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 electro 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 II.

3 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:

?? ?????? = 3.7 + 0.69?? (1) Where: ?? ?????? : optimal tilt angle in degrees. ?? ? 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/m 2 , 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:?? ?? = 1.11 ?? ?? ??????. ????**(2)**

Where: ?? ?? ?Photovoltaic generator power in Wp. ?? ?? ? Daily energy consumption for the calculation of the PV generator in kWh, which is equivalent to 288 kWh.

??????: Peak solar hours in h, which equals 4.24 h. ???? ? 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.

?? ?????? = 0.8 ? 0.9 ?? ??

Where: ?? ?????? ? Inverter power in W. ?? ?? ? Photovoltaic generator power in Wp.

? Inverter MPP follower voltage range(U inv.min ? U inv.

6 máx.):

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(?? ???????? (70°??) y ?? ???????? (?10°??)).In both cases with an irradiance of 1000 W/m 2 . ?? ??????.??í?? ? ?? ???????? (????°??) (4)?? ???????? (70°??) = ?? ?? . ?? ?????? (70°??) (**5**)?? ?????? (70°??) = ?? ?????? + ?? . (?? ? 25) (**6**)?? ??????.??á?? ? ?? ???????? (?????°??) (**7**)?? ???????? (?10°??) = ?? ?? . ?? ?????? (?10°??) (**8**)?? ?????? (?10°??) = ?? ?????? + ?? . (?? ? 25)**(9)**

Where: ?? ???????? : Voltage of the photovoltaic generator at its maximum power point (V) at a certain temperature. ?? ?????? : Voltage of the photovoltaic module at its maximum power point (V) at standard measurement conditions. ?? ?? : 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/m 2 .?? ??á?? .?????? í?? ? ?? ?????? (?10°??) (**10**)?? ?????? (?10°??) = ?? ?? . ?? ?????? (?10°??)(**11**)?? ???? (?10°??) = ?? ???? + ?? . (?? ? 25)(**12**)

Where: ?? ?????? : It is the voltage 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 / m 2 . ?? ??á?? .?????? í?? ? ?? ?????? (?10°??) (13)?? ?????? (70°??) = ?? ?? . ?? ???? (70°??) (14) ?? ???? (70°??) = ?? ???? + ? . (?? ? 25)(**15**)

Where: ?? ?????? : It is the maximum short-circuit current intensity of the photovoltaic generator in (A) at a given temperature. ?? ???? :

It 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:?? ?? = 1.5 ? 2?? ????(**16**)

Where: ?? ???? : It 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:?? ?? ? 1.2 ?? ???????(**17**)

Where: ?? ??????? : It is the voltage of the photovoltaic generator in vacuum (V). ?? ?? : It is the rated 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 250 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 14666 kWh per year. According to the Peruvian Ministry of Energy and Mines, the emission reduction factor [12] for 2016 is 0.4082 tCO 2 /MWh. They consider a degradation factor of 0.5% of the photovoltaic modules. It is estimated that 1111.33 tCO 2 would no longer be emitted. To 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 [1] [2]

1

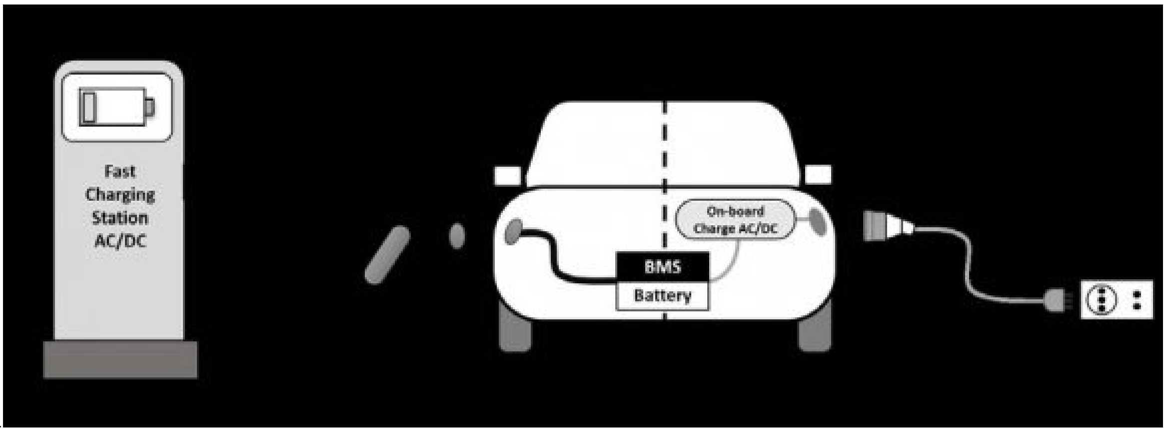


Figure 1: Figure 1 :

2

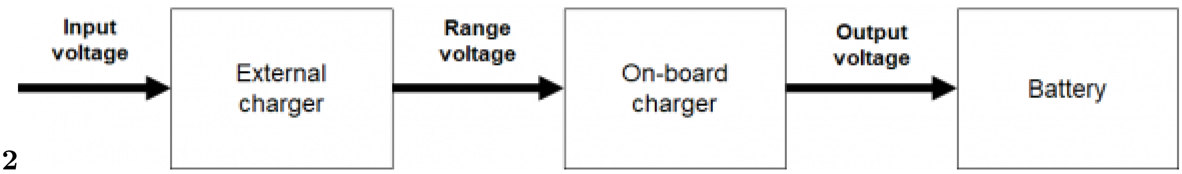


Figure 2: Figure 2 :

[1] ( ) F

[2]

3

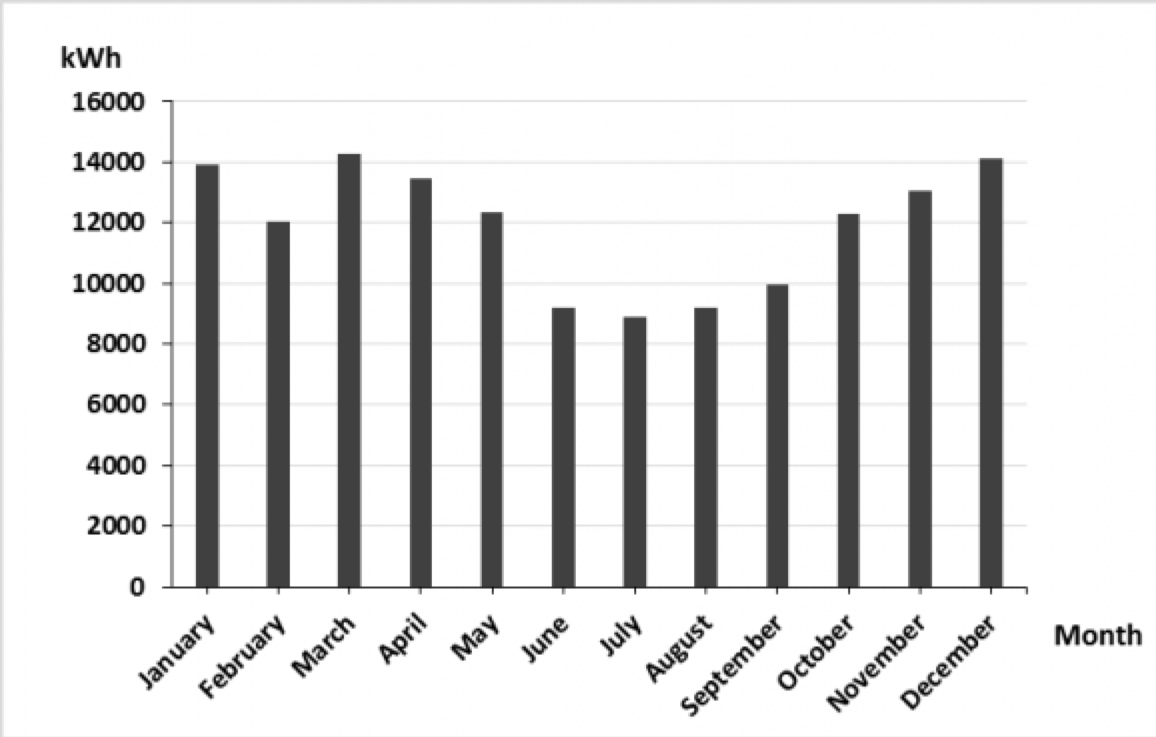


Figure 3: Figure 3 :

4

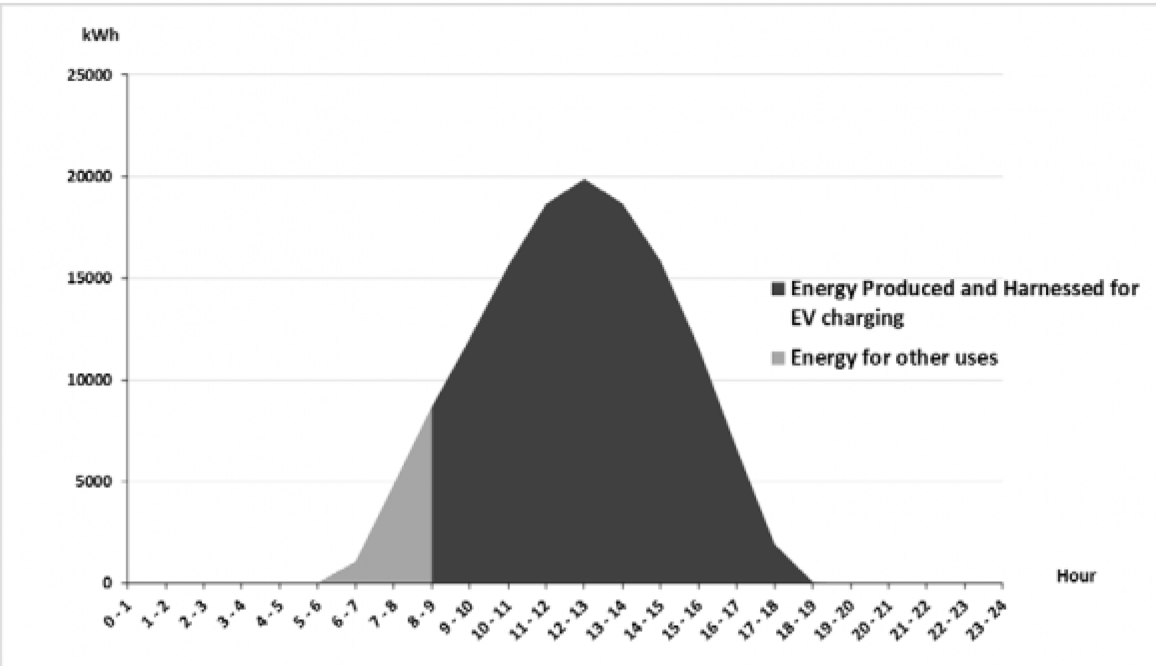


Figure 4: FFigure 4 :

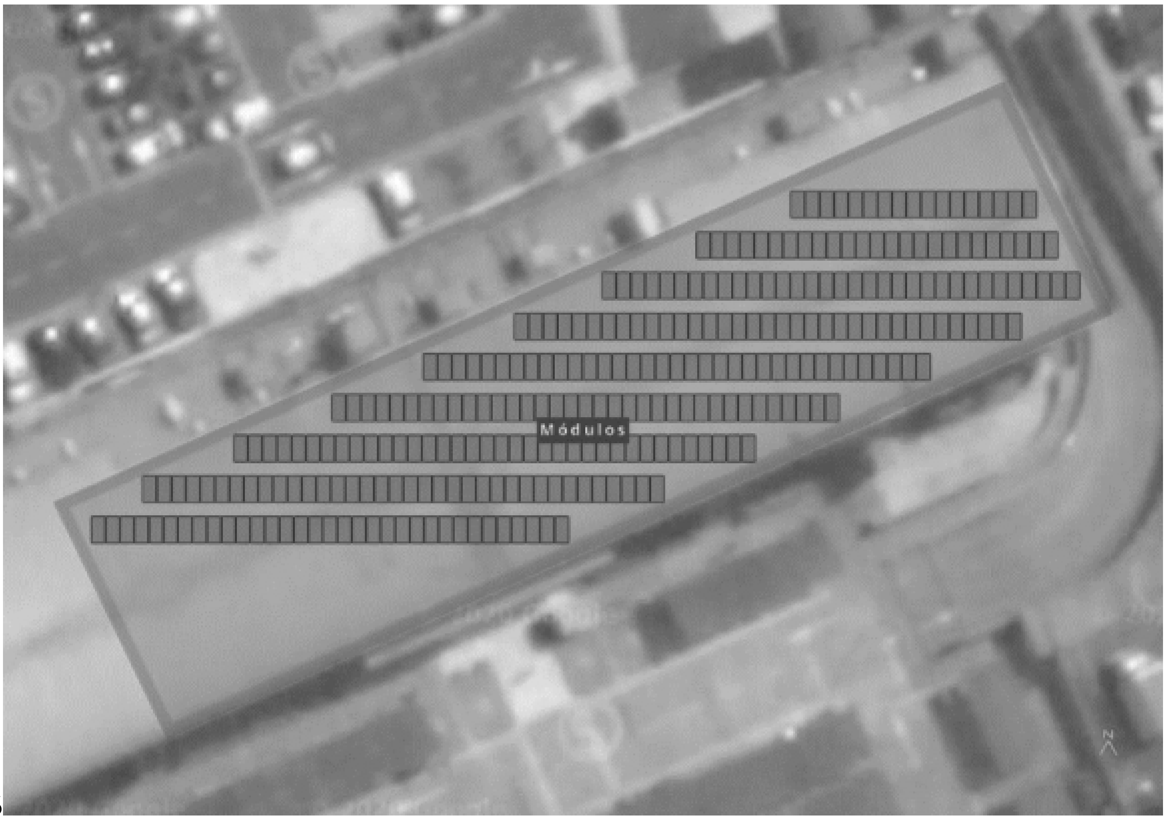
5


Figure 5: Figure 5 :

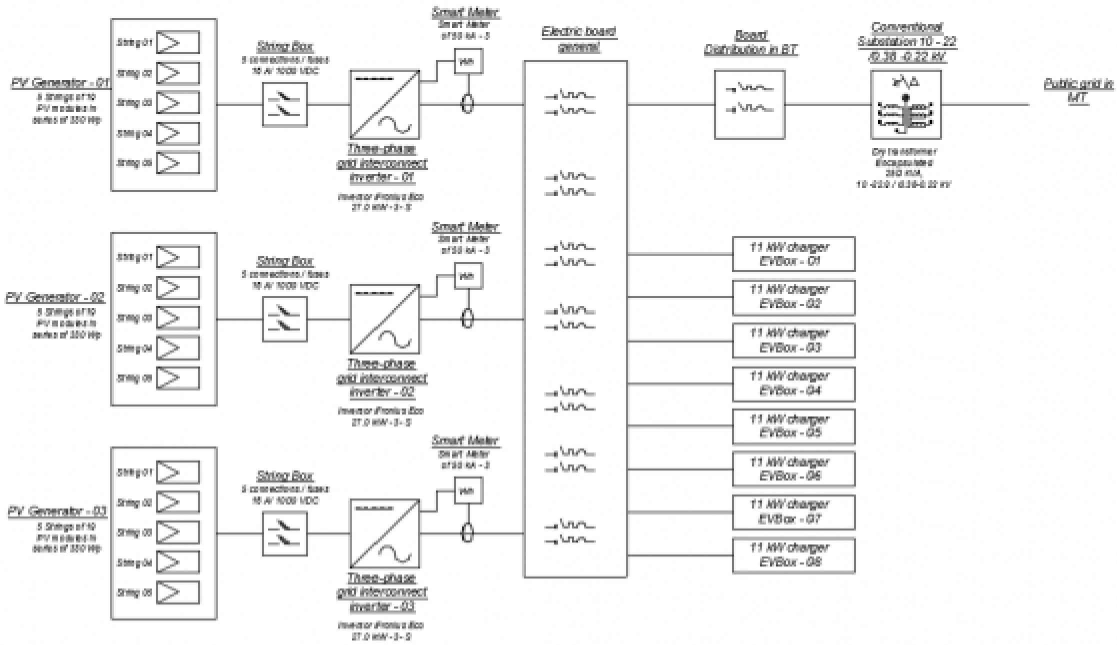


Figure 6:

1

	Hyundai Ioniq Eléctrico	Kia eSoul Standard	Kia eSoul Autonomía Extendida	Nissan Leaf S	Nissan Leaf S Plus	BYD E5-400
Type	EV	EV	EV	EV	EV	EV
Year of production	2019	2019	2019	2019	2019	2019
Maximum speed (km/h)	165	155	167	144	157	130
Battery capacity (kWh)	38.3	39.2	64	40	62	60.5
Autonomy (km)	293	277	452	270	385	400
Motor power (kW)	100	100	150	110	160	160
Torque (N.m.)	295	395	395	320	340	310
Internal charger power (kW)	7.2	7.2	7.2	6.6	6.6	7
Fast charge time from 100 kW to 80% (min)	54	42	42	40 (50kW)	45 y 60 (50 kW)	
Price (USD.)	38639.00	40121.00	47320.00	29990.00	36550.00	34760.00

Figure 7: Table 1 :

2

Brand and model of the car	Battery capacity for one hour of charge (kWh)	Autonomy for one hour of charge (km)
Hyundai Ioniq Eléctrico	7.2	55.08
Kia eSoul Standard	7.2	50.88
Kia eSoul Autonomía Extendida	7.2	50.85
Nissan Leaf S	6.6	44.55
Nissan Leaf S Plus	6.6	40.98
ByD E5-400	7.0	46.28
Porsche Taycan 4S	9.6	49.33
Porsche Taycan Turbo	9.6	46.25
Tesla Model S -Perfomance	10	56.00
Average	8.00	49.00
ii. Current situation of charging stations with renewable energies		

Figure 8: Table 2 :

34

		? Encourage and spread the use of renew energy
Temperature Data		for electrified transport.
Maximum temperature	28 °C	c) Memory of Justifying Calculations i. lar irradiation
Medium temperature	18 °C	With geographic coordinates and u NASA's
Minimum temperature	11 °C	Power Data Access Viewer applica Monthly global
ii. Objectives ? Dimension the grid-connected photovoltaic system		horizontal mean irradiance is obtained the NASA database (1983-2005) and N (1984-2013).

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 :

5

	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	
Hor. global	6.48	6.32	6.72	6.17	5.04	3.86	3.73	4.09	4.83	5.84	6.31	6.52	kWh/m 2 .day

Figure 10: Table 5 :

6

Global Average Monthly Irradiation in a 12° angle	6.63 6.33 6.79 6.62 5.87 4.53 4.24 4.37 4.90 5.84 6.41 6.72 5.77 kWh/m 2 .day

Figure 11: Table 6 :

7

Figure 12: Table 7 :

8

	Technical specifications Wallbox charger 11 kW
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 :

9

Type	Policristalino
Power	330 Wp
Imp	8.85 A
Vmp	37.3 V

Figure 14: Table 9 :

10

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 :

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 :

12

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 :

13

		Load chart				
Load	Pot.unit (kW)	I. currents total (A)	Quantity(Un d.)	P. total (kW)	I. currentstotal (A)	Pot. transformer (kVA)
Grid connection inverter - de 27 kW. 380/220 V-	27	48.26	3	81	144.78	
Fronius Wallbox charger 11Kw - 380/220 V	11	19.66	8	88	157.28	250
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 :

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 (kWh)	142708

Figure 19: Table 14 :

15

Period	Energy produced (kWh)	Emission factor (t CO_2 /MWh)	CO_2 emissions (tCO_2)
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

Figure 20: Table 15 :

16

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 :

17

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

Figure 22: Table 17 :

18

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 :

20

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 :

21

	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 :

22

	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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