274.86 kWp grid-connected photovoltaic system for self-consumption

Petitioner:

University of La Laguna, faculty of science, physics section
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Scope of action:

solar photovoltaic energy for self-consumption

Situation and location:

main road, TF-47, km 9, 38687 Guía de Isora, Santa Cruz de Tenerife
UTM:
X:323274.242
Y:31177389.216
Zone: 28
Land register reference: 3274203CS2137S0001WD

Project drafter:

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Date:

June 28, 2018

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Master of Science in Renewable Energy

274 kW_p GRID-CONNECTED PHOTOVOLTAIC SYSTEM FOR SELF-CONSUMPTION

Project Report

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June 28, 2018

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1 Object of study

The object of study of this project is the design of a grid-connected PV system for self-consumption for the Hotel Abama, in Guia de Isora, Tenerife. The project itself is a solar carport, which are overhead canopies built to cover parking areas, mounted in the parking lot next to the hotel. This choice has been made in order to eliminate the need for a surface on which the panels could be mounted, offering a more efficient use of space.

As a rule, the energy produced by the PV system will be consumed instantaneously by the hotel, but if in a given moment in time, the energy produced by the system is larger than the hotel's electric energy consumption, the surplus energy would be fed into the grid, receiving a economic remuneration.

The PV system will be complementary to the existing electric grid, which covers the entire electric energy demand of the hotel nowadays, and will decrease the active energy term of the electricity bill.

2 Scope

Project scope encompasses the sizing of all components of the PV system in order to ensure its proper functioning. The study of the civil construction works required for the installation of the structure of the solar carports and the underground cables is beyond the scope of this project.

3 Background of the project

The parking lot next to the hotel, where the PV system is to be installed, is a public car park with an available surface area of over 3,000 m^2 which is mainly used by the employees of the hotel.

The chief of engineering of the hotel has provided the annual data from the pyranometer that is installed in the rooftop of the hotel, as well as the quarter hourly demanded electric power by the hotel.

In a survey carried out by energy company E.ON, where 2,000 travellers were polled, half of the travellers said that sustainability and energy use of a hotel is important to them, with solar panels and low energy lighting highlighted [1]. Therefore, by installing a PV system for self-consumption, not only a reduction of the electricity bill of the hotel is intended to accomplish, it goes far beyond that. This project is seen as a good opportunity to promote the hotel as sustainable and efficient.

4 Standards and references

4.1 Legal provisions and standards applied

- Law 54/1997, of November 27, regarding the electrical sector.
- Ordinance ITC/2794/2007, of September 17, which revises electricity tariffs from October 1, 2007 on.

- Ordinance of April 16, 2010, by which the Particular Regulations for the Linking Facilities are approved, in the scope of supply of Endesa Distribución Eléctrica, S.L.U. and Electrical Distributor of the Puerto de La Cruz, S.A.U., in the territory of the Autonomous Community of the Canary Islands.
- Resolution of 27 July 2004, of the General Direction of Energy Policy and Mines, which establishes the month of minimum energy demand for the electric systems of the Canary Islands and Balear Islands archipelago and for the non-mainland electric systems of Ceuta and Melilla, for the application of the access tariffs to the networks of transport and distribution, type 6.
- Royal Decree 900/2015, of October 9, which regulates the administrative, technical and economic conditions for the supply of electric energy with self-consumption and production with self-consumption.
- Royal Decree 1955/2000, of December 1, which regulates the transport, distribution, commercialization, supply activities and authorization procedures of the electric energy installations.
- Royal Decree 413/2014, of June 6, which regulates the electric energy production from renewable energy sources, cogeneration and waste treatment.
- Royal Decree 1544/2011, of October 31, which establishes the access tolls to the transport and distribution networks that electric power producers must satisfy.
- Royal Decree 1110/2007, of August 24, which approves the unified regulation of points of measurement of the electrical system.
- Royal Decree 842/2002, of August 2, which approves the Low Voltage Electrical Regulation and its technical complementary instructions (ITC, for its acronym in Spanish) LV 01 to LV 51.
- Royal Decree 1164/2001, of October 26, by which access tariffs to the networks of transport and distribution of electrical energy are established.

4.2 Softwares used to carry out measurements and calculations

In order to carry out the measurements and calculations needed to develop the present project, the following softwares have been used:

- Python: Python is an interpreted, object-oriented, high-level programming language with dynamic semantics. It has been used to carry out the simulation of the performance of the PV system, i.e, estimate the annual energy produced by the PV system, determine the savings, plot graphics, etc.
- AutoCAD: AutoCAD is a computer-aided design (CAD) program used for 2-D and 3-D design and drafting. It has been used to draw the drawings of the PV system, measure the lengths of the cables, measure the distances of the location, draw the Gantt chart, etc.
- Microsoft Excel: Microsoft Excel is a software program produced by Microsoft that allows users to organize, format and calculate data with formulas using a spreadsheet system. It has mainly used for organizing and manipulating data provided by the chief of engineering of the hotel prior to use it in Python.

- CYPE: software for architecture, engineering and construction. It allows to obtain prices for civil works as close as possible to reality, facilitating the preparation of a good quality project documentation [2].

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5 Definitions and abbreviations

For this thesis, following frequent occurring measures and terms have to be defined and in which units they are measured:

5.1 List of abbreviations

°C: Degrees Centigrade

AC: Alternating current

CB: Circuit Breaker

DC: Direct Current

DPP: Discounted Payback Period

GLVB: General Low Voltage Board

I_{mp}: Current at MPP

IRR: Internal Rate of Return

I_{SC}: Short-circuit current (zero voltage)

kW_p: Kilowatt Peak Power = 1,000 W_p

kWh: Kilowatt hour = 1,000 Wh

LV: Low Voltage

MPP: Maximum power point

MPPT: Maximum power point tracker (in inverter)

NPV: Net Present Value

NREL: National Renewable Energy Laboratory

O&M: Operations and Maintenance

P_{mp}: Power at MPP

PR: Performance Ratio

PV: Photovoltaics, i.e. electric power generation with solar cells

V_{mp}: Voltage at MPP

V_{OC}: Open-circuit voltage (zero current)

Wh: Energy (Power (W)·time (h))

W_p: Peak Power (Watt) at STC

STC: Standard test conditions (defined below)

5.2 Definitions and explanations

- Grid-connected: PV system connected to the electrical grid.
- Installed PV peak power: DC power of the PV module or system at STC conditions given in W_p. Also called Rated power.
- Inverter: converts DC from the PV modules into AC to make it possible to connect to the surrounding electric grid. The inverter also includes a MPPT trying to find the MPP of the PV modules.
- Net Present Value: sum of present value for every future income and cost.
- Photovoltaics: a method of generating DC electricity from solar radiation with semiconductors (solar cells).
- PV system: complete system including PV modules, inverters and exterior equipment such as cables and installation equipment.
- Self-consumption: PV production consumed directly by the consumer. Self-consumption replaces the need to buy electricity from an energy supplier.
- Self-consumption ratio and self-sufficiency ratio: the self-consumption relative to the total electricity production (self-consumption ratio) or electricity consumption (self-sufficiency ratio), respectively. Measured in percent.
- Solar irradiance: power received by a surface per unit area from the Sun in the form of electromagnetic radiation in the wavelength range of the measuring instrument. The international system of unit of irradiance is the watt per square metre (W/m^2).
- Solar irradiation: energy received by a surface per unit area per uni time. The solar irradiance integrated over time is called solar irradiation.
- STC: Standard Test Conditions: solar radiation 1000 W/m^2, PV cell temperature of 25°C and AM1.5 global solar spectrum (Fraunhofer ISE, n.d.). The air mass (AM) defines how long the light has to travel through the atmosphere and thus its spectrum and intensity. AM 1.0 means the sun in zenith and AM 1.5 an angle of 48.2° from the zenith angle.
- String: multiple PV panels connected in series.

- Tilt angle: angle defining the slope of the PV modules, where 0° is a horizontal plane and 90° a vertical plane.

6 Design requirements

6.1 Petitioner

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6.2 Student and project drafter

- Title: 274.86 kW_p grid-connected photovoltaic system for self-consumption
- Author: Aritz Uribe-etxeberria Jauregi
- Master of science: MSc in Renewable Energy
- ID number: 44171872-G
- Email address: alu0101064512@ull.edu.es

6.3 Situation and location

- Address: main road, TF-47, km 9, 38687 Guia de Isora, Santa Cruz de Tenerife
- UTM:

  X:323274.242

  Y:3117389.216

  Zone: 28

- Land register reference: 3274203CS2137S0001WD

- Driving directions to The Ritz-Carlton, Abama (TF-47) from Tenerife South Airport:
  1. Head east - 500 m
  2. Slight left - Go through 1st roundabout - 1.0 km
  3. Continue straight - 270 m
  4. Take the ramp to San Miguel/Arona/Los Cristianos - 280 m
  5. Merge onto TF-1 - 21.4 km
  6. Take the exit toward TF-47/Playa San Juan/Puerto Santiago/Los Gigantes
  7. At the roundabout, take the 3rd exit onto TF-47 - Go through 2 roundabouts - 8.7 km
  8. Resort is on your right

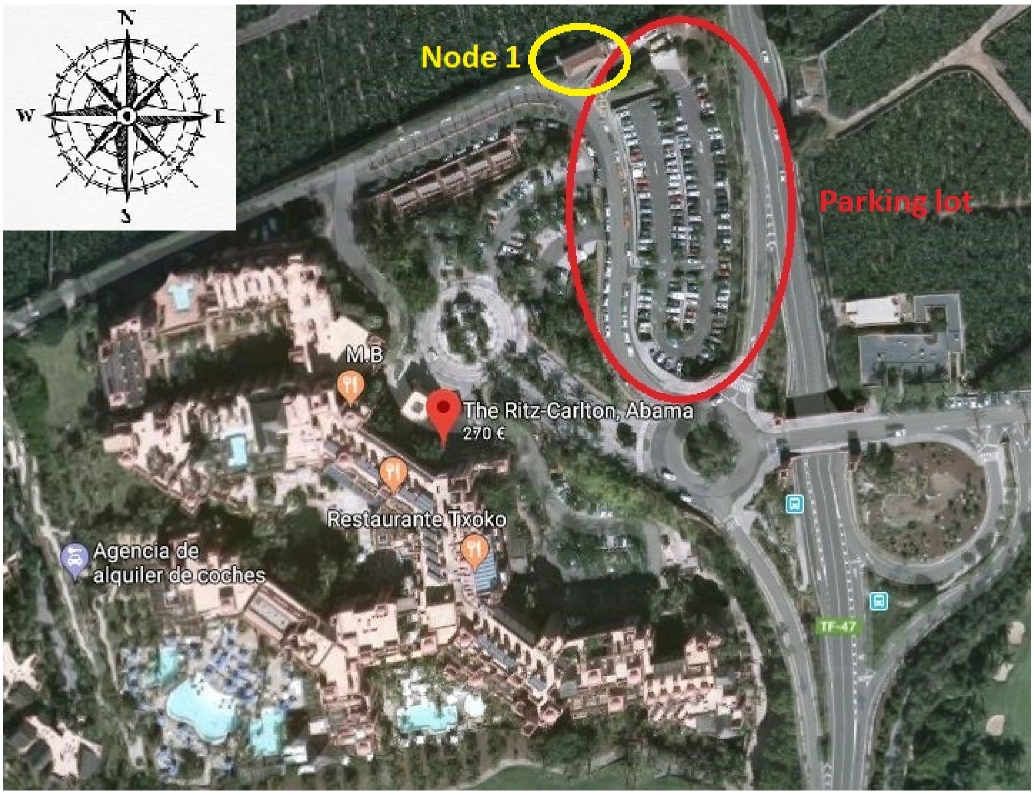

Figure 1: Location of the parking lot where the PV system is to be installed [3].

6.4 Description of the location

As previously mentioned in section 3, the PV system will be installed in the parking lot next to the hotel, which is a public car park mainly used by the employees of the hotel with an available surface area of over 3,000 m^2.

Despite its relatively large surface, the parking lot is usually either full or has few empty spaces due to the large number of people who work in the hotel. That is why the solution adopted for this location is a solar carport, thus eliminating the need for a surface on which the panels could be mounted, and therefore, preserving all the parking spaces. Furthermore, as can be seen from Figure 1, the parking lot is predominantly on south-facing orientation.

Even though the parking lot belongs to the city council, the hotel is in fact the developer of the project and consequently, the energy produced by the PV system will be instantaneously consumed by the hotel. The hotel is a luxurious moorish-inspired resort including two restaurants with coveted Michelin stars, a luxury spa and one of Spain's most renowned golf courses.

6.5 Evacuation of the PV production

Immediately beside the parking lot, there is a hut, also known as Node 1. That is where the hotel's electric connection with the 20 kV distribution network of the island is made. Moreover, there is a transformation center where the PV system will connect to.

The hotel has its own 20 kV loop distribution system throughout the facilities and there are four transformation center located in different areas of the hotel where the voltage is lowered to 230/400 V.

The energy produced by the PV system will be evacuated to the internal 20 kV loop distribution network of the hotel using the transformer of the Node 1. More specifically, the PV system will be connected to the GLVB of the transformer. Prior to the connection, a bi-directional meter for monitoring the solar generation must be properly installed with required electric protections.

7 Analysis of the solutions

In the kick-off meeting, even though the option of a solar carport was considered since the very beginning, several solar carport models and manufacturers were contemplated for this PV project. Initially, the chief engineering of the hotel proposed the solar carport of manufacturer Circutor, S.A., a complete solar carport with its own electric vehicle recharging point and integrated energy administration and control system (Power Studio SCADA) (see Figure 2).

Figure 2: Solar carport designed by Circutor manufacturer [4].

However, when deciding the PV system layout it is essential to know the underlying technical conditions and prerequisites in the location where the PV system is to be installed. In this regard, there was a problem with the orientation of the solar carport designed by Circutor and the orientation of the parking spaces. As it can be seen in Figure 1, the parking spaces are predominantly on either due east or due west orientation, and, as a consequence, so would be the solar carports oriented (see Figure 2) as the orientation of the solar carports matches with the orientation of the parking spaces.

Taking into account that the hotel's electric power consumption is extremely large, the self sufficiency ratio will always be 100%, whatever the orientation or tilt angle of the PV panels might be. For this reason, the main objective of the PV system is to maximize the amount of electricity that the PV panels produce, facing them due south (as much as the current parking lot configuration allows) for optimal sun exposure.

For that matter, after a market research conducted to identify potential solar carport models that allows PV panels to face south, the solar carport model from the company Carport Structures Corporation has been chosen (see Figure 3 and 4). The main drawback of this model is that it does not incorporate its own electric vehicle recharging point nor an integrated energy administration and control system as Circutor's solar carport model does.

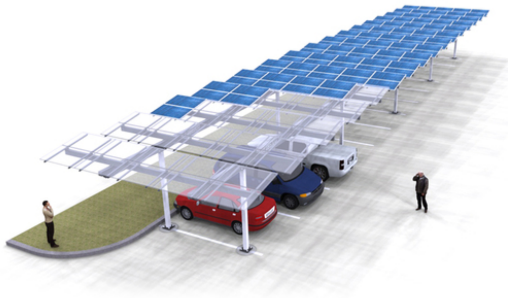

Figure 3: Louvered single carport style [5].

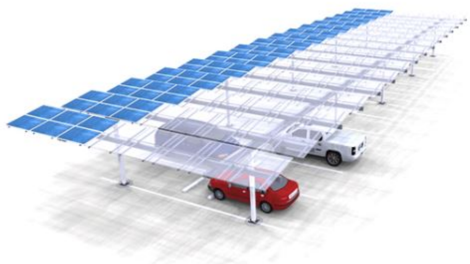

Figure 4: Louvered double carport style [5].

As shown in Figure 3 and 4, there are two types of solar carport styles: the louvered single and the louvered double solar carport styles. In the former solar carport 10 PV panels are to be mounted in each row while in the latter, 16 PV panels will be installed.

In order to cover all the parking spaces with the solar carports, the parking lot has been divided in 4 different zones depending on the orientation of the solar carports (see Table 1 and Drawing No. 3: PV modules layout).

Zone	Tilt angle (°)	Orientation (°)	Peak Power (kW_p)
Zone 1	15	8 (south-west)	83.16
Zone 2	15	0 (due south)	111.24
Zone 3	15	-13 (south-east)	45.9
Zone 4	15	-8 (south-east)	34.56

Table 1: Tilt angle, orientation and the peak power of each solar carport zone.

The resulting peak power of the PV system is 274.86 kW_p.

Under the regulation established by the RD 900/2015, two types of self-consumption modalities are clearly differentiated:

- Self-consumption modality type 1

The installations regarded as type 1 will meet the following requirements:

a) The contracted power of the consumer will not be greater than 100 kW

b) The sum of the installed generation capacity will be equal or smaller than the contracted capacity of the consumer.

c) The supply point holder will be the same as the holder of all consumption and generation installation equipment connected to its grid.

d) The generation facilities and the supply point must comply with the technical requirements contained in the regulations of the electricity sector and in the regulations on quality and industrial safety that may apply to them. In particular, those established in RD 1699/2011, of November 18, which regulates the connection to the network of small-scale electric power production facilities. For the exclusive purposes of the application of the aforementioned RD 1699/2011, of November 18, generation facilities regarded as self-consumption type 1 will be considered production facilities.

- Self-consumption modality type 2

The installations regarded as type 2 will meet the following requirements:

a) The sum of the installed generation capacity will be equal or smaller than the contracted capacity of the consumer.

b) In the event that there are several production facilities, the owner of each and every one of them must be the same natural or legal person.

c) The production facilities must comply with the technical requirements contained in the regulations of the electricity sector and in the regulation of quality and industrial safety that may be applicable to them, in particular RD 1955/2000, of December 1, RD 1699/2011, of November 18, for production facilities included in its scope of application and RD 413/2014, of June 6, which regulates the electric energy production from renewable energy sources, cogeneration and waste treatment.

d) When the production facilities share infrastructures for connection to the transport or distribution network or connect to the internal network of a consumer, they shall be liable for the breach of the precepts contained in this royal decree, accepting the consequences of the disconnection of the mentioned connection point, in application of the current regulations, could entail for any of the parties, among them, the impossibility of the producer of energy sales and the perception of the compensation that would have corresponded or the impossibility of the consumer to acquire energy and the perception of the remuneration associated to it. The distribution company or carrier will not have any legal obligation on the connection facilities to the network that are not of their ownership. The access contract that the consumer, directly or through the commercializing company, subscribes with the distribution company, will collect everything stipulated in this section.

The PV installations classified as self-consumption modality type 2, can receive economic compensation for the energy that is fed into the grid. If this happens, the owner of the production installation must satisfy the access tolls established in RD 1544/2011, of October 31,which establishes the access tolls to the transport and distribution networks that electric power producers must satisfy.

8 End result

According to the RD 900/2015 explained in section 7, the PV system proposed in this project is classified as self-consumption modality type 2, since the contracted power of the hotel is far greater than 100 kW. This means that if the PV generation is greater than the hotel's energy consumption, the surplus energy can be fed into the grid in exchange for economic compensation as any other producer.

However, in the simulation of the performance of the PV system in the first full year of operation, it has been observed that there would not be any surplus energy on the basis that the energy produced by the PV system is nowhere near as large as the energy consumption of the hotel, being the latter extremely huge. The energy delivered by the PV system in the first full year of operation is 428,109.08 kWh. The monthly energy production of the PV system can be seen in Figure 5.

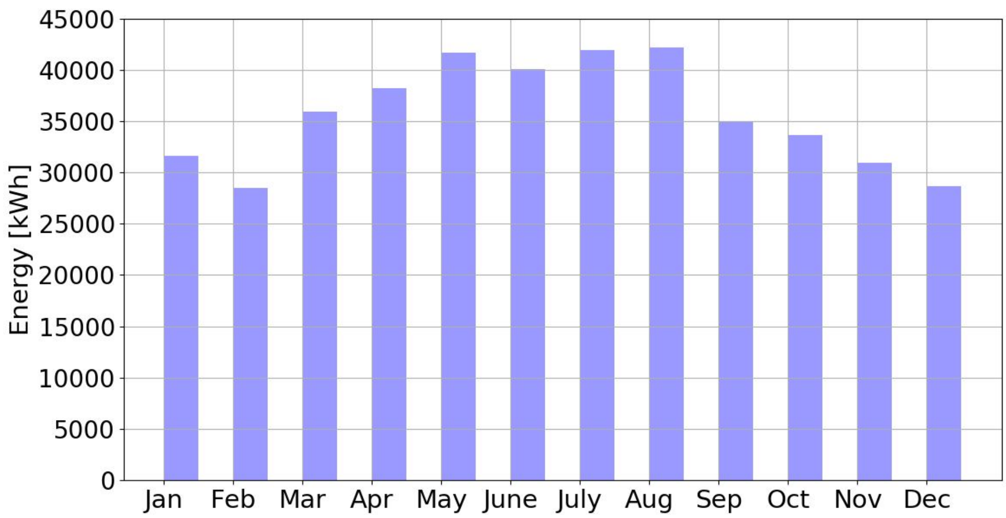

Figure 5: Energy delivered by the PV system in each month of the first full year of operation.

As far as the savings is concerned, the annual saving produced in the variable energy term of the electricity bill of the hotel due to the self-consumption of the energy delivered by the PV system in the first full year of operation has been estimated in 38,384.21 €. This annual saving distributed among the pricing periods can be seen in Figure 6.

8.1 Material Execution Budget

	Total (€)
Budget item 1: mounting and set up of the PV equipment	237,709.31
Budget item 2: mounting and set up of the earthing installation	1,935.47
Budget item 3: mounting and set up of the wires and protective tubes and channels	30,244.06
Budget item 4: mounting and set up of the electric board with DC protection devices	365.50
Budget item 5: mounting and set up of the electric board with AC protection devices	5,279.66
Budget item 6: mounting and set up of the net energy meter equipment	536.69
Material Execution Budget:	276,070.69

The Material Execution Budget of this project amounts to **TWO HUNDRED SEVENTY SIX THOUSAND AND SEVENTY EUROS WITH SIXTY NINE CENTS**.

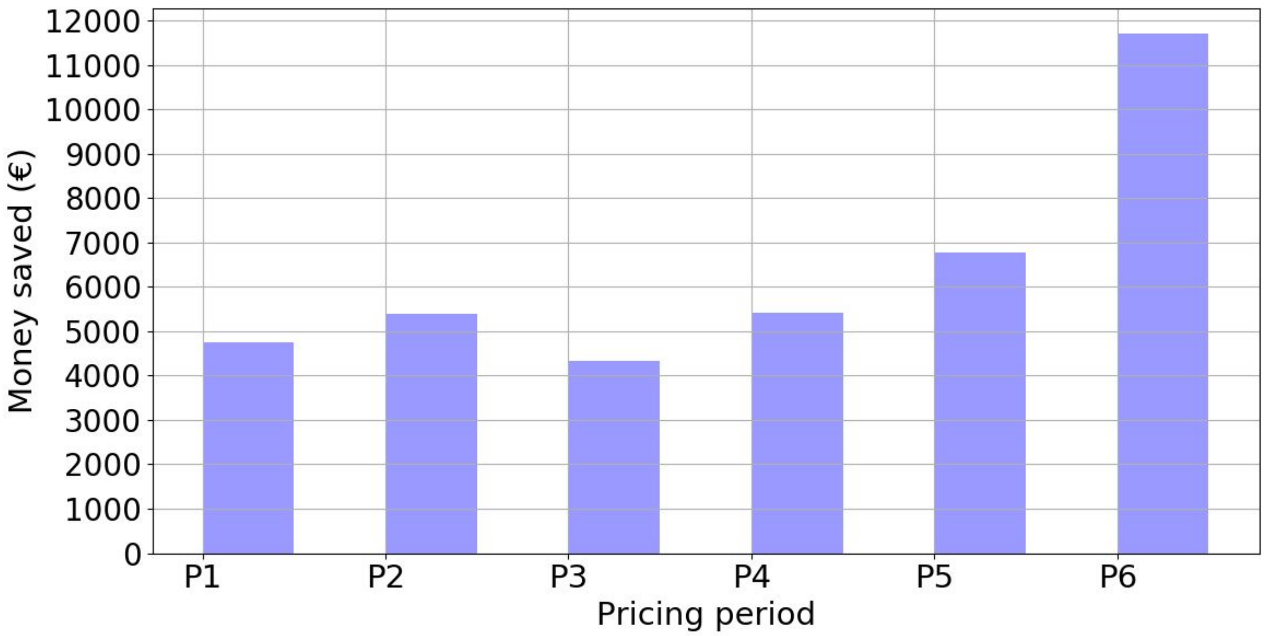

Figure 6: Money saved in each pricing period due to the PV production in the first full year of operation.

8.2 Contracted Operation Budget

	Total (€)
Material Execution Budget:	276,070.69
Industrial Benefit (6%):	16,564.24
Overhead Costs (13%):	35,889.19
Tax Base:	328,524.12
General Indirect Canary Islands Tax (IGIC, by its Spanish acronym) (7%):	22,996.69
Contracted Operation Budget:	351,520.81

The Contracted Operation Budget of this project amounts to **THREE HUNDRED FIFTY ONE THOUSAND, FIVE HUNDRED TWENTY EUROS WITH EIGHTY ONE CENTS**.

Therefore, the initial investment of the PV system under study amounts to 351,520.81 €. It has been assumed that it will be self-financed in its entirety by the hotel.

The NPV estimated in the period of 25 years results to be positive and equal to 223,340.83 €. The IRR of the project has been estimated to be 7% and the DPP is 12.94 years. Bearing all this in mind, the investment is profitable and convenient from a financial point of view.

8.3 PV panels

For the project implementation, a total of 1,018 polycristalline PV panels of 270 W_p from the manufacturer Amerisolar will be installed on top of the solar carports. Thus, the peak power of the installation amounts to 274.86 kW_p as discussed in the section 7. The chosen PV panel has a high module conversion efficiency 16.6% in STC conditions due to superior manufacturing technology.

In the Table 2 and 3 PV panel's electrical and mechanical parameters can be seen.

8.3.1 Electrical characteristics

Electrical characteristics at STC	
Nominal Power P_{max}	270 W
Open circuit voltage V_{OC}	38.4 V
Short circuit current I_{SC}	9.06 A
Voltage at nominal power V_{mp}	31.1 V
Current at nominal power I_{mp}	8.69 A
Module efficiency (%)	16.6

Table 2: Electrical characteristics of the chosen PV module.

8.3.2 Mechanical characteristics

Mechanical characteristics	
Cell type	Polycristalline 156x156mm
Number of cells	60 (6x10)
Module dimension	1640x992x40mm
Weight	18.5 kg
Front cover	3.2mm low-iron temperes glass
Frame	Anodized aluminum alloy
Junction box	IP67, 6 diodes
Cable	$4mm^2$, 900mm
Connector	MC4 or MC4 compatible
Standar packaging	26pcs/pallet
Module quantity per container	728pcs/40'HQ

Table 3: Mechanical characteristics of the chosen PV module.

8.4 Inverters

Owing to the fact that the solar carports have been divided in four zones depending on the orientation of the PV panels, it has been proposed that each zone will have its own inverter, except for the Zone 2 with two inverters (60 kW and 50 kW), due to that zone's large peak power. The reason behind it is that PV panels with different orientations can receive different irradiance levels and, if this PV panels are then connected in series, the output of the entire string is determined by the PV panel with the lowest output current.

Therefore, five inverters from the manufacturer SunGrow will be installed, amounting to a nominal power of 273 kW_n. In Table 4 can be seen the inverter's nominal AC output power of each solar carport zone. The inverters will be placed inside the Node 1 hut and it will be of utmost importance for the proper functioning of the equipment to maintain a correct service temperature.

Zone	Peak Power (kW_p)	Inverter's nominal AC output power (kW)	DC/AC ratio
Zone 1	83.16	80	1.04
Zone 2	111.24	110	1.01
Zone 3	45.9	50	0.92
Zone 4	34.56	33	1.05

Table 4: Inverter's nominal AC output power of each solar carport zone.

The technical characteristics of the four inverter models installed are shown in Table 5.

Inverter's technical characteristics				
Model	SG80KTL	SG60KTL	SG50KTL-M	SG33KTL-M
Input (DC)				
Max. PV input voltage	1,000 V	1,000 V	1,000 V	1,100 V
MPP voltage range	570 - 850 V	570 - 850 V	500 - 850 V	500 - 850 V
No. of MPPTs	1	1	4	3
Max. PV strings per MPPTs	18	14	3	3 / 3 / 2
Max. PV input current	144 A	120 A	112 A	88 A
Max. current per string	12 A	12 A	12 A	12 A
Output (AC)				
Nom. AC power ouput	80 kW	60 kW	50 kW	33 kW
Max. AC ouput current	116 A	96 A	80 A	53.5 A
Nom. AC voltage	3P +4 PE, 230 / 400			
Power factor	$>$ 0.99 at default value at nom. power, (adj. 0.8 leading - 0.8 lagging)			
Protections and functions				
Anti-islanding prot.	Yes	-	Yes	-
LVRT.	Yes	-	Yes	-
DC reverse connection prot.	Yes			
AC shortcircuit prot.	Yes			
Leakage current prot.	Yes			
DC switch	Yes			
DC fuse	Yes			
Overvoltage prot.	DC Type II SPD (40 kA)/AC Type II SPD			
System data				
Euro efficiency	98.7 %	98.7 %	98.5 %	98.3 % kW
Isolation method	Transformerless			
Ingress prot. rating	IP 65			
Night power consumption	$< 1\ W$	$< 1\ W$	$< 1\ W$	$< 2\ W$
Cooling method	Smart forced air cooling			
Communication	RS485			

Table 5: Inverter's technical characteristics.

8.5 AC box combiner

An AC box combiner has been used to bring the output power of the five inverters together. The chosen AC box combiner, from the manufacturer SolarBOS, has 5 input circuits, one per inverter and has a maximum output current of 600 A. Each input can be disconnected by means of a switch and it also features an output disconnect of 600 A disconnect ampere capacity.

Figure 7: SolarBos AC box combiner [6].

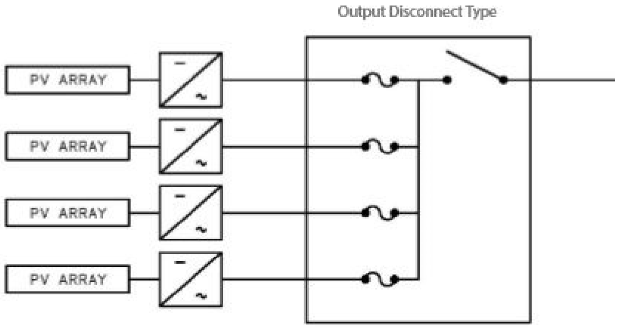

Figure 8: Representation of the inner circuit [6].

8.6 Electrical protection components

8.6.1 Electric board with DC protection components

The positive and negative ends of the strings are routed through the structure of the solar carport, although in some areas the cable routing is underground, to the electric board with DC protections before they are connected to the inverter. This cable is a single core flexible photovoltaic Topsolar PV ZZ 6 mm^2 cable. The electric board with DC protections is placed inside the Node 1 hut, alongside the inverters.

The electric board with DC protections is composed of a fuse for each positive and negative end of the strings and their corresponding fuse holder. There are a total of 47 strings, therefore, 94 fuses and fuse holder are needed.

Nominal current (I_n)	Rated voltage	Size	Quantity
12 A	1,000 V_{DC}	10x38 (mm)	94 Nos

Table 6: Nominal current, rated voltage, size and quantity of the fuses.

Figure 9: 12 A fuse and the fuse holder [7].

8.6.2 Electric board with AC protection components

Current leaves each inverter on a three-phase line, all three phases sharing a neutral line. Subsequently, the cables are connected to the electric board with AC protection components.

Each inverter is protected with a 4-pole thermal-magnetic circuit breaker with an ampere rating according to the electric current flowing through the wire. In addition, prior to the each inverter's thermal-magnetic CB, a 4-pole differential CB with 30 mA sensitivity have been installed to protect users from electric shocks in case of leakage.

Furthermore, there is a main differential circuit breaker of 630 A ampere rating and 300 mA sensitivity, as well as the main automatic moulded-case thermal-magnetic CB. Lastly, a type 2 surge protector against transient and permanent overvoltages has been installed. The AC protection components that compose the AC protection electric board are shown in Table 7.

Protection component	Protected device	Quantity	Characteristics
Thermal-magnetic CB	80 kW inverter	1	125 A, 25 kA, 4-pole, C Curve
Thermal-magnetic CB	60 kW inverter	1	100 A, 15 kA, 4-pole, C Curve
Thermal-magnetic CB	50 kW inverter	2	80 A, 25 kA, 4-pole, C Curve
Thermal-magnetic CB	33 kW inverter	1	63 A, 10 kA, 4-pole, C Curve
Differential CB	80 kW inverter	1	125 A, 30 mA, 4-pole, AC Class
Differential CB	60 kW inverter	1	125 A, 30 mA, 4-pole, AC Class
Differential CB	50 kW inverter	2	100 A, 30 mA, 4-pole, AC Class
Differential CB	33 kW inverter	1	80 A, 30 mA, 4-pole, AC Class
Thermal-magnetic CB	General instl.	1	450 A, 36 kA, 4-pole
Differential CB	General instl.	1	630 A, 300 mA, 4-pole
Type II surge protection	General instl.	1	15 kA, 400 V_{AC}, 1.8 kV

Table 7: AC protection components that compose the AC protection electric board.

8.7 Bi-directional energy meter

As stated in the RD 900/2015, it is compulsory to install a bi-directional energy meter that measures the net energy produced by a PV system classified as self-consumption modality type 2.

For this specific project, the 3-phase bi-directional energy meter of the manufacturer SMA has been chosen (see Figure 10).

Figure 10: SMA energy meter [8].

Since the output current of the PV system is too large (up to 425.5 A), it is necessary to install a current transformer in order to decrease the current so that the energy meter can bear it. The nominal current of the SMA energy meter is 5 A.

For this purpose, 3 external current transformers model TRMC 210.2, one for each phase, of the manufacturer Circutor will be installed prior to the SMA energy meter. The secondary current of this CT is 5 A, same as the nominal current of the energy meter.

9 Planning

As it has been explained in section 2, the study of the civil construction work required for the installation of the structure of the solar carport is beyond the scope of this project. Therefore, this planning refers only to the mounting and set up of the PV installation itself and it will start once the mounting of the structure of the solar carports and the civil construction work associated to it are finished.

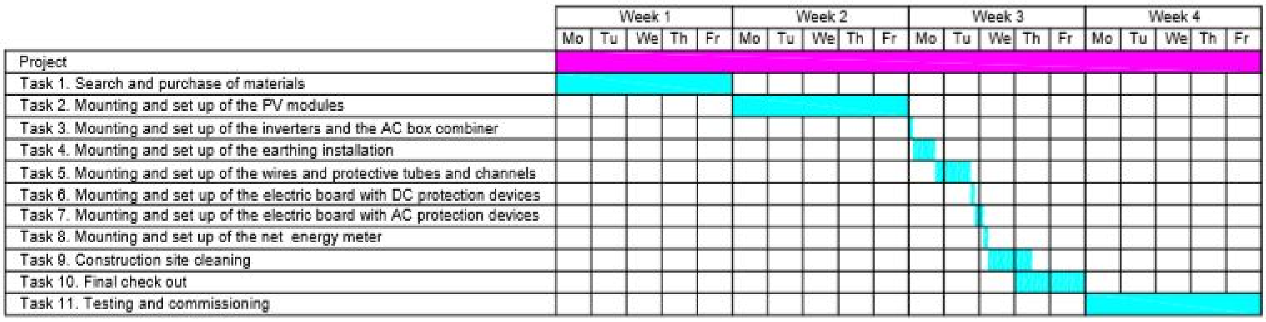

Figure 11: Gantt chart showing project management timelines.

10 Order of priority of the constituent documents

The order of priority of the constituent documents is as follows:

- Project's budget
- Technical specification document
- Drawings
- Project report

Master of Science in Renewable Energy

274 kW_p GRID-CONNECTED PHOTOVOLTAIC SYSTEM FOR SELF-CONSUMPTION

Appendix

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Faculty of science: physics section

June 28, 2018

Master of Science in Renewable Energy

274 kW_p GRID-CONNECTED PHOTOVOLTAIC SYSTEM FOR SELF-CONSUMPTION

Appendix 1. Supporting calculations

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June 28, 2018

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1 Determining the minimum module inter-row spacing

For a 4 hour solar window between 10 AM and 2 PM (solar time) on the winter solstice (December 21st), the technical specifications document for grid-connected PV installations by IDAE proposes the following equation [9]:

$$d = h \cdot k = \frac{h}{tan(61^\circ - latitude)} \tag{1}$$

where:

d: minimum module inter-row spacing. Measured in m.

h: PV module or obstacle height. Measured in m.

latitude: latitude where the PV panels are installed. Measured in degrees (°).

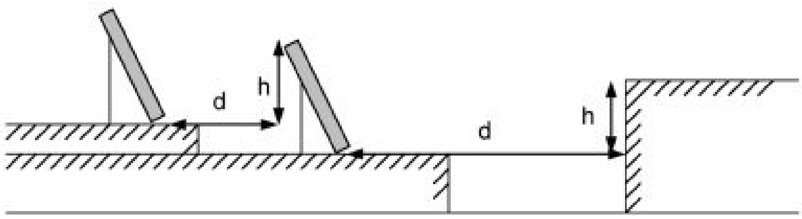


Figure 1: Minimum module inter-row spacing (d) for a given height (h) [9].

In each row, two lines of PV panels will be installed horizontally on top of the solar carport with a tilt angle of 15°. Therefore the height of each row would be:

$$h = 2 \cdot 0.992\,[m] \cdot Sin15^\circ = 0.51\,m$$

The latitude of the parking lot where the PV system will be installed is 28.17°. If these variables are introduced in equation (1), a minimum module inter-row spacing of 0.79 m is obtained.

$$d = \frac{0.51\,[m]}{tan(61^\circ - 28.17^\circ)} = 0.79\,m$$

As stated in the datasheet of the solar carport, the distance between the center of a PV panel row and the next one must be between 2.44 and 2.74 m (see Figure 2). If a minimum inter-row space of 0.79 m is kept, the total distance between the center of a row and the next center of the row would be 2.71 m. This way, the requirements of the solar carport structure are met.

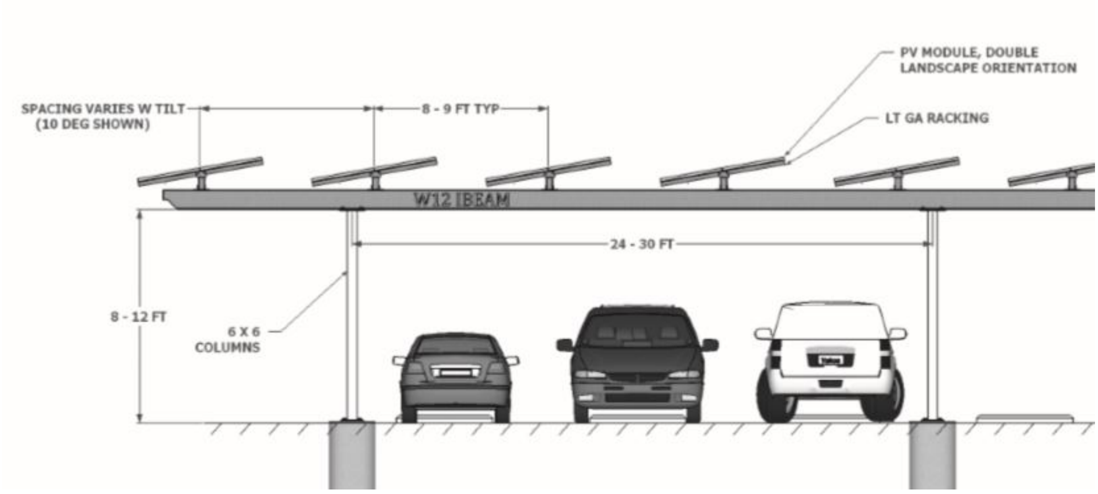


Figure 2: Inter-row distance in the solar carport to be kept [5].

2 Inverters

2.1 Inverter's input connections

2.1.1 Zone 1

The peak power of the Zone 1 amounts to 83.16 kW_p. For this zone, the inverter model SG80KTL with a 80 kW nominal AC output power is used. This inverter has one independent MPPT input and a maximum of 18 PV strings can be connected per MPPT . In the Table 1 how the PV strings are connected to the inverter is shown.

SG80KTL inverter					
String	No. PV panels	$V_{mp}(STC)$ (V)	MPP Voltage range (V)	I_{mp} (STC) (A)	P_{mp} (STC) (W)
No. 1	-	-	570 - 850	-	-
No. 2	-	-	570 - 850	-	-
No. 3	22	684.2	570 - 850	8.69	5,940
No. 4	22	684.2	570 - 850	8.69	5,940
No. 5	22	684.2	570 - 850	8.69	5,940
No. 6	22	684.2	570 - 850	8.69	5,940
No. 7	22	684.2	570 - 850	8.69	5,940
No. 8	22	684.2	570 - 850	8.69	5,940
No. 9	22	684.2	570 - 850	8.69	5,940
No. 10	22	684.2	570 - 850	8.69	5,940
No. 11	22	684.2	570 - 850	8.69	5,940
No. 12	22	684.2	570 - 850	8.69	5,940
No. 13	22	684.2	570 - 850	8.69	5,940
No. 14	22	684.2	570 - 850	8.69	5,940
No. 15	22	684.2	570 - 850	8.69	5,940
No. 16	22	684.2	570 - 850	8.69	5,940
No. 17	-	-	570 - 850	-	-
No. 18	-	-	570 - 850	-	-

Table 1: PV strings connected to the SG80KTL inverter.

2.1.2 Zone 2

The peak power of the Zone 2 amounts to 111.24 kW_p. For this zone, two inverters have been used: a inverter model SG60KTL with a 60 kW nominal AC output power and a inverter model SG50KTL with a 50 kW nominal AC output power.

The SG60KTL inverter has one independent MPPT input and a maximum of 14 PV strings can be connected per MPPT. In the Table 2 how the PV strings are connected to the inverter is shown.

On the other hand, the SG50KTL-M inverter has 4 independent MPPT inputs and a maximum of 3 PV strings can be connected per MPPT. In the Table 3 how the PV strings are connected to the inverter is shown.

SG60KTL inverter					
String	No. PV panels	$V_{mp}(STC)$ (V)	MPP Voltage range (V)	I_{mp} (STC) (A)	P_{mp} (STC) (W)
No. 1	-	-	570 - 850	-	-
No. 2	-	-	570 - 850	-	-
No. 3	22	684.2	570 - 850	8.69	5,940
No. 4	22	684.2	570 - 850	8.69	5,940
No. 5	22	684.2	570 - 850	8.69	5,940
No. 6	22	684.2	570 - 850	8.69	5,940
No. 7	22	684.2	570 - 850	8.69	5,940
No. 8	22	684.2	570 - 850	8.69	5,940
No. 9	22	684.2	570 - 850	8.69	5,940
No. 10	22	684.2	570 - 850	8.69	5,940
No. 11	22	684.2	570 - 850	8.69	5,940
No. 12	22	684.2	570 - 850	8.69	5,940
No. 13	-	-	570 - 850	-	-
No. 14	-	-	570 - 850	-	-

Table 2: PV strings connected to the SG60KTL inverter.

SG50KTL-M inverter					
No. 1 independent MPPT input					
String	No. PV panels	$V_{mp}(STC)\,(V)$	MPP Voltage range (V)	$I_{mp}\,(STC)\,(A)$	$P_{mp}\,(STC)\,(W)$
No. 1	21	653.1	500 - 850	8.69	5,670
No. 2	21	653.1	500 - 850	8.69	5,670
No. 3	21	653.1	500 - 850	8.69	5,670
No. 2 independent MPPT input					
String	No. PV panels	$V_{mp}(STC)\,(V)$	MPP Voltage range (V)	$I_{mp}\,(STC)\,(A)$	$P_{mp}\,(STC)\,(W)$
No. 1	21	653.1	500 - 850	8.69	5,670
No. 2	21	653.1	500 - 850	8.69	5,670
No. 3	21	653.1	500 - 850	8.69	5,670
No. 3 independent MPPT input					
String	No. PV panels	$V_{mp}(STC)\,(V)$	MPP Voltage range (V)	$I_{mp}\,(STC)\,(A)$	$P_{mp}\,(STC)\,(W)$
No. 1	22	684.2	500 - 850	8.69	5,940
No. 2	22	684.2	500 - 850	8.69	5,940
No. 3	22	684.2	500 - 850	8.69	5,940
No. 4 independent MPPT input					
String	No. PV panels	$V_{mp}(STC)\,(V)$	MPP Voltage range (V)	$I_{mp}\,(STC)\,(A)$	$P_{mp}\,(STC)\,(W)$
No. 1	-	-	500 - 850	-	-
No. 2	-	-	500 - 850	-	-
No. 3	-	-	500 - 850	-	-

Table 3: PV strings connected to the Zone 2 SG50KTL-M inverter.

2.1.3 Zone 3

The peak power of the Zone 3 amounts to 45.9 kW_p. For this zone, the inverter model SG50KTL-M with a 50 kW nominal AC output power is used. This inverter has 4 independent MPPT inputs and a maximum of 3 PV strings can be connected per MPPT. In the Table 4 how the PV strings are connected to the inverter is shown.

SG50KTL-M inverter					
No. 1 independent MPPT input					
String	No. PV panels	$V_{mp}(STC)\,(V)$	MPP Voltage range (V)	$I_{mp}\,(STC)\,(A)$	$P_{mp}\,(STC)\,(W)$
No. 1	21	653.1	500 - 850	8.69	5,670
No. 2	21	653.1	500 - 850	8.69	5,670
No. 3	21	653.1	500 - 850	8.69	5,670
No. 2 independent MPPT input					
String	No. PV panels	$V_{mp}(STC)\,(V)$	MPP Voltage range (V)	$I_{mp}\,(STC)\,(A)$	$P_{mp}\,(STC)\,(W)$
No. 1	21	653.1	500 - 850	8.69	5,670
No. 2	21	653.1	500 - 850	8.69	5,670
No. 3	21	653.1	500 - 850	8.69	5,670
No. 3 independent MPPT input					
String	No. PV panels	$V_{mp}(STC)\,(V)$	MPP Voltage range (V)	$I_{mp}\,(STC)\,(A)$	$P_{mp}\,(STC)\,(W)$
No. 1	22	684.2	500 - 850	8.69	5,940
No. 2	22	684.2	500 - 850	8.69	5,940
No. 3	-	-	500 - 850	-	-
No. 4 independent MPPT input					
String	No. PV panels	$V_{mp}(STC)\,(V)$	MPP Voltage range (V)	$I_{mp}\,(STC)\,(A)$	$P_{mp}\,(STC)\,(W)$
No. 1	-	-	500 - 850	-	-
No. 2	-	-	500 - 850	-	-
No. 3	-	-	500 - 850	-	-

Table 4: PV strings connected to the Zone 3 SG50KTL-M inverter.

2.1.4 Zone 4

The peak power of the Zone 4 amounts to 34.56 kW_p. For this zone, the inverter model SG33KTL-M with a 33 kW nominal AC output power is used. This inverter has 3 independent MPPT inputs and a maximum of 3 / 3 / 2 PV strings can be connected per MPPT. In the Table 5 how the PV strings are connected to the inverter is shown.

SG33KTL-M inverter					
No. 1 independent MPPT input					
String	No. PV panels	$V_{mp}(STC)$ (V)	MPP Voltage range (V)	I_{mp} (STC) (A)	P_{mp} (STC) (W)
No. 1	-	-	500 - 850	-	-
No. 2	21	653.1	500 - 850	8.69	5,670
No. 3	21	653.1	500 - 850	8.69	5,670
No. 2 independent MPPT input					
String	No. PV panels	$V_{mp}(STC)$ (V)	MPP Voltage range (V)	I_{mp} (STC) (A)	P_{mp} (STC) (W)
No. 1	21	653.1	500 - 850	8.69	5,670
No. 2	21	653.1	500 - 850	8.69	5,670
No. 3	-	-	500 - 850	-	-
No. 3 independent MPPT input					
String	No. PV panels	$V_{mp}(STC)$ (V)	MPP Voltage range (V)	I_{mp} (STC) (A)	P_{mp} (STC) (W)
No. 1	22	684.2	500 - 850	8.69	5,940
No. 2	22	684.2	500 - 850	8.69	5,940

Table 5: PV strings connect to the SG33KTL-M inverter.

2.2 Maximum input voltage and current scenarios

In this section, it will be proven that the maximum PV input voltage (1,000 V) and the maximum current input connector (12 A) of the inverters are never surpassed.

.

As stated by the State Meteorological Agency of Spain (AEMET, by its Spanish acronym) [10], the lowest temperature ever registered in the closest weather station to the hotel (South Tenerife Airport) is 9°C. On the other hand, the highest temperature ever documented is 44.3°C.

For this calculation, equation (2), (3) and (4) will be used. Furthermore, the following information about the chosen PV moudle is also necessary:

- the open-cicuit voltage temperature coefficient: $\beta = -0.33\%/°C$.
- the short-cicuit current temperature coefficient: $\alpha = 0.056\%/°C$.
- NOCT: $45°C$.

$$T_{cell} = T_{ambient} + G \cdot \frac{NOCT - 20\ [°C]}{0.8\ [kW/m^2]} \tag{2}$$

Where:

T_{cell}: temperature of the PV cell. Measured in °C.

$T_{ambient}$: ambient temperature. Measured in °C.

G: incident irradiance. Measured in kW/m^2.

$NOCT$: Nominal Operating Cell Temperature. Measured in °C.

$$V_{OC}(T_{cell}) = V_{OC}(STC) - \beta(T_{cell} - 25\ [°C]) \tag{3}$$

Where:

$V_{OC}(T_{cell})$: open-circuit voltage at a given T_cell . Measured in V.

$V_{OC}(STC)$: open-circuit voltage at STC conditions. Measured in V.

β: temperature coefficient of V_{OC}. Measured in $°C^{-1}$.

$$I_{SC}(T_{cell}, G) = I_{SC}(STC) \cdot \frac{G}{1\ [kW/m^2]} \cdot [1 + \alpha(T_{cell} - 25\ [°C])] \tag{4}$$

Where:

$I_{SC}(T_{cell}, G)$: short-circuit current at a given T_{cell} and G . Measured in A.

$I_{SC}(STC)$: short-circuit current at STC conditions. Measured in A.

G: incident irradiance. Measured in kW/m^2.

α: temperature coefficient of I_{SC}. Measured in $°C^{-1}$.

Two worst case scenario will be simulated to ensure that even if those critical and highly unlikely situations occur, the inverter are capable of functioning properly.

- Worst case scenario 1 (maximum V_{OC}):
  - lowest temperature ever registered (9°C)
  - no irradiance ($G = 0\,W/m^2$)

$$T_{cell} = T_{ambient} = 9°C$$

$$V_{OC,MAX} = 38.4\ [V] - 0.0033\ [°C^{-1}] \cdot (9[°C] - 25[°C]) = 38.45\ V$$

The maximum number of PV panels connected in series in a string is 22. Hence, the resulting maximum open-circuit voltage of the string would be:

$$V_{OC,MAX,string} = 38.45\ [V] \cdot 22 = 845.9\ V$$

In conclusion, even in this critical situation the inverter would be working in the MPP voltage range for nominal power (until 850 V), so it can be said that maximum PV input voltage of 1,000 V would never be surpassed.

- Worst case scenario 2 (maximum I_{SC}):
  - highest temperature ever registered (44.3$°C$)
  - $G = 1\,kW/m^2$

$$T_{cell} = 44.3\,[°C] + 1\,[kW] \cdot \frac{(45\,[°C] - 20\,[°C])}{0.8\,[kW]} = 75.55°C$$

$$I_{SC,MAX} = 9.06\,[A] \cdot \frac{1\,[kW/m^2]}{1\,[kW/m^2]} \cdot [1 + 0.00056\,[°C^{-1}](75.55\,[°C] - 25\,[°C]) = 9.32\,A$$

All the strings connected to the inverters are composed of PV panels connected in series. Therefore, the output current of the string is the same as the output current of one PV panel.

$$I_{SC,MAX,string} = I_{SC,MAX} = 9.32\,A$$

In conclusion, it has been proved that the maximum current for input connector of 12 A would never be reached even if these critical conditions occur.

3 Determining the wire section

3.1 PV wire

When it comes to determining the section of the PV wire, the fact that in some parts the PV wire will be routed underground is a key factor. According to the section 1 of the Electro Technical Regulation on Low Voltage that includes the technical instruction ITC-BT-07 (Underground networks for low voltage distribution), the section of the underground wire will not be smaller than 6 mm^2 for copper conductors. As a consequence, the PV wire section will be 6 mm^2.

According to the technical specifications document for grid-connected PV installations by IDAE [9], the section of the copper wire must be large enough to ensure a voltage drop lower than 1.5 %. The voltage drop for DC PV wires has been calculated with the equation (5).

$$u = \frac{2 \cdot \rho \cdot L \cdot I_{mp}}{S \cdot V_{mp,String}} \tag{5}$$

Where:

u: voltage drop. Measured in %.

ρ: resistivity of annealed copper for electrical applications. ($1/58\ \Omega \cdot mm_2/m$ according to norm UNE 20003).

L: cable length. Measured in m.

I_{mp}: string current at MPP. (8.69 A in all strings).

S: wire's section. (6 mm^2 for all wires).

$V_{mp,String}$: string voltage at MPP. Measured in V.

In the DC PV wires, the voltage drop is purely resistive. As a result, the percentage of the voltage drop coincides with the percentage of power loss:

$$\Delta U\% = \frac{\Delta U}{U_n} = \frac{\Delta U \cdot I_n}{U_n \cdot I_n} = \frac{\Delta P}{P_n} = \Delta P\%$$

It can be seen in Table 6, 7, 8, 9 and 10 that the string's voltage drop is always lower than 1.5% limit. Furthermore, if all the power losses from Table 6, 7, 8, 9 and 10 are added, a total power loss of 1,743.01 W due to resistance of the PV wire has been estimated. The total power loss in percent is 0.64 %.

$$P_{loss}(\%) = \left(\frac{\Sigma\, Zone's\, power\, loss}{Zone's\, peak\, power}\right) \cdot 100 \tag{6}$$

$$P_{loss}(\%) = \left(\frac{1.74301\ [kW]}{274.86\ [kW_p]}\right) \cdot 100 = 0.64\%$$

3.1.1 Zone 1 voltage drop and power loss

Strings connected to the SG80KTL inverter					
String	V_{mp} (V)	$2 \cdot L$ (m)	Voltage drop (%)	P_{mp} (STC) (W)	Power loss (W)
No. 1	-	-	-	-	-
No. 2	-	-	-	-	-
No. 3	684.2	219.4	0.8	5,940	47.56
No. 4	684.2	209.76	0.76	5,940	45.47
No. 5	684.2	216.24	0.79	5,940	46.88
No. 6	684.2	228.28	0.83	5,940	49.49
No. 7	684.2	232.8	0.85	5,940	50.47
No. 8	684.2	241.3	0.88	5,940	52.31
No. 9	684.2	247.64	0.90	5,940	53.69
No. 10	684.2	261.27	0.95	5,940	56.64
No. 11	684.2	276.84	1.01	5,940	60.02
No. 12	684.2	299.56	1.09	5,940	64.94
No. 13	684.2	279.28	1.02	5,940	60.54
No. 14	684.2	271.04	0.99	5,940	58.76
No. 15	684.2	261.52	0.95	5,940	56.69
No. 16	684.2	253.8	0.93	5,940	55.02
No. 17	-	-	-	-	-
No. 18	-	-	-	-	-

Table 6: Voltage drop and power loss of the PV strings connected to the SG80KTL inverter.

The percentage of power loss in the Zone 1 is 0.91 % according to the equation (6).

3.1.2 Zone 2 voltage drop and power loss

The percentage of power loss in the Zone 2 is 0.61 % according to the equation (6).

Strings connected to the SG60KTL inverter					
String	$V_{mp}\,(V)$	$2 \cdot L\,(m)$	Voltage drop (%)	$P_{mp}\,(STC)\,(W)$	Power loss (W)
No. 1	-	-	-	-	-
No. 2	-	-	-	-	-
No. 3	684.2	157.68	0.57	5,940	34.18
No. 4	684.2	154.1	0.56	5,940	33.41
No. 5	684.2	142.96	0.52	5,940	30.99
No. 6	684.2	122.28	0.45	5,940	26.51
No. 7	684.2	113.82	0.41	5,940	24.67
No. 8	684.2	216.3	0.79	5,940	46.89
No. 9	684.2	210.38	0.77	5,940	45.61
No. 10	684.2	200.9	0.73	5,940	43.55
No. 11	684.2	186.08	0.68	5,940	40.34
No. 12	684.2	171.74	0.63	5,940	37.23
No. 13	-	-	-	-	-
No. 14	-	-	-	-	-

Table 7: Voltage drop and power loss of the PV strings connected to the SG60KTL inverter.

Strings connected to the SG50KTL inverter					
No. 1 independent MPPT input					
String	$V_{mp}\,(V)$	$2 \cdot L\,(m)$	Voltage drop (%)	$P_{mp}\,(STC)\,(W)$	Power loss (W)
No. 1	653.1	195.06	0.74	5,670	42.29
No. 2	653.1	176.56	0.67	5,670	38.28
No. 3	653.1	179.16	0.68	5,670	38.84
No. 2 independent MPPT input					
String	$V_{mp}\,(V)$	$2 \cdot L\,(m)$	Voltage drop (%)	$P_{mp}\,(STC)\,(W)$	Power loss (W)
No. 1	653.1	164.4	0.63	5,670	35.64
No. 2	653.1	159.64	0.61	5,670	34.61
No. 3	653.1	151	0.58	5,670	32.73
No. 3 independent MPPT input					
String	$V_{mp}\,(V)$	$2 \cdot L\,(m)$	Voltage drop (%)	$P_{mp}\,(STC)\,(W)$	Power loss (W)
No. 1	684.2	152.64	0.56	5,940	33.09
No. 2	684.2	136.6	0.50	5,940	29.61
No. 3	684.2	144.4	0.53	5,940	31.30
No. 4 independent MPPT input					
String	$V_{mp}\,(V)$	$2 \cdot L\,(m)$	Voltage drop (%)	$P_{mp}\,(STC)\,(W)$	Power loss (W)
No. 1	-	-	-	-	-
No. 2	-	-	-	-	-
No. 3	-	-	-	-	-

Table 8: Voltage drop and power loss of the PV strings connected to the Zone 2 SG50KTL-M inverter.

3.1.3 Zone 3 voltage drop and power loss

Strings connected to the SG50KTL-M inverter					
No. 1 independent MPPT input					
String	$V_{mp}\,(V)$	$2 \cdot L\,(m)$	Voltage drop (%)	$P_{mp}\,(STC)\,(W)$	Power loss (W)
No. 1	653.1	89.4	0.34	5,670	19.38
No. 2	653.1	73.12	0.28	5,670	15.85
No. 3	653.1	63.6	0.24	5,670	13.79
No. 2 independent MPPT input					
String	$V_{mp}\,(V)$	$2 \cdot L\,(m)$	Voltage drop (%)	$P_{mp}\,(STC)\,(W)$	Power loss (W)
No. 1	653.1	102.04	0.39	5,670	22.12
No. 2	653.1	110.66	0.42	5,670	23.99
No. 3	653.1	121.66	0.46	5,670	26.37
No. 3 independent MPPT input					
String	$V_{mp}\,(V)$	$2 \cdot L\,(m)$	Voltage drop (%)	$P_{mp}\,(STC)\,(W)$	Power loss (W)
No. 1	684.2	129.48	0.47	5,940	28.07
No. 2	684.2	138.46	0.50	5,940	30.01
No. 3	-	-	-	-	-
No. 4 independent MPPT input					
String	$V_{mp}\,(V)$	$2 \cdot L\,(m)$	Voltage drop (%)	$P_{mp}\,(STC)\,(W)$	Power loss (W)
No. 1	-	-	-	-	-
No. 2	-	-	-	-	-
No. 3	-	-	-	-	-

Table 9: Voltage drop and power loss of the PV strings connected to the Zone 3 SG50KTL-M inverter.

The percentage of power loss in the Zone 3 is 0.39 % according to the equation (6).

3.1.4 Zone 4 voltage drop and power loss

Strings connected to the SG33KTL-M inverter					
No. 1 independent MPPT input					
String	$V_{mp}\,(V)$	$2 \cdot L\,(m)$	Voltage drop (%)	$P_{mp}\,(STC)\,(W)$	Power loss (W)
No. 1	-	-	-	-	-
No. 2	653.1	97.26	0.37	5,670	21.08
No. 3	653.1	100.58	0.38	5,670	21.08
No. 2 independent MPPT input					
String	$V_{mp}\,(V)$	$2 \cdot L\,(m)$	Voltage drop (%)	$P_{mp}\,(STC)\,(W)$	Power loss (W)
No. 1	653.1	99.46	0.38	5,670	21.56
No. 2	653.1	117.26	0.45	5,670	25.42
No. 3	-	-	-	-	-
No. 3 independent MPPT input					
String	$V_{mp}\,(V)$	$2 \cdot L\,(m)$	Voltage drop (%)	$P_{mp}\,(STC)\,(W)$	Power loss (W)
No. 1	684.2	82.22	0.30	5,940	17.82
No. 2	684.2	80.36	0.29	5,940	17.42

Table 10: Voltage drop and power loss of the PV strings connect to the SG33KTL-M inverter.

The percentage of power loss in the Zone 4 is 0.36 % according to the equation (6).

3.2 AC wire

3.2.1 Determining the section of the AC wires

In order to determine the section of the AC wires, Figure 3 from the Electro Technical Regulation on Low Voltage that includes the technical instruction ITC-BT-19 (General prescriptions) has been consulted.

Inverter model	Maximum AC output current (A)
SG80KTL	116
SG60KTL	96
SG50KTL-M	80
SG80KTL-M	53.5

Table 11: Maximum AC output current (A) of each inverter model.

It is known the maximum AC current of each inverter (see Table 12). The inverters are going to be placed inside the Node 1, and the AC wires will be routed in surface mount firstly to the AC box combiner, and subsequently, to the transformer. The selected type of insulation is Polyvinyl Chloride (PVC) and the number of conductors is 3 as the inverters deliver three-phase electric power.

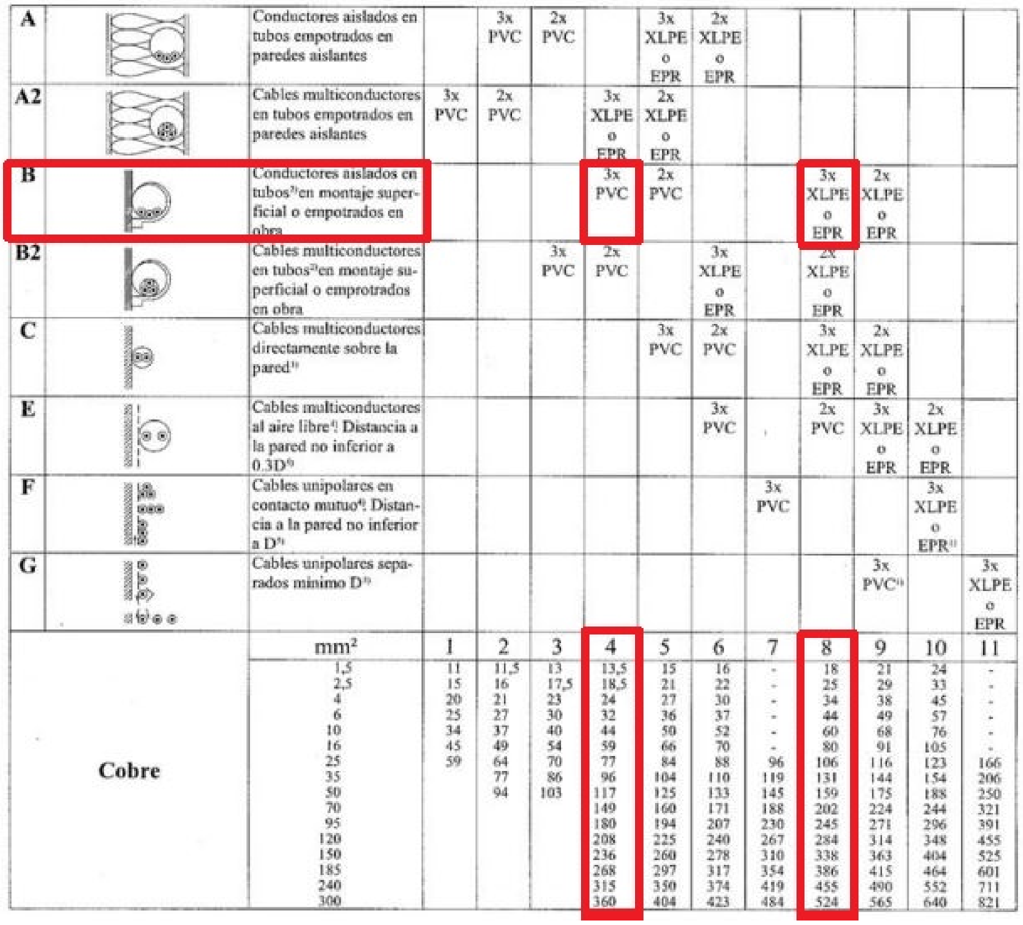
The ambient temperature is another factor to take into account. The admissible current values from the Figure 3 are established for a 40°C ambient temperature. It has been previously seen in section 2.2 that the highest ever recorded ambient temperature in the closest weather station was 44.3°C. Accordingly, as the wire's current conducting capacity is diminished with higher temperatures, a reduction coefficient of 0.91 has to be applied at the admissible current values of the Figure 3 as stated in the Technical Application Papers No. 10, Photovoltaic plants by ABB [11].

Bearing in mind that the admissible current of the wire must be greater than the maximum output current of the inverter, the section of the inverters' AC wire can be now determined.

Inverter model	Maximum AC output current (A)	Section of the AC wire (mm^2)
SG80KTL	116	70
SG60KTL	96	50
SG50KTL-M	80	35
SG33KTL-M	53.5	25

Table 12: Section of the inverters's AC wire.

Lastly, the wire that connects the AC box and the transformer must be sized. If in a given moment in time all the inverters deliver the maximum AC output power at the same time, the AC output power of the combiner box would be 425.5 A. As can be seen from the Figure 3, there is no PVC insulated wire that can withstand that current. That is why a XLPE or EPR insulation wire must be chosen. Among this type of insulated wires, the only wire section that could withstand the abovementioned current once applied the temperature reduction coefficient is the 300 mm^2 section wire.



A	Conductores aislados en tubos empotrados en paredes aislantes		3x PVC	2x PVC		3x XLPE o EPR	2x XLPE o EPR					
A2	Cables multiconductores en tubos empotrados en paredes aislantes	3x PVC	2x PVC		3x XLPE o EPR	2x XLPE o EPR						
B	Conductores aislados en tubos²⁾en montaje superficial o empotrados en obra				3x PVC	2x PVC			3x XLPE o EPR	2x XLPE o EPR		
B2	Cables multiconductores en tubos²⁾en montaje superficial o emprotrados en obra			3x PVC	2x PVC		3x XLPE o EPR		2x XLPE o EPR			
C	Cables multiconductores directamente sobre la pared¹⁾					3x PVC	2x PVC		3x XLPE o EPR	2x XLPE o EPR		
E	Cables multiconductores al aire libre³⁾. Distancia a la pared no inferior a 0.3D⁵⁾						3x PVC		2x PVC	3x XLPE o EPR	2x XLPE o EPR	
F	Cables unipolares en contacto mutuo⁴⁾. Distancia a la pared no inferior a D⁵⁾							3x PVC			3x XLPE o EPR¹⁾	
G	Cables unipolares separados mínimo D⁵⁾									3x PVC¹⁾		3x XLPE o EPR
Cobre	mm²	1	2	3	4	5	6	7	8	9	10	11
	1,5	11	11,5	13	13,5	15	16	-	18	21	24	-
	2,5	15	16	17,5	18,5	21	22	-	25	29	33	-
	4	20	21	23	24	27	30	-	34	38	45	-
	6	25	27	30	32	36	37	-	44	49	57	-
	10	34	37	40	44	50	52	-	60	68	76	-
	16	45	49	54	59	66	70	-	80	91	105	-
	25	59	64	70	77	84	88	96	106	116	123	166
	35		77	86	96	104	110	119	131	144	154	206
	50		94	103	117	125	133	145	159	175	188	250
	70				149	160	171	188	202	224	244	321
	95				180	194	207	230	245	271	296	391
	120				208	225	240	267	284	314	348	455
	150				236	260	278	310	338	363	404	525
	185				268	297	317	354	386	415	464	601
	240				315	350	374	419	455	490	552	711
	300				360	404	423	484	524	565	640	821

Figure 3: Admissible current (A) at 40°C ambient temperature. Number of conductors and type of insulation.

3.2.2 AC wires' voltage drop and power loss

As it has been explained in section 3.1, the section of the copper wire must be large enough to ensure a voltage-drop lower than 1.5%. As can be seen from the Table 13, the voltage-drop of the AC wires is far below the maximum allowed 1.5%. Moreover, the power loss through the AC wires is shown as well. Lastly, the power loss in percent of each zone due to the resistance of AC wires is shown in Table 14.

The voltage-drop of the three-phase AC wires has been calculated making use of the equation (7):

$$u_{ac} = \frac{\sqrt{3} \cdot \rho \cdot L \cdot I_{max} \cdot cos(\phi)}{S \cdot V} \tag{7}$$

Where:

u_{ac}: voltage drop of the AC wire. Measured in %.

ρ: resistivity of annealed copper for electrical applications. ($1/58\ \Omega \cdot mm_2/m$ according to norm UNE 20003).

L: cable length. Measured in m

I_{max}: maximum AC output current. Measured in A.

$cos(\phi)$: power factor ($cos(\phi) = 1$).

S: wire's section. Measured in mm^2.

V: voltage between any two phases (400 V).

On the other hand, the power loss of the three-phase AC wires has been determined using the equation (8):

$$P_{loss} = 3 \cdot I^2 \cdot \frac{\rho \cdot L \cdot}{S} \tag{8}$$

Where:

P_{loss}: power loss through the AC wire. Measured in W.

ρ: resistivity of annealed copper for electrical applications. ($1/58\ \Omega \cdot mm_2/m$ according to norm UNE 20003).

L: cable length. Measured in m

I_{mp}: maximum AC output current. Measured in A.

S: wire's section. Measured in mm^2.

V: voltage between any two phases. (400 V).

AC wire	L (m)	AC wire's section (mm^2)	voltage drop (%)	Power loss (W)
SG80KTL - AC Box	10	70	0.12	99.43
SG60KTL - AC Box	10	50	0.14	95.34
SG50KTL-M - AC Box	10	35	0.17	94.58
SG33KTL-M - AC Box	10	25	0.16	59.31
AC box - transformer	10	300	0.10	312.15

Table 13: Voltage drop and power loss due to the resistance of AC wires.

In order to calculate the percentage of power loss of each zone, the equation (9) has been used. The results can be seen in the Table 14.

$$P_{loss}(\%) = \frac{\Sigma \; Power \; loss}{Zone's \; nominal \; output \; power} \tag{9}$$

Zone	Nominal output power (kW_n)	Power loss (kW)	Power loss (%)
Zone 1	80	0.09943	0.12
Zone 2	110	0.18992	0.17
Zone 3	50	0.09458	0.19
Zone 4	33	0.05931	0.18

Table 14: Power loss in each zone due to resistance of AC wires.

4 Protection element sizing

In order to provide security both to the equipment that forms the PV system and to the personnel in charge of its maintenance and correct operation, it is necessary to set up a series of protection elements that ensure a correct operation of the installation.

4.1 Protection components against overcurrents

According to the the Electro Technical Regulation on Low Voltage that includes the technical instruction ITC-BT-22 (Protection against overcurrents), operating characteristics of the device that protects a wire against overcurrents must meet the following conditions:

- $I_B \leq I_n \leq I_Z$
- $I_2 \leq 1.45 \cdot I_Z$

Where:

I_B: current for which the circuit has been designed. Measured in A.

I_Z: maximum admissible current of the wire (see section 2.2.3 of the ITC-BT-19). Measured in A

I_n: rated current of the protecting device. Measured in A.

I_2: current that ensures the the performance of the protection device for a long period of time (t_c conventional time according to the norm). Measured in A.

4.1.1 DC protection components: fuse

In the case of the PV wires, the maximum current that would flow through the string is the short-circuit current of the PV panel. Hence, $I_B = 9.06\ A$.

The section of the PV wire is 6 mm^2, therefore, according to the section 2.2.3 of the ITC-BT-19, the maximum admissible current for a PVC insulated in surface mount is $I_Z = 32.76\ A$, once the temperature reduction coefficient is applied.

Furthermore, as stated in the datasheet of the chosen PV panel, the maximum series fuse rating is 15 A. So, it is determined that the fuse rating will be 12 A ($I_n = 12\ A$), in order to protect the inverters as well, since the maximum input current per string of all inverters is 12 A. This way, the first condition of the section 4.1 is met.

When it comes to fuses, the equivalent feature to the I_2 is the so-called I_f (functioning current), which for the gG type fuses takes the following values:

$$I_f = 1.60 \cdot I_n \qquad \text{if} \qquad I_n \geq 16\ A$$

$$I_f = 1.90 \cdot I_n \qquad \text{if} \qquad 4\ A < I_n < 16\ A$$

$$I_f = 2.10 \cdot I_n \qquad \text{if} \qquad I_n \leq 4\ A$$

Since the rating current of the fuse is $I_n = 12\ A$, $I_f = 1.90 \cdot 12\ A = 22.8\ A$. Therefore, as $22.8\ A \leq 1.45 \cdot 32.76\ A$, the second condition of the section 4.1 is met as well.

4.1.2 AC protection components: thermal-magnetic CBs

Thermal-magnetic circuit breakers protect simultaneously against overcurrents and short-circuits.

As far as the two conditions mentioned in the section 4.1, in the case of the thermal-magnetic circuit breakers it is not necessary to check the second condition, since for the TMCB $I_2 = 1.45 \cdot I_n$ (according to the UNE EN 60898). Therefore, it is enough if the first condition ($I_B \leq I_n \leq I_Z$) is met.

Furthermore, as stated in the ITC-BT-22, the breaking capacity of the thermal-magnetic CB must be greater than the prospective short-circuit current at the point of installation. Calculation of I_{cc} is therefore essential for selection of equipment. It has been calculated following the guidelines of the technical report by Schneider Electrics [12]. It is determined with the equation (10):

$$I_{cc} = \frac{U/\sqrt{3}}{Z_{cc}} \tag{10}$$

Where:

I_{cc}: 3-phase short-circuit current at the point of installation. Measured in A.

U: phase to phase voltage, corresponds to the transformer no-load voltage. Measured in V.

Z_{cc}: the impedance equal to all the impedances through which I_{cc} flows from the generator to the location of the fault. Measured in Ω.

$$Z_{cc} = \sqrt{(\Sigma R_L)^2 + (\Sigma X_L)^2} \tag{11}$$

Where:

Z_{cc}: the impedance equal to all the impedances through which I_{cc} flows from the generator to the location of the fault. Measured in Ω.

ΣR_L: the sum of the series resistances. Measured in Ω.

ΣX_L: the sum of the series reactances. Measured in Ω.

The upstream network impedance has been neglected for the sake of simplicity. When it comes to the internal transformer impedance, since the technical information of the transformer located in the Node 1 is unknown, it has been assumed that the transformer is a 400 kVA rated power transformer from the Manufacturer Ormazabal. The technical characteristics of the transformer are shown in Figure 4. The internal transformer impedance can be determined with the equation (12):

$$Z_T = \frac{U_{sc}}{100} \cdot \frac{U^2}{S_n} \tag{12}$$

Where:

Z_T: the internal transformer impedance. Measured in Ω.

$U_{sc}/100$: voltage that must be applied to the primary winding of the transformer for the rated current to flow through the secondary winding, when the LV secondary terminals are short-circuited.

U: no-load phase-to-phase voltage of the transformer. Measured in V.

S_n: transformer's rated power. Measured in VA.

Characteristics 24 kV: A_0 B_K

Electrical characteristics			24 kV A_0 B_K											
Rated Power [kVA]			50	100	160	250	400	630	800	1000	1250	1600	2000	2500*
Rated Voltage (Ur)	Primary [kV]		<24											
	No-load Secondary [V]		420											
Vector Group			Dyn11											
No-Load Losses - P_0 [W]		List A_0	90	145	210	300	430	600	650	770	950	1200	1450	1750
Load Losses - P_k [W]		List B_k	875	1475	2000	2750	3850	5400	7000	9000	11000	14000	18000	22000
Short-Circuit Impedance (%) at 75°C			4						6					
Sound Power Level LwA [dB]		List A_0	39	41	44	47	50	52	53	55	56	58	60	60
Voltage drop at full load (%)		cos$f$=1	1.81	1.54	1.32	1.17	1.04	0.93	1.05	1.08	1.06	1.05	1.08	1.06
		cos$f$=0.8	3.57	3.43	3.31	3.22	3.13	3.06	4.35	4.37	4.35	4.35	4.37	4.35
Efficiency (%)	LOAD 100%	cos$f$=1	98.11	98.41	98.64	98.79	98.94	99.06	99.05	99.03	99.05	99.06	99.04	99.06
		cos$f$=0.8	97.64	98.02	98.30	98.50	98.68	98.82	98.82	98.79	98.82	98.83	98.80	98.83
	LOAD 75%	cos$f$=1	98.47	98.72	98.90	99.02	99.14	99.24	99.24	99.23	99.24	99.25	99.23	99.25
		cos$f$=0.8	98.10	98.40	98.63	98.78	98.93	99.05	99.05	99.04	99.06	99.06	99.04	99.07

Figure 4: Technical characteristics of the transformer located in Node 1 [13].

$$Z_T = \frac{4}{100} \cdot \frac{420^2\,[V^2]}{400,000\,[VA]} = 0.01764\,\Omega$$

Therefore, the internal transformer impedance of the transformer located in Node 1, where the PV system is to be connected, is 0.01764 Ω.

As far as the line impedance is concerned, depends on the resistance per unit length, the reactance per unit length and the length of the line. In practice, for LV and conductors with cross-sectional areas less than 150 mm^2, only the resistance is taken into account.

$$R_L = \frac{\rho \cdot L}{S} \tag{13}$$

Where:

R_L: resistance of the line. Measured in Ω.

ρ: resistivity of annealed copper for electrical applications. ($1/58\ \Omega \cdot mm_2/m$ according to norm UNE 20003).

L: length of the line. Measured in m.

S:cross-sectional area of the conductor. Measured in mm^2.

The reactance of the line is determined according to the Figure 5. The cables that connect the inverters to the AC box combiner and subsequently, the AC box combiner to the transformer are spaced single core cables.

Wiring system	Busbars	Three-phase cable	Spaced single-core cables	Touching single core cables (triangle)	3 touching cables (flat)	3 «d» spaced cables (flat) d = 2r	d = 4r
Diagram							
Reactance per unit length, values recommended in UTE C 15-105 (mΩ/m)		0.08	0.13	0.08	0.09	0.13	0.13
Average reactance per unit length values (mΩ/m)	0.15	0.08	0.15	0.085	0.095	0.145	0.19
Extreme reactance per unit length values (mΩ/m)	0.12-0.18	0.06-0.1	0.1-0.2	0.08-0.09	0.09-0.1	0.14-0.15	0.18-0.20

Figure 5: Cables reactance values depending on the wiring system [12].

- Main automatic moulded-case thermal-magnetic CB

  The maximum possible AC output power of the AC box combiner is 425.5 A. Hence, $I_B = 425.5\ A$.

According to the section 2.2.3 of the ITC-BT-19, the maximum admissible current for a 300 mm^2 XLPE insulated in surface mount is $I_Z = 476.84\ A$, once the temperature reduction coefficient is applied.

Therefore, the rated current of the main automatic moulded-case thermal-magnetic CB will be 430 A in order to meet the above mentioned first condition. ($425.5\ A \leq 450\ A \leq 476.84\ A$).

The short-circuit current at the point of the main automatic moulded-case thermal-magnetic CB installation has been calculated as follows:

Since the cross-section of the cables that connect the AC box combiner with the transformer of the Node 1 is 300 mm^2, greater than 150 mm^2, it is necessary to determine the reactance of the cable as well.

$$R_L = \frac{(1/58)[mm^2 \cdot \Omega/m] \cdot 10\ [m]}{300\ [mm^2]} = 5.75 \cdot 10^{-4}\ \Omega$$

$$X_L = 1.5 \cdot 10^{-4}\ [\Omega/m] \cdot 10\ [m] = 1.5 \cdot 10^{-3}\ \Omega$$

$$Z_L = \sqrt{(5.75 \cdot 10^{-4}\ [\Omega])^2 + (1.5 \cdot 10^{-3}\ [\Omega])^2} = 1.61 \cdot 10^{-3}\ \Omega$$

The prospective short-circuit current at the point of the main automatic moulded-case thermal-magnetic CB is:

$$I_{cc} = \frac{420/\sqrt{3}\ [V]}{0.01764\ [\Omega] + 1.61 \cdot 10^{-3}\ [\Omega]} = 12,596.73\ A = 12.60\ kA$$

Therefore, as the breaking capacity of the main automatic moulded-case thermal-magnetic CB model DPX 630 is 36 kA, the above stated second condition is met.

- Thermal-magnetic CB protecting the inverter SG80KTL

The maximum AC output power of the SG80KTL inverter is 116 A. Hence, $I_B = 116\ A$.

According to the section 2.2.3 of the ITC-BT-19, the maximum admissible current for a 70 mm^2 PVC insulated in surface mount is $I_Z = 139.59 A$, once the temperature reduction coefficient is applied.

Therefore, the rated current of the thermal-magnetic CB will be 125 A in order to meet the above mentioned first condition. ($116\ A \leq 125\ A \leq 139.59\ A$).

The short-circuit current at the point of the thermal-magnetic CB installation has been calculated as follows:

Since the cross-section of the cables that connect the SG80KTL with the AC box combiner is 70 mm^2, that is, less than 150 mm^2, only the resistance is taken into account.

$$Z_L = R_L = \frac{(1/58)[mm^2 \cdot \Omega/m] \cdot 10\ [m]}{70\ [mm^2]} = 2.46 \cdot 10^{-3}\,\Omega$$

The prospective short-circuit current at the point of this thermal-magnetic CB is:

$$I_{cc} = \frac{420/\sqrt{3}\ [V]}{0.01764\ [\Omega] + 1.61 \cdot 10^{-3}\ [\Omega] + 2.46 \cdot 10^{-3}\ [\Omega]} = 11.17\,kA$$

Therefore, as the breaking capacity of the chosen thermal-magnetic CB is 25 kA, the above stated second condition is met.

- Thermal-magnetic CB protecting the inverter SG60KTL

The maximum AC output power of the SG60KTL inverter is 96 A. Hence, $I_B = 96\ A$.

According to the section 2.2.3 of the ITC-BT-19, the maximum admissible current for a 50 mm^2 PVC insulated in surface mount is $I_Z = 106.47A$, once the temperature reduction coefficient is applied.

Therefore, the rated current of the thermal-magnetic CB will be 100 A in order to meet the above mentioned first condition. ($96\ A \leq 100\ A \leq 106.47\ A$).

The short-circuit current at the point of the thermal-magnetic CB installation has been calculated as follows:

Since the cross-section of the cables that connect the SG60KTL with the AC box combiner is 50 mm^2, that is, less than 150 mm^2, only the resistance is taken into account.

$$Z_L = R_L = \frac{(1/58)[mm^2 \cdot \Omega/m] \cdot 10\ [m]}{50\ [mm^2]} = 3.45 \cdot 10^{-3}\,\Omega$$

The prospective short-circuit current at the point of this thermal-magnetic CB is:

$$I_{cc} = \frac{420/\sqrt{3}\ [V]}{0.01764\ [\Omega] + 1.61 \cdot 10^{-3}\ [\Omega] + 3.45 \cdot 10^{-3}\ [\Omega]} = 10.68\,kA$$

Therefore, as the breaking capacity of chosen thermal-magnetic CB is 15 kA, the above stated condition is met.

- Thermal-magnetic CB protecting the inverter SG50KTL-M

The maximum AC output power of the SG50KTL-M inverter is 80 A. Hence, $I_B = 80\,A$.

According to the section 2.2.3 of the ITC-BT-19, the maximum admissible current for a 35 mm^2 PVC insulated in surface mount is $I_Z = 87.36\,A$, once the temperature reduction coefficient is applied.

Therefore, the rated current of the thermal-magnetic CB will be 80 A in order to meet the above mentioned first condition. ($80\,A \leq 80\,A \leq 87.36\,A$).

The short-circuit current at the point of the thermal-magnetic CB installation has been calculated as follows:

Since the cross-section of the cables that connect the SG50KTL-M with the AC box combiner is 35 mm^2, that is, less than 150 mm^2, only the resistance is taken into account.

$$Z_L = R_L = \frac{(1/58)[mm^2 \cdot \Omega/m] \cdot 10\,[m]}{35\,[mm^2]} = 4.93 \cdot 10^{-3}\,\Omega$$

The prospective short-circuit current at the point of this thermal-magnetic CB is:

$$I_{cc} = \frac{420/\sqrt{3}\,[V]}{0.01764\,[\Omega] + 1.61 \cdot 10^{-3}\,[\Omega] + 4.93 \cdot 10^{-3}\,[\Omega]} = 10.03\,kA$$

Therefore, as the breaking capacity of the chosen thermal-magnetic CB is 25 kA, the above stated condition is met.

- Thermal-magnetic CB protecting the inverter SG33KTL-M

The maximum AC output power of the SG33KTL-M inverter is 53.5 A. Hence, $I_B = 53.5\,A$.

According to the section 2.2.3 of the ITC-BT-19, the maximum admissible current for a 25 mm^2 PVC insulated in surface mount is $I_Z = 70.07\,A$, once the temperature reduction coefficient is applied.

Therefore, the rated current of the thermal-magnetic CB will be 63 A in order to meet the above mentioned first condition. ($53.5\,A \leq 63\,A \leq 70.07\,A$).

The short-circuit current at the point of the thermal-magnetic CB installation has been calculated as follows:

Since the cross-section of the cables that connect the SG33KTL-M with the AC box combiner is 25 mm^2, that is, less than 150 mm^2, only the resistance is taken into account.

$$Z_L = R_L = \frac{(1/58)[mm^2 \cdot \Omega/m] \cdot 10\ [m]}{25\ [mm^2]} = 6.90 \cdot 10^{-3}\, \Omega$$

The prospective short-circuit current at the point of this thermal-magnetic CB is:

$$I_{cc} = \frac{420/\sqrt{3}\ [V]}{0.01764\ [\Omega] + 1.61 \cdot 10^{-3}\ [\Omega] + 6.90 \cdot 10^{-3}\ [\Omega]} = 9.27\, kA$$

Therefore, as the breaking capacity of the thermal-magnetic CB is 10 kA, the above stated condition is met.

4.2 Protection components against direct and indirect contacts

A differential circuit breaker is a device that opens the circuit in case of leakage (current measured on the phase line is different than the current returned to neutral line), therefore protects users from direct and indirect contacts that might happen in the PV installation and also provides protection to the installation itself since they detect leaks to ground by measuring the current flowing through the conductors.

Differential CBs with 30 mA sensitivity are used to protect people from harm, while 300 mA differential CBs, less sensitive, are used to protect the equipment of the installation.

From the Electro Technical Regulation on Low Voltage that includes the technical instruction ITC-BT-25 (Number of circuits and characteristics), it is understood the rated current of the differential CB should be greater than or equal to that of the thermal-magnetic CB.

On the one hand, each inverter will protected with a 4-pole thermal-magnetic CB. Prior to the each inverter's thermal-magnetic CB, a 4-pole differential CB with a 30 mA sensitivity will be installed. The rated nominal current of the differential CB should be equal or greater than the thermal-magnetic CB's rated current that follows. The nominal rated current of the 30 mA sensitivity differential CBs that have been chose can be seen in Table 15.

Inverter model	Thermal-magnetic CB rated current (A)	Differential CB rated current (A)
SG80KTL	125	125
SG60KTL	100	125
SG50KTL-M	80	100
SG33KTL-M	63	80

Table 15: Rated nominal current of the 30 mA sensitivity differential CBs.

On the other hand, in order to protect the equipment of the PV system, a 4-pole differential CB of 630 A rated current will be installed prior to the main automatic moulded-case thermal-magnetic CB of 500 A rated current.

4.3 Protection components against overvoltages

In order to size the characteristics of the protection device against transient overvoltages, the Electro Technical Regulation on Low Voltage that includes the technical instruction ITC-BT-23

(Protection against overvoltages) has been used.

The whole PV system has to be protected against transient and permanent overvoltages with a type II surge protection.

- Protection level (U_p): according to Figure 6 taken from the ITC-BT-23, for a type II surge, the U_p must be lower than 2.5 kV.

TENSIÓN NOMINAL DE LA INSTALACIÓN		TENSIÓN SOPORTADA A IMPULSOS 1,2/50 (kV)			
SISTEMAS TRIFÁSICOS	SISTEMAS MONOFÁSICOS	CATEGORÍA IV	CATEGORÍA III	CATEGORÍA II	CATEGORÍA I
230/400	230	6	4	2,5	1,5
400/690 1000	-- --	8	6	4	2,5

Figure 6: Protection level for a type II surge.

- Maximum permanent service voltage (U_c): in a 230/400 V network, the U_c must be greater than 253 V.

- Nominal discharge current (I_n): as stated in UNE-HD 60364-5-534, I_n must be greater than 5 kA 8/20 μs, between phase and neutral.

In order to ensure the proper functioning of the protecting device, the minimum section of the copper conductor that connects the device and the earthing installation is 4 mm^2 for a type 2 surge.

5 Earthing installation

The earthing installation is the direct electrical connection, without fuses or any kind of protection, of any part of the electrical circuit or of a conductive part that does not belong to it, by means of a ground connection with an electrode or groups of electrodes buried in the ground.

With the help of the earthing installation, it must be ensured that no dangerous potential differences appear and that, at the same time, it allows grounding of the fault or discharge currents of atmospheric origin.

The Electro Technical Regulation on Low Voltage that includes the technical instruction ITC-BT-18 (Earthing installation) has been used to size the earthing installation.

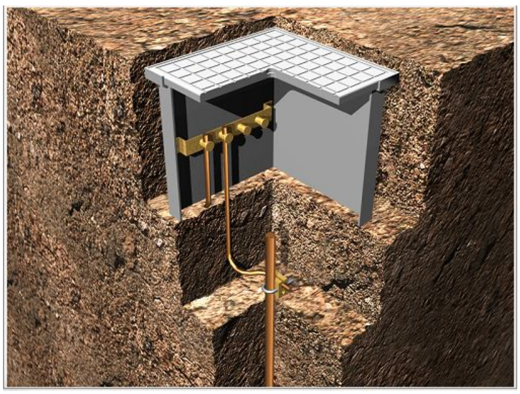


Figure 7: Earthing installation [2].

Lastly, it must be taken into account that in PV installations connected to the grid, the earthing installation of the PV system must be independent of the grounding of the neutral.

5.1 Earth electrode

The earth electrode chosen for the earthing installation is a 1.5 m long and 14 mm in diameter earthing rod. The number of the earthing rods will be determined in such way that the resistance value of the earthing installation will low enough in order to ensure that in any mass of the installation the contact voltage is lower than:

- 24 V in local or conductor position
- 50 V in all remaining cases

According to the Electro Technical Regulation on Low Voltage that includes the technical instruction ITC-BT-26 (Protection against direct and indirect contacts), the equation (14) should be applied:

$$R_A \cdot I_a \leq U \tag{14}$$

Where:

R_A: the sum of resistances of the earthing rods and protecting conductors of the masses. Measured in Ω.

I_a: the residual current assigned to the differential circuit breaker. Measured in A

U: contact voltage. Measured in V.

The maximum contact voltage allowed in any mass of the installation is 24 V. On the other hand, the biggest residual current of the PV system is 300 mA. Hence:

$$R_{A,max} = \frac{24\,[V]}{0.3\,[A]} = 80\Omega$$

The sum of the resistance of the earthing rods and protecting conductors of the masses can not be greater than 80 Ω.

The resistance of the protecting conductor of the masses has been determined as follows:

- The total length of the protecting conductors (6 mm^2) that connect the masses of the PV panels with the ground conductor is 1,820.57 m.

$$R_{PV\ wire} = \frac{(1/58)[\Omega \cdot mm^2/m] \cdot 1,820.57\,[m]}{6\,[mm^2]} = 5.23\,\Omega$$

- The total length of the protecting conductors (35 mm^2) that connect the masses of the inverters with the ground conductor is 25 m.

$$R_{inverters} = \frac{(1/58)[\Omega \cdot mm^2/m] \cdot 25\,[m]}{35\,[mm^2]} = 0.012\,\Omega$$

$$R_{prot.\,conductors} = R_{PV\,wire} + R_{inverters} = 5.23\,[\Omega] + 0.012\,[\Omega] = 5.24\,\Omega$$

The resistance of the protecting conductor is 5.24 Ω.

$$R_{earthing\,rods} = R_A - R_{prot.\,conductors} = 80\,[\Omega] - 5.24\,[\Omega] = 74.76\,\Omega$$

The resistance of a single earthing rod is determined with the equation (15):

$$R_{single\,rod} = \frac{\rho}{L} \tag{15}$$

Where:

$R_{single\,rod}$: resistance of a single the earthing rod. Measured in Ω.

ρ: resistivity of the ground. Measured in $\Omega \cdot m$.

L: length of the earthing rod. Measured in m.

In order to obtain a first approximation of the resistance of a single earthing rod, the calculations can be made using the guidance values of the Figure 8. It has been assumed that the earth surrounding the Node 1 hut is of type stony ground covered with grass, with a resistivity value of 500 $\Omega\,m$.

Naturaleza terreno	Resistividad en Ohm.m
Terrenos pantanosos	de algunas unidades a 30
Limo	20 a 100
Humus	10 a 150
Turba húmeda	5 a 100
Arcilla plástica	50
Margas y Arcillas compactas	100 a 200
Margas del Jurásico	30 a 40
Arena arcillosas	50 a 500
Arena silícea	200 a 3.000
Suelo pedregoso cubierto de césped	300 a 5.00
Suelo pedregoso desnudo	1500 a 3.000
Calizas blandas	100 a 300
Calizas compactas	1.000 a 5.000
Calizas agrietadas	500 a 1.000
Pizarras	50 a 300
Roca de mica y cuarzo	800
Granitos y gres procedente de alteración	1.500 a 10.000
Granito y gres muy alterado	100 a 600

Figure 8: Approximate values of the resistivity according to the earth.

Thus, the resistance of a single earthing rod would be:

$$R_{single\,rod} = \frac{500\,[\Omega \cdot m]}{1.5\,[m]} = 333.33\,\Omega$$

Since the resistance of a single earthing rod is far greater than 74.76 Ω, it is necessary to install several earthing rods in parallel, until the resistance is decreased to the desired value:

$$\frac{1}{R_{earthing\,rods}} = \frac{1}{R_{single\,rod}} + \frac{1}{R_{single\,rod}} + ... = n \cdot \left(\frac{1}{R_{single\,rod}}\right)$$

$$n = \frac{R_{single\,rod}}{R_{earthing\,rods}} = \frac{333.33\,[\Omega]}{74.73\,[\Omega]} = 4.46 \approx 5$$

As a conclusion, it is necessary to install 5 earthing rods in order to ensure that the sum of the resistances of the earthing rods and protecting conductors of the masses is not greater than 80 Ω.

$$R_{earthing\,rods} = \frac{R_{single\,rod}}{n} = \frac{333.33\,[\Omega]}{5} = 66.67\,\Omega$$

$$R_A = R_{prot.\,conductors} + R_{earthing\,rods} = 5.24\,[\Omega] + 66.67\,[\Omega] = 71.91\,\Omega$$

$$71.91\,[\Omega] \cdot 0.3\,[A] = 21.57\,V \leq 24\,V$$

This way, the condition of the equation (14) is fulfilled. Lastly, it is of utmost importance to separate the earthing rods at least 4 times their length (6 m), in order not to influence each other.

5.2 Protection conductors

The protection conductors are used for electrically connecting the masses of the installation to the ground conductor in order to ensure protection against indirect contacts.

The sizing of the protection conductors has been made according to the Figure 9 taken from the ITC-BT-18.

The section of the PV wire is 6 mm^2, as previously explained in section 3.1. Therefore, the section of the protection conductor that connects the masses of the PV panels will be 6 mm^2 as well, since the PV wire's section is smaller than 16 mm^2.

On the other hand, the inverters must be connected to the ground conductor too. As seen in section 3.2.1, the biggest section of an inverter's wire is 70 mm^2. Hence, as this section is greater than 35 mm^2, the minimum section of the protection conductor will be 35 mm^2, half of the 70 mm^2 wire's section.

Sección de los conductores de fase de la instalación S (mm²)	Sección mínima de los conductores de protección S_p (mm²)
S ≤ 16	S_p = S
16 < S ≤ 35	S_p = 16
S > 35	S_p = S/2

Figure 9: Minimum section (mm^2) of the protection conductors.

5.3 Ground conductor

The ground conductor of the earthing installation is a bare cooper cable and it is routed underground. According to the section 3.4 of the ITC-BT-18, the section of the ground conductor must comply with the values of the Figure 10 when the ground conductor is routed underground. Therefore, its minimum section would be 25 mm^2.

In addition, this section will not be smaller than the minimum section required to the protection conductors. As it has been determined in the previous section, since the biggest section of the protection conductors is 35 mm^2, the section of the ground conductor will be 35 mm^2 as well.

TIPO	Protegido mecánicamente	No protegido mecánicamente
Protegido contra la corrosión*	Según apartado 3.4	16 mm² Cobre 16 mm² Acero Galvanizado
No protegido contra la corrosión	25 mm² Cobre 50 mm² Hierro	
* La protección contra la corrosión puede obtenerse mediante una envolvente		

Figure 10: Minimum section (mm^2) of the ground conductor.

6 Determining the section of the protective tubes and channels

The PV wires as well as the AC wires must be protected making use of protective tubes and channels. The characteristics of the protective tubes will be according to that established in the norm UNE-EN 50.86 2-4. Moreover, it is recommended installing the underground tubes at a minimum depth of 0.6 m.

6.1 PV wires

On the one hand, the PV wires and the protection conductors that connect the masses of the PV panels have to be conducted from the solar carports to the Node 1 hut, where the electric board with DC protection components and the inverters are placed. As stated in the technical specifications document for grid-connected PV installations by IDAE [9], the positive and negative ends of the PV strings must be conducted separately.

The PV wires will be routed in surface mount the structure of the solar carport at a height of 3.05 m using a 40x25 mm PVC 2-way cord channel. It has been estimated that a minimum of 260.66 m of cord channel will be necessary to conduct the PV wires through the structure of the solar carport.

In some stretches, more specifically, between the solar carports and the last stretch to reach the Node 1, there is no other option than routing the cables underground. In order to size the protective tubes for this underground stretches, the section 1.2.4 of the Electro Technical Regulation on Low Voltage that includes the technical instruction ITC-BT-21 (Protective tubes and channel) has been followed (see Figure 11). resulting in that it is necessary protecting tubes of 50 and 63 mm external diameter, with a total length of 589 and 79 m, respectively.

Sección nominal de los conductores unipolares (mm²)	Diámetro exterior de los tubos (mm)				
	Número de conductores				
	< 6	7	8	9	10
1,5	25	32	32	32	32
2,5	32	32	40	40	40
4	40	40	40	40	50
6	50	50	50	63	63
10	63	63	63	75	75
16	63	75	75	75	90
25	90	90	90	110	110
35	90	110	110	110	125
50	110	110	125	125	140
70	125	125	140	160	160
95	140	140	160	160	180
120	160	160	180	180	200
150	180	180	200	200	225
185	180	200	225	225	250
240	225	225	250	250	--

Figure 11: Minimum external diameter of the protecting tube according to the number and the section of the conductors.

6.2 AC wires

The AC wires that connect each inverter to the AC box combiner and the wires that connect the AC box combiner to the transformer will be conducted using a blind cable tray Unex 60x100 mm 66 EN U23X. Since the inverters, the AC box combiner and the transformer are all placed inside the Node 1 hut, the length of each blind cable tray will not be longer than 10 m.

7 Energy meter equipment

As stated in the RD 900/2015, in general, PV systems that belong to the self-consumption modality type 2 must have:

- a bi-directional energy meter that measures the net energy produced.
- an energy meter that measures the total energy consumed by the end consumer.
- optionally, a bi-directional energy meter placed in the connection point of the installation.

The energy meters will be installed in the internal network, as close as possible to the connection point.

Furthermore, the energy meters will have to comply with requirements and conditions established by the RD 1110/2007. According to it, the measuring point of the installation is classified as type 3.

The energy meter chosen for the installation is a 3-phase bi-directional energy meter from the manufacturer SMA. It is necessary to use 3 external current transformers, one per phase, since the nominal rated current of the meter is 5 A, while the maximum current that can flow in the point where the energy meter is going to be installed is 425.5 A. The current transformer chosen for the energy meter is a CT from the manufacturer Circutor with primary current levels up to 600 A and a 5 A secondary current.

Figure 12: Current transformer from the manufacturer Cicutor [14].

8 Determining the energy delivered by the PV system

In order to determine the PV production, equation (2), equation (16) and equation (17) have been developed in Python programming language.

$$\eta(T_{ambient}, G) = \eta(STC) \cdot [1 - \gamma \cdot (T_{cell} - 25°)] \tag{16}$$

Where:

$\eta(T_{ambient}, G)$: efficiency of the PV module at a given ambient temperature and irradiance. Dimensionless quantity.

$\eta(STC)$: efficiency of the PV module in STC conditions. Dimensionless quantity.

γ: temperature coefficient of P_{max} (0.0043 °C^{-1}).

T_{cell}: temperature of the PV cell. Measured in °C.

$$\eta(T_{ambient}, G) = \frac{P_{out}}{P_{in}} = \frac{P_{out}}{G \cdot A} \tag{17}$$

Where:

$\eta(T_{ambient}, G)$: efficiency of the PV module at a given ambient temperature and irradiance. Dimensionless quantity.

P_{in}: incident power on all PV modules. Measured in W.

A: total area of all PV modules. Measured in m^2.

P_{out}: power produced by all PV modules. Measured in W.

8.1 Solar resource

The chief of engineering of the hotel has provided the annual data from the pyranometer that is installed in the rooftop (see Figure 13). The tilt angle of the pyranometer is 28° and it is oriented 39° south-west. The quarter hourly data obtained from the pyranometer gives a great opportunity to simulate how the PV system would perform under real conditions in terms of ramping events due to variable weather conditions.

Figure 13: Pyranometer installed in the hotel's rooftop.

Due to the fact that the tilt angle and the orientation of the PV panels of the solar carports differ significantly from those of the pyranometer (see Table 16), different correction factors have been applied for each solar carport zone so that the data from the pyrnometer can be used to calculate the energy yield of the PV system.

	Tilt angle (°)	Orientation (°)
Pyranometer	28	39 (south-west)
Zone 1	15	8 (south-west)
Zone 2	15	0 (due south)
Zone 3	15	-13 (south-east)
Zone 4	15	-8 (south-east)

Table 16: Tilt angle and orientation of the pyranometer and each solar carport zone.

In order to obtain the correction factors, quarter hourly irradiance data of the PV system's location has been downloaded from PVGIS database for the tilt angle and orientation of the pyranometer, as well as for all solar carport zones [15]. Subsequently, the irradiance values of each month of each solar carport zone's tilt angle and orientation have been divided by the irradiance values of the pyranometer's tilt angle and orientation of the same month, resulting in the correction factor for that solar carport zone in that particular month. Each solar carport zone has a different correction factor for each month.

An example of the correction factor applied for the solar carport zone 1 in December can be seen in Table 17.

Hour	Minute	Pyranometer's irradiance (W/m^2)	Zone 1 irradiance (W/m^2)	Correction factor
8	22	46	111	2.41
8	37	82	158	1.93
8	52	122	205	1.68
9	07	166	251	1.51
9	22	210	297	1.41
9	37	255	341	1.34
9	52	300	383	1.28
10	07	344	422	1.23
10	22	386	459	1.19
10	37	427	493	1.15
10	52	466	525	1.13
11	07	502	553	1.10
11	22	536	578	1.08
11	37	567	600	1.06
11	52	596	618	1.04
12	07	622	634	1.02
12	22	644	645	1.00
12	37	664	654	0.98
12	52	680	659	0.97
13	07	692	660	0.95
13	22	702	659	0.94
13	37	707	653	0.93
13	52	709	644	0.91
14	07	707	632	0.89
14	22	701	616	0.88
14	37	691	597	0.86
14	52	678	574	0.85
15	07	660	548	0.83
15	22	638	519	0.81
15	37	612	487	0.79
15	52	581	541	0.78
16	07	546	413	0.76
16	22	506	371	0.73
16	37	462	328	0.71
16	52	413	282	0.68
17	07	358	233	0.65
17	22	297	184	0.62
17	37	230	134	0.58
17	52	140	76	0.54

Table 17: Correction factor for the solar carport zone 1 in December. The hour and minutes correspond to the official time. Irradiance values have been obtained from the PVGIS database [15].

Once the correction factors are applied, the corrected incident irradiance values on each solar carport zones are obtained. The incident irradiance values measured in the pyranometer and those calculated for each solar carport zones on the summer and winter solstices after the correction factors are applied can be seen in Figure 14 and 15, respectively.

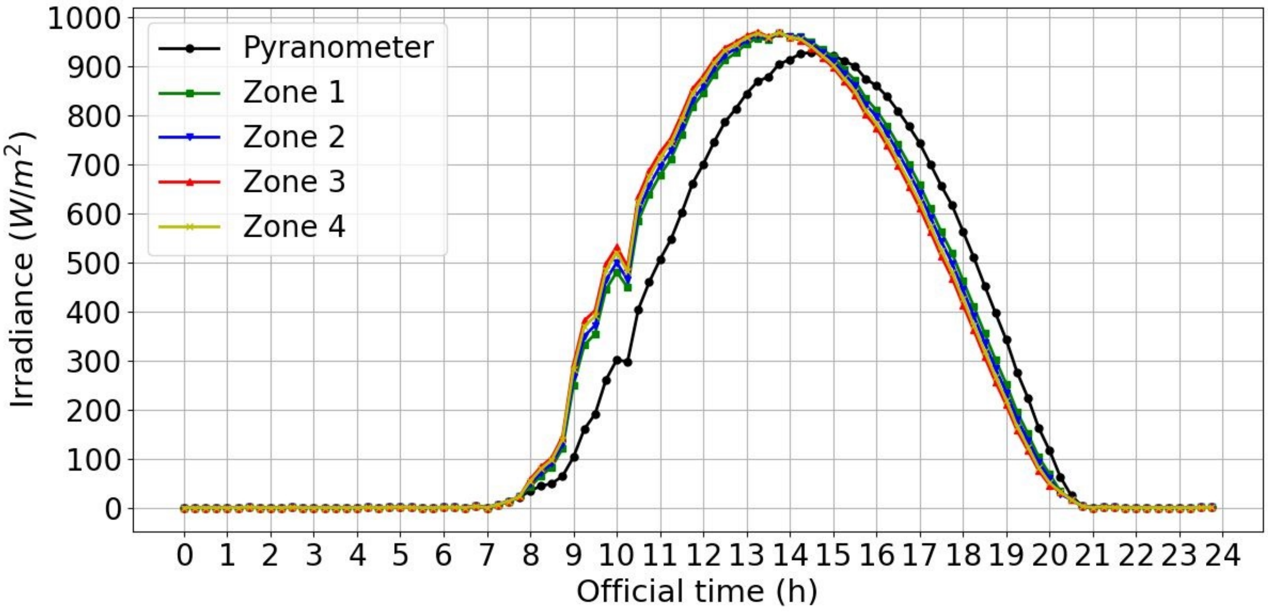


Figure 14: Incident irradiance values measured on the pyranometer and those calculated for each solar carport zones on the 21st of June after the correction factors are applied .

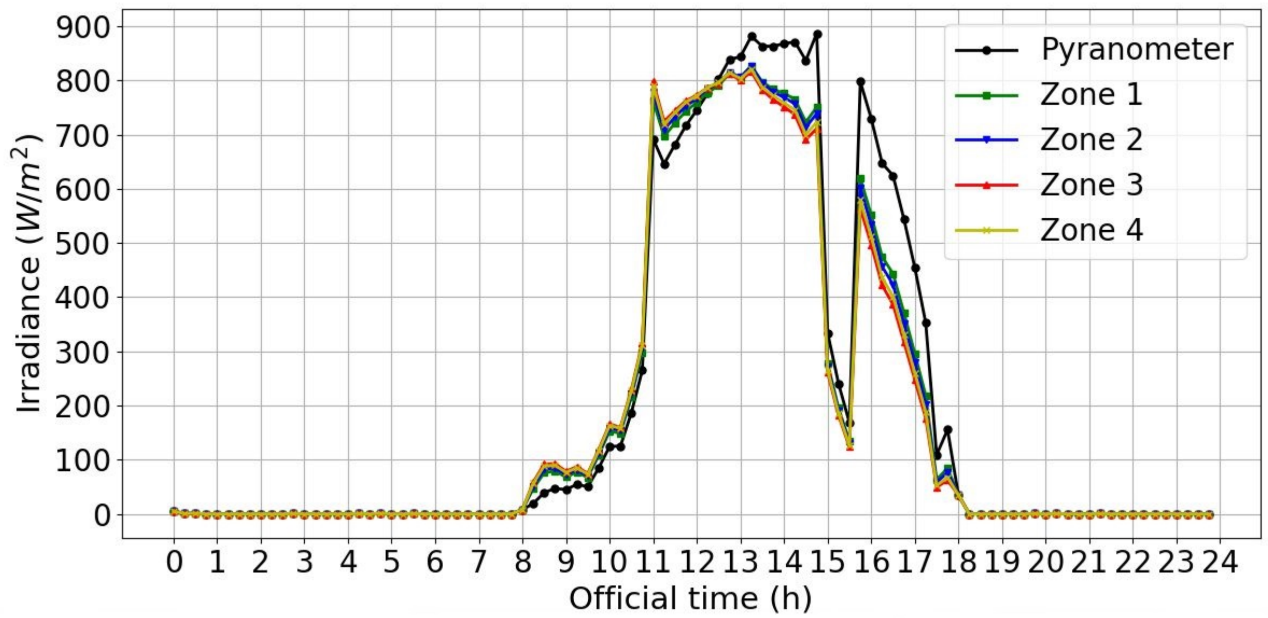


Figure 15: Incident irradiance values measured on the pyranometer and those calculated for each solar carport zones on the 21st of December after the correction factors are applied .

When it comes to the annual irradiation incident on the pyranometer and those values calculated for each solar carport zones, it can be said that they are fairly similar, as can be seen from Table 18.

	Annual irradiation (kWh/m^2)
Pyranometer	2,014.84
Zone 1	2,027.72
Zone 2	2,027.42
Zone 3	2,019.31
Zone 4	2,023.48

Table 18: Annual irradiation incident on the pyranometer and those values calculated for each solar carport zones.

8.2 Calculation of the variation of the ambient temperature

As seen in equation (2), equation (16) and equation (17) the behaviour of the PV modules depends, to some extent, on the ambient temperature. To calculate the variation of the ambient temperature throughout the day, the model of Eduardo Lorenzo published in the book *Handbook of Photovoltaic Science and Engineering* has been used [16].

The data available as a starting point for this calculation are, in general, the maximum and minimum temperature of the day, T_{aM} and T_{am}, respectively. This data has been taken from the closest weather station to the PV system's location, South Tenerife Airport, downloaded from the AEMET database (see Table 19) [10].

Month	Maximum temperature(°C)	Minimum temperature (°C)
January	21.7	15.2
February	22.0	15.0
March	23.1	15.6
April	23.1	16.0
May	23.9	17.0
June	25.4	18.8
July	27.7	20.2
August	28.4	21.1
September	27.9	21.1
October	26.8	20.0
November	24.8	18.2
December	22.8	16.5

Table 19: Average daily maximum and minimum ambient temperature of each month in Tenerife South Airport.

The following set of equations allows the ambient temperature throughout a day j to be calculated as follows:

- For -180 $< \omega \leq \omega s$

$$T_a(j,\omega) = T_{aM}(j-1) - \frac{T_{aM}(j-1) - T_{am}(j)}{2} \cdot [1 + cos(a \cdot \omega + b)] \quad (18)$$

$$a = \frac{-180}{\omega s + 330} \quad and \quad b = -a \cdot \omega s$$

- For $w_S < w \leq 30$

$$T_a(j,\omega) = T_{am}(j) + \frac{T_{aM}(j) - T_{am}(j)}{2} \cdot [1 + cos(a \cdot \omega + b)] \tag{19}$$

$$a = \frac{180}{\omega s - 30} \quad and \quad b = -30a$$

- For $30 < w \leq 180$

$$T_a(j,\omega) = T_{aM}(j) - \frac{T_{aM}(j) - T_{am}(j+1)}{2} \cdot [1 + cos(a \cdot \omega + b)] \tag{20}$$

$$a = \frac{180}{\omega s + 330} \quad and \quad b = -(30 + 180)$$

Where:

$T_a(j,\omega)$: ambient temperature of a given j day.

T_{aM}: maximum temperature of the day. Measured in °C. Occurs two hours after midday ($\omega = 30°$).

$T_{aM}(j-1)$: maximum temperature of the previous day. Measured in °C.

T_{am}: minimum temperature of the day. Measured in °C. Occurs at sunrise ($\omega = \omega s$).

$T_{am}(j+1)$: minimum temperature of the next day. Measured in °C.

ω: hour angle. Measured in °.

ωs: hour angle at sunrise. Measured in °.

As an illustrative example, the variation of the ambient temperature on the 31st of March can be seen in the Figure 16.

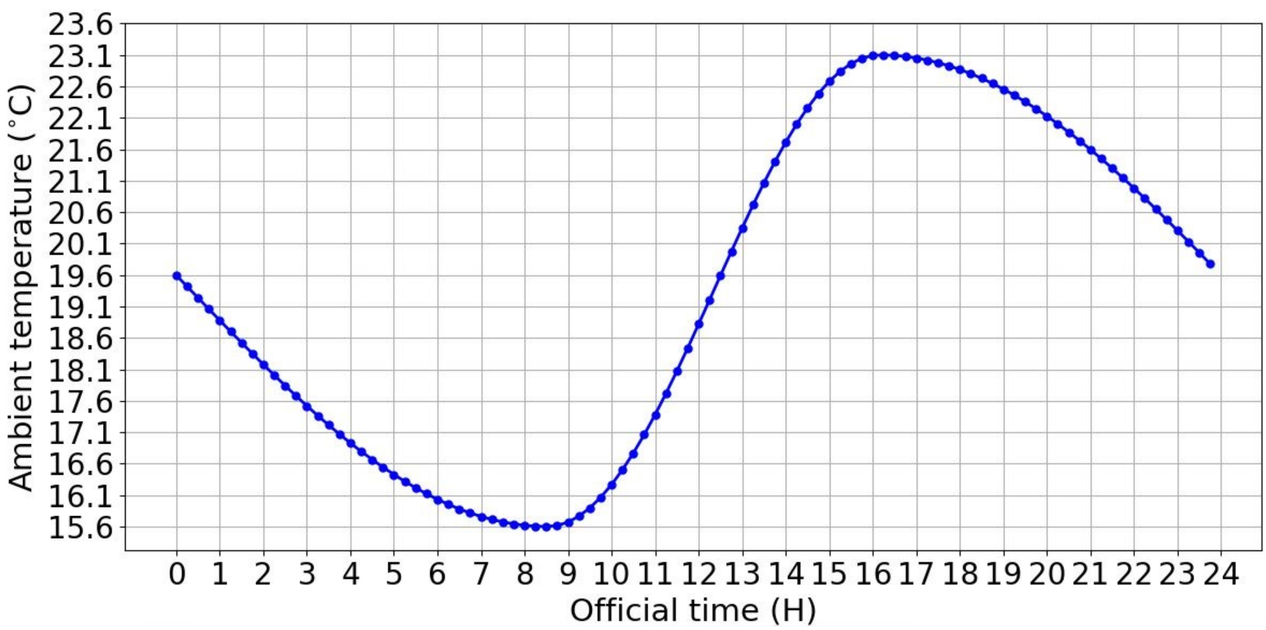


Figure 16: Variation of the ambient temperature on the 31st of March.

8.3 PV system's losses

In this section the factors that reduce the PV system's output are explained and quantified.

- Light-Induced Degradation (LID): PV panels suffer a loss in output power when they are initially exposed to sunlight. According to the datasheet of the chosen PV module, this loss is estimated to be 3%.
- Shading: shade loss has a great impact on the energy production of a solar installation. The default value of Aurora [17], the NREL-validated performance simulation engine, has been chosen, which is 3%.
- Soiling: soiling occurs due to dirt and dust accumulation on the PV modules. A default value of 2% has been selected, as Aurora does, although it depends heavily on the location of the PV system.
- Mismatch: even though PV modules of a given type have the same datasheet, in reality their IV characteristics can vary slightly due to variability in manufacturing processes. This mismatch in IV characteristics leads to a reduction in energy production in string inverter designs. According to Aurora, industry consensus is that around 2% of system energy production is lost by cause of module mismatch.
- Connections: represents resistive losses in connectors in the PV system. A 0.5% loss has been chosen based on the Aurora's default value.
- DC losses: resistive losses owing to the PV wires' resistance. Each solar carport zone has its own DC loss.
  - Zone 1: 0.91% loss
  - Zone 2: 0.61% loss
  - Zone 3: 0.39% loss
  - Zone 4: 0.36% loss
- Clipping: every inverter has a maximum rated power. When the generated DC power is greater than the inverter's power rating, the 'extra' power generated by the array is 'clipped' by the inverter to ensure it is operating within its capabilities. The energy lost due to clipping in the first full year of operation of the PV system is negligible as can be seen below:
  - Zone 1: 0.00007 % loss (SG80KTL)
  - Zone 2: no clipping occurs (SG60KTl and SG50KTL-M)
  - Zone 3: no clipping occurs (SG50KTL-M)
  - Zone 4: 0.0002 % loss (SG33KTL-M)
- Inverter efficiency: there is a power loss in the inverters when converting DC power into usable AC power. Inverter's european efficiency has been taken into account:
  - Zone 1: 1.3% loss (SG80KTL)
  - Zone 2: 1.39% loss (SG60KTl and SG50KTL-M)
  - Zone 3: 1.5% loss (SG50KTL-M)
  - Zone 4: 1.7% loss (SG33KTL-M)

- AC losses: resistive losses owing to the AC wires' resistance. Each AC cable has its own loss.
  - Wires that connect Zone 1 inverter to AC box combiner: 0.12% loss
  - Wires that connect Zone 2 inverter to AC box combiner: 0.17% loss
  - Wires that connect Zone 3 inverter to AC box combiner: 0.19% loss
  - Wires that connect Zone 4 inverter to AC box combiner: 0.18% loss
  - Wires that connect the AC box combiner to the transformer: 0.11% loss
- Angular dependent loss: according to [18], the effect on the yearly yield for standard module orientations (e.g. 30° South) is not of significant impact. Therefore, it has not been taken into account.

8.4 Energy delivered by the PV system

Taking into account everything that has been explained in section 8 so far, the energy delivered by the PV system in the first full year of operation is 428,109.08 kWh. The monthly energy production of the PV system can be seen in Figure 17.

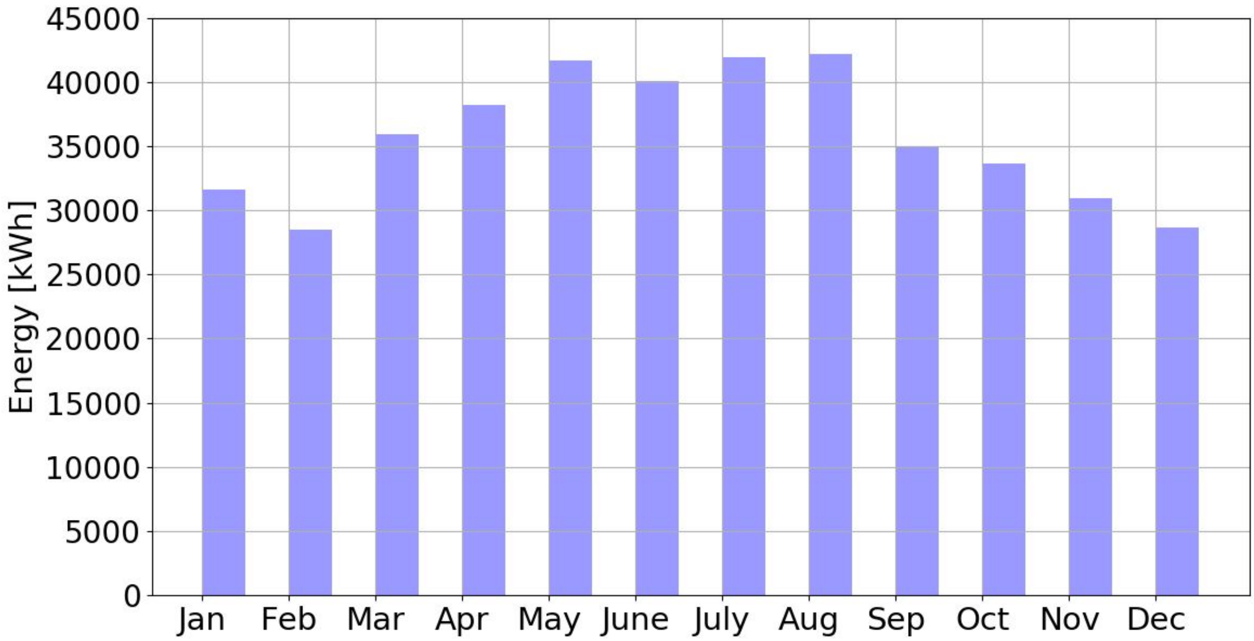


Figure 17: Energy delivered by the PV system in each month of the first full year of operation.

9 Determining the Performance Ratio (PR) of the PV system

The PR is the ratio of the actual and theoretically possible energy outputs of the PV system. It has been calculated using equation (21):

$$PR = \frac{Actual\ reading\ of\ PV\ plant\ output\ in\ kWh}{Nominal\ PV\ plant\ output\ in\ kWh} \tag{21}$$

Where:

- *Actual reading of PV plant output in kWh*: the actual PV system's energy production in kWh.
- *Nominal PV plant output in kWh*: annual incident solar irradiation at the generator surface of the PV plant multiplied by the efficiency of the PV modules.

The actual reading of PV plant output in the first year of operation has been estimated in 428,109.08 kWh in section 8.4. On the other hand, the nominal PV plant output can be seen in Table 20. It has been calculated taking into account that the efficiency of the chosen PV module is 16.6%.

Zone	Annual irradiation (kWh/m^2)	Area (m^2)	Nominal zone output (kWh)
Zone 1	2,027.72	501.08	168,664.29
Zone 2	2,027.42	670.27	225,580.52
Zone 3	2,019.31	276.57	92,707.77
Zone 4	2,023.48	208.24	69,947.33
Total nominal PV plant output in kWh in the first year			556,899.91

Table 20: Nominal output of each solar carport zone and the total nominal PV plant output in kWh in the first year of operation.

Therefore:

$$PR = \left(\frac{428,109.08\ kWh}{556,899.91\ kWh}\right) \cdot 100 = 76.87\ \%$$

In conclusion, the PR of the PV system in the first full year of operation is 76.87 %. However, the chosen PV module suffers a linear performance degradation throughout the years that affect negatively the PR of the PV system. According to the datasheet of the PV module, it delivers 97% of the nominal power output in the first year, while this value is reduced to 80.6% in the year 30 of operation.

The development of the PR of the PV system throughout the 25 years of operation can be seen in Figure 18.

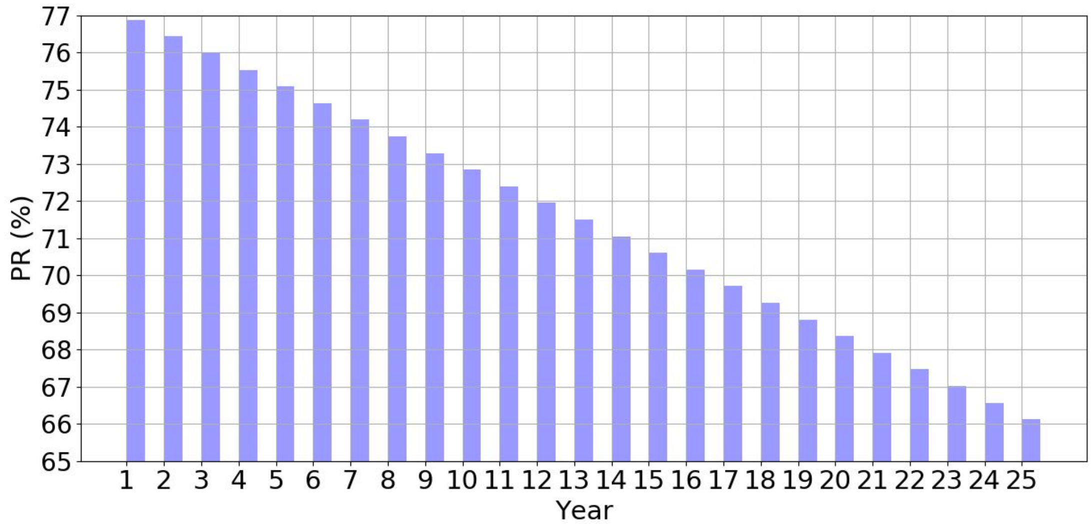


Figure 18: Development of the PR of the PV system throughout the years.

10 Determining the saving produced by the PV system

In this section, the saving produced in the variable energy term of the electricity bill of the hotel due to the self-consumed energy delivered by the PV system will be calculated.

First of all, it should be noted that the hotel has currently contracted a 6.1 A high-voltage 6 pricing period electricity tariff. The pricing periods are defined in the Ordinance ITC/2794/2007, of September 17, which modifies the RD 1164/2001, of October 26. According to it, the electric seasons for the Canary Islands are defined as follows:

- High season with consumption peak in the morning and afternoon: September, October, November and December
- Mid season with morning consumption peak: July and August
- Mid season with afternoon consumption peak: January and February
- Low season: March, April, May and June

According to the Resolution of 27 July 2004, of the General Direction of Energy Policy and Mines, the Month of May is classified as the month of minimum energy demand for the Canary Islands.

On the other hand, the type of days are defined as follows:

- Type A: high season working days from Monday to Friday with a consumption peak in the morning and afternoon
- Type A1: high season working days from Monday to Friday with morning consumption peak
- Type B: mid season working days from Monday to Friday with morning consumption peak
- Type B1: mid season working days from Monday to Friday with afternoon consumption peak
- Type C: low season working days from Monday to Friday, except August for the mainland's system, April for the Balear Islands' system and May for the Canary Islands, Ceuta and Melilla's electric systems
- Type D: Saturdays, Sundays, holidays and August for the mainland's system, April for the Balear Islands' system and May for the Canary Islands, Ceuta and Melilla's electric system.

Since the data of the electric power consumption of the hotel provided by the chief of engineering covers the period from 1 October of 2016 to 30 September of 2017, official national holiday calendar of both years have been taken into account. The result can be seen in Table 21, where each day of the year has been classified according to the above stated guidelines.

Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
January	D	B1	B1	B1	B1	D	D	D	B1	B1	B1	B1	B1	D	D	B1	B1	B1	B1	B1	D	D	B1	B1	B1	B1	B1	D	D	B1	B
February	B1	B1	B1	D	D	B1	B1	B1	B1	B1	D	D	B1	B1	B1	B1	B1	D	D	B1	B1	B1	B1	B1	D	D	B1	B1			
March	C	C	C	D	D	C	C	C	C	C	D	D	C	C	C	C	C	D	D	C	C	C	C	C	D	D	C	C	C	C	C
April	D	D	C	C	C	C	C	D	D	C	C	C	D	D	D	D	C	C	C	C	C	D	D	C	C	C	C	C	D	D	
May	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
June	C	C	D	D	C	C	C	C	C	D	D	C	C	C	C	C	D	D	C	C	C	C	C	D	D	C	C	C	C	C	
July	D	D	B	B	B	B	B	D	D	B	B	B	B	B	D	D	B	B	B	B	B	D	D	B	B	B	B	B	D	D	B
August	B	B	B	B	D	D	B	B	B	B	B	D	D	B	D	B	B	B	B	D	B	B	B	B	B	D	D	B	B	B	B
September	A	D	D	A	A	A	A	A	D	D	A	A	A	A	A	D	D	A	A	A	A	A	D	D	A	A	A	A	A	D	
October	D	D	A	A	A	A	A	D	D	A	A	D	A	A	D	D	A	A	A	A	A	D	D	A	A	A	A	A	D	D	A
November	D	A	A	A	D	D	A	A	A	A	A	D	D	A	A	A	A	A	D	D	A	A	A	A	A	D	D	A	A	A	
December	A	A	D	D	A	D	A	D	A	D	D	A	A	A	A	A	D	D	A	A	A	A	A	D	D	A	A	A	A	A	D

Table 21: Classification of each day of the year.

Furthermore, the pricing periods for the Canary Islands are shown in Figure 19.

Periodo tarifario	Tipo de día					
	Tipo A	Tipo A1	Tipo B	Tipo B1	Tipo C	Tipo D
1	De 11 a 14 h. De 18 a 21h	De 11a 19 h.	---	---	---	---
2	De 8 a 11 h. De 14 a 18h. De 21 a 24 h.	De 8 a 11 h. De 19 a 24 h.	---	---	---	---
3			De 9 a 15 h.	De 16 a 22 h.	---	---
4			De 8 a 9 h. De 15 a 24 h.	De 8 a 16 h. De 22 a 24 h.	---	---
5			---	---	De 8 a 24 h.	---
6	De 0 a 8	De 0 a 8	De 0 a 8	De 0 a 8	De 0 a 8	De 0 a 24

Figure 19: Definition of the pricing periods for the Canary Islands.

Taking into account how each day of the year has been classificated and which hours of day correspond to each pricing period, the energy produced by the PV system in each pricing period in the first full year of operation has been determined (see Figure 20).

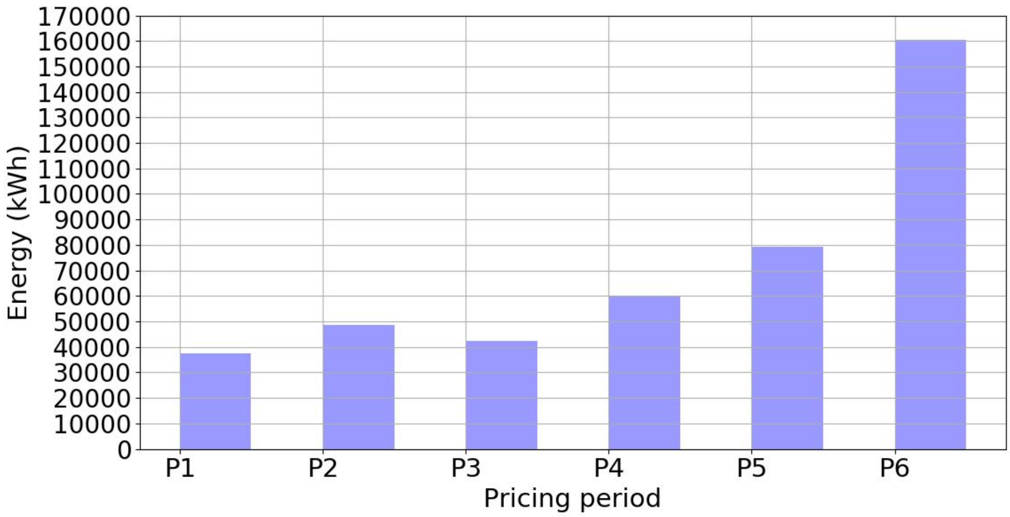


Figure 20: Energy produced by the PV system in each pricing period in the first full year of operation.

Once the energy produced by the PV system in each pricing period is known, the 6.1 A electricity tariff for Canary Islands' industry offered by the energy supplier company Aura Energía has been chosen to estimate the saving that the PV system will produce in the variable energy term [19]. This electricity tariff has a fixed price for both the capacity and variable energy term, which can be seen in Table 22.

Pricing period	Fixed energy term price (€/kWh)	Produced PV energy (kWh)	Saving (€)
P1	0.126534	37,508.79	4,746.14
P2	0.111166	48,591.32	5,401.70
P3	0.102299	42,333.62	4,330.69
P4	0.090893	59,737.36	5,429.71
P5	0.085245	79,423.89	6,770.49
P6	0.072925	160,514.09	11,705.49
Total money saved in the variable energy term in the first year			38,384.21

Table 22: Saving due to the self-consumed energy produced by the PV system in the first full year of operation.

The self-consumed energy produced by the PV system will have a positive impact in the variable energy term of the electricity bill, since the electric energy demanded from the grid will decrease, while the capacity term of the electricity bill remains intact. This saving has been estimated in 38,384.21 €in the first full year of operation of the PV system.

11 Economic analysis of the investment

The comprehensive economic analysis is carried out through a cost-benefit analysis, consisting in a comparison between the initial investment and the NPV which is expected to inflow during the life of the PV system [11].

11.1 Net Present Value (NPV)

The NPV represents the difference between the sum of the discounted cash flows generated throughout the lifetime of the project and the initial investment I_o as can be seen from the equation (22):

$$NPV = \sum_{j=1}^{n} \frac{FC_j}{(1+C_c)^j} - I_0 \tag{22}$$

Where:

- NPV: Net Present Value. Measured in €.
- FC_j: cash flow in the j-th year. Measured in €.
- C_c: cost of the capital given by the relation $C_c = i - f$, difference between the estimated interest rate i and the rate of inflation f. Dimensionless.
- n: years of duration of investment. Dimensionless.

- I_0: initial investment. Measured in €.

If the NPV happens to be positive, it means that at the end of the lifetime of the project, the produced discounted cash flows will have given greater returns than the cost of the initial investment and consequently, the execution of the project would be convenient from a financial point of view.

In order to calculate the NPV of the project, the cost of the capital C_c has been determined first. On the one hand, the average of last ten auctions of the 30-year Government Bond has been selected as the estimated interest rate i, resulting in 4.55% [20]. On the other hand, the average value of the inflation of the period that covers 2000 to 2017 has been chosen as the rate of inflation f, resulting in 2.2% [21]. Therefore, the cost of the capital C_c has been estimated in 2.35%.

The annual operation and maintenance of the PV system has been estimated in 19.28 €/kW_p according to [22].

The initial investment I_0 of this project has been estimated in 351,520.81 €, as can be seen from document Bill of Material and Budget.

Lastly, the lifetime of the project has been considered to be 25 years. Thus, the development of the non discounted cash flow, earnings, discounted cash flow and the NPV throughout the lifetime of the project are shown in Table 23.

Once the relevant cash flow for each year has been determined, the NPV estimated in the period of 25 years by applying equation (22) results to be positive and equal to 223,340.83 €, and as a consequence, the investment is profitable.

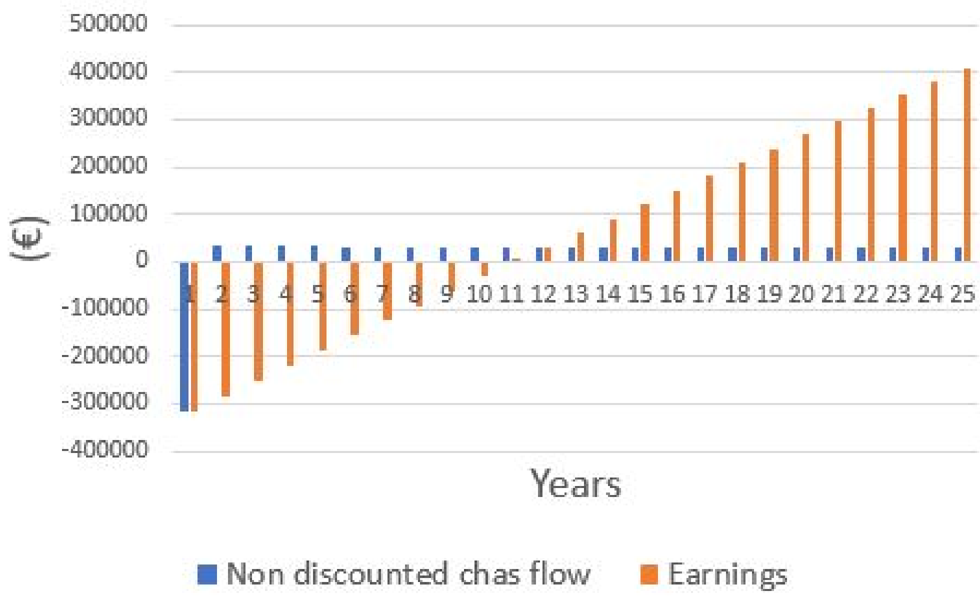


Figure 21: Development of the non discounted cash flow and the earnings throughout the years.

Year	Produced energy (kWh)	Revenues (€)	O&M (€)	Non discounted CF (€)	Earnings (€)	Discounted CF (€)	NPV (€)
1	428,109.08	38,384.21	5,299.30	-318,435.90	-318,435.90	-319,195.54	-319,195.54
2	425,613.31	38,160.44	5,299.30	32,861.14	-285,574.76	31,369.45	-287,826.10
3	423,117.45	37,936.66	5,299.30	32,637.36	-252,937.40	30,440.48	-257,385.60
4	420,621.58	37,712.88	5,299.30	32,413.58	-220,523.82	29,537.63	-227,848.00
5	418,125.67	37,489.10	5,299.30	32,189.80	-188,334.02	28,660.19	-199,187.80
6	415,629.76	37,265.32	5,299.30	31,966.02	-156,368.00	27,807.47	-171,380.30
7	413,133.85	37,041.53	5,299.30	31,742.23	-124,625.78	26,978.79	-144,401.50
8	410,637.94	36,817.75	5,299.30	31,518.45	-93,107.33	26,173.51	-118,228.00
9	408,142.03	36,593.97	5,299.30	31,294.67	-61,812.66	25,391.00	-92,837.03
10	405,646.12	36,370.18	5,299.30	31,070.88	-30,741.79	24,630.60	-68,206.42
11	403,150.21	36,146.40	5,299.30	30,847.10	105.32	23,891.75	-44,314.67
12	400,654.30	35,922.62	5,299.30	30,623.32	30,728.64	23,173.84	-21,140.82
13	398,158.39	35,698.84	5,299.30	30,399.54	61,128.18	22,476.31	1,335.48
14	395,662.48	35,475.05	5,299.30	30,175.75	91,303.93	21,798.58	23,134.06
15	393,166.57	35,251.27	5,299.30	29,951.97	121,255.90	21,140.13	44,274.195
16	390,670.67	35,027.49	5,299.30	29,728.19	150,984.09	20,500.43	64,774.62
17	388,174.76	34,803.70	5,299.30	29,504.40	180,488.49	19,878.95	84,653.57
18	385,678.85	34,579.92	5,299.30	29,280.62	209,769.11	19,275.20	103,928.77
19	383,182.94	34,356.14	5,299.30	29,056.84	238,825.94	18,688.71	122,617.48
20	380,687.03	34,132.35	5,299.30	28,833.05	267,658.99	18,118.97	140,736.46
21	378,191.12	33,908.57	5,299.30	28,609.27	296,268.26	17,565.56	158,302.02
22	375,695.21	33,684.79	5,299.30	28,385.49	324,653.75	17,028.00	175,330,02
23	373,199.30	33,461.01	5,299.30	28,161.71	352,815.46	16,505.87	191,835.90
24	370,703.39	33,237.22	5,299.30	27,937.92	380,753.38	15,998.73	207,834.63
25	368,207.48	33,013.44	5,299.30	27,714.14	408,467.52	15,506.19	223,340.83

Table 23: Development of the non-discounted and discounted cash flows, earnings and the NPV throughout the years.

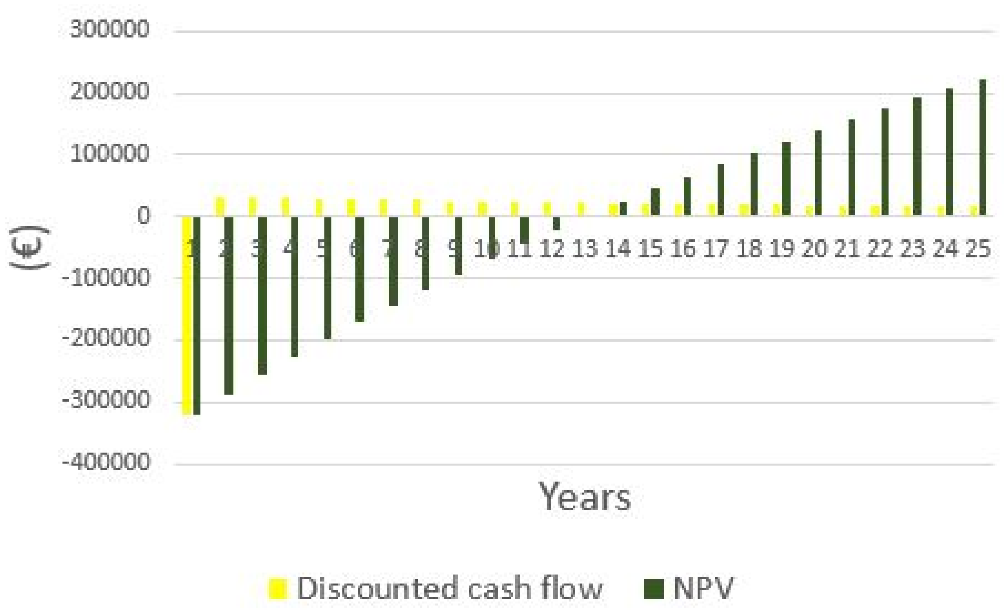


Figure 22: Development of the discounted cash flow and NPV throughout the years.

11.2 Internal Rate of Return (IRR)

It is the value of the cost of the capital C_c for which the NPV is equal to null and it represents the profitability of the investment whose suitability is being evaluated [11].

In order to calculate the IRR, the IRR function in Microsoft Excel has been used. According to it, the IRR of this project is equal to 7% and since it is higher than the cost of the capital (7% > 2.35%), the investment is appropriate.

11.3 Discounted Payback Period (DPP)

The DPP occurs when the negative cumulative discounted cash flows turns into positive cash flows [23]. It is calculated with the equation (23):

$$DPP = Year\,before\,DPP\,occurs + \frac{Cumulative\,cash\,flow\,in\,year\,before\,recovery}{Discounted\,cash\,flow\,in\,year\,after\,recovery} \tag{23}$$

$$DPP = 12\,[years] + \frac{21,140.82\,[€]}{22,476.31\,[€]} = 12.94\,years$$

The DPP of this project is 12.94 years, consequently, the investment is favourable.

Master of Science in Renewable Energy

274 kW_p GRID-CONNECTED PHOTOVOLTAIC SYSTEM FOR SELF-CONSUMPTION

Appendix 2. Basic Health and Safety Study

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Faculty of science: physics section

June 28, 2018

Contents

1 Object of study

The present document contains the Basic Safety and Health Study required to obtain the construction permits for the installation of the PV system in the parking lot located in main road, TF-47, km 9, 38687 Guia de Isora, Santa Cruz de Tenerife.

2 Regulation

As a result of the Law 31/1995, of November 8, on Prevention of Occupational Risks, the ministry of presidency approved the RC 1627/1997, of 24 October, published in the B.O.E. no. 256 of October 25, 1997, which establishes the minimum safety and health provisions in the works of construction.

This RD defines the new health and safety study, as well as the Basic Health and Safety Study and the Health and Safety Plan at Work.

According to article 17 of this RD, it is compulsory to include the Health and Safety Study or the Basic Health and Safety Study in the project, so that such project can be approved and obtain the required municipal license and other authorizations and procedures by the different public administrations.

The preparation of the Health and Safety Study will be mandatory in the case of:

- contracted operation budget equal or greater than 451,000 €.
- duration of the work exceeding 30 working days and simultaneous presence of more than 20 workers in the work.
- sum of the days of work of the total of the workers in the construction greater than 500.
- works of tunnels, galleries, underground conduits and dams.

In the rest of the works projects that do not meet any of the condition mentioned above, a Basic Health and Safety Study will be compulsory.

According to current regulations, this Basic Health and Safety Study must identify all occupational risks, both those the ones that can be avoided, indicating the technical measures necessary for that, and those that can not be avoided, indicating the necessary prevention and protection measures.

Once indicated the type of safety and health study to be carried out, the following regulations will be used to guarantee the safety of the workers in the execution of the work:

- Statute of Workers Rights
- Law 31/1995 of November 8, on Prevention of Occupational Risks.
- RD 485/1997 of April 14, on Signals of Safety at Work.
- RD 486/1997 of April 14, on Health and Safety in workplaces.
- RD 487/1997 of April 14, on Cargo Handling.

- RD 773/1997 of May 30, on the Use of Individual Protection Equipment.
- RD 39/1997 of January 17, Regulation of Prevention Services.
- RD 1215/1997 of July 18, on the Use of Work Equipment.
- RD 1627/1997 of October 24, which establishes the Minimum Health and Safety Regulations for Construction Works.

3 Characteristics of the installation

3.1 Description of the installation and location

The scope of the present basic Health and Safety Study is the execution of a grid-connected PV system for self-consumption in a public parking lot.

3.2 Description of the processes

In chronological order, the processes to be carried out are as follows:

- Assembly of systems to ensure the safety of people and objects.
- Mounting of the solar carports' structure.
- Mounting of the PV panels on top of the solar carports.
- Laying of power and control cables.
- Earthing connections
- Mounting of the inverters and laying of DC and AC lines.
- Mounting of the meter, protection and measurement box.
- Testing and commissioning.

3.3 Expected maximum number of personnel and estimated duration of the works of installation

The maximum personnel for electrical installations is expected in 4 people. On the other hand, the expected duration of the works of electrical installation is 2 weeks.

4 Definition of risks

In this section the foreseeable risks inherent to the planned execution activities as well as those derived from the use of machinery and auxiliary means or the manipulation of electrical installations, machines or tools are analysed.

Firstly the general risks that may occur in any of the activities are analysed. Subsequently, the analysis of the specific aspects of each activity, including those that may affect third parties alien to the work is carried out.

Thus, it is intended to make this plan operational since it allows an overview of the risks on which it will be necessary to act systematically based on specific activities.

4.1 General risks

It is understood as general risks those that affect all the people who work in the activities or processes above mentioned, independently of the concrete activity that they carry out. It is anticipated that the following may occur:

- Fall of objects, or components of the installation on people.
- Fall of people at different levels (through a gap, from platforms).
- Fall of people on the same level.
- Projections of particles to the eyes.
- Conjunctivitis due to welding arc or others
- Wounds, in hands or feet, for the handling of materials.
- Overstress.
- Blows and cuts due to the use of tools.
- Wounds from sharp or sharp objects.
- Blows against objects.
- Catching between objects.
- Burns due to thermal contacts.
- Exposure to electric shocks.
- Entrapment by machine overturning
- Running over or hitting vehicles in motion
- Dust, noise, etc.

4.2 Specific risks

In this section reference is made to the risks inherent in specific activities that affect only the personnel who perform work in it. These personnel will be exposed to the general risks listed above, plus the specific risks of their specific activity.

Consequently, the most significant activities are analysed below:

4.2.1 Transport of materials and equipment within the work

In this activity, in addition to the general risks described above, the following specific risks are foreseen:

- Detachment and falling of the load, or of a part, for being this excessive or poorly secured.
- Blows against protruding parts of the load.
- Running over people.
- Overturning.

- Collision against other vehicle or machines.
- Collision of the load against the installations.

4.2.2 Electromechanical assemblies of equipment and accessories

In this activity, in addition to the general risks described above, the following specific risks are foreseen:

- Material fall due to poor execution of lifting and coupling maneuvers or mechanical failure of the equipment.
- Fall of materials.
- Fall of people from ladders or from pipes or structures.
- Explosions or fires due to the use of gases in torch work.

4.2.3 Risks derived from the use of machines and auxiliary means

In this section the risks that, in addition to the general ones, can be presented in the use of machinery, electrical or mechanical tools and auxiliary means are analysed.

In order to make this plan as operational as possible, the foreseeable risks in these auxiliary means of execution will be classified in the following groups:

4.2.3.1 Fixed machines, tools and electrical panels

The most significant risks are:

- The characteristics risks of work on elements with electrical voltage in which accidents can occur due to both direct and indirect contacts.
- Injuries due to improper use, or bad conditions of rotating or cutting machines.
- Particles projection.
- Cuts in hands for handling residual material.

4.2.3.2 Lifting means

In this activity, in addition to the general risks described above, the following specific risks are foreseen:

- Drop of the load due to poor securing.
- Cable break, hook, strobe, shackle or any other auxiliary lifting device.
- Blows or collisions due to uncontrolled movements of the load.
- Crane overturning.
- Excess of load with the consequent breakage or overturn.
- Failure of mechanical or electrical elements.
- Fall of people at different levels during the movement of loads.
- Entrapment of any body during the placement of the load.

4.2.3.3 Scaffolding, platforms and ladders.

The following risks are foreseeable:

- Falls of people at different levels.
- Ladder collapse due to failure, overturning or sliding.
- Drop of materials or tools from the ladders.

4.2.3.4 Welding and cutting equipment

The most significant risks are:

- Fires.
- Burns.
- Explosion of gas bottles.
- Incandescent projections.

5 Protection and prevention measures

5.1 Collective and general preventive measures

The following preventive measures of the work will be adopted:

- The general preventive measures of the work to be foreseen by the construction contractor and the expected specific measures of the electrical installation work.
- In the phases of aid to the palette a special interest in fixing the transit surfaces and evacuating the debris will be put.
- The assembly of electrical appliances must always be carried out by specialized personnel.
- The lighting with portable lights will be made by means of a watertight lampholder with an insulating handle and a light bulb protection grille, powered at 220 V.
- No conductor connections can be established in the provisional construction panels without male-female plugs.
- The ladders will be of the scissor type, with non-slip slippers and an opening limiting chain.
- The formation of scaffolds using ladders is expressly prohibited.
- Ladders or capital scaffolds may not be used in places where there is a risk of falling from a height, if the networks or corresponding safety protections have not been installed before.
- The tools to be used will be protected with standardized insulation material against contacts with electrical energy.
- The tools with defective insulation will be removed immediately, changing them with others in good condition.

- The functional tests of the electrical installation will be announced in writing before they begin to all the personnel of the work, in order to prevent potential accidents.
- Before connecting the electrical installation, an in-depth review of the connections of mechanisms, protections and unions of all electrical panels and appliances will be made.
- Before the previous operation, the existence of dry powder extinguishers, warning signs and first aid kit in the room of the transformation center will be checked. Operators will have to wear personal protective equipment.

5.2 Personal preventive measures

In this section, the necessary and most frequent clothing for personal protection in the work is indicated:

- Approved polyethylene helmet for permanent use inside the work.
- Insulating boots for electrical connections.
- Safety boots.
- Insulating gloves.
- Work clothes.
- Elastic waistband for the support of the waist.
- Insulating manoeuvring bench.
- Voltage testers.
- Insulating tools.

6 Technical specifications

6.1 Applicable legal provisions

The provisions that are within the regulations previously mentioned in the section 2 will be of mandatory compliance.

6.2 Conditions for the means of protection

All personal protection parts and collective protection elements will have a period of useful life. Once this useful period is over, it will be replaced by a new one.

When, due to the circumstances of the work, a deterioration of a specific piece or equipment occurs faster than expected, it will be immediately replaced, rejected and replaced immediately.

Parts and equipment that due to use have been deformed and do not have the recommended shape by the manufacturer will be replaced.

The use of a piece or protective equipment will never be a risk in itself.

6.2.1 Personal protections

The following are the characteristics of the most common personal protective clothing:

- Helmet

  The helmet must be for personal use and its use is compulsory in the construction works.

  It must be approved in accordance with the Technical Standard Regulatory M.T.1. (Resolution of the G.D. of Labour of 12/14/74, B.O.E. no. 312 of 30/12/74).

  Those helmets that have suffered violent impacts or that are more than 10 years old, even if they have not been used, have to be replaced by new ones.

  In extreme cases, the same helmet may be used by different workers, as long as the inner parts that in contact with the head are changed.

  The principal characteristics are the following:

  - Class N: it should be used in jobs of electrical risk, at lower voltages or equal to 1,000 V.
  - Weight: must not exceed 450 grams.

- Boots

  Because workers in the construction industry are subject to the risk of accidents, and there is a possibility of piercing the soles by nails, the use of safety shoes (boots, shoes or sandals) approved according to the Technical Standard Regulatory M.T.5. (Resolution of the G.D. of Labour of 01/31/80, B.O.E. no. 37 of 12/02/80) is obligatory.

  The principal characteristics are the following:

  - Class III: footwear with toe and insole.
  - Weight: must not exceed 800 grams.

  When working in humid lands where water or mortar splashes may be received, the boots shall be of rubber and Class E, according to the Technical Standard Regulatory M.T.27 (Resolution of the G.D. of Labour of 03/12/81, B.O.E. no. 305 of 22/12/81).

- Gloves

  In order to avoid aggressions in the hands of the workers (dermatosis, cuts, scratches, stings, etc.) gloves will be used. They can be of different materials such as:

  - Cotton knit: light works.
  - Leather: handling in general.
  - Metal mesh: handling of cutting sheets.
  - Canvas: wood handling, etc.

For the protection against chemical aggressions, gloves must be approved according to the Technical Standard Regulatory M.T.11 (Resolution of the G.D. of Labour of 06/05/77, B.O.E no. 158 of 04/07/77).

For work in which there may be risks of electric shocks, gloves approved in accordance with the Technical Standard Regulatory M.T.4 (Resolution of the G.D. of Labor of 28/07/75, B.O.E. no. 2111 of 03/11/75) will be used.

- Safety belts

  When working in a high place and in danger of eventual falls, the use of approved safety belts in accordance with the following Technical Regulations is mandatory:

  - Technical Standard Regulatory M.T.13 (Resolution of the G.D. of Labor of 08/06/77, B.O.E. no. 210 of 02/09/77)
  - Technical Standard Regulatory M.T.21 (Resolution of the G.D. of Labor of 21/02/81, B.O.E. no. 654 of 16/03/81)
  - Technical Standard Regulatory M.T.22 (Resolution of the G.D. of Labor of 23/02/81, B.O.E. no. 65 of 17/03/81)

  The principal characteristics are the following:

  - Class A: support belt

    They will be used when the worker does not have to move or when their trips are limited. The coupling element will always be tight to prevent free fall.

  - Class B: suspension belt

    It will be used when the worker can be suspended, but only with the possibility of static efforts (weight of the worker), there will never be the possibility of free fall.

  - Class C: fall belt

    It will be used when the worker can move and there is the possibility of free fall. The safety of the anchor point and its resistance have to be monitored in a special way.

- Devices against falls

  When workers perform lifting and lowering operations, fall arrest devices will be used according to the classification, regulated by the Technical Standard Regulatory M.T.28 (Resolution to the G.D. of Labor of 25/09/82, B.O.E. no. 229 of 14/12/82).

  - Class A

    The worker will do lifting and lowering operations and needs freedom of movements.

- Class B

  For descent operations or on the occasions when a rapid evacuation of people.

- Class C

  For short-term jobs and replacing scaffolding.

- Auditive protectors

  When workers are in a place or work area with a noise level higher than 80 dB, it is mandatory to use hearing protectors that are always for individual use. These protectors shall be approved in accordance with the Technical Standard Regulatory M.T.2. (Resolution of the G.D. of Labour of 28/07/85 B.O.E. no. 209 of 01/09/75).

  The hearing protectors can be: earplugs, earmuffs or headphones against noise. According to the attenuation values, they are classified in categories A, B, C, D, E.

- Eye protectors

  When workers are exposed to the projection of particles, dust and smoke, liquid splashes, dangerous radiation or glare, they will have to protect their eyesight with safety glasses and / or screens. The protective eyewear must be approved in accordance with the Technical Standard Regulatory M.T.16 (Resolution of the G.D. of Labour of 28/06/78, B.O.E. no. 2116 of 09/09/78).

  The screens against the projection of physical bodies must be made of organic material, transparent, free of streaks, scratches or deformations.

  In the case of soldering iron screens, they will be adjusted to the approvals included in the Technical Standard Regulatory M.T.3. (Resolution of the G.D. of Labour of 28/07/70) and M.T.18. (Resolution of the G.D. of Labour of 19/01/79, B.O.E. no. 33 of 07/09/70) and M.T.19. (Resolution of the G.D. of Labour of 24/05/79, B.O.E. no. 48 of 27/06/79).

  Protective goggles will have double glass; It will be dark and retractable to facilitate that the particles do not scratch or sting.

  These screens can be hand-held, with their own harness for workers to adjust to the head, or coupled to the safety helmet.

- Protectors of the respiratory tract

  It is considered as more frequent in this sector the inhalation of dust in the operations of cutting with disk of ceramic pieces or of prefabricated concrete. To protect the respiratory tract of the workers dedicated to this work, masks with approved mechanical filter will be made in accordance with the Technical Standard Regulatory M.T.7. (Resolution of the G.D. of Labour of 28/07/75, B.O.E. no. 215 of 08/09/75) and M.T.9. (Resolution of the G.D. of Labour of 28/08/75, B.O.E. no. 216 of 09/09/75).

- Work clothes

  The workers will use work clothes provided free of charge by the company. The clothes will be of a light and flexible fabric, adjusted to the body, without additional elements and easy to clean.

6.2.2 Tools and equipment related protections

- Hand tools for electrical work in L.V.

  If electrical work and installations of L.V. are to be done, the manual tools used, such as screwdrivers, pliers, pliers, etc. must be approved in accordance with the Technical Standard Regulatory M.T.26. (Resolution of the G.D. of labour of 03/09/81, .B.O.E. no. 243 of 10/10/81).

- Edge protection

  They must be placed around the perimeter of the holes where electrical or mechanical installers work and there is a danger that people might fall. They will have a height of 90 *cm* and with an intermediate skirting bar. They will be anchored and dimensioned in a way that guarantees the retention of people, without permanent deformation or fracture.

- Fixing cables for safety belts and anchoring points

  They will have sufficient strength to withstand the efforts they may receive as a result of their protective function.

- Ladders

  Types:

  - Simple: to overcome heights that do not exceed 5 meters.
  - Reinforced: to overcome heights that do not exceed 7 meters.
  - Extensible: Not used in the construction industry.

  Materials:

  - Made of iron Iron: they are not used to work in the presence of electric current.
  - Made of aluminum: they are light and manageable.
  - Made of wood: they are the most suitable for the construction industry, both for its main and secondary functions.

Use: throughout the work and especially in the mounting of the PV panels on top of the solar carports.

Constructive conditions: defined in article 19 of the General Decree of Security and Hygiene in the Work (OGSHT, for its acronym in Spanish):

- The ladder will always have the guarantees that are needed when it comes to solidity, stability and security, and if it is the case, electric and thermal isolation.
- When the uprights are made of wood they will be in one piece and their steps will be well fitted and not only stuck.
- The ladders can only be painted with varnish and not with paint, since this possible defects could be hidden.
- It is forbidden to join ladders (except for extensible ladders that are guaranteed by the respective manufacturers).
- They have to include heels, iron tips staples and other anti-slip mechanisms in the feet, or hooks on the top. The different fixing elements will be depending on the terrain where they are held. Examples: painted surfaces with tendency to slip (rubber, sand or earth heels, metal tips), uneven ground: articulated rubber support clips.

- Portable tools

Taking into account the importance and duration of the use that these tools have for the works of facilities, a specific study extracted from the publication 'Security in the construction. Guide for the extension of RD 555/1986 of the Generalitat of Catalonia, Department of Labour' is described.

There are four types of portable tools, based on the power source:

- Portable electric tools.
- Portable pneumatic tools.
- Portable combustion tools.
- Portable hand tools.

  * Portable electric tools

    Analysis of the risks:

    · Direct electrical contact.
    · Indirect electrical contact.
    · Cuts and erosions.
    · Entrapment.
    · Projection of particles (incandescent or not).
    · Blows or cuts due to violent rebounds of the tools.
    · Burns.
    · Environment with dust.

Preventive measures:

- The isolation of the electrical power cables will be in a state of correct preservation. If serve prolongations are to be made, they will be done with suitable connectors and will never be temporarily spliced even if insulating ribbon is served as protector.
- The portable tools will have the following security systems: double insulation, grounding of the masses or use with transformer security or separation of circuits.
- The worker will wear tight clothes, no rings nor chains nor anything that entails possibility of getting caught are allowed.
- These tools will be used with care, especially those of abrasion, which have a very high rotation speed. Accidental contact of the casing or the handle while working, a slight hitch or a stop can cause the tool to bounce suddenly and violently, cutting or eroding the part of the body it finds in its path.
- Drills, discs, etc. will not be touched right after they have been used since they are very hot. The case of welders is special, since they will be put on a special support once disconnected, to avoid burns.
- Taking into account that the emission of dust is punctual, when working, masks will be worn.
- When working, tools will be used with great care, with bits and discs tightly closed, keeping the cutting trajectories well perpendicular to the work surface and with correct centering of the work point, etc.

∗ Portable pneumatic tools

Analysis of the risks:

- Blows due to breakage of the hose.
- Blows, cuts and perforation in general.
- Sound stress.
- Vibrations.
- Projections of particles.

Preventive measures:

- Check the air supply hoses, change immediately those that are cracked or cracked, and in general all those that have lost elasticity when bending.
- Place safety valves (by pressure relief) in order to avoid lashes when the hoses are broken.
- No part of the body will be placed on the same side of the point of operation in nor in the trajectory of the nailer guns in particular.
- Ear protectors will be used when the noise level exceeds 80 dB whether it is followed or intermittent (by impact).
- Antivibration will be used when working with picking hammers.
- Safety footwear with metallic tips will be used to avoid knocks on the feet.
- Also and as a rule the workers will wear safety glasses and when there is emanations of dust masks.

· All work done with these tools requires the use of leather gloves.

* Portable combustion tools

Analysis of the risks:

· Burns.
· Fires.

Preventive measures:

· Check that the torch is in good condition and correctly fixed to the tank fuel.
· Check that the connection hose is in good condition.
· The burner pressure must be properly regulated so that the flame is not too long.
· Do not work near combustible materials.
· Have good ventilation in closed spaces.
· All work carried out with these tools requires the use of leather gloves.
· Have Glasses or protective screens must be worn.

* Portable hand tools

Analysis of the risks:

· Blows, cuts, punctures.
· Particle projection.

Preventive measures:

· Correct state of conservation of tools, hoses, etc.
· Knowledge and proper use by the relatives of those who use them.
· Cleaning and conservation, both in the warehouse and at work, keeping them clean and in good use.
· Periodic control of its status (checking and maintenance).
· Use of clothing for personal protection with reference to risk: safety glasses, boots, hand protectors, etc.

* Nail gun

In reality it is a portable tool, but due to its characteristics it can be considered a firearm, and for this reason, it is necessary to use extreme caution.

Analysis of the risks:

· Puncture wounds due to: bounces, projections or perforations.

Preventive measures:

- Serve the appropriate load according to the manufacturer's instructions. Only by applying this measure, a significant number of perforations and bounces are eliminated.
- Make use of a protective hood even with hammer nailers, in which the exit speed is lower than in the pistols.
- Under no circumstance should be nailed in: corners (there will be a minimum distance of 10 cm.) In curved surfaces, easily perforable materials, elastic materials or very hard or very fragile.
- Do not point at anyone.
- Do not have it loaded in hand.
- Transport it upside down and unloaded.
- Carry out the shot from behind the tool and never from the side.
- Keep the tool in an adequate state of preservation.
- Always use a helmet and safety glasses.

6.3 Prevention services

6.3.1 Technical health and security service

The installer will have an advisory service for health and safety issues.

6.3.2 Medical service

The installer will have an own or shared medical service.

6.4 Medical facilities

The kit will be reviewed monthly, replacing the material that has been used.

7 Follow-up and control period

The coordinator in matters of health and safety during the execution of the work will have to carry out the implementation, monitoring and control in an integrated manner with the project management and follow the guidelines of the coordinator of the health and security elements during the project.

It will be necessary to describe a standardized manual of safety standards to be followed for each specific task, and a follow-up will have to be done to verify compliance.

The person in charge or responsible for each work will design pamphlets where the follow-up of each of the safety guidelines will be written. The will have to be signed by the same person in charge.

It also foreseen the creation of courses to raise awareness and educate workers on both health and safety issues. In these courses, the working methods and the risks that these can cause, together with the security measures that will have to be used to avoid them will be discussed.

These courses or talks will have to be attended by all workers on a regular basis. A first aid course will also be taught.

It is foreseen the promotion of initiatives and actions of any person of the work so that it can raise the possible problems or impediments to the application of the security measures, as well as the existence of unnecessary risks, special circumstances and their resolution.

Finally, it is necessary to emphasize that in order to carry out all these norms it is necessary a good organization, an exhaustive control of all the activities and a clear description of the duties and of each level of the personnel, fomenting the cooperation and the instruction of all the agents included in the construction, operation and maintenance of the facilities described in the project.

Master of Science in Renewable Energy

274 kW_p GRID-CONNECTED PHOTOVOLTAIC SYSTEM FOR SELF-CONSUMPTION

Appendix 3. Datasheets of the main components of the PV system

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Dr. Juan Albino Méndez Pérez

Faculty of science: physics section

June 28, 2018

Contents

1 PV module

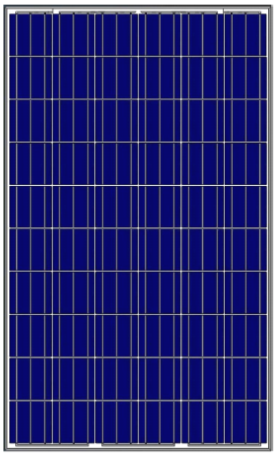
New Energy

New World

Worldwide Energy and Manufacturing USA Co., Limited

AS-6P30

Amerisolar's photovoltaic modules are designed for large electrical power requirements. With a 30-year warranty, AS-6P30 offers higher-powered, more reliable performance for both on-grid and off-grid solar projects.



Key Features

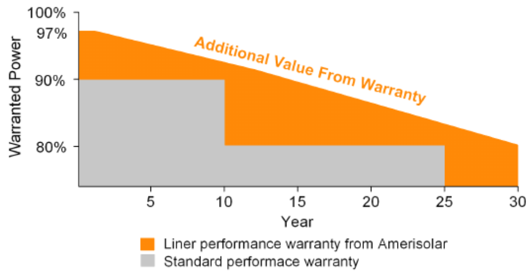
- High module conversion efficiency up to 16.29% through superior manufacturing technology.
- Low degradation and excellent performance under high temperature and low light conditions.
- Robust aluminum frame ensures the modules to withstand wind loads up to 2400Pa and snow loads up to 5400Pa.
- Positive power tolerance of 0 ~ +3 %.
- High ammonia and salt mist resistance.

Quality Certificates

- IEC61215, IEC61730, IEC62716, IEC61701, UL1703, CE, MCS, CEC, Israel Electric, Kemco
- ISO9001:2008: Quality management system
- ISO14001:2004: Environmental management system
- OHSAS18001:2007: Occupational health and safety management system

Special Warranties

- 12 year limited product warranty.
- Limited power warranty: 12 years 91.2% of the nominal power output, 30 years 80.6% of the nominal power output.



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Electrical Characteristics

Electrical parameters at STC								
Nominal Power (P_{max})	240W	245W	250W	255W	260W	265W	270W	275W
Open Circuit Voltage (V_{OC})	37.7V	37.9V	38.0V	38.1V	38.2V	38.3V	38.4V	38.5V
Short Circuit Current (I_{SC})	8.57A	8.66A	8.75A	8.83A	8.90A	8.98A	9.06A	9.15A
Voltage at Nominal Power (V_{mp})	29.9V	30.1V	30.3V	30.5V	30.7V	30.9V	31.1V	31.3V
Current at Nominal Power (I_{mp})	8.03A	8.14A	8.26A	8.37A	8.47A	8.58A	8.69A	8.79A
Module Efficiency (%)	14.75	15.06	15.37	15.67	15.98	16.29	16.60	16.90

STC: Irradiance 1000W/m^2, Cell temperature 25°C, AM1.5

Electrical parameters at NOCT								
Nominal Power (P_{max})	175W	179W	183W	186W	190W	194W	197W	201W
Open Circuit Voltage (V_{OC})	34.7V	34.9V	35.0V	35.1V	35.2V	35.3V	35.4V	35.5V
Short Circuit Current (I_{SC})	6.94A	7.01A	7.09A	7.15A	7.21A	7.27A	7.34A	7.41A
Voltage at Nominal Power (V_{mp})	27.2V	27.4V	27.6V	27.8V	27.9V	28.1V	28.3V	28.5V
Current at Nominal Power (I_{mp})	6.44A	6.54A	6.64A	6.70A	6.81A	6.91A	6.99A	7.06A

NOCT: Irradiance 800W/m^2, Ambient temperature 20°C, Wind speed 1 m/s

Mechanical Characteristics

Cell type	Polycrystalline 156x156mm
Number of cells	60 (6x10)
Module dimension	1640x992x40mm
Weight	18.5kg
Front cover	3.2mm low-iron tempered glass
Frame	Anodized aluminum alloy
Junction box	IP67, 6 diodes
Cable	4mm^2, 900mm
Connector	MC4 or MC4 compatible
Standard packaging	26pcs/pallet
Module quantity per container	728pcs/40'HQ

Temperature Characteristics

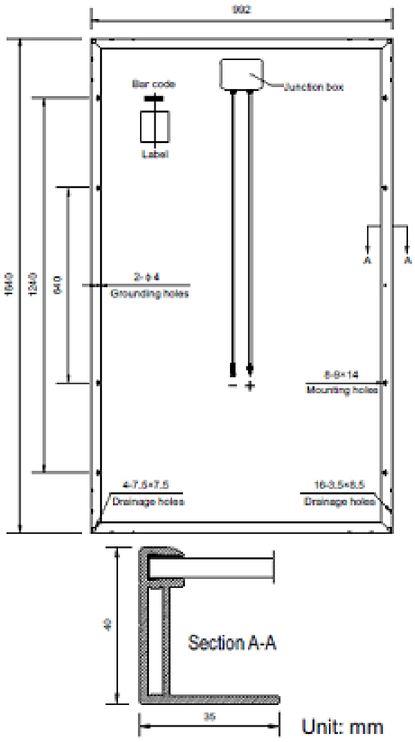
Nominal Operating Cell Temperature (NOCT)	45°C±2°C
Temperature Coefficients of P_{max}	-0.43%/°C
Temperature Coefficients of V_{OC}	-0.33%/°C
Temperature Coefficients of I_{SC}	0.056%/°C

Maximum Ratings

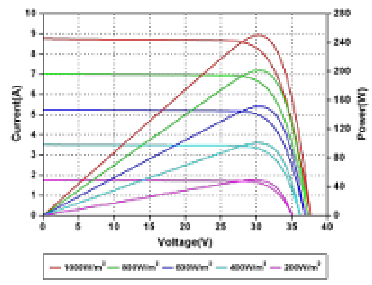
Operating Temperature	-40°C to +85°C
Maximum System Voltage	1000V DC
Maximum Series Fuse Rating	15A

Specifications in this datasheet are subject to change without prior notice.

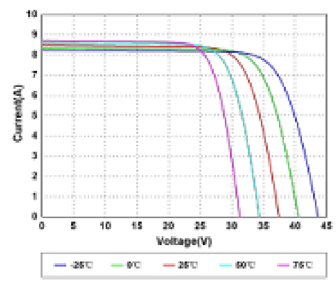
Drawings



I-V Curves



Current-Voltage and Power-Voltage Curves at Different Irradiances



Current-Voltage Curves at Different Temperatures

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2 Inverters

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SG80KTL NEW
String Inverter

Secured Yield
- Max. efficiency 99 %
- Max. DC/AC ratio up to 1.4

Flexible
- Power line communication optional

Intelligent Design
- Integrated string current monitoring function
- Integrated DC fuses and DC/AC surge protection

Qualified
- TÜV, CE, G59/3, BDEW

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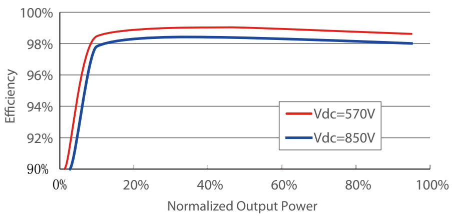
SG80KTL

Input (DC)	
Max. PV input voltage	1000 V
Startup voltage	620 V
MPP voltage range	570 - 950 V
MPP voltage range for nominal power	570 - 850 V
No. of MPPTs	1
Max. number of PV strings per MPPT	18
Max. PV input current	144 A
Max. current for input connector	12 A
Output (AC)	
Nominal AC output power	80000 W
Max AC output power (PF=1)	80000 W
Max. AC output apparent power	80000 VA
Max. AC output current	116 A
Nominal AC voltage	3P + PE, 230 / 400 V
AC voltage range	310 - 480 V
Nominal grid frequency	50 Hz / 60 Hz
Grid frequency range	45 - 55 Hz / 55 - 65 Hz
THD	< 3 % (at nominal power)
DC current injection	< 0.5 % In
Power factor	> 0.99@default value at nominal power, (adj. 0.8 leading - 0.8 lagging)
Protections & Functions	
Anti-islanding protection	Yes
LVRT	Yes
AC short circuit protection	Yes
Leakage current protection	Yes
DC switch	Yes
DC fuse	Yes
PV string current monitoring	Yes
DC overvoltage protection	DC Type II SPD (40 kA)
AC overvoltage protection	AC Type II SPD (40 kA)
System Data	
Max. efficiency	99.00 %
Euro. efficiency	98.70 %
Isolation method	Transformerless
Ingress protection rating	IP65
Night power consumption	<1W
Operating ambient temperature range	-25 to 60 ℃
Allowable relative humidity range	0 - 100 %
Cooling method	Smart forced air cooling
Max. operating altitude	4000 m (> 3000 m derating)
Display	Graphic LCD
Communication	RS485 / PLC (optional)
DC connection type	MC4
AC connection type	Screw clamp terminal
Certification	EN62109-1, EN62109-2, G59/3, BDEW
Mechanical Data	
Dimensions (W*H*D)	634*959*267 mm
Mounting method	Wall bracket
Weight	60 kg

Note：this inverter only be used in industrial area

Efficiency Curve



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SUNGROW

SG60KTL

String Inverter

High Yield

- Max. efficiency 98.9 %, European efficiency 98.7 %
- Long-term overload at 1.1 Pn
- Full power operation without derating at 50 ℃

Easy O&M

- Compact design and light weight for easy installation
- Plug-in design of fan and SPD, convenient for on-site maintenance
- Integrated string current monitoring function for fast trouble shooting

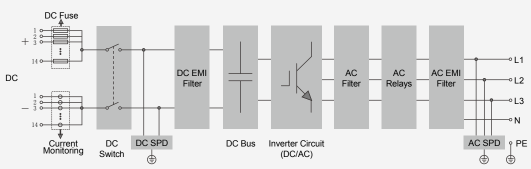
Saved Investment

- Max. DC/AC ratio up to 1.4
- Integrated DC combiner box and DC/AC overvoltage protection

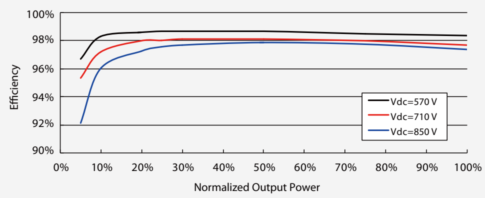
Grid Support

- Compliance with standards: IEC 62109, IEC 61727, IEC 62116, VDE0126-1-1, G59/3, VDE-AR-N-4105, VDE-AR-N-4120, BDEW
- Low/High voltage ride through (L/HVRT)
- Active & reactive power control and power ramp rate control

Circuit Diagram



Efficiency Curve



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SG60KTL

Input (DC)	SG60KTL
Max. PV input voltage	1000 V
Min. PV input voltage / Startup input voltage	570 V / 620 V
Nominal input voltage	710 V
MPP voltage range	570 – 950 V
MPP voltage range for nominal power	570 – 850 V
No. of independent MPP inputs	1
Max. number of PV strings per MPPT	14
Max. PV input current	120 A
Max. current for input connector	12 A
Max. DC short-circuit current	140 A
Output (AC)	
AC output power	66000 VA @ 45 ℃ / 60000 VA @ 50 ℃
Max. AC output current	96 A
Nominal AC voltage	3 / N / PE or 3 / PE, 230 / 400 V
AC voltage range	310 – 480 V
Nominal grid frequency / Grid frequency range	50 Hz / 45 – 55 Hz, 60 Hz / 55 – 65 Hz
THD	< 3 % (at nominal power)
DC current injection	< 0.5 % In
Power factor at nominal power / Adjustable power factor	> 0.99 / 0.8 leading – 0.8 lagging
Feed-in phases / Connection phases	3 / 3
Efficiency	
Max. efficiency / Euro. efficiency	98.9 % / 98.7 %
Protection	
DC reverse connection protection	Yes
AC short-circuit protection	Yes
Leakage current protection	Yes
Grid monitoring	Yes
DC switch / AC switch	Yes / No
DC fuse	Yes (positive, 15A)
PV string current monitoring	Yes
Overvoltage protection	DC Type II / AC Type III
General Data	
Dimensions (W*H*D)	634*959*267 mm
Weight	60 kg
Isolation method	Transformerless
Degree of protection	IP65
Night power consumption	< 1 W
Operating ambient temperature range	-25 to 60 ℃ (> 50 ℃ derating)
Allowable relative humidity range (non-condensing)	0 – 100 %
Cooling method	Smart forced air cooling
Max. operating altitude	4000 m (> 3000 m derating)
Display / Communication	Graphic LCD / RS485
DC connection type	MC4 (Max. 6mm²)
AC connection type	Screw clamp terminal (Max. 95 mm²)
Compliance	IEC 62109, IEC 61727, IEC 62116, IEC 60068, IEC 61683, VDE0126-1-1, G59/3, VDE-AR-N-4105, VDE-AR-N-4120, BDEW, IEC 61000-3-11/-12, EN 50438, UTE C 15-712-1/07.13, CEA, PEA, MEA
Grid support	LVRT, HVRT, active & reactive power control and power ramp rate control
Type designation	SG60KTL-182

SUNGROW
www.sungrowpower.com

SG50KTL-M/SG60KTL-M

String Inverter

Secured Yield

- Max. efficiency 98.9 %
- Max. DC/AC ratio up to 1.3
- Long-term overload at 1.1Pn
- Up to 4 MPP Trackers

Intelligent Design

- Integrated DC fuses and DC/AC surge protection
- String current monitoring function (optional)

Reliable

- TÜV, CE, G59/3, BDEW

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SUNGROW
www.sungrowpower.com

SG50KTL-M/SG60KTL-M

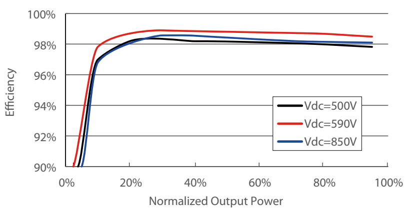
Input (DC)	SG50KTL-M	SG60KTL-M
Max. input voltage	1000 V	
Startup voltage	300 V	
Nominal input voltage	590 V	710 V
MPP voltage range	300 - 950 V	
MPP voltage range for nominal power	500 - 850V	550 - 850 V
No. of MPPTs	4	
Max. number of PV strings per MPPT	3	
Max. PV input current	112 A (28 A / 28 A / 28 A / 28 A)	
Max. current for input connector	12 A	
Output (AC)		
Nominal AC output power	50000 W	60000 W
Max. AC output power (PF=1)	55000 W	66000 W
Max. AC output apparent power	55000 VA	66000 VA
Max. AC output current	80A	
Nominal AC voltage	3P + N + PE, 230 / 400 V	3 / PE, 227 / 480V
AC voltage range	310 - 480 V	422 - 528 V
Nominal grid frequency	50 Hz / 60 Hz	
Grid frequency range	45 - 55 Hz / 55 - 65 Hz	
THD	< 3 % (at nominal power)	
DC current injection	< 0.5 % In	
Power factor	> 0.99 @default value at nominal power, (adj. 0.8 leading - 0.8 lagging)	
Protections & Functions		
Anti-islanding protection	Yes	
LVRT	Yes	
DC reverse connection protection	Yes	
AC short circuit protection	Yes	
Leakage current protection	Yes	
DC switch	Yes	
DC fuse	Yes	
Overvoltage protection	DC Type II SPD (40 kA)/AC Type II SPD	
System Data		
Max. efficiency	98.90 %	
Euro. efficiency	98.50 %	98.60 %
Isolation method	Transformerless	
Ingress protection rating	IP65	
Night power consumption	<1W	
Operating ambient temperature range	-25 to 60 ℃ (>50 ℃ derating)	
Allowable relative humidity range	0 - 100 %	
Cooling method	Smart forced air cooling	
Max. operating altitude	4000 m (> 3000 m derating)	
Display	Graphic LCD	
Communication	RS485	
DC connection type	MC4	
AC connection type	Screw clamp terminal	
Certification	VDE0126-1-1, EN62109-1, EN62109-2, G59/3, BDEW	

Mechanical Data	
Dimensions (W*H*D)	665*906*256 mm
Mounting method	Wall bracket
Weight	70 kg

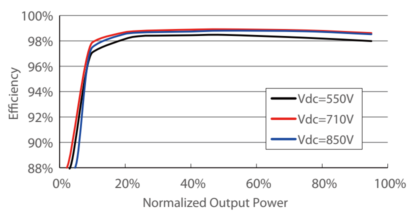
Note：this inverter may only be used for industrial applications

Efficiency Curve

SG50KTL-M



SG60KTL-M



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SUNGROW

SG33KTL-M/SG36KTL-M

String Inverter

High Yield

- Max. efficiency 98.5 %, European efficiency 98.3 %
- Long-term overload at 1.1 Pn (SG33KTL-M)
- Full power operation without derating at 50 ℃ Up to 3 MPP trackers

Easy O&M

- Integrated string current monitoring function for fast trouble shooting
- Compact design and light weight for easy installation
- Plug-in design of fan and SPD, easy for on-site maintenance.

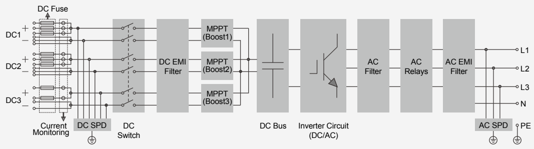
Saved Investment

- Max. DC/AC ratio up to 1.4
- Can be installed horizontally, saving installation cost
- Integrated DC combiner box and DC/AC overvoltage protection

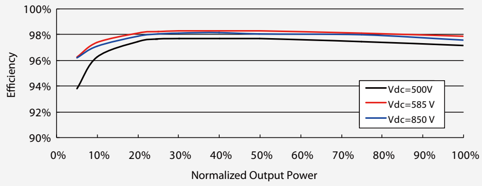
Grid Support

- Compliance with standards: CE, IEC 62109, IEC 61727, IEC 62116, VDE 0126-1-1, VDE-AR-N-4105
- Low/High voltage ride through (L/HVRT)
- Active & reactive power control and power ramp rate control

Circuit Diagram



Efficiency Curve



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SG33KTL-M/SG36KTL-M

Input (DC)	SG33KTL-M	SG36KTL-M
Max. PV input voltage	1100 V	
Min. PV input voltage / Startup input voltage	200 V / 250 V	
Nominal input voltage	585 V	
MPP voltage range	200 – 1000 V	
MPP voltage range for nominal power	500 – 850 V	
No. of independent MPP inputs	3	
Max. number of PV strings per MPPT	3 / 3 / 2	
Max. PV input current	88 A (33 A / 33 A / 22 A)	
Max. current for input connector	12 A	
Max. DC short-circuit current	96 A (36 A / 36 A / 24 A)	
Output (AC)		
AC output power	36000 VA @ 45 ℃ / 33000 VA @ 50 ℃	36000 VA @ 50 ℃
Max. AC output current	53.5 A	
Nominal AC voltage	3 / PE or 3 / N / PE, 230 / 400 V	
AC voltage range	310 – 480 V	
Nominal grid frequency / Grid frequency range	50 Hz / 45 – 55 Hz, 60 Hz / 55 – 65 Hz	
THD	< 3 % (at nominal power)	
DC current injection	< 0.5 % In	
Power factor at nominal power / Adjustable power factor	> 0.99 / 0.8 leading – 0.8 lagging	
Feed-in phases / Connection phases	3 / 3	
Efficiency		
Max. efficiency / Euro. efficiency	98.5 % / 98.3 %	
Protection		
DC reverse connection protection	Yes	
AC short-circuit protection	Yes	
Leakage current protection	Yes	
Grid monitoring	Yes	
DC switch / AC switch	Yes / No	
DC fuse	Yes (positive, 15A)	
PV string current monitoring	Yes	
Overvoltage protection	DC Type II / AC Type II	
General Data		
Dimensions (W*H*D)	525*740*240 mm	
Weight	48 kg	
Isolation method	Transformerless	
Degree of protection	IP65	
Night power consumption	< 2 W	
Operating ambient temperature range	-25 to 60 ℃ (> 50 ℃ derating)	
Allowable relative humidity range (non-condensing)	0 – 100 %	
Cooling method	Smart forced air cooling	
Max. operating altitude	4000 m (> 3000 m derating)	
Display / Communication	Graphic LCD / RS485	
DC connection type	MC4 (Max. 6 mm²)	
AC connection type	Screw clamp terminal (Max. 50 mm²)	
Compliance	IEC 62109, IEC 61727, IEC 62116, IEC 60068, IEC 61683, CE, IEC 61000-3-11/-12, VDE 0126-1-1, VDE-AR-N-4105, CEA	
Grid support	LVRT, HVRT, active & reactive power control and power ramp rate control	
Type designation	SG33KTL-M-10	SG36KTL-M-10

3 AC box combiner

AC Combiners

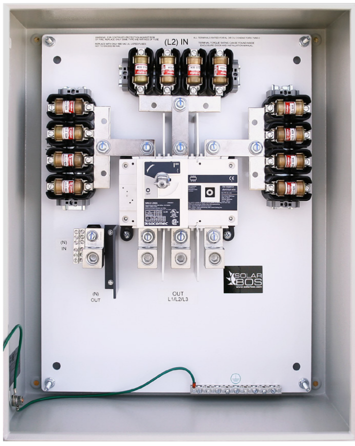
SolarBOS AC Combiners provide cost effective means to combine AC equipment. Individual fused inputs facilitate string inverter output aggregation. SolarBOS AC Combiners support all string inverters and are highly configurable to fit any application.

SPECIFICATIONS

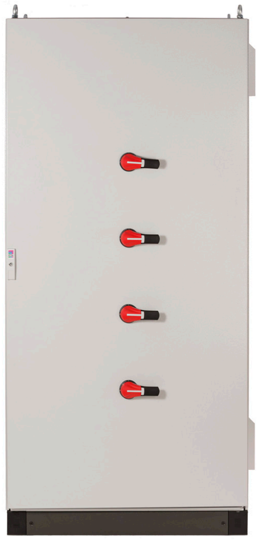
- Listed to UL-508A
- 600 VAC or 800 VAC
- 200 kAIC
- 2 to 16 input circuits
- 35A to 800A fuse sizes

AVAILABLE OPTIONS

- Integrated output or input disconnect switch(es)
- Neutral terminals
- Transient surge suppression
- Auxiliary breakers
- Convenience receptacles
- Breather and drain vents
- Padlockable enclosures
- NEMA-3R/4 or 4X rated enclosure options
- Custom solutions available upon request



SolarBOS AC Combiner, 600 VAC, 4 input circuits, 200A output disconnect, NEMA-4 steel enclosure



SolarBOS AC Combiner, 600 VAC, 4 input circuits, 400A fused input disconnects, NEMA-4 steel enclosure

FUNCTION

- **Bi-directional fuses** - Some breakers are directional and cannot be back fed. Breaker panels are typically designed for load applications, when they are used "backwards" for supply equipment the breakers must be back feed capable. Fuses work in both directions and back feeding is not a concern.
- **Inverter isolation** - Many string inverters include load break disconnecting means. This allows the use of non-load break fuseholders to isolate inverters and realize significant cost savings.
- **Output bussing** - Custom output busses allow direct and convenient connection to transformer.
- **Outdoor rated enclosures** - SolarBOS AC Combiners can be mounted on their back reducing shading and racking requirements.
- **Factory pre-wiring** - Pre-terminated and custom length input conductors reduces field installation time.

PERFORMANCE

- **High temperature performance** - Breakers nuisance trip, particularly at high ambient temperatures. Breakers are commonly oversized to avoid this and cause oversized, more costly conductors.
- **Interrupt rating** - Breaker cost increases drastically as interrupt ratings increase. Fuses offer high interrupt rating as standard, commonly 200kAIC.
- **Supply vs load application** - AC Combiners are designed for supply as opposed to load applications. Breakers are good when there are variable loads (when you plug in a hair dryer and trip a breaker the ease of resetting is very convenient). In solar applications, loads are not variable and sources are current limited.

RELIABILITY

- **Reduced PPE requirements** - Current limiting fuses reduce arc flash energy and the level of PPE required for servicing.
- **100% operation and reliability** - Breakers degrade every time they trip or are used as a disconnect and require maintenance to ensure they will function properly. Fuses do not.
- **OCPD coordination** - OCPD coordination is required to make sure the correct OCPD trips if an overcurrent event takes place. "Correct" refers to the OCPD most appropriate and closest to the fault. This is easily ensured with fuse coordination ratios. Breakers require a more complicated study involving trip curves. Additionally, the trip curves are specific to each breaker model (as opposed to common across a fuse class) and complicate breaker replacement.

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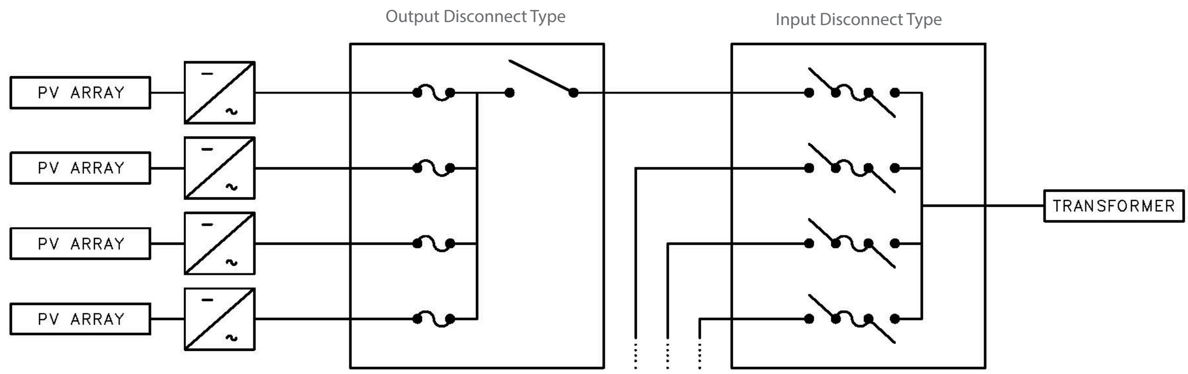
AC Combiners

SOLAR BOS

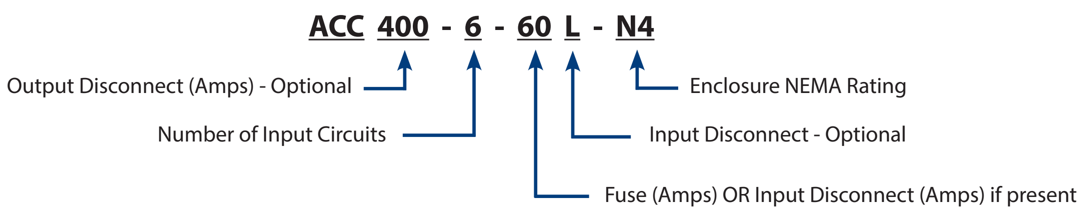


Secondary AC Combiners are typical for sites where further agreggation of AC Combiners is needed.

Fuse Sizes (Amps)	35 A to 60 A		70 A to 800 A	
Disconnect(s)	None	Output Disconnect	None	Input Disconnect(s)
Disconnect Ampacity	N/A	200A / 400 A / 600 A / 800 A	N/A	200 A / 400 A / 600 A / 800 A
Number of Input Circuits	2 to 12	2 to 12	2 to 16	2 to 16
Input Conductor Size (AWG)	#12 - 1	#12 - 1	#6 to 350 / #2 to 600	#6 to 350 / #2 to 600
Max Output Current	200A / 400 A / 600 A / 800 A	200A / 400 A / 600 A / 800 A	1280 A / 2560 A	1280 A / 2560 A
Voltage (VAC)	600 VAC 3 Φ / 800 VAC 3 Φ	600 VAC 3 Φ / 800 VAC 3 Φ	600 VAC 3 Φ / 800 VAC 3 Φ	600 VAC 3 Φ / 800 VAC 3 Φ
Neutrals	Optional	Optional	Optional	Optional
Output Conductor Size Range (AWG)	#6 to 350 / #2 to 600	#6 to 350 / #2 to 600	#2 to 600	#2 to 600
Typical Enclosure Dimensions (Inches)	20x20x8	30x24x8	36x36x8	60x36x12
Enclosure NEMA Ratings	3R, 4, 4X	3R, 4, 4X	3R, 4, 4X	3R, 4, 4X

Other options available upon request. Please note dimensions and weight vary for each solution. Contact SolarBOS for details.

SOLARBOS PART NUMBER EXAMPLE



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4 Type II surge protection

FICHA DE PRODUCTO

APLICACIONES TECNOLÓGICAS

> PROTECCIÓN DE LÍNEAS DE SUMINISTRO ELÉCTRICO

> SERIE ATSUB

> ATSUB-D T

Protector compacto trifásico

> **AT-8217 ATSUB-D T**: corriente de pico 15 kA. U_n 230 V
> **AT-8017 ATSUB40-D T**: corriente de pico 40 kA. U_n 230 V

Protección eficaz mediante varistores de óxido metálico y descargadores de gas contra sobretensiones transitorias, para líneas de suministro eléctrico trifásico con neutro tipo TT. Protección media según la protección en cascada recomendada en el Reglamento de Baja Tensión (REBT ITC23). Especialmente preparado para instalarse en viviendas según la ITC-25 del REBT.

Ensayado y certificado como protector de **tipo 2 y 3** según la norma UNE-EN 61643-11 y la GUÍA-BT-23 del REBT. Adecuado para equipos de **categorías I, II, III y IV** según la ITC-BT-23 del REBT.

- > Coordinable con los protectores de las series ATSHOCK, ATSHIELD y ATCOVER.
- > Constituidos por varistores de óxido de zinc y descargadores de gas con capacidad de soportar corrientes altas.
- > Tiempo de respuesta corto.
- > No producen deflagración.
- > Protección compacta.
- > No producen en ningún momento la interrupción de las líneas de suministro.
- > Dispositivo termodinámico de control y avisador mecánico. Cuando el avisador está amarillo, protector en buen estado. Si no sustituir.

Los protectores de la serie ATSUB han sido sometidos a ensayos en **laboratorios oficiales e independientes** para obtener sus características según las normas de aplicación (relacionadas en la tabla).

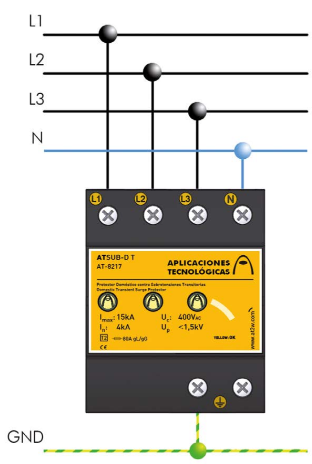
Es imprescindible la **conexión a tierra**. Para que la protección sea correcta, las tomas de tierra de toda la instalación deben estar unidas, directamente o mediante vía de chispas, y su resistencia debe ser inferior a 10 Ω. Si en su uso o instalación no se respetan las indicaciones de esta ficha, la protección asegurada por este equipo puede verse comprometida.

> INSTALACIÓN

Se instalan **en paralelo** con la línea de baja tensión, con conexiones a las fases que se precise proteger (o al neutro) y la tierra.

La instalación debe realizarse **sin tensión en la línea**.

Se recomienda su utilización en instalaciones en las que se puedan producir grandes sobretensiones después del cuadro principal pero que no alimenten equipos especialmente sensibles.



Aplicaciones Tecnológicas S.A. - Parque Tecnológico de Valencia - Nicolás Copérnico, 4 - 46980 Paterna (Valencia), España T +34 961 318 250 - F +34 961 318 206 - atsa@at3w.com - www.at3w.com

FICHA DE PRODUCTO

APLICACIONES TECNOLÓGICAS

> PROTECCIÓN DE LÍNEAS DE SUMINISTRO ELÉCTRICO

> SERIE ATSUB

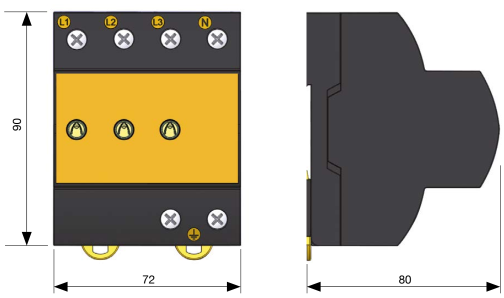
> DATOS TÉCNICOS

Referencia:		ATSUB-D T **AT-8217**	ATSUB40-D T **AT-8017**
Categorías de protección según REBT:		I, II, III, IV	
Tipo de ensayos según UNE-EN 61643-11:		Tipo 2	
Tensión nominal:	U_n	400 V_{AC} (L-L) / 230 V_{AC} (L-N, L-GND)	
Tensión máxima de funcionamiento:	U_c	460 V_{AC} (L-N, L-GND)	
Frecuencia nominal:		50 - 60 Hz	
Corriente nominal de descarga por polo (onda 8/20 µs):	I_n	5 kA	15 kA
Corriente máxima por polo (onda 8/20 µs):	I_{max}	15 kA	40 kA
Nivel de protección para onda 8/20 µs a I_n:	$U_p(I_n)$	1500 V	1800 V
Tiempo de respuesta:	t_r	< 25 ns	
Fusibles previos(1):		80 A gL/gG	
Corriente máxima de cortocircuito:		25 kA (para el fusible máximo)	
Temperatura de trabajo:	ϑ	-40 °C a +70 °C	
Situación del protector:		Interior	
Tipo de conexión:		Paralelo (un puerto)	
Nº de polos:		4	
Dimensiones:		72 x 90 x 80 mm (2 módulos DIN43880)	
Fijación:		Carril DIN	
Material de la carcasa:		Poliamida	
Protección de la carcasa:		IP20	
Resistencia de aislamiento:		> 10^{14} Ω	
Carcasa autoextinguible:		Tipo V-0 según UNE-EN 60707 (UL94)	
Conexiones L/N/GND:		Sección mínima / máxima multifilar: 4 / 35 mm² Sección mínima / máxima unifilar: 1 / 35 mm²	

Ensayos certificados según norma UNE-EN 61643-11
Cumple con los requisitos de UL 1449
Normas de aplicación: UNE 21186, UNE-EN 62305

(1) Se precisan en caso de que exista una protección de igual o mayor corriente nominal instalada aguas arriba del protector

> DIMENSIONES (MM)



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5 SMA energy meter

SMA

SMA ENERGY METER

Sencillo

- Rápida instalación con el sistema plug & play
- Visualización gráfica de los valores de medición actuales en Sunny Portal y la interfaz web local

Flexible

- Formato de carcasa compacto que ahorra espacio en el montaje sobre carril DIN en la red de distribución de la casa
- Uso flexible en aplicaciones de > 63 A mediante transformadores de corriente externos

- Modo de uso universal, independiente de los contadores de energía existentes

Potente

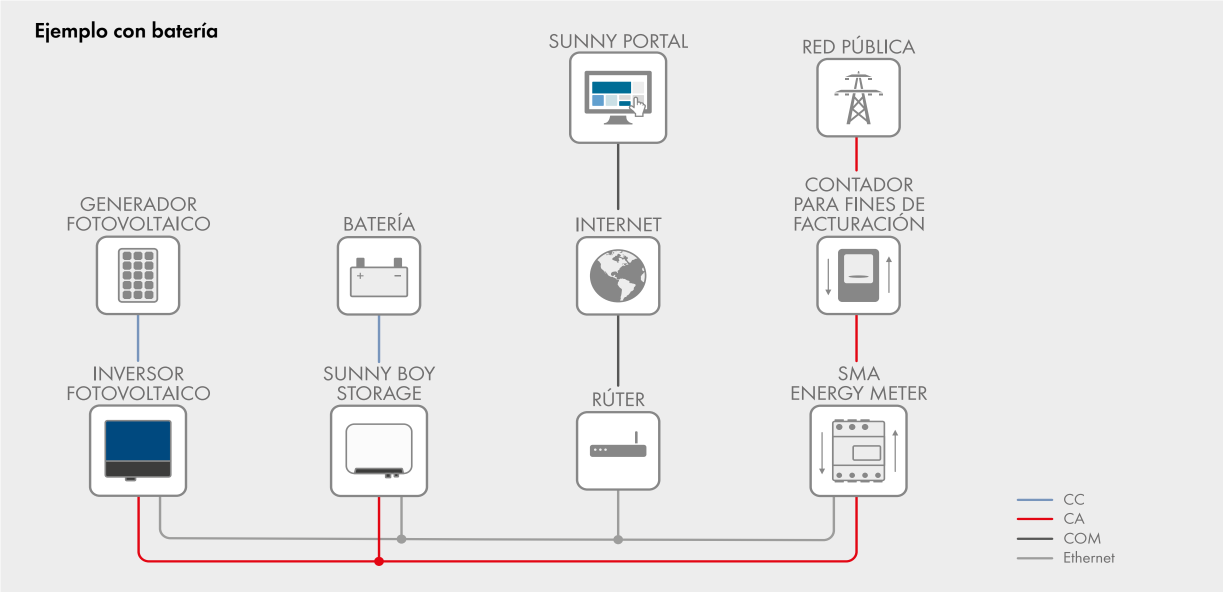
- Registro trifásico rápido y bidireccional de los valores de medición para gestionar la energía de manera eficaz*
- Perfecta coordinación con los equipos de SMA para una actividad de regulación estable

SMA ENERGY METER

Registro universal de los valores de medición para una gestión inteligente de la energía

Esta potente solución de medición garantiza una gestión inteligente de la energía en plantas fotovoltaicas con equipos de SMA. El SMA Energy Meter determina los valores de medición eléctricos de forma precisa para cada conductor de fase y en forma de valores saldados, y los comunica a través de ethernet en la red local. Esto permite transmitir todos los datos de inyección a red y consumo de red, e incluso los relativos a la generación de energía fotovoltaica de otros inversores fotovoltaicos, con una precisión y frecuencia elevadas a los sistemas de SMA.
La combinación con el SMA Energy Meter supone en todos los casos una configuración de sistema perfectamente coordinada, la cual garantiza un mejor rendimiento y estabilidad para un ahorro de costes máximo y la optimización del autoconsumo.

* También se puede utilizar en sistemas monofásicos.



Datos técnicos	**SMA Energy Meter**
Comunicación	
Conexión con el rúter local	A través de cable ethernet (10/100 Mbit/s, conector RJ45)
Entradas (tensión y corriente)	
Tensión nominal	230 V/400 V
Frecuencia	50 Hz/±5 %
Corriente nominal/límite por cada conductor de fase	5 A/63 A (>63 A combinado con transformadores de corriente externos)
Corriente de arranque	<25 mA
Sección de conexión	De 10 mm^2 a 16 mm^2 [1)] (para protección de 63 A)
Par de apriete para bornes roscados	2,0 Nm
Condiciones ambientales durante el funcionamiento	
Temperatura ambiente	De -25 °C a +40 °C
Rango de temperatura de almacenamiento	De -25 °C a +70 °C
Clase de protección (según IEC 62103)	II
Tipo de protección (según IEC 60529)	IP2X
Valor máximo permitido para la humedad relativa del aire (sin condensación)	De 5 % a 90 %[2)]
Altitud sobre el nivel del mar	De 0 m a 2000 m
Datos generales	
Dimensiones (ancho/alto/fondo)	70 mm/88 mm/65 mm
Espacios necesarios en el cuadro de distribución del carril DIN	4
Peso	0,3 kg
Lugar de montaje	Armario de distribución o de contadores
Tipo de montaje	Montaje sobre carril DIN
Indicación de estado	2 leds
Autoconsumo	<3 W
Exactitud de medición, ciclo de medición	1 %, 1000 ms
Equipamiento	
Garantía	2 años
Certificados y autorizaciones (otros a petición)	www.SMA-Solar.com
Compatibilidad del sistema (versión: enero de 2017)	
Los siguientes equipos pueden usarse junto con el SMA Energy Meter[3)]:	
Gestión de la energía de SMA	Sunny Home Manager
Inversores fotovoltaicos de SMA	Sunny Boy 1.5/2.5, Sunny Boy 3.0–5.0
Sistemas de almacenamiento de SMA[4)]	Sunny Boy Storage, Sunny Boy Smart Energy, Sunny Island X.XH/M
Equipos de comunicación de SMA	SMA Cluster Controller
Actualizado: marzo de 2017	
Modelo comercial	EMETER-20

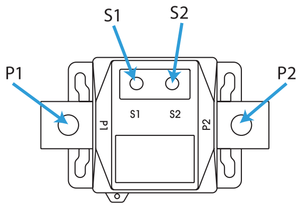
1) mecánica de 1,5 mm^2 a 25 mm^2
2) 95 % solo encendido hasta 30 días al año
3) con un SMA Energy Meter en el punto de conexión a la red, en el caso de equipos de autoconsumo normalmente pueden visualizarse el consumo local y la inyección a red de energía fotovoltaica
4) los sistemas de baterías de SMA suelen necesitar un SMA Energy Meter o Sunny Home Manager 2.0 en el punto de conexión a la red

6 Current transformer

CIRCUTOR

TRMC 210.2

(E) (GB)



P1	Primario del transformador. Transformer primary.
P2	Primario del transformador. Transformer primary.
S1	Secundario del transformador. Transformer secondary.
S2	Secundario del transformador. Transformer secondary.

Este manual es una guía de instalación del **TRMC 210.2**. Para más información, se puede descargar el manual completo en la página web de **CIRCUTOR**: www.circutor.es

¡IMPORTANTE!

Antes de efectuar cualquier operación de instalación, reparación o manipulación de cualquiera de las conexiones del equipo debe desconectar el aparato de toda fuente de alimentación, tanto alimentación como de medida. Cuando sospeche un mal funcionamiento del equipo póngase en contacto con el servicio posventa.

El fabricante del equipo no se hace responsable de daños cualesquiera que sean en caso de que el usuario o instalador no haga caso de las advertencias y/o recomendaciones indicadas en este manual ni por los daños derivados de la utilización de productos o accesorios no originales o de otras marcas.

1. DESCRIPCIÓN

El **TRM C210.2** es un transformador de corriente precintable, que permite obtener la medida de corriente en instalaciones eléctricas desde 50 hasta 600 A.

2. INSTALACIÓN

El **TRMC210.2** debe ser instalado dentro de un cuadro eléctrico o envolvente.

¡IMPORTANTE!

Tener en cuenta que con el equipo conectado, los bornes pueden ser peligrosos al tacto, y la apertura de cubiertas ó eliminación de elementos puede dar acceso a partes peligrosas al tacto. El equipo no debe ser utilizado hasta que haya finalizado por completo su instalación

3. CONEXIONADO

El **TRMC 210.2** es un transformador de tipo primario bobinado, por lo que se debe insertar el primario del transformador en el cable conductor que se quiere medir.
Normalmente es necesario cortar el cable conductor a medir.
Conectar la pletina P1 del primario de transformador en un extremo del cable conductor y el otro extremo a la pletina P2 del transformador.
Una vez conectado el primario, cablear el secundario del transformador (S1 y S2) al equipo de medida.
Si no se conecta ningún equipo en el secundario, cortocircuitar los bornes del secundario S1 y S2 para prevenir daños en la instalación.

This manual is a **TRMC 210.2** installation guide. For further information, please download the full manual from the **CIRCUTOR** web site: www.circutor.com

IMPORTANT!

The device must be disconnected from its power supply sources (power supply and measurement) before undertaking any installation, repair or handling operations on the device's connections. Contact the after-sales service if you suspect that there is an operational fault in the device.

The manufacturer of the device is not responsible for any damage resulting from failure by the user or installer to heed the warnings and/or recommendations set out in this manual, nor for damage resulting from the use of non-original products or accessories or those made by other manufacturers.

1. DESCRIPTION

El **TRMC 210.2** is a current transformer sealable, for obtaining current measurement in electrical installations from 50 to 600 A.

2. INSTALLATION

TRMC210.2 must be installed inside an electric panel or enclosure.

IMPORTANT!

Take into account that when the device is connected, the terminals may be hazardous to the touch, and opening the covers or removing elements may provide access to parts that are dangerous to the touch. Do not use the device until it is fully installed

3. CONNECTION

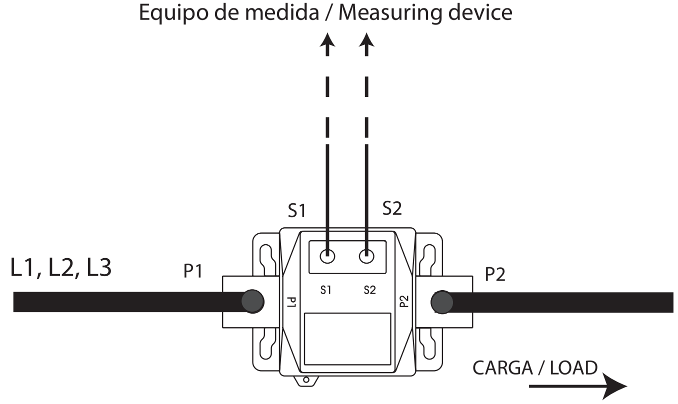
TRCM 210.2 is a wound primary current transformer, therefore the primary of the transformer must be inserted into the wire which current must be measured.
It is usually required to cut the wire
Connect primary winding P1 bus bar to one wire end, and P2 bus bar to the other wire end. After connecting the primary winding, wire the secondary winding (S1 and S2) to the current measurement device.
If there is nothing connected to the secondary winding, shortcircuit S1 and S2 terminals, to avoid damage

Características técnicas / Technical features

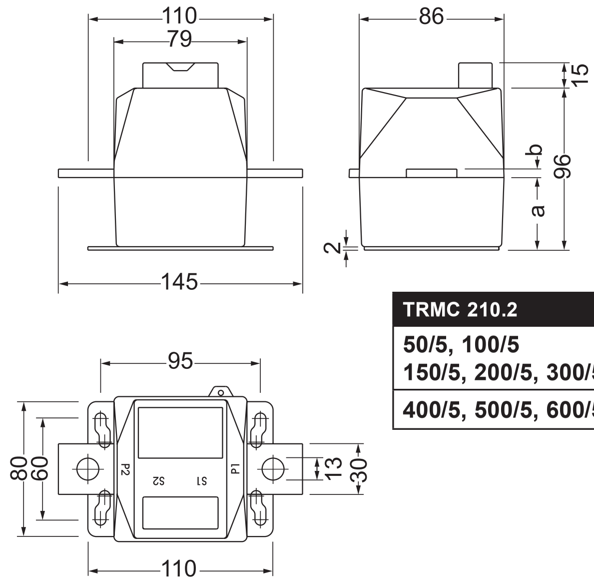
Características técnicas	Technical features	
Tipo	Type	Primario bobinado / Wound primary Monofásico / Single-phase
Corriente primario	Primary current	50 ... 600 A
Corriente secundario (In)	Secondary current (In)	5 A
Corriente térmica de cortocircuito (Ith)	Thermal short-circuit current (Ith)	60 In
Corriente dinámica (Idyn)	Dynamic current (Idyn)	2.5 Ith
Frecuencia	Fequency	50 - 60 Hz
Tensión máxima de trabajo	Maximum operating voltage	0.72 kV ~ (Baja tensión / Low voltage)
Tensión de aislamiento	Insulation voltage	3 kV
Clase	Class	0.5s
Potencia de precisión	Precision power	2.5 VA
Factor de seguridad	Safety factor	FS5
Gama extendida	Extended range	150 %
Características ambientales	**Environmental features**	
Temperatura de trabajo	Operating temperature	-5ºC... +40ºC
Temperatura de almacenamiento	Storage temperature	-15ºC... +50ºC
Humedad relativa (sin condensación)	Relative humidity(non-condensing)	5 ... 95%
Altitud máxima	Maximum altitude	1000 m
Características mecánicas	**Mechanical features**	
Conexión del primario	Primary connection	P1, P2
Tornillo + Tuerca	screw + nut	M12
Par de apriete máximo	maximum torque	30 Nm
Conexión del secundario	Secondary connection	S1, S2
Tornillo + Tuerca	screw + nut	M5
Par de apriete máximo	maximum torque	3 Nm
Dimensiones	Dimensions	145 x 111 x 86 mm
Peso	Weight	1.5 kg
Encapsulado	Enclosure	Autoextinguible V0, relleno de resina sintética Self-extinguishung VO, synthetic resin filler
Clase térmica	Thermical class	B (130ºC)
Uso	Use	Interior / Indoor
Normas / Standars		
IEC 61869-2:2012, IEC 60038:2009, IEC 60071-1:1993, IEC 60071-2:1996, IEC 60721-3-3:1994, IEC 60085:2007, EN 60076-5:2006, UNE 21-305-90, UNE-EN 60695-2-10:2002, UNE-EN 60695-2-11:2001, UL94		

Nota : Las imágenes de los equipos son de uso ilustrativo únicamente y pueden diferir del equipo original.
Note: Devices images are for illustrative purposes only and may differ from the actual device.

Conexiones / Connections



Dimensiones / Dimensions



TRMC 210.2	a	b
50/5, 100/5 150/5, 200/5, 300/5	43	5
400/5, 500/5, 600/5	38	10

Servicio técnico / Technical service

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M111A01-20-16A

Master of Science in Renewable Energy

274 kW_p GRID-CONNECTED PHOTOVOLTAIC SYSTEM FOR SELF-CONSUMPTION

Drawings

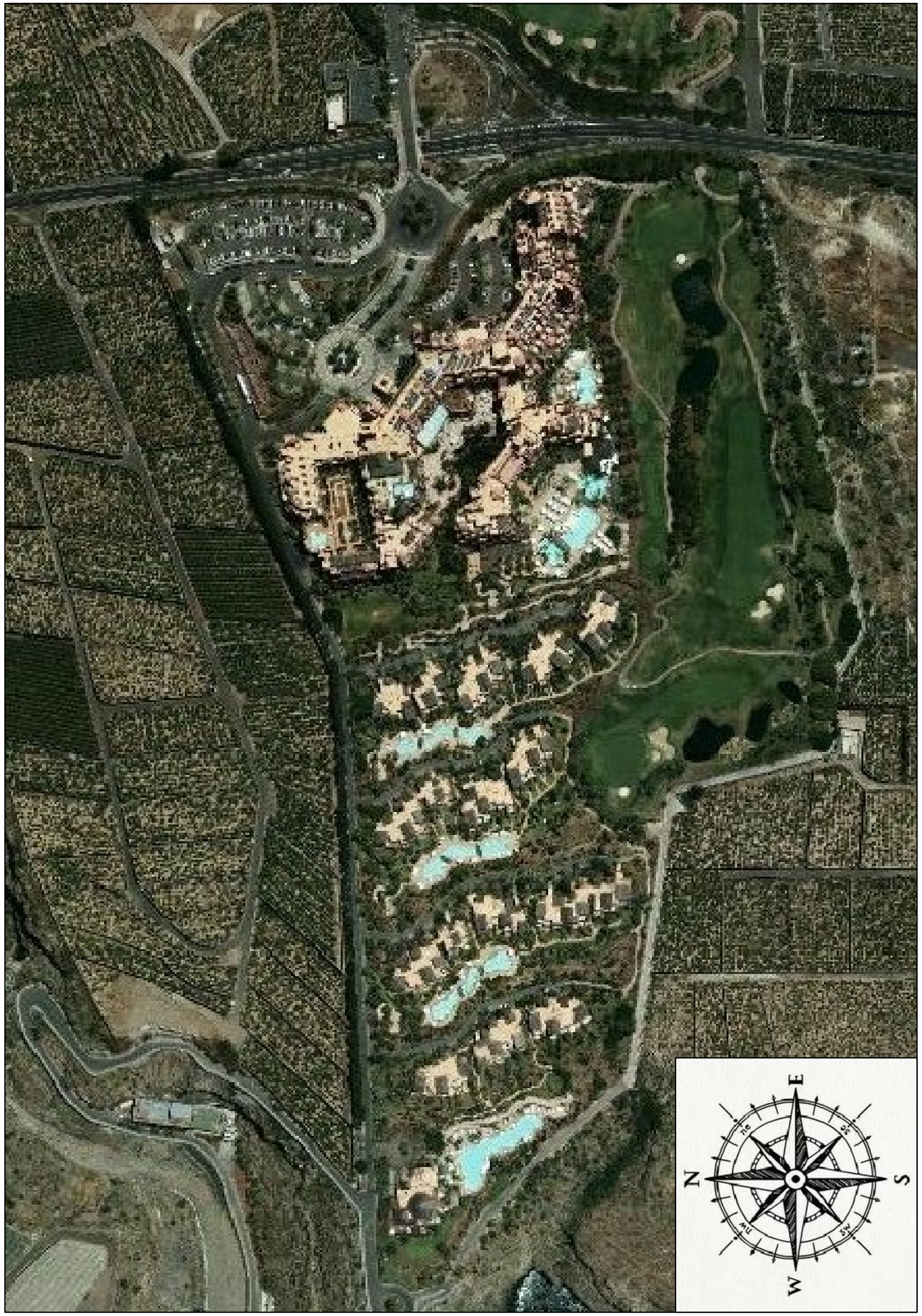
Author:
Aritz Uribe-etxeberria Jauregi

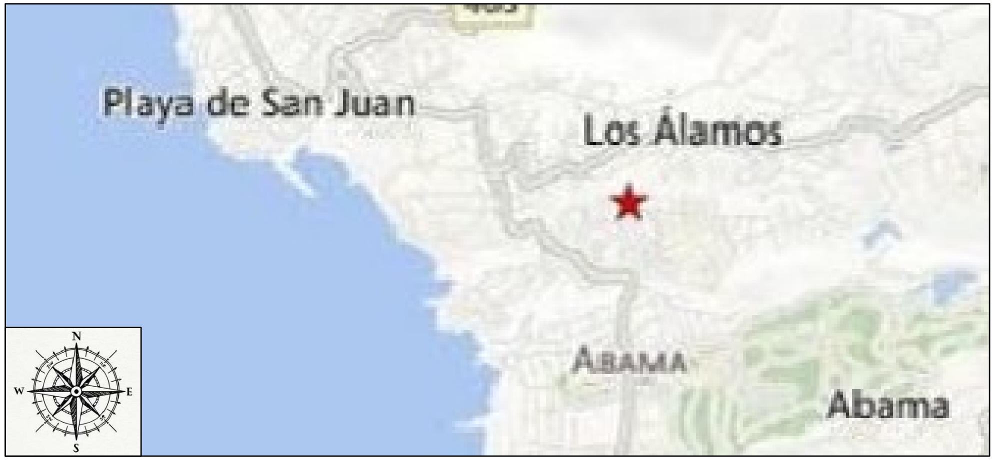
Supervisors:
Dr. José Francisco Gómez González
Dr. Juan Albino Méndez Pérez

Faculty of science: physics section

June 28, 2018

Contents



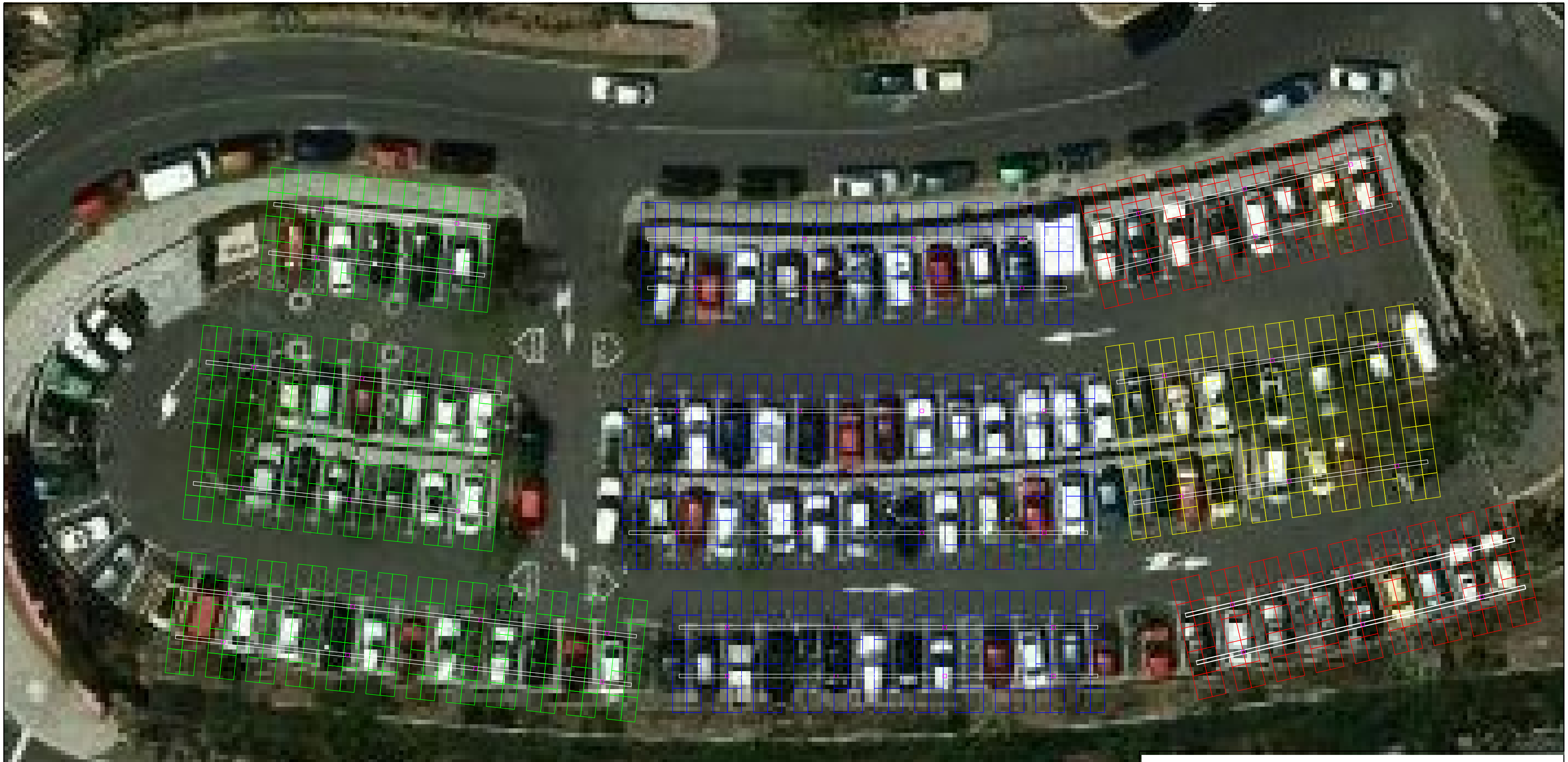


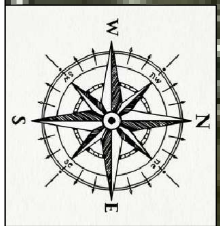
	Name	Date	ULL Universidad de La Laguna	MSc in Renewable Energy
Designed	A. Uribe-etxeberria	16/06/2018		
Drawed by	A. Uribe-etxeberria	16/06/2018		
Approved	J.F. Gómez			Faculty of science: physics section

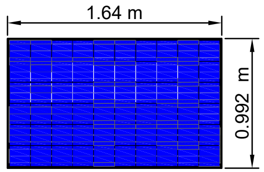
Scale various	274.86 kW_p grid-connected PV system for self-consumption	UNE-EN ISO 7200 A3 size
	Site	Drawing No. 1 / 5 Sheet 1 of 1

Geographical information	
Address: main road, TF-47, km 9, 38687 Guia de Isora, Santa Cruz de Tenerife	
UTM coordinates:	X:323274.242
	Y:3117389.216
	Zone:28
Land register reference: 3274203CS2137S0001WD	

	Name	Date	ULL Universidad de La Laguna	MSc in Renewable Energy	
Designed	A. Uribe-etxeberria	12/06/2018			
Drawed by	A. Uribe-etxeberria	12/06/2018			
Approved	J.F. Gómez			Faculty of science: physics section	
Scale	274.86 kW_p grid-connected PV system for self-consumption				UNE-EN ISO 7200
1 : 887					A3 size
	Location				Drawing No. 2 / 5
					Sheet 1 of 1







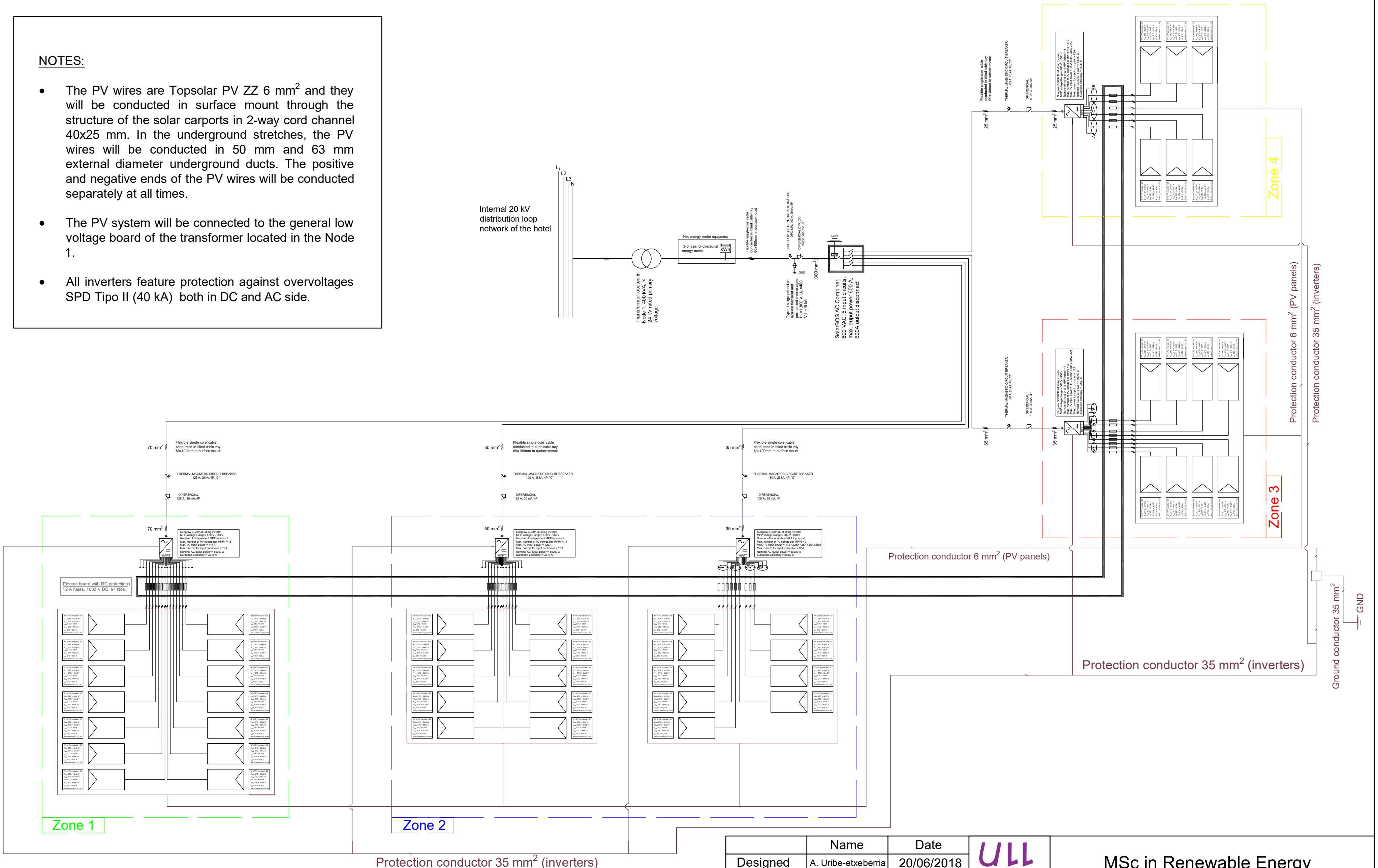
Legend of the PV module	
Electrical Parameters at STC	
Nominal Power (P_{max})	270 W
Open Circuit Voltage(V_{OC})	38.4 V
Short Circuit Current (I_{SC})	9.06 A
Voltage at Nominal Power (V_{mp})	31.1 V
Current at Nominal Power (I_{mp})	8.69 A
Module Efficiency (%)	16,6000

Legend of the solar carports				
Color of the PV modules	Zone	Tilt angle (º)	Orientation (º)	Peak Power (kW_p)
(green)	Zone 1	15	8 (South-west)	83.16
(blue)	Zone 2	15	0 (South)	111.24
(red)	Zone 3	15	-13 (South-east)	45.9
(yellow)	Zone 4	15	-8 (South-east)	34.56
Total installed peak power of the grid-connected PV system for self-consumption				274.86

	Name	Date		
Designed	A. Uribe-etxeberria	19/06/2018	ULL Universidad de La Laguna	MSc in Renewable Energy
Drawed by	A. Uribe-etxeberria	19/06/2018		
Approved	J.F. Gómez			Faculty of science: physics section
Scale 1 : 264	274.86 kW_p grid-connected PV system for self-consumption			UNE-EN ISO 7200
				A3 size
	PV modules layout			Drawing No. 3 / 5
				Sheet 1 of 1

NOTES:

- The PV wires are Topsolar PV ZZ 6 mm^2 and they will be conducted in surface mount through the structure of the solar carports in 2-way cord channel 40x25 mm. In the underground stretches, the PV wires will be conducted in 50 mm and 63 mm external diameter underground ducts. The positive and negative ends of the PV wires will be conducted separately at all times.
- The PV system will be connected to the general low voltage board of the transformer located in the Node 1.
- All inverters feature protection against overvoltages SPD Tipo II (40 kA) both in DC and AC side.



	Name	Date
Designed	A. Uribe-etxeberria	20/06/2018
Drawed by	A. Uribe-etxeberria	20/06/2018
Approved	J.F. Gómez	

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MSc in Renewable Energy

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Scale N / A

274.86 kW$_p$ grid-connected PV system for self-consumption

Single Line Diagram

UNE-EN ISO 7200

A3 size

Drawing No. 4 / 5

Sheet 1 of 1

NOTE:

The PV wires are Topsolar PV ZZ 6 mm^2 and they will be conducted in surface mount through the structure of the solar carports in 2-way cord channel 40x25 mm. In the underground stretches, the PV wires will be conducted in 50 mm and 63 mm external diameter underground ducts. The positive and negative ends of the PV wires will be conducted separately at all times.

Legend	
(line symbol)	Underground stretch
(red line symbol)	PV string with 22 modules in series
(yellow line symbol)	PV string with 21 modules in series
(red triangle symbol)	Inverter

Legend of the solar carports

Color of the PV modules	Zone	Tilt angle (º)	Orientation (º)	Peak Power (kW$_p$)
Green	Zone 1	15	8 (South-west)	83.16
Blue	Zone 2	15	0 (South)	111.24
Red	Zone 3	15	-13 (South-east)	45.9
Yellow	Zone 4	15	-8 (South-east)	34.56
Total installed peak power of the grid-connected PV system for self-consumption				274.86

	Name	Date
Designed	A. Uribe-etxeberria	25/06/2018
Drawed by	A. Uribe-etxeberria	25/06/2018
Approved	J.F. Gómez	

ULL Universidad de La Laguna

MSc in Renewable Energy

Faculty of science: physics section

Scale 1 : 322

274.86 kW$_p$ grid-connected PV system for self-consumption

PV strings and cable routing

UNE-EN ISO 7200

A3 size

Drawing No. 5 / 5

Sheet 1 of 1

Master of Science in Renewable Energy

274 kW_p GRID-CONNECTED PHOTOVOLTAIC SYSTEM FOR SELF-CONSUMPTION

Technical Specification Document

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June 28, 2018

Contents

The present Technical Specification Document has been based on the technical specifications document for grid-connected PV installations by IDAE [9].

1 Components and materials

1.1 Generalities

- As a general principle, electrical insulation of basic type class I must be ensured for both equipment (modules and inverters), as well as materials (conductors, boxes and connection cabinets). As an exception, DC side wiring will have a double insulation of class 2 and a minimum degree of protection of IP65.
- The installation will incorporate all the necessary elements and features to guarantee the quality of the electricity supply at all times.
- The operation of the photovoltaic installations should not cause faults in the network, decreases in safety conditions or alterations higher than those admitted by the regulations.
- In addition, the operation of these facilities should not give rise to dangerous working conditions for the maintenance and operation personnel of the network of distribution.
- Materials placed in the open will be protected against environmental agents, in particular against the effect of solar radiation and humidity.
- All the necessary security and protection elements will be included, ensuring protection against direct and indirect contact, short circuits, overloads, as well as other elements and protections considered by the current legislation.
- For the safety and correct operation of equipment, their indicators, labels, etc. will be in Spanish.

1.2 Photovoltaic modules

- Photovoltaic modules must incorporate the CE marking, according to Directive 2006/95/EC of the European Parliament and of the Council of 12 December 2006, on the approximation of the laws of the Member States on electrical equipment intended to be used with certain voltage limits.

  In addition, they must comply with the UNE-EN 61730 standard, harmonized for Directive 2006/95/EC, on the qualification of the safety of photovoltaic modules, and the UNE-EN 50380 standard, on information of the data sheets and the data plates for the photovoltaic modules. They will also comply the UNE-EN 61215 standard, on the qualification of the design and homologation of crystalline silicon photovoltaic modules for terrestrial use.
- The photovoltaic module will show clearly and indelibly the model and the name or logo of the manufacturer, as well as an individual identification or a serial number traceable to the date of manufacture.
- The photovoltaic modules must:
  - The modules must include the bypass diodes to avoid possible breakdowns of the cells and their circuits by partial shading and will have a degree of protection IP65.

  - The side frames will be made of aluminum or stainless steel.
  - The maximum power and actual short-circuit current referred to standard conditions should be within the margin of ± 3% of corresponding nameplate values.
  - Any module will be rejected if it has manufacturing defects such as breakage or damage, spots on any of its elements, as well as lack of alignment in the cells or bubbles in the encapsulant.

- The structure of the generator will be connected to ground.
- For reasons of safety and to facilitate the maintenance and repair of the generator, the necessary elements (fuses, switches, etc.) for the disconnection will installed, independently and in both terminals, at each one of the branches of the rest of the generator.
- The photovoltaic modules will be guaranteed by the manufacturer for a minimum period of 10 years and will have a performance guarantee for 25 years.

1.3 Support structure

- Support structures must meet the specifications of this section. In all cases the Technical Building Code regarding safety will be complied.
- The support structure with the modules must withstand the overloads caused by wind and snow, according to what is indicated in the Technical Building Code and other regulations of application.
- The design and construction of the structure and the module fixing system will allow the necessary thermal expansions, without transmitting loads that may affect the integrity of the modules, following the manufacturer's instructions.
- The attachment points of the photovoltaic module will be sufficient in number, taking into account the support area and the relative position, so that there are no pressures in the modules higher than those allowed by the manufacturer and the methods approved for the module model.
- The design of the structure will be made for the orientation and the angle of inclination specified for the photovoltaic generator, taking into account the ease of assembly and disassembly, and the possible need for substitutions of elements.
- The structure will be superficially protected against the action of environmental agents. The drilling of the structure will be carried out before proceeding to galvanize the structure.
- The screws will be made of stainless steel. In the case that the structure is galvanized, galvanized screws will be accepted; however, the screws for the fastening of the modules to the structure will be made of stainless steel.
- The module clamping blocks and the structure itself will not shade the modules.
- The support structure will be calculated according to current regulations to support extreme loads due to adverse weather conditions, such as wind, snow, etc.
- If it is built with laminated steel profiles formed by cold forming process, it will comply with the standards UNE-EN 10219-1 and UNE-EN 10219-2 to guarantee all its mechanical characteristics and chemical composition.

- If it is hot-dip galvanized, it will comply with UNE-EN ISO 14713 standards (parts 1, 2 and 3) and UNE-EN ISO 10684 and the thicknesses will comply with the minimum requirements of the standard UNE-EN ISO 1461.

1.4 Inverters

- They will be suitable for the connection to the electrical grid, with an input power variable so that they are able to extract the maximum power that the photovoltaic generator can provide at each time.
- The basic characteristics of the investors will be the following:
  - Principle of operation: current source.
  - Auto-switched.
  - Automatic tracking of the maximum power point of the generator.
  - They will not work in isolated mode.
- Inverters should comply with the following rules:
  - UNE-EN 62093: Accumulation, conversion and energy management components of photovoltaic systems. Design qualification and environmental tests.
  - UNE-EN 61683: Photovoltaic systems. Power conditioners. Process for the measurement of performance.
  - IEC 62116. Testing procedure of islanding prevention measures for utility interactive photovoltaic inverters.
- Inverters will comply with the Community Directives on Electrical Safety and Electromagnetic Compatibility (both will be certified by the manufacturer), incorporating protections against:
  - Alternating current short circuits.
  - Grid voltage out of range.
  - Grid frequency out of range.
  - Overvoltages, by means of varistors or similar.
  - Perturbations present in the grid, such as micro-cuts, pulses, defects of cycles, absence and return of the grid, etc.
- In addition, they must comply with Directive 2004/108/EC of the European Parliament and of the Council of 15 December 2004, on the approximation of the laws of the member states in the field of electromagnetic compatibility.
- Each inverter will have the necessary signaling for its correct operation, and will incorporate the essential automatic controls that ensure adequate supervision and management.
- Each inverter will incorporate, at least, the following manual controls: a) General on and off switching of the inverter, b) Connection and disconnection of the inverter to the CA interface.
- The electrical characteristics of the investors will be the following:

  - The inverter will continue to deliver power to the grid on a continuous basis in conditions of solar irradiance 10% higher than STC. It will also support peaks of 30% higher than STC for periods of up to 10 seconds.
  - The power efficiency of the inverter (quotient between active output power and active input power), for an output power in alternating current equal to 50% and at 100% of the rated power, it will be at least 92% and 94% respectively. The calculation of the performance will be carried out in accordance with the UNE-EN 6168 standard: Photovoltaic Systems. Power conditioners. Procedure for efficiency measuring.
  - The self-consumption of the equipment (losses in "empty") in "stand-by" or night mode should be less than 2% of its rated output power.
  - The power factor of the generated power must be greater than 0.95, between 25% and 100% of the rated power.
  - From powers greater than 10% of its nominal power, the inverter must inject to the grid.

- Inverters will have a minimum degree of protection IP 20 if they are inside of buildings and inaccessible places, IP 30 if they are inside buildings and accessible places, and of IP 65 if they are installed outdoors. In any case, it will comply with current legislation.

- Inverters will be guaranteed for operation under the following environmental conditions: between 0 degree C and 40 degree C temperature and between 0% and 85% relative humidity.

- The inverters of the photovoltaic installation will be guaranteed by the manufacturer during a minimum period of 3 years.

1.5 Wiring

- The positives and negatives of each group of modules will be conducted separately and protected from according to the current regulations.

- The conductors' material will be copper and they will have the adequate section to avoid voltage drops and warm ups. Specifically, for any work condition, conductors must have enough section so that the voltage drop is less than 1.5%.

- The cable must have the necessary length to not generate stress in the various elements nor the possibility of being hooked by the normal transit of people.

- All CC wiring will be double insulated and suitable for outdoor use, air or buried, in accordance with the UNE 21123 standard.

1.6 Grid connection

- The installation will comply with the Royal Decree 1955/2000.

1.7 Measurement

- The installation will comply with Royal Decree 1110/2007, of August 24, whereby the Unified Regulation of points of measurement of the electrical system is approved.

1.8 Protections

- The installation will comply with the Royal Decree 1699/2011 about protections.
- In three-phase connections to the grid the protections for the interconnection of maximum and minimum frequency (51 Hz and 49 Hz respectively) and maximum and minimum voltage (1.1 Um and 0.85 Um) respectively) will be for each phase.

1.9 Earthing of photovoltaic installations

- The installation will comply with the Royal Decree 1699/2011 about conditions for the earthing of photovoltaic installations.

1.10 Harmonics and electromagnetic compatibility

- The installation will comply with the Royal Decree 1699/2011 about harmonics and electromagnetic compatibility.

1.11 Security measures

- The photovoltaic system will be equipped with a protection system that disconnects the system if a failure occurs in the grid or in the installation. Therefore, the proper functioning of the grid to which it is connected will not be disrupted, both in the normal operation conditions as well as during the incident.
- The photovoltaic system must avoid unintentional island operation with part of the distribution grid, in the case of disconnection from the general grid. The anti-island protection must detect the grid disconnection in a time according to the protection criteria of the distribution grid to which it is connected, or in the maximum time set by the regulations or corresponding technical specifications.
- Photovoltaic power plants must be equipped with the necessary means to enable a re-hook-up of the distribution network without causing damage. Likewise, they will not produce surges that may cause damage to other equipment, even in the transitory passage to island, with low charges or no load. Similarly, installed equipment must comply with the limits of emission of disturbances indicated in national and international standards of electromagnetic compatibility.

2 Reception and tests

- The installer will provide the user with a document-delivery note stating the supply of components, materials and manuals for the use and maintenance of the installation. This document will be signed in duplicate by both parties, each one retaining a copy. The manuals delivered to the user will be in one of the official Spanish languages to facilitate their correct interpretation.
- Before putting into service all the main elements (modules, inverters, counters) these must have passed the factory performance tests, of which minutes will be drawn up which will be attached with the quality certificates.
- The tests to be carried out by the installer will be at least the following:

  - Operation and start-up of all systems.
  - Start and stop tests at different times of operation.
  - Tests of the elements and protection measures, security and alarm, as well as their performance, with the exception of the tests referred to the disconnection circuit breaker.
  - Determination of installed capacity.

- Once the tests and start-up have been completed, the Provisional Reception phase will be initiated. However, the Provisional Acceptance Certificate will not be signed until it has been verified that all systems and elements have worked correctly for a minimum of 240 continuous hours, without interruptions or stops caused because of failures or errors of the supplied system, and in addition the following requirements are met:
  - Delivery of all the documentation required in this technical specification document, and at least the required in the UNE-EN 62466 standard: Photovoltaic systems connected to the grid. Minimum requirements documentation, start-up and inspection of a system.
  - Withdrawal of all excess material from the work site.
  - Cleaning of occupied areas, and transporting all waste to landfill.
- During this period the supplier will be the only responsible for the operation of the systems supplied, although it must train the operating personnel.
- All the elements supplied, as well as the installation as a whole, will be protected against manufacturing, installation or design defects for a three-year warranty, except for the photovoltaic modules, for which the minimum guarantee will be 10 years counted from the date of signing the provisional acceptance certificate.
- However, the installer will be obliged to repair the malfunctions that can be produced if it can be seen that its origin comes from hidden design, construction, materials or assembly flaws. It will correct them without charge.

3 Technical requirements of the maintenance contract

3.1 Generalities

- A preventive and corrective maintenance contract of at least three years will be made.
- The maintenance contract will include all elements of the installation, with the preventive maintenance tasks recommended by the different manufacturers.

3.2 Maintenance program

- Maintenance must be carried out by qualified technical personnel under the responsibility of the installation company.
- The preventive maintenance of the installation will include, at least, one visit (annual for installations with an installed power up to 100 kWp and half-yearly for the rest) in which they will be carried out the next activities:
  - Checking of the electrical protections.

  - Checking the modules and connections.
  - Checking the status of the inverter: operation, signaling lamps, alarms, etc.
  - Checking the mechanical state of cables and terminals (including earth cables and re-tighten of terminals), plates, transformers, fans / extractors, joints, re-tightening, cleaning.

- Making a technical report of each of the visits, which includes the state of the installations and incidents that have occurred.

- Keeping a record of performed maintenance operations in a maintenance book, which will include the identification of maintenance staff (name, title and authorization of the company).

3.3 Guarantee

- Deadlines

  - The supplier will guarantee the installation for a minimum 3 years, including all the materials and the procedure used in their assembly.The photovoltaic modules will have a minimum 10-years guarantee.
  - If the exploitation of the supply is interrupted due to reasons under the responsibility the supplier, or due to repairs that the supplier has to carry out as described by the guarantee's stipulations, the term shall be extended for the total duration of these interruptions.

- Economic conditions

  - The guarantee includes the repair or replacement of the components if they happen to be defective, as well as the labor employed in the repair or replacement during the term of the warranty.
  - All other expenses are included, such as travel times, means of transport, depreciation of vehicles and tools, availability of other means and eventual collection and return of repair equipment at the manufacturer's workshops.
  - Similarly, labor and materials necessary to make the adjustments for the correct operation of the installation must be included.
  - If within a reasonable period of time the supplier fails to fulfill the obligations arising from the guarantee, the purchaser of the installation may, upon written notification, set a final date for said supplier fulfills its obligations. If the supplier does not comply with obligations in said last term, the buyer of the installation may, at his own risk of the supplier, make the necessary repairs by itself, or contract for it to a third party, without prejudice to the claim for damages that may have been incurred the supplier.
  - If the supplier fails to fulfill the obligations arising from the guarantee within a reasonable period of time, the purchaser can, by a written notification, set a final date for fulfilling the obligations. If the supplier does not comply with the obligations within this deadline, the purchaser can make the necessary repairs by itself or contract a third party to do it. The purchaser will not be prejudiced by the possible claims for damages from the supplier.

- Cancellation of the guarantee

  - The guarantee may be canceled when the installation has been repaired, modified or disassembled, by people unrelated to the supplier or to the technical assistance services provided by the manufacturers and expressly authorized by the supplier. An exception is the previous item.

- Place and time for the service
  - When the user detects a malfunction in the installation it will communicate it to the supplier. If the supplier considers that it is a manufacturing defect of any component, it will communicate it to the manufacturer.
  - The supplier will attend any incident within one week and the malfunction will be repaired in a maximum time of 10 days, unless a cause of force majeure is justified.
  - The faults of the system will be repaired by the supplier and where the installation is located. If any component could not be repaired at this location, the component must be sent to the manufacturer's official workshop, on behalf and in charge of the supplier.
  - The supplier will perform the repairs or replacements as soon as possible once the fault notification has been received. However, the supplier will not be responsible for the damages caused by the delay, provided it is less than 10 calendar days.

Master of Science in Renewable Energy

274 kW_p GRID-CONNECTED PHOTOVOLTAIC SYSTEM FOR SELF-CONSUMPTION

Bill of Material and Budget

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Faculty of science: physics section

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Contents

1 Bill of material

Budget item 1: mounting and set up of the PV equipment		
1.1- PV equipment		
Srl. No	**Description**	**Quantity**
1.1.1	Amerisolar PV module, 270 W_p nominal power, 60 Pollycristalline cells, 38.04 V (V_{OC}), 9.06 A (I_{SC}), 31.1 V (V_{mp}), 8.69 A (I_{mp}), 16.6 % module efficiency	1,018 Nos
1.1.2	SunGrow SG80KTL string inverter, 80,000 W nominal AC output power, 3-phase, 1 independent MPPT input, maximum 18 PV strings per MPPT	1 No
1.1.3	SunGrow SG60KTL string inverter, 60,000 W nominal AC output power, 3-phase, 1 independent MPPT input, maximum 14 PV strings per MPPT	1 No
1.1.4	SunGrow SG50KTL-M string inverter, 50,000 W nominal AC output power, 3-phase, 3 independent MPPT inputs, maximum 3 PV strings per MPPT	2 Nos
1.1.5	SunGrow SG33KTL-M string inverter, 33,000 W nominal AC output power, 3-phase, 3 independent MPPT inputs, 3 / 3 / 2 PV strings per MPPT	1 No
1.1.6	SolarBos AC box combiner, 5 input circuits, 600 V_{AC},600 A output disconnect, 600 A maximum output power	1 No
1.2- Labour		
Srl. No	**Description**	**Quantity**
1.2.1	Chief electric officer's labour to mount and set up the PV panel on top of the solar carports	18 h
1.2.2	Chief electric officer's first helper's labour to mount and set up the PV panel on top of the solar carports	18 h
1.2.3	Chief electric officer's second helper's labour to mount and set up the PV panel on top of the solar carports	18 h
1.2.4	Chief electric officer's third helper's labour to mount and set up the PV panel on top of the solar carports	18 h
1.2.5	Chief electric officer's labour to mount and set up the inverters and the AC box combiner	1 h
1.2.6	Chief electric officer's helper's labour to mount and set up the inverters and the AC box combiner	1 h
1.3- Complementary direct costs		
Srl. No	**Description**	**Quantity**
1.3.1	Complementary direct costs	2 %

Budget item 2: mounting and set up of the earthing installation		
2.1- Earthing installation equipment		
Srl. No	**Description**	**Quantity**
2.1.1	Bare cooper cable 35 mm^2	10 Mtrs

Srl. No	Description	Quantity
2.1.2	Earthing rod 1.5 m, 14 mm external diameter	5 Nos
2.1.3	Earthing rod bichromate clamp 14 mm external diameter	5 Nos
2.1.4	PVC manhole for grounding cables	5 Nos
2.1.5	Single-pole grounding cable 6 mm^2 halogen-free (PV panels' protection conductors)	1,821 Mtrs
2.1.6	Single-pole grounding cable 35 mm^2 halogen-free (inverters' protection conductors)	25 Mtrs
2.2- Labour		
Srl. No	**Description**	**Quantity**
2.2.1	Chief electric officer's labour to mount and set up the earthing installation	5 h
2.2.2	Chief electric officer's first helper's labour to mount and set up the earthing installation	5 h
2.3- Complementary direct costs		
Srl. No	**Description**	**Quantity**
2.3.1	Complementary direct costs	2 %

Budget item 3: mounting and set up of the wires and protective tubes and channels		
3.1- Wires		
Srl. No	**Description**	**Quantity**
3.1.1	100 m Flexible photovoltaic cable Topsolar PV ZZ 6 mm^2	81 Nos
3.1.2	Flexible single-pole cable 70 mm^2 RZ1-K 0.6/1 halogen-free kV	40 Mtrs
3.1.3	Flexible single-pole cable 50 mm^2 RZ1-K 0.6/1 halogen-free kV	40 Mtrs
3.1.4	Flexible single-pole cable 35 mm^2 RZ1-K 0.6/1 halogen-free kV	80 Mtrs
3.1.5	Flexible single-pole cable 25 mm^2 RZ1-K 0.6/1 halogen-free kV	40 Mtrs
3.1.6	Flexible single-pole XLP copper cable 300 mm^2 0.6/1 kV halogen-free	40 Mtrs
3.2- Protective tubes and channels		
Srl. No	**Description**	**Quantity**
3.2.1	Blind cable tray Unex 60x100 mm 66 EN U23X	240 Mtrs
3.2.2	50 m flexible underground duct 50 mm^2	12 Nos
3.2.3	50 m flexible underground duct 63 mm^2	2 Nos
3.2.4	2 m PVC 2-way cord channel 40x25 mm	131 Nos
3.3- Labour		
Srl. No	**Description**	**Quantity**
3.3.1	Chief electric officer's labour to mount and set up the wires and protective tubes and channels of the installation	8 h
3.3.2	Chief electric officer's first helper's labour to mount and set up the wires and protective tubes and channels of the installation	8 h
3.3.3	Chief electric officer's second helper's labour to mount and set up the wires and protective tubes and channels of the installation	8 h

3.4- Complementary direct costs		
Srl. No	**Description**	**Quantity**
3.4.1	Complementary direct costs	2 %

Budget item 4: mounting and set up of the electric board with DC protection devices		
4.1- DC protection devices		
Srl. No	**Description**	**Quantity**
4.1.1	5 PV fuse, 12 A, 1,000 V_{DC}, 10x38 mm with its fuse holder	20 Nos
4.2- Labour		
Srl. No	**Description**	**Quantity**
4.2.1	Chief electric officer's labour to mount and set up the DC protection devices on the electric board	1 h
4.2.2	Chief electric officer's first helper's labour to mount and set up the DC protection devices on the electric board	1 h
4.3- Complementary direct costs		
Srl. No	**Description**	**Quantity**
4.3.1	Complementary direct costs	2 %

Budget item 5: mounting and set up of the electric board with AC protection devices		
5.1- AC protection devices		
Srl. No	**Description**	**Quantity**
5.1.1	Main automatic moulded-case thermal-magnetic circuit breaker, 450 A, 36 kA breaking capacity, 4-pole, model DPX 630	1 No
5.1.2	Thermal-magnetic circuit breaker, 125 A, 25 kA breaking capacity, 4-pole	1 No
5.1.3	Thermal-magnetic circuit breaker, 100 A, 15 kA breaking capacity, 4-pole	1 No
5.1.4	Thermal-magnetic circuit breaker, 80 A, 25 kA breaking capacity, 4-pole	2 Nos
5.1.5	Thermal-magnetic circuit breaker, 63 A, 10 kA breaking capacity, 4-pole	1 No
5.1.6	DPX differential circuit breaker block , 630 A, 300 mA,4-pole	1 No
5.1.7	Differential circuit breaker, 125 A, 30 mA, 4-pole	2 Nos
5.1.8	Differential circuit breaker, 100 A, 30 mA, 4-pole	2 Nos
5.1.9	Differential circuit breaker, 80 A, 30 mA, 4-pole	1 No
5.1.10	3-phase type II surge protection against transient and permanent overvoltages, $U_p = 1,800\,V$, $U_c = 400\,V$, $I_n = 15\,kA$	1 No
5.2- Labour		
Srl. No	**Description**	**Quantity**
5.2.1	Chief electric officer's labour to mount and set up the AC protection devices on the electric board	1 h
5.2.2	Chief electric officer's first helper's labour to mount and set up the AC protection devices on the electric board	1 h

5.3- Complementary direct costs		
Srl. No	**Description**	**Quantity**
5.3.1	Complementary direct costs	2 %

Budget item 6: mounting and set up of the net energy meter equipment		
6.1- Equipment		
Srl. No	**Description**	**Quantity**
6.1.1	3-phase bi-directional energy meter from SMA	1 No
6.1.2	External current transformer model TRMC 201.2 by manufactuer Circutor	3 Nos
6.2- Labour		
Srl. No	**Description**	**Quantity**
6.2.1	Chief electric officer's labour to mount and set up the DC protection devices on the electric board	1 h
6.2.2	Chief electric officer's first helper's labour to mount and set up the DC protection devices on the electric board	1 h
6.3- Complementary direct costs		
Srl. No	**Description**	**Quantity**
6.3.1	Complementary direct costs	2 %

2 Budget

Budget item 1: mounting and set up of the PV equipment

1.1- PV equipment

Srl. No	Description	Quantity	Unit price €	Total €
1.1.1	Amerisolar PV module, 270 W_p nominal power, 60 Pollycristalline cells, 38.04 V (V_{OC}), 9.06 A (I_{SC}), 31.1 V (V_{mp}), 8.69 A (I_{mp}), 16.6 % module efficiency	1,018 Nos	197.52	201,075.36
1.1.2	SunGrow SG80KTL string inverter, 80,000 W nominal AC output power, 3-phase, 1 independent MPPT input, maximum 18 PV strings per MPPT	1 No	7,748.58	7,748.58
1.1.3	SunGrow SG60KTL string inverter, 60,000 W nominal AC output power, 3-phase, 1 independent MPPT input, maximum 14 PV strings per MPPT	1 No	5,811.44	5,811.44
1.1.4	SunGrow SG50KTL-M string inverter, 50,000 W nominal AC output power, 3-phase, 3 independent MPPT inputs, maximum 3 PV strings per MPPT	2 No	5,572.59	11,145.18
1.1.5	SunGrow SG33KTL-M string inverter, 33,000 W nominal AC output power, 3-phase, 3 independent MPPT inputs, 3 / 3 / 2 PV strings per MPPT	1 No	3,677.91	3,677.91
1.1.6	SolarBos AC box combiner, 5 input circuits, 600 V_{AC}, 600 A output disconnect, 600 A maximum output power	1 No	862.14	862.14

1.2- Labour

Srl. No	Description	Quantity	Unit price €	Total €
1.2.1	Chief electric officer's labour to mount and set up the PV panel on top of the solar carports	40 h	18.13	725.20
1.2.2	Chief electric officer's first helper's labour to mount and set up the PV panel on top of the solar carports	40 h	16.40	656.00
1.2.3	Chief electric officer's second helper's labour to mount and set up the PV panel on top of the solar carports	40 h	16.40	656.00
1.2.4	Chief electric officer's third helper's labour to mount and set up the PV panel on top of the solar carports	40 h	16.40	656.00
1.2.5	Chief electric officer's labour to mount and set up the inverters and the AC box combiner	1 h	18.13	18.13
1.2.6	Chief electric officer's helper's labour to mount and set up the inverters and the AC box combiner	1 h	16.40	16.40

1.3- Complementary direct costs				
Srl. No	**Description**	**Quantity**	**Unit price €**	**Total €**
1.3.1	Complementary direct costs	2 %	233,048.34	4,660.97

Budget item 2: mounting and set up of the earthing installation				
2.1- Earthing installation equipment				
Srl. No	**Description**	**Quantity**	**Unit price €**	**Total €**
2.1.1	Bare cooper cable 35 mm^2	10 Mtrs	7.5	75.00
2.1.2	Earthing rod 1.5 m, 14 mm external diameter	5 Nos	14.4	72.00
2.1.3	Earthing rod bichromate clamp 14 mm external diameter	5 Nos	1.75	8.75
2.1.4	PVC manhole for grounding cables	5 Nos	32.35	161.75
2.1.5	Single-pole grounding cable 6 mm^2 halogen-free (PV panels' protection conductors)	1,821 Mtrs	0.72	1,311.12
2.1.6	Single-pole grounding cable 35 mm^2 halogen-free (inverters' protection conductors)	25 Mtrs	3.85	96.25
2.2- Labour				
Srl. No	**Description**	**Quantity**	**Unit price €**	**Total €**
2.2.1	Chief electric officer's labour to mount and set up the earthing installation	5 h	18.13	90.65
2.2.2	Chief electric officer's first helper's labour to mount and set up the earthing installation	5 h	16.40	82.00
2.3- Complementary direct costs				
Srl. No	**Description**	**Quantity**	**Unit price €**	**Total €**
2.3.1	Complementary direct costs	2 %	1,897.52	37.95

Budget item 3: mounting and set up of the wires and protective tubes and channels				
3.1- Wires				
Srl. No	**Description**	**Quantity**	**Unit price €**	**Total €**
3.1.1	100 m Flexible photovoltaic cable Topsolar PV ZZ 6 mm^2	81 Nos	245.00	19,845.00
3.1.2	Flexible single-pole cable 70 mm^2 RZ1-K 0.6/1 halogen-free kV	40 Mtrs	9.04	361.60
3.1.3	Flexible single-pole cable 50 mm^2 RZ1-K 0.6/1 halogen-free kV	40 Mtrs	6.49	259.60
3.1.4	Flexible single-pole cable 35 mm^2 RZ1-K 0.6/1 halogen-free kV	80 Mtrs	4.59	367.20
3.1.5	Flexible single-pole cable 25 mm^2 RZ1-K 0.6/1 halogen-free kV	40 Mtrs	3.30	132.00
3.1.6	Flexible single-pole XLP copper cable 300 mm^2 0.6/1 kV halogen-free	40 Mtrs	80.64	3,225.60

3.2- Protective tubes and channels				
Srl. No	**Description**	**Quantity**	**Unit price €**	**Total €**
3.2.1	Blind cable tray Unex 60x100 mm 66 EN U23X	240 Mtrs	10.22	2,452.80
3.2.2	50 m flexible underground duct 50 mm^2	12 Nos	41.13	493.56
3.2.3	50 m flexible underground duct 63 mm^2	2 Nos	43.11	86.22
3.2.4	2 m PVC 2-way cord channel 40x25 mm	131 Nos	15.42	2,020.02
3.3- Labour				
Srl. No	**Description**	**Quantity**	**Unit price €**	**Total €**
3.3.1	Chief electric officer's labour to mount and set up the wires and protective tubes and channels of the installation	8 h	18.13	145.04
3.3.2	Chief electric officer's first helper's labour to mount and set up the wires and protective tubes and channels of the installation	8 h	16.40	131.2
3.3.3	Chief electric officer's second helper's labour to mount and set up the wires and protective tubes and channels of the installation	8 h	16.40	131.2
3.4- Complementary direct costs				
Srl. No	**Description**	**Quantity**	**Unit price €**	**Total €**
3.4.1	Complementary direct costs	2 %	29,651.04	593.02

Budget item 4: mounting and set up of the electric board with DC protection devices				
4.1- DC protection devices				
Srl. No	**Description**	**Quantity**	**Unit price €**	**Total €**
4.1.1	5 PV fuse, 12 A, 1,000 V_{DC}, 10x38 mm with its fuse holder	20 Nos	16.19	323.80
4.2- Labour				
Srl. No	**Description**	**Quantity**		
4.2.1	Chief electric officer's labour to mount and set up the DC protection devices on the electric board	1 h	18.13	18.13
4.2.2	Chief electric officer's first helper's labour to mount and set up the DC protection devices on the electric board	1 h	16.40	16.40
4.3- Complementary direct costs				
Srl. No	**Description**	**Quantity**	**Unit price €**	**Total €**
4.3.1	Complementary direct costs	2 %	358.33	7.17

Budget item 5: mounting and set up of the electric board with AC protection devices				
5.1- AC protection devices				
Srl. No	**Description**	**Quantity**	**Unit price €**	**Total €**
5.1.1	Main automatic moulded-case thermal-magnetic circuit breaker, 450 A, 36 kA breaking capacity, 4-pole, model DPX 630	1 No	1,528.20	1,528.20

Srl. No	Description	Quantity	Unit price €	Total €
5.1.2	Thermal-magnetic circuit breaker, 125 A, 25 kA breaking capacity, 4-pole	1 No	31.91	604.06
5.1.3	Thermal-magnetic circuit breaker, 100 A, 15 kA breaking capacity, 4-pole,	1 No	604.06	333.47
5.1.4	Thermal-magnetic circuit breaker, 80 A, 25 kA breaking capacity, 4-pole	2 Nos	31.91	453.87
5.1.5	Thermal-magnetic circuit breaker, 63 A, 10 kA breaking capacity, 4-pole	1 No	29.32	29.32
5.1.6	DPX differential circuit breaker block , 630 A, 300 mA,4-pole	1 No	455.31	455.31
5.1.7	Differential circuit breaker, 125 A, 30 mA, 4-pole	2 Nos	313.35	626.70
5.1.8	Differential circuit breaker, 100 A, 30 mA, 4-pole	2 Nos	185.99	371.98
5.1.9	Differential circuit breaker, 80 A, 30 mA, 4-pole	1 No	220.86	220.86
5.1.10	3-phase type II surge protection against transient and permanent overvoltages, $U_p = 1,800\,V$, $U_c = 400\,V$, $I_n = 15\,kA$	1 No	465.18	465.18
5.2- Labour				
Srl. No	**Description**	**Quantity**	**Unit price €**	**Total €**
5.2.1	Chief electric officer's labour to mount and set up the AC protection devices on the electric board	2 h	18.13	54.39
5.2.2	Chief electric officer's first helper's labour to mount and set up the AC protection devices on the electric board	2 h	16.40	32.80
5.3- Complementary direct costs				
Srl. No	**Description**	**Quantity**	**Unit price €**	**Total €**
5.3.1	Complementary direct costs	2 %	5,176.14	103.52

Budget item 6: mounting and set up of the net energy meter equipment				
6.1- Equipment				
Srl. No	**Description**	**Quantity**	**Unit price €**	**Total €**
6.1.1	3-phase bi-directional energy meter from SMA	1 No	306.12	306.12
6.1.2	External current transformer model TRMC 201.2 by manufactuer Circutor	3 Nos	61.84	185.52
6.2- Labour				
Srl. No	**Description**	**Quantity**		
6.2.1	Chief electric officer's labour to mount and set up the net energy meter equipment	1 h	18.13	18.13
6.2.2	Chief electric officer's first helper's labour to mount and set up the net energy meter equipment	1 h	16.40	16.40

6.3- Complementary direct costs				
Srl. No	**Description**	**Quantity**	**Unit price €**	**Total €**
6.3.1	Complementary direct costs	2 %	526.17	10.52

3 Summary budget

	Total (€)
Budget item 1: mounting and set up of the PV equipment	237,709.31
Budget item 2: mounting and set up of the earthing installation	1,935.47
Budget item 3: mounting and set up of the wires and protective tubes and channels	30,244.06
Budget item 4: mounting and set up of the electric board with DC protection devices	365.50
Budget item 5: mounting and set up of the electric board with AC protection devices	5,279.66
Budget item 6: mounting and set up of the net energy meter equipment	536.69
Material Execution Budget:	276,070.69
Industrial Benefit (6%):	16,564.24
Overhead Costs (13%):	35,889.19
Tax Base:	328,524.12
General Indirect Canary Islands Tax (IGIC, by its Spanish acronym) (7%):	22,996.69
Contracted Operation Budget:	351,520.81

The Material Execution Budget of this project amounts to **TWO HUNDRED SEVENTY SIX THOUSAND AND SEVENTY EUROS WITH SIXTY NINE CENTS**.

The Tax Base of this project amounts to **THREE HUNDRED TWENTY EIGHT THOUSAND, EIGHT HUNDRED EIGHTY NINE EUROS WITH NINETEEN CENTS**.

The Contracted Operation Budget of this project amounts to **THREE HUNDRED FIFTY ONE THOUSAND, FIVE HUNDRED TWENTY EUROS WITH EIGHTY ONE CENTS**.