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DESIGN OF A 1MVA GRID-TIED PHOTOVOLTAIC PLANT IN BUGASONG (VISAYAN ISLANDS-PHILIPPINES)

AUTHOR: SALVADOR TORREGROSA MARCO

SUPERVISOR: MIGUEL ÁNGEL SÁNCHEZ ROMERO

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APPRECIATIONS

“To my girlfriend

To my family”

RESUMEN

El propósito de este proyecto trata del diseño de una planta fotovoltaica de 1 MVA situada en Bugasong cerca del río Paliwan. La idea principal del diseño es aprovechar la subestación eléctrica existente, próxima a la parcela de la planta fotovoltaica, para aportar energía procedente del recurso solar.

Existe una planta hidroeléctrica de 8 MW de potencia (objeto de otro proyecto) a una distancia menor de 2 km de la planta fotovoltaica, causante de la existencia de la subestación eléctrica que se utilizará como medio de conexión a la red distribuidora. La ventaja es que no es necesario proyectar ni construir una línea eléctrica de gran longitud capaz de distribuir la energía generada en la planta fotovoltaica.

La finalidad es obtener el máximo beneficio económico de la planta fotovoltaica, teniendo en cuenta los factores que afectan a la producción debidos a la situación y la configuración de dicha planta.

Palabras Clave: Fotovoltaica Energía Solar Filipinas

ABSTRACT

The purpose of this Project is the design of a photovoltaic plant of 1 MVA located in Bugasong, next to Paliwan river. The principal idea is to take advantage of the existent electrical substation, situated close enough to the terrain where the photovoltaic plant will be installed, in order to provide clean energy originated from solar energy.

There is an existing hydroelectric power plant of 8 MW of power (object from another project) at a distance less than 2 km away from the photovoltaic plant, source of the existence of the electrical substation which will be used as a mean of connection with the grid. The advantage is there is no need to design or construct any electrical line of great length capable of carrying and distribute the energy generated by the photovoltaic plant.

The objective is to obtain the maximum economical profit from the photovoltaic plant, taking into account the factors which affect energy production, due to the location and the configuration of the plant.

Keywords: Photovoltaic Energy Solar Philippines

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DOCUMENT 1 - REPORT

1. REPORT

1.1. INTRODUCTION

Objectives of the project

The objective of this project is the design of a photovoltaic plant in Bugasong in order to provide sustainable and clean energy to the province of Antique.

The photovoltaic plant will be located next to a hydroelectric power plant which has an electrical substation less than 500 m away from it. This hydroelectric plant was designed in another project which consisted on the construction of several hydroelectric plants by the company Suweco.

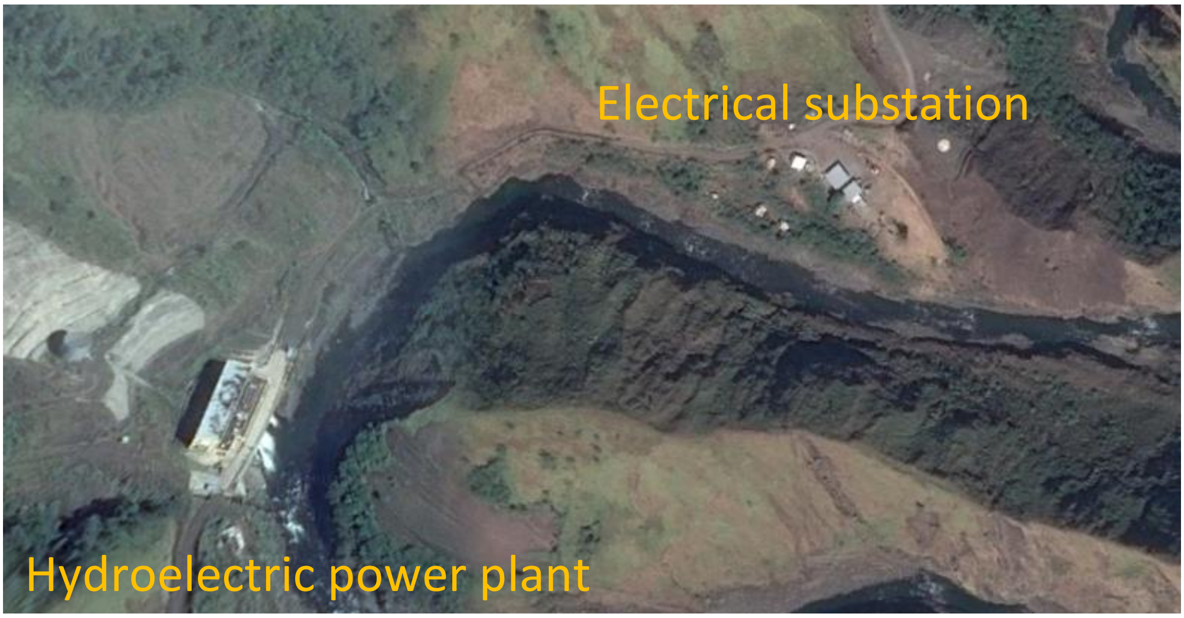


Figure 1. Hydroelectric power plant and associated electrical substation. Image obtained from google earth.

Suweco aims to complete nine hydropower projects in Panay island, with a total capacity of 47 MW. There is only one of them installed and currently operating, Villasiga 1, with a power of 8 MW. The rest of the hydropower plants have not been built yet. Therefore, the aim of the photovoltaic plant is to support the existing hydroelectric plant to provide clean energy and help the sustainability of the province of Antique. As well as obtaining the maximum economic profit.

Part of the project is going to be financed by the Development Bank of the Philippines. An agreement has been reached between SUWECO and DBP.

The main portion of the financing is going to be provided by the German federal Ministry for Economic Cooperation and Development (BMZ) with UPV acting as the subcontracted project executing agency on behalf of the BMZ. UPV provides services in the field of international development cooperation along with other services.

Motivation and justification

The development of this project is based on the acquisition of knowledge related to the field of activity related to photovoltaic energy, in order to carry on the study in this area.

Carrying out this project in English is simply a personal challenge to be able to perform projects in a different language from Spanish. As well as learning the technical words and expressions of this area of work.

Scope of the project

The content of the project is based on the description of the photovoltaic installation of 1056000 W peak power, including the design of the low and high voltage system. Furthermore, an analysis of the profit, in a period of 25 years, is taken to decide whether or not this project is profitable.

1.2. REGULATORY FRAMEWORK

The regulatory framework used is the Philippine electrical code and distribution code. However, it is worth mentioning that in most cases the Spanish norms are more restrictive than the ones used in the Philippines and therefore, in most of the cases, the norms applied to this project will be from Spanish origin.

These norms will be taken from the RBT and RAT in Spain and will be mentioned anytime any of them are used in the design of the photovoltaic plant.

It is worth mentioning that the tables and graphs from Spanish origin use a comma instead of a point as separator for decimal places.

1.3. LOCATION

The terrain used for the photovoltaic plant is located around 1.5 km away from the existing hydroelectric plant. It is located next to a storage zone which has already been cleared and levelled by Suweco when they built the hydropower plant. This storage zone will be used to store the materials and machinery used in the construction site and any other materials originated from the construction.

Image

Figure 2. Storage zone (red) and photovoltaic plant terrain (orange). Image obtained from google earth (see drawings for a more accurate area of the terrain)

The coordinates of the terrain used for the photovoltaic plant are 11.16 latitude and 122.15 altitude. It has an access road and vegetation all over the area, so it will need to be cleared before construction. It has an inclination level of 10 degrees positively orientated from east to west. Given that the location of the photovoltaic plant is located in the northern hemisphere, the modules should be orientated to the south. This orientation is beneficial as it lacks of obstacles which could lower incident solar radiation.

The advantages of this location are the proximity of the electrical substation and wind speed which will help with the refrigeration of the modules. Three of the most important factors that affect the decision of the location of a photovoltaic plant, are ambient temperature, solar radiation of the zone and wind speed.

At high ambient temperatures the energy production lowers due to a significant drop in voltage, and at the same time high radiation levels increase production. These two factors counter each other, as at higher radiation levels the ambient temperature increases. On the other hand, wind speed will grant good refrigeration to the modules and hence an increase in efficiency will happen.

It is worth mentioning that the available area is reduced given that a perimeter fence will be installed, and therefore, modules will be mounted 5 m away from this fence so that no shadows are casted on them.

1.4. PHOTOVOLTAIC INSTALLATION

Basic data

In the photovoltaic installation the modules used for the design are model A-320P GS from ATERSA, 3300 of them in total of 320 Wp each. They will be installed in 150 groups connected in parallel of 22 modules connected in series. And therefore, a peak power of 1056 kWp.

The inverter used, PVS800-57-1000kW-C has 1 kW nominal power, while the transformer has a nominal power of 1000 kW and it is oil immersed.

Modules will be mounted on a structure which allows them to be 15º respect to the horizontal plane and south orientated. The structure will be built in-situ.

Previous studies

Previous studies are not part of this project. However, it is interesting to mention briefly the type of studies that would have to take place before the construction.

It is assumed that the geotechnical studies are already done and it is possible to build in the terrain where the photovoltaic plant has been situated.

Another previous study would be the topographical and land study, in order to obtain a clear idea of how the location is. This study includes where buildings, pipes or any type of existing structure is.

The last study is the hydrological study which consists on the movement and distribution of water such as mitigating and preventing floods in the area.

In addition, an initial environmental examination of the proposed photovoltaic plant must be carried out. The impacts to the environment associated to the photovoltaic plant are three, construction, operation and maintenance, and abandonment.

Related to the construction phase, the expected alterations are mainly six: soil erosion, dust, noise, safety, health and sanitation. All of the possible impacts named above should carry with them protective and corrective measures. For the operation and maintenance phase there are five potential environmental impacts: noise from transformer, transformer oil hazards, aesthetic problems, and hazard to electromagnetic field radiation. Finally, it is considered that the abandonment of the photovoltaic plant could happen; in this case, existing structures or any element left behind could lead to physical or biological hazards to nearby residents if the situation is not handled properly. As in the phase of construction, each and every of the possible impacts described above should carry with them protective and corrective measures.

Some of these problems may seem to be harmless, but if exposed to them for long periods of time and repeatedly, can be extremely dangerous, and therefore, a need for protective measures is essential.

Once the previous studies have been done, the project can take place. The following Gantt diagram represents a possible schedule of the photovoltaic plant project:

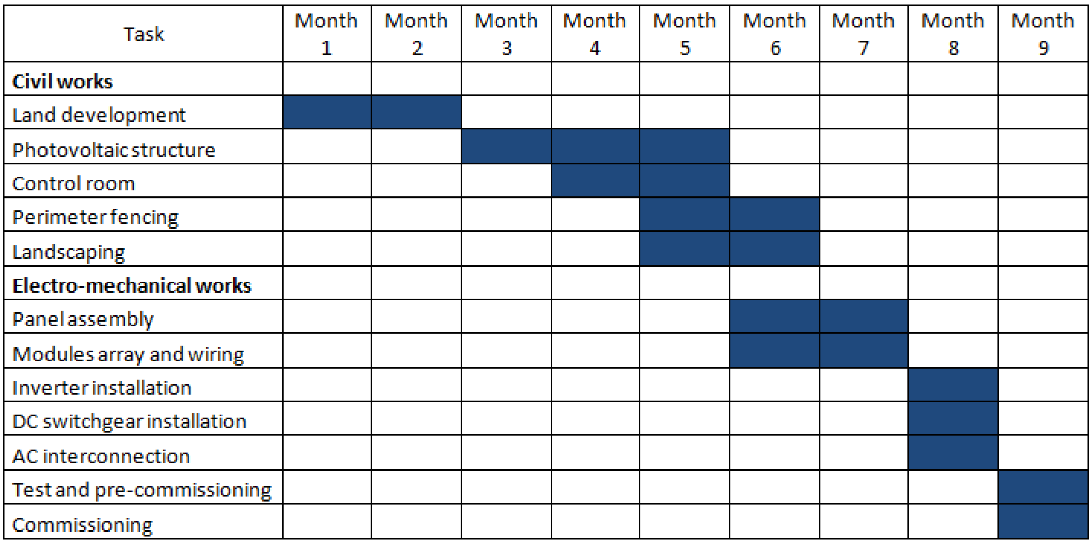


Figure 3. Gantt diagram. Own work.

Solar radiation and solar gain

The solar radiation incident on the solar cells varies depending on a series of factors. The main factors are the season of the year, the tilt angle, the geographical area and meteorology conditions such as the presence of clouds.

The incident solar radiation can be divided in three types:

Direct solar radiation, which is the one that arrives at a given surface without any dispersion or reflection.

Diffuse solar radiation which is the one that arrives at a given surface after suffering dispersion in its trajectory.

Reflected solar radiation is the one which arrives at a given surface after suffering reflection off objects such as buildings or the floor. Albedo radiation would be the relation between the incident radiation on a surface and the reflected radiation off that same surface.

It is also worth mentioning the definitions of tilt angle and azimuth angle:

Tilt angle is the angle formed by the surface of the earth and the surface of a photovoltaic module. While azimuth angle is defined as the angle between the projection on the horizontal surface of the normal to the surface of the module and the meridian of the place. In this case the tilt angle used in the design is 15º with an azimuth angle of 0º (orientated to the south).

Data sources used to obtain solar radiation and ambient temperatures in the geographical area of the terrain used for the photovoltaic plant are, Atmospheric data centre from NASA and the data base of PVsyst for the irradiance data and meteoblue for ambient temperature. Given that the data obtained from PVsyst is more unpromising, it is the one that will be used in the calculations.

The optimum tilt angle according to PVsyst is 17º. However, comparing the values of solar radiation between tilt angles of 17º and 15 º it is decided to use a tilt angle of 15º, as the average value of total irradiance is very similar.

In the following table the data of solar radiation from PVsyst data source is represented for each month of the year, for a tilt angle of 15º:

	Horiz. (kWh/m2.day)	Tilted (kWh/m2.day)
JAN	4.71	5.39
FEB	5.40	5.93
MAR	6.11	6.35
APR	6.39	6.23
MAY	5.73	5.32
JUN	4.95	4.50
JUL	4.59	4.23
AUG	4.55	4.36
SEP	4.81	4.86
OCT	4.72	5.05
NOV	4.48	5.04
DEC	4.28	4.95
	5.06	5.18

Table 1. Solar radiation in horizontal and tilted surface. Own work.

The total value of the solar radiation for a year for the location of the photovoltaic plant is therefore, 1890.7 kWh/m2.year.

The values of the minimum and maximum temperatures are essential for the determination of the photovoltaic system configuration, as it has influence on the values of current and voltages used to decide the maximum number of modules in series and groups of modules in parallel.

In the following table the data of maximum and minimum temperatures along the years are recorded:

	Minimum temperature (ºC)	Maximum temperature (ºC)
JAN	19	32
FEB	19	33
MAR	20	35
APR	22	36
MAY	24	36
JUN	24	34
JUL	23	32
AUG	23	32

SEP	23	32
OCT	23	32
NOV	21	32
DEC	20	32
	19	36

Table 2. Maximum and minimum temperatures. Own work.

The minimum and maximum temperatures of the location are 19ºC and 36 ºC respectively.

Photovoltaic module and configuration

Photovoltaic modules are the ones in charge of transforming the received sun radiation into electrical energy. Each module is formed by a number of photovoltaic cells, usually all of them connected in series in order to increase power and voltage. Power is increased due to the drop of power losses when you increase the voltage, and therefore, lower the current. Losses due to the Joule effect are reduced.

The curves of a photovoltaic module vary significantly depending on two variables, solar radiation and cell temperature. With an increase in cell temperature, the maximum voltage provided by the module decreases. While the maximum current decreases when solar radiation lowers. In the following images, the behaviour of the module used in the design is shown:

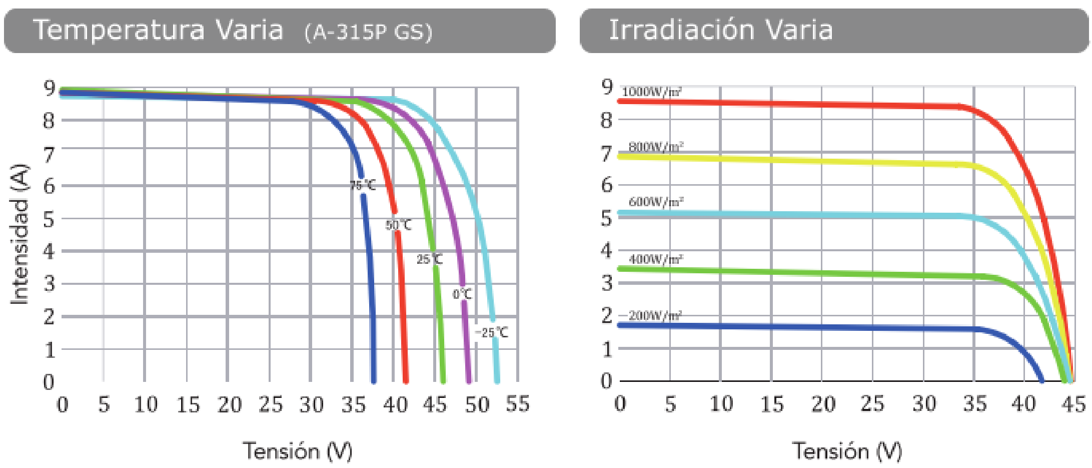


Figure 4. Curves of the photovoltaic module (provided by manufacturer ATERSA).

At the same time, modules have different characteristics which determine energy production. The most important data from a photovoltaic module needed to calculate the configuration of the photovoltaic plant is shown in the next table:

Pmax	320 W
Vmp	37.56 V
Imp	8.52 A
Voc	45.82 A
Isc	9.03 A
Eff	16.50 %
Ptol	0/+3 %
MSFus	15 A
Vmax	DC 1000 V
NOCT	45±2 ºC

Table 3. Electrical characteristics of the module (provided by manufacturer ATERSA).

Pmax: Maximum power of the module.

Vmp: Maximum power point voltage.

Imp: Maximum power point current.

Voc: Short circuit voltage.

Isc: Short circuit current.

Eff: Efficiency of the module.

Ptol: Power tolerance.

MSFus: Maximum series of fuses.

Vmax: Maximum voltage of the system.

NOCT: Normal operating cell temperature.

See data sheets for more information.

Two other parameters that are important in order to achieve the best configuration of the photovoltaic system are temperature coefficients. They can be expressed as a percentage or by the unit. In this case, the temperature coefficients for the module used are:

Coef. Temp. de Isc (TK Isc)	0.06% /°C
Coef. Temp. de Voc (TK Voc)	-0.34% /°C

Table 4. Temperature coefficients (provided by manufacturer ATERSA)

As explained before, the inclination of the modules used is 15º. The distance between rows can be reduced in comparison with an inclination of 17º, and therefore, shadow problems are minimized.

To calculate the separation between rows the following equation is used:

Equation 1: $\gamma = 90 - lat - 23.5$

$$\gamma = 55.3º$$

Equation 2: $dmin = L(\cos\beta + \frac{\sin\beta}{\tan\gamma})$

$$dmin = 4.5\ m$$

$dmin$: Minimum distance between rows to avoid shadow problems.

β: Inclination of the structure in degrees.

lat: Latitude of the location.

γ: Incident angle of sun radiation.

L: Length of the supporting structure.

The following image represents these parameters:

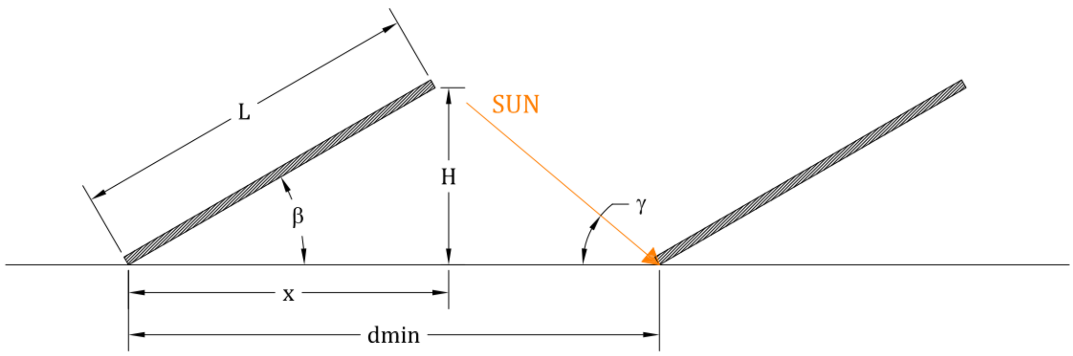


Figure 5. Separation between rows. Own work.

Therefore, the minimum distance that there should be between rows to reduce shadows is 4.5 m. It is worth mentioning that the length of the structure will be twice the length of the module plus the width of the hook used.

In order to determine the number of modules connected in series and the number groups connected in parallel, the open circuit voltage and the short circuit current at cell operating temperatures, different from standard conditions, must be calculated.

The expressions used for this depend on initial data of the characteristics of the module. The minimum operating temperature used for the calculations is the minimum ambient temperature, as it will never go below that value. For the maximum operating temperature the applied equation is as follows:

Equation 3: $Tcell = Tamb + (NOCT - 20)\frac{E}{800}$

$$Tcell = 36 + (47 - 20)\frac{264}{800}$$

$$Tcell_{max}: 44.93 \text{ ºC} \approx 45 \text{ ℃}$$

$$Tcell_{min}: 19 \text{ ºC}$$

$NOCT$: Normal operating cell temperature (ºC) when the photovoltaic cell is submitted to an ambient temperature of 20 ºC, 800 W/m^2 of irradiance and a wind speed of 1 m/s.

E: Irradiance (W/m^2).

$Tamb$: Ambient temperature (ºC).

$Tcell_{max}$: Maximum cell temperature (ºC).

$Tcell_{min}$: Minimum cell temperature (ºC).

Once the maximum and minimum temperatures the photovoltaic cell can reach are known, the following step is to determine the short circuit current and open circuit voltage at that temperature. As well as the maximum and minimum maximum power point voltages (Vmpp). The expressions used in this case are:

Equation 4: $Isc_{Tcell} = Isc_{25ºC}(1 + (Tcell - 25)\frac{\alpha}{100})$

Equation 5: $Voc_{Tcell} = Voc_{25ºC}(1 + (Tcell - 25)\frac{\beta}{100})$

Equation 6: $Vmpp_{Tcell} = Vmpp_{25ºC}(1 + (Tcell - 25)\frac{\beta}{100})$

Isc_{Tcell}: Short circuit current at operating cell temperature (A).

Voc_{Tcell}: Open circuit voltage at operating cell temperature (V).

$Vmpp_{Tcell}$: Maximum power point voltage at operating cell temperature (V).

β: Voltage temperature coefficient (1/ºC).

α: Current temperature coefficient (1/ºC).

$Isc_{25ºC}$: Short circuit current at 25 ºC (A).

$Voc_{25ºC}$: Open circuit voltage at 25 ºC (V).

$Tcell$: Functioning cell temperature (ºC).

Given this equations, the results are the following:

$$Isc_{45ºC} = 9.138\ A$$

$$Voc_{19ºC} = 46.755\ V$$

$$Voc_{45ºC} = 42.718\ V$$

$$Vmpp_{19ºC} = 38.326\ V$$

$$Vmpp_{45ºC} = 35.017\ V$$

When connecting modules in series, the voltage is increased while the current stays the same. This increase in voltage is limited by the characteristics of the inverter. In the case of the inverter used in the design, the maximum voltage the inverter can handle is 1100 V. At the same time, the upper and lower boundaries of the maximum power point voltage in the input of the inverter are 850 V and 600V respectively.

The maximum number of modules connected in series depends on two equations, which are function of the maximum Vmpp and the maximum input voltage of the inverter:

Equation 7: $Nº\ modules \leq \frac{1100}{Voc_{19ºC}}$

Equation 8: $Nº\ modules \leq \frac{850}{Vmpp_{19ºC}}$

$$Nº\ modules \leq 22.178$$

On the other hand, the minimum number is defined by the following inequality:

Equation 9: $Nº\ modules \geq \frac{600}{Vmpp_{45ºC}}$

$$Nº\ modules \geq 17.134$$

Given these two inequalities, the range of modules connected in series allowed by the inverter and the type of modules used is:

$$18 \leq Nº\ modules \leq 22$$

It can be appreciated that there are 5 possibilities. From those possibilities, it will be chosen to connect 22 modules in series, in order to reduce as much as possible the power losses. This configuration allows the system to obtain the greatest voltage and the minimum current for each group of modules, and therefore, the losses due to the Joule effect are minimized.

Once the number of modules connected in series is determined, the maximum number of series in parallel must be calculated. This value depends on the maximum input short circuit current of the inverter, 1710 A. It also depends on the maximum short circuit current of each group of modules (or photovoltaic array) in series, which occurs at the maximum cell temperature, $Isc_{45ºC} = 9.138\ A$.

Equation 10: $Nº\ series\ in\ parallel \leq \frac{1710}{Isc_{45ºC}}$

$$Nº\ series\ in\ parallel \leq 187.133$$

Given that the maximum power of each module, 320 W, is obtained in optimum conditions, which are hard to achieve, a 5% increase in power respect to the power of the inverter (1000 kW) will be considered:

$$Nº\ total\ modules \leq \frac{1.05 \times 1\ MW}{320\ W}$$

$$Nº\ total\ modules \leq 3281.25$$

$$Nº\ series\ in\ parallel \geq \frac{3281.25}{22}$$

$$Nº\ series\ in\ parallel \geq 149.148$$

$$Nº\ series\ in\ parallel = 150$$

The number of groups of modules in series selected from the conditions above is 150 groups of 22 modules in series connected in parallel. This configuration provides a maximum power, or peak power, of the installation of:

Equation 11: $Peak\ power = 150\ groups \times 22 modules \times 320\ W$

$$Peak\ power = 1056\ kW$$

Structure

An important issue about photovoltaic installations is the supporting structure for the modules used. A correctly designed structure can provide benefits such as:

- Facilitates the installation and maintenance of the photovoltaic plant.
- Problems can be reduced if high quality materials are used.
- Avoids partial shades from objects in the surroundings.
- Reduces the wiring required for the interconnection between devices, and therefore, improves overall performance.

The calculations needed to determine if the structure used fulfills the required conditions stipulated in the norm are not object of this project. However, the starting data needed for this calculations will be explained.

Given that there is an inclination of 10º orientated positively from east to west the length of one of the pillar will be larger than the other in order to correct that difference in height created by the inclination. The inclination of the modules should be 15º orientated to the south with a distance between rows of 4.5 m.

According to the manufacturer of the modules (Atersa):

Especificaciones mecánicas	
Dimensiones	1956x992x40 mm
Peso (± 0.5 kg)	21.6 kg
Máx. carga estática, frontal (nieve y viento)	5400 Pa
Máx. carga estática, posterior (viento)	2400 Pa
Máx. impacto granizo (diámetro/velocidad)	25 mm / 23 m/s

Table 5. Mechanic characteristics of the module (provided by manufacturer ATERSA).

Mounting structures without solar tracking have to be orientated to the south if situated on the northern hemisphere and orientated to the north if situated on the opposite hemisphere. They must be mounted with an optimum tilt angle (in this case 15º) to generate the maximum energy.

On the other hand, solar trackers are electromechanical systems used to increase the radiation received from the sun. They work by orientating the modules perpendicularly to the sun at all times. This may increase energy production between 30% to 50%.

Using solar trackers in the photovoltaic plant reduces losses. Some of the reasons are:

- Losses due to angular reflectance are reduced.
- Better ventilation
- Dust and dirtiness of the modules is reduced.

However, solar tracks also have disadvantages. One of the most relevant disadvantages is that structures consume energy when moving, and the other being that the cost of the maintenance is much higher. Their use could be justified if the use of the photovoltaic plant would be orientated to water pumping, where solar trackers can improve production up to a 70%.

For the photovoltaic plant studied, it is decided to use a mounting structure without solar tracking as maintenance is reduced and the installation will be easier. Along with reduced costs of the initial investment. In addition, it is considered that when maintenance actions are required, the delay in time of the maintenance could have very negative effects on the energy production.

The disposal of the modules on the structure will be two rows of modules vertically mounted as shown in the following image:

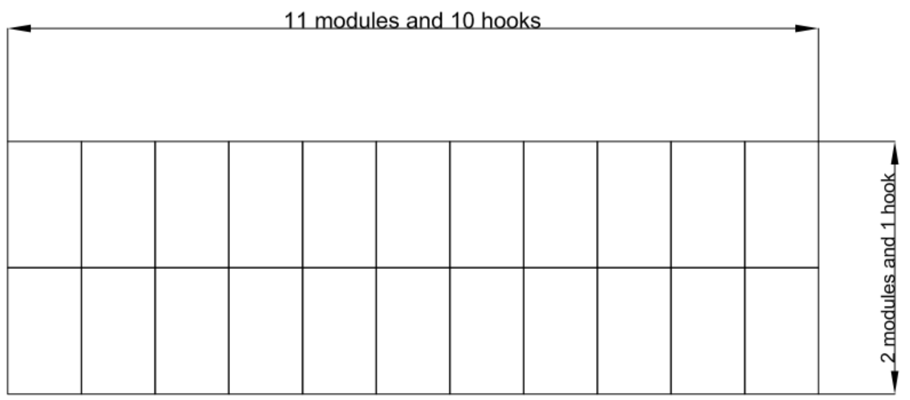


Figure 6. Supporting structure. Own work.

It is worth mentioning that for the attachment it is only necessary to leave 20 mm due to the hook in one of the sides of the module. However, leaving the same distance in the other side will grant more benefits to the installation. These benefits are reduced operating temperature of the module due to an increase in ventilation and allow thermal expansion to avoid mechanical problems and reduce maintenance.

Inverter

The inverter is one of the most important components in grid-connection systems. The purpose of the inverter is to transform DC current to AC current in order to be able to connect the photovoltaic generator system to the power network. Apart from the main benefit of using an inverter, which is the conversion to AC current, some inverters have the possibility to control the generation of active and reactive power at the output of the DC/AC converter. The inverter used in the design has this ability, so that the conditions to connect the photovoltaic system to the grid are achieved. Usually a power factor of 0.95 is required.

The inverter also includes an islanding operation mode detection, which consists on verifying the situation of the grid from time to time and check if the electrical grid power is no longer present. If this happens, the inverter must be disconnected, as it may be dangerous for utility workers.

Figure 7. Detail of the central inverter (provided by manufacturer ABB).

The chosen inverter, 1 MW nominal output power, is composed of various modules which coordinate with one another to obtain the maximum efficiency depending on the power being generated. In the following images the functioning of the central inverter is shown:

In relation to the DC/AC converters, the main parameters of an inverter are the following:

- AC power at the output.
- Maximum and minimum voltage allowed at the AC output.
- Maximum current allowed at the AC output.
- Output waveform.

See data sheets for more information.

Transformer

The performance of the inverter is highly dependent of the use of a transformer, as introducing a transformer in the system will cause power losses and eventually energy production will be reduced. As well as increasing the total weight of system.

In the other hand, it grants electrical isolation. Electrical isolation is required in some countries so it is necessary to use a transformer. For the design of the photovoltaic plant, electrical isolation is not required, but the fact that the total power loss will increase due to power losses in the wires forces the system to include a transformer so that power losses from the inverter to the electrical substation meet the required conditions, which is a maximum of 0.8%.

The processing plant where the transformer will be situated is closer than 10 m away from the inverter (see drawings for more information). Its objective is to increase voltage to 20 kV to evacuate the energy produced which is the required voltage of the electrical substation to connect the photovoltaic plant.

The processing plant will be situated inside of a prefabricated building and the characteristics of the transformer used are the following for a nominal power of 1 MW:

Características eléctricas para el material hasta 24 kV de aislamiento

Potencia asignada (kVA)			50	100	160	250	400	630	800	1.000	1.250	1.600	2.000	2.500
Tensión primaria asignada			de 6 kV hasta límite máximo de 24 kV incluida regulación											
Tensión secundaria		B2	420 V											
Pérdidas (W)		en vacío	145	260	375	530	750	1.030	1.200	1.400	1.730	2.200	2.640	3.200
		por carga a 75 °C	1.100	1.750	2.350	3.250	4.600	6.500	8.340	10.500	13.210	17.000	21.220	26.500
Tensión de cortocircuito (%)			4	4	4	4	4	4	6	6	6	6	6	6
Caída de tensión a plena carga		$\cos\varphi = 1$	2,26	1,81	1,54	1,37	1,22	1,10	1,21	1,22	1,23	1,23	1,23	1,23
		$\cos\varphi = 0{,}8$	3,77	3,57	3,43	3,33	3,25	3,18	4,46	4,47	4,48	4,48	4,48	4,47
Rendimiento	carga 100%	$\cos\varphi = 1$	97,55	98,03	98,33	98,51	98,68	98,82	98,82	98,82	98,82	98,81	98,82	98,83
		$\cos\varphi = 0{,}8$	96,98	97,55	97,92	98,15	98,36	98,53	98,53	98,53	98,53	98,52	98,53	98,54
	carga 75%	$\cos\varphi = 1$	98,00	98,37	98,61	98,76	98,90	99,02	99,03	99,04	99,03	99,03	99,04	99,04
		$\cos\varphi = 0{,}8$	97,52	97,97	98,26	98,45	98,63	98,78	98,79	98,80	98,79	98,79	98,80	98,81
	carga 50%	$\cos\varphi = 1$	98,35	98,62	98,81	98,94	99,06	99,16	99,19	99,20	99,20	99,20	99,21	99,22
		$\cos\varphi = 0{,}8$	97,94	98,29	98,52	98,68	98,83	98,96	98,98	99,00	99,00	99,00	99,02	99,03
	carga 25%	$\cos\varphi = 1$	98,32	98,54	98,71	98,84	98,97	99,10	99,15	99,18	99,19	99,19	99,21	99,23
		$\cos\varphi = 0{,}8$	97,91	98,19	98,40	98,55	98,72	98,87	98,94	98,98	98,99	98,99	99,02	99,04
Ruido dB (A)	potencia acústica Lwa		50	54	57	60	63	65	66	68	69	71	73	76

Estas características hacen referencia a transformadores con una sola tensión en primario y secundario. Otras tensiones bajo pedido.

Table 6. Electrical characteristics of the transformer (provided by manufacture Schneider electric).

The chosen model is made by the manufacturer Schneider electric, it will be oil-based and has a tap option to regulate the primary and secondary voltages in case there is need to adapt the input or output voltages. The range of the tap is ±12% of the nominal voltage.

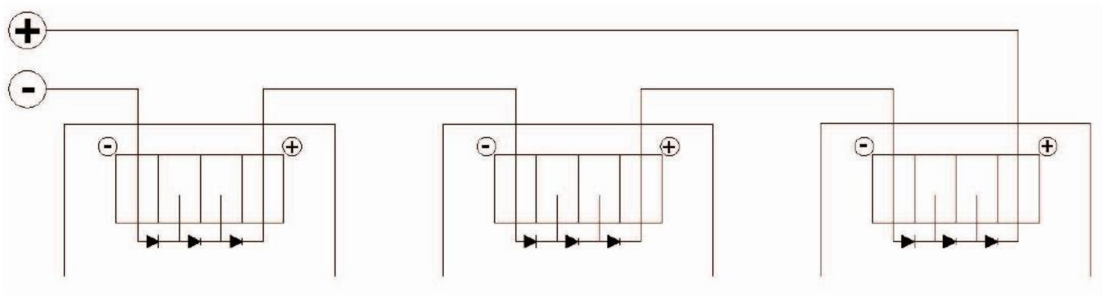
Wiring

The criteria used for the design of the wiring in the installation are to limit the voltage drop and the power losses, as well as taking into account the maximum current that the wire of a specific cross-section area can handle.

The distribution of the wiring is as follows:

- Each photovoltaic array (or group) of 22 modules connected in series will be connected to a junction box, through electrical trays, which will join up to a maximum of 15 groups. The area of the terrain has been divided into 3 divisions (division 1, division 2 and division 3), each one of them with a number of junction boxes for all the modules contained in that division (Box 1-1, Box 1-2, Box 1-3, Box 1-4, Box 1-5, Box 2-1, Box 2-2, Box 2-3, Box 2-4, Box 3-1 and Box 3-2).
- Every junction box will be directly connected to the inverter by means of buried wires through trenches.
- The output of the inverter will be connected to the low voltage part of the transformer by a buried wire through a trench, no longer than 10 m, in order to increase voltage and achieve the required conditions to connect the photovoltaic system to the existing electrical substation and subsequently to the power grid.

Photovoltaic modules will be connected by the use of the preinstalled wire with a cross-section area of 4 mm^2. Modules of each group will be connected in series in the following way:



Typical wiring connections in series

Figure 8. Module connection (provided by manufacturer ATERSA).

The end of each series will be connected to the junction boxes through electrical trays and limiting voltage drop to a maximum of 0.5%. In addition, every cable used in the design will have 1 kV isolation unless specified otherwise.

Group of modules - Junction box

The type of wire used for the connection between each group and the junction boxes is P-Sun 2.0. Made of copper, produced by the manufacturer Prysmian, has a cross-section area of 6 mm^2 and it is specifically fabricated for photovoltaic plants.

In order to determine if the current flowing through the wire is below the admissible current, a series of factors must be taken into account:

- Correction factor due to ambient temperature, K_t.
- Correction factor due to aggrupation of conductors, K_A.
- Admissible current at a certain ambient temperature, I_{table}.

Equation 12: $Iz = I_{table} \times K_t \times K_A$

Where Iz is the allowable current at the design conditions.

Aislamiento	Temperatura ambiente (θ_a) (°C)										
	10	15	20	25	30	35	40	45	50	55	60
Tipo PVC (termoplástico)	1,40	1,34	1,29	1,22	1,15	1,08	1,00	0,91	0,82	0,70	0,57
Tipo XLPE o EPR (termoestable)	1,26	1,23	1,19	1,14	1,10	1,05	1,00	0,96	0,90	0,83	0,78

Table 7. Correction factor due to ambient temperature (provided by manufacturer Prysmian group).

Punto	Disposición	Número de circuitos o cables multiconductores									Instalación tipo
		1	2	3	4	6	9	12	16	20	
1	Empotrados, embutidos (dentro de un mismo tubo, canal o grapados sobre una superficie al aire	1,0	0,80	0,70	0,70	0,55	0,50	0,45	0,40	0,40	A a F
2	Capa única sobre los muros o los suelos o bandejas no perforadas	1,00	0,85	0,80	0,75	0,70	0,70	0,70	0,70	0,70	C
3	Capa única en el techo	0,95	0,80	0,70	0,70	0,65	0,60	0,60	0,60	0,60	
4	Capa única sobre bandejas perforadas horizontales o verticales	1,0	0,90	0,80	0,75	0,75	0,70	0,70	0,70	0,70	E y F
5	Capa única sobre escaleras de cables, abrazaderas, etc.	1,0	0,85	0,80	0,80	0,80	0,80	0,80	0,80	0,80	

Table 8. Correction factor due to aggrupation (provided by manufacturer Prysmian group).

DIMENSIONES, PESOS Y RESISTENCIAS (aproximado)

Número de conductores x sección mm²	Diámetro del conductor mm	Diámetro exterior del cable (valor máximo) mm	Peso kg/km	Resistencia del conductor a 20°C Ω/km	Intensidad admisible al aire (1) A	Caída de Tensión V/A km (corriente continua)
1x1,5	1,6	4,7	31	13,7	25	26,5
1x2,5	1,9	5,2	43	8,21	34	15,92
1x4	2,4	5,7	58	5,09	46	9,96
1x6	2,9	6,4	79	3,39	59	6,74
1x10	3,9	7,8	120	1,95	82	4
1x16	5,4	9,0	175	1,24	110	2,51
1x25	6,4	10,2	265	0,795	140	1,59
1x35	7,5	11,9	360	0,565	174	1,15
1x50	9	13,3	485	0,393	210	0,85
1x70	10,8	15,6	690	0,277	269	0,59
1 x 95	12,6	16,8	875	0,210	327	0,42
1 x 120	14,3	19,4	1100	0,164	380	0,34
1x 150	15,9	21,1	1420	0,132	438	0,27
1 x 185	17,5	23,5	1655	0,108	500	0,22
1 x 240	20,5	26,3	2200	0,0817	590	0,17

(1) Instalación monofásica en bandeja al aire (40 °C). Con exposición directa al sol, multiplicar por 0,9.
→ XLPE2 con instalación tipo F → columna 13 (Al)

Table 9. Admissible current at 40 ºC (provided by manufacturer Prysmian group).

Therefore, the value of Iz, considering 15 circuits in the same tray and a maximum ambient temperature of 45 ºC, is:

$$I_z = 59 \times 0.96 \times 0.7$$

$$I_z = 39.648\ A$$

This value of I_z is much higher than the maximum current that can flow through the wire joining each group to the junction box, which is the short circuit current 9.138 A. So it is proved that the cable used for the design is more than enough for this type of installation.

For the calculation of the voltage drop, the functioning temperature must be determined, as well as, the resistivity of the cable at that same temperature.

To calculate the temperature at which the cable will be functioning, the following equation is used:

Equation 13: $Tc = Tamb + (Tz - Tamb)(\frac{I_B}{I_z})^2$

$$Tc = 36 + (250 - 36)(\frac{9.138}{39.648})^2$$

$$Tc = 47.368\ ℃$$

Equation 14: $\rho_{Tc} = \rho_{20}(1 + \alpha\Delta\theta)$

$$\rho_{Tc} = 0.01724(1 + 0.00393(47.368 - 20))$$

$$\rho_{Tc} = 0.0192\ \Omega mm^2/m$$

Tc: Functioning temperature of the conductor, ºC.

$Tamb$: Ambient temperature, ºC.

Tz: Maximum temperature that the cable can reach (short circuit), ºC.

I_B: Maximum current flowing through the cable, A.

I_z: Maximum admissible current that can flow through the wire, A.

ρ_{Tc}: Resistivity of the conductor at functioning temperature, $\Omega mm^2/m$.

ρ_{20}: Resistivity of copper at 20 ºC, $\Omega mm^2/m$.

α: Copper constant, $ºC^{-1}$.

$\Delta\theta$: Difference in temperature between the functioning temperature of the conductor and ambient temperature.

Once the resistivity is determined, the calculation of the voltage drop can be done. As said before, the condition the system has to meet in this part of the wiring is a 0.5% maximum voltage drop. Voltage drop is calculated by the following equation:

Equation 15: $Cdt(\%) = \frac{2\times\rho_{Tc}(\Omega mm^2/m)\times L(m)\times I_{mpp}(A)}{U(V)\times S(mm^2)}$

$U(V)$: Voltage generated by each group of 22 modules, that would be the sum of every voltage provided by each module, 826.32 V.

$S(mm^2)$: Cross-section area of the cable, all of them 6 mm^2.

$L(m)$: Length of the cable from the end of the series to the junction box.

$I_{mpp}(A)$: Maximum power point current of the module.

$Cdt(\%)$: Percentage voltage drop.

The length of the cables from the end of each series until the junction boxes depends on the location of each junction box and the end of each series. An increase in 5% of the length has been considered to avoid any imprecise measuring.

The results obtained for voltage drop from the end of each photovoltaic array to the junction box are represented in the tables below:

	Box 1-1	Box 1-2	Box 1-3	Box 1-4	Box 1-5
	CdT (%)	CdT (%)	CdT (%)	CdT (%)	CdT (%)
Series 1	0.104	0.111	0.117	0.111	0.104
Series 2	0.028	0.028	0.028	0.028	0.304
Series 3	0.152	0.456	0.463	0.463	0.235
Series 4	0.069	0.387	0.387	0.387	0.152
Series 5	0.028	0.304	0.311	0.311	0.076
Series 6	0.311	0.235	0.228	0.235	0.035
Series 7	0.235	0.159	0.152	0.159	0.352
Series 8	0.159	0.076	0.076	0.076	0.270
Series 9	0.090	0.035	0.028	0.035	0.194
Series 10	0.097	0.477	0.484	0.463	0.124
Series 11	0.401	0.408	0.408	0.394	0.359
Series 12	0.332	0.332	0.325	0.318	0.263
Series 13	0.256	0.249	0.256	0.242	0.035
Series 14	0.180	0.173	0.180		

Table 10. Voltage drops in division 1. Own work.

	Box 2-1	Box 2-2	Box 2-3	Box 2-4	Box 2-1
	CdT (%)	CdT (%)	CdT (%)	CdT (%)	CdT (%)
Series 1	0.069	0.422	0.394	0.228	0.069
Series 2	0.041	0.332	0.311	0.152	0.041
Series 3	0.242	0.394	0.235	0.076	0.242
Series 4	0.173	0.311	0.159	0.041	0.173
Series 5	0.097	0.235	0.076	0.387	0.097
Series 6	0.090	0.159	0.028	0.311	0.090
Series 7	0.346	0.083	0.408	0.235	0.346
Series 8	0.270	0.028	0.332	0.159	0.270
Series 9	0.194	0.415	0.256	0.090	0.194
Series 10	0.111	0.332	0.180	0.408	0.111
Series 11	0.138	0.256	0.111	0.332	0.138
Series 12	0.290	0.187	0.076	0.256	0.290
Series 13	0.214	0.111	0.422	0.180	0.214
Series 14	0.131	0.083	0.346	0.422	0.131
Series 15	0.194			0.339	0.194

Table 11. Voltage drops in division 2. Own work.

	Box 3-1	Box 3-2
	CdT (%)	CdT (%)
Series 1	0.076	0.076
Series 2	0.152	0.152
Series 3	0.235	0.235
Series 4	0.124	0.124
Series 5	0.207	0.207
Series 6	0.283	0.283
Series 7	0.187	0.187
Series 8	0.263	0.263
Series 9	0.332	0.332
Series 10	0.242	0.263
Series 11	0.311	0.332
Series 12	0.394	0.290

Table 12. Voltage drops in division 3. Own work.

L (m): Measured length of the cable.

L_corr (m): Maximised length (5%) used in the voltage drop calculation.

Power losses due to wiring are due to overheating of conductors and voltage drops. The main wire losses derive from the length of the wire, and therefore, the expression used for its calculation is:

Equation 16: $P = R_{cab} \times I^2 = I^2(\rho_{Cu}\frac{L_{cab}}{S_{cab}})$

R_{cab}: Resistance of the cable, Ω.

I^2: Current flowing through the cable, the same as the one used for the voltage drop calculation, A.

ρ_{Cu}: Resistivity of copper, $\Omega mm^2/m$.

S_{cab}: Cross-section area of the cable, mm^2.

L_{cab}: Maximised length of the cable, m.

The results obtained are shown below:

	Box 1-1	Box 1-2	Box 1-3	Box 1-4	Box 1-5
	P_lost (W)	P_lost (W)	P_lost (W)	P_lost (W)	P_lost (W)
Series 1	3.649	3.893	4.136	3.893	3.649
Series 2	0.973	0.973	0.973	0.973	10.705
Series 3	5.352	16.057	16.301	16.301	8.272
Series 4	2.433	13.624	13.624	13.624	5.352
Series 5	0.973	10.705	10.948	10.948	2.676
Series 6	10.948	8.272	8.029	8.272	1.216
Series 7	8.272	5.596	5.352	5.596	12.408
Series 8	5.596	2.676	2.676	2.676	9.488
Series 9	3.163	1.216	0.973	1.216	6.812
Series 10	3.406	16.787	17.030	16.301	4.379
Series 11	14.111	14.354	14.354	13.868	12.651
Series 12	11.678	11.678	11.435	11.191	9.245
Series 13	9.002	8.759	9.002	8.515	1.216
Series 14	6.326	6.082	6.326		

Table 13. Power losses (W) in division 1. Own work.

	Box 2-1	Box 2-2	Box 2-3	Box 2-4
	P_lost (W)	P_lost (W)	P_lost (W)	P_lost (W)
Series 1	2.433	14.841	13.868	8.029
Series 2	1.460	11.678	10.948	5.352
Series 3	8.515	13.868	8.272	2.676

Series 4	6.082	10.948	5.596	1.460
Series 5	3.406	8.272	2.676	13.624
Series 6	3.163	5.596	0.973	10.948
Series 7	12.165	2.920	14.354	8.272
Series 8	9.488	0.973	11.678	5.596
Series 9	6.812	14.598	9.002	3.163
Series 10	3.893	11.678	6.326	14.354
Series 11	4.866	9.002	3.893	11.678
Series 12	10.218	6.569	2.676	9.002
Series 13	7.542	3.893	14.841	6.326
Series 14	4.623	2.920	12.165	14.841
Series 15	6.812			11.921

Table 14. Power losses (W) in division 2. Own work.

	Box 3-1	Box 3-2
	P_lost (W)	P_lost (W)
Series 1	2.676	2.676
Series 2	5.352	5.352
Series 3	8.272	8.272
Series 4	4.379	4.379
Series 5	7.299	7.299
Series 6	9.975	9.975
Series 7	6.569	6.569
Series 8	9.245	9.245
Series 9	11.678	11.678
Series 10	8.515	9.245
Series 11	10.948	11.678
Series 12	13.868	10.218

Table 15. Power losses (W) in division 3. Own work.

P_los (W): Power losses in the wire.

Junction box - Inverter

Now that the wiring from each group of modules to the junction box is calculated, the next part is to determine the voltage drop and power losses of the stretch between the junction box and the inverter. In this case, the design has been carried out taking into account a maximum voltage drop of 1 %. For the calculation of the voltage drop, functioning temperature and resistivity, the equations used are the same as the ones used for the stretch between each group of modules to the junction box.

However, not the same cable is used. The type of wire used is Al Voltalene N, aluminium made. According to the manufacturer, this cable has the following characteristics (Type A is the cable used):

TABLA C.2 - CONDUCTORES DE ALUMINIO

Sección nominal mm^2	Terna de cables unipolares (1)		1 cable tripolar o tetrapolar		2 cables unipolares		1 cable bipolar	
	Tipo de aislamiento							
Aluminio	A	B	A	B	A	B	A	B
16	97	94	90	86	118	115	110	105
25	125	120	115	110	153	147	140	134
35	150	145	140	135	183	177	171	165
50	180	175	165	160	319	214	202	196
70	220	215	205	200	269	263	251	245
95	260	255	240	235	318	312	294	287
120	295	290	275	270	361	355	336	330
150	330	325	310	305	404	398	379	373
185	375	365	350	345	459	447	428	422
240	430	420	405	395	526	514	496	483
300	485	475	460	445	594	581	563	545
400	550	540	520	500	673	661	637	612

(1) incluye el conductor neutro, si existe.

Table 16. Admissible currents (provided by manufacturer Prysmian group).

For each junction box, a different cross-section area has been used depending on the voltage drop value. The values vary from 95 mm^2 to 150 mm^2 in order to achieve a maximum voltage drop of the required value, 1%. The following table shows the results:

	L	L_corr	CdT	S	Res	Tc	Iz
Box 1-1	105	110.25	0.857	120	0.0323	55.40	198.99
Box 1-2	119	124.95	0.971	120	0.0323	55.40	198.99
Box 1-3	133	139.65	0.856	150	0.0318	51.49	222.70
Box 1-4	140	147.00	0.830	150	0.0316	49.36	222.70
Box 1-5	164	172.20	0.973	150	0.0316	49.36	222.70
Box 2-1	23	24.15	0.262	95	0.0334	64.70	175.29
Box 2-2	46	48.30	0.483	95	0.0329	61.00	175.29
Box 2-3	59	61.95	0.620	95	0.0329	61.00	175.29
Box 2-4	71	74.55	0.810	95	0.0334	64.70	175.29
Box 3-1	23	24.15	0.202	95	0.0322	54.37	175.29
Box 3-2	48	50.40	0.383	95	0.0318	51.44	175.29

Table 17. Voltage drop and admissible current. Own work.

L: Measured length of the cable, m.

L_corr: Maximized length of the cable, m.

Cdt: Voltage drop, %.

S: Cross-section area of the cable, mm^2.

Res: Resistivity of the cable at functioning temperature, Ωmm^2/m.

Tc: Functioning temperature of the cable, ºC:

Iz: Admissible current, A.

Iz has been calculated taking into account the correcting factors that affect this type of installation.

$$I_z = K_T \times K_R \times K_A \times K_P \times I_{table}$$

$$I_z = 0.96 \times 1 \times 0.58 \times 0.99 \times I_{table} = 0.551 I_{table}$$

In order to obtain the correction factors the tables provided by the manufacturer have been used.

TABLA C.4 - FACTOR DE CORRECCIÓN F, PARA TEMPERATURAS DEL TERRENO DISTINTAS DE 25 °C.

Temperatura de servicio (θ_S) (en °C)	Temperatura del terreno (θ_t) (en °C)								
	10	15	20	25	30	35	40	45	50
90	1,11	1,07	1,04	1	0,96	0,92	0,88	0,83	0,78

Table 18. Correction factor due to the temperature of the terrain (provided by manufacturer Prysmian group).

It is estimated that the temperature of the terrain can reach a maximum of 30 ºC, so the coefficient which needs to be applied is 0.96.

TABLA C.5 - FACTOR DE CORRECCIÓN PARA UNA RESISTIVIDAD TÉRMICA DEL TERRENO DISTINTA DE 1 K · m / W.

Tipo de cable	Resistividad térmica del terreno (en K · m / W)										
	0,80	0,85	0,90	1	1,10	1,20	1,40	1,65	2,00	2,50	2,80
Unipolar	1,09	1,06	1,04	1	0,96	0,93	0,87	0,81	0,75	0,68	0,66
Tripolar	1,07	1,05	1,03	1	0,97	0,94	0,89	0,84	0,78	0,71	0,69

Table 19. Correction factor due to the thermal resistivity of the terrain (provided by manufacturer Prysmian group).

In this case, the resistivity of the terrain it is assumed to be 1 Km/W, which entails a correction factor of 1, and therefore, it has no effect in the calculations.

TABLA C.6 - FACTOR DE CORRECCIÓN PARA AGRUPACIONES DE VARIOS CABLES TRIFÁSICOS O TERNAS DE CABLES UNIPOLARES ENTERRADOS EN LA MISMA ZANJA

Separación entre cables o ternas	Número de cables o ternas en la zanja							
	2	3	4	5	6	8	10	12
En contacto	0,80	0,70	0,64	0,60	0,56	0,53	0,50	0,47
d = 0,07 m	0,85	0,75	0,68	0,64	0,60	0,56	0,53	0,50
d = 0,10 m	0,85	0,76	0,69	0,65	0,62	0,58	0,55	0,53
d = 0,15 m	0,87	0,77	0,72	0,68	0,66	0,62	0,59	0,57
d = 0,20 m	0,88	0,79	0,74	0,70	0,68	0,64	0,62	0,60
d = 0,25 m	0,89	0,80	0,76	0,72	0,70	0,66	0,64	0,62

Table 20. Correction factor due to cable aggrupation (provided by manufacturer Prysmian group).

The determination of this factor can be confusing, because the maximum number of cables which pass through the same tray is 5. However, just at the entry of the inverter all of them come together, and therefore, 11 of them are very close together. Taking the most counterproductive situation, a factor of 0.58 will be applied. 11 cables with a separation of 0.15 m between them.

TABLA C.7 - FACTOR DE CORRECCIÓN PARA DIFERENTES PROFUNDIDADES DE TENDIDO

Profundidad (en metros)	0,40	0,50	0,60	0,70	0,80	0,90	1,00	1,20
Factor de corrección	1,03	1,02	1,01	1	0,99	0,98	0,97	0,95

Table 21. Correction factor due to deepness of cables (provided by manufacturer Prysmian group).

The deepness of the cables for the design is 0.8 m beneath the floor, which gives a correction factor of 0.99.

The results show that the maximum voltage drop is 0.952% from Box1-5 to the inverter. At the same time this same stretch has the maximum cross-section area along with Box1-3 and Box1-4. It is worth mentioning that not every box has the same current flowing through them. This depends on the number of photovoltaic arrays grouped. The following table shows the current flowing through each of them:

	Series	I_box (A)
Box 1-1	14	119.28
Box 1-2	14	119.28
Box 1-3	14	119.28
Box 1-4	13	110.76
Box 1-5	13	110.76
Box 2-1	15	127.8
Box 2-2	14	119.28
Box 2-3	14	119.28
Box 2-4	15	127.8
Box 3-1	12	102.24
Box 3-2	12	102.24

Table 22. Current flowing through each of the junction boxes. Own work.

Comparing both tables, it can be appreciated that the current flowing through each box is significantly smaller than the one admissible by each cable, so it can be said that the cables used are appropriate for the installation.

As well as the voltage drop, the power losses have been calculated using the same expressions as the ones used for the stretch from each group to the junction box.

	P_lost (W)
Box 1-1	422.11
Box 1-2	478.39
Box 1-3	421.84
Box 1-4	379.95
Box 1-5	445.08
Box 2-1	138.47
Box 2-2	238.20
Box 2-3	305.52
Box 2-4	427.46
Box 3-1	85.50
Box 3-2	148.37

Table 23. Power losses from junction boxes to inverter. Own work.

P_los (W): Power losses in the wire.

Inverter - Transformer

Given that the distance between the inverter and the transformer in the photovoltaic plant is very low, a distance of 10 m will be considered. Even though the real length of the wire will be smaller. For this part of the installation, a 3-phase cable of the same type as the ones used in the stretch from each junction box to the inverter will be used, from Prysmian manufacturer. In this case, the cross-section area of the cable is 240 mm^2 and the current will be divided into 8 cables of that same cross-section area. To calculate to total current flowing through the cable stretch, the power of the transformer has to be taken into account. As the power of the transformer is 1 MW, the maximum current that could possible flow, with exception of the short circuit current, is:

Equation 17: $I = \frac{S}{\sqrt{3} \times U_{inv}}$

$$I = \frac{10^6}{\sqrt{3} \times 400} A$$

$$I = 1443.38 A$$

I: Maximum current, A.

S: Nominal power of the transformer, VA.

U_{inv}: Output voltage of the inverter, V.

Therefore, the current flowing through each cable would be one eighth part of the one calculated above, so 180.43 A. Given that in this part a three-phase system is considered, the expressions for voltage drop and power losses vary.

The equations taken into account for voltage drop are:

Equation 18: $$CdT = \frac{\sqrt{3} \times \rho_{Al} \times L \times I \times cos\varphi}{U \times S} \times 100$$

Equation 19: $$CdT = \frac{\sqrt{3}((R \times I \times cos\varphi) + (X \times I \times sen\varphi))}{U} \times 100$$

CdT: Voltage drop, %.

ρ_{Al}: Resistivity of aluminium at functioning temperature, $\Omega mm^2/m$.

L: Length of the wire, m.

I: Current flowing through each of the eight wires, A.

$cos\varphi$: Power factor, 0.95.

U: Output voltage of the inverter, V.

S: Cross-section area of the cable used, mm^2.

R: Resistance of the cable, Ω.

X: Inductance of the cable, Ω.

From these two equations the one used is the one including the effect of the inductance, as it is more realistic. However, the other is more restrictive and it should be used if the priority is to be more conservative.

The results obtained are the following:

L	L_corr	CdT	S	Res	Tc	Iz	R	Ia	Ir	X
10	10.5	0.088	240	0.0339	69.61	228.70	0.0015	171.41	-56.34	0.000085

Table 24. Voltage drop from inverter to transformer. Own work.

L: Considered length of the cable, m.

L_corr: Maximized length of the cable, m.

Cdt: Voltage drop, %.

S: Cross-section area, mm^2.

Res: Resistivity at functioning temperature, $\Omega mm^2/m$.

Tc: Functioning temperature, ºC.

Iz: Admissible current, A.

R: Resistance of the cable, Ω.

Ia: Active current, A.

Ir: Reactive current, A.

X: Inductance, Ω.

To determine the power losses, the following expression has been used:

Equation 20: $P\ (W) = \frac{3\times\rho_{Al}\left(\frac{\Omega mm^2}{m}\right)\times L(m)\times I\ (A)^2}{S\ (mm^2)} \times 8$

Equation 21: $P\ (W) = \frac{3\times 0.0339\times 10.5\times 180.43^2}{240} \times 8$

$$P = 1159.097\ W$$

ρ_{Al}: Resistivity of aluminium at functioning temperature.

L: Length of the wire.

I: Current flowing through each of the eight wires.

S: Cross-section area of the cable used.

P: Power losses.

The correction factors used for this cable stretch are the following:

A coefficient with value 0.96, due to the estimated temperature of the terrain reaching a maximum of 30 ºC.

As before, the resistivity of the terrain it is assumed to be 1 Km/W, which entails a correction factor of 1, and therefore, it has no effect in the calculations.

The worst scenario possible is for 6 conductors to flow through the same trench with a separation between them of 0.15 m. This gives a correction factor of 0.66.

The deepness of the cables for the design is 0.8 m beneath the floor, which gives a correction factor of 0.99.

Transformer – electrical substation

The transformer in the photovoltaic plant will be connected to the electrical substation by means of a cable with cross-section area 240 mm^2. It will be different from the ones used before. The difference in the current flowing is due to the increase in voltage after the transformer. The voltage will rise from 400 V to 20 kV. This will cause a reduction in the current, and therefore less voltage drop and energy losses, even though the length of the cable stretch is much higher.

Sección nominal mm²	Tensión nominal (Temperatura máxima en el conductor 90 °C) 1,8/3 kV a 18/30 kV					
	(1)	(2)	(3)	(4)	(5)	(6)
Conductores de Cu						
10	-	-	-	-	-	-
16	115	105	100	91	98	90
25	155	140	130	120	125	115
35	185	170	155	145	150	140
50	220	205	180	170	175	160
70	275	255	225	205	220	200
95	335	305	265	245	260	235
120	385	345	300	280	290	265
150	435	395	340	315	325	300
185	500	445	380	355	370	335
240	590	525	440	415	425	395
300	680	600	490	460	475	445
400	790	-	560	520	-	-
500	930	-	635	605	-	-
630	1095	-	715	675	-	-
Conductores de Al						
16	92	80	78	74	76	70
25	120	110	100	94	95	90
35	145	130	120	110	115	105
50	170	155	140	130	135	125
70	210	195	170	160	165	155
95	**255**	235	**205**	**190**	200	180
120	295	270	235	215	225	205
150	**335**	305	**260**	**245**	255	230
185	385	345	295	280	285	260
240	**455**	405	**345**	**320**	330	305
300	520	465	390	365	375	345
400	**610**	-	**445**	**415**	-	-
500	715	-	505	480	-	-
630	830	-	575	545	-	-

Table 25. Admissible currents (provided by manufacturer Prysmian group).

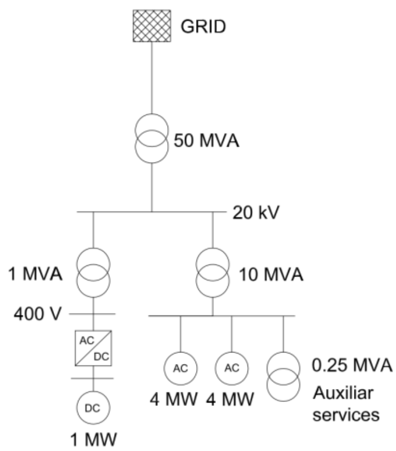


Figure 9. Interconnection between the photovoltaic plant and the electrical substation. Own work.

The transformer of the electrical substation that will be used for the connection of the photovoltaic plant has a considered power of 50 MW, which will also be connected to the hydroelectric power plant be means of another transformer. Figure 9 represents the line diagram for better understanding.

Given that there is a lack of information of the hydroelectric power plant and the electrical substation most of the data represented has been needed to be approximated in order to continue with the project.

The equations used for the voltage drop calculation and power losses are the same as the ones for the part from the inverter to the transformer in the photovoltaic plant:

Equation 22: $$CdT = \frac{\sqrt{3}((R \times I \times cos\varphi) + (X \times I \times sen\varphi))}{U} \times 100$$

CdT: Voltage drop, %.

ρ_{Al}: Resistivity of aluminium at functioning temperature, $\Omega mm^2/m$.

L: Length of the wire, m.

I: Current flowing through the wire, A.

$cos\varphi$: Power factor, 0.95.

U: Output voltage of the transformer in the photovoltaic plant, V.

S: Cross-section area of the cable used, mm^2.

R: Resistance of the cable, Ω.

X: Inductance of the cable, Ω.

L	L_corr	CdT	S	Res	Tc	Iz	R	Ia	Ir	X
1505	1580.3	0.034	240	0.0301	36.42	304.13	0.198	27.42	-9.01	0.000103

Table 26. Voltage drop from transformer to electrical substation. Own work.

L: Considered length of the cable, m.

L_corr: Maximized length of the cable, m.

Cdt: Voltage drop, %.

S: Cross-section area, mm^2.

Res: Resistivity at functioning temperature, $\Omega mm^2/m$.

Tc: Functioning temperature, ºC.

Iz: Admissible current, A.

R: Resistance of the cable, Ω.

Ia: Active current, A.

Ir: Reactive current, A.

X: Inductance, Ω.

Equation 23: $P\ (W) = \frac{3 \times \rho_{Al} \left(\frac{\Omega mm^2}{m}\right) \times L(m) \times I\ (A)^2}{S\ (mm^2)}$

$$P = 527.3\ W$$

ρ_{Al}: Resistivity of aluminium at functioning temperature.

L: Length of the wire.

I: Current flowing through the wire.

S: Cross-section area of the cable used.

P: Power losses.

The most relevant difference between this cable stretch and the one from the inverter to the transformer in the photovoltaic plant, is the increase in voltage and a decrease in the current flowing through the cable connecting the electrical substation to the photovoltaic plant. As said before, the results show a lower voltage drop and power losses. The determination of the current is as follows:

Equation 24: $I = \frac{S}{\sqrt{3} \times U_{trafo}}$

$$I = \frac{10^6}{\sqrt{3} \times 20000}\ A$$

$$I = 28.87\ A$$

I: Maximum current, A.

S: Nominal power of the transformer, VA.

U_{inv}: Output voltage of the photovoltaic plant transformer, V.

Given that the cable used is not the same and the trench is not shared with other cables, the correction factors which need to be applied in order to obtain the admissible current are:

A coefficient with value 0.96, due to the estimated temperature of the terrain reaching a maximum of 30 ºC.

As before, the resistivity of the terrain it is assumed to be 1 Km/W, which entails a correction factor of 1, and therefore, it has no effect in the calculations.

Given that only one cable will go through the trench, there is no need to apply any correction factor for aggrupation.

The deepness of the cables for the design is 0.8 m beneath the floor, which gives a correction factor of 0.99.

After all the calculations, the overall power losses can be determined, which are 6355.6 W. This value represents 0.64% power losses, which is acceptable.

Junction boxes

The purpose of the junction boxes is to join each of the groups of modules (or photovoltaic arrays) in order to be able to transport the energy generated to the inverter and eventually to the transformer and the electrical substation. The next image shows the configuration of the modules with the junction box for better understanding:

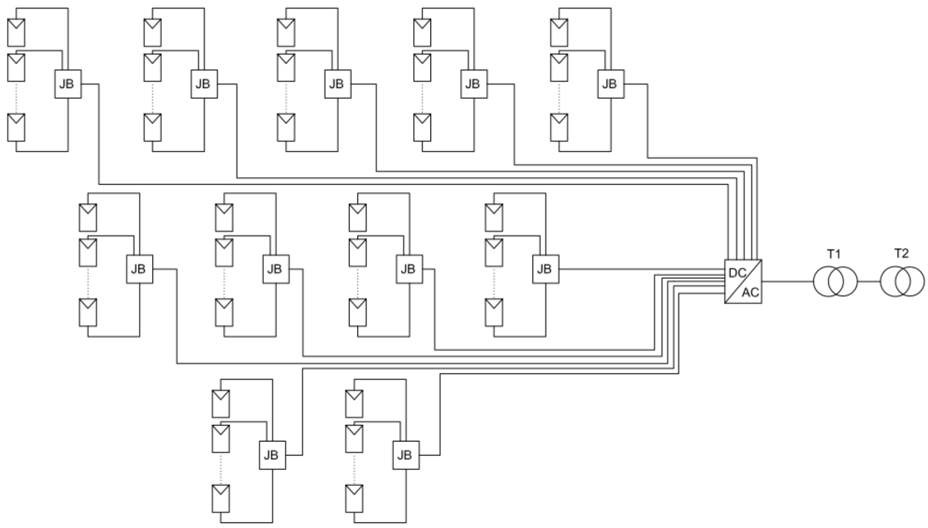


Figure 10. Configuration of junction boxes in the photovoltaic plant. Own work.

As shown in the image above, each junction box will be connected to the inverter. At the same time, a number of groups of modules are connected to each junction box, each of the boxes with a different quantity of groups connected to them.

Different junction boxes will be used depending on the number of series required to be connected together. In particular two types of junction boxes are used, one of them allows up to a maximum of 12 series (or strings) to be connected, while the other allows up to 16 series. These two types of junction boxes are enough given that the maximum number of series connected to the same junction box is 15, according to the design. So, 2 junction boxes of 12 series and 9 of 16 series will be needed.

These junction boxes incorporate fuses of 16 A for the protection of each string. This is no problem given that the maximum current flowing through each string will be the short circuit current, which is lower than 16 A.

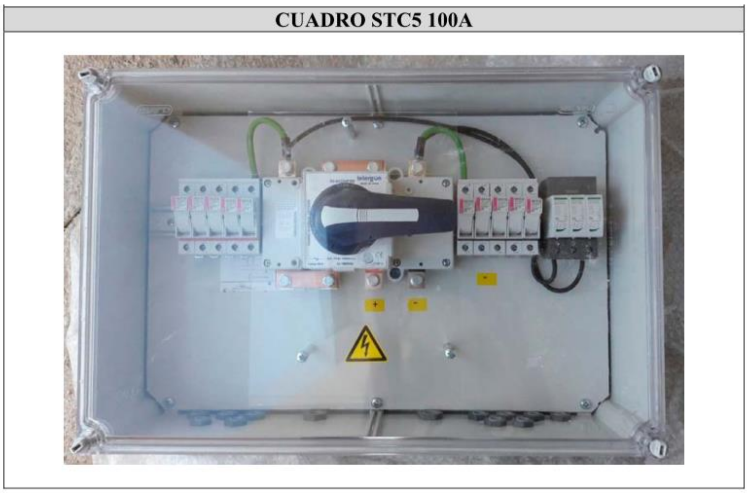


Figure 11. Junction box of a maximum of 100 A (provided by manufacturer AMB Greenpower).

The junction boxes used will have a limitation of 160 A which is more than enough for the photovoltaic plant, as the maximum current flowing will never exceed that value.

Trenches

Trenches will be used in the part from the junction boxes to the electrical substation, which means that every cable will be buried except for the ones connecting the photovoltaic modules to the corresponding junction boxes.

These trenches will be done by excavation methods and all of them will have a deepness of 0.8 m. They will run parallel to the road and with a distance from it appropriately chosen when the construction is carried out.

Some trenches will be shared by different cables. At the input of the inverter a trench will be shared by 11 different conductors each of them coming from each junction box, as well as the trench from the inverter to the transformer in the photovoltaic plant which will be shared by 8 conductors.

In the cases in which the trenches pass through (or below) the road or any part where vehicles can travel, the use of concrete to fill up the trench will be needed in order to provide enough protection for the cables. Otherwise, compacted earth can be enough for this function.

When using concrete in the trenches, the wires will go through PVC tubes to grant more protection and avoid the concrete damaging the wires. There is only one case in which this will be necessary, and it is just before the electrical substation, between the hydroelectric plant and the electrical substation. 5 m of this type of trench will be needed. See drawings for more information.

Protections

DC part

The use of electrical protections is essential to guarantee the safeness of people. This part of the configuration will have an IT network configuration. This means that the electrical distribution system has no direct connection to earth or it is connected through a high electrical resistance, while the consuming devices are grounded.

As the electrical distribution system is not grounded, when an insulation fault occurs and a wire comes into contact with a conductive device, both the wire and the conductive device will have the same voltage, the same would happen to the ground. However, no current will be deviated to ground. If in this situation a person contacted the conductive device, no current would flow through that person, and therefore, no damage will be caused. This can be explained as the difference in voltage between the conductive device and ground is null. Even if the wire connecting the conductive device and earth was defective (improperly grounded), there would be no problem, as the person coming into contact with the conductive device will act as that same wire, and therefore, the null difference in voltage to avoid current flowing would be granted.

The only problem that could happen is if a fault between two conductors occurred. The odds of this happening are very low, as a system of fault controlling will be installed. The idea is that whenever a fault occurs, a luminous and sounding signal activates in order to warn that a first fault has occurred. This will allow disconnecting the system and avoiding a second fault to happen before the first fault has been solved.

This system is considered to be more than enough for the protection of indirect contacts so no differential circuit breaker will be needed for the direct current part.

As an IT configuration is used, an isolation detector must be used. If an isolation fault occurs this device will check if it is required to open the circuit and disconnect before a second fault occurs.

Figure 12. Image of isolation detector (provided by manufacturer BENDER).

The characteristics of the isolation detector chosen must by the appropriate ones for the installation.

For the protection of overcurrent situations the fuse included in the junction box will be used, while overvoltage protection will be solved by overvoltage suppressors. This fuse has a nominal current of 16A. In the following paragraphs it will be shown that this fuse is appropriate for the protection of the wires from the modules to the junction boxes:

$$I_B = I_{sc} = 9.03\ A$$

Equation 25: $I_B \leq I_n \leq I_z$

Equation 26: $I_2 \leq 1.45 \times I_z$

Equation 27: $I_2 = 1.6 \times I_n$

$$I_z = 42.952\ A$$

$$9.03\ A \leq I_n \leq 38.93\ A$$

I_n: Nominal current of the fuse, A.

I_z: Admissible current by the cable used, A.

I_2: Current that guarantees the effective protection by the device, A.

I_B: Current flowing through the cable, A.

The worst scenario that can happen is that a short circuit occurs in each of the series, which will produce a maximum current of:

15 series: 135.45 A.

14 series: 126.42 A.

13 series: 117.39 A.

12 series: 108.36 A.

So the fuse should have a breaking capacity power of at least 135.45 A, which is lower than what the fuse really has, 40 kA. It can be said then that the fuse provided by the manufacturer of the junction box reaches the requisites for the protection of the conductors.

From the junction box to the inverter a different protection must be used for overcurrent and overvoltage. In this case, the expressions used are the following:

Equation 28: $I_B \leq I_n \leq I_z$

Equation 29: $I_2 \leq 1.45 \times I_z$

Equation 30: $I_2 = 1.6 \times I_n$

I_n: Nominal current of the circuit breaker, A.

I_z: Admissible current by the cable used, A.

I_2: Current that guarantees the effective protection by the device, A.

I_B: Current flowing through the cable, A.

The next table shows the results of limits between which the nominal current of the circuit breaker must be in order to grant the correct protection:

	Series	S (mm2)	Iz (A)	IB (A)	Imax (A)	In (A)
Box 1-1	14	120	198.99	126.42	180.34	150
Box 1-2	14	120	198.99	126.42	180.34	150
Box 1-3	14	150	222.70	126.42	201.82	150
Box 1-4	13	150	222.70	117.39	201.82	150
Box 1-5	13	150	222.70	117.39	201.82	150
Box 2-1	15	95	175.29	135.45	158.86	150
Box 2-2	14	95	175.29	126.42	158.86	150
Box 2-3	14	95	175.29	126.42	158.86	150
Box 2-4	15	95	175.29	135.45	158.86	150
Box 3-1	12	95	175.29	108.36	158.86	150
Box 3-2	12	95	175.29	108.36	158.86	150
		Breaking capacity (A)		1354.5		

Table 27. Nominal current of the protection. Own work.

S: Cross-section area of the cable.

Iz: Admissible current of the cable used.

IB: Current flowing through the wire.

Imax: Upper boundary of the nominal current of the protection.

In: Nominal current of the protection chosen.

As represented in the table, every cable is correctly protected by a fuse of nominal current 150 A. Furthermore, a last result is represented, which coincides with the minimum breaking capacity the protection should have. This situation where the maximum current flowing is 1354.5 A is when a short circuit occurs in all of the conductors which is highly improbable.

AC part

For the alternate current part between the inverter and the transformer it will only be needed to use circuit breakers for overcurrent protection, as it can be said that the system is already protected against indirect contacts. The reason is the same as for the DC part; an IT network distribution is used. The maximum touch voltage is under 24 V which according to the norm is enough to guarantee protection for any user. This will be further explained in the earth grounding paragraph. As in the DC part, an isolation detector must be used.

Overvoltage protection will be solved by overvoltage suppressors as in the DC part. In this case, for overcurrent protection a circuit breaker of nominal current 250 A regulated at 225 A will be used for each of the 8 wires which go from the inverter to the transformer. This circuit breaker has 3 poles and a breaking capacity power of 50 kA.

Figure 13. Circuit breaker for overcurrent protection (provided by manufacturer Schneider electric).

For the dimensioning of this electrical device, the same considerations as before have been taken into account:

Equation 31: $I_B \leq I_n \leq I_z$

Equation 32: $I_2 \leq 1.45 \times I_z$

Equation 33: $I_2 = 1.45 \times I_n$

I_n: Nominal current of the circuit breaker, A.

I_z: Admissible current by the cable used, A.

I_2: Current that guarantees the effective protection by the device, A.

I_B: Current flowing through the cable, A.

The election of the overvoltage suppressor will depend on the maximum voltage that the inverter can handle and the maximum voltage at permanent service of the system.

Medium voltage part

In order to show that the cable used from the transformer in the photovoltaic plant to the electrical substation will be good enough to handle the maximum short circuit current that can appear, a series of resistances and currents must be calculated. The next diagram shows the interconnection between the transformer of the photovoltaic plant, the transformer of the hydroelectric power and the transformer in the electrical substation:

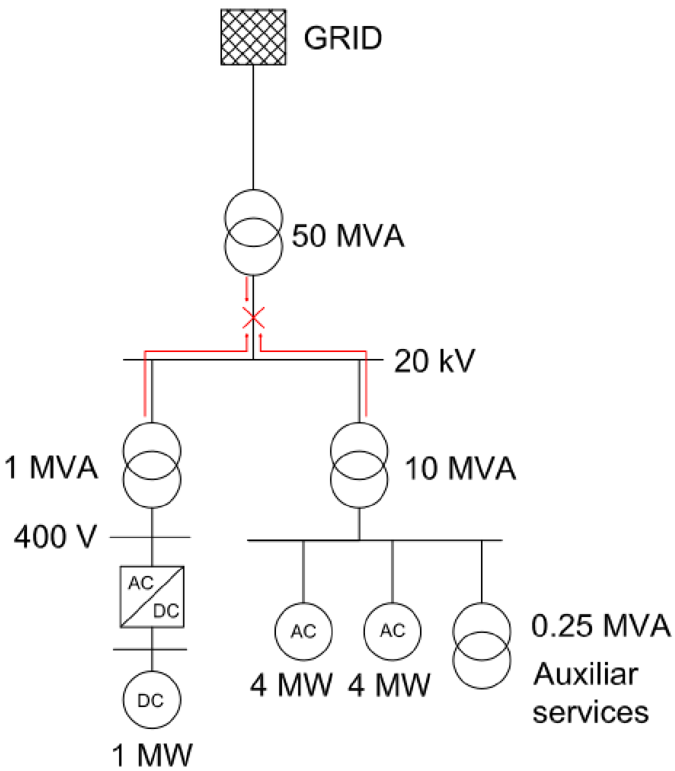


Figure 14. Maximum fault which can occur in the system. Own work.

The maximum short circuit current will occur when the three transformers are providing their corresponding short circuit current to the same point. Given that no data of the transformers from the electrical substation and the hydroelectric power plant is provided, a short circuit impedance of

6% will be considered. The same as the one the transformer in the photovoltaic plant has. The procedure followed to calculate the maximum short circuit current is as follows:

Equation 34: $Z_{cc} = \frac{6}{100} \times \frac{U^2}{S_{nt}}$

Equation 35: $I_k'' = \frac{U}{\sqrt{3} \times Z_{cc}}$

The effect of the resistance and reactance of the cables are not taken into account as it has a very low effect on the final result. It is also assumed that the grid provides infinite power.

$$Z_{cc1} = \frac{6}{100} \times \frac{20\ kV^2}{1\ MW} = 24\ \Omega$$

$$Z_{cc2} = \frac{6}{100} \times \frac{20\ kV^2}{10\ MW} = 2.4\ \Omega$$

$$Z_{cc3} = \frac{6}{100} \times \frac{20\ kV^2}{50\ MW} = 0.48\ \Omega$$

$$I''_{k1} = \frac{20\ kV}{\sqrt{3} \times 24} = 481.13\ A$$

$$I''_{k2} = \frac{20\ kV}{\sqrt{3} \times 2.4} = 4811.3\ A$$

$$I''_{k3} = \frac{20\ kV}{\sqrt{3} \times 0.48} = 24.06\ kA$$

Z_{cci} (Ω): Short circuit impedance of each of the transformer, which corresponds with the total resistance.

I''_{ki} (A): Short circuit current provided by each of the transformers.

U (V): Distribution voltage of the system.

Therefore, the maximum short circuit current would be the sum of the three currents calculated above, 29.35 kA.

According to the following graphs provided by the manufacturer of the conductors, this current is admissible considering a circuit breaking before 0.4s.

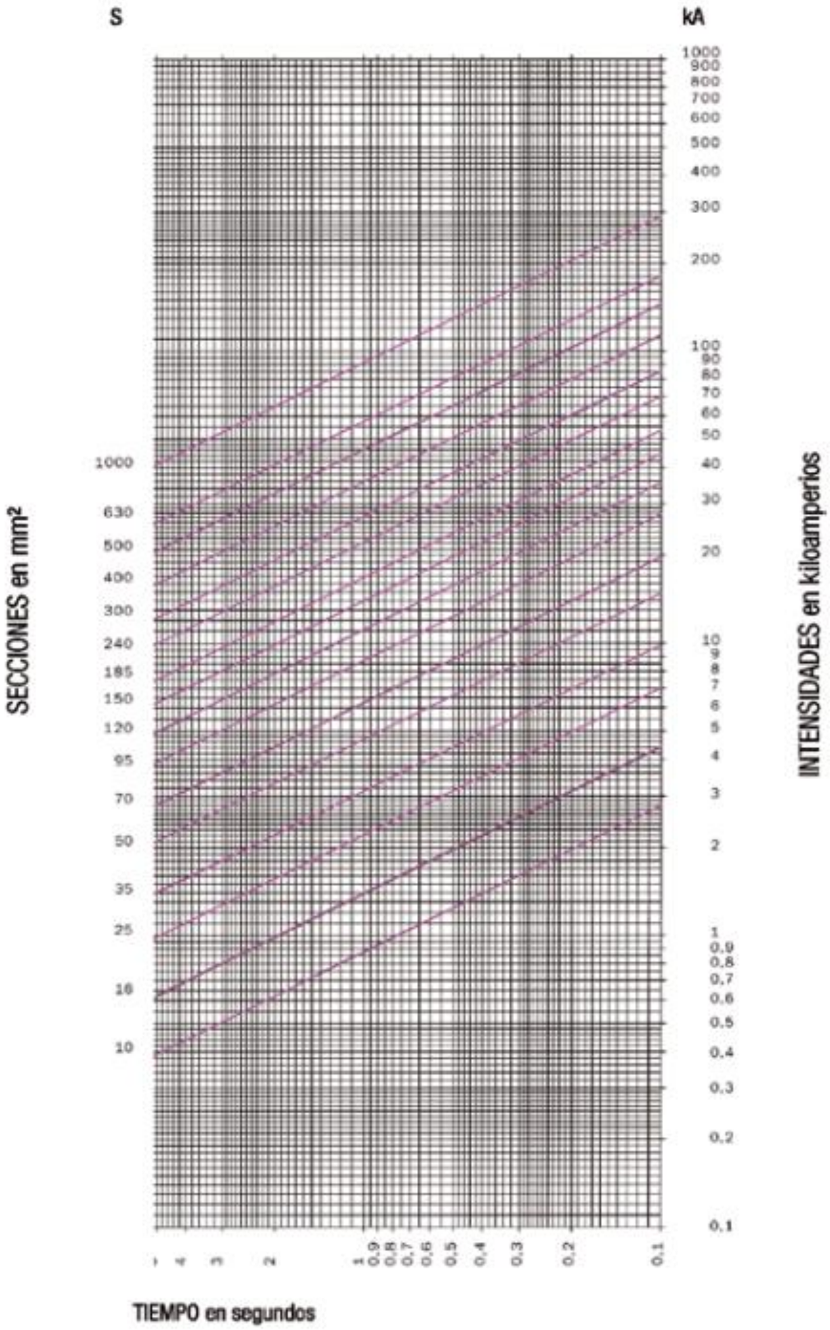


Figure 15. Admissible currents before a certain time (provided by manufacturer Prysmian group).

In addition, the cells of the transformer should be able to handle this current.

Low voltage part

The procedure for the calculation of the short circuit current provided by the secondary of the transformer in the photovoltaic plant is the same as for the medium voltage part. The only difference is the values used in the expressions.

Equation 36: $Z_{cc} = \frac{6}{100} \times \frac{U^2}{S_{nt}}$

Equation 37: $I_k'' = \frac{U}{\sqrt{3} \times Z_{cc}}$

$$I_k'' = 24.06kA$$

Z_{cci} (Ω): Short circuit impedance of the transformer, which corresponds with the total resistance.

I_{ki}'' (A): Short circuit current provided by the transformer.

U (V): Distribution voltage of the system.

The effect of the resistance and reactance of the cables are not taken into account as it has a very low effect on the final result. It is also assumed that the grid provides infinite power. This current calculated can be interrupted by an automatic circuit breaker.

Earth grounding

The objective of earth grounding is to avoid any voltage difference that could be dangerous for humans and the photovoltaic system from appearing, and therefore, reduce fault risks or accidents. It also allows the flow of fault currents to ground.

Grounding means joining electrically, without fuses or any kind of protection, a part of the electrical circuit to an electrode or group of buried electrodes. Every conductive device in contact with the wires, photovoltaic modules, structure, junction boxes, electrical trays, etc. trays will be connected to the earth conductor by means of a protective earth conductor with cross-section area of 6 mm^2, 95 mm^2 or 120 mm^2 copper made. The following table comes from RBT ITC-BT-28 in the Spanish norm.

Sección de los conductores de fase de la instalación S (mm^2)	Sección mínima de los conductores de protección S_p (mm^2)
$S \leq 16$	$S_p = S$
$16 < S \leq 35$	$S_p = 16$
$S > 35$	$S_p = S/2$

Table 28. Conductor size. Image taken from the Spanish norm RBT ITC-BT-28.

The grounding conductor will go through the trenches next to the other conductors; it will have a cross-section area of 35 mm^2 copper made. Its purpose is to join together every electrode. The following table comes from RBT ITC-BT-28 in the Spanish norm.

TIPO	Protegido mecánicamente	No protegido mecánicamente
Protegido contra la corrosión*	Según apartado 3.4	16 mm^2 Cobre 16 mm^2 Acero Galvanizado
No protegido contra la corrosión	25 mm^2 Cobre 50 mm^2 Hierro	
* La protección contra la corrosión puede obtenerse mediante una envolvente		

Table 29. Earthing conductor size depending on the type of protection. Image taken from the Spanish norm RBT ITC-BT-28.

These electrodes are earthing rods of 2 m length with a diameter of 30mm^2.

These two tables used to determine the size of the conductors comes from the Spanish norm, which is more restrictive than the Philippines electrical code.

In order to determine the maximum admissible earthing resistance, a simple division must be carried out:

Equation 38: $R_A(\Omega) = \frac{U_d(V)}{I_d(A)}$

$$R_A = \frac{24}{9.03}$$

$$R_A = 2.658\ \Omega$$

I_d: Fault current, in this case coincides with the short circuit current of the module.

U_d: Fault voltage, limited to 24 V to grant appropriate protection.

R_A: Maximum earthing resistance allowed.

The resistivity of the terrain considered for the design is 100 Ohmxm. This is helpful because in order to calculate the minimum length of the grounding conductor to achieve the resistance above, the value of the resistivity is needed:

Equation 39: $L(\mathrm{m}) = \frac{\rho(\Omega m)}{R_t(\Omega)}$

$$\mathrm{L} = 37.62\ \mathrm{m}$$

$L(\mathrm{m})$: Length of the grounding conductor.

$\rho(\Omega m)$= Resistivity of the terrain.

$R_t(\Omega)$: Earthing resistance.

The grounding conductor has a greater length than the one calculated above, so there is no need to include earthing rods. However, it is decided to include 4 rods distributed around the terrain where the photovoltaic plant will be. This is done in case there is any difference between the resistivity of the ground considered (100 Ohmxm) and the real resistivity of the place.

The resistance for an earthing rod vertically buried is as follows:

Equation 40: $R_{rod}(\Omega) = \frac{\rho(\Omega m)}{l(m)}$

While the resistance for a horizontally buried conductor is:

Equation 41: $R_{cond}(\Omega) = \frac{2\times\rho(\Omega m)}{l(m)}$

$R_{rod}(\Omega)$: Resistance provided by one single rod electrode.

$R_{cond}(\Omega)$: Resistance provided by one single buried conductor electrode.

$\rho(\Omega m)$: Resistivity of the terrain.

$l(m)$: Length of the earthing rod or conductor.

Once decided the rods used and the length of the grounding conductor, the earthing resistance can be calculated. It is considered that the length of the earthing conductor will be at least 160 m. The calculation is as follows:

Equation 42: $\frac{1}{R_t} \leq \frac{1}{R_{rods}} + \frac{1}{R_{cond}}$

Equation 43: $\frac{1}{R_t} \leq \frac{1}{R_{rod}} + \frac{1}{R_{cond}}$

Equation 44: $\frac{\rho}{R_t} \leq \frac{l_{cond}}{2} + (n \times l_{rod})$

$$\frac{100}{R_t} \leq \frac{160}{2} + (4 \times 2)$$

$$R_t = 1.136\ \Omega$$

$\rho(\Omega m)$= Resistivity of the terrain.

$R_t(\Omega)$: Earthing resistance.

$R_{rod}(\Omega)$: Resistance provided by one single rod electrode.

$R_{rods}(\Omega)$: Resistance provided by every rod electrode in the earthing system.

$R_{cond}(\Omega)$: Resistance provided by one single buried conductor electrode.

$l_{cond}(m)$: Length of the conductor.

n: Number of rods used.

Rods will be distributed uniformly along the grounding conductor. This distribution will grant protection to humans given that the maximum fault voltage that can occur is 24 V. While the resistance of human body is around 2000 Ohms which gives a maximum current flowing through it too low to cause health damage.

In the alternate current part the resistance calculated above takes part in the calculation of the fault current:

Equation 45: $I_d(\text{A}) = \frac{U_f(V)}{R_{total}(\Omega)}$

Equation 46: $I_d(\text{A}) = \frac{U_f(V)}{R_t(\Omega)+R_N(\Omega)}$

$$I_d(\text{A}) = \frac{\frac{400}{\sqrt{3}}}{1500 + 1.136}$$

$$I_d(\text{A}) = 0.154\ A$$

$I_d(\text{A})$: Maximum fault current which can appear.

$U_f(V)$: Voltage between phases.

$R_{total}(\Omega)$: Total resistance of the system.

$R_t(\Omega)$: Earthing resistance.

$R_N(\Omega)$: Resistance of the neutral conductor.

Only the resistances of the neutral conductor and the earthing resistances of the conductive devices of the photovoltaic plant are considered, as the others have little effect on the final result. Once the fault current is determined, the maximum fault voltage that can appear is:

Equation 47: $U_d(V) = I_d(A) \times R_t(\Omega)$

$$U_d(V) = 0.154 \times 1.136$$

$$U_d(V) = 0.175\ V < 24\ V$$

$I_d(\mathrm{A})$: Maximum fault current which can appear.

$U_d(V)$: Maximum fault voltage which can appear.

$R_t(\Omega)$: Earthing resistance.

It is proven then, that the maximum fault voltage is lower than 24 V, and therefore, correct protection is guaranteed. No harm can be done when a single fault occurs. However, if no actions are taken before a second fault occurs, protection is not granted.

Processing plant (transformation centre)

The grounding system for the processing plant will be formed by 8 vertical rods joined together by a buried electrode with rectangular ring shape.

Configuración	Lp (m)	Resistencia Kr	Tensión de paso Kp	Tensión de contacto ext. Kc=Kp (acc)
Sin picas	-	0,131	0,0200	0,0816
4 picas	2	0,096	0,0160	0,0491
	4	0,077	0,0124	0,0347
	6	0,065	0,0101	0,026
	8	0,056	0,0084	0,0214
8 picas	2	0,084	0,0143	0,0388
	4	0,065	0,0104	0,0247
	6	0,054	0,0081	0,0178
	8	0,046	0,0066	0,0138

Table 30. Parameters of the grounding system used (image obtained from TELEC slides, see bibliography for more information).

Therefore, the parameters are the following:

Deepness: 0.8m.

Number of rods: 8.

Length of rods: 4m.

Kr: 0.065.

Kp: 0.0104.

Kc: 0.0247.

Once these parameters are identified, the next step is to determine the maximum step and touch voltages:

Equation 48: $V_{pm} = K_p \times \rho \times I_d$

Equation 49: $V_{cm} = K_c \times \rho \times I_d$

Equation 50: $R_t = K_r \times \rho$

Equation 51: $I_d = \frac{U}{\sqrt{3} \times \sqrt{(R_n + R_t)^2 \times X_n{}^2}}$

$V_{pm}(V)$: Maximum step voltage.

$V_{cm}(V)$: Maximum touch voltage.

$\rho(\Omega m)$: Resistivity of the terrain.

$I_d(A)$: Fault current.

$R_t(\Omega)$: Earthing resistance.

$U(V)$: Distribution voltage.

$X_n(\Omega)$: Reactance of the grid provided by the distributor.

$R_n(\Omega)$: Resistance of the grid provided by the distributor.

In this case no starting data is available from the distributor in Bugasong, and therefore, the values of impedance of the grid cannot be used in the calculations. As the fault current cannot be calculated it is assumed to be 500 A. This value corresponds with the one IBERDROLA would recommend for their connections. Obviously, this is not the correct value for the Philippines, but in order to complete the calculations this value must be approximated.

Tensión nominal de la red U_n (kV)	Tipo de puesta a tierra	Reactancia equivalente X_{LTH} (Ω)	Intensidad máxima de corriente de defecto a tierra* (A)
13,2	Rígido	1,863	4500
13,2	Reactancia 4 Ω	4,5	1863
15	Rígido	2,117	4500
15	Reactancia 4 Ω	4,5	2117
20	Zig-Zag 500 A	25,4	500
20	Zig-Zag 1000 A	12,7	1000
20	Reactancia 5,2 Ω	5,7	2228
30	Zig-Zag 1000 A	2,117	9000

Table 31. Maximum current that can appear. Table obtained from "Manual técnico de distribución 2.11.34" from IBERDROLA related to the design of the grounding system of processing centres.

For this value of fault current the results are the following:

$$V_{pm} = 520\ V$$

$$V_{cm} = 1235\ V$$

$$R_t = 6.5\ \Omega$$

The next graphs shows the security curve, which represents the maximum applied touch voltage values needed to determine if the conditions required are meet. This curve is based on many different studies for each of the voltages. The duration represented is the maximum time a person can suffer a certain voltage with a minimum risk of health damage.

Therefore, the applied touch voltage of an installation it is obtained by entering the curve through the x axis with a limited time of the fault. This limit time is defined by the characteristics of the protection devices used in the installation. It can also be used the next table for more accurate values.

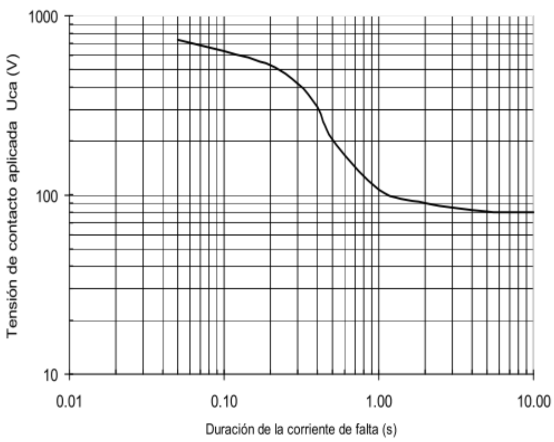


Figure 16. Security curve according to the Spanish norm ITC- RAT-13.

Duración de la corriente de falta, t_F (s)	Tensión de contacto aplicada admisible, Uca (V)
0.05	735
0.10	633
0.20	528
0.30	420
0.40	310
0.50	204
1.00	107
2.00	90
5.00	81
10.00	80
> 10.00	50

Table 32. Admissible values for applied touch voltage according to the Spanish norm ITC- RAT-13.

For a time of 0.4 s the maximum voltage value is 310 V. This value will determine the maximum admissible step and touch voltage. It is assumed that anyone who enters the processing centre will be appropriately dressed and will wear the type of shoes required for maintenance. These conditions have an effect on the expressions used, which are the variation of the human resistance due to footwear.

Equation 52: $V_c, adm = V_{ca}, adm(1 + \frac{1.5\rho}{1000} + \frac{0.5R_z}{1000})$

Equation 53: $V_p, adm = 10V_{ca}, adm(1 + \frac{6\rho}{1000} + \frac{2R_z}{1000})$

$V_c, adm(V)$: Maximum admissible touch voltage.

$V_p, adm(V)$: Maximum admissible step voltage.

$V_{ca}, adm(V)$: Maximum admissible applied touch voltage.

$\rho(\Omega m)$: Apparent superficial resistivity. Takes into account the resistivity of the terrain and the pavement which are the same, so this value will be the same as the one used for the terrain.

$R_z(\Omega)$: Electrical resistance provided by footwear.

$$V_c, adm = 666.5\ V$$

$$V_p, adm = 17360\ V$$

The conditions required to guarantee an appropriate protection are the following:

Equation 54: $V_{pm} \leq V_p, adm$

Equation 55: $V_{cm} \leq V_c, adm$

Equation 56: $I_a \leq I_d$

I_a: Activating current of the protection device.

All of these conditions are met except for the touch voltage. This usually happens, and therefore, additional security measures must be taken. The norm allows exempting this condition if measures such as mechanic protection to avoid direct contact between the conductive devices and people. With these measures, a new expression can be used in place of the one used before:

Equation 57: $V_p, acc, adm = 10V_{ca}, adm(1 + \frac{3\rho_{concrete}}{1000} + \frac{3\rho}{1000})$

$V_p, acc, adm(V)$: Admissible step voltage at the access.

$\rho_{concrete}$: Resistivity of concrete, 3000(Ωm).

The resistivity of concrete is used as the floor of the processing plant will be made of concrete. The condition required in this place is as follows:

Equation 58: $V_p, acc, adm \geq V_{cm}$

The maximum step voltage at the access (which coincides with the maximum touch voltage in the exterior) must be smaller than the admissible step voltage at the access. Therefore, it can be said that all the conditions required are met.

In order to guarantee the independence of the grounding system, so that any transferred voltage to the conductive devices in the low voltage part due to a fault in the medium voltage part, does not result in a dangerous situation for users, the following expression must be used:

Equation 59: $D = \frac{\rho I_d}{2\pi U}$

$$D = 7.96\ m$$

$D(m)$: Minimum distance between electrodes.

$\rho(\Omega m)$: Resistivity of the terrain.

$I_d(A)$: Fault current.

$U(V)$: Induced voltage, 1000 V.

The minimum distance between the grounding system in the low voltage part and the medium voltage part is 7.96 m, which can be easily obtained.

1.5. FEASIBILITY STUDY

The expected life of the photovoltaic plant is meant to be 25 years, and the actual selling price of the energy is 82USD/MWh (70 €/MWh). In the past years, new privately owned generation facilities have been encouraged by regulatory policy, which has increased the selling price of electricity. This can be explained because the Panay Island has an isolated electric grid feed by different power plants of medium capacity and now that the power market has become more competitive, sustainable energy is being encouraged.

In order to calculate the total energy production and eventually the total profits, the performance ratio must be determined.

In all real installations there are factors that have an important influence in the production. A photovoltaic installation has the following main losses:

- Losses due to partial shadings. These losses are not common in well-designed photovoltaic installations. In this case, a 2% loss is considered for winter and 1% in summer. Which means 1.5% will be considered.
- Losses due to dirtiness and dust on the modules. This value depends highly on the location of the plant, if there are roads or industries in the proximity which can emit dust into the air and eventually on the surface of the modules. In some cases the tilt angle is increased to reduce this type of loss. The percentage estimated for the photovoltaic plant designed is 3% in summer and 1% in winter, which leaves with an overall percentage loss of 2%.
- Losses due to wiring. These losses have already been calculated in the wiring section, 0.64%.
- Mismatching losses. This value depends on the quality of the modules used, due to the variations in the parameters of the modules used in the installation. As there is no information available, a 2% loss is estimated.
- Losses due to the inverter and transformer. According to the manufacturers, a 3% should be considered in the calculations.
- Losses due to high temperatures. If the functioning temperature of the module is higher than the one of standard conditions, losses will appear. An 8% loss can be considered when accurate information is not available. In any case, these losses can be calculated, the procedure for this calculation is explained below.

Equation 60: $\left(1 - g(T_{PVcell} - 25)\right) = (1 - L_{temp})$

$g(\frac{1}{°C})$: Power temperature coefficient of the module. According to the manufacturer of the module, this value corresponds to -0.45 %/ºC.

$T_{PVcell}(°C)$: Functioning temperature of the module, 45 ºC.

L_{temp}: Losses to high functioning temperatures.

This expression provides a 9% loss due to high temperature. So this will be the value considered for the calculation of energy production as it is more restrictive.

There are other losses which have not been considered given that they are already included in starting data, such as the irradiance received on the modules. As well as losses due to protection devices which are difficult to determine and have low effect on the final result.

Once all the factors affecting the production are identified, the performance ratio and energy yield of the system can be calculated:

Equation 61: $PR = (1 - L_{shad})(1 - L_{dirt})(1 - L_{missm})(1 - L_{inv-traf})(1 - L_{temp})(1 - L_{wiring})$

$$PR = (1 - 0.015)(1 - 0.02)(1 - 0.02)(1 - 0.03)(1 - 0.09)(1 - 0.0064)$$

$$PR = 0.83$$

PR: Performance ratio.

L_{shad}: Losses due to shadings.

L_{dirt}: Losses due to dirtiness.

L_{missm}: Losses due to mismatching.

$L_{inv-traf}$: Losses due to the inverter and transformer.

L_{temp}: Losses due to temperatures.

L_{wiring}: Losses to wiring.

Month	PSH	Peak power (kWp)	Days	PR	kWh/day	kWh/month
JAN	5.39	1056	31	0.83	4724.2	146451.0
FEB	5.93	1056	28	0.83	5197.5	145530.7
MAR	6.35	1056	31	0.83	5565.6	172535.1
APR	6.23	1056	30	0.83	5460.5	163814.1
MAY	5.32	1056	31	0.83	4662.9	144549.1
JUN	4.5	1056	30	0.83	3944.2	118324.8
JUL	4.23	1056	31	0.83	3707.5	114932.8
AUG	4.36	1056	31	0.83	3821.5	118465.0
SEP	4.86	1056	30	0.83	4259.7	127790.8
OCT	5.05	1056	31	0.83	4426.2	137212.9
NOV	5.04	1056	30	0.83	4417.5	132523.8
DEC	4.95	1056	31	0.83	4338.6	134495.9
		TOTAL ANNUAL PRODUCTION				1656626.1

Table 33. Annual production. Own work.

The total annual production of the photovoltaic plant is 1656.63 MWh. The peak sun hours are obtained dividing the solar incident irradiance (kWh/m^{2}day) by 1 kWh/m^2.

In order to obtain the annual incomes, a 0.5% degradation of the modules has been considered. Which means its production will be reduced by 0.5% for each year of active operation. The total investment as shown in the budget, is 1.98 million of USD which means that the photovoltaic plant could be built at a cost to SUWECO of approximately 1.98 USD per Watt. It is supposed that all the profit produced during the first years by the photovoltaic plant will be used to cover the cost of the initial investment. In addition to this, annual fixed costs of 20000 USD are considered.

Year	Annual incomes (USD)	Amortization (USD)	Annual fixed costs (USD)	Annual benefits (USD)	Taxes 10% (USD)	Annual balance (USD)
1	136837.31	116837.31	20000	0.00	0.00	0.00
2	135468.94	115468.94	20000	0.00	0.00	0.00
3	134100.57	114100.57	20000	0.00	0.00	0.00
4	132732.20	112732.20	20000	0.00	0.00	0.00
5	131363.82	111363.82	20000	0.00	0.00	0.00
6	129995.45	109995.45	20000	0.00	0.00	0.00
7	128627.08	108627.08	20000	0.00	0.00	0.00
8	127258.70	107258.70	20000	0.00	0.00	0.00
9	125890.33	105890.33	20000	0.00	0.00	0.00
10	124521.96	104521.96	20000	0.00	0.00	0.00
11	123153.58	103153.58	20000	0.00	0.00	0.00
12	121785.21	101785.21	20000	0.00	0.00	0.00
13	120416.84	100416.84	20000	0.00	0.00	0.00
14	119048.46	99048.46	20000	0.00	0.00	0.00
15	117680.09	97680.09	20000	0.00	0.00	0.00
16	116311.72	96311.72	20000	0.00	0.00	0.00
17	114943.34	94943.34	20000	0.00	0.00	0.00
18	113574.97	93574.97	20000	0.00	0.00	0.00
19	112206.60	84187.38	20000	8019.22	801.92	7217.30
20	110838.22	0	20000	90838.22	9083.82	81754.40
21	109469.85	0	20000	89469.85	8946.99	80522.87
22	108101.48	0	20000	88101.48	8810.15	79291.33
23	106733.11	0	20000	86733.11	8673.31	78059.79
24	105364.73	0	20000	85364.73	8536.47	76828.26
25	103996.36	0	20000	83996.36	8399.64	75596.72
			TOTAL BENEFIT (€)	532522.97		479270.68

Table 34. Incomes and benefit. Own work.

The following table shows the yearly balance of the photovoltaic plant if decided to use all of the profit produced to pay the initial investment until it is completely payed. A more illustrative figure follows this table. Therefore, the designed photovoltaic plant has a payback period of 19 years.

Year	Balance (USD)	Year	Balance (USD)	Year	Balance (USD)	Year	Balance (USD)	Year	Balance (USD)
1	-1864833	6	-1317980	11	-801915	16	-316639	21	137848
2	-1752999	7	-1212304	12	-702397	17	-223279	22	225051
3	-1642397	8	-1107860	13	-604110	18	-131150	23	311023
4	-1533026	9	-1004647	14	-507055	19	-40252	24	395762
5	-1424887	10	-902665	15	-411232	20	49414	25	479271

Table 35. Yearly balance. Own work.

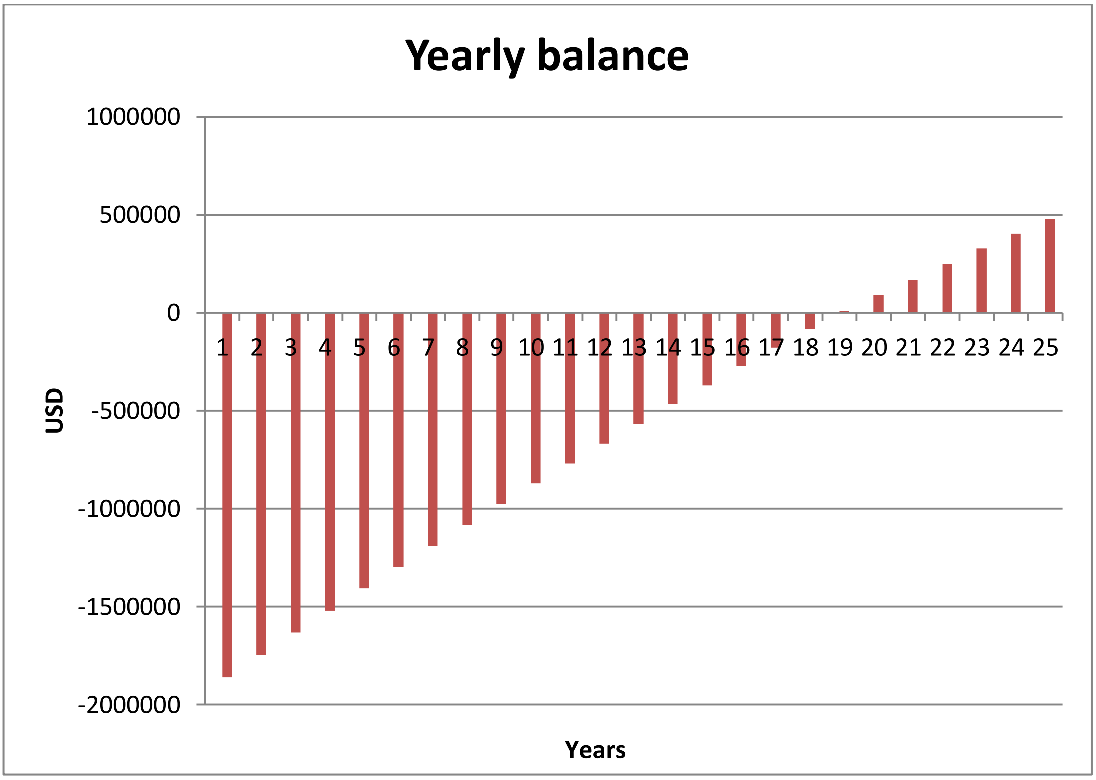


Figure 17. Total balance. Own work.

It can be appreciated that the total income and benefit are acceptable, but to analyse the feasibility of the project the net present value (NPV), the payback and the internal rate of return (IRR) need to be determined. In order to do this the annual cash flow must be known.

Year	Annual balance after taxes (USD)	Amortization (USD)	Amortization + Balance after taxes (USD)	Annual cash flow, CF (USD)	(1+r)^n	Updated cash flow, CF/[(1+r)^n] (USD)	Payback (USD)
0				-1977897.95	1.00	-1977897.95	-1977897.95
1	0.00	116837.31	116837.31	116837.31	1.01	115680.51	-1862217.44
2	0.00	115468.94	115468.94	115468.94	1.02	113193.75	-1749023.69
3	0.00	114100.57	114100.57	114100.57	1.03	110744.89	-1638278.80
4	0.00	112732.20	112732.20	112732.20	1.04	108333.42	-1529945.38
5	0.00	111363.82	111363.82	111363.82	1.05	105958.86	-1423986.52
6	0.00	109995.45	109995.45	109995.45	1.06	103620.69	-1320365.83
7	0.00	108627.08	108627.08	108627.08	1.07	101318.43	-1219047.40
8	0.00	107258.70	107258.70	107258.70	1.08	99051.61	-1119995.79
9	0.00	105890.33	105890.33	105890.33	1.09	96819.75	-1023176.04
10	0.00	104521.96	104521.96	104521.96	1.10	94622.36	-928553.68
11	0.00	103153.58	103153.58	103153.58	1.12	92459.00	-836094.68
12	0.00	101785.21	101785.21	101785.21	1.13	90329.21	-745765.47
13	0.00	100416.84	100416.84	100416.84	1.14	88232.52	-657532.95
14	0.00	99048.46	99048.46	99048.46	1.15	86168.50	-571364.46
15	0.00	97680.09	97680.09	97680.09	1.16	84136.69	-487227.76
16	0.00	96311.72	96311.72	96311.72	1.17	82136.68	-405091.08
17	0.00	94943.34	94943.34	94943.34	1.18	80168.02	-324923.06
18	0.00	93574.97	93574.97	93574.97	1.20	78230.30	-246692.76
19	7217.30	84187.38	91404.68	91404.68	1.21	75659.30	-171033.46
20	81754.40	0.00	81754.40	81754.40	1.22	67001.37	-104032.10
21	80522.87	0.00	80522.87	80522.87	1.23	65338.68	-38693.41
22	79291.33	0.00	79291.33	79291.33	1.24	63702.35	25008.94
23	78059.79	0.00	78059.79	78059.79	1.26	62092.02	87100.96
24	76828.26	0.00	76828.26	76828.26	1.27	60507.33	147608.30
25	75596.72	0.00	75596.72	75596.72	1.28	58947.94	206556.24

Table 36. Feasibility study. Own work.

It is shown then that the NPV is positive with a value of 206556.24 USD and a payback period of 21 years according to this study, and therefore, the project is accepted. A discount rate of 1% has been considered in the calculations of the NPV, using the following equation:

Equation 62: $\sum_{t=0}^{N} \frac{CF}{(1+i)^t} - I_0$

CF: Cash flow, USD.

i: Discount rate, 0.01.

I_0: Initial investment, USD.

N: Number of years.

Finally, the IRR is the value of i for which the NPV would be cero. In this case the IRR is 1.9%.

In conclusion, the results obtained are acceptable. However, it must be taken into account that the selling price of the energy may vary with the years and drop to values which could make this project unfeasible. On the other hand, this is a social project to improve the sustainability of the province of Antique, so the fact that it does not have benefits would not be a problem if the losses are not extremely high.

1.6. BIBLIOGRAPHY

The bibliography used is the following:

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- http://www.pvsyst.com
- RBT (Spanish norm)
- RAT (Spanish norm)

DOCUMENT 2 - BUDGET

2. BUDGET

	Item	Units	Description	Quantity	Price per unit (USD)	Total price (USD)
TERRAIN	Terrain	ha	Terrain for the photovoltaic plant	1.5	25960.00	38940.00
GENERATING ELEMENTS	Photovoltaic module	ud	Photovoltaic module A-320P GS including assembly.	3300	198.00	653413.20
	Inverter	ud	PVS800 inverter 1MW.	1	207680.00	207680.00
STRUCTURE	Supporting structure	ud	Supporting structure for the modules, including assemby and any other materials needed for the construction.	1	118000.00	118000.00
WIRING AND TRENCHES	PRYSMIAN conductor 6 mm2	m	Conductor P-Sun 2.0, 6mm2 Cu.	5806	1.70	9865.56
	PRYSMIAN conductor 95 mm2	m	Conductor Al Voltalene N BT 95mm2 Al.	284	22.51	6394.09
	PRYSMIAN conductor 120 mm2	m	Conductor Al Voltalene N BT 120mm2 Al.	236	30.07	7095.67
	PRYSMIAN conductor 150 mm2	m	Conductor Al Voltalene N BT 150mm2 Al.	459	36.01	16530.24
	PRYSMIAN conductor 240 mm2 - BT	m	Conductor Al Voltalene N BT 240mm2 Al.	88	55.79	4909.56
	PRYSMIAN conductor 240 mm2 - MT	m	Conductor Al Voltalene MT 240mm2 Al.	1581	83.23	131579.36
	Trench (inv-trafo)	m	Trench 1.2mx0.8m including warning tape and PVC tubes. Including filling materials and excavation.	11	43.72	480.91

	Trench trafo-SET	m	Trench 0.4mx0.8m including warning tape. Including filling materials and excavation.	1528	13.30	20320.26
	Trench trafo-SET - cross	m	Trench 0.4mx0.8m including warning tape and PVC tubes. Including filling materials and excavation.	8	24.27	194.18
	Trench 1 conductor	m	Trench 0.4mx0.8m including warning tape. Including filling materials and excavation.	48	13.30	638.33
	Trench 2 conductors	m	Trench 0.4mx0.8m including warning tape. Including filling materials and excavation.	30	13.30	398.96
	Trench 3 conductors	m	Trench 0.5mx0.8m including warning tape. Including filling materials and excavation.	21	16.63	349.15
	Trench 4 conductors	m	Trench 0.65mx0.8m including warning tape. Including filling materials and excavation.	45	21.63	973.32
	Trench 5 conductors	m	Trench 0.8mx0.8m including warning tape. Including filling materials and excavation.	105	26.62	2795.18
	Trench 6 conductors	m	Trench 1mx0.8m including warning tape. Including filling materials and excavation.	49	33.26	1629.95

	Electrical tray	m	Eletcrical tray from ATERSA or similar for a maximum of 15 conductors of 6mm2.	1450	47.20	68440.00
LV - GROUNDING	Protective earth conductors	ud	Protective earth conductors Cu.	1	7375.00	7375.00
	Earthing conductor Cu	m	Grounding conductor flowing through trenches Cu made 35mm2.	307	5.70	1749.72
	Horizontal electrode	m	Horizontal electrode, Cu made.	160	6.14	981.76
	Earthing rods	ud	Vertical electrodes 2m length and 30mm2 Cu made.	4	39.79	159.16
JUNTION BOXES	Junction box STC12	ud	Junction box for 12 strings, including fuses and any material or equipment needed for installation. From manufacturer AMB Green power.	2	697.38	1394.76
	Junction box STC16	ud	Junction box for 16 strings, including fuses and any material or equipment needed for installation. From manufacturer AMB Green power.	9	775.26	6977.34
PROTECTION DEVICES	Overvoltage suppressor	ud	Overvoltage suppressor.	2	128.70	257.41
	Fuse 150 A	ud	Fuse 150A adecuate for installation.	11	19.91	218.97
	Isolation detector	ud	Isolation vigilant appropriate for installation	1	4720.00	4720.00
	Circuit breaker 250 A	ud	Compact NSX250N from Schneider electric.	8	1287.33	10298.66
	Protective equipment	ud	Complete protective equipment for workers.	1	135.70	135.70

ILUMINTAION AND SUPPORT GENERATOR	Ilumination	ud	Ilumination for photovoltaic plant.	1	1026.46	1026.46
	Low voltage board	ud	Low voltage bord, including protections a connductors need for full installation.	1	3488.91	3488.91
	Generator set	ud	Generator set 6kVA.	1	12120.85	12120.85
CONDITIONING AND PREPARITION OF THE TERRAIN AND PHOTOVOLTAIC PLANT	Excavation of trenches	m	Mechanical excavation for trenches.	555	13.30	7380.72
	Conditioning of the terrain	m2	Complete conditioning of the terrain for appopriate construction.	155228	1.96	304060.61
	Perimetral fencing	m	Meters of fence 2m high aluminium made.	555	26.67	14800.74
	Concrete	m3	Concrete for CT, inverter or any other possible needs.	1	3705.20	3705.20
PROCESSING CENTRE	Transformer	ud	Transformer Schneider electric 1MW oil-immersed.	1	23836.00	23836.00
	CT grounding	ud	Complete CT grounding. Including rods, conductors or any other materials or devices needed for full installation.	1	573.83	573.83
	Prefabricated building CT	ud	Prefabricated building for CT.	1	6667.00	6667.00
	Protection cubicle	ud	Protective cubicle for transformer. Including protection devices, conductors and any materials needed for complete installation.	1	3509.49	3509.49

Table 37. Budget. Own work.

Total (USD)	1706066.20
Overhead (10%) (USD)	170606.62
Subtotal (USD)	1876672.82
Industrial profit (6%) (USD)	102363.97
Total investement (USD)	1979036.79

Table 38. Total investment. Own work.

The decomposed prices are shown in the following tables:

Item code	Item
1	Terrain
2	Photovoltaic module
3	Inverter
4	Supporting structure
5	PRYSMIAN conductor 6 mm2
6	PRYSMIAN conductor 95 mm2
7	PRYSMIAN conductor 120 mm2
8	PRYSMIAN conductor 150 mm2
9	PRYSMIAN conductor 240 mm2 - BT
10	PRYSMIAN conductor 240 mm2 - MT
11	Trench (inv-trafo)
12	Trench trafo-SET
13	Trench trafo-SET - cross
14	Trench 1 conductor
15	Trench 2 conductors

16	Trench 3 conductors
17	Trench 4 conductors
18	Trench 5 conductors
19	Trench 6 conductors
20	Electrical tray
21	Protective earth conductors
22	Earthing conductor Cu
23	Horizontal electrode
24	Earthing rods
25	Junction box STC12
26	Junction box STC16
27	Overvoltage suppressor
28	Fuse 150 A
29	Isolation detector
30	Circuit breaker 250 A
31	Protective equipment
32	Ilumination
33	Low voltage board
34	Generator set
35	Excavation of trenches
36	Conditioning of the terrain
37	Perimetral fencing
38	Concrete
39	Transformer
40	CT grounding
41	Prefabricated building CT
42	Protection cubicle

Table 39. Item codes. Own work.

Item code	Decomp. code	Units	Description	Quantity	Price per unit (USD)	Total price (USD)
1	1.1	ha	Terrain for the photovoltaic plant.	1.50	25960.00	25960.00
	Total					25960.00
2	2.1	m²	Photovoltaic solar module A-320P GS of peak power (Wp) 320 W, maximum power voltage (Vmp) 37.56 V, maximum power current (Imp) 8.52 A,shortcircuit current (Isc) 9.03 A,open circuit voltage (Voc) 45.82 V, efficiency 16.5%, 72 cells, and dimensiones 1956x992x40 mm from ATERSA or similar.	1.00	137.25	137.30
	2.2	Ud	Required accesories for complete installation.	1.00	18.00	18.00
	2.3	Ud	Required electrical elements. for complete installation.	1.00	25.00	25.00
	2.4	h	First class photovoltaic solar module installer.	0.40	18.13	7.27
	2.5	h	Assistant of photovoltaic solar module installer.	0.40	16.40	6.58
	2.6	%	Direct costs.	2.00	194.15	3.88
	Total					198.03
3	3.1	Ud	Inverter of 1MW nominal power PVS800 from ABB or similar.	1.00	203587.00	203587.00
	3.2	h	First class electrician.	0.60	18.13	10.91
	3.3	h	Assistant of electrician.	0.60	16.40	9.87
	3.4	%	Direct costs.	2.00	203607.79	4072.16
	Total					207680.00
4	4.1	Ud	Aluminium and any other materials for the construction of the photovoltaic structure. Including hours of profesional instalators and constructor in order to build and completely install the whole structure.	1.00		115686.27
	4.2	%	Direct costs.	2.00	115686.27	2313.73
	Total					118000.00
5	5.1	m	Conductor of 6 mm² cross-section area P-Sun 2.0 for photovoltaic installations and low voltage from prysmian group or similar.	1.00	0.28	0.28
	5.2	h	First class electrician.	0.04	18.13	0.73

	5.3	h	Assistant of electrician.	0.04	16.40	0.66
	5.4	%	Direct costs.	2.00	1.67	0.03
	Total					1.70
6	6.1	m	Conductor of 95 mm² cross-section area Al Voltalene N for low voltage from prysmian group or similar.	1.00	20.68	20.68
	6.2	h	First class electrician.	0.04	18.13	0.73
	6.3	h	Assistant of electrician.	0.04	16.40	0.66
	6.4	%	Direct costs.	2.00	22.07	0.44
	Total					22.51
7	7.1	m	Conductor of 120 mm² cross-section area Al Voltalene N for low voltage from prysmian group or similar.	1.00	28.09	28.09
	7.2	h	First class electrician.	0.04	18.13	0.73
	7.3	h	Assistant of electrician.	0.04	16.40	0.66
	7.4	%	Direct costs.	2.00	29.48	0.59
	Total					30.07
8	8.1	m	Conductor of 150 mm² cross-section area Al Voltalene N for low voltage from prysmian group or similar.	1.00	33.91	33.91
	8.2	h	First class electrician.	0.04	18.13	0.73
	8.3	h	Assistant of electrician.	0.04	16.40	0.66
	8.4	%	Direct costs.	2.00	35.30	0.71
	Total					36.01
9	9.1	m	Conductor of 240 mm² cross-section area Al Voltalene N for low voltage from prysmian group or similar.	1.00	53.31	53.31
	9.2	h	First class electrician.	0.04	18.13	0.73
	9.3	h	Assistant of electrician.	0.04	16.40	0.66
	9.4	%	Direct costs.	2.00	54.70	1.09
	Total					55.79
10	10.1	m	Conductor of 240 mm² cross-section area Al Voltalene N for medium voltage from prysmian group or similar.	1.00	80.21	80.21
	10.2	h	First class electrician.	0.04	18.13	0.73
	10.3	h	Assistant of electrician.	0.04	16.40	0.66
	10.4	%	Direct costs.	2.00	81.60	1.63
	Total					83.23
11	11.1	h	Hydraulic backhoe excavator, of 115 kW. Incluiding sand filling for the trench.	0.38	48.48	18.54
	11.2	h	Ordinary constructor.	0.45	16.16	4.09

	11.3	m	Plastified tape.	4.00	0.14	0.56
	11.4	h	Frontal discharging dumper of 2 t of usefull load.	0.10	9.25	0.93
	11.5	h	Vibrating tray with manual guide, of 300 kg, working width of 70 cm, reversible.	0.15	6.38	0.96
	11.6	h	Tanker truck of 8 m³ capacity.	0.01	40.02	0.40
	11.7	h	Basculating truck of 12 t of load, 162 kW.	0.02	40.09	0.60
	11.8	m	PVC tube for burried conductors of appropriate dimensions.	8.00	0.95	7.60
	11.11	h	First class electrician.	0.51	18.13	9.17
	11.12	%	Direct costs.	2.00	42.85	0.86
	Total					43.71
12	12.1	h	Hydraulic backhoe excavator, of 115 kW. Incluiding sand filling for the trench.	0.12	48.48	5.82
	12.2	h	Ordinary constructor.	0.15	16.16	2.42
	12.3	m	Plastified tape.	1.00	0.14	0.14
	12.4	h	Frontal discharging dumper of 2 t of usefull load.	0.39	9.25	3.61
	12.5	h	Vibrating tray with manual guide, of 300 kg, working width of 70 cm, reversible.	0.07	6.38	0.45
	12.6	h	Tanker truck of 8 m³ capacity.	0.01	40.02	0.28
	12.7	h	Basculating truck of 12 t of load, 162 kW.	0.01	40.09	0.32
	12.8	%	Direct costs.	2.00	13.04	0.26
	Total					13.30
13	13.1	h	Hydraulic backhoe excavator, of 115 kW. Incluiding sand and concrete filling for the trench.	0.15	104.04	15.61
	13.2	h	Ordinary constructor.	0.21	16.16	3.39
	13.3	m	Plastified tape.	1.00	0.14	0.14
	13.4	h	Frontal discharging dumper of 2 t of usefull load.	0.39	9.25	3.61
	13.5	h	Vibrating tray with manual guide, of 300 kg, working width of 70 cm, reversible.	0.07	6.38	0.45
	13.6	h	Tanker truck of 8 m³ capacity.	0.01	40.02	0.28
	13.7	h	Basculating truck of 12 t of load, 162 kW.	0.01	40.09	0.32
	13.8	%	Direct costs.	2.00	23.79	0.48

	Total					24.27
14	14.1	h	Hydraulic backhoe excavator, of 115 kW. Incluiding sand filling for the trench.	0.12	48.48	5.82
	14.2	h	Ordinary constructor.	0.15	16.16	2.42
	14.3	m	Plastified tape.	1.00	0.14	0.14
	14.4	h	Frontal discharging dumper of 2 t of usefull load.	0.39	9.25	3.61
	14.5	h	Vibrating tray with manual guide, of 300 kg, working width of 70 cm, reversible.	0.07	6.38	0.45
	14.6	h	Tanker truck of 8 m³ capacity.	0.01	40.02	0.28
	14.7	h	Basculating truck of 12 t of load, 162 kW.	0.01	40.09	0.32
	14.8	%	Direct costs.	2.00	13.04	0.26
	Total					13.30
15	15.1	h	Hydraulic backhoe excavator, of 115 kW. Incluiding sand filling for the trench.	0.12	48.48	5.82
	15.2	h	Ordinary constructor.	0.14	16.16	2.28
	15.3	m	Plastified tape.	2.00	0.14	0.28
	15.4	h	Frontal discharging dumper of 2 t of usefull load.	0.39	9.25	3.61
	15.5	h	Vibrating tray with manual guide, of 300 kg, working width of 70 cm, reversible.	0.07	6.38	0.45
	15.6	h	Tanker truck of 8 m³ capacity.	0.01	40.02	0.28
	15.7	h	Basculating truck of 12 t of load, 162 kW.	0.01	40.09	0.32
	15.8	%	Direct costs.	2.00	13.03	0.26
	Total					13.29
16	16.1	h	Hydraulic backhoe excavator, of 115 kW. Incluiding sand filling for the trench.	0.18	48.48	8.73
	16.2	h	Ordinary constructor.	0.15	16.16	2.49
	16.3	m	Plastified tape.	3.00	0.14	0.44
	16.4	h	Frontal discharging dumper of 2 t of usefull load.	0.39	9.25	3.61
	16.5	h	Vibrating tray with manual guide, of 300 kg, working width of 70 cm, reversible.	0.07	6.38	0.45
	16.6	h	Tanker truck of 8 m³ capacity.	0.01	40.02	0.28

	16.7	h	Basculating truck of 12 t of load, 162 kW.	0.01	40.09	0.32
	16.8	%	Direct costs.	2.00	16.31	0.33
	Total					16.64
17	17.1	h	Hydraulic backhoe excavator, of 115 kW. Incluiding sand filling for the trench.	0.27	48.48	13.28
	17.2	h	Ordinary constructor.	0.17	16.16	2.71
	17.3	m	Plastified tape.	4.00	0.14	0.56
	17.4	h	Frontal discharging dumper of 2 t of usefull load.	0.39	9.25	3.61
	17.5	h	Vibrating tray with manual guide, of 300 kg, working width of 70 cm, reversible.	0.07	6.38	0.45
	17.6	h	Tanker truck of 8 m³ capacity.	0.01	40.02	0.28
	17.7	h	Basculating truck of 12 t of load, 162 kW.	0.01	40.09	0.32
	17.8	%	Direct costs.	2.00	21.21	0.42
	Total					21.64
18	18.1	h	Hydraulic backhoe excavator, of 115 kW. Incluiding sand filling for the trench.	0.37	48.48	18.03
	18.2	h	Ordinary constructor.	0.17	16.16	2.71
	18.3	m	Plastified tape.	5.00	0.14	0.70
	18.4	h	Frontal discharging dumper of 2 t of usefull load.	0.39	9.25	3.61
	18.5	h	Vibrating tray with manual guide, of 300 kg, working width of 70 cm, reversible.	0.07	6.38	0.45
	18.6	h	Tanker truck of 8 m³ capacity.	0.01	40.02	0.28
	18.7	h	Basculating truck of 12 t of load, 162 kW.	0.01	40.09	0.32
	18.8	%	Direct costs.	2.00	26.10	0.52
	Total					26.63
19	19.1	h	Hydraulic backhoe excavator, of 115 kW. Incluiding sand filling for the trench.	0.50	48.48	24.34
	19.2	h	Ordinary constructor.	0.17	16.16	2.78
	19.3	m	Plastified tape.	6.00	0.14	0.84
	19.4	h	Frontal discharging dumper of 2 t of usefull load.	0.39	9.25	3.61

	19.5	h	Vibrating tray with manual guide, of 300 kg, working width of 70 cm, reversible.	0.07	6.38	0.45
	19.6	h	Tanker truck of 8 m³ capacity.	0.01	40.02	0.28
	19.7	h	Basculating truck of 12 t of load, 162 kW.	0.01	40.09	0.32
	19.8	%	Direct costs.	2.00	32.61	0.65
	Total					33.26
20	20.1	m	PVC electrical tary for conductors with appropriate dimensions.	1.00	44.31	44.31
	20.2	h	First class electrician.	0.06	18.13	1.03
	20.3	h	Assistant of electrician.	0.06	16.40	0.93
	20.4	%	Direct costs.	2.00	46.28	0.93
	Total					47.20
21	21.1	m	Bare copper conductor, of 6 mm² cross-section area.	2191.00	0.48	1051.68
	21.2	m	Bare copper conductor, of 95 mm² cross-section area.	284.00	4.10	1164.40
	21.3	m	Bare copper conductor, of 120 mm² cross-section area.	135.00	4.80	648.00
	21.4	m	Bare copper conductor, of 150 mm² cross-section area.	460.00	5.30	2438.00
	21.5	Ud	Auxiliar materials for the grounding system.	100.00	1.15	115.00
	21.6	h	First class electrician.	100.00	18.13	1813.00
	21.7	%	Direct costs.	2.00	7230.08	144.60
	Total					7374.68
22	22.1	m	Bare copper conductor, of 35 mm² cross-section area.	1.00	3.60	3.60
	22.2	Ud	Auxiliar materials for the grounding system.	0.15	1.15	0.17
	22.3	h	First class electrician.	0.11	18.13	1.94
	22.4	%	Direct costs.	2.00	5.71	0.11
	Total					5.83
23	23.1	m	Copper conductor for horizontal electrode.	1.00	1.50	1.50
	23.2	Ud	Auxiliar materials for the grounding system.	1.00	0.50	0.50
	23.3	h	Hydraulic backhoe excavator, of 115 kW.	0.01	45.65	0.46
	23.4	h	Frontal discharging dumper of 2 t of usefull load.	0.08	8.00	0.64

	23.5	h	Vibrating tray with manual guide, of 300 kg, working width of 70 cm, reversible.	0.06	6.38	0.38
	23.6	h	Tanker truck of 8 m³ capacity.	0.06	10.85	0.65
	23.7	h	First class electrician.	0.05	18.13	0.91
	23.8	h	Assistant of electrician.	0.05	16.40	0.82
	23.9	h	Ordinary constructor.	0.01	16.16	0.16
	23.11	%	Direct costs.	2.00	6.02	0.12
	Total					6.14
24	24.1	Ud	Earthing rods for grounding system. ·0mm diameter and 2 m height.	1.00	26.31	26.31
	24.2	m	Bare copper conductor, of 35 mm² cross-section area.	0.25	2.81	0.70
	24.3	Ud	Staple for rod connection.	1.00	1.00	1.00
	24.4	Ud	Bag of 5 kg mineral salts to improve conductivity of the grounding system.	0.33	3.50	1.17
	24.5	Ud	Auxiliar materials for the grounding system.	1.00	1.15	1.15
	24.6	h	First class electrician.	0.25	18.13	4.55
	24.7	h	Assistant of electrician.	0.25	16.40	4.12
	24.8	h	Ordinary constructor.	0.00	16.16	0.02
	24.9	%	Direct costs.	2.00	39.01	0.78
	Total					39.79
25	25.1	Ud	Junction box for 12 different circuits from AMB Green power or similar.	1.00	666.44	666.44
	25.2	h	First class electrician.	0.50	18.13	9.07
	25.3	h	Assistant of electrician.	0.50	16.40	8.20
	25.4	%	Direct costs.	2.00	683.71	13.67
	Total					697.38
26	26.1	Ud	Junction box for 16 different circuits from AMB Green power or similar.	1.00	742.79	742.79
	26.2	h	First class electrician.	0.50	18.13	9.07
	26.3	h	Assistant of electrician.	0.50	16.40	8.20
	26.4	%	Direct costs.	2.00	760.06	15.20
	Total					775.26
27	27.1	Ud	Overvoltage suppressor,of second class II, Second protection category II and voltage service of 400 V.	1.00	119.92	119.92
	27.2	h	First class electrician.	0.35	17.82	6.25
	27.3	%	Direct costs.	2.00	126.17	2.52
	Total					128.70

28	28.1	Ud	Fuse of nominal current 150 A and breaking capacity equal or higher than 50 kA.	1.00	2.67	2.67
	28.2	Ud	Modular base for fuses of 150 A nominal current.	1.00	13.21	13.21
	28.3	h	First class electrician.	0.20	18.13	3.64
	28.4	%	Direct costs.	2.00	19.52	0.39
	Total					19.91
29	29.1	Ud	Isolation detector	1.00	4621.20	4621.20
	29.2	h	First class electrician.	0.35	17.82	6.25
	29.3	%	Direct costs.	2.00	4627.45	92.55
	Total					4720.00
30	30.1	Ud	Authomatic circuit breaker of 250 A and breaking capacity equal or higher than 50 kA Compact NSX250N from Schneider electric or similar.	1.00	1251.17	1251.17
	30.2	h	First class electrician.	0.60	18.13	10.91
	30.3	%	Direct costs.	2.00	1262.08	25.24
	Total					1287.33
31	Total		No decomposition			135.70
32	32.1	Ud	Lamps and luminaries from adhorna or similar.	1.00	995.42	995.42
	32.2	h	First class electrician.	0.60	18.13	10.91
	32.3	%	Direct costs.	2.00	1006.33	20.13
	Total					1026.46
33	33.1	Ud	Low voltage board with a minimum admissible voltage of 440 V, including any protection devices or materials needed for a complete installation.	1.00	3346.12	3346.12
	33.2	h	First class electrician.	2.15	18.13	39.05
	33.3	h	Assistant of electrician.	2.15	16.40	35.33
	33.4	%	Direct costs.	2.00	3420.50	68.41
	Total					3488.91
34	34.1	Ud	Generator supporting set of 230/400V for the photovoltaic plant of 10 kVA from Geiner or similar.	1.00	11833.12	11833.12
	34.2	h	First class electrician.	1.45	18.13	26.29
	34.3	h	Assistant of electrician.	1.45	16.40	23.78
	34.4	%	Direct costs.	2.00	11883.19	237.66
	Total					12120.85
35	35.1	h	Hydraulic backhoe excavator, of 115 kW. Incluiding sand filling for the trench.	0.12	48.48	5.82

	35.2	h	Ordinary constructor.	0.15	16.16	2.42
	35.3	m	Plastified tape.	1.00	0.14	0.14
	35.4	h	Frontal discharging dumper of 2 t of usefull load.	0.39	9.25	3.61
	35.5	h	Vibrating tray with manual guide, of 300 kg, working width of 70 cm, reversible.	0.07	6.38	0.45
	35.6	h	Tanker truck of 8 m³ capacity.	0.01	40.02	0.28
	35.7	h	Basculating truck of 12 t of load, 162 kW.	0.01	40.09	0.32
	35.8	%	Direct costs.	2.00	13.04	0.26
	Total					13.30
36	36.1	h	Chainsaw of 2 kW nominal power.	0.02	3.00	0.07
	36.2	h	Loader of 120 kW/1,9 m³.	0.02	40.23	0.74
	36.3	h	Ordinary constructor.	0.07	16.16	1.12
	36.4	%	Direct costs.	2.00	1.92	0.04
	Total					1.96
37	37.1	Ud	Intermediate post of galvanised steel, 48 mm diameter and 1,5 mm thicknes plus 1 m height.	0.22	15.00	3.30
	37.2	Ud	Lower supporting post of galvanised steel, 48 mm diameter and 1,5 mm thicknes plus 1 m height.	0.06	10.00	0.60
	37.3	Ud	End post of galvanised steel, 48 mm diameter and 1,5 mm thicknes plus 1 m height.	0.04	10.00	0.40
	37.4	Ud	Squadron post of galvanised steel, 48 mm diameter and 1,5 mm thicknes plus 1 m height.	0.20	22.68	4.54
	37.5	m²	Simple torque mesh, 8 mm mesh step and 1,1 mm diameter.	1.20	1.40	1.68
	37.6	m³	Concrete HM-20/B/20/I.	0.10	73.13	7.31
	37.7	h	Civil construction assistant.	0.20	16.13	3.23
	37.8	h	First class constructor.	0.15	17.82	2.67
	37.9	h	Assistant constructor.	0.15	16.13	2.42
	37.11	%	Direct costs.	2.00	26.15	0.52
	Total					26.67
38	38.1	m³	Concrete mortar for spill.	13.35	133.30	1779.56
	38.2	m²	Rigid panel.	16.67	0.92	15.34
	38.3	h	First class constructor.	50.67	17.24	873.55
	38.4	h	Assistant constructor.	60.56	15.92	964.12
	38.5	%	Direct costs.	2.00	3632.56	72.65
	Total					3705.21

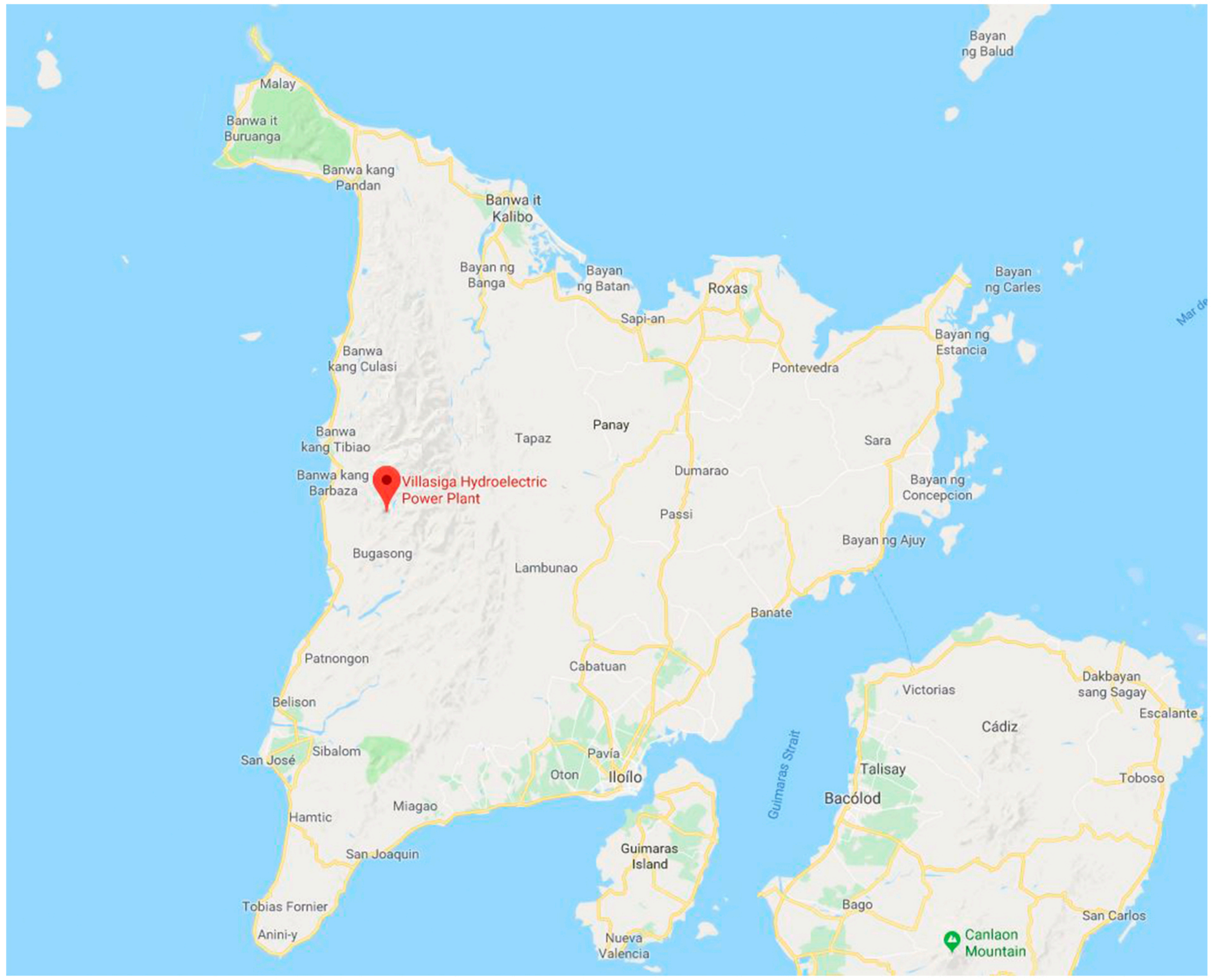
39	39.1	Ud	Transformer of 1000 kVA from Schneider electric or similar.	1.00	23071.12	23071.12
	39.2	h	First class electrician.	8.62	18.13	156.21
	39.3	h	Assistant of electrician.	8.62	16.40	141.30
	39.4	%	Direct costs.	2.00	23368.63	467.37
	Total					23836.00
40	40.1	Ud	Earthing rods for grounding system. ·0mm diameter and 2 m height.	8.00	13.15	105.20
	40.2	m	Bare copper conductor, of 35 mm^2 cross-section area.	80.00	2.81	224.80
	40.3	Ud	Staple for rod connection.	1.00	14.42	14.42
	40.4	Ud	Bag of 5 kg mineral salts to improve conductivity of the grounding system.	5.00	3.38	16.88
	40.5	Ud	Auxiliar materials for the grounding system.	1.00	16.58	16.58
	40.6	h	First class electrician.	5.00	18.13	90.65
	40.7	h	Assistant of electrician.	5.00	16.40	82.00
	40.8	h	Ordinary constructor.	0.75	16.16	12.04
	40.9	%	Direct costs.	2.00	562.58	11.25
	Total					573.83
41	41.1	Ud	Prefabricated building for CT for a maximum of 24 kV.	1.00	6463.10	6463.10
	41.2	h	First class constructor.	2.15	17.54	37.78
	41.3	h	Assistant constructor.	2.15	16.43	35.39
	41.4	%	Direct costs.	2.00	6536.27	130.73
	Total					6667.00
42	42.1	Ud	Protection and measuring cubicle for transformer for a maximum of 24 kV.	1.00	3366.30	3366.30
	42.2	h	First class electrician.	2.15	18.13	39.05
	42.3	h	Assistant of electrician.	2.15	16.40	35.33
	42.4	%	Direct costs.	2.00	3440.68	68.81
	Total					3509.49

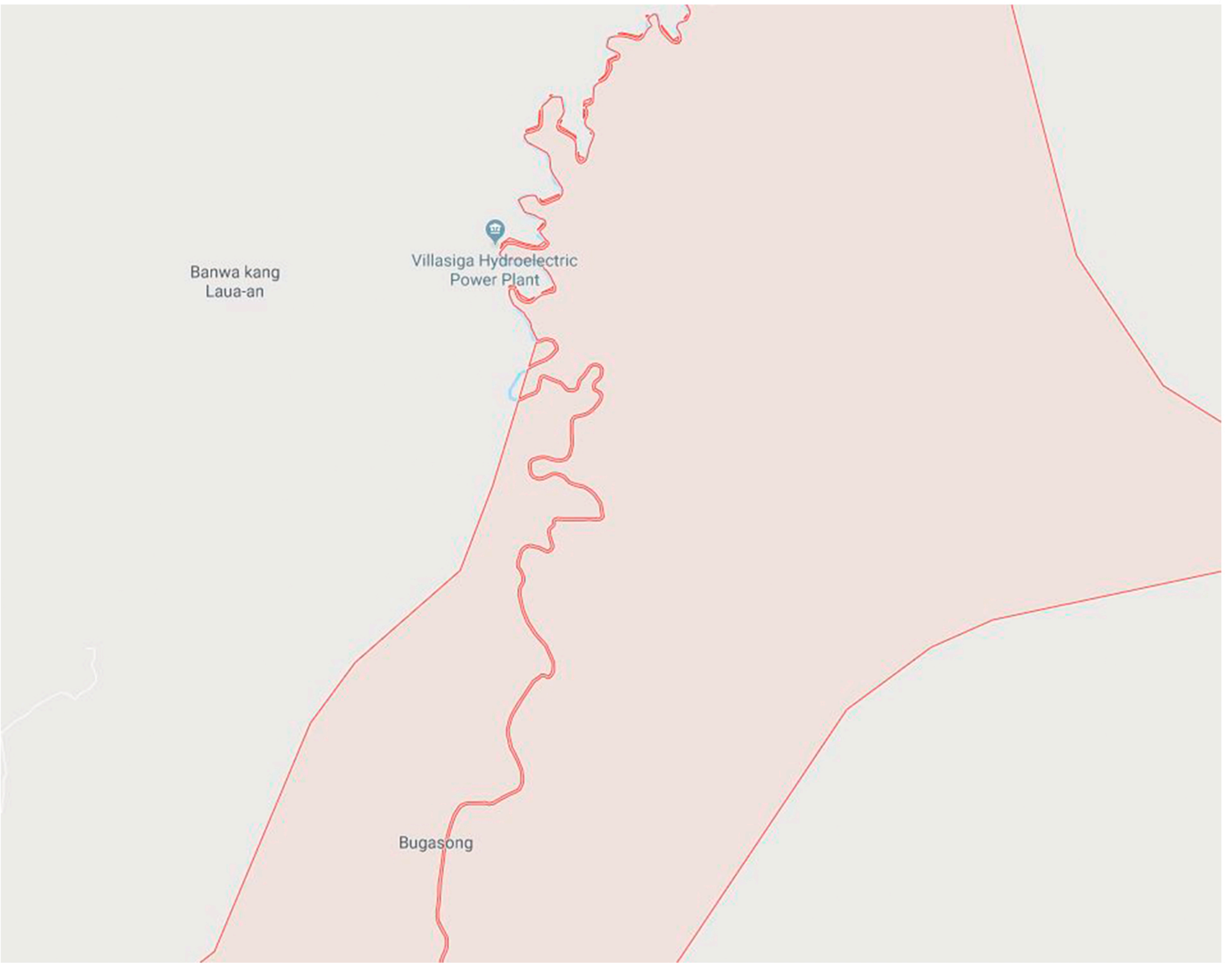
Table 40. Decomposed prices. Own work.

DOCUMENT 3 - DRAWINGS

3. DRAWINGS

- Location
- Photovoltaic plant terrain
- Photovoltaic plant interconnection
- Line diagram
- Line diagram – Strings – DC part – AC part
- Trenches





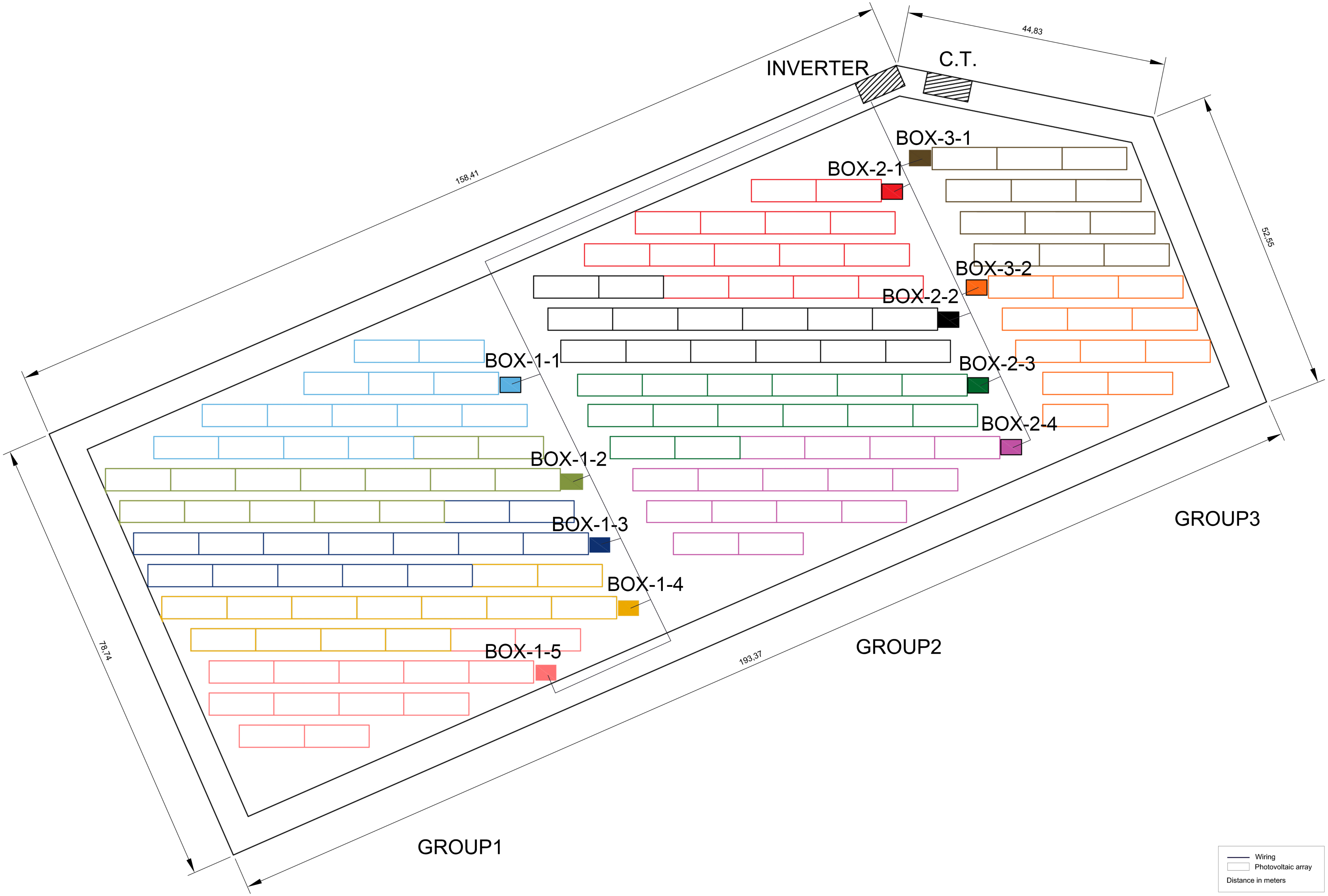
TRABAJO FINAL DE GRADO EN INGENIERÍA EN TECNOLOGÍAS INDUSTRIALES UNIVERSITAT POLITÈCNICA DE VALÈNCIA ESCUELA TÉCNICA SUPERIOR INGENIEROS INDUSTRIALES VALENCIA	Project: DESIGN OF A 1MVA GRID-TIED PHOTOVOLTAIC PLANT IN BUGASONG (VISAYAN ISLANDS-PHILIPPINES)	Drawing: Location Author: Salvador Torregrosa Marco	Date: June 2018 Scale:	Drawing number: 1

TRABAJO FINAL DE GRADO EN INGENIERÍA EN TECNOLOGÍAS INDUSTRIALES

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

ESCUELA TÉCNICA SUPERIOR INGENIEROS INDUSTRIALES VALENCIA

Project:	Drawing:	Date:	Drawing number:
DESIGN OF A 1MVA GRID-TIED PHOTOVOLTAIC PLANT IN BUGASONG (VISAYAN ISLANDS-PHILIPPINES)	Photovoltaic plant terrain	June 2018	2
	Author: Salvador Torregrosa Marco	Scale: 1:1000	



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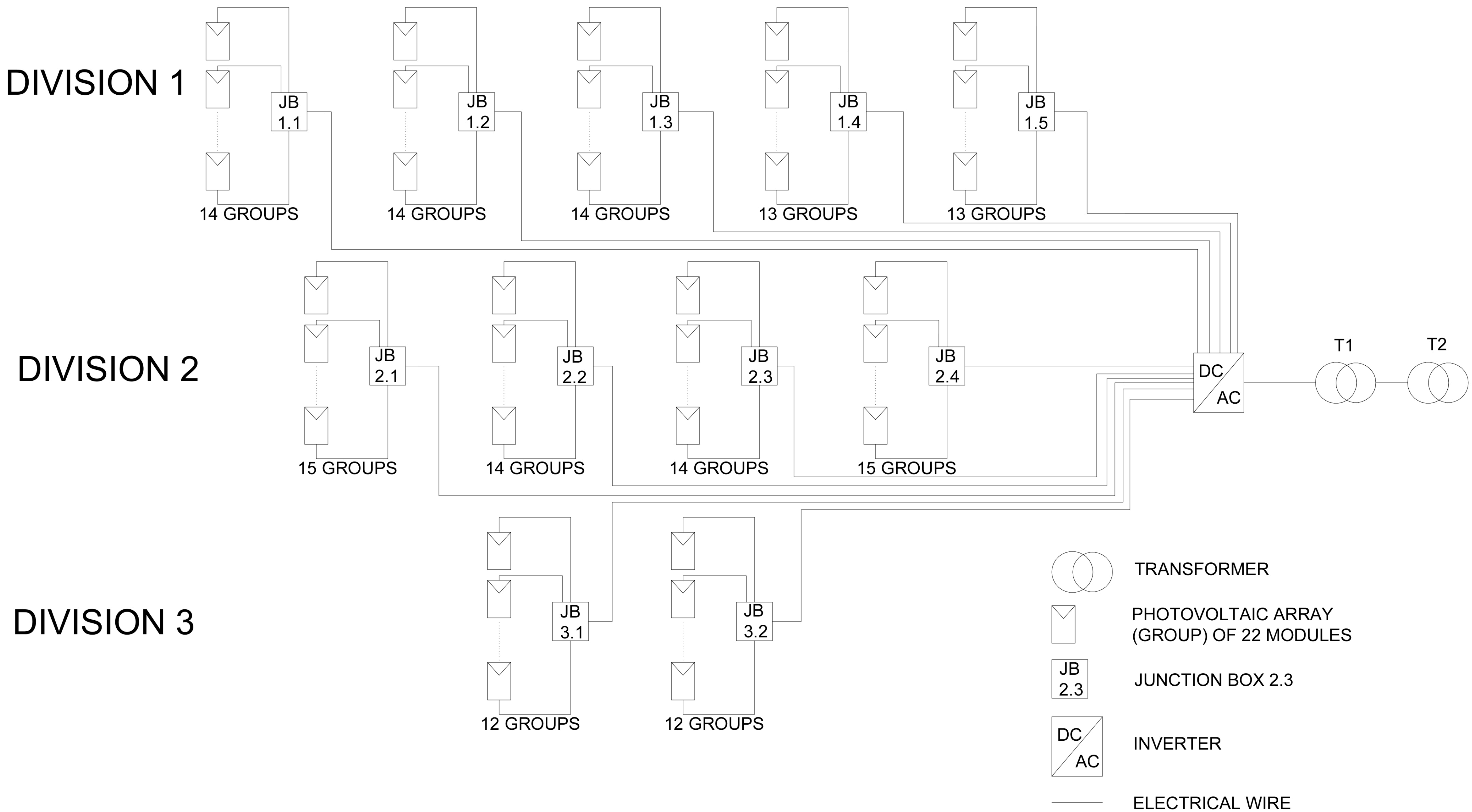
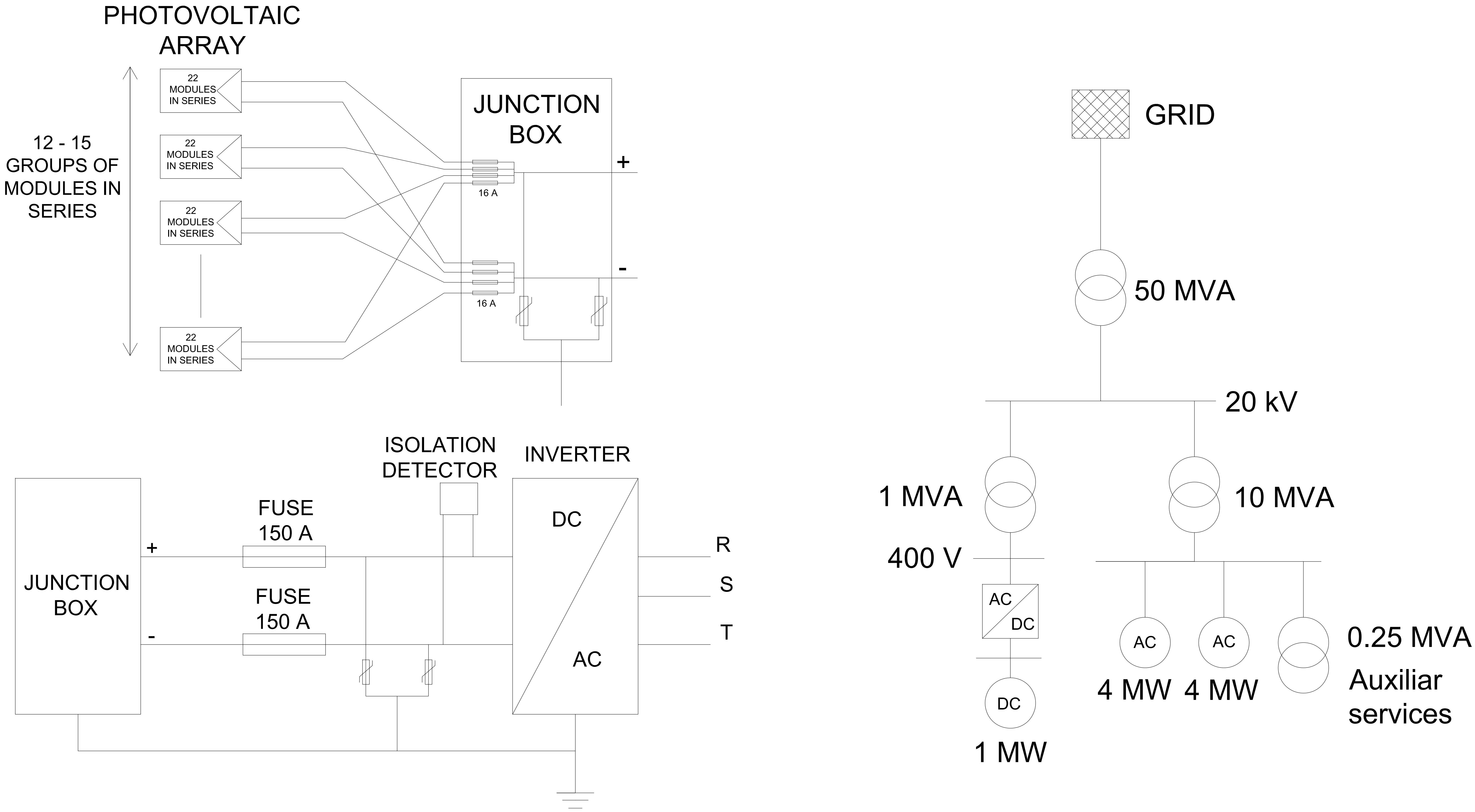
UNIVERSITAT POLITÈCNICA DE VALÈNCIA

ESCUELA TÉCNICA SUPERIOR INGENIEROS INDUSTRIALES VALENCIA

Project:	Drawing:	Date:	Drawing number:
DESIGN OF A 1MVA GRID-TIED PHOTOVOLTAIC PLANT IN BUGASONG (VISAYAN ISLANDS-PHILIPPINES)	Photovoltaic plant interconnection	June 2018	3
	Author: Salvador Torregrosa Marco	Scale: 1:600	



TRABAJO FINAL DE GRADO EN INGENIERÍA EN TECNOLOGÍAS INDUSTRIALES UNIVERSITAT POLITÈCNICA DE VALÈNCIA ESCUELA TÉCNICA SUPERIOR INGENIEROS INDUSTRIALES VALENCIA	Project: DESIGN OF A 1MVA GRID-TIED PHOTOVOLTAIC PLANT IN BUGASONG (VISAYAN ISLANDS-PHILIPPINES)	Drawing: Line diagram Author: Salvador Torregrosa Marco	Date: June 2018 Scale:	Drawing number: 4



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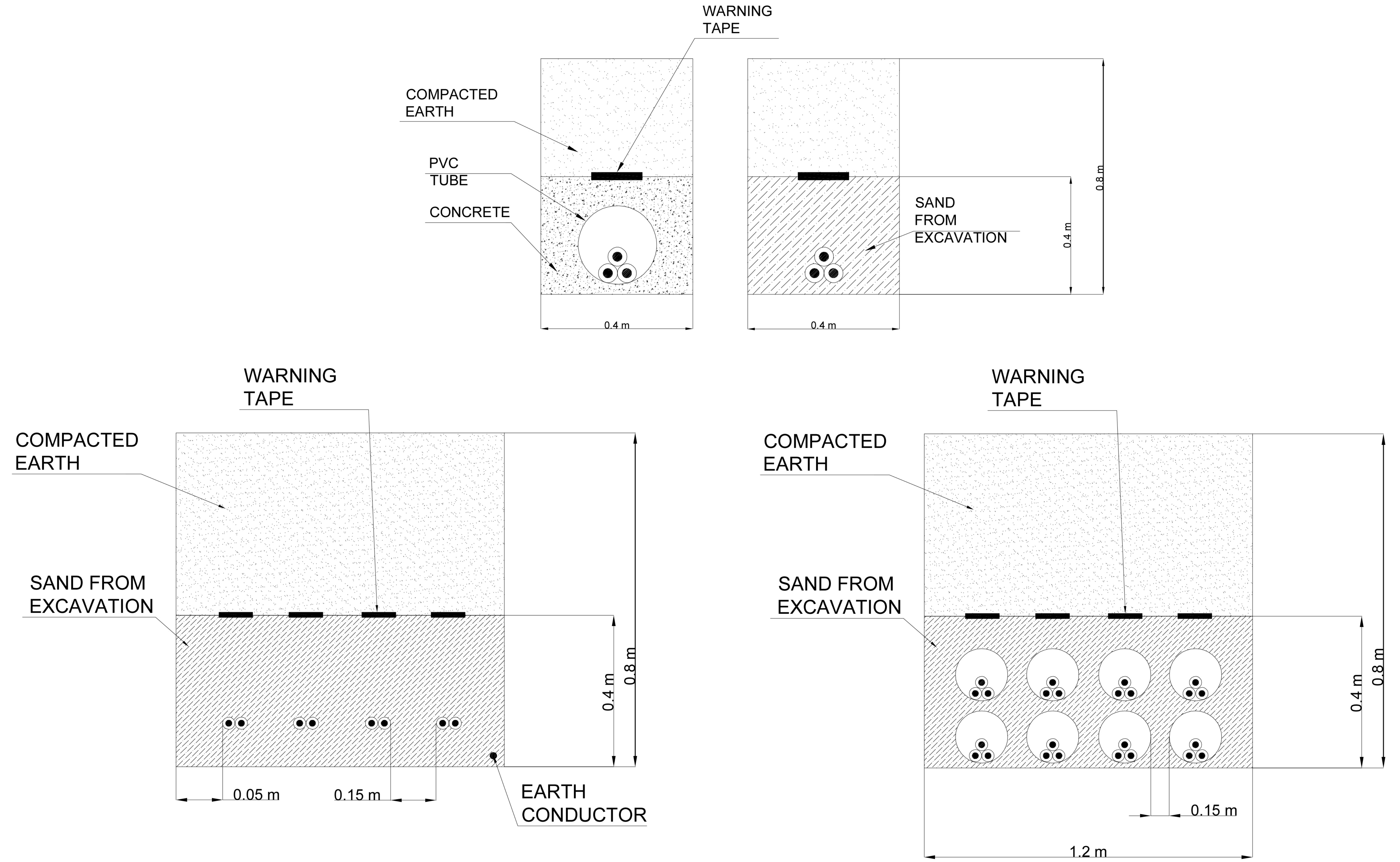
Project: DESIGN OF A 1MVA GRID-TIED PHOTOVOLTAIC PLANT IN BUGASONG (VISAYAN ISLANDS-PHILIPPINES)	Drawing: Line diagram - Strings - DC part - AC part	Date: June 2018	Drawing number: 5
	Author: Salvador Torregrosa Marco	Scale:	



TRABAJO FINAL DE GRADO EN INGENIERÍA EN TECNOLOGÍAS INDUSTRIALES UNIVERSITAT POLITÈCNICA DE VALÈNCIA ESCUELA TÉCNICA SUPERIOR INGENIEROS INDUSTRIALES VALENCIA	Project: DESIGN OF A 1MVA GRID-TIED PHOTOVOLTAIC PLANT IN BUGASONG (VISAYAN ISLANDS-PHILIPPINES)	Drawing: Trenches Author: Salvador Torregrosa Marco	Date: June 2018 Scale:	Drawing number: 6