 2. Graphical representation of the different coefficients for PV technology

It is possible to observe that for all PV technologies there is a small difference between the coefficients. Then, a generic mathematical equation (2) applicable to any type of PV technologies that allows to calculate $E_d(m)$ as a function of the month is calculated.

$$
\begin{aligned}
Ed(m) = &\left(0.0028 \cdot m^4 - 0.0711 \cdot m^3 + 0.485 \cdot m^2 - 0.484 \cdot m + 1.29\right) + \\
&+\left(-4E^{-5} \cdot m^4 + 0.0011 \cdot m^3 - 0.0088 \cdot m^2 + 0.0245 \cdot m + 3E^{-4}\right) \cdot T + \left(-2E^{-8} \cdot m^4 + 5E^{-0.7} \cdot m^3 + \right. \\
&\left. +3E^{-0.6} \cdot m^2 - 7E^{-5} \cdot m - 9E^{-6}\right) \cdot T^2 + \left(2E^{-7} \cdot m^4 - 5E^{-6} \cdot m^3 + 5E^{-5} \cdot m^2 - 1E^{-5} \cdot m + 5E^{-6}\right) \cdot A^2
\end{aligned} \quad (2)
$$

### 3. Description of the charging system

The charging system analyzed in this work is composed of charge point for two plug-in electrical vehicles (PEVs) that can be supplied from the grid and/or from the photovoltaic generator installed on the shelter [14], [15], [16]. The interaction of the photovoltaic shelter with the other elements of the charging system is illustrated in Fig 3.

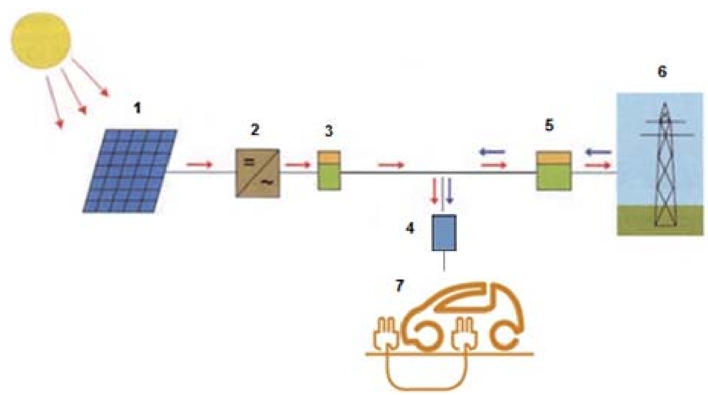


Fig. 3. Diagram of the charging system: (1) Photovoltaic generator; (2) Inverter; (3) Energy meter; (4). Charging point; (5) Bidirectional energy meter; (6) Electric grid; (7) Electric vehicle

The photovoltaic shelter is designed for two electric vehicle and takes up an area of about 25 m² and its PV generator consists of 15 monocrystalline photovoltaic modules for a total power of 3675 Wp.

**4. Study cases**

The evaluation of the energy required for the charge of two electric vehicles for day is carried out. In this work, two electric vehicles are taken: the car (with battery capacity of 24 kWh) and the quadricycle (with capacity of 9 kWh). Charging power has been assumed constant throughout the charging period.

The annual most energy-consuming demand consists of two cars, based on the medium distance travelled annually in Italy, and it is similar to the PV production from the carport. In the worst condition at most 30% energy have to be absorbed from the grid.

However, there is a limit to the annual analysis, which regards the non coordinability between the production curve (bell-shaped and fixed to the climatic conditions) and the load curve (constant power and whose position throughout the day depends on the user's needs). To assess in detail the potential of PV charging stations, it is necessary to carry out the comparison between power curves. Fig. 4 gives an example of the coupling of the power curves (in this case two cars are being charged at the same time, at different charging powers) and the energy flows are highlighted. Many parameters influence the shape of the power curves; the present study takes into account more than 9000 different scenarios.

The study is divided in two main scenarios [17]:

- Contemporary charging of vehicles: charging begins on arrival at work, at 9 am.

- Sequential charging of vehicles: it is hypothesized that the company organizes shifts for charging PEVs, one that starts at 9 am and one at 1:30 pm.

Each scenario considers:

- Three combinations of PEVs: two cars, a car and a quadricycle, two quadricycles.
- The energy that must be provided to the vehicles will depend on the difference between the initial and final states of charge of the battery (ΔSOC). For each of the above scenarios we will consider three values of ΔSOC: 0.6, 0.4, 0.2.
- Different values of charging power: 3.7 kW, 7 kW, 11 kW and 22 kW. However, current available models of quadricycles cannot be charged with power exceeding 3.7 kW; in light of this condition, which the number of scenarios in the combination of two quads is reduced. Only for this case, ΔSOC of 0.5 and 0.3 will be considered.

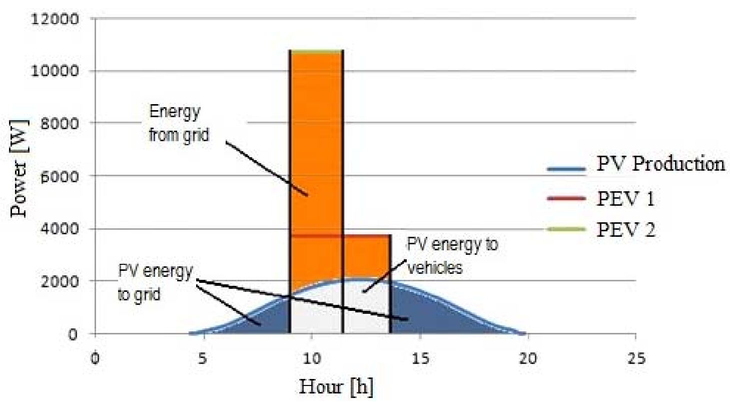


Fig. 4. Example of the non coordinability of the production curve and absorption curve

### 5. Discussion of results

The most significant results of this work is the percentage of energy coming from the PV system to the electric vehicles with respect to the energy required by the charging point.

The results on monthly and annual basis are highly variable depending on the scenario considered, ranging from a maximum of 56-72% to a minimum of 1-3%. The sequential charging allows an energy flow from PV system to the electric vehicle higher than the simultaneous charging, with an average increase between 10 and 15 percentage points. The combination of two quadricycles shows the greater advantage in changing from the simultaneous charging to the sequential charging. The reduced energy demand and the short charge times during the hours when the photovoltaic production is low allow a small energy flow from PV system to the electric vehicle. Sequential charge moves one of the two charge in the time slot that starts at 13:30 that is characterized by high photovoltaic production.

For both charging scenario, the more favorable combination of electric vehicles that maximize the energy flow from PV system to the electric vehicle is the combination of car and quadricycle, ΔSOC maximum and minimum recharge power. On the contrary, the worst case in terms of energy flow from PV system to the electric vehicle is the combination of two cars and maximum charging power, equal to 22 kW. It is evident that, by requiring highest power charging, most of the energy has to be absorbed from the grid. To maximize the energy flow from PV system to electric vehicle, the power of the charge has to be limited and the load curve has to be moved in the hours when production of the photovoltaic shelter is high. This is possible if there are no time constraints, as during the working hours in office. It can also be noted that the minimum percentage of supplied energy is very low, highlighting the need for energy storage, in this case consisting of the grid.

## 6. Conclusions

The aim of research is to investigate the potential and the technical benefits of photovoltaic charging systems in the context of electric mobility, in terms of energy supply.

Suitable mathematical functions have been developed to estimate the energy production from PV systems. The coefficients of the equations have been obtained by taking as reference the climatic conditions typical of the North Italy (Milan) and allow to evaluate the energy production as a function of tilt, azimuth and month. The photovoltaic system analyzed in this work is a solar carport combined with a charging system for two electric cars. The aspects linked to the energy flows, considering the production of PV system, the absorption by charging vehicles and the imported and exported energy to the utility grid are evaluated, highlighting the technical sustainability of the project.

Different scenarios are analyzed in terms of absorption profiles and energy. The most significant results of this work is the percentage of energy coming from the PV system to the electric vehicles with respect to the energy required by the charging point, that ranges from 1-3% to 56-72%. Moreover, the energy flows strongly depends on month.

The maximization of the energy flow from PV system to electric vehicle requires quite long and low power charges that allow exploiting the hours when production of the photovoltaic shelter is high. However, an energy storage system is necessary.

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