Chapter

Dimensioning of an Autonomous Photovoltaic Installation: Case Study in Msaken, Sousse (Tunisia)

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Abstract

Renewable energy production has the potential to replace traditional fossil energy and reduce the consumption invoice. In this context, a client wants to realize an autonomous photovoltaic installation for his house that is under construction, located in the city of Msaken, Sousse (Tunisia), in an isolated area of the network of the Tunisian Company of Electricity and Gas (STEG) and will be inhabited by the end of the year 2019. The installation autonomy must be 72 hours in case of bad weather. Therefore, in this chapter, we will determine the technical characteristics of each component of the installation to meet the customer's energy needs and ultimately provide the total price.

Keywords: autonomous PV installation, Msaken, Sousse (Tunisia), electrical need estimation, PV field cost

1. Introduction

Among the major stakes of modern times is the electricity supply, either for domestic consumption (of people) or for industrial consumption [1].

Tunisia is a country in the Middle East that lacks oil reserves. It depends entirely on oil imports from neighboring countries to meet its energy needs. The continued rise in oil prices as a result of increasing world demand and the contraction of oil supply and regional instability put extreme pressure on the Tunisian economy, resulting in difficulties and economic disturbances. The government has responded quickly and actively to overcome the negative effects and deterioration of its economy by gradually reducing its support for consumer prices for electricity and petroleum products.

For more than two decades, Tunisia has focused on the rational use of energy and the development of renewable energies [2, 3]. Ambitious energy demand management programs have reduced the rate of growth of energy consumption and substantially lowered energy intensity. In Tunisia, despite the great efforts and works carried out by the Tunisian Company of Electricity and Gas (STEG), several regions remain unconnected to the public electricity network. For example, outside regions are far from cities. This is a major problem for the inhabitants of these places.

In this context, a client wants to realize an autonomous photovoltaic installation for his house which is under construction, located in the city of Msaken, Sousse (Tunisia), in an isolated area of the network of STEG, and will be inhabited by the end of the year 2019. The installation autonomy must be 72 hours in case of bad weather.

Therefore, an energy efficiency expert is contacted in order to determine the technical characteristics of each component of the installation to meet the customer's energy needs and ultimately provide the total price.

This chapter is divided into three sections. In the first, we will determine the energy needs of the customer. Then, through the second chapter, we will detail the steps of sizing the solar system and its components. Finally, we will give the total cost of the installation.

2. Electrical need estimation

Estimating the electrical needs consists of calculating the daily electrical energy consumed by the users. Thus, the electrical needs will be expressed in Wh/day (or kWh/day).

The methodology is as follows [4]:

- First, we have to identify all the electrical devices that will be powered by the autonomous photovoltaic system. For each of these devices, the rated operating power must be identified. So, we can rely on measurements directly on site or the indications on the data sheets/signs of the devices.

- Then, we will estimate the daily use time.

- The electrical power product (in W) by the usage time (in h) will indicate the daily energy consumed (in Wh) of the device. In the electricity field, it is customary to use the W and the Wh as measurement units of the power and the electrical energy, respectively.

Devices	Unit power (W)	Number	Duration of use (h)	Power (W)	Daily energy production (E_c) (kWh/day)
Incandescent lamp	75	5	4	375	1.500
Incandescent lamp	25	2	1	50	0.050
TV LED	210	1	3	210	0.630
Mini fridge	180	1	24	180	4.320
Laptop	150	1	2	150	0.300
Laptop charger	3	2	1	6	0.006
Phone	10	1	5	10	0.050
Modem	4	1	9	4	0.036
Surveillance camera	12	1	24	12	0.288
Washing machine	250	1	1	250	0.25
	Total			1247	7.43

Table 1.
Daily energy consumption.

- Finally, the sum of the calculated daily energies will give an overall assessment of the building electrical needs.

The power needs and daily energy consumption are reported in **Table 1**.

The previous inventory allows us to draw up a balance of power and energy:

Total power: $P = 1247W$.

Daily consumption: $E = 7.43\ \text{kWh/day}$.

3. Evaluation of the optimal PV module orientation and inclination

Latitude and longitude for Msaken: 35°43′45“ North and 10°34’50” East. This city is located in the northern hemisphere [5].

Optimal inclination angle formula (autonomous PV system) is given by PVGIS Software, and it is equal to 30° [6].

In Tunisia, the best orientation for a photovoltaic field is that of the south. Indeed, it allows capturing a maximum of solar radiation throughout a day and a year.

Solar irradiation represents the energy and the quantity of this energy depending on the exposure of the object or the material that receives it. A horizontal surface does not receive the same amount of solar energy as a vertical one. Thus it is necessary to specify the configuration of the receiver.

The radiation varies along the year, and to project the system, it is necessary to choose which irradiance to consider. Thus, in order to calculate the average value of irradiation received by an optimally oriented and inclined surface, we use PVGIS Software (**Figure 1**).

Assessing the available energy in Msaken area from PVGIS software, the following values are obtained for an optimal inclination of 30° with annual irradiation deficit due to shadowing (horizontal) equal to 0% (**Table 2**):

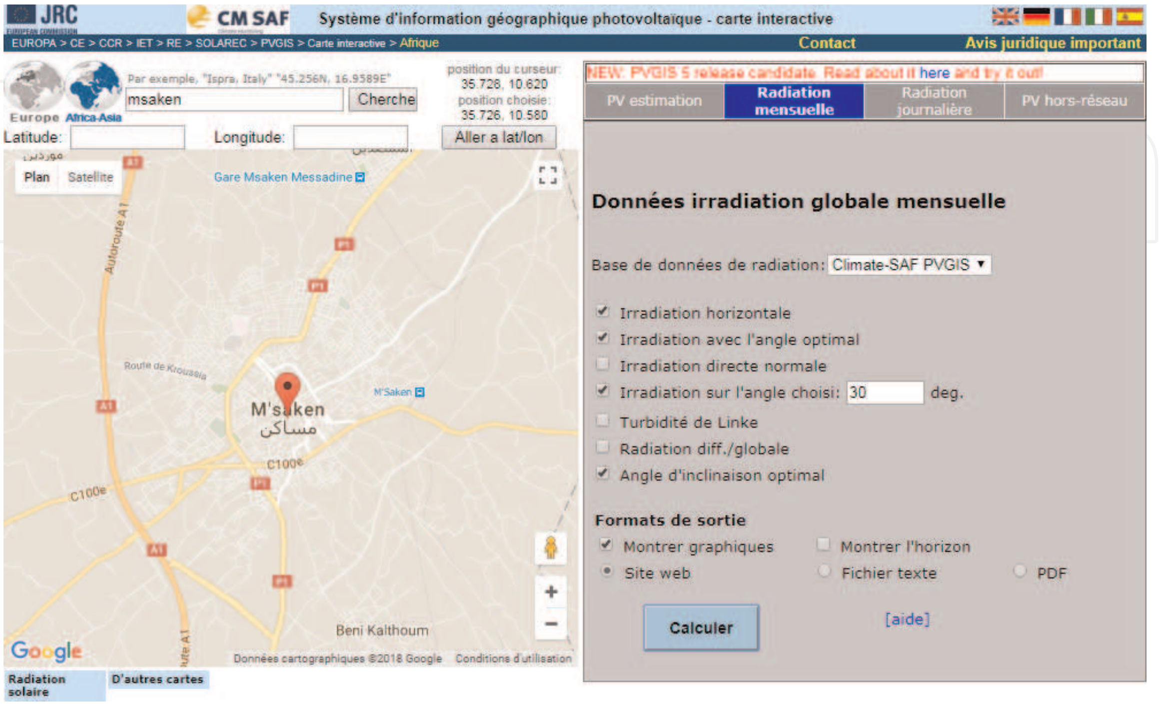

Figure 1.
Map of Msaken with coordinates [6].

Month	H_h	H_{opt}	H(30)	I_{opt}
Jan	2210	3220	3500	57
Feb	3110	4170	4380	50
Mar	4290	5070	5070	38
Apr	5330	5610	5300	23
May	6180	5950	5360	9
Jun	6760	6240	5470	2
Jul	6730	6340	5620	6
Aug	6300	6400	5910	17
Sep	4880	5560	5460	33
Oct	3720	4810	4980	47
Nov	2550	3680	3970	56
Dec	1960	5910	3180	59
Year	4510	5000	4850	30

H_h: irradiation on horizontal plane (Wh/m^2/day); H_{opt}: irradiation on optimally inclined plane (Wh/m^2/day); H(30): irradiation on plane at angle: 30deg. (Wh/m^2/day); I_{opt}: optimal inclination (deg.).

Table 2.
The calculation results using PVGIS software [6].

Total integration Total integration is a mode which the module is considered a roof element. This module plays the role as a cover. As a result, ventilation on the underside is difficult if not impossible.	
Superimposed The superimposed assembly consists of fixing the photovoltaic modules above the cover. This type of installation allows a simple and fast installation of photovoltaic modules without roofing. Air can circulate between the cover and the modules providing better ventilation than full integration.	
On chassis The modules are usually mounted on a flat roof or simply on the ground, this integration mode allows maximum natural ventilation.	

Table 3.
Types of PV panel integration in the building.

Then in Msaken, the average value of irradiation received by an optimally oriented and inclined surface, noted E_i and calculated using PVGIS Software is about 5 $\text{kWh/m}^2/\text{day}$.

4. Integration of PV modules in the building

The house is under construction, so one of three methods (described in **Table 3**) can be used for integrating PV modules [7]:

Consulting the client, he told us that the PV modules will be arranged using superimposed method.

5. Installation production

5.1 Ratio performance (RP)

The ratio performance (RP) makes possible the quantification of the intrinsic losses of the electrical installation. The performance ratio is, therefore, a number ranging between 0 and 1 (or 0 and 100%) [8].

The RP is specific to each installation. Nevertheless, it is possible to estimate the RP value [9]:

- The temperature coefficient of the power KT (P) is similar from one module to another (order of magnitude: −0.4%/°C).
- The voltage drop in the cables is limited to 3%.
- Regulator output is similar from one regulator to another (97% of order of magnitude).
- Battery performance is about 85%.
- The inverter efficiency is similar from one inverter to another (order of magnitude: 95%).
- Other miscellaneous losses are similar from one facility to another (2% order of magnitude).

The only really variable parameters are the integration mode and the presence or absence of a MPPT device. Thus, we can draw up a general summary table of the RP value (**Table 4**):

Ratio performance (RP)	Modules with very little ventilation	Modules with little ventilation	Modules with ventilation	Modules with well ventilation
Without MPPT	0.55	0.60	0.65	0.70
With MPPT	0.60	0.65	0.70	0.75

Table 4.
Value of the ratio performance according to the breakdown of the modules.

In our case, PV modules are superimposed. Therefore, it will be considered that this configuration allows the ventilation. In addition, we choose a regulator equipped with a MPPT device: then, the ratio performance is equal to $RP = 0.7$.

5.2 Peak power determination of the PV field

There is a simple analytical formula to estimate the peak power of the PV field, noted as P_c:

$$P_c = \frac{E_c}{E_i} \times \frac{P_i}{RP} \tag{1}$$

where P_c is the peak power of the photovoltaic field; E_c is the daily electrical energy potentially produced by the photovoltaic system, expressed in kWh/day, in our case $E_c = 7.43 \text{ kWh/day}$; P_i is the illumination power under standard test conditions (STC), expressed in kW/m^2. So $P_i = 1 \text{ kW/m}^2$; E_i is the daily solar irradiation, expressed in $\text{kWh/m}^2\text{/day}$, received by the photovoltaic field, in our case $E_i = 5 \text{ kWh/m}^2\text{/day}$; RP is the performance ratio of the photovoltaic system, in our case $RP = 0.7$.

Then, the peak power of the photovoltaic field P_c is equal to $P_c = 2.123 \text{ kWp}$.

Thus, to ensure customer comfort, we suggest installing a PV array power greater than or equal to 2.123 kWp.

6. PV field dimensioning

Figure 2 shows an autonomous photovoltaic installation schematic.

6.1 Number of solar modules and characteristics

Following the electrical requirement evaluation and the solar field, here, it is possible to size the photovoltaic field. This operation consists firstly to calculate the installation module number (Eq. (2)) [10]:

$$N = \frac{P_c}{P_r} \tag{2}$$

where N is the modules number; P_c is the peak power of the photovoltaic field; in our case P_c should be greater than or equal to 2.123 kWp; and P_r is the rated power of a PV module.

In the international market, there are several photovoltaic solar module technologies, as described in **Figure 3**:

Due to reduced manufacturing costs and maturity of the technology, crystalline modules are expected to maintain a market share of up to 80% until at least 2017 [8]. Both monocrystalline and multi-crystalline module prices have decreased considerably in the last years.

In this study, the PV module was selected due to few reasons that are worth to mention: its performance, warranty, and high efficiency. Thus, the "**Polycrystalline solar panel IBC PolySol 260W (265Wc)**" is chosen, so $P_r = 260W$. The datasheet of this module is given in [11].

Then, the installation modules number is equal to $N = 10$.

To size the solar controller, inverter, cables, etc., the following PV characteristic parameters in the Standard Test Conditions (STC) will be used later. We remember that the Standard Test Conditions (STC) are [8]:

- Cell temperature: $\theta = 25° = T = 298.16\ \text{K}$
- Incident radiation: $G = 1000\ \text{W/m}^2$
- Spectral distribution of solar radiation: $AM1.5$

The electrical characteristics of the PV module in the STC:

- Rated power: $P_{mpp} = 260\ \text{W}$.
- Open-circuit voltage: $V_{oc} = 38.07\ \text{V}$.

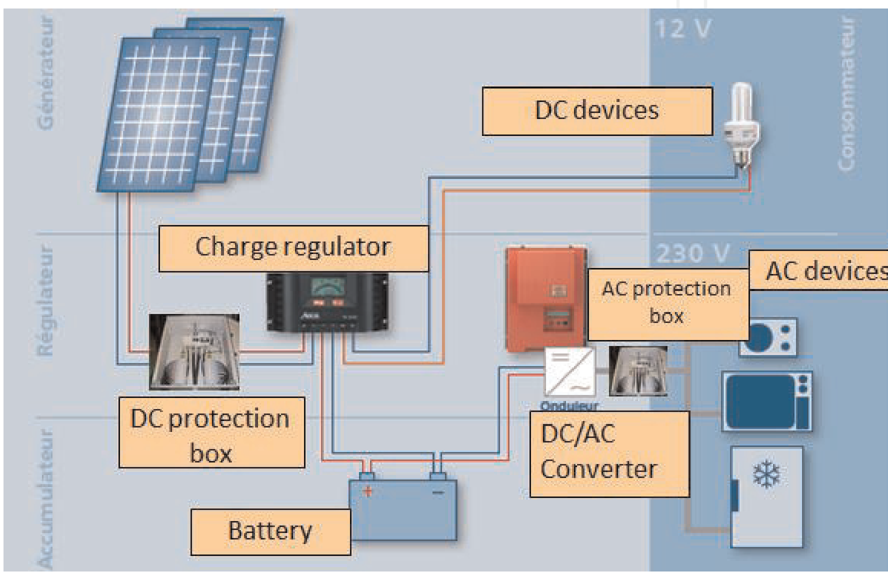

Figure 2.
Schematic of autonomous photovoltaic installation.

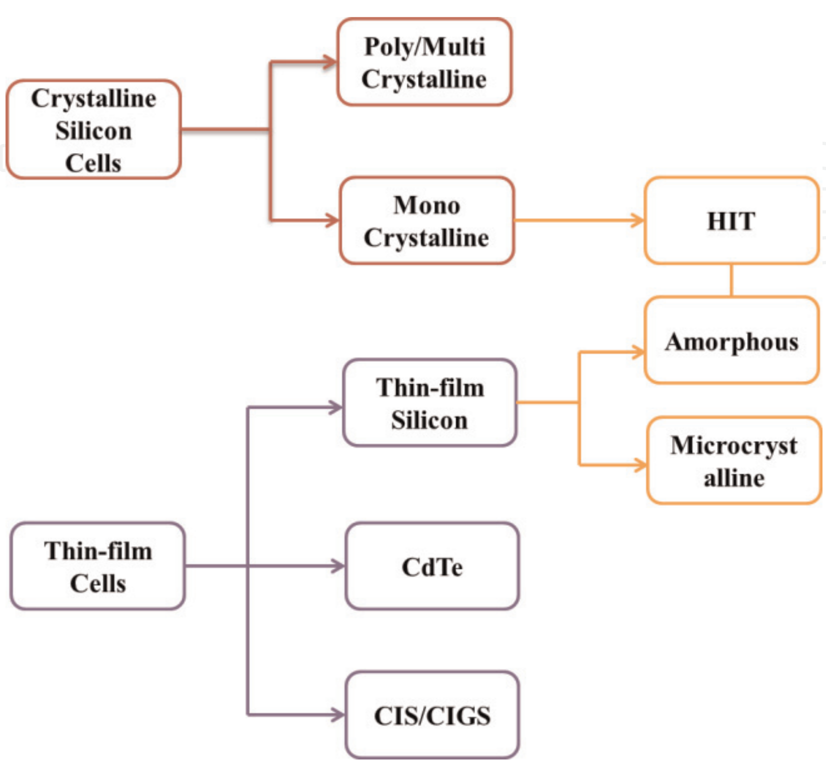

Figure 3.
PV technology classes [8].

- Maximum voltage: $V_{mpp} = 30.57\ \text{V}$.
- Short circuit current: $I_{sc} = 9.19\ \text{A}$.
- Maximum current: $I_{mpp} = 8.56\ \text{A}$
- Efficiency: $\eta = 15.5\%$

The thermal characteristics of the PV module in the STC:

- Temperature coefficient: $T_{cP_{mpp}} = -0.42\%/\text{K}$.
- Temperature coefficient: $T_{cV_{oc}} = -0.315\%/\text{K}$.
- Temperature coefficient: $T_{cI_{sc}} = 0.04\%/\text{K}$.

6.2 Dimensioning of the solar regulator

The solar regulator is a device that is positioned between the solar modules and the batteries, also known as a charge controller. It is the guarantor of the energy level stored in the batteries [12].

Its main missions are:

- To convert the output voltage of the solar panel into voltage adapted to the charge of the batteries
- To protect the batteries by controlling their charge level. Once the batteries are full, the regulator will cut off the park recharge. At the same time, it will stop the power consumption of connected devices if the battery charge level falls below a certain safety threshold (deep discharge limit)
- To avoid reverse currents and thus protect the panel

The solar regulator is therefore an indispensable control component for the photovoltaic system. It protects the panels and batteries, thus, ensuring the system durability.

Depending on the technologies used, current charge regulators have very good yields, ranging from 85 to 98%.

On the market, there are two technologies of charge controller:

- ***PWM (pulse width modulation):*** This technology makes it possible to modify the voltage of the signal coming from the panels to obtain a signal with a voltage adapted to the charge of the batteries.
- ***Maximum power point tracking (MPPT):*** This technology, which is specific to solar charge controllers, consists of scanning the voltage range across the panel and determining the voltage for which the power produced will be optimal. This allows optimizing the efficiency of the solar panels; the gain in yield is around 10%. However, regulators equipped with MPPT technology are more expensive than conventional regulators.

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For most installations, a PWM regulator will be suitable. For large installations with multiple panels, MPPT regulators will be preferred. In our case, we use a MPPT regulator.

The solar regulator dimensioning is carried out according to three major parameters:

- Current compatibility
- Voltage compatibility
- Power compatibility

In this study, we choose **Victron energy BlueSolar charge MPPT 150/100** as a solar regulator. Thus, we will have to check the compatibility of this regulator with this installation based on its datasheet [13] (**Figure 4**):

- ***Current compatibility:*** The PV module short circuit current is equal to $I_{sc} = 9.19\ \ \text{A}$ under the STC conditions. The safety factor 1.25 should be applied to the I_{sc}, so, $1.25 \times 9.19 = 11.48\ \ \text{A}$.

Thus, in order to not exceed the regulator maximum current 30 A, the maximum number of PV strings to be paralleled is $100/11.48 = 8.7$. Therefore, with this regulator, we will be able to wire 5 strings in parallel.

- ***Voltage compatibility:*** If we use 5 strings in parallel, then each string will consist of 2 modules in series. In this case, the open circuit voltage of the string V_{ocT} is $38.07\ \ \text{V} \times 2 = 76.14\ \ \text{V}$under STC conditions.

A coefficient of 20% is added to this value to account for the ambient temperature influence, $76.14 \times 1.2 = 91.368\ \ \text{V}$. According to the regulator datasheet, the regulator input voltage must not exceed 150 V. Therefore, the use of 2 modules in series validates this condition.

- ***Power compatibility:*** The photovoltaic module rated power (8 modules) is equal to: $P_{mppT(\text{modules})} = 10 \times P_{mpp} = 10 \times 260\ \ \text{W} = 2600\ \ \text{W}$. We identify,

Contrôleur de charge BlueSolar	MPPT 150/45	MPPT 150/60	MPPT 150/70	MPPT 150/85	MPPT 150/100
Tension de la batterie	12 / 24 /48 V Sélection automatique (outil logiciel nécessaire pour sélectionner 36 V)				
Courant de charge nominal	45 A	60 A	70 A	85 A	100 A
Puissance maximale PV, 12 V 1a, b)	650 W	860 W	1000 W	1200 W	1450 W
Puissance maximale PV, 24V 1a, b)	1300 W	1720 W	2000 W	2400 W	2900 W
Puissance maximale PV, 48V 1a, b)	2600 W	3440 W	4000 W	4900 W	5800 W
Courant maxi. de court-circuit PV 2)	50A	50A	50A	70A	70A
Tension PV maximale de circuit ouvert	150 V maximum absolu dans les conditions les plus froides 145 V maximum pour le démarrage et le fonctionnement				
Efficacité maximale	98 %				
Autoconsommation	10 mA				
Tension de charge « d'absorption »	Configuration par défaut : 14,4 / 28,8 / 43,2 / 57,6 V (réglable)				
Tension de charge « Float »	Configuration par défaut : 13,8 / 27,6 / 41,4 / 55,2 V (réglable)				
Algorithme de charge	adaptative à étapes multiples				
Compensation de température	-16 mV / -32 mV / -68 mV / °C				
Protection	Polarité inversée de la batterie (fusible, non accessible par l'utilisateur) Polarité inversée PV / Court-circuit de sortie / Surchauffe				
Température d'exploitation	-30 à +60°C (puissance nominale en sortie jusqu'à 40°C)				
Humidité	95 %, sans condensation				
Port de communication de données et allumage/arrêt à distance	VE.Direct (Consultez notre livre blanc concernant les communications de données qui se trouve sur notre site Web)				
Fonctionnement en parallèle	Oui (pas synchronisé)				

Figure 4.
Victron energy 'BlueSolar charge MPPT 150/100' datasheet.

in **Figure 4**, that the rated power of the MPPT regulator is $P_{mppT(24\ \text{V})} = 2900\ \text{W} \rightarrow P_{mppT(regulator)} \succ P_{mppT(\text{modules})}$.

Figure 5 shows the photovoltaic module association (5 strings, each string is composed by 2 modules in series).

6.3 Battery dimensioning

The battery capacity must be able to cover all the electrical needs (E_c).

When we size the batteries' capacity, we apply the following dimensioning rule [12, 14]:

- Over the duration of the reserve autonomy (*NJ*)
- Without any solar energy contribution
- Without ever exceeding the maximum depth of discharge (*PD*)

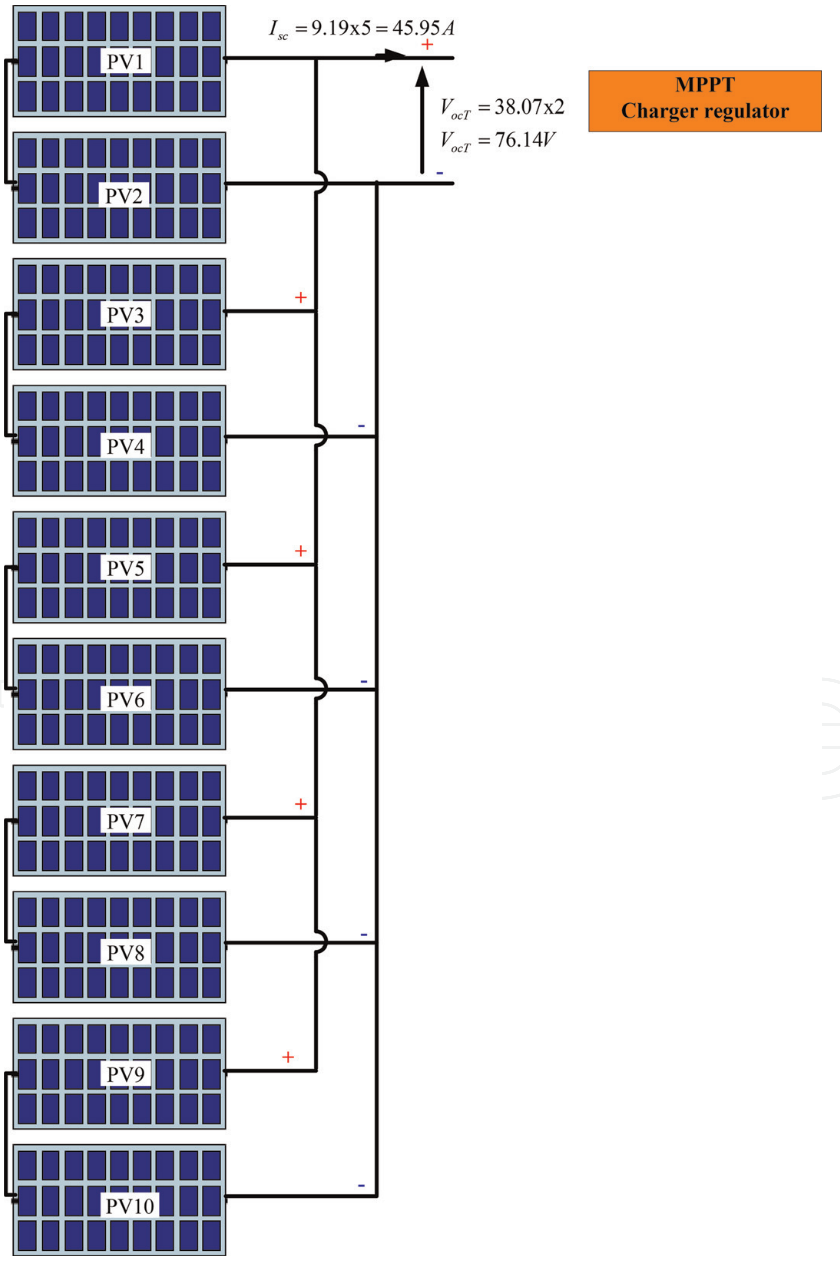

Figure 5.
Photovoltaic modules association.

6.3.1 Reserve autonomy

We define the notion of reserve autonomy which corresponds to the desired day's number during which the batteries are able to supply, without any additional contribution from the photovoltaic field, all the electrical needs. We note *NJ* the day's number of reserve autonomy. The choice of *NJ* depends on the climatic conditions of the site and more particularly the number of consecutive days without sunshine. Usually, in Tunisia, *NJ* is fixed on 3 days.

6.3.2 Maximum depth of discharge

Repetition of deep discharges of the batteries should be avoided. Indeed, a too deep discharge tends to produce lead sulfate which agglomerates at the level of the electrodes. This phenomenon develops during the charging/discharging cycles and amplifies all the more as the discharge is deep. Eventually, an insulating layer of

EnerSys ASSAD INDUSTRIAL — FICHE TECHNIQUE DE LA BATTERIE SDV200

Marque		ENERSYS-ASSAD
Type		SDV200
Tension nominale (V)		12
Courant nominal (A)		0,1 C
Nature de la batterie		06 éléments de 02 V connectés en série dans un coffret métallique
Technologie		Tubulaire
Capacité à 25°C (1,8 Vpc)	*C20 (Ah)*	200
	C100 (Ah)	230
Longueur hors tout (mm)		320
Largeur hors tout (mm)		203
Hauteur hors tout (mm)		481
Bac		Transparent
Type borne		Plate en L
Marquage borne	*Positive*	Signe +
	Négative	Signe -
Plaque positive	*Type*	Tubulaire
	Epaisseur (mm)	9,5
	Nbre de tubes/plaque	19
	Nbre de plaques/élément	2
Plaque négative	*Type*	Plane
	Epaisseur (mm)	2,5 et 04
	Nbre de plaques/élément	02 et 01
Pureté du plomb		99,99%
Taux d'antimoine		6,5% pour les plaques positives et 5% pour les plaques négatives
Type séparateur		Microporeux à faible résistance mécanique
Etiquettes		Etiquette face SDV200
		Etiquette de niveau sur les côtés
Electrolyte		Acide sulfurique H_2SO_4
Volume d'électrolyte (L)		16
Densité de l'électrolyte à 25°C (g.cm^{-3})		1,240
Poids de la batterie avec électrolyte (Kg)		68
Température nominale de service (°C)		25
Paletisation	*Type palette*	Europalette
	Nombre/palette	20

Figure 6.
SOLAR ASSAD battery datasheet.

lead sulfate appears and prevents chemical reactions from occurring. Then, the accumulator becomes unusable, or at least it is able to fall dramatically.

We note *PD* the maximum discharge depth of a battery.

In this study, we chose **"SOLAR ASSAD" as solar battery, 12 V, capacity** $C_b = 230$ Ah. Thus, we will have to check the necessary batteries number and serial or parallel association based on its datasheet [15] (**Figure 6**).

The battery capacity C_T is calculated using the following expression:

$$C_T(Ah) = (E_c \times \mathrm{NJ})/(PD \times \mathrm{U_T}) \tag{3}$$

where NJ is the number of days with insufficient sunshine (in our case $NJ = 3$ days); E_c is the daily electrical energy potentially produced by the photovoltaic system expressed in kWh/day, in our case $E_c = 7.43$ kWh/day; $\mathrm{U_T}$ is the voltage in volt under which the battery is installed (12 V, 24 V, 48 V); in our case, 2 battery chains will be installed ➔ $\mathrm{U_T} = 24$ V; and *PD* is the maximum discharge depth of the batteries. In practice, a maximum depth of discharge of 70% is chosen.

Then, the battery capacity C_T is equal to $C_T = 1327$ Ah.

When we size the capacity of the batteries, we can calculate the battery number N_b to be paralleled:

$$N_b = \frac{C_T}{C_b} \tag{4}$$

where C_T is the batteries capacity, $C_T = 1327Ah$; and C_b is the battery capacity, according to **Figure 5**, $C_b = 230$ Ah.

Then, the battery number to be paralleled is equal to $N_b = 6$.

So the total battery number is equal to $N_{bT} = 12$: 2 battery chains (to obtain 24 V) on 6 parallel (to obtain capacity of 1327 Ah) (**Figure 7**).

6.4 Autonomous or off-grid inverter dimensioning

The off-grid inverter is the essential electronic device that converts DC low voltage from a battery or other power source to 100–120 V or 220–240 V AC voltage. Off-grid inverter produces a voltage wave, with an independent frequency from the grid. Not only does the inverter convert DC to AC power, but it may also regulate the PV system if correctly dimensioned according to the battery voltage levels [12, 14].

Table 5 summarizes the recommended international standards for inverters intended for photovoltaic applications. Each country adapts them to the specificities of national functioning and regulation. Manufacturers are therefore slightly modifying the final design of their products to meet the requirements of each country [16].

In our case, the solar inverter is used to convert a 24 V battery DC voltage into 230 V AC voltage identical to that of the building electricity grid.

The off-grid inverter choice is based on three criteria:

- ***Part DC:*** On the DC side, the inverter must be adapted to the system voltage imposed by the battery bank. In our case, the battery output voltage is equal to 24 V.

- ***Part AC:*** On the AC side, the inverter will impose an output signal adapted to the devices it feeds. In our case, the frequency voltage is equal to 50 Hz, and the effective voltage value is equal to 230 V.

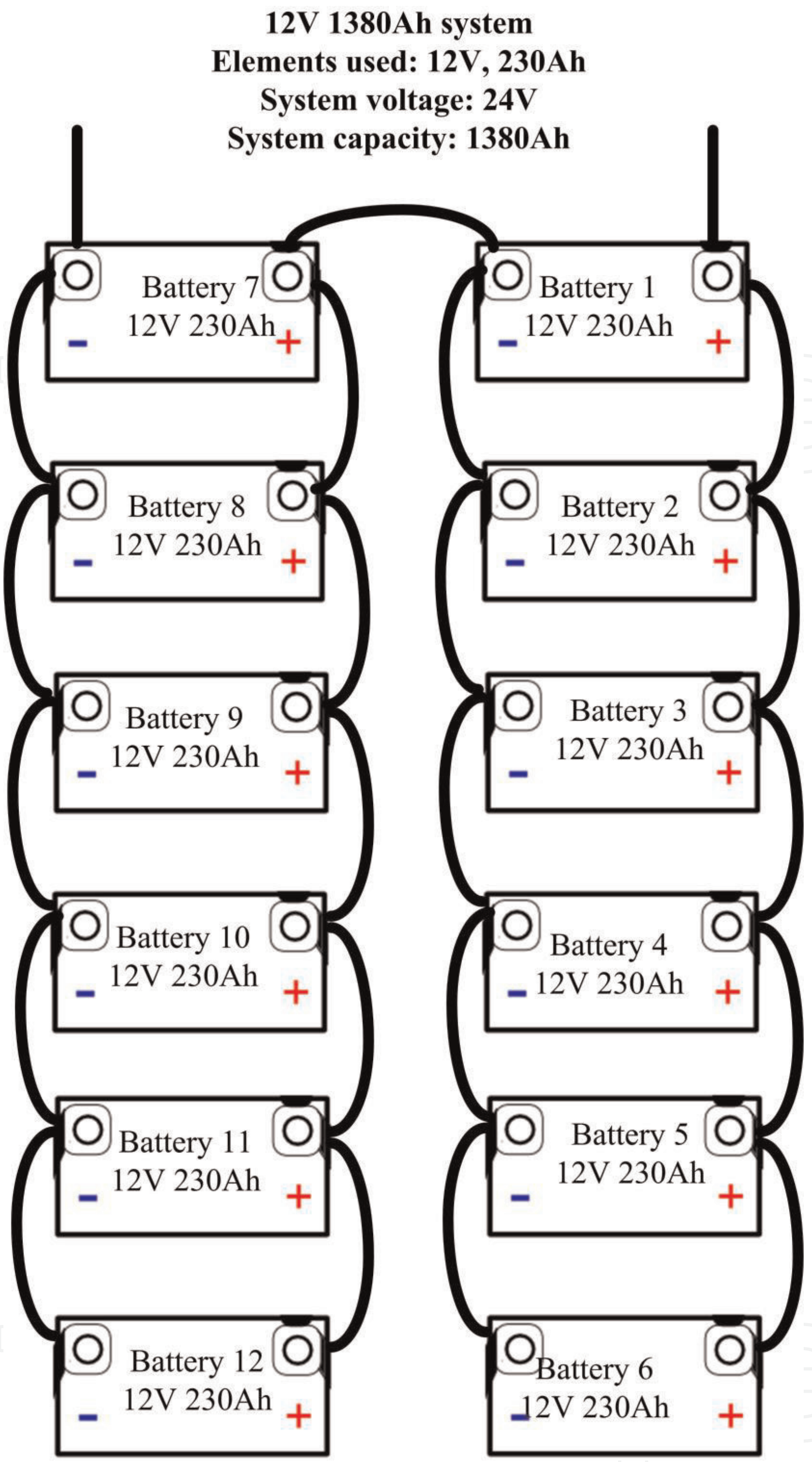

Figure 7.
Batteries association.

- ***Rated power:*** The inverter rated power should cover the sum of the all user powers. A sizing margin of 20–30% is recommended to ensure that the inverter operates at an ambient temperature of 25°C. In this study, the user powers are equal to 2123 Wp, so the inverter rated power should be greater than $2123 \times 1.3 = 2760$ W.

In this study, we chose **P3000–482 Off-grid DC to AC pure sine wave 24 V–220 V solar inverter** (**Figure 8**). Thus, we will have to check the compatibility of this inverter with this installation based on its datasheet [17] (**Figure 9**):

In the next study, it is necessary to:

- Determine the cables sections that cause the least possible drop in voltage between the modules and battery-regulator-inverter and also between the inverter and loads.

- Dimension the protection components such as fuses, switch, etc.

6.5 Dimensioning of the DC and AC cable

6.5.1 DC cable

The solar cables must comply with several regulatory constraints summarized in the guide of the ETU C32–502 [18, 19].

These are specific cables subject to particular operating conditions. They must be designed to operate with ambient temperatures between −35 and +70°C.

Thus, it is expected that:

- The maximum permissible core temperature at steady state is 90°C.

	CODES AND STANDARDS	SCOPE AND CONTENT OF THE STANDARD
Grid connected	IEC 60364-7-712, IEC 61727, IEC 61683, IEC 62093, IEC 62116, IEC 62446, UL 1741	Installations of buildings Utility interface and measuring efficiency Interconnected PV inverters System documentation, commissioning tests, and inspection Use in independent power systems
Off grid	IEC 62509, IEC 61194 IEC 61702, IEC/PAS 62111, IEEE Standard 1526, IEC 62124	Battery charge controllers Stand-alone systems Rating of direct-coupled pumping systems Specifications for rural decentralized electrification
Rural systems	IEC/TS 62257	Small renewable energy and hybrid systems Protection against electrical hazards Selection of generator sets and batteries Micropower systems and microgrids Household lighting equipment
Monitoring	IEC 61724, IEC 61850-7, IEC 60870	Measurement, data exchange, and analysis Communication networks and systems for power utility automation Distributed energy resources and logical nodes
Electromagnetic compatibility (EMC)/ electromagnetic interference emissions	EN 61000, FCC Part 15	European Union EMC directive for residential, commercial, light industrial, and industrial facilities U.S. EMC directive for residential, commercial, light industrial, and industrial facilities

Table 5.
A summary of typical international codes and standards for PV applications.

Figure 8.
P3000-482 Off-grid DC to AC pure sine wave 24–220 V solar inverter.

Product Details

Product Description

Output power	3000W					
Peak power	6000W					
Input voltage	DC12V	DC24V	DC48V	DC12V	DC24V	DC48V
Input voltage range	9.55-15.5V	19.8-30.2V	40.2-60.4V	9.55-15.5V	19.8-30.V	40-60.4V
Output voltage	100VAC or 110VAC or 120VAC ±5%			220VAC or 230VAC or 240VAC ±5%		
No-loadcurrent less-than	2A	0.9A	0.5A	2A	0.9A	0.5A
Output frequency	50HZ±1HZ or 60HZ±1HZ					
Output wave	Pure sine wave/Pure sine wave					
USB	5V 1000MA/2000MA					
Max. working efficiency	93.80%					
Operating temperature range	-10°- +50°					
Storage temperature	-30°- +70°					
Humidity	Max. 90%, non-condensing					
Warranty	One year					
Dimensions(W*H*D)	405*200*154mm					
Package size(W*H*D)	510*285*210mm					
Starting	bipolar soft start					
Low voltage alarm	10V±0.5V	21V±0.5V	42V±1V	10V±0.5V	21V±0.5V	42V±1V
Low voltage shut down	9.5±0.5V	20V±0.5V	40V±1V	9.5±0.5V	20V±0.5V	40V±1V
Low voltage recovery	13±0.5V	24V±0.5V	48V±1V	13±0.5V	24V±0.5V	48V±1V
Over voltage shu t down	15.5±0.5V	31V±0.5V	61V±1V	15.5±0.5V	31V±0.5V	61V±1V
Over voltage recovery	14.8±0.5V	29V±0.5V	59V±1V	14.8±0.5V	29V±0.5V	59V±1V
LED Lights	Blue indicator light (inverter output, normal operation); the red indicator flashes (under / over voltage, overload, temperature, short circuit)					
Protection	Battery over under / over voltage, overload, temperature, AC short circuit protection (positive and negative polarity protection)					
Fuse	DC short circuit protection					
Display	LED high-definition digital display					

Figure 9.
Solar inverter datasheet [17].

- The maximum permissible core temperature in the overload condition is 120°C.

The cable section choice of the installation is made according to two major criteria:

- Tolerated voltage drop
- The maximum current allowed in the cables

6.5.2 Determination of the conductor section between the panels and the regulator

The conductors section between the panels and the regulator can be calculated using (Eq. (5)):

$$S = \frac{\rho \times L}{R_{\max}} \tag{5}$$

where

1. ρ is the substance conductivity:

   Copper: $\rho_{copper} = 1.7 \times 10^{-8} \Omega\ \text{m}$

   Aluminum: $\rho_{\text{Aluminum}} = 2.8 \times 10^{-8}\ \ \Omega.\text{m}$

Both values are calculated at 27°C. At higher temperatures, the material resistance increases and the conductivity decreases.

In our case, the used conductors are copper.

2. The distance between the solar PV panels and the regulator is $L = 16\ \text{m}$ (outgoing and incoming cable).

3. The UTE C15-712 guide for PV installations indicates that the DC voltage drop must be less than 3% and ideally 1%. In our case, it's fixed at σ=1%. Then, at a current of $I_{scT} = 9.19 \times 5 = 45.95\ \text{A}$, the maximum resistance of the cable can be calculated using (Eq. (6)):

$$R_{\max} = \frac{V_{ocT} \times \sigma}{I_{scT}} = \frac{38.07 \times 2 \times 0.01}{45.95} \Rightarrow R_{\max} = 0.0165\ \Omega \tag{6}$$

Then, the conductor section is equal to:

$$S = \frac{\rho \times \text{L}}{R_{\max}} = \frac{1.7 \times 10^{-8} \times 16}{0.0165} = 16.48\ \text{mm}^2$$

A cable cross-section of 16 mm^2 is sufficient to maintain the loss below 1%.

6.5.3 Determination of the conductor section between the regulator and the batteries

Calculating the output current of a panels at its rated power:

$$I = \frac{P_c}{U_T} = \frac{2600}{24} \Rightarrow I = 108.33\ \text{A} \tag{7}$$

The distance between the regulator and the batteries is $L = 3\ \text{m}$ (outgoing and incoming cable).

Then the conductor section is equal to:

$$S = \frac{\rho \times \text{L} \times \text{I}}{\sigma \times U_T} = \frac{1.7 \times 10^{-8} \times 3 \times 108.33}{0.01 \times 24} = 23\ \text{mm}^2$$

A cable cross-section of 25 mm^2 is sufficient to maintain the loss below 1%.

6.5.4 AC cable

The AC cable section formula is as follows:

$$S = \frac{(\rho \times b \times L \times I_b)}{(\varepsilon \times V_n)} \tag{8}$$

where S is the conductors section (m^2); b is the coefficient which is 1 in three-phase and 2 in single-phase; V_n is the nominal voltage: $V_n = 230\ \text{V}$ in single-phase or $V_n = 380\ \text{V}$ in three-phase; I_b is the maximum current; $I_b = \frac{P_c}{V_n} = \frac{2123}{230} \Rightarrow I = 9.23\ \text{A}$; ρ is the material resistivity (Ω m); in our case, the used conductors are copper; and L is the conductor length (m). The distance between the inverter and the loads is 30 m; ε is the AC voltage drop; and in our case, it's fixed at 1%.

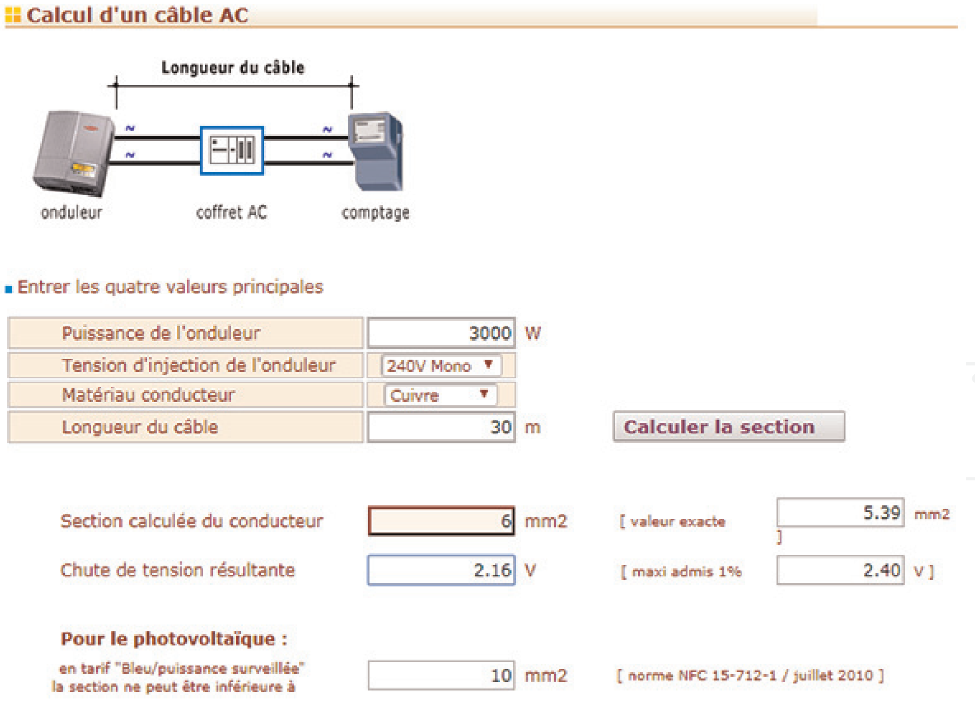

Figure 10.
The calculation results using "Sigma Tec" online calculator.

Then,

$$S = \frac{(1.7 \times 10^{-8} \times 2 \times 30 \times 9.23)}{(0.01 \times 230)} = 4.09 \ \text{mm}^2$$

AC cable cross-section of 6 mm^2 is sufficient to maintain the loss below 1%.

To validate this calculation, we can use "SigmaTec" which is an online calculator of cable sections [20]. **Figure 10** shows an example of calculation.

6.6 Dimensioning of DC protection components

Every PV installation requires an AC protection box and a DC protection box. These AC/DC electrical boxes protect the photovoltaic system on the DC part as well as on the AC part.

The protection component characteristics will be chosen based on the following standards and guides [18, 19]:

Standards:

1. ***IEC 60364–7-712:*** Rules for installations and locations special—photovoltaic power supplies

2. ***Solar (PV) NF C 15–100:*** Low-voltage electrical installations and regulations

Guides:

1. ***Guide UTE C 15–712-1:*** Practical guide, installation of solar photovoltaic (PV) generators.

2. ***UTEC guide 61,740–51 (2009):*** It concerns the tests of surge arresters for DC application only. These tests are based on AC surge arrester standards but differentiate for "end of life tests."

6.6.1 DC fuses

According to the UTE C15–712-1, the presence of fuse is always obligatory for each of the photovoltaic chains, in order to protect the photovoltaic modules and the cables of the currents being able to flow from the park of batteries toward the panels (in particular in the dark period when the battery is able to discharge through the photovoltaic field), in the case where the regulator's nonreturn device is inoperative.

In our case, we need five fuses on each of the two extremities of PV panels (**Figure 11**).

6.6.1.1 Calibration of fuses

On the DC side, overcurrent occurs as back current. Above certain intensity, the return currents can damage the photovoltaic modules.

In general, photovoltaic modules can support a maximum return current that depends on the number of branches in parallel presented in **Table 6**:

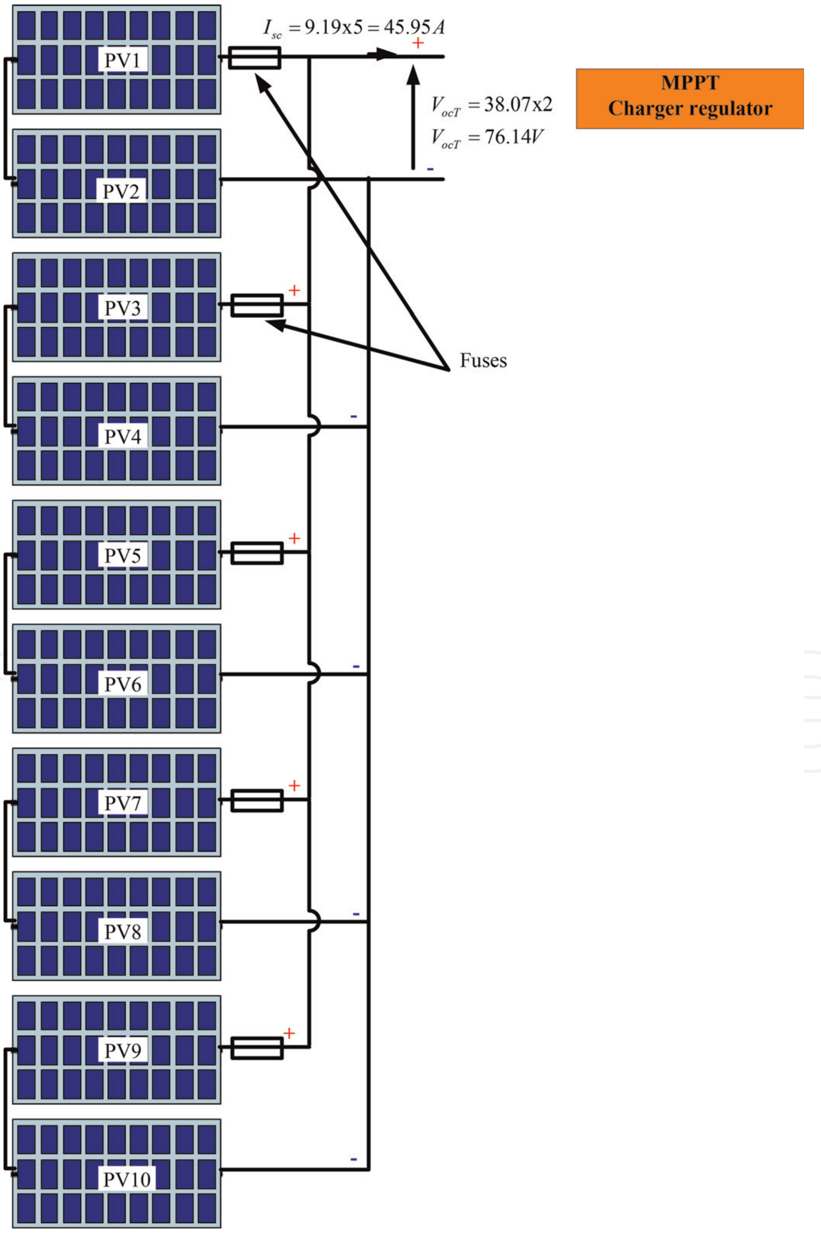

Figure 11.
Fuses location in the PV system.

Number of parallel chain	Maximum value of the return current in a chain
$N_c = 1$	0
$N_c = 2$	$1.25 \times I_{sc}$
$N_c = 3$	$2 \times 1.25 \times I_{sc}$
$N_c \geq 1$	$(N_c - 1) \times 1.25 \times I_{sc}$

Table 6.
Fuses choice.

The use of fuses also allows the shutdown of a single photovoltaic chain in the event of maintenance activities, thus avoiding the shutdown of the entire installation.

The rated current I_N of the fuses must, in accordance with the guide of the UTE C15 712-1, comply with the following condition, (Eq. (9)):

$$1.1 \times I_{sc,\max\,1.25 \times I_{sc}} \leq I_N \leq I_{RM\,2 \times I_{sc}} \tag{9}$$

with I_N being the rated current of the fuse or rated current of the fuse and I_{RM} being the maximum return current that can support a module without being damaged

$$\begin{aligned} & 1.1 \times 1.25 \times I_{sc} \leq I_N \leq 2 \times I_{sc} \\ \text{Then,}\ & 1.1 \times 1.25 \times 9.19 \leq I_N \leq 2 \times 9.19 \\ & 12.6362\text{A} \leq I_N \leq 18.38\ \ \text{A} \end{aligned}$$

In addition, the fuses used must have the following characteristics:

- Being specific to a DC application
- "Fast-melting"
- Being independent of the flow direction
- Having the gPV mark

By consulting the marketed product catalogs, the choice was set for gPV fuses of 15 A caliber and 50 kA breaking capacities. **Table 7** shows the fuse characteristics [21]:

6.6.2 DC lightning protection

A lightning protection is required to protect the installations from high transient voltages. Placed between the fuse of the panels and the batteries, it will be

Number	2
Rated current	15 A
Rated voltage	DC 1000 V
Breaking capacity	50 kA

Table 7.
Fuse characteristics.

connected to the ground in order to evacuate the lightning potentially attracted by the metallic structure of the modules (itself connected to the ground) [22].

Lightning protection can contain different internal components such as spark gaps or clipping diodes. These components are intended to quickly limit the voltages appearing at their terminals.

The choice between type 1 and type 2 lightning protections is determined from **Table 8**.

The keraunic level of a site NK defines the number of thunderstorms per year in a given place. It is determined by the map given by the weather Tunisia [23].

The Sousse keraunic level equals to 47, so in our case, $NK \geq 25$; and so, the type of surge arrester is type 2.

- The recommended minimum discharge current I_n is 5 kA. A higher value will give a longer life.

- The voltage U_c of a lightning protection must be greater than or equal to $1.2 \times V_{oc}$ of PV generator; we obtain $U_c \geq 1.2 \times 38.07 = 45.68$ V.

Table 9 shows the following lightning protection characteristics.

6.6.3 DC switch disconnector

An electrical distribution from solar energy requires the same protections as for a conventional network. However, the DC side protections are special because direct current is difficult to interrupt if an arc occurs.

In a photovoltaic installation, it is essential to be able to cut off the power, for example, to carry out maintenance operations.

The switch disconnector choice must take into account the following criteria:

$$I_n \geq 5 \times 1.25 \times I_{sc} \Rightarrow I_n \geq 57.43 \text{ A}$$
$$U_e \geq 2 \times \text{V}_{oc} \Rightarrow U_e \geq 76.14 \text{ V}$$

where I_n is the rated current of the switch disconnector (A) and U_e is the rated voltage of the switch disconnector (V).

Installation characteristics	***NK* ≤ 25**		***NK* ≥ 25**	
	DC side	**AC side**	**DC side**	**AC side**
Building or structure equipped with a lightning rod	Type 2	Type 1	Type 2	Type 1
Medium voltage supply by a line wholly or partly overhead	Type 2	Type 2	Type 2	Type 2
Medium voltage supply via a completely underground line	Type 2	Type 2	Type 2	Type 2

Table 8.
Lightning protection type choice [23].

Type	2
Rated voltage	DC 1000 V
Nominal discharge current In (8/20) μs	15 kA
Maximum discharge current I total (8/20) μs	20 kA

Table 9.
Lightning protection characteristic.

Rated voltage	230/400VAC-50 Hz
Rated current	15 A

Table 10.
Switch disconnector characteristic.

6.7 Dimensioning of AC protection components

6.7.1 AC switch disconnector

The voltage at the inverter output is 230 V. In fact, the disconnector voltage must be better than:

$$V_e \geq 230 \times 1.14 = 262.2 \text{ V}$$

The inverter output current is equal to 10A. So the disconnector current is given by:

$$I_n \geq 1.25 \times 10 = 12.5 \text{ A}$$

Table 10 shows the characteristics of the switch disconnector.

6.7.2 Differential circuit breaker

The electrical installation is generally considered the occurrence seat of abnormally high currents such as short circuit, overload, and indirect contacts. To guard against the pervious defects, it is preferable to install a differential circuit breaker to cut the installation if necessary. On the AC side of a photovoltaic installation, a differential magnetothermic circuit breaker upstream of each inverter must be installed.

6.7.3 AC lightning protection

On the AC side of a photovoltaic installation, we will install a lightning protection in order to protect the entire installation.

7. Results and discussion

This study throws light on the following points:

1. In Msaken, the solar irradiation varies between a minimum of 3.22 kWh/m^2/day and a maximum of 6.4 kWh/m^2/day, while mean value remained as 5 kWh/m^2/day.

2. The energy need of the customer was identified at 7.43 kWh/day which corresponds to a photovoltaic field peak power P_c equal to $P_c = 2.123$ kWp.

3. The proposed solution is to install 10 PV modules of total power 2600 W, while the necessary power is 2123Wp. Thus, the customer can supply another electrical device without the need to modify the PV installation.

4. It is recommended to improve the energy efficiency of the building by studying the characteristics of each load and by proposing to the customer to replace the existing loads by others that are more economic.

Components	Quantity	Unit price (Euro)	Total price (Euro)
Solar panel polycrystalline IBC PolySol 260 W	10	253	2530
Victron energy e BlueSolar charge MPPT 150/100	1	816	816
Solar battery ASSAD	12	202,617	2431,404
P3000-482 Off-grid DC to AC pure sine wave 24–220 V	1	305	305
Differential circuit breaker	1	26	26
AC/DC lightning protection	2	88.96	177.92
DC fuses	5	12	72
AC switch disconnector	1	36	36
DC switch disconnector	1	170	170
DC cables 25 mm^2	3 m	9.9	29.7
DC cables 16 mm^2	16 m	2.6	41.6
AC cables 6 mm^2	30 m	1.32	39.6
Structure	5	30	150
Maintenance and operational costs (Euro/year)			31.5
Total			6856.724

Table 11.
PV field installation cost.

7.1 Cost analysis

The PV field installation cost is reported in **Table 11**.

8. Conclusion and prospects

The objective of this chapter was to design and present a photovoltaic system, in the form of an autonomous power supply system for a future house located in an isolated area in Msaken, Sousse (Tunisia). An energy need analysis of the customer was carried out in order to properly size the various components of the installation.

The autonomous system presented in this chapter leads to a continuous lighting supply of the load for 72 hours. In comparison, a system connected to the network in Tunisia would lead to occasional power outages, affecting the entire installation.

To obtain a robust solar system, the photovoltaic panels must be supplemented by a charge controller, a group of batteries, and an inverter. The recommended panel assembly consists of 10 polycrystalline 260 W photovoltaic modules. The installation must be installed at an angle of 30° south. A charge controller regulates the charge of 12 batteries “SOLAR ASSAD” of 230 Ah. An inverter is used to supply loads with alternating current. The total investment cost of the system is 6856.724Euro.

Although the results obtained in the calculations can be considered valid, some improvements can be made to the calculation method to obtain more accurate results. Thus, as short-term prospects, it will be necessary to:

- Obtain more accurate meteorological data for optimized sizing of plant components.
- Reconfigure the PV modules taking into account the optimal spacing between the rows, and optimize the shading losses.
- Validate the sizing performed using specific software such as PVsyst and Archelios™.
- Study in more detail the future requirements of the customer such as external lighting systems with auxiliary energy saving and efficiency systems such as LEDs, voltage stabilizers, etc., and calculate whether the PV system designed meets these requirements.
- Conduct a more in-depth study on the costs associated with the PV installation analyzed. Try to obtain the cost of the components/services of a photovoltaic project located in Tunisia.
- Include an environmental analysis of the PV project.
- Try to apply the calculation method developed with other photovoltaic modules, regulators, batteries, and inverters, with a different tracking system or located on another site, and check if the results are consistent with the results previously obtained.

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Conflict of interest

The authors declare no conflict of interest.

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