DESIGN OF A PHOTOVOLTAIC INSTALATION TO RECHARGE ELECTRIC VEHICLES

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Content

1. DESCRIPTION OF THE PROJECT

This document is intended to show the process that has been carried out in order to design a solution for charging electric vehicles based on the consumption of photovoltaic energy of the own production.

All the followed steps are shown, from the theoretical calculations to the sketch of the product structure, including also the design of the electric circuit. Finally, a detailed budget of the offered product will be attached.

2. TECHNICAL REPORT

According to the power hired in the customer's house, the product has been designed for a 16 A current, which leads to a consumption of 36 W of power. In the following lines several details about the calculations performed and the selection of the most suitable elements are shown.

2.1. Location and orientation of the installation

The installation is localized in Avenida Mare Nostrum, Nº15, 46120, Alboraya, Valencia. Situated in the Patacona beach, this area corresponds to the following coordinates: 39.494182, -0.3259709.

In order to optimize the energy production of the photovoltaic field, the solar modules will be placed according to the following data:

- Inclination: 30º
- South disorientation: 0º

On the other hand, and as usual, the alternating current system available at the costumer's house is 230 V.

2.2. Consumption

Table 1 gathers the information related to the energy consumption required to charge the customer's vehicle. This consumption is oversized so that the product is capable of covering the user needs even in the most critical situations, although it is not usual a fully discharge of the battery every day of the year.

Description	Power (W/day)	Hours	Energy (Wh/day)
Electric vehicle charge	3600	8	28800

Table 1. Estimated daily consumption.

According to this table, the theoretical total energy that will be consumed has a value of 28800 Wh/day.

The addition of a performance ratio in the design of the installation is required in order to obtain more realistic results. To calculate this coefficient, the numerical values shown in table 2 has been considered. If this factor is considered, the real total energy consumed by the user 33582.09 Wh/day, being this figure the one which will fix the requirements of the installation during the designing task of the product.

As previously mentioned, a constant consumption will be considered along the different months of the year.

Loss coefficient of the battery	5%
Auto-discharging coefficient of the battery	0.5%
Depth of discharge of the battery	70%
Loss coefficient when transforming DC into AC current	3%
Loss coefficient of the wires	5%
Autonomy of the system	2 days
Performance ratio	85.76%

Table 2. Data taken into account in order to calculate the performance ratio.

2.3. Sun Peak Hours

The Sun Peak Hour (SPH) is a unit that measures the solar irradiation and it can be understood as the time, in hours, of a constant hypothetical solar irradiation of 1000 W/m^2. The NREL-NASA database has been selected to carry out this calculation, considering the previously defined inclination and orientation, as well as the location of the installation. Different intermediate factors have been defined to obtain the SPH and all of them are detailed here below. In order to calculate the numerical data, one day of each month has been selected.

To calculate the solar declination:

$$\delta = 23{,}45 \cdot sen\left(360 \cdot \frac{284+\delta_n}{365}\right)$$

Being δ the declination in degrees and δ_n the day of the year (1,…,365 being 1 the 1st January)

To calculate the solar elevation, the following expressions have been considered:

- $(90º - \varphi - \delta)$ in winter solstice
- $(90º - \varphi + \delta)$ in summer solstice

Being φ the latitude of the location and δ the declination

To determine the optimal inclination, the following premises have been considered:

- $\beta = \varphi - \delta$ in summer solstice
- $\beta = \varphi + \delta$ in winter solstice

Being φ the latitude of the location and δ the declination and reaching $\beta = \varphi$ in the equinox.

To estimate the optimal global radiation:

$$G_a(\beta_{opt}) = \frac{G_a(0)}{1-4{,}46\cdot 10^{-4}\cdot\beta_{opt}-1{,}19\cdot 10^{-4}\cdot{\beta_{opt}}^2}$$

$G_a(\beta_{opt})$: Average yearly value for the global radiation on the surface with optimal inclination (kWh/m^2).
$G_a(0)$: Average yearly value for the global radiation on a horizontal surface (kWh/m^2).
β_{opt}: Optimal inclination of the surface (º)

To calculate the Irradiation Factor (IF) the following expressions have been used:

$$IF = 1 - \left[1{,}2 \cdot 10^{-4}(\beta - \beta_{opt})^2 + 3{,}5 \cdot 10^{-5} \cdot \alpha^2\right] \quad for\ 15º < \beta < 90º$$

$$IF = 1 - \left[1{,}2 \cdot 10^{-4}(\beta - \beta_{opt})^2\right] \quad for\ \beta \leq 15º$$

IF = Irradiation Factor (/)
β: real inclination of the surface (º)
β_{opt}: Optimal inclination (º)
α=azimuth of the surface (º)

Finally, the SPH are obtained by multiplying the optimal global radiation by the irradiation factor.

All those values, intermediates and final ones, have been gathered in table 3.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Days in the month	31	28	31	30	31	30	31	31	30	31	30	31
Declination	-21.27°	-13.62°	-2.02°	9.78°	19.26°	23.39°	21.18°	13.12°	1.81°	-10.33°	-19.6°	-23.4°
Day of the year	15	45	76	106	137	168	198	229	259	290	321	351
Solar elevation	29.25°	36.9°	48.5°	60.3°	69.78°	73.91°	71.7°	63.64°	52.33°	40.19°	30.92°	27.12°
Optimal inclination	60.75°	53.1°	41.5°	29.7°	20.22°	16.09°	18.3°	26.36°	37.67°	49.81°	59.08°	62.88°
rad_glo_hour	2.54	3.46	4.77	6.15	6.84	7.67	7.73	6.77	5.3	3.77	2.62	2.14
rad_glo_op	4.76	5.4	6.14	6.97	7.26	7.97	8.12	7.48	6.51	5.52	4.69	4.27
IF	0.89	0.94	0.98	1	0.99	0.98	0.98	1	0.99	0.95	0.9	0.87
SPH/day	4.24	5.08	6.02	6.97	7.19	7.81	7.96	7.48	6.44	5.25	4.22	3.71
SPH/month	131.44	142.24	186.62	209.1	222.89	234.3	246.76	231.88	193.2	162.75	126.6	115.01
Max temp of the day	14.02°	14.12°	15.46°	16.93°	19.54°	23.19°	25.82°	26.45°	24.5°	21.66°	17.74°	15.22°
Consump/SPH day	7920.3	6610.65	5578.42	4818.09	4670.67	4299.88	4218.86	4489.58	5214.61	6396.59	7957.84	9051.78

Table 3. Numerical values of the SPH for every month.

2.4. Photovoltaic modules calculations

The photovoltaic modules are the main part of the whole installation, as they will capture the solar radiation and convert it into electricity, generating a direct current. The number of modules will depend on the supply power and the connection between them will vary according to the nominal voltage and current that is intended to be generated.

The following data have been considered in order to evaluate the suitability of the studied modules:

- Most favorable month according to the ratio consumption/SPH day: December
- Annual optimal inclination: 30.94º
- Annual optimal inclination according to consumptions: 39.62º
- Chosen inclination: 30º
- Azimuth angle: 0º
- Average maximum monthly temperature during the day: 15.66ºC
- Sun peak hours in the most unfavorable month: 3.71HSP
- Real daily energy that must be produced by the modules: 33582.09 Wh/day
- Calculated peak power of the modules: 9207 Wp

The election of the modules takes into account the different electric parameters, which will determine the performance, the required units and their coupling with other elements such as regulator and battery. Finally, the chosen module has been ATERSA A-240 Polycrystalline, whose properties are gathered in table 4.

ATERSA A-240 POLYCRYSTALLINE			
Open circuit voltage (Voc):	37.16 V	Maximum power voltage (Vmp):	29.21 V
Shortcircuit current (Isc):	8.73 A	Maximum power current (Imp):	8.21 A
Maximum power:	240 W	Temperature coefficient of Pmax:	-0.43 %/ºC
Real power at max average temperature:	244.0162 Wp	Modules in series:	2
Module total peak power:	9120 Wp	Modules in parallel:	19
Installation optimization/ needs most unfavorable month:	0.99	Total modules:	38
Optimization: equipment selection/ real needs:			99 %

Table 4. Characteristics of the module ATERSA A-240 Polycrystalline.

2.5. Regulator calculations

The regulator is in charge of controlling the charging and discharging process if the battery, from the modules to the batteries and from the batteries to the vehicle respectively. In order to avoid risks, it will prevent the installation from excessive charges and discharges.
The data that have been taken into account to evaluate the suitability of the regulators are the following ones:

- Voltage of the system: 48V
- Open circuit voltage of the module: 37.16 V
- Maximum power voltage of the module: 29.21 V
- Short-circuit current of the module: 8.73 A
- Maximum power current of the module: 8.21 A
- Number of modules in series: 2
- Number of modules in parallel: 19
- Total number of modules: 38
- Current in the modules when open system voltage: 8.73 A
- Current in the modules when closed system voltage: 8.21 A
- Total current open system: 166 A
- Total current closed system: 0 A

The selected regulator is MORNINGSTAR TRISTAR MPPT 45, whose properties are shown in table 5.

MORNINGSTAR TRISTAR MPPT 45 MPPT			
Voltage:	12-24-48 V	Maximum voltage:	150 V
Nominal power:	2400 Wp	Own consumption :	56 mA
Charge capacity:	45 A	Exploitation ratio :	0.98
Optimization: equipment selection/ real needs:	108 %	Nbr regulators :	4

Table 5. Characteristics of the regulator MORNINGSTAR TRISTAR MPPT 45.

2.6. Battery calculations

The battery is the element that will store the energy produced during the day by the solar modules and will deliver it to the vehicle when it is desired.

The data that have been analyzed to evaluate the suitability of the batteries are shown in the following list:

- Nominal voltage: 48 V
- Depth of discharge: 70%
- Autonomy: 2 days
- Real daily energy: 33582 Wh/ day
- Calculated useful capacity: 1399 Ah
- Calculated real capacity: 1999 Ah

A high voltage has been selected with the aim of reducing the number of photovoltaic modules, fact that will lead to a smaller required surface in the structure and a considerable decrease in the cost. The value of the autonomy has been chosen considering the fact that the costumer's house is next to the installation, so if a failure persists, the vehicle would be connected to the house.

The selected accumulator is HAWKER TZS-12 12OPZS. Being more precise, 4 batteries of 12 V, whose properties are shown in table6, will be connected in series.

HAWKER TZS-12 12OPZS TUBULAR-PLATE									
Capacity as function of the discharging hours :									
C 10:	1710 Ah	C 20:	1850 Ah	C 40:	1950 Ah	C 100:	2120 Ah	C 120:	2335 Ah
Voltage:	12 V	Nbr elements in series :	4						
Nominal capacity:	1950 Ah	Nbr series in parallel :	1						
Nominal voltage:	48 V	Total elements:	4						
Optimization: equipment selection/ real needs:	98 %								

Table 6. Characteristics of the accumulator HAWKER TZS-12 12OPZS.

2.7. Inverter calculations

The inverter is the device that will convert the direct current produced by the modules into an alternating one, because although the vehicle batteries are work with DC current, the chargers present nowadays in the market convert AC into DC, so alternating current must arrive to them.

The following data have been considered to validate the studied inverters:

- DC voltage of the system: 48 V
- AC voltage at the exit: 230 V
- Maximum power: 3600 W
- Simultaneity coefficient: 1
- Minimum required power: 3600 W
- Safety coefficient: 0.9
- Power used in the calculations: 4000 W

The selected inverter has been the model SUNTEAMS 5000, whose main features are shown in table 7.

SUNTEAMS SUNTEAMS 5000			
Voltage:	48 V	Nominal power:	4900 W
Continuous power:	5200 W	Peak power:	6000 W
Vacuum consumption :	6 W	Efficiency:	97 %
Exploitation ratio :	77 %	Nbr inverters:	1
Optimization: equipment selection/ real needs:	130 %		

Table 7. Characteristics of the inverter SUNTEAMS 5000.

2.8. Summary of the selection

The final selection of the elements is summarized in table 8.

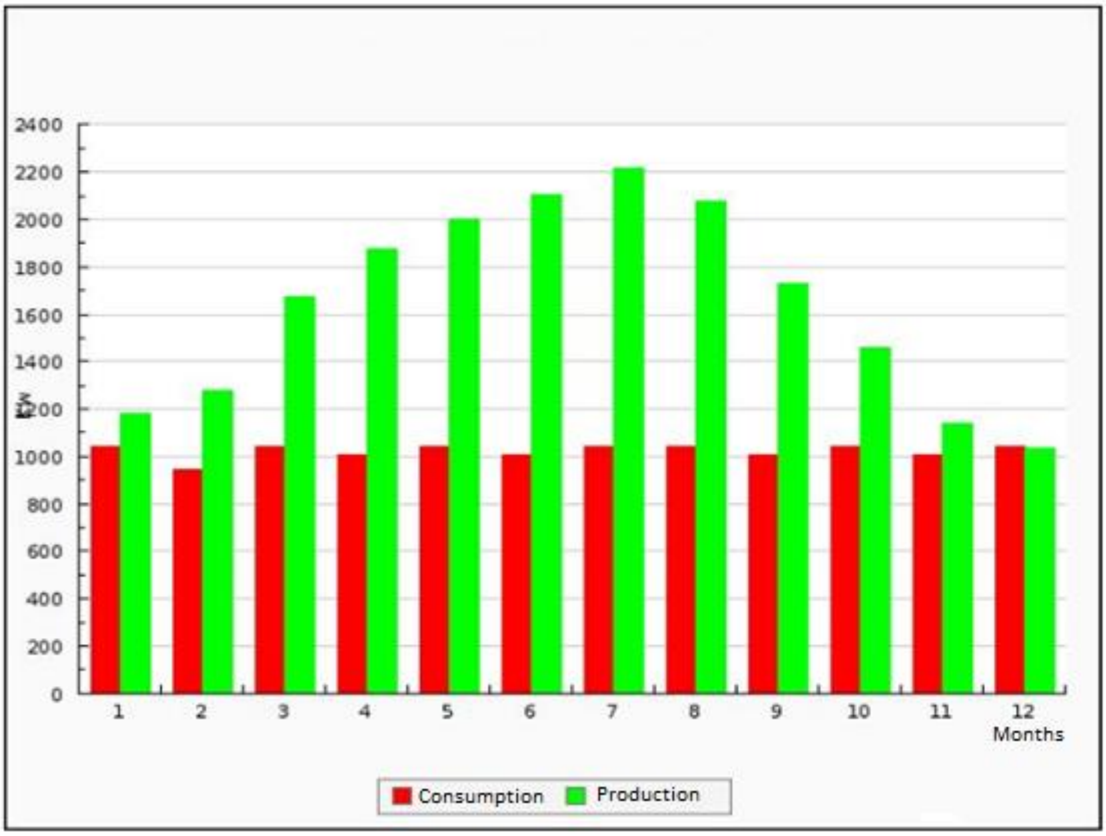
Units	Elements
38	Module – ATERSA A-240 Polycrystalline
4	Regulator – MORNINGSTAR TRISTAR MPPT 45
4	Battery – HAWKER TZS-12 12OPZS Tubular plate
1	Inverter – SUNTEAMS 5000

Table 8. Chosen elements for the installation.

According to the elements presented in table 8, and their corresponding features, it is possible to elaborate the following comparative between consumption and estimated production during a whole year.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Consumption	1041	940	1041	1007	1041	1007	1041	1041	1007	1041	1007	1041
Production	1179	1275	1673	1875	1999	2101	2213	2079	1732	1459	1135	1031

Table 9. Annual comparative production-consumption.



Graph 1. Annual comparative production-consumption.

As additional information, the following numerical values can be estimated:

- Yearly consumption: 12255 KW
- Yearly production: 19751 KW
- Avoided kg CO2/year: 10705

3. ANALYSIS OF THE REQUIRED SAFETY MEASURES THAT THE CIRCUIT MUST INCLUDE

Before showing the electric circuit of the installation, it is required to evaluate the safety measures that must be included attending to the current legislation. Three aspects must be analyzed: direct and indirect contact, overvoltage protections and overcurrent protections. These factors have been evaluated for direct and alternating current, as the legislation is different for both cases.

A voltage of 230 V is present in the alternating current side, so attending to the IEC-61140 standard, protections must be included against direct and indirect contact.

- To avoid direct contact, differentials will be used.
- To avoid indirect contact, the equipment (inverter) will be connected to ground with a TN-S configuration.

In the direct current side the open circuit voltage has a value smaller than 50 V, so no especial safety measures are required in this installation.

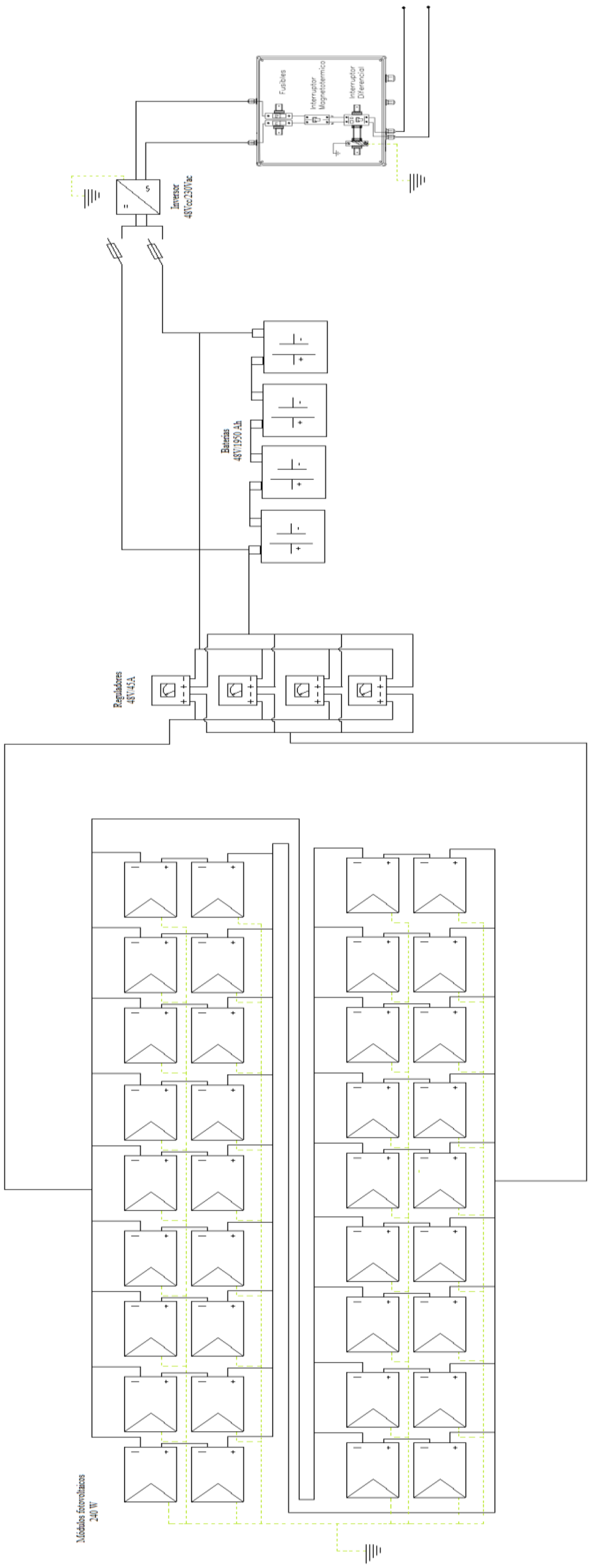
Regarding to overvoltage measures, including protection against rays and other similar phenomena, the regulators already include varistors in their internal electronics, therefore there is no need of adding complementary protections against these contingencies. This decision has been taken according to the European Committee for Standardization guidelines and considering the geographic location of the installation (low keraunic level).

The following aspects are considered to evaluate the need of adding protections against overcurrents:

- Overcurrent values that can appear in this installation in the DC side are small and the regulator has internal protections to avoid these contingencies, so no extra protections are required, as they will be redundant.
- In the alternating side circuit important overcurrents can appear and they can damage equipment and/or people, so protections must be included. The protections selected against direct and indirect contact are also valid for this problem, as overcurrents can be caused due to them.
- According to REBT, a house fed by alternating current must include differentials and an automatic switch.

Then it can be concluded that no protections against short-circuits and overloads will be installed in the DC side but a differential and/or a magnetothermic must be added at the AC side.

4. ELECTRIC CIRCUIT



5. SKETCH OF THE PRODUCT

As it can be seen in figure 1, the appearance of the product is similar to a garage-shelter.

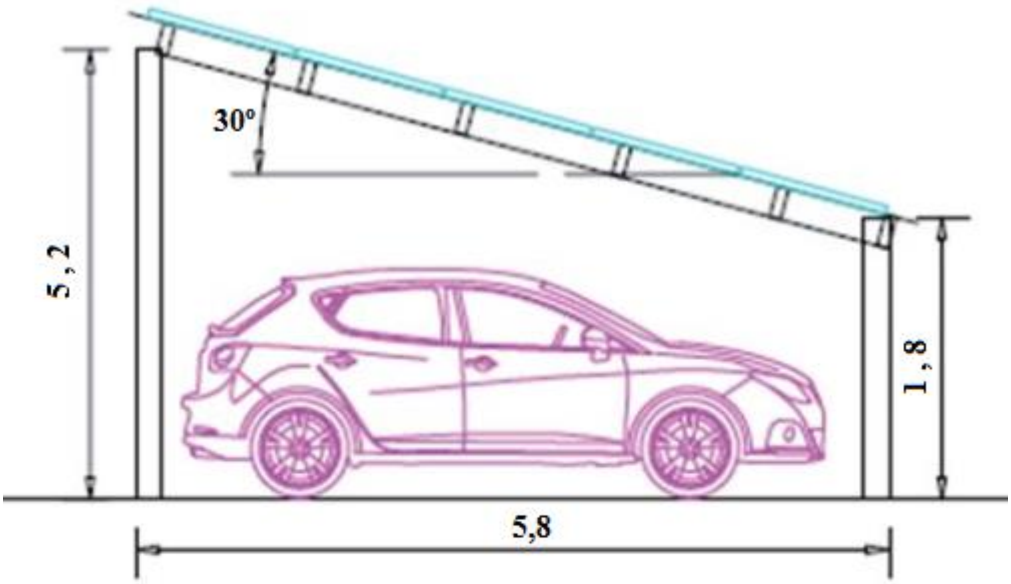


Figure 1. Front view of the installation.

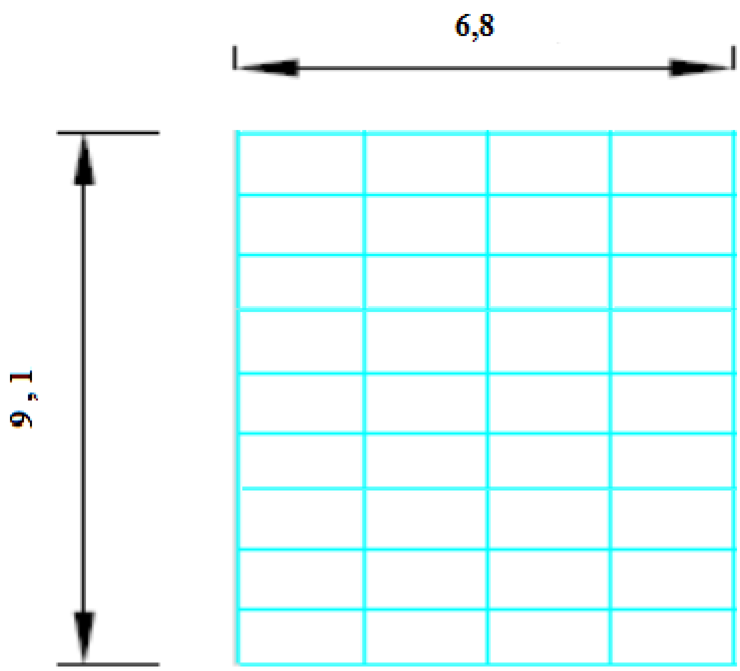


Figure 2. Top view of the installation.

6. BUDGET

Concept	Units	€/unit	Total
Photovoltaic modules ATERSA A-240 POLYCRYSTALLINE	38	227.27	8636.36
Regulator MORNINGSTAR TRISTAR MPPT 45 MPPT	4	169.46	677.85
Battery HAWKER TZS-12 12OPZS TUBULAR PLATE	4	2493	9972
Inverter SUNSTEAMS 5000	1	1005.29	1005.29
Shelter structure	1	4000	4000
Labor	-	1100	1100
Wires and preparation of the installation	-	700	700
Charging device with connectors Schuko and IEC 62196	2	690	1380
Grounding	1	90	90
	SUBTOTAL		27561.5
	IVA 21%		5787.92
	TOTAL		**33349.42**

Table 10. Budget of the installation.