SISIFO

An open webservice for the simulation of PV systems

User manual

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1 Introduction

1-1 Overview

This manual describes the characteristics of an open-source simulation toolbox of PV systems in general and PV irrigation in particular, called "SISIFO". The work of development of the simulation of PV irrigation systems has been done under the support of the European project MASLOWATEN [1].

This manual is focused on the explanation of the simulation of a PV irrigation system.

In its present version, SISIFO allows the simulation of different types of PV irrigations systems, such as the so-called, pumping systems to a water pool, or the pumping systems at constant pressure (also called direct pumping).

Figure 1 displays the general configuration of the simulated PV irrigation system, which is composed of a PV generator, a frequency converter, an AC motor and a centrifugal pump. On the other hand, Figure 2 shows the general configuration of the simulated grid-connected PV system, which includes a PV generator, an inverter and a low voltage/medium voltage (LV/MV) transformer.

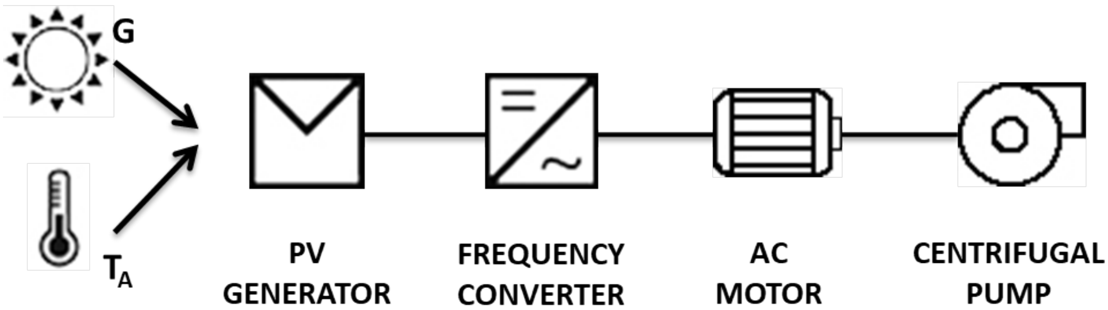


Figure 1. General configuration of the simulated PV irrigation system.

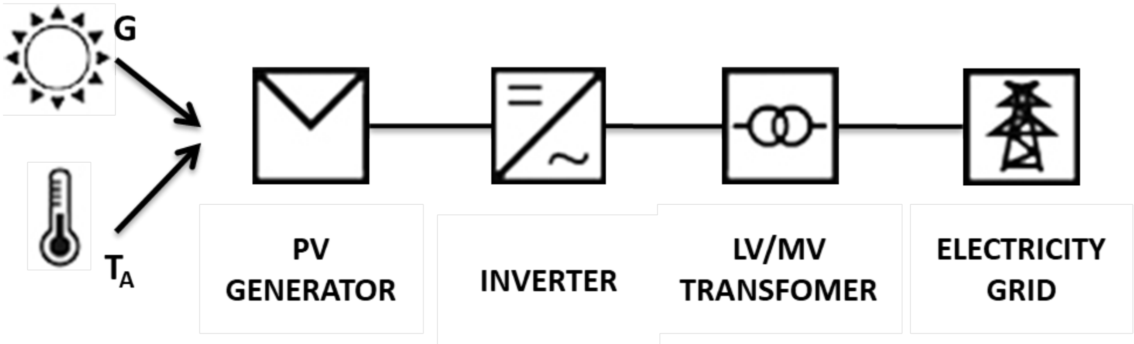


Figure 2. General configuration of the simulated grid-connected PV system.

Simulations require as input data 12 daily monthly average global horizontal irradiation and ambient temperature values, which are, at present, the most common available information for any site.

From these average values, the program is capable to generate synthetic series of daily and hourly data for the whole year.

Next the toolbox determines the irradiance on the inclined surface of the PV generator. In particular, four static surfaces and five sun-trackers (with/without backtracking option) may be simulated, which are displayed in Table 1.

Table 1. Static and tracking structures available for simulation.

Static	· Ground, roof, façade, and delta (double static surface)
Tracking	· One axis horizontal or inclined
	· One axis vertical (azimuthal)
	· Two axis (1st vertical, 2nd horizontal)
	· Two axis (1st vertical, 2nd horizontal - Venetian blind type)
	· Two axis (1st horizontal, 2nd perpendicular)

SISIFO simulates the behaviour of the main technology of PV modules currently present in the market (crystalline silicon (Si-c)) but in the next future, other technologies will be available such as cadmium telluride (Te-Cd), amorphous silicon (Si-a), multi-junction solar cells (e.g., III-V for concentrators) and other compound semiconductors, such as CIS/CIGS. Besides, the modeling also takes into account the effects of shading, dirt and incidence-angle losses, and spectrum.

The modelling of the system components (PV generator, frequency converter and transformer) is based on parameters that can be obtained either from standard information (datasheets, catalogs, specifications, etc.) or from on-site experimental measurements, and considers energy losses parameters and scenarios whose suitability has been validated in the commissioning of several PV projects carried out in Spain, Portugal, France and Italy, whose aggregated capacity is nearly 700MW.

1-2 Home page

The current version of SISIFO is accessible through the following website:

http://sisifo.adminia.es/

This link gives access to the Home page displayed in Figure 3.

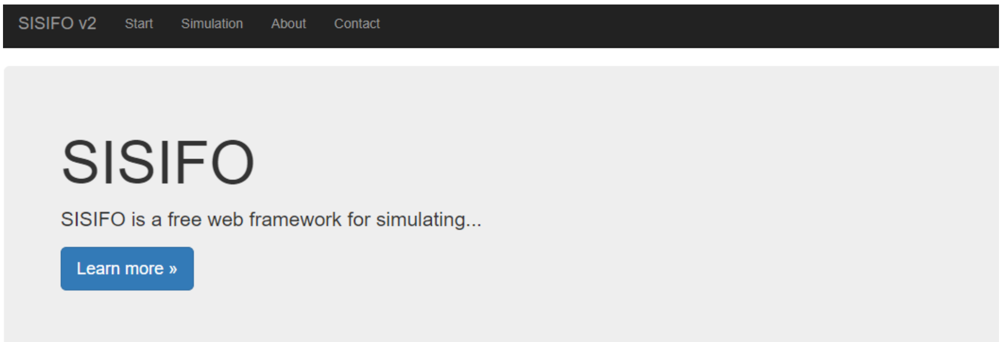


Figure 3. Home page of SISIFO.

At the top of the screen, there is a bar composed of different tabs. By selecting "Simulation", the user will enter in the simulation tool and will be able to perform different simulations. By clicking "Simulation", one has access to the input data interface and, through the webservice technology, the calculations are carried out remotely in a server that sends back the results to the remote user. At present, all the features of the tool are only available in English.

The input interface (Figure 4) is composed of several tabs (Site, Meteo Data, PV modules, PV generators, Converters, Wiring, Pumping, Options, and Time) that contain the different parameters and options that must be introduced or selected by user in order to perform a simulation. After filling all the required inputs, the user should press the red button called "Simulation" and the simulation starts.

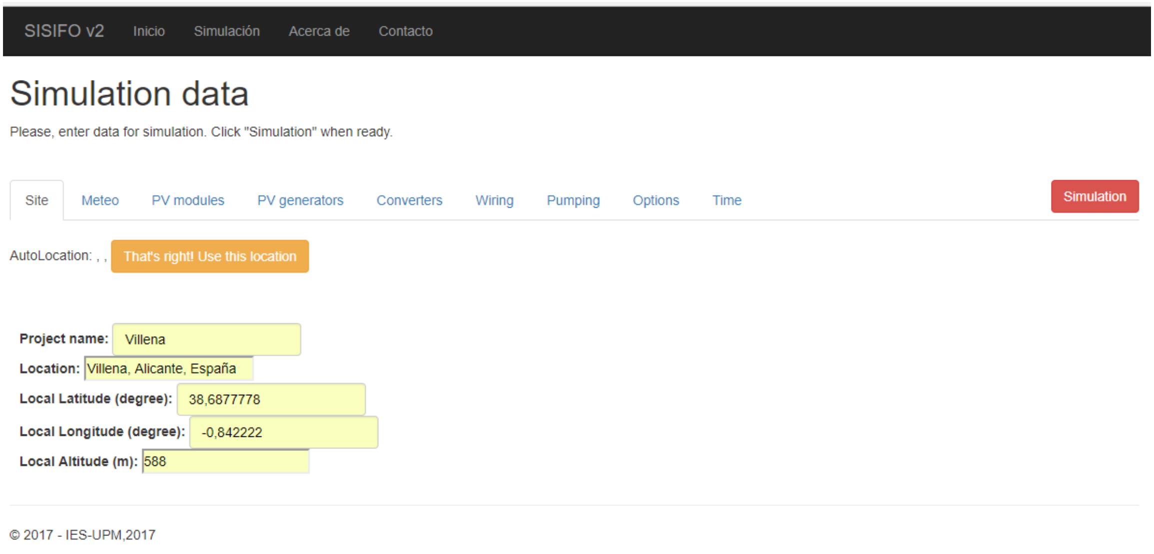


Figure 4. Input interface of SISIFO.

Next two chapters, called “Input interface” and “Output interface”, describe, respectively, the input parameters and the options to be selected by the user in order to perform a simulation, and the results of the simulation. Then, a list of all the simulation variables is presented. The final chapter contains the bibliographic and web references mentioned through this manual.

2 Input interface

2-1 Introduction

The top of the input interface (see Figure 4) is composed of the following eight tabs:

-Site

-Meteo

-PV modules

-PV generators

-Converters

-Wiring

-Pumping

-Options

-Time

Besides, there is one tab called: “Simulation”, which runs a simulation.

Each of these nine tabs contains several input parameters and simulation options that must be introduced or selected by the user in order to perform a simulation, which are described below.

2-2 Site

This tab contains the geographical data of the location, which are specified by the parameters given in Table 2.

Table 2. Geographical data of the location.

Parameters	**Unit**	**Definition**
Location		Location of the project.
Local Latitude	Degree	Latitude of the location, positive in the Northern Hemisphere and negative in the Southern Hemisphere. Valid values: from -90 to 90
Local Altitude	Meter	Altitude of the location over sea level.
Local Longitude	Degree	Longitude of the location, negative towards West and positive towards East. Valid values: from -180 to 180

2-3 Meteo

This tab allows selecting the "Meteo data type" and the "Sky type" that will be used in the simulation, which are summarised in the Table 3.

"Meteo data type" may be either "Monthly averages" or "Time series" (this second option will be available soon).

Table 3. Options of METEO.

Parameters	Unit	Description
Meteo data type	Dimensionless	Options 1 Monthly averages 2 Time series (in construction)
Sky type	Dimensionless	Options 1 Mean 2 Daily synthetic series 3 Hourly synthetic series

If the selected data type option is "Monthly averages", the program generates the time series starting from the 12 monthly mean values of daily global horizontal irradiation, and maximum and minimum ambient temperatures. The first time series is automatically downloaded from the PVGIS database [2] or introduced manually by the user for the twelve months of the year (see Figure 5), while temperatures need to be introduced manually by the user. In addition, the ratio of diffuse to global irradiation can also be downloaded from PVGIS. The generation of the time series may use three different approaches, which are selected in the "Sky type" options, which are called "Mean", "Daily synthetic series" and "Hourly synthetic series".

The first approach, mean-sky, is the most common used in simulation software packages, and involves two steps. First, monthly mean daily horizontal global irradiation is split in beam and diffuse components, which are calculated using global-diffuse correlations, for example, those of Page [3], Erbs [4] or Macagnan [5]. These correlations are selected by the user in the "OPTIONS" tab (section 2-9).

The second step involves the estimation of the instantaneous values of beam and diffuse irradiances, which are calculated from the corresponding beam and diffuse irradiations as described by Collares-Pereira and Rabl [6].

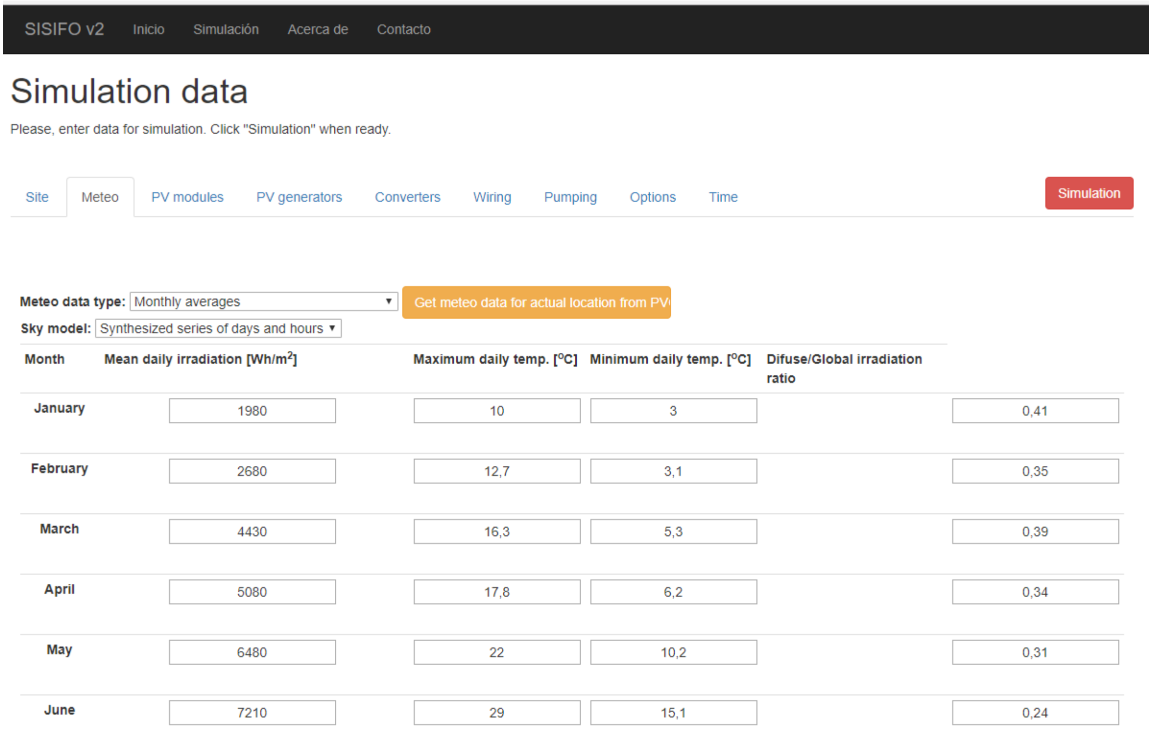
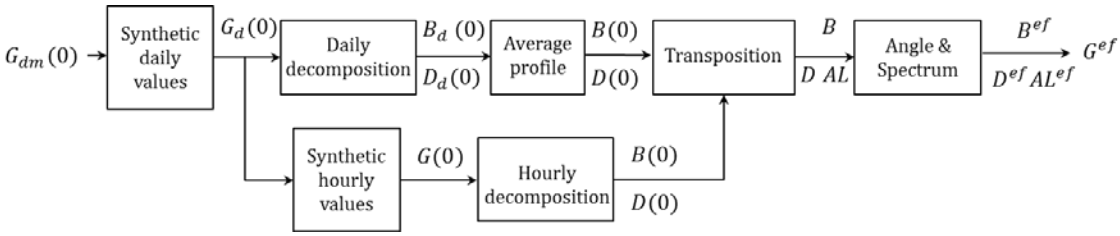


Figure 5. Meteo Data tab.

The second approach, "Daily synthetic series", is rather simple to implement but, because of the monthly averaging, the weight of the medium ranges in the irradiance frequency distribution tends to be larger than the observed one. Note that as the relationship between PV output power and irradiance is affected by non-linear effects, this frequency distribution affects the PV yearly yield estimation (in some cases, up to 2-3% differences are observed).

This problem can be overcome by the synthetic generation of series of daily irradiation values by the method proposed by Aguiar-Collares. This way, a different irradiation value, $G_d(0)$, is available for each day of the month. Then, a decomposition model, adapted to individual daily values, allows the diffuse component, $D_d(0)$, to be derived. The four alternatives selected for such decomposition model are the following: two general polynomial relations, proposed by Collares and Erbs, the latter depending also on the sunrise angle, w_S, and two local correlations, proposed by Macagnan and de Miguel, for Madrid and for the Mediterranean belt, respectively. These correlations are selected by the user in the "OPTIONS" tab (section 2-9). Then, the aforementioned procedure for deriving irradiance profiles can be applied, leading to $G(0)$ and $D(0)$ values for each day.

The third approach, “Hourly synthetic series”, consists on of the direct generation of synthetic irradiance values, also following an Aguiar-Collares proposition. This way, a series of $G(0)$ is obtained.



Regarding to the ambient temperature, the program generates the time series starting from the monthly average of the minimum and maximum daily ambient temperatures using cosine type interpolation model [7].

Once time series of horizontal irradiances and ambient temperatures have been calculated by any of the above described methods, next steps involve the calculation of the time series of irradiances on the inclined surface of PV generators and the cell temperature, which are described, respectively in sections 2-9 (Options) and 2-4 (PV modules).

2-4 PV modules

This tab allows the selection of PV modules with different solar cell materials, crystalline silicon and thin films (in construction), whose maximum output DC power, P_{DC}, is calculated using the following power model:

$$P_{DC} = P^* \frac{G}{G^*} \frac{\eta}{\eta^*}$$

Where P^* is the maximum power under Standard Test Conditions (STC, defined by a normal irradiance of G^*=1000W/m^2 and a cell temperature of $T_C^* = 25^\circ C$, and AM1.5 spectrum), $\eta=\eta(G,T_C)$ is the power efficiency as a function of the incident irradiance, G, and cell temperature, T_C, and η^* is the power efficiency under STC, $\eta^*=P^*/AG^*$, where A is the active area of the PV generator.

Depending on the calculation of the power efficiency η, the user may select between two power models. The first one, called "Only temperature effect", only takes into account the dependence of the efficiency with the temperature:

$$\frac{\eta}{\eta^*} = 1 + \gamma (T_C - T_C^*)$$

Where γ is the coefficient of variation of power with temperature, in ºC^{-1}, and T_C is calculated from the ambient temperature, T_A, using the well know equation with the nominal operation cell temperature, $NOCT$, obtained from the manufacturer datasheet:

$$T_C = \left(T_A + 0{,}9 \frac{NOCT - 20}{800} G \right) = T_A + k.G$$

Where T_A and $NOCT$ are given in ºC, and G is given in W·m^{-2}., and k is a thermal resistance sometimes called in the literature as Ross coefficient [8], which is given in ºC·m2/W. The experimental correction factor of 0,9 is used to consider the effect of wind speed. The factor 0.9 is an experimental correction factor, based on authors experience, which averages the cooling effect of wind speed on openback mounted PV modules. For example, for a typical value of NOCT=45ºC the previous equation gives k=0.028 ºC·m2/W.

Depending on the mounting and ventilation of the PV modules, k may typically vary from 0.02 to 0.07 ºC·m2/W. If the Ross coefficient is knew for a particular PV module and mounting, this value can also be used in the simulation calculating an "equivalent" NOCT. Table 6 displays some examples.

In the last years, direct measurements of the cell temperature are also available from the monitoring of some grid-connected PV systems. Such measurements are normally performed either attaching a temperature sensor (thermocouple or similar) to the back surface of the modules or calculating it from the measurements of the open-circuit voltage of a reference module [9].

The second power model, called "Irradiance and temperature effects", is now in construction, so its explanation is not included in this manual.

Table 4, Table 5 and Table 6 summarize all the parameters of this tab, while Figure 6 is an image of this input data tab.

Table 4. Available options for the PV modules tab.

Parameters	**Unit**	**Definition**
Cell Material	Dimensionless	Material of the solar cell: Value Material 1 Si-c 2 Thin Film (in construction)
Power Model	Dimensionless	Power model: Value Model 1 Only temperature effect. 2 Irradiance and temperature effects (in construction).

Table 5. Coefficients of the power module model that considers only temperature effects.

Parameters	**Unit**	**Definition**
CVPT	$\%ºC^{-1}$	Coefficient of Variation of module Power with Temperature γ (absolute value).
NOCT	ºC	Nominal Operation Cell Temperature

Table 6. Ross coefficient and equivalent TONC for typical mounting of PVmodules [10].

Mounting	k [ºC·m^2/W]	Equivalent TONC [ºC]
Well cooled	0.020	37.8
Free standing	0.021	38.5
Flat on roof	0.026	43.1
Façade integrated	0.054	67.8
On sloped roof	0.056	70.0

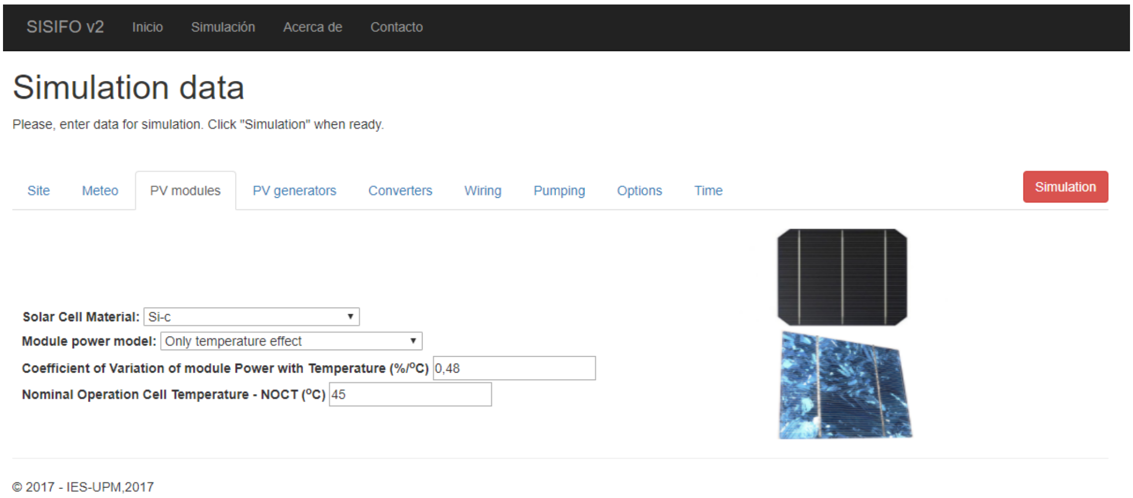


Figure 6. PV modules tab.

2-5 PV generator

This tab allows the selection of PV generator electrical and geometrical characteristics.

The first parameters are electrical characteristics, which are the same for all the PV generators. They are showed in Figure 7 and defined in Table 7. The last two parameters of the table are the number of bypass diodes in the horizontal and vertical dimension, which are used by the Martinez shading model described below.

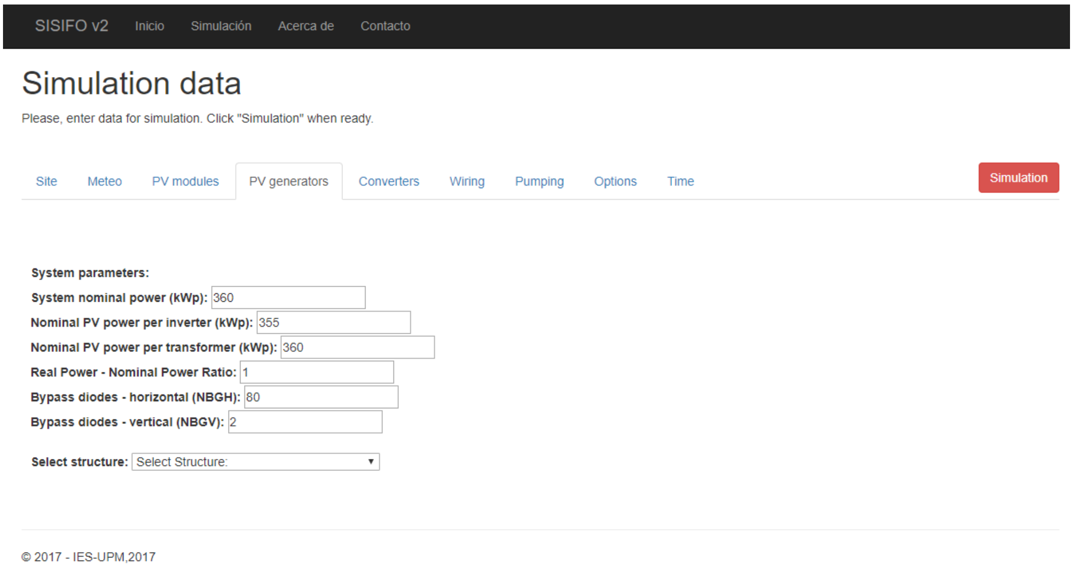


Figure 7. PV generator tab before selecting the structure.

Table 7. Electrical parameters of the PV generators.

Parameter	Unit	Definition
Total nominal power	kWp	Sum of the nominal power of all the PV generators of the system.
PV power per inverter	kWp	Nominal PV power connected to a single inverter.
PV power per transformer	kWp	Nominal PV power connected to each LV/MV transformer.
PRVPN	Dimensionless	Ratio of the real power to the nominal PV power.

Bypass diodes – horizontal (NBGH)	Dimensionless	Number of bypass diodes in the horizontal dimension.
Bypass diodes – vertical (NBGV)	Dimensionless	Number of bypass diodes in the vertical dimension.

An example to correctly understand the parameters NBGH and NBGV is shown in the next figure:

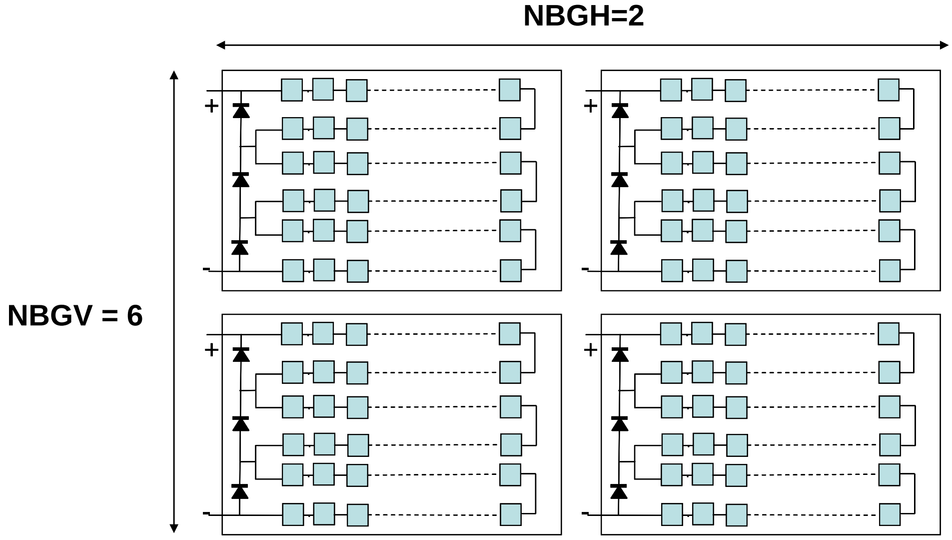


Figure 8. Example of the way of calculating the number of bypass diodes in the horizontal and vertical dimension.

Then, a PV structure must be selected among the four static and five sun-tracking structures available for simulation (Parameter "Struct"), which are displayed in Table 8. Once one of these structures has been selected, a list of geometrical parameters appears (Figure 9 shows an example). These parameters are particular for each structure (tilt, separation between structures, maximum rotation angles, etc.). In the case of trackers with flat-plate modules, the last parameters allow the selection of the backtracking mode of operation [11].

Table 8. Static and tracking structures available for simulation.

Static	· Ground, roof, façade, and delta (double static surface)
Tracking	· One axis horizontal or inclined
	· One axis vertical (azimuthal)
	· Two axis (1st vertical, 2nd horizontal)

· Two axis (1st vertical, 2nd horizontal - Venetian blind type)

· Two axis (1st horizontal, 2nd perpendicular)

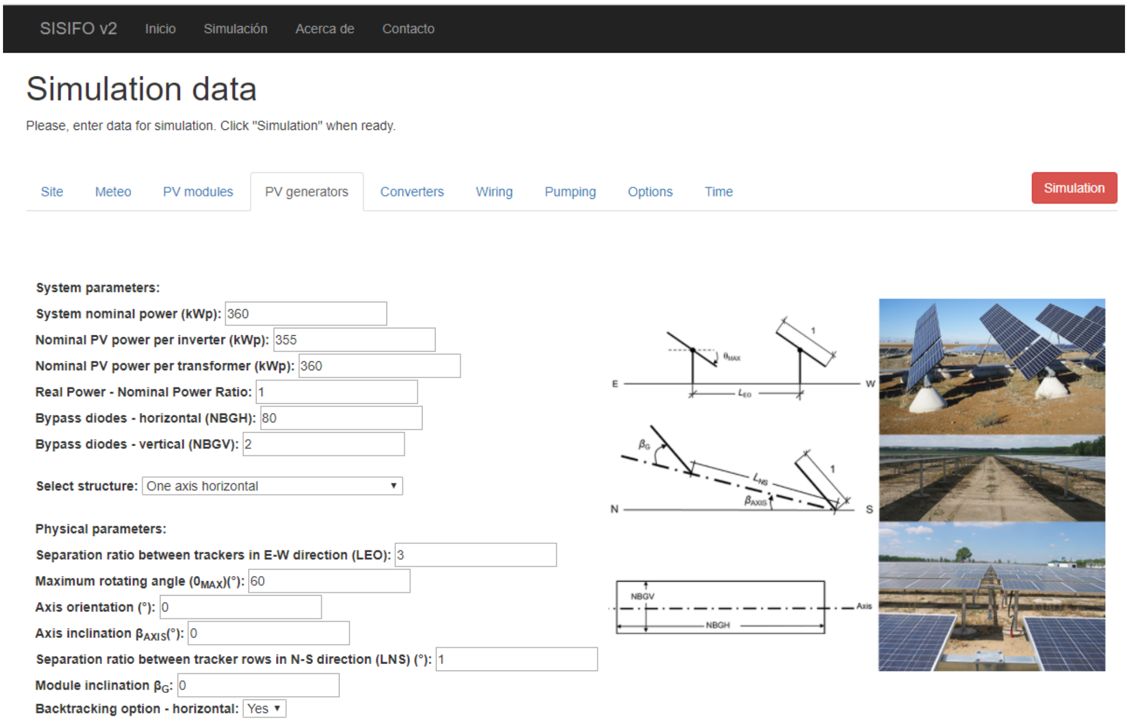


Figure 9. Example of a PV Generator tab: One axis horizontal.

Next sections display geometrical layouts and define the relevant parameters for each particular PV generator structure. It is worth noting that, in these layouts, all the distances are dimensionless because they are relative to the transversal dimension of the PV generator, which is indicated as "1" in the figures.

2-5-1 Ground or roof static structure

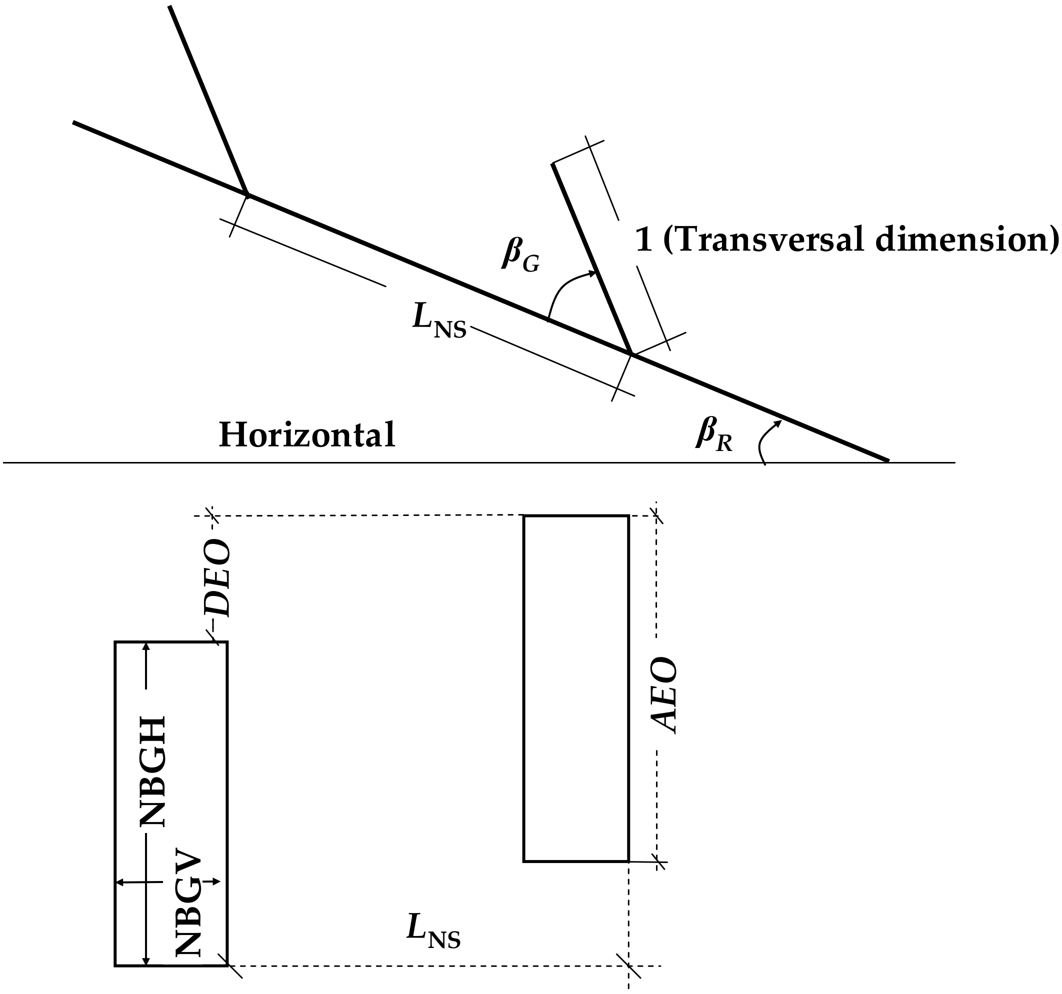


Figure 10. Geometrical layout.

Table 9. Parameters of the ground or roof PV generators.

Parameters	Unit	Definition
Roof inclination (β_R)	Degree	Inclination of the roof regarding the horizontal. For a ground-mounted structure, this parameter should be zero. Valid values: from 0 to 90
Roof orientation	Degree	Azimuth of the roof, which refers to either the South (Northern Hemisphere) or to the North (Southern Hemisphere). Negative towards the East and positive towards the West. For a ground-mounted structure, this parameter should be zero. Valid values: from -90 to 90
Generator inclination (β_G)	Degree	Inclination of the PV generator with respect to the roof. For a ground-mounted structure, this inclination is with respect tothe horizontal. Valid values: from 0 to 90
Generator orientation	Degree	Deviation of the PV generator with respect to the roof, negative towards the East and positive towards the West. Valid values: from -90 to 90
Separation among structures N-S (L_{NS})	Dimensionless	North-South separation among structures, specified as the ratio between this separation and transversal dimension of the PV generator. Valid values: from 1 to 100
PV generator width (AEO)	Dimensionless	Ratio of the PV generator width to its transversal dimension. Valid values: >0
Deviation of back structure (DEO)	Dimensionless	Deviation of back structure, toward the West, with respect to the front structure. It must be provided as the ratio of this deviation to the transversal dimension of the PV generator.

		Positive towards the West and negative towards the East. Valid values: ≥0

2-5-2 Façade static structure

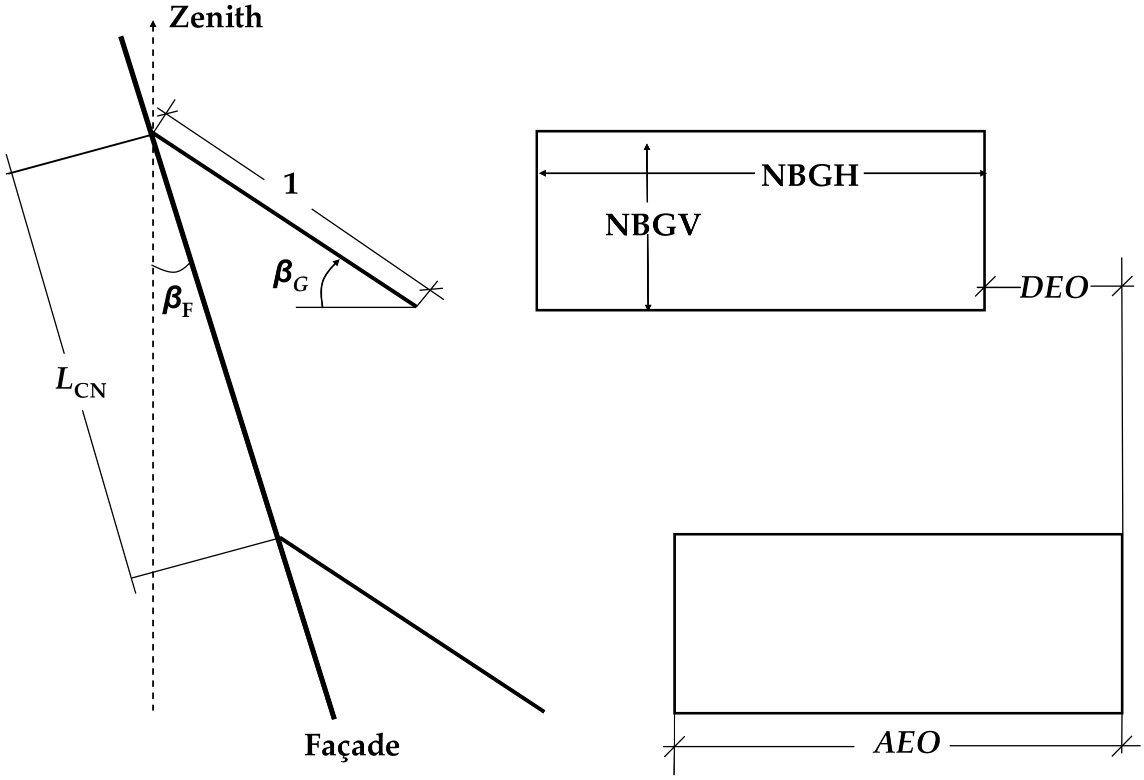


Figure 11. Geometrical layout.

Table 10. Parameters of the façade PV generators.

Type	Façade	
Generator inclination (β_G)	Degree	Inclination of the PV generator with respect to the horizontal. Valid values: from 0 to 90
Façade orientation	Degree	Orientation of the façade with respect to the South, negative East and positive West. Valid values: from -90 to 90
Façade inclination (β_F)	Degree	Inclination of the façade with respect to the vertical. Valid values: from 0 to 90
Separation among modules, zenith-nadir (L_{CN})	Dimensionless	Ratio of the PV modules separation (direction Zenit-Nadir) to its transversal dimension. Valid values: >1
PV generator width (AEO)	Dimensionless	Ratio of the PV generator width to its transversal dimension. Valid values: >0
Deviation of back structure (DEO)	Dimensionless	Deviation of back structure, toward the West, with respect to the front structure. It must be provided as the ratio of this deviation to the transversal dimension of the PV generator. Positive towards the West and negative towards the East. Valid values: ≥0

2-5-3 One axis horizontal or inclined tracker

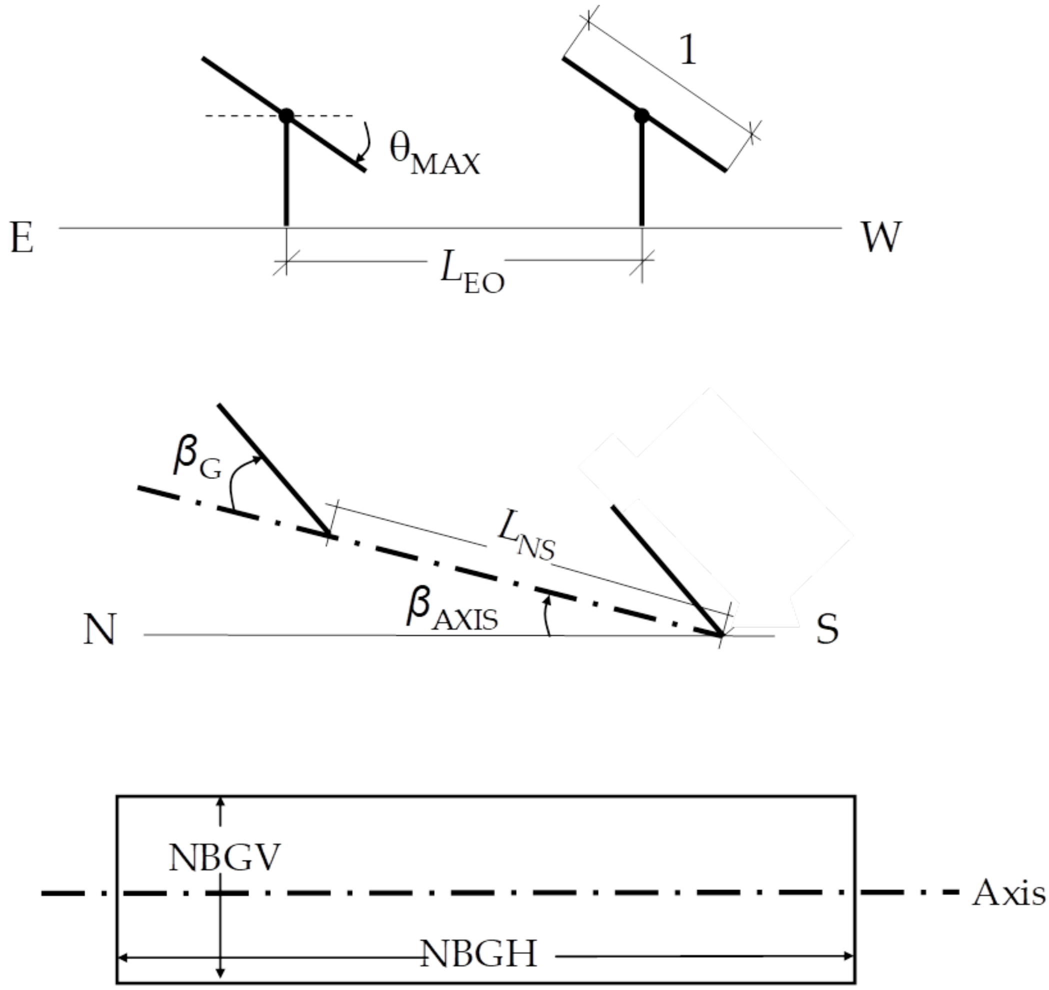


Figure 12. Geometrical layout.

Table 11. Parameters of the one axis horizontal PV generators.

Parameters	Unit	Definition
LEO: Separation between trackers in E-W direction	Dimensionless	Ratio of the East-West separation (node-to-node) between trackers to their width. Valid values: ≥1
Rotation max (θ_{MAX})	Degree	Maximum rotation angle. Valid values: from 0 to 90
Axis orientation	Degree	Deviation of the rotating axis regarding the South (axis azimuth), negative towards East and positive towards West. Valid values: from -90 to 90
Axis inclination (β_{AXIS})	Degree	Inclination of the rotating axis with respect to the horizontal. Valid values: from 0 to 90
LNS: Separation between tracker rows in N-S direction	Dimensionless	Ratio of the distance separating two PV generators rows (North-South direction) to their transversal dimension. Valid values: ≥1
Module inclination (β_G)	Degree	Inclination of the PV modules regarding to the rotating axis. Valid values: from 0 to 90
RSEH	Dimensionless	Backtracking option. The tracker rotates with respect to the horizontal axis. Valid values: [0 =No] / [1 =Yes]

2-5-4 One axis vertical (azimuthal) tracker

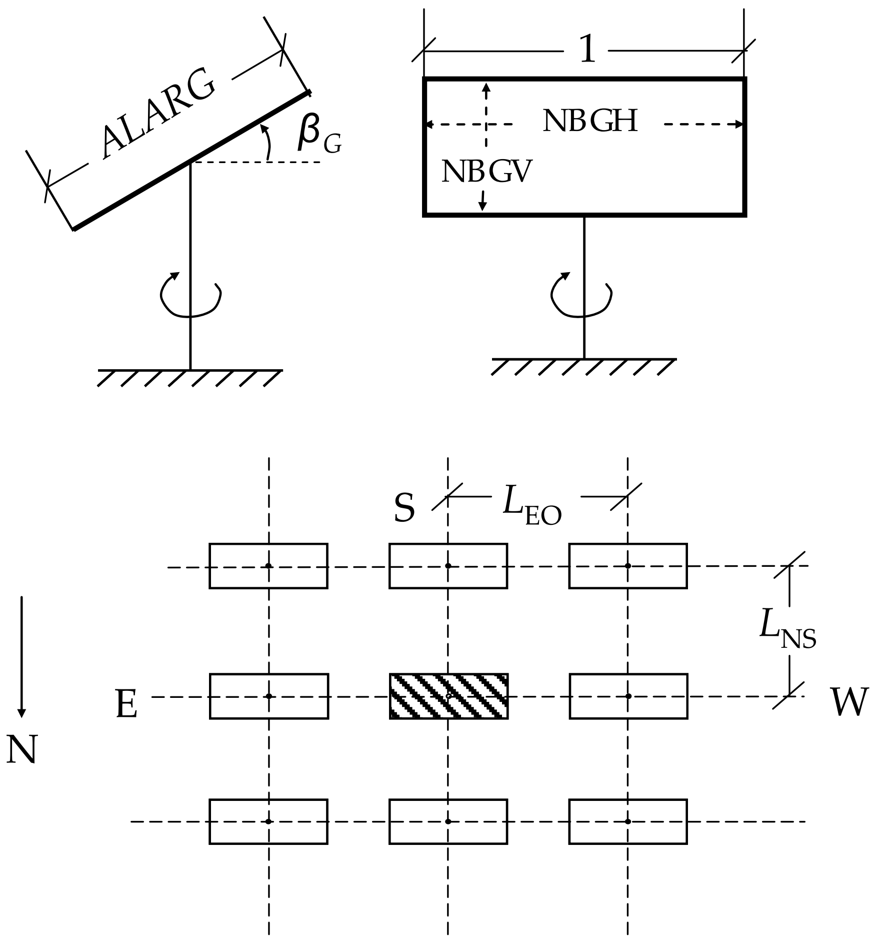


Figure 13. Geometrical layout.

Table 12. Parameters of the one axis vertical (Azimuthal) PV generators.

Parameters	**Unit**	**Definition**
Rack inclination (β_G)	Degree	Inclination respect to horizontal Valid values: from 0 to 90
LEO: Separation between trackers in E-W direction	Dimensionless	Ratio of the East-West separation (node-to-node) between trackers to their width. Valid values: ≥1
LNS: Separation between tracker rows in N-S direction	Dimensionless	Ratio of the distance separating two PV generators rows (North-South direction) to their transversal dimension. Valid values: ≥ALARG
Tracker height-width ratio (ALARG)	Dimensionless	Ratio of the height to the width of the tracker. Valid values: >0
RSEV	Dimensionless	Backtracking option. The tracker rotates with respect to the vertical axis. Valid values: [0 =No] / [1 =Yes]

2-5-5 Two axes tracker (1st vertical / 2nd horizontal)

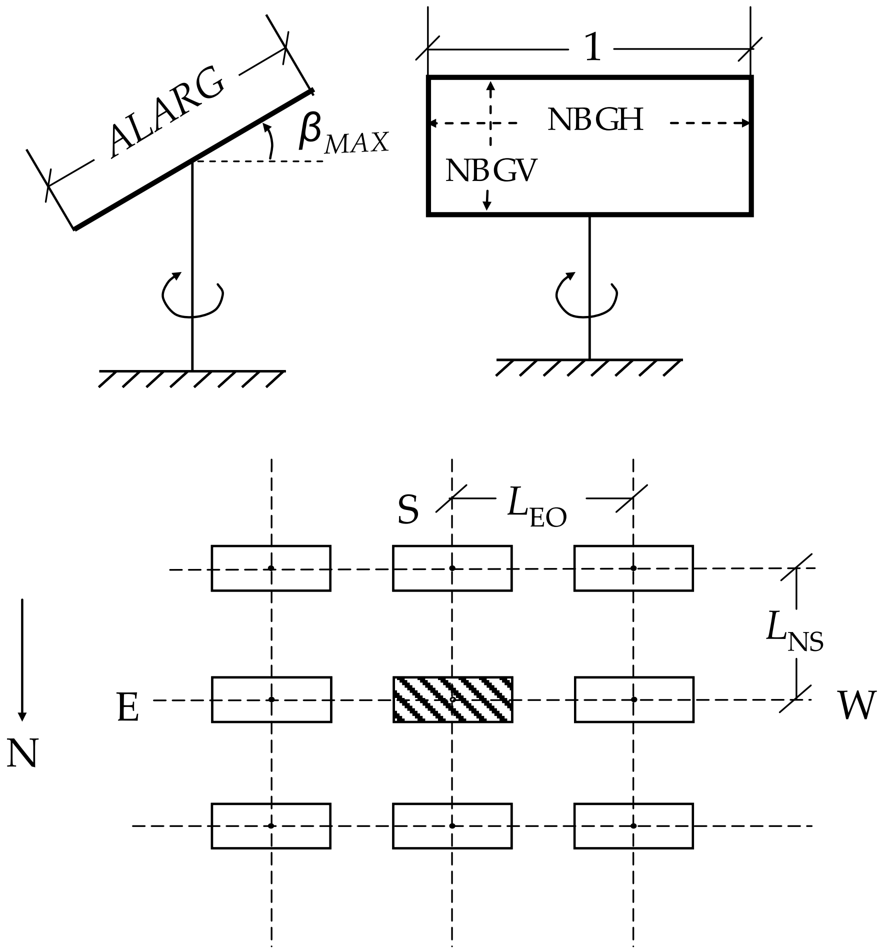


Figure 14. Geometrical layout.

Table 13. Parameters of the two axis (Primary vertical / Secondary horizontal) PV generators.

Parameters	Unit	Definition
Azimuth rotation angle limit	Degree	Limit for azimuthal rotation angle. Valid values: from 90 to 180
Maximum inclination (β_{MAX})	Degree	Maximum tilt angle for the tracker. Valid values: from 0 to 90
LEO: Separation between trackers in E-W direction	Dimensionless	Ratio of the East-West separation (node-to-node) between trackers to their width. Valid values: ≥1
LNS: Separation between tracker rows in N-S direction	Dimensionless	Ratio of the distance separating two PV generators rows (North-South direction) to their transversal dimension. Valid values: ≥ALARG
ALARG: Tracker height-width ratio	Dimensionless	Ratio of the height to the width of the tracker. Valid values: >0
RSEV	Dimensionless	Backtracking option. regarding to the vertical axis. The tracker rotates with respect to the vertical axis. Valid values: [0 =No] / [1 =Yes]
RSEH	Dimensionless	Backtracking option. regarding to the horizontal axis. The tracker rotates with respect to the vertical axis. Valid values: [0 =No] / [1 =Yes]

2-5-6 Two axes tracker (1st vertical / 2nd horizontal) – Venetian blind type

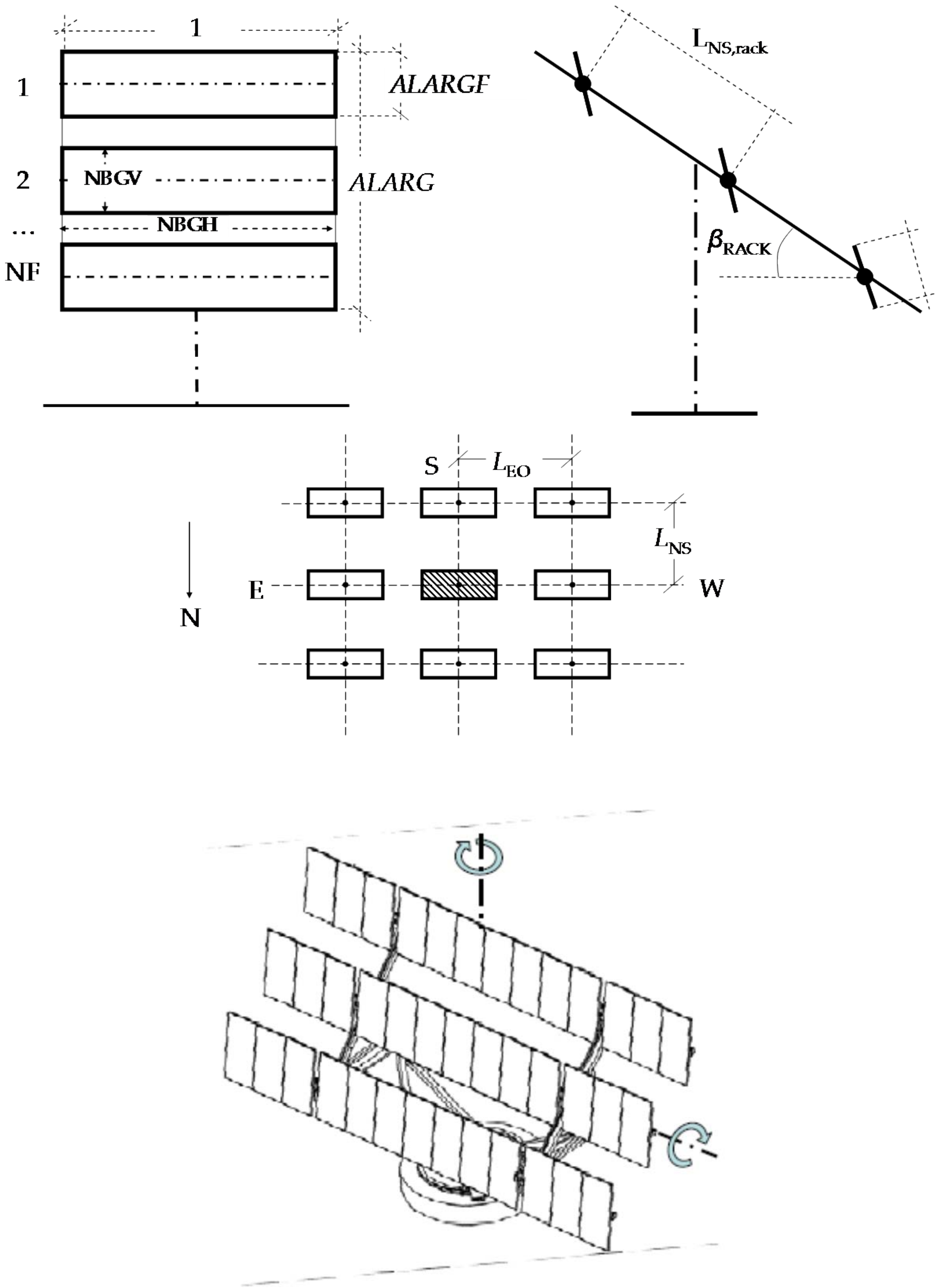


Figure 15. Geometrical layout.

Table 14. Parameters of the two axis (Primary vertical / Secondary horizontal) Venetian blind PV generators.

Parameters	Unit	Definition
Rack inclination (β_{RACK})	Degree	Inclination of the rack with respect to the horizontal. Valid values: from 0 to 90
LEO: Separation between trackers in E-W direction	Dimensionless	Ratio of the East-West separation (node-to-node) between trackers to their width. Valid values: ≥1
LNS: Separation between tracker rows in N-S direction	Dimensionless	Ratio of the distance separating two trackers (North-South direction) to their transversal dimension. Valid values: ≥ALARG
ALARG	Dimensionless	Ratio of the height to the width of the tracker. Valid values: ≥0
RSEV	Dimensionless	Backtracking option. The tracker rotates with respect to vertical axis. Valid values: [0 =No] / [1 =Yes]
RSEH	Dimensionless	Backtracking option. The tracker rotates with respect to horizontal axis. Valid values: [0 =No] / [1 =Yes]
LNS_rack: Separation between rows in rack	Dimensionless	Separation of the rows in the rack, relative to the width of the tracker and measured in the rack plane. Valid values: ≥ALARGF
ALARGF	Dimensionless	Ratio of the height to the width of a row in the rack Valid values: ≥ALARG
NF	Dimensionless	Number of rows per tracker.

		Valid values: ≥1
NBFV	Dimensionless	Number of bypass diodes per row in the vertical sense. Valid values: ≥1

2-5-7 Two axes tracker (1st horizontal/ 2nd perpendicular)

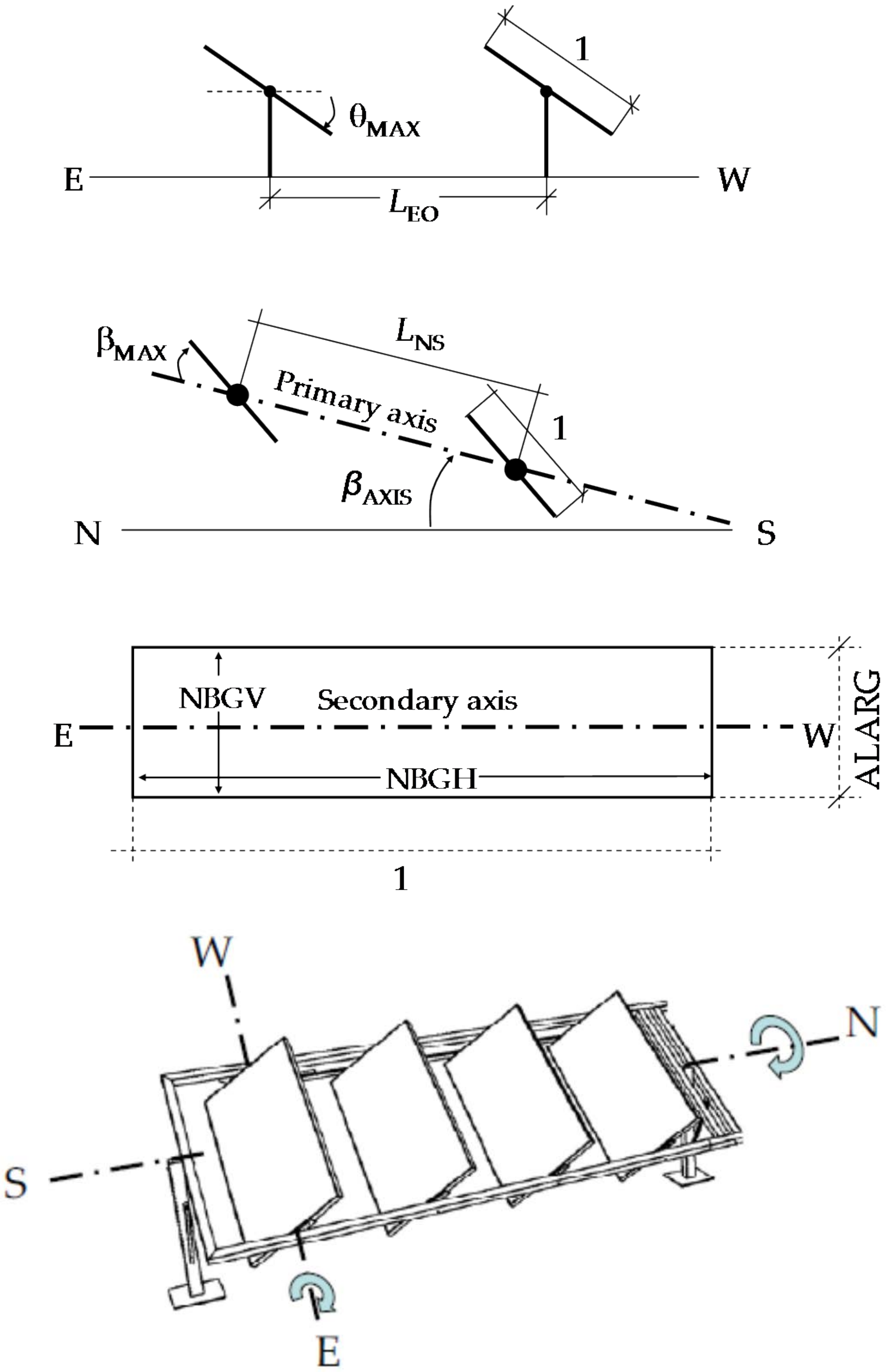


Figure 16. Geometrical layout.

Table 15. Parameters of the two axis (Primary horizontal / Secondary perpendicular) PV generators.

Parameters	Unit	Definition
LEO: Separation between trackers in E-W direction	Dimensionless	Ratio of the East-West separation (node-to-node) between trackers to their width. Valid values: ≥1
LNS: Separation between tracker rows in N-S direction	Dimensionless	Ratio of the distance separating two PV generators rows (North-South direction) to their transversal dimension. Valid values: ≥ALARG
ALARG	Dimensionless	Ratio of the height to the width of the tracker. Valid values: >0
Rotation_MAX (θ_{MAX})	Degree	Maximum rotating angle. Valid values: from 0 to 90
Axis inclination (β_{AXIS})	Degree	Inclination of the rotating axis with respect to the horizontal. Valid values: from 0 to 90
Inclination_MAX (β_{MAX})	Degree	Maximum inclination of the PV modules with respect to the rotating axis. Valid values: from 0 to 90
RSEV	Dimensionless	Backtracking option. The tracker rotates with respect to vertical axis. Valid values: [0 =No] / [1 =Yes]
RSEH	Dimensionless	Backtracking option. The tracker rotates with respect to horizontal axis. Valid values: [0 =No] / [1 =Yes]

2-5-8 Delta structure

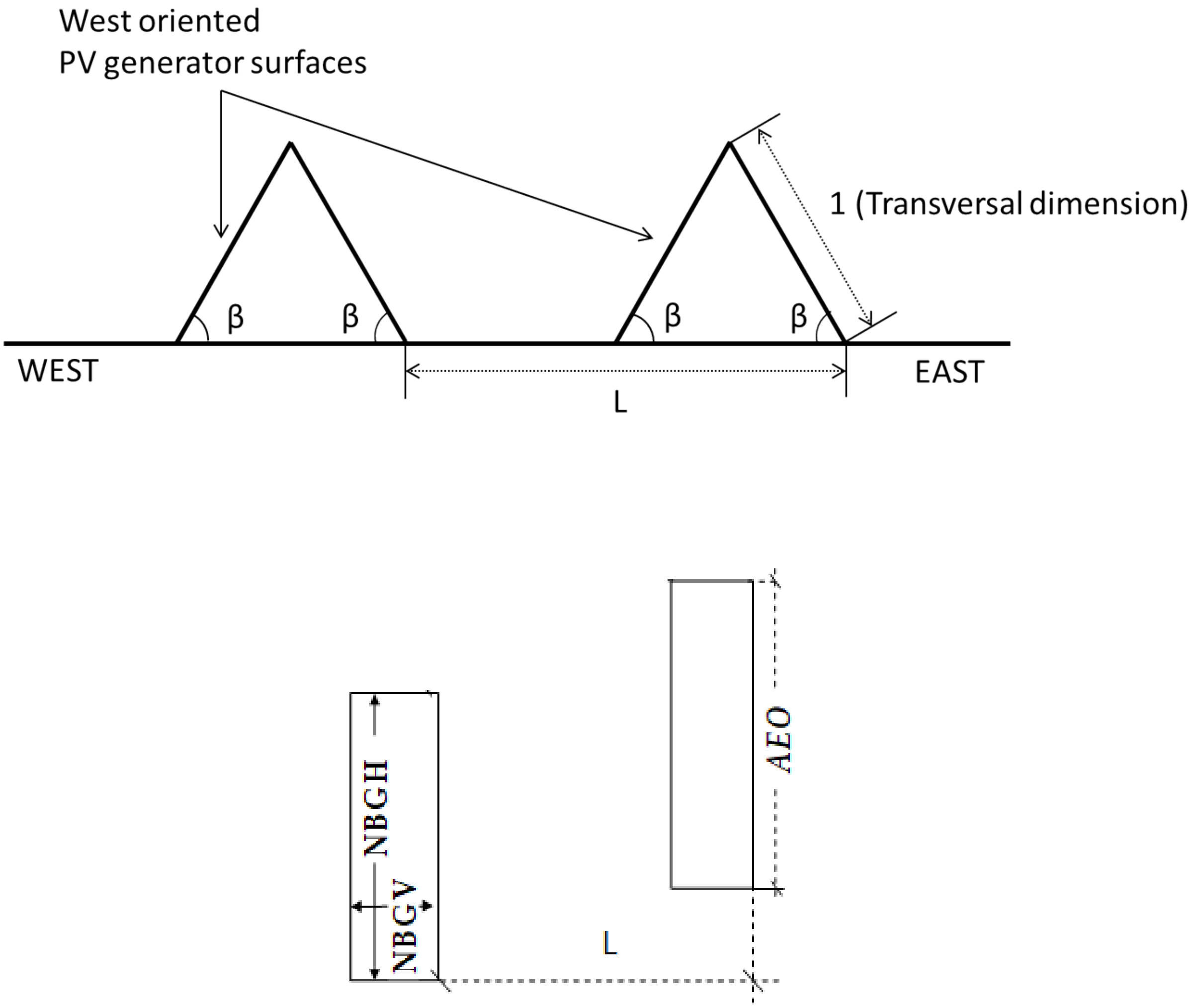


Figure 17. Geometrical layout.

Table 16. Parameters of the delta generators – West oriented surface.

Parameters	**Unit**	**Definition**
Generator inclination (β_W)	Degree	Inclination of the PV generator regarding the ground. Valid values: from 0 to 90
Separation among structures (L)	Dimensionless	Separation East-West among structures, specified as the ratio between this separation and transversal dimension of the PV generator. Valid values: ≥2
PV generator width (AEO)	Dimensionless	Ratio of the PV generator width to its transversal dimension.
Total West power	kWp	Nominal power of the West surface. Valid values: ≤ Total nominal Power of PV generator

Table 17. Parameters of the delta generators – East oriented surface.

Parameters	**Unit**	**Definition**
Generator inclination (β_E)	Degree	Inclination of the PV generator regarding the ground. Valid values: from 0 to 90
Total East power	kWp	This value is automatically calculated and did not appear in the input interface. Valid values: Total nominal Power of PV generator - Total West power

2-6 Converters

This tab, displayed in Figure 18, allows to select the electrical characteristics of the inverter or frequency converter, as well as LV/MV and MV/HV transformers.

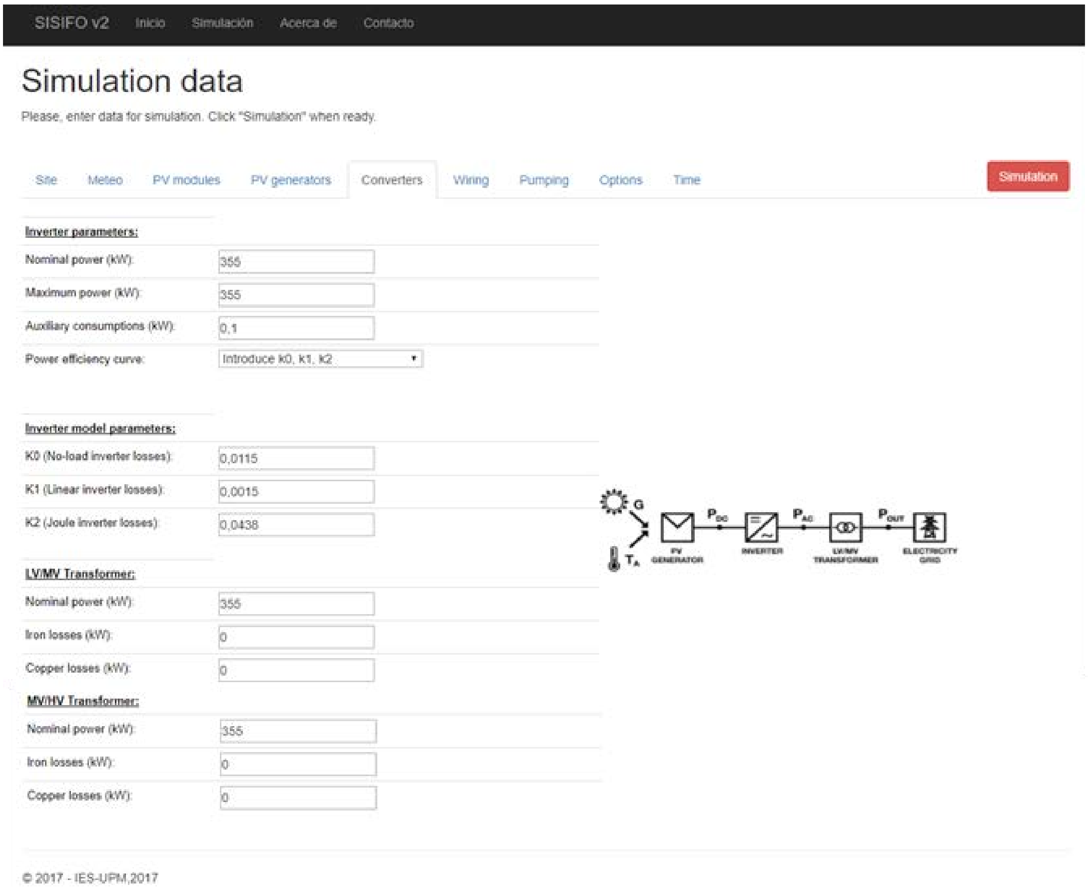


Figure 18. Converters tab.

2-6-1 Inverter / Frequency Converter

The inverter is characterized by its nominal (P_I) and maximum output powers and three experimental parameters (k_0, k_1 and k_2), which are associated, respectively, to the no-load, linear, and Joule inverter losses of the inverter. These parameters are used to calculate its power efficiency, η_I, by means of this equation [12]:

$$\eta_I = \frac{P_{AC}}{P_{DC}} = \frac{p_{ac}}{p_{ac} + (k_0 + k_1 p_{ac} + k_2 p_{ac}^2)}$$

Where $p_{ac}=P_{AC}/P_I$, being P_{AC} the output AC power of the inverter/frequency converter, which can be determined from P_{DC} (power at the inverter input) and parameters k_0, k_1 and k_2, which must be fitted either from the power efficiency curve provided by the manufacturer or from experimental measurements [13].

If the k_i parameters are not available, they are calculated internally using the values of the power inverter efficiency curve for normalized 10%, 50% and 100% output power points obtained from the manufacturer's information. Inverter/frequency converter parameters are summarized in Table 18.

Table 18. Inverter/Frequency converter parameters.

Parameters	**Unit**	**Description**
Nominal power	kW	Nominal power of the inverter. Valid values: from 0,5*Total nominal Power of PV generator to 1,5*Total nominal Power of PV generator
Maximum power	kW	Maximum power of the inverter. Valid values: from 0,5*Total nominal Power of PV generator to 1,5*Total nominal Power of PV generator
Auxiliary consumptions		Consumption of auxiliary equipment. Valid values:<10% of Nominal power
Power efficiency specification		Specification of the power efficiency curve (excluding auxiliary consumptions). Valid values: [1 =Model parameters k_0, k_1 and k_2] / [2 =point of the power efficiency curve]
K0	Dimensionless	No-load inverter losses. Valid values: from 0 to 1
K1	Dimensionless	Linear inverter losses.

		Valid values: from 0 to 1
K2	Dimensionless	Joule inverter losses. Valid values: from 0 to 1
$\eta_{100\%}$	%	Value of power inverter efficiency for normalised 100% output power. Manufacturer data. Valid values: from 0 to 100
$\eta_{50\%}$	%	Value of power inverter efficiency for normalised 50% output power. Manufacturer data. Valid values: from 0 to 100
$\eta_{10\%}$	%	Value of power inverter efficiency for normalised 10% output power. Manufacturer data. Valid values: from 0 to 1

2-6-2 Transformer

The LV/MV transformer is characterized by its nominal power, copper and iron losses. The power efficiency of this transformer, η_T, is calculated as a function of the output power, P_{out}, by [14]:

$$\eta_T = \frac{P_{out}}{P_{AC}} = \frac{P_{out}}{P_{out} + P_{Core} + P_{Cu}}$$

Where P_{Core} are the core losses, and P_{Cu} the copper losses, which can be calculated by:

$$P_{Cu} = P_{Cu,nom} \cdot \left(\frac{P_{out}}{P_T} \right)^2$$

Where $P_{Cu,nom}$ are the copper losses when the transformer operates at its nominal output power, P_T. Transformer parameters are summarized in Table 19 and it is possible values for two different types of transformer: LV/MV (low to medium voltage transformer) and MV/HV (medium to high voltage transformer).

Table 19. Transformer parameters.

Parameters	**Unit**	**Description**
Nominal power	kW	Nominal power of the transformer. Valid values: from 0,5*Total nominal Power of PV generator to 1,5*Total nominal Power of PV generator
Iron losses	kW	No-load transformer losses. Valid values:<10% of Nominal power
Copper losses	kW	Copper transformer losses. Valid values:<10% of Nominal power

2-7 Wiring

This tab (see Figure 19) contains the wiring losses, which are included in Table 20.

Wiring losses are indicated in percent of the nominal PV power and they are calculated using an equation similar to the previous one:

$$P_W = P_{Wnom} \cdot \left(\frac{P}{P_{NOM}} \right)^2$$

Where P_{Wnom} are the wiring losses when the input power at the wiring section is equal to the nominal PV power, P_{NOM}. Wiring parameters are summarized in Table 20.

Table 20. Wiring parameters.

Parameters	**Unit**	**Description**
WDC	%	DC wiring losses between PV generator and inverter at nominal PV power. Valid values: from 0 to 10%
WBT	%	AC wiring losses between inverter and MV transformer at nominal PV power. Valid values: from 0 to 10%
WMT	%	AC wiring losses between MV and HV transformers at nominal PV power. Valid values: from 0 to 10%
WAT	%	AC wiring losses between HV transformer and the PPC at nominal PV power. Valid values: from 0 to 10%

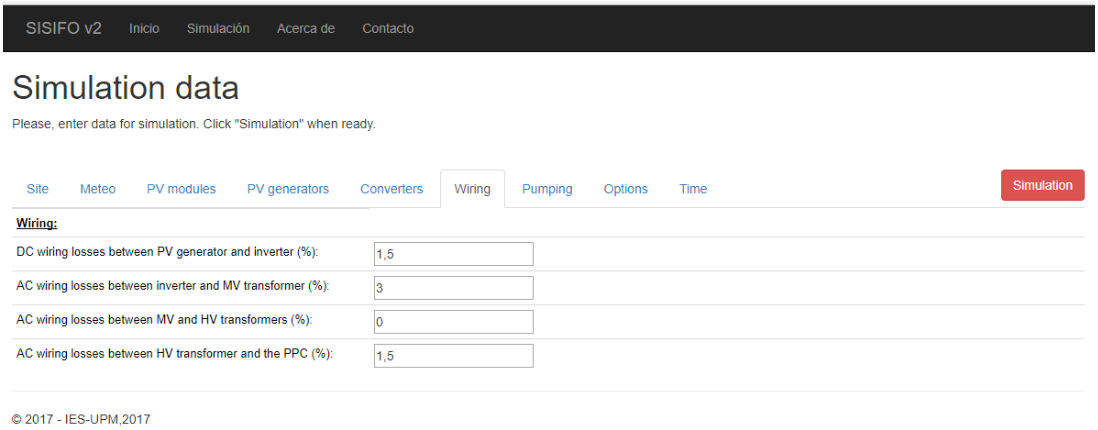


Figure 19. Wiring tab.

2-8 Pumping

This tab allows the selection of the pumping parameters and it is only necessary if one is simulating a pumping system.

The program will calculate the input power to the motor (P1) - accordingly to the available electric input power (PAC) - as well as the shaft power (P2), hydraulic power (PH), flow (Q) and frequency of operation (ω) instantaneously. Before these calculations there is a need to obtain all the curve parameters needed to perform it. The detailed procedure can be found in [15] and a summary of it is presented below.

First, it is necessary to fit the parameters of the motor efficiency curve (km0, km1 and km2), computed with the following equation:

$$\eta_M = \frac{P2}{P1} = \frac{p2}{p2 + (k_{m0} + k_{m1}p2 + k_{m2}p2^2)}$$

where $p2 = P2/P2_{nom}$.

In addition, both the pump and shaft power curves are fitted with second order polynomials, as you can see in the next two equations:

$$H(Q) = k_{B0} + k_{B1}Q + k_{B2}Q^2$$

$$P2(Q) = k_{P0} + k_{P1}Q + k_{P2}Q^2$$

where H is the pump head, and k_{B0}, k_{B1}, and k_{B2} are the second degree polynomial coefficients that represent the best fit for H, while k_{P0}, k_{P1}, and k_{P2} are these coefficients for P2.

Regarding the system curve, it is computed with the static head and friction losses of the system and it is also a second order polynomial:

$$H_S(Q) = k_{S0} + k_{S2}Q^2$$

where H_s is the system head, and k_{S0} and k_{S2} are constants that represent, respectively, static head and friction losses.

The previously mentioned equations are for nominal frequency. Since the system can work at different frequencies because the operating point of the pump varies with the available PV power, it is necessary to obtain different pump curves for a range of frequencies to find the operating points of each one. This means that the well-known affinity laws for pumping needs to be taken into account.

$$\frac{Q_1}{Q_2} = \frac{\omega_1}{\omega_2} \quad ; \quad \frac{H_1}{H_2} = \left(\frac{\omega_1}{\omega_2}\right)^2 \quad ; \quad \frac{P2_1}{P2_2} = \left(\frac{\omega_1}{\omega_2}\right)^3$$

where subscripts 1 and 2 indicate two different points in the same affinity parabola and in different pump curves.

The final goal of the pump modelling is to obtain the relationship between flow (Q) and shaft power (P2), which means having access to the following equation:

$$Q(P2) = k_{Q0} + k_{Q1}P2 + k_{Q2}P2^2 + k_{Q3}P2^3$$

where k_{Q0}, k_{Q1}, k_{Q2} and k_{Q3} are the third degree polynomial coefficients that represent the best fit for Q.

In the case of the direct pumping, the operating point is unique. Even so, all the previous procedure is executed because the operating point can means a frequency different than the nominal one.

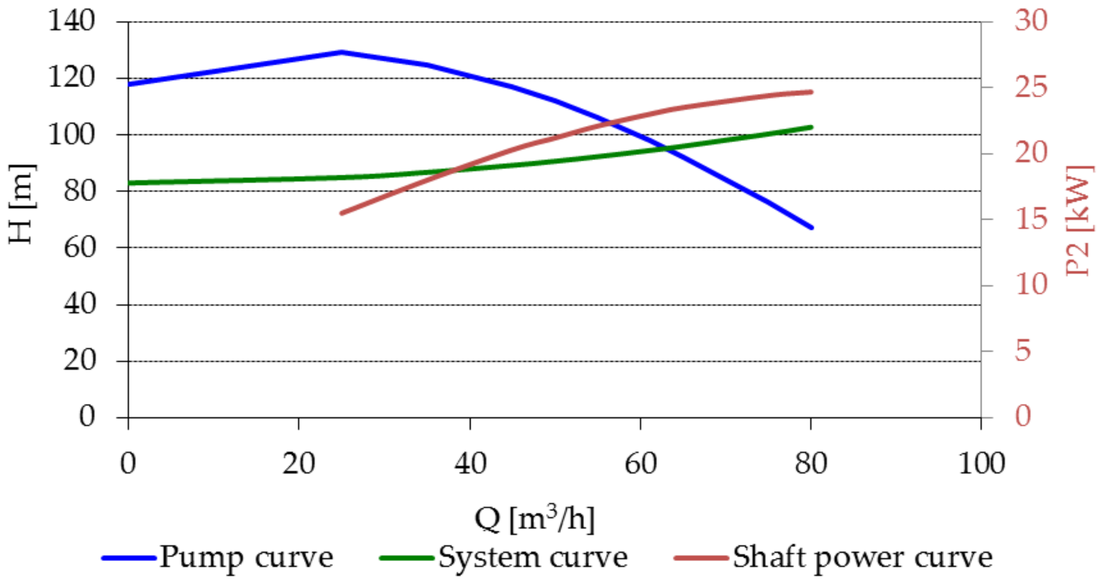
In order to perform the pumping simulation one needs to start by selecting the type of pumping: water pool or direct. For pump and motor selection, two options are available:

1. To use Caprari online catalog, or

2. To introduce data manually (without the need to use Caprari online catalog). If one is using this option it is necessary to introduce the rated flow (Q_{nom}) and rated head (H_{nom}) and to provide the different points of the pump curve (H(Q)), shaft power curve (P2(Q)) and power efficiency curve (η(P2)). It is very important to mention that it is mandatory to include the point H(Q=0) in the first curve, i.e., the height at zero flow. In addition, the pumped liquid and its density, the nominal shaft power, the rated speed (as well as its minimum and maximum), the nominal frequency and the rated voltage are also required.

Then, it is necessary to insert the system curve parameters, i.e., the static head (H_e) and the friction losses at rated flow (H_f).

With the previous parameters, the information included in the next figure is obtained.



If the type of pumping is direct, then one also needs to select both the working pressure (H) and flow (Q). Furthermore, it is also mandatory to include the first and last month of irrigation (if irrigation is all over the year, one can just select January and December accordingly).

Table 21, Table 22, Table 23, Table 24, and Table 25 summarize all these parameters (it is important to remind that the parameters of Table 23 are only necessary for direct pumping).

Table 21. System characteristics.

Parameters	**Unit**	**Description**
H_e	m	Static Head
H_f	m	Friction losses at rated flow

Table 22. Type of pumping.

Parameters	**Unit**	**Description**
Type of PV irrigation system	Dimensionless	Selection between "Stand-alone PV" or "Hybrid system" (in construction) Valid values: [1 =Stand-alone]
Type of pumping		Selection between "Pumping to a water pool" or "Direct pumping".

		Valid values: [1 =Water pool] / [2=Direct]

Table 23. Direct pumping characteristics.

Parameters	**Unit**	**Description**
Working pressure	m	Select the working pressure of the system in terms of equivalent height (in meters) Valid values: from 0 to the maximum height included in the pump curve
Working flow	m^3/h	Select the working flow of the system Valid values: from 0 to the maximum flow included in the pump curve
First month of irrigation		Select the first month of irrigation Valid values: from 1 to 12 (month of the year)
Last month of irrigation		Select the last month of irrigation Valid values: from 1 to 12 (month of the year)

Table 24. Pump characteristics.

Parameters	**Unit**	**Description**
Model		Product name
Rated flow	m^3/h	
Rated head	m	
Pumped liquid		Type of pumped liquid
Density	kg/m^3	Liquid density
Pump curve	$Q[m^3/h]$ $H[m]$	Height for different flows (at nominal power)

Shaft power curve	Q[m^3/h] P2[kW]	Shaft power (mechanical output power of the motor) for different flows (at nominal power)

Table 25. Motor characteristics.

Parameters	**Unit**	**Description**
Model		Product name
P2nom	kW	Rated shaft power
RPMnom	RPM	Rated speed used for pump data
RPMcool	%	Minimum speed, relative to the rated speed, for water cooling
RPMmax	%	Maximum speed, relative to the rated speed
Frequency	Hz	Nominal frequency
Rated voltage	V	
Power efficiency	P2[kW] Efficiency [%]	Efficiency for different shaft power values (at nominal power)

2-9 Simulation options

This tab (see Figure 20) contains the simulation options that can be selected by the user, which are summarised in Table 26, at the end of this section.

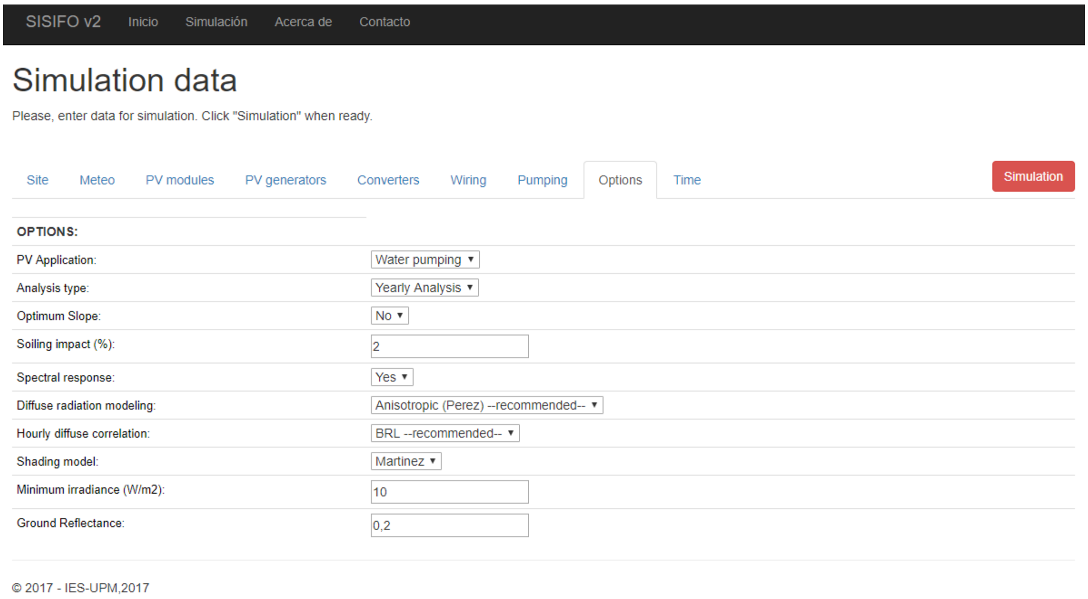


Figure 20. Simulation options tab.

2-9-1 Basic Options

The first two options, "Application" and "Analysis", indicate, respectively, the PV application to be simulated (Grid connected or Irrigation PV systems) and the type of analysis to be performed (in the current version, the simulator only performs yearly analysis).

2-9-2 Advanced Options

The next options, which should be modified by advanced users, deal with the models to be used by the sequence of algorithms, which involves two main steps. The first one is the translation of irradiance values from the horizontal surface to the plane of PV modules and second step involves the discount of power losses caused by shading, dirt, angle-of-incidence and spectrum. The transposition procedure follows the next sequence of calculations, based on previous work [11], [16]:

1. Position of the Sun, position of the PV generator surface, and incidence angle [7].

2. Shaded area on the PV generator. If this shaded area is not null and the backtracking mode of operation has been selected, the tracker rotates on the corresponding axis to eliminate the shadow [11].

3. Irradiance on the PV generator plane using different diffuse radiation models: isotropic, Hay [17] or Perez [18], which is selected in the option "Diffuse Model".

4. Dirt and incidence losses. The implemented model [19] calculates both types of losses and the user must select the degree of dust in the option "Soiling".

5. Shading losses, calculated using different the model of Martinez et al. Refinement of the previous classic model using an empirical approach [20]. This model and the previous one require specifying the number of bypass diodes or blocks along the dimensions of the PV generator. Figure 21 shows an example.

6. Spectral correction [21], selected in the option "Spectral Response".

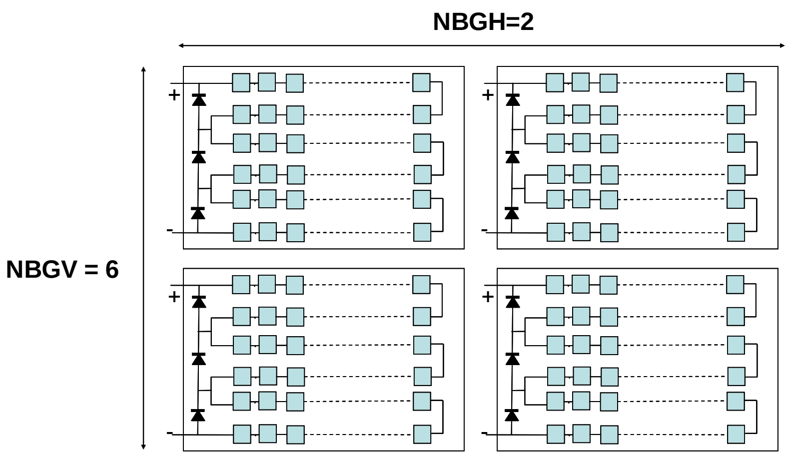


Figure 21. Example of a PV generator composed by four modules, each one with three bypass diodes. In this example, the number of bypass diodes (or groups of cells protected by the same bypass diode) in the horizontal dimension is 2, while in the vertical dimension is 6.

Finally, the last three options are:

“Minimum irradiance” is the threshold irradiance above which power can be injected into the grid. This parameter is usually provided by the inverter manufacturer. By default, its value is zero.

The “Ground reflectance” is the reflectance of the ground, which may vary from 0.1 for grass up to 0.8 for snow [22]. The default value is 0.2, which is the recommended value for the monthly mean of the ground reflectance when the value of this parameter is unknown.

The option “Daily diffuse correlation” is the global-diffuse model to be used in the estimation of the beam and diffuse components of the horizontal global irradiation, which is the first step of the generation of time series described in section 2-3. There are three available correlations: Page [2], Erbs [4] or Macagnan [5]. This option is only available if the option Synthetized Series of daily data is selected as Sky Type (see section METEO).

The option “Hourly diffuse correlation” is used to select the correlation used to calculate the irradiance values. This option is only available if the option Synthetized Series of hourly data is selected as Sky Type (see section METEO).

All the above described options are summarized in Table 26.

Table 26. Simulation options.

Parameters	**Unit**	**Description**
PV Application		PV application to be simulated. Valid values: [1 =Grid connected] / [2 =PV irrigation].
Analysis type		Analysis type. Valid values: [1 =Yearly analysis]
Soiling	%	Degree of Dust in %. Valid values: from 0 to 10%
Spectral Response	Dimensionless	Consideration of the spectral response of the PV modules Valid values: [0 =No] / [1 =Yes]
Diffuse Model	Dimensionless	Models: Isotropic, Anisotropic (Hay), and Anisotropic (Perez). The recommended one is Anisotropic

		(Perez) Valid values: [1 =Isotropic / [2 =Anisotropic (Hay)] / [3 =Anisotropic (Perez)].
Monthly Diffuse Correlation	Dimensionless	Model for the monthly diffuse fraction (only used if Sky Type is "mean"). Valid values: [0 =Database / [1=Page] / [2=Collares-Pereira] / [3=Erbs] / [4=Macagnan]
Daily Diffuse Correlation	Dimensionless	Model for the daily diffuse fraction (only used if Sky Type is "Daily synthetized Series") [0 =Database / [1=Collares-Rabl] / [2=Erbs] / [3= Macagnan] / [4=de Miguel]
Hourly Diffuse Correlation	Dimensionless	Model for the hourly diffuse fraction (only used if Sky Type is "Hourly synthetized Series"). The recommended one is BRL Valid values: [1 =Orgill-Hollands / [2 =Erbs] / [3 =BRL] / [4 =de Miguel].
Shading Model	Dimensionless	Model to calculate shading losses. Valid values: [1 =Martinez]
Minimum irradiance	W/m^2	Minimum irradiance required to generate power. Valid values: from 0 to 500 W/m^2
Ground Reflectance	Dimensionless	Ground reflectance of the surrounding floor. Valid values: from 0 to 0.8

2-10 Simulation time

The simulation time tab (see Figure 22) allows the selection of the number of days to be simulated:

- All the days, which performs the simulation for the 365 days of the year.
- Characteristic days, which only simulates with the characteristic day of each month (i.e., day numbers 17, 45, 74, 105, 135, 161, 199, 230, 261, 292, 322 and 347). It is in construction.

Another parameter to be selected in this tab is the “Simulation Step”, in minutes, which establishes the time resolution of the simulation. The solar time is used as time reference.

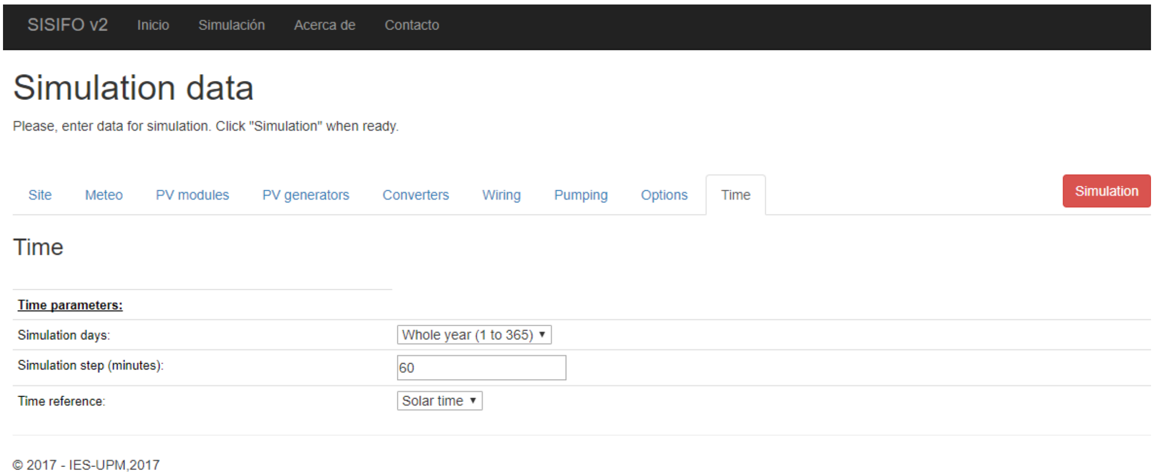


Figure 22. Simulation time tab.

2-11 Simulation

Once the options are selected by the user, the simulation starts when simulation button (in red) is pressed (see Figure 22). Next, a new tab is opened in the web browser, which shows the results of the simulation. It is worth pointing out that the simulation will only start if all the required drop-down menus are selected. These menus are indicated in Table 27.

Table 27. Tabs of the input interface and required drop-down menus to be selected in order to perform a new simulation.

Tab	Drop-down menus
Site	None.
Meteo	"Data type" , "Sky model".
PV modules	"Solar cell material" (default: Si-c), "Module power model" (default: only temperature effect).
PV generators	"Structure".
Converters	"Power efficiency curve".
Wiring	None.
Pumping (required only for water pumping)	"Type of PV system" (default: Stand-alone), "Type of pumping" (default: water pool), "First month of irrigation" (default: April), "Last month of irrigation" (default: October).
Options	"PV application" (default: Water pumping), "Analysis type" (default: Yearly Analysis), "Spectral response" (default: Yes), "Diffuse radiation modeling" (default: Anisotropic – Perez), "Monthly diffuse correlation" (default: Database), "Daily diffuse correlation" (default: Erbs), "Hourly diffuse correlation" (default: BRL), "Shading model" (default: Martinez).
Time	"Simulation days" (default: Whole year – 1 to 365), "Time reference" (default: Solar time).

3 Output interface

3-1 Overview

The output interface of SISIFO is a new webpage (opened in a new tab) where different options are displayed in the main bar (see Figure 23). Here, it is possible to see yearly, monthly and detailed results. In addition, an “exit” button is presented, which will close the results tab, maintaining the simulation tab if one wants to perform a new simulation. In the following, the results visualization will be explained.


Simulation results

Yearly results | Monthly results | Detailed results

Yearly results

Irradiations, kWh/m2	Yearly value
- horizontal	1781
- incident	2383
- effective (dust and incidence):	2282
- effective with adjacent shadows:	2282
- effective with total shadows:	2282
- effective with shading and spectrum:	2303

Figure 23. Output interface: part of yearly parameters

3-2 Yearly parameters

The first tab, displayed in Figure 23, shows the following yearly parameters in the left-hand table: irradiations, in kWh/m^2, energy yields, in kWh/kWp, pumping, in m^3/kWp, performance ratios (PR), capture and system losses and BOS efficiency (see Table 28). Besides, a breakdown of energy losses, relative to each step, is displayed in the right hand figure (see Table 29).

Table 28. Yearly parameters: irradiations, energy yields, PRs, losses and BOS efficiency.

Irradiations, in kWh/m^2
- Horizontal
- Incident
- Effective (dust and incidence)
- Effective with adjacent shadows
- Effective with total shadows
- Effective with shading and spectrum
Energy yields, in kWh/kWp
- DC
- AC
- Hydraulic
Volume of pumped water, m^3/kWp
Performance ratios, PR, in %
- DC
- AC
- Hydraulic
BOS efficiency, in %
Losses, in %
- Capture
- System

Table 29. Yearly energy losses.

Breakdown losses (relative for each step), in %
Dust and incidence
By shading
Spectral
Inverter input power
Wind
Cell temperature
Low irradiance
DC wiring
Irradiance below the threshold and the inverter's saturation
DC/AC inverter
LV wiring
Pump motor

3-3 Monthly parameters

The second tab displays in tables and figures the monthly mean values of:

- Irradiations, in Wh/m^2: horizontal, incident on the PV generator plane, effective (discounting dust and incidence losses), effective with adjacent shadow, effective with total shadows and effective with shading and spectrum (see Figure 24).
- Energy yields, in kWh/kWp, at the output of the PV generator (DC), at the inverter output (AC) and hydraulic.
- Volume of pumped water, in m^3/kWp.

- Performances ratios at the output of the PV generator (DC), at the inverter output (AC) and hydraulic.

Simulation results

Yearly results | Monthly results | Detailed results | Exit

Monthly results

Monthly mean of daily irradiations, Wh/m2	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
- horizontal	2622	3270	4581	5758	6760	7543	7716	6742	5037	3797	2727	2347
- incident	3647	4380	6091	7633	8863	10002	10397	9121	6709	5135	3683	3278
- effective (dust and incidence)	3384	4125	5832	7355	8569	9664	10055	8827	6441	4876	3439	3010
- effective with adjacent shadows	3384	4125	5832	7355	8569	9664	10055	8827	6441	4876	3439	3010
- effective with total shadows	3384	4125	5832	7355	8569	9664	10055	8827	6441	4876	3439	3010
- effective with shading and spectrum	3423	4180	5906	7430	8637	9719	10089	8872	6514	4948	3487	3044

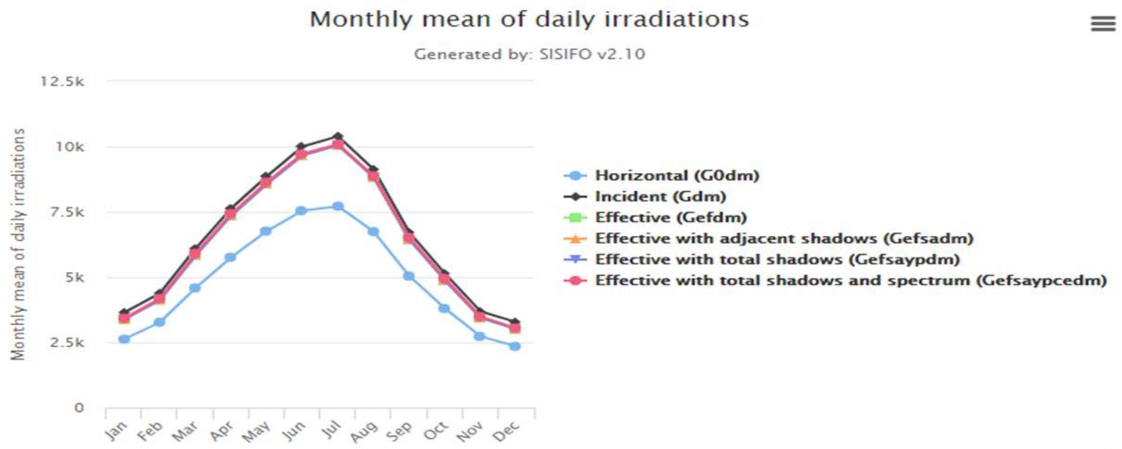


Figure 24. Output interface: part of monthly parameters.

3-4 Detailed Results

This tab allows the visualization of additional and detailed data divided in 4 main groups:

- Irradiation on the horizontal surface
- Irradiation on the inclined surface
- Electric energies
- Pumping

Monthly mean values (12 values), monthly values (12 values), and daily values (365 values) are available.

3-5 Generate technical report

This tab will be available soon and will allow the generation of a pdf technical report.

3-6 New simulation

A new simulation can be performed because the input tab is still available. This way, one can redefine some of the parameters and adjust the simulation results to an optimized case.

4 ANNEX: Simulation variables

4-1 Introduction

This annex includes a detailed list of the variables that can be selected in Yearly, Monthly and Detailed Results to be analysed.

4-2 List of simulation variables

4-2-1 Meteorological variables - Radiation on the horizontal surface

Table 30. Horizontal irradiances.

Variable	Unit	Definition
G0	$W \cdot m^{-2}$	Global
B0	“	Beam
D0	“	Diffuse

4-2-2 Meteorological variables - Radiation on the inclined surface

Table 31. Irradiances on the inclined surface.

Variable	Unit	Definition
G	$W \cdot m^{-2}$	Global
B	“	Beam
D	“	Diffuse
R	“	Reflected
Gef	“	Global effective (includes dust and incidence effects)
Bef	“	Beam effective

Def	“	Diffuse effective
Ref	“	Reflected effective
Gefsa	“	Global effective plus adjacent shading
Befsa	“	Beam effective plus adjacent shading
Defsa	“	Diffuse effective plus adjacent shading
Gefsayp	“	Global effective plus adjacent and back shading
Befsayp	“	Beam effective plus adjacent and back shading
Defsayp	“	Diffuse effective plus adjacent and back shading
Gefsaypce	“	Global effective plus adjacent and back shading, and spectral correction
Befsaypce	“	Beam effective plus adjacent and back shading, and spectral correction
Defsaypce	“	Diffuse effective plus adjacent and back shading, and spectral correction
Refce	“	Reflected effective and spectral correction

4-2-3 Meteorological variables - Daily, monthly and yearly irradiations

Daily, monthly and yearly irradiations are indicated, respectively, with the suffixes “d”, “m” and “a” after the irradiance name.

For example:

G0d is the daily horizontal irradiation, $Wh \cdot m^{-2}$ (365 values).

G0m is the monthly horizontal irradiation, $Wh \cdot m^{-2}$ (12 values).

G0dm is the monthly mean of daily horizontal irradiation, $Wh \cdot m^{-2}$ (12 values).

G0a is the yearly horizontal irradiation, $Wh \cdot m^{-2}$ (1 value).

4-2-4 PV system - Powers

Table 32. PV system powers.

Variable	Unit	Definition
PDCSP	kW/kWp	Nominal DC power
PDCPP	“	Less mismatch losses, power below the nominal one, and other effects (all these losses are included in the PRVPN parameter of PVGEN)
PDCPT	“	Less temperature losses

PDCPC	“	Less the losses in DC wiring
PDC	“	DC power at the input of the inverter after taking into account the saturation of the inverter and the irradiance threshold
PACAC	“	AC power at the output of the inverter
PAC	“	AC power at the input of the LV/MV transformer after discounting LV wiring losses between the inverter and the LV/MV transformer.
PACMTAC	“	AC power at the output of the LV/MV transformer
PACMT	“	AC power at the input of the MV/HV transformer after discounting MV wiring losses between LV/MV and MV/HV transformers
PACATAC	“	AC power at the output of the MV/HV transformer
PACAT	“	Final AC power in HV after discounting the HV wiring losses.

4-2-5 PV system - Electric energies

Daily, monthly and yearly energies are obtained by the integration of the all powers indicated in the previous section (with the exception of PPVPOT).

The names of these energies are created using the following convention. First, the initial P (of power) is replaced by E (of energy). Second, one of the suffixes “d”, “m” or “a” is added after the name to indicate, respectively, the daily, monthly or yearly energy. For example:

EACd is the daily AC energy at the input of the LV/MV transformer, in kWh/kWp (365 values).

EACm is the monthly AC energy at the input of the LV/MV transformer, in kWh/kWp (12 values)

EACdm is the monthly mean of daily AC energy at the input of the LV/MV transformer, in kWh/kWp (12 values).

EACa is the yearly AC energy at the input of the LV/MV transformer, in kWh/kWp (1 value).

4-2-6 Performance ratios

Different performance ratios are calculated: DC, AC and Hydraulic. Monthly and yearly values are presented.

4-2-7 Other performance indices

The following performance indices are also calculated, but only on yearly basis.

Table 33. Other performance indices.

Variable	Unit	Efficiency of
LCa	%	Capture losses, relative to Yr
LSa	%	System losses, relative to Yr

4-2-8 PV pumping system - Instantaneous values

Table 34. Hydraulic variables.

Variable	Unit	Definition
H	m	Head
Q	m^3/h	Flow rate
FLOW	$(m^3/h)/kWp$	Normalised flow rate

Table 35. Pumping powers.

Variable	Unit	Definition
P1	kW/kWp	Input power to the motor
P2	"	Shaft power (mechanical output power of the motor)
PH	"	Hydraulic power

4-2-9 PV pumping system - Daily, monthly and yearly parameters

Daily, monthly and yearly energies are obtained by the integration of the all powers indicated in the previous section.

The names of the energies are created replacing the initial P (of power) by E (of energy) and adding the suffixes “d”, “m” or “a”, respectively, to indicate daily, monthly or yearly energy. For example:

E1d	is the daily PV energy, in kWh/kWp (365 values).
E1m	is the monthly PV energy, in kWh/kWp (12 values).
E1dm	is the monthly mean of daily PV energy, in kWh/kWp (12 values).
E1a	is the daily PV energy, in kWh/kWp (1 value).

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