Design of a Solar Charging Station for Electric Vehicles in Shopping Malls By C Peña & M Céspedes

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Abstract

In this article, we present the design, sizing and modeling of a grid-connected solar charging station for recharging electric vehicles in shopping malls. The applied method consists of an analysis of the solar resource available at the location of the shopping mall, as well as the analysis, evaluation and selection of the components of the grid-connected photovoltaic system with the support of simulation software such as PVsyst and Helioscope, as well as analysis, evaluation and selection of the components of the charging points of electric vehicles and finally the economic analysis of the solar charging station in the shopping mall.

Index terms—

1 Introduction

Here are two alternatives to mitigate greenhouse gas emissions, the first is the electrification of transport and the second is the generation of electricity using renewable energy.

For electric mobility to be successful, it is necessary that the used energy comes from renewable energies such as solar, wind or biomass.

This article proposes the design of a solar charging station for electric vehicles in shopping malls. Which consists of the dimensioning of a grid-connected photovoltaic system and analysis, evaluation and selection of the charging components for electric vehicles.

In this sense, one of the ways to charge the energy of the batteries of electric vehicles is to use the recharging points that the shopping mall install in their parking lots, all this while users come to make purchases or spend their leisure time in the malls.

2 Methodology a) Background i. Current situation of electric vehicles

Currently the battery of new versions of electric vehicles has a capacity that varies between 38 and 64 kWh, except for high-end cars such as the Taycan by Porsche and the Model S by Tesla, whose capacity varies between 70 and 100 kWh. In most electric cars the internal charger is 7.2 kW except for Tesla which is 10 kW. Figure 1 shows the electric vehicle charging system [1]. In Spain, the SIRVE project (Integrated Systems for Recharging Electric Vehicles) was developed, the objective of which is to desaturate the electrical network in LV, if the aggregate demand for fast charging and moderate charging systems exceeds the capacity of the line or of the transformation malls from which it is supplying. The SIRVE project is made up of a 1kWp photovoltaic system, which provides power to the 30 kWh lithium batteries. [2] In 2017, Shanghai launched its first solarpowered charging station for electric vehicles as a test. It is made up of 40 solar panels on the roof of the building. In addition, it had backup batteries and was connected to the electrical network. In half an hour with fast charge the battery was charged with 70% and around two hours to completely fill the electric vehicle. [3] b) Descriptive memory i. Description of the study area For the study analysis of the project, the ”Molina Plaza” shopping mall was selected, located in the La Molina district, Lima, Peru.
The Molina Plaza shopping mall was selected for two reasons. The first is that it is located in an area of considerable solar radiation during the year. According to the Global Solar Atlas, the specific output photovoltaic energy is 1435 kWh/kWp \[4\]. The second reason is because the residents of the district have enough purchasing power to buy electric vehicles. The optimal inclination is determined using the following formula:

\[ \theta = 3.7 + 0.69 \theta \] (1) Where: \( \theta \): optimal tilt angle in degrees, \( \phi \): latitude of unsigned place in degrees.

The optimal inclination of the photovoltaic modules is approximately 12°, using NASA’s Power Data Access Viewer application the monthly global mean irradiation on a surface tilted at its optimal angle, facing north. The month that has the least irradiation according to the previous table, is the month of July \[5\] \[6\]. If the irradiance is considered equal to 1000 W/m², then the peak solar hours \(HSP\) equals 4.24 h.

4 ii. Calculation of the energy consumed by charging electric vehicles

To calculate the energy consumed, the following should be considered:

- Eight Wallbox chargers \[7\] 11 kW are being taken into account for charging electric vehicles.
- According to Table 2, the average battery capacity per 1 hour of charge is equivalent to 8 kWh. Thus, if the charging time is 1 hour, 8 vehicles can be charged simultaneously every hour. The energy consumed from 9:00 a.m. until 06:00 p.m. is 576 kWh, while the energy consumed from 06:00 p.m. until 09:00 p.m. is 192 kWh.
- The grid-connected photovoltaic system will be dimensioned to provide 50% of the energy consumed during 09:00 a.m. until 06:00 p.m. which is equivalent to 288 kWh. The chargers will be available from 09:00 a.m. until 09:00 p.m. Being 12 hours the available time considering the 37.5% supplied by the photovoltaic system and 62.5% by the electrical network.
- The energy consumed during the day is estimated to be 768 kWh. If the charging time increases and considering the number of cars constant for the respective charging time (1, 2, 3 or 4), the energy consumed is the same, the only thing that changes is the number of cars supplied per day. iii. Calculation of the power of the photovoltaic generator

The power of the photovoltaic generator is determined using the following formula:

\[ \text{PV generator power in W} = \text{Daily energy consumption for the calculation of the PV generator in kWh, which is equivalent to 288 kWh.} \]

\( \theta \): Peak solar hours in h, which equals 4.24 h. \( \phi \): Energy performance of the installation, which is equivalent to 80%. 03 photovoltaic generators will be required whose power amounts to 31415.09 Wp. Considering 330 Wp polycrystalline photovoltaic modules, from the manufacturer Amerisolar \[8\]. Thus, the power of each real photovoltaic generator is 31350 Wp. Each one will be made up of 95 photovoltaic modules, distributed in 5 chains of 19330 Wp polycrystalline photovoltaic modules.

5 iv. Selection of grid interconnect inverters

Each photovoltaic generator will be connected to a grid interconnection inverter \[9\]. The following parameters must be taken into account when selecting the Inverter:

- Inverter nominal power, must be between 80% and 90% of the power of the photovoltaic generator.

\[ \text{Inverter power in W} = 0.8 \times 0.9 \times \text{Photovoltaic generator power in Wp}\]

Where: \( \theta \): Inverter power in W, \( \theta \): Photovoltaic generator power in Wp.

? Inverter MPP follower voltage range \((U_{\text{inv.min}} - U_{\text{inv.max}})\): This range must contain the maximum and minimum values that the photovoltaic generator can supply at the point of maximum power specified for a cell temperature of -10° C and 70° C respectively. \( \theta \): Voltage coefficient -module temperature \((V/°C)\).

\[ \theta \] : Number of panels in series.

7 ???:

Voltage coefficient -module temperature \((V/°C)\). ??:

Temperature \((°C)\).
8 Inverter maximum voltage (U máx. vacío.):

The inverter must withstand the maximum voltage that the open-circuit photovoltaic generator can produce with a cell temperature of -10° C and an irradiance of 1000 W/m². The formula to determine this is:

\[ U_{\text{máx. vacío.}} = 1.5 \times U_{\text{máx. vacío. 70°C}} \times \left(1 - \frac{T - 25}{30}ight) \]

Where: \( T_{\text{70°C}} \) is the temperature of the photovoltaic generator in vacuum (V) at a certain temperature.

9 Maximum intensity (I inv. máx.):

The inverter must withstand the short-circuit current of the generator with a cell temperature of 70 °C and an irradiance of 1000 W/m². The formula to determine this is:

\[ I_{\text{inv. máx.}} = 1.2 \times I_{\text{máx. vacío. 70°C}} \times \frac{T - 25}{30} \]

Where: \( I_{\text{máx. vacío. 70°C}} \) is the short circuit current intensity of the photovoltaic module (A) or string at standard measurement conditions. ?? ?? ;

Parallel panel chain number.

10 ??:

Current coefficient -module temperature (A/°C).

11 ??:

Temperature (°C).

Taking into account the above, 03 three-phase inverters for grid interconnection of 27 kW -380/220 VAC, from the Fronius brand [10] with their respective Smart Meter 50kA-3 are selected. The fuse rating is determined with the following formula:

\[ I_{\text{fusible}} = 1.2 \times I_{\text{máx. vacío. 70°C}} \times \frac{T - 25}{30} \]

Where: \( I_{\text{máx. vacío. 70°C}} \) is the short circuit current intensity of the photovoltaic module (A) or string at standard measurement conditions. ?? ?? ;

It is the current intensity (A) that the fuse supports.

The assigned voltage is determined with the following formula:

\[ V_{\text{fusible}} = 1.2 \times V_{\text{máx. vacío. 70°C}} \times \frac{T - 25}{30} \]

Where: \( V_{\text{máx. vacío. 70°C}} \) is the voltage of the photovoltaic generator in vacuum (V). ?? ?? ;

It is the assigned voltage (V) that the fuse supports.

In the string box, for each chain there must be two 16 A (gR) fuses with a rated voltage of 1000 VDC cylindrical 10 x 38 mm. One will be connected to the positive pole and the other to the negative pole of each chain.

Investor Protection: A thermomagnetic switch will be placed at the output of each inverter, having to meet the output characteristics of the inverter.:

? Nominal intensity: \( I_n = 48.26 \) A ? Nominal working voltage: \( U_n = 380 \) VAC Wallbox charger protection:

A thermomagnetic switch will be placed in each circuit of each 11 kW Wallbox charger.:

? Nominal intensity: \( I_n = 19.66 \) A ? Nominal working voltage: \( U_n = 380 \) VAC vi. Network connection For the connection of the electric chargers and the grid interconnection inverters, a new MV power supply (10 kV or 22.9 kV) and a new primary network will be necessary. The conventional three-phase substation must have a 230 kVA encapsulated dry transformer -10-22.9 / 0.38-0.22 kV.

For the analysis, the inverters are considered as a load, and a power factor of 0.85. With the data in Table 6 and 10, the annual energy produced by the grid-connected photovoltaic system is calculated. Which amounts to 142705 kWh.

The plant factor is 17.32%. According to the Global Solar Atlas [11], the energy produced is 135675 kWh and the specific production 1443 kWh / kWp. The solar charging station will be available from 09:00 a.m. until 09:00 p.m. Being a total period of 12 hours. The energy produced by the photovoltaic system during the first hours of the morning may be used for other uses such as refrigeration, ventilation or any other auxiliary circuit.

With the information obtained from the report generated by the Global Solar Atlas. The energy produced by the photovoltaic system in the early hours of the day destined for others would be

\[ \text{Energy Produced} = \frac{135675 \times 12}{12} \]

\[ = 135675 \text{kWh} \]

Perform the simulation in the PVsyst software, the Typical Meteorological Year (TMY) was selected, which the software obtains from the PVGIS platform data. The PVGIS platform works with the 2005-2015 database, provided by the National Renewable Energy Laboratory (NREL). The main parameters of the system and the main results of the simulation with the PVsyst software are as follows: ii. Simulation with Helioscope software The Helioscope software performs the simulation with the Typical Meteorological Year (TMY), which it obtains from the data from Meteonorm. In addition, it distributes the photovoltaic modules on the roof of the Molina Plaza shopping mall. To perform the investment valuation, it was necessary to determine the FC (Cash Flow). For this, it is necessary to determine the net operating flow, thus we consider the following parameters: Once the net operating flow has been determined, the net financial flow of the project is determined.
For this project, the NPV is: S 161113.86, which indicates that the project is financially viable since the NPV is > 0.

### 12 Volume

In this case the IRR is 10.04%, compared to the discount rate, it is feasible to invest in a project under these conditions.

It is evident that the PRI period of time to recover the investment is up to about 8 years, which determines that it would make viable the start-up of the project under the proposed scenario.

### 13 III.

### 14 Conclusions

? The project is economically viable, as the NPV and IRR are viable, and the return on investment time is around 8 years. ? The project is technically feasible, current technology would allow this project to be carried out. ? With this project, 1111.35 tCO2 would no longer be emitted, contributing to the environment and demonstrating that the use of renewable energy is the solution to environmental pollution. ? According to the simulations and calculations, the proposed objectives will be able to meet. More than 50% of the energy consumed by the charge of electric vehicles would be covered during the hours of 9:00 am -6:00 pm. ? Interconnection inverters will be configured so that they do not inject energy into the public grid and are only used for self-consumption. ? The interconnect inverter will stop working if there is a grid disconnection. It is because the inverter needs to be synchronized with the frequency of the public electrical network. ? In order for the grid interconnection inverters to work with a backup system such as a generator set in the event of a disconnection from the public grid. It is recommended to make a modification and change the Smart Meter 50kA-3, for a Fronius PV system controller with its two accessories to optimize the operation of the photovoltaic system with the

![Figure 1: Figure 1](image1)

![Figure 2: Figure 2](image2)
Figure 3: Figure 3:

Figure 4: Figure 4:
1

| Brand and model                  | Battery capacity for one hour of charge (kWh) | Autonomy for one hour of charge (km) |
|----------------------------------|-----------------------------------------------|-------------------------------------|
| Hyundai Ioniq Eléctrico          | 7.2                                           | 55.08                               |
| Kia eSoul Eléctrico              | 7.2                                           | 50.88                               |
| Kia eSoul Standard               | 7.2                                           | 50.85                               |
| Kia eSoul Autonomía Extendida    | 7.2                                           | 44.55                               |
| Nissan Leaf S                    | 6.6                                           | 40.98                               |
| Nissan Leaf S Plus               | 6.6                                           | 46.28                               |
| BYD E5-400                       | 9.6                                           | 49.33                               |
| Porsche Taycan 4S                | 9.6                                           | 46.25                               |
| Porsche Taycan Turbo             | 10                                            | 56.00                               |
| Tesla Model S -Performance       | 8.00                                          | 49.00                               |
| Average                          |                                               |                                     |

Figure 7: Table 1:

2

ii. Current situation of charging stations with renewable energies

Figure 8: Table 2:
Encourage and spread the use of renewable energy for electrified transport.

Point 3) Memory of Justifying Calculations

i. Solar irradiation

With geographic coordinates and using NASA’s Power Data Access Viewer application.

ii. Objectives

Dimension the grid-connected photovoltaic system to provide 50% of the energy needed by electric vehicle batteries during the hours that the solar resource is available.

Figure 9: Table 3 : Table 4 :

Jan. Feb. Mar. Apr. May. Jun. Jul. Aug. Sep. Oct. Nov. Dec.

Hor. global

| Jan  | Feb  | Mar  | Apr  | May  | Jun  | Jul  | Aug  | Sep  | Oct  | Nov  | Dec  |
|------|------|------|------|------|------|------|------|------|------|------|------|
| 6.48 | 6.32 | 6.72 | 6.17 | 5.04 | 3.86 | 3.73 | 4.09 | 4.83 | 5.84 | 6.31 | 6.52 |

Figure 10: Table 5 :

Global Average Monthly Irradiation in a 12° angle

| Jan  | Feb  | Mar  | Apr  | May  | Jun  | Jul  | Aug  | Sep  | Oct  | Nov  | Dec  |
|------|------|------|------|------|------|------|------|------|------|------|------|
| 6.63 | 6.33 | 6.79 | 6.62 | 5.87 | 4.53 | 4.24 | 4.37 | 4.90 | 5.84 | 6.41 | 6.72 |

Figure 11: Table 6 :

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### Technical specifications  Wallbox charger

| Specification                  | Details                                      |
|-------------------------------|----------------------------------------------|
| Brand and model               | EV Box                                       |
| Charging mode                 | Mode 3                                       |
| Connector load capacity       | 11 kW                                        |
| Number of connectors          | 1                                            |
| CE certification              | Yes                                          |
| Output values                 | 1 phase o 3 phases, 230 V -400 V, 16 A -32 A |
| Temperature range             | Since -25°C until 60°C                       |
| Cable length                  | 4 m.                                         |
| RH                            | 0.95                                         |
| Activation / Identification   | Automatic start / card or keychain RFID       |
| Status indicator              | Ring LED                                     |

Figure 13: Table 8:

### Table 9:

| Type                        |
|-----------------------------|
| Policristalino              |

| Power                       |
|-----------------------------|
| 330 Wp                      |

| Imp                         |
|-----------------------------|
| 8.85 A                      |

| Vmp                         |
|-----------------------------|
| 37.3 V                      |

Figure 14: Table 9:

### Technical characteristics of the photovoltaic generator

| Generator power PV          |
|-----------------------------|
| 31350 Wp                    |

| Module power PV             |
|-----------------------------|
| 330 Wp                      |

| Number of chains            |
|-----------------------------|
| 5                           |

| Number of PV modules, by serie |
|--------------------------------|
| 19                             |

| Number of PV modules         |
|-----------------------------|
| 95                           |

| Isc, by chain                |
|-----------------------------|
| 9.26 A                      |

| Voc , by chain               |
|-----------------------------|
| 872.10 V                    |

Figure 15: Table 10:

### Table 11:

| Inverter power               |
|------------------------------|
| 25080 ? 28215 W              |

| Minimum value of the MPP voltage range |
|----------------------------------------|
| 587.10 V                               |

| Maximum value of MPP voltage range     |
|----------------------------------------|
| 803.32 V                               |

| Maximum no-load voltage               |
|----------------------------------------|
| 966.72 V                               |

| Maximum intensity                    |
|----------------------------------------|
| 47.35 A                                |

Figure 16: Table 11:
Main technical specifications of the inverter
Brand and model: Fronius Eco 27.0-3-S
Inverter power: 27 kW
MPP voltage range (Ucc min -Ucc max.): 580 V -850V
Maximum no-load voltage: 1000 V
Maximum PV input intensity: 47.7 A
Maximum short-circuit current per PV series: 71.6 A
Number of MPP followers: 1
Number of DC inputs: 6
Maximum PV generator output: 37.8 kWp
Link to the network: 3~NPE 400/230, 3~NPE 380/220 V
Frequency: 50/60 Hz
Nominal output current at 400 V: 39 A

v. Selection of protection devices
PV generator protection: For each photovoltaic generator, 1 string box will be installed to connect 5 chains in parallel with 19 photovoltaic modules connected in series. Each string box must have at least 10 cylindrical rifle bases for 10 x 38 mm fuses.

Figure 17: Table 12:

| Load                                | Load chart                                                                 |
|-------------------------------------|---------------------------------------------------------------------------|
| Grid connection inverter - de 27 kW. 380/220 V- | Pot. unit total (kW) | I. currents total (A) | Quantity (Un d.) | I. current total (kW) | Pot. transformer (kVA) |
| Fronius Wallbox charger 11Kw - 380/220 V | 27 | 48.26 | 3 | 81 | 144.78 |
| Street lighting luminaires          | 0.07 | 0.00040 | 8 | 0.56 | 0.0032 |
| Total                              | 169.56 | 302.0632 | 250 |

d) Estimated annual energy produced per year

Figure 18: Table 13:
### Table 14:

| Month     | Monthly energy (kWh) |
|-----------|----------------------|
| January   | 13932                |
| February  | 12014                |
| March     | 14268                |
| April     | 13462                |
| May       | 12335                |
| June      | 9212                 |
| July      | 8910                 |
| August    | 9183                 |
| September | 9964                 |
| October   | 12272                |
| November  | 13035                |
| December  | 14121                |
| Annual    | 142708               |

### Table 15:

| Period | Energy produced (kWh) | Emission factor (t CO₂ /MWh) | CO₂ emissions (t CO₂) |
|--------|-----------------------|-----------------------------|-----------------------|
| 1      | 142708                | 0.4082                      | 58.25                 |
| 2      | 141994                | 0.4082                      | 57.96                 |
| 3      | 141284                | 0.4082                      | 57.67                 |
| 4      | 140578                | 0.4082                      | 57.38                 |
| 5      | 139875                | 0.4082                      | 57.10                 |
| 6      | 139176                | 0.4082                      | 56.81                 |
| 7      | 138480                | 0.4082                      | 56.53                 |
| 8      | 137788                | 0.4082                      | 56.25                 |
| 9      | 137099                | 0.4082                      | 55.96                 |
| 10     | 136413                | 0.4082                      | 55.68                 |
| 11     | 135731                | 0.4082                      | 55.41                 |
| 12     | 135052                | 0.4082                      | 55.13                 |
| 13     | 134377                | 0.4082                      | 54.85                 |
| 14     | 133705                | 0.4082                      | 54.58                 |
| 15     | 133037                | 0.4082                      | 54.31                 |
| 16     | 132372                | 0.4082                      | 54.03                 |
| 17     | 131710                | 0.4082                      | 53.76                 |
| 18     | 131051                | 0.4082                      | 53.50                 |
| 19     | 130396                | 0.4082                      | 53.23                 |
| 20     | 129744                | 0.4082                      | 52.96                 |
| Total  |                      |                             | 1111.35               |

f) Simulation with PVsyst software and Helioscope
i. Simulation with the software PVsyst
Main parameters for the PVsyst simulation
PV field orientation and inclination  Azimuth 0° y 12° tilt
PV modules  Model AS6P33-330 Pnom.330 Wp
PV set  285 modules Pnom total 94.05 kWp
Investor  Model Fronius Eco 27.0-3-S
Amount of Investors  3 units Pnom. Total 81 kW AC

Figure 21: Table 16:

Energy produced  138.3 MWh/year
Specific production  1471 kWh/kWp/year
Performance index (PR)  86.58%

Figure 22: Table 17:

Energy produced  144.4 MWh/year
Specific Production  1535.5 kWh/kWp/year
Performance Index (PR)  78.2%
Investors  3 Fronius Eco 27.0-3-S. Total 81 kW AC
Chains  15
PV modules  285, Amerisolar, AS-6P-330. Total 94.1 kWp

Figure 23: Table 18:

| Ítem                  | Detalle                          | Total          |
|-----------------------|----------------------------------|----------------|
| A                     | Suministro de materiales         | 563693.93      |
| B                     | Montaje electromecánico          | 121329.17      |
| C                     | Gastos adicionales aproximados   | 28252.20       |
| D                     | Gastos administrativos           | 34870.00       |
|                       | Total                            | S/. 748145.30  |

h) Economic evaluation

Figure 24: Table 20:
### Parameters

| Item | Detail                           | Total               |
|------|----------------------------------|---------------------|
| r    | Discount rate                    | 7.5%                |
| d    | Degradation rate                 | 0.5%                |
| e    | Energy cost as a free client     | 0.1510 S./kWh       |
| i    | Rate of inflation                | 2.0 %               |
| s    | Hourly rental price of each parking space | 2.54 soles     |
| p    | Project period                   | 20 years            |

Figure 25: Table 21:

### Values

| Item | Detail                             | Total               |
|------|------------------------------------|---------------------|
| NPV  | Net present value                  | S/. 161113.86       |
| IRR  | Internal rate of return            | 10.04%              |
| PRI  | Return on investment period        | 8 years             |

Figure 26: Table 22:
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