

GRAPHICAL INTERFACE FOR ELECTRICAL DIMENSIONING OF AN ON-GRID PHOTOVOLTAIC SYSTEM

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ABSTRACT:

Energy is an essential element in the development of mankind and is the engine that has made possible all the discoveries and innovations of recent decades. It is found behind the comfort we have in everyday life, whether at home, at the office, or when traveling: an optimal temperature in the room, light at anytime, appliances to ease us and make our lives more beautiful. An energy system based on renewable energy has the ability to provide electricity in an economical, sustainable, long-term, non-polluting way and can serve the increasing population. One such example is represented by photovoltaic (PV) panels, which produces electricity from captured solar energy and is one of the solutions considered for reducing energy. The dimensioning of a photovoltaic system, from a technical and economic efficiency point of view, involves the analysis of input data, output data and hence the characteristics of an efficient system. The analysis can be done analytically, but also with the help of dedicated software, the result being, in the end, a safe system in terms of preventive operation and maintenance. In the article was made the dimensioning of a system, analytical and automatic – using software application – to determine if the result obtained – the photovoltaic system – is the same regardless of the method used.

1. INTRODUCTION

Energy is an essential element in the development of mankind and is the engine that has made possible all the discoveries and innovations of recent decades. It is found behind the comfort we have in every day life, whether at home, at the office, or when traveling: an optimal temperature in the room, light at any time, appliances to ease us and make our lives more beautiful.

An energy system based on renewable energy has the ability to provide electricity in an economical, sustainable, long-term, non-polluting way and can serve a population in full population explosion. One such example is represented by photovoltaic (PV) panels, which produces electricity from captured solar energy, is one of the solutions considered for reducing energy consumption and is considered the fastest growing technology for electric power production and pollutant reduction (Aguilar-Jimenez, 2020).

The dimensioning of a photovoltaic system, from a technical and economic efficiency point of view, involves the analysis of input data, output data and hence the characteristics of an efficient system.

The analysis can be done analytically, but also with the help of dedicated software, the result being, in the end, a safe system in terms of preventive operation and maintenance (Gomaa, 2020).

Renewable energy is also an optimal solution to the problem of global warming. In terms of energy sources and combating the lack of energy, the renewable energy could represent an adequate solution. The development of renewable energy sources can also boost employment by creating jobs in new 'green' technologies. In recent years, but especially in the current period, in the context of policy changes at regional / global level, renewable energy, sustainable development and environmental protection have become main topics, of first urgency (Hudișteanu, 2021).

2. THEORETICAL CONSIDERATIONS

2.1 Solar energy

Solar energy is the most abundant energy resource on Earth. It can be captured and used in many ways, and as a renewable energy source it is an important part of our clean future.

The sun provides us with solar radiation during the day and does much more for us, so every particle of solar radiation (photon) that reaches Earth contains energy that powers our planet (Math, 2015).

Solar energy can be harnessed and transformed into usable energy using photovoltaic panels or solar thermal panels. Although solar energy accounts for only a small amount of global energy consumption, the low cost of installing solar panels means that more people in more places can take advantage of solar energy (Sornek, 2022).

2.2 Photovoltaic conversion

The photovoltaic effect namely the transformation of solar energy ("photon") into electricity ("volt") was discovered in 1839 by physicist A.Becquerel. To achieve these conversion devices called solar cells are used, made up of semiconductor materials in which a constant electric field has been artificially created (Johnston, 2021; Selimli, 2021).

The photovoltaic effect is the generation of voltage and electric current in a material upon exposure to light. It is a physical and chemical phenomenon (Barkat, 2020).

Photovoltaic/thermal (PV/T) systems are innovative cogeneration systems that ensure the cooling of photovoltaic (PV) (Hudişteanu, 2022). The photovoltaic effect is closely related to the photoelectric effect. In both cases, light is absorbed, causing an electron or other charge carrier to excite to a higher energy state. The main distinction is that the term photoelectric effect is usually used when the electron is ejected from the material (usually in a vacuum), and the term photovoltaic effect is used when the excited charge carrier is still contained in the material.

In both cases, an electric potential (or voltage) is produced by charge separation, and the light must have sufficient energy to overcome the potential barrier of excitation. In addition to direct excitation of free electrons, a photovoltaic effect can occur due to heating caused by light absorption. Heating leads to an increase in the temperature of the semiconductor material, this is accompanied by temperature gradients.

A common way for property owners to take advantage of solar energy is with a solar photovoltaic (PV) system. With the help of a solar photovoltaic system, photovoltaic panels convert sunlight into electricity (Hudişteanu, 2020). The electricity obtained from the transformation of solar energy can be used immediately, which is stored in a solar battery (Aguilar-Jimenez, 2020). Solar radiation produced by the sun, which is captured by solar panels, hits a semiconductor material (usually silicon) and knocks electrons open, setting them in motion and generating a direct electric current that can be captured with wiring and converted into alternating current using a solar inverter.

Solar photovoltaic energy was not wide spread in 1999. After that, the grow was of major importance, reaching 43.4% between 2002 and 2003. The installed capacity in the European Union was 562.3 MW in 2003. Leading the list of EU countries were Germany (397.6 MW), the Netherlands (48.63 MW), Spain (27.26 MW) and Italy (26.02 MW). For

comparison, here are the installed powers in several other countries in 2003: France (21.71 MW), Portugal (2.07 MW) and Belgium (1.06 MW), as seen in Figure 1. It is noted that it is not the countries located in southern Europe that develop the photovoltaic chain the most (Ghosh, 2021).

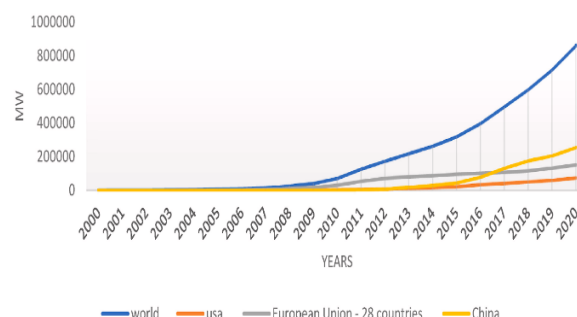


Figure 1. Solar photovoltaic capacity (Mega Watt) in the world, China, the EU and the USA

Starting with 2011 most countries started to implement PV and the most significant changes took place. As a result of changes in PV capacity, in 2023 production increased to 150.502 MW in the EU (EU) countries. More than one-third of PV capacity is produced in Germany, followed by Italy and Austria, Spain, and France (Irena, 2021; Borawski, 2023).

2.3 Photovoltaic panel efficiency

The photovoltaic cell represents an electronic device, made of semiconductor materials, which generates electron pairs and free holes by absorbing light, the charge carriers being spatially separated due to a potential barrier formed by internal discontinuities that drive electrons in the opposite direction to the gaps (Arifin, 2020).

Separating the charge carriers results in a voltage at the cell terminals and a current through a load resistance, so that the photovoltaic cell functions as an electric generator.

The efficiency of a photovoltaic cell is determined as the ratio between the power generated by the cell at the output at a specified temperature and the power of solar radiation (Al-Amri, 2021; Selimi, 2021; Hudişteanu, 2021):

$$\eta = \frac{P_M}{S \cdot E} \quad (1)$$

where P_M = cell electrical power [Wp];
 S = cell/module area [m²];
 E = global radiation incident on the surface of the cell or module [W/m²]

3. NUMERICAL PHOTOVOLTAIC SYSTEM DIMENSIONING

3.1 General input data

For example it considers a configuration of a grid-connected photovoltaic system with **150 kWp** installed power.

The choice of location. Orientation of photovoltaic panels:
- location: 47° 8' 57" North, 27° 37' 48" East (47.149, 27.629 - Iași);
- correct placement of the system in order to avoid shading;
- system orientation: South, fixed tilt 35°.

The installed power in photovoltaic modules is:

$$P_{inst} = 150 [kWp]$$

Calculation of the number of panels: choose a monocrystalline solar panel with the following technical characteristics (table no 1):

Maximum power STC (P_{max})	500 Wp
Maximum supply voltage P_{max} (V_{mp})	42,2 V
Maximum power current P_{max} (I_{mp})	11,12 A
Open circuit voltage (V_{oc})	49,9 V
Short circuit current (I_{sc})	11,95 A
Module efficiency (%)	21,2
P_{max} temperature coefficient ($C_{tP_{max}}$)	- 0,45 %/°C
V_{oc} temperature coefficient ($C_{tV_{oc}}$)	- 0,27 %/°C
I_{sc} temperature coefficient ($C_{tI_{sc}}$)	0,05%/°C
Maximum system voltage	1500 V
Maximum recommended value for maximum current protection safety	20 A
Operating temperature	- 40°C ÷ +85°C
Nominal Operating Cell Temperature (NOCT)	45°C
Dimensions	2108x1048x40 mm
Height	24 kg

Table 1. Technical characteristics of the photovoltaic panel

$$N_p = \frac{P_{inst}}{P_{max}} = \frac{150000}{500} = 300 PV \quad (2)$$

Calculation of the surface area of the photovoltaic system (Gomaa, 2020):

$$A_{SPV} = N_p \cdot A_p = N_p \cdot L_p \cdot l_p \quad (3)$$

$$A_{SPV} = 300 \cdot 2,108 \cdot 1,048 = 662,75 [m^2]$$

For the installation of solar panels, an area of at least 662,75 m² facing south is needed. Basically, the occupied area will be larger because mounting distances from the roof edges and certain technological distances necessary for the maintenance of the photovoltaic system must be provided.

3.2 Case studies

Choosing the connection diagram of panels: 3 connection variants will be analyzed to configure the subsystems, as follows:

Case 1: $N_s = 6$ strings, each string with $N_{ps} = 25$ PV linked in series

Case 2: $N_s = 5$ strings, each string with $N_{ps} = 30$ PV linked in series

Case 3: $N_s = 3$ strings, each string with $N_{ps} = 50$ PV linked in series

Calculation of photovoltaic generator characteristics

Maximum power DC (P_{maxDC}) represents the maximum power generated by the DC photovoltaic system. It must be less than or equal to the power accepted by the inverter on the DC input.

$$P_{maxDC} = N_p \cdot P_{max} = 150 \cdot 500 = 75 kW \quad (4)$$

Maximum voltage DC (V_{maxDC}) represents the maximum voltage of the photovoltaic generator. It must be less than or equal to the voltage accepted by the inverter at the DC input.

In determining this parameter, account shall be taken of:

- the number of panels in the string;
- the value of the idle voltage of one panel;
- the correction thermal coefficient for voltage;
- the minimum working temperature of the panels.

The computational relationship is as follows (Bica, 2019):

$$V_{maxDC} = N_{ps} \cdot V_{oc} \cdot \left[1 + \frac{C_{tV_{oc}}}{100} \cdot (T_{min} - T_{STC}) \right] \quad (5)$$

where: N_{ps} = number of panels connected in series

$C_{tV_{oc}}$ = thermal correction coefficient for idle voltage

V_{oc} = idle voltage of a panel

T_{STC} = standard temperature $T_{STC} = 25^\circ C$

T_{min} ($-20^\circ C$) = minimum temperature in the area.

3.3 System dimensioning

Case 1: $N_{ps} = 25$

$$V_{maxDC} = 25 \cdot 49,9 \left[1 + \frac{-0,27}{100} (-20 - 25) \right] = 1.398,5 [V] \quad (6)$$

Case 2: $N_{ps} = 30$

$$V_{maxDC} = 30 \cdot 49,9 \left[1 + \frac{-0,27}{100} (-20 - 25) \right] = 1.678,1 [V] \quad (7)$$

Case 3: $N_{ps} = 50$

$$V_{maxDC} = 50 \cdot 49,9 \left[1 + \frac{-0,27}{100} (-20 - 25) \right] = 2.796,9 [V] \quad (8)$$

Minimum voltage DC (V_{minDC}) represents the minimum voltage of the photovoltaic generator. It must be greater than or equal to the minimum voltage (accepted by the inverter at the DC input) from which the inverter starts the conversion from DC to AC.

In determining this parameter, account shall be taken of:

- the number of panels in the string;
- the value of the voltage of one panel at maximum power;
- the correction thermal coefficient for voltage;
- the maximum working temperature of the panels.

The computational relationship is as follows (Bica, 2019):

$$V_{min DC} = N_{ps} \cdot V_{mp} \cdot \left[1 + \frac{C_{tVoc}}{100} \cdot (T_{max} - T_{STC}) \right] \quad (9)$$

where: N_{ps} = number of panels connected in series,
 C_{tVoc} = thermal correction coefficient for idle voltage,
 V_{mp} = voltage panel for P_{max} ,
 T_{STC} = standard temperature $T_{STC} = 25^{\circ}\text{C}$,
 T_{max} (+70°C) = maximum temperature in the area.

Case 1: $N_{ps} = 25$

$$V_{min DC} = 25 \cdot 42,2 \cdot \left[1 + \frac{-0,27}{100} (70 - 25) \right] = 926,3 \text{ [V]} \quad (10)$$

Case 2: $N_{ps} = 30$

$$V_{min DC} = 30 \cdot 42,2 \cdot \left[1 + \frac{-0,27}{100} (70 - 25) \right] = 1.112 \text{ [V]} \quad (11)$$

Case 3: $N_{ps} = 50$

$$V_{min DC} = 50 \cdot 42,2 \cdot \left[1 + \frac{-0,27}{100} (70 - 25) \right] = 1.853 \text{ [V]} \quad (12)$$

Maximum power current ($I_{max DC}$) represents the maximum current of the photovoltaic generator. It shall be less than or equal to the maximum current accepted by the inverter at the DC input(s).

The computational relationship is as follow (Bica, 2019):

$$I_{max DC} = N_s \cdot I_{sc} \cdot \left[1 + \frac{C_{tIsc}}{100} \cdot (T_{max} - T_{STC}) \right] \quad (13)$$

where: N_s = number of strings connected in parallel to one inverter input,

V_{mp} = voltage panel for P_{max} ,
 C_{tIsc} = thermal correction coefficient for idle current,
 T_{STC} = standard temperature $T_{STC} = 25^{\circ}\text{C}$,
 T_{max} = +70°C - maximum temperature in the area.

Case 1: $N_s = 6$

$$I_{max DC} = 6 \cdot 11,95 \cdot \left[1 + \frac{0,05}{100} (70 - 25) \right] = 73,3 \text{ [A]} \quad (14)$$

Case 2: $N_s = 5$

$$I_{max DC} = 5 \cdot 11,95 \cdot \left[1 + \frac{0,05}{100} (70 - 25) \right] = 61,1 \text{ [A]} \quad (15)$$

Case 3: $N_s = 3$

$$I_{max DC} = 3 \cdot 11,95 \cdot \left[1 + \frac{0,05}{100} (70 - 25) \right] = 36,6 \text{ [A]} \quad (16)$$

Inverter dimensioning:

For the choice of inverter, five criteria will be taken into account:

- compliance with the minimum technical conditions imposed by legislation: in order to be allowed to connect to the electricity distribution network, it is necessary that the inverter complies with the grid connection requirements established by ANRE Order 228/28.12.2018 (Ghosh, 2021).

- maximum input power $P_{max DC}$: the inverter must accept at the DC input a power greater than or equal to **150 kW**.

- maximum input voltage ($V_{max DC}$) for which the inverter must accept at the DC input a **voltage greater than or equal** to minimum input voltage ($V_{min DC}$) for which the inverter begins to convert from DC to AC must be less than or equal and the maximum input current ($I_{max DC}$) representing the maximum allowable inverter current on a DC input shall be equal to or greater than the values in the table 2:

	Case 1	Case 2	Case 3
$V_{max DC}$ [V]	1.398	1.678	2.797
$V_{min DC}$ [V]	926	1.112	1.853
$I_{max DC}$ [A]	73	61	36

Table 2. Values of electrical input characteristics for the inverter

Taking into account the five criteria, one inverter was selected that meet the conditions set out above, according to the table 3.

Parameter/Type of inverter	Inverter 75KTL-C1
Maximum input power	84.200 W
Maximum input voltage	1100 V
Operating voltage range	200-1000 V
Maximum input current (per MPPT)	25 A
Maximum input current (per STRING)	18 A
Maximum short-circuit current (1 MPPT)	39 A
Full power MPPT voltage range	625-850 V
Rated input voltage	750V
Number of inputs	12
Number of MPP trackers	6

Table 3. Technical characteristics for the inverter

The total power (150kWp) will be split with 2 inverters; it will come from each string to an MPPT input of the inverter. Inverters with several independent inputs have the advantage of greater operational safety, the failure of one string or input not affecting the operation of the others (the photovoltaic

system will still produce less electricity. Also, this type of inverters is recommended for optimizing production when panel strings have different orientations.

3.4 Cable dimensioning

Solar cables are designed to have a life span of 40 years or more and at the same time minimize energy losses. It must also with stand temperatures between 20 and 80°C. The correct choice of cable is very important, because if it has too small a section, it will heat up and fail.

It will determine the maximum DC voltage generated by a row of photovoltaic panels as the product of the number of panels in a string, the voltage of a panel and a correction coefficient that depends on the permissible temperature of the cable (table no 4):

No.	Ambient temperature °C	Correction coefficient with conductor temperature	
		75°C	90°C
1	21÷25	1.05	1.04
2	26÷30	1.00	1.00
3	31÷35	0.94	0.96
4	36÷40	0.88	0.91
5	41÷45	0.82	0.87
6	46÷50	0.75	0.82
7	51÷55	0.67	0.76
8	56÷60	0.58	0.71
9	61÷70	0.33	0.58
10	71÷80	0.00	0.41

Table. 4 Temperature correction coefficient

The maximum DC voltage:

$$U_{PV} = N_{ps} \cdot U_p \cdot k_t \text{ [V]} \quad (17)$$

where: N_{ps} = number of PV ;
 U_p = maximum supply voltage for PV;
 k_t = correction coefficient with temperature;

Case 1: $U_{PV} = 25 \cdot 42,2 \cdot 0,75 = 791,2 \text{ [V]} \quad (18)$

Case 2: $U_{PV} = 30 \cdot 42,2 \cdot 0,75 = 949,5 \text{ [V]} \quad (19)$

Case 3: $U_{PV} = 50 \cdot 42,2 \cdot 0,75 = 1.582,5 \text{ [V]} \quad (20)$

- it will determine the acceptable voltage drop on the cable, normally 2-3%, which will be used to calculate the cable cross section:

$$\Delta U = 0,02 \cdot U_{pv} \text{ [V]} \quad (21)$$

Case 1: $\Delta U = 0,02 \cdot 791,2 = 15,8 \text{ [V]} \quad (21)$

Case 2: $\Delta U = 0,02 \cdot 949,5 = 19,0 \text{ [V]} \quad (22)$

Case 3: $\Delta U = 0,02 \cdot 1.582,5 = 31,6 \text{ [V]} \quad (23)$

- it will calculate the maximum direct current which shall be taken to be 1,25 times the rated short-circuit current I_{sc} of the module:

$$I_{SC} = 11,95 \text{ A} \Rightarrow \text{maximum value} = 1,25 \cdot 11,95 = 15 \text{ [A]}$$

- it will calculate the maximum direct current flowing through the conductor, taking into account the worst case:

$$I_{nom} = 1,25 \cdot 15 = 18,7 \text{ [A]}$$

The current determined above is at a temperature of 70°C. In order to determine the current value to be taken into account in the calculation of the conductor section, the temperature shall be taken into account by the correction coefficient with temperature k_t (table 4) and the number of conductors in a cable by the correction coefficient k_c (table 5):

No. of current-carrying	Adjustment factor
1-3 conductors	1.00
4-6 conductors	0.80
7-9 conductors	0.70
10-20 conductors	0.50

Table 5. Correction factor in a cable

For the numerical example presented, the ambient temperature will be considered 61÷70 °C and the cable temperature will be considered 75 °C ($k_t = 0,33$). It will consider 3 conductors in a cable ($k_c = 1$), the calculating current of the conductor section being (Bica, 2019):

$$I_{calc} = \frac{I_{nom}}{k_t k_c} = \frac{18,7}{0,33 \cdot 1} = 56,6 \text{ [A]} \quad (24)$$

Next it will calculate the cross-sectional area:

Consider a 10 m copper cable with resistivity $\rho = 1.724 \cdot 10^{-8} \Omega m$. The total resistance of the cable will be (there are two cables, one carrying and one returning between the panels and the charging controller)

$$R = 2 \cdot \frac{\rho \cdot l}{S} \quad (25)$$

From the relationship of the allowable voltage drop on the cable:

$$\Delta U = R \cdot I_{calc} = 2 \cdot \frac{\rho \cdot l}{S} \cdot I_{calc} \quad (26)$$

The minimum conductor cross section it will determined:

$$S = 2 \frac{\rho \cdot l \cdot I_{calc}}{\Delta U} = \frac{2 \cdot 1,724 \cdot 10^{-8} \cdot 10 \cdot 56,6}{4,56} = 4,78 \text{ mm}^2 \quad (27)$$

It will choose a cable with a standard section of 6 [mm²].

Cable sizing between inverter and consumers (network):

An allowable voltage drop of 2% shall be considered and the length of the connecting cable shall be 20 m:

$$\Delta U = 0,02 \cdot 230 = 4,6 \text{ [V]} \quad (28)$$

For three-phase case (for powers greater than 6-7 kW). From the relationship of inverter power:

$$P_{nec} = 3 \cdot U \cdot I \quad (29)$$

result the value of electricity:

$$I = \frac{P_{nec}}{3U} = \frac{15.000}{3 \cdot 230} = 21,74 \text{ [A]} \quad (30)$$

From the relationship of the allowable voltage drop:

$$\Delta U = RI = \frac{\rho l}{s} I \quad (31)$$

Finally it will determine the minimum conductor crosssection (copper)

$$s = \frac{\rho l I}{\Delta U} = \frac{1,724 \cdot 10^{-8} \cdot 20 \cdot 21,74}{4,6} = 1,63 \text{ [mm}^2\text{]} \quad (32)$$

It will choose a cable with a standard section of 2,5 [mm²].

4. GRAPHICAL INTERFACE FOR PHOTOVOLTAIC SYSTEM DIMENSIONING

4.1 General presentation

Cool-PV software is an application developed at Faculty of Civil Engineering and Building Services – Technical University „Ghe. Asachi” of Iasi. It is realized in the Microsoft Visual Studio platform C#, with its own resources and is intended for analyzing, performing calculations and dimensioning of a photovoltaic system, depending on the number and type of electrical receivers or estimated energy consumption (kWh / month) for a household or non-household consumer (view at <http://www.cool-pv.ci.tuiasi.ro/>).

Another function of the software is the economic calculation of investment amortization, after an analysis that takes into account all input data (location, PV orientation, tilt angle, etc.) and output data (average energy production of photovoltaic panels and photovoltaic system) over a period of 20 years.

The start page of the software is divided into 3 sections, on modules and the steps that the beneficiary must go through are materialized, in order to obtain the most accurate information, according to figure 2. The steps to be taken by the user are for information purposes only; if the application user does not intervene on predefined input data, the software warns him about not completing the algorithm entirely, but this does not mean that the output data is erroneous.

These are calculated and made available to the user according to the input data, both those predefined by the application, on which the user has not intervened, and according to the modified / entered data by the beneficiary.

In section no. 1 it can be find the main dimensioning key of the photovoltaic system (energy requirements) and the logo of the CoolPV software.

Input data:

The energy requirement can be calculated by accessing one of the 3 options:

1. number of electrical consumers owned by the beneficiary
2. power demanded (kWp)
3. estimated energy consumption (kWh/month)

In order to record the value of the **requested power** or the value of the **estimated energy consumption**, it is enough to check the desired option (ticking the radio-button corresponding to the chosen option), enter a numerical value in the text-box attached to the option and validate the value by pressing the **OK** button. After validating the estimated energy consumption or the requested power, its value can be found in the *readonly text-box Estimated energy consumption*, located at the bottom of section 2.

Figure 2. Photovoltaic system dimensioning CoolPV software

After the user has entered all the data that most faithfully represents his own conditions and the sizing method of the photovoltaic system (calculation of electricity needs depending on the degree of energy independence), he must validate this data, which will lead to the next step in the sizing algorithm. The validation is done by pressing the **OK** button with the left-click, button located immediately below *Dimensioning method* (figure no. 2).

After the data is validated, by pressing the OK button (it is recommended to review the information entered in the dedicated fields), the text-box fields in SECTION 3 will be populated with data strictly related to photovoltaic panels.

The *Panel Type* field will be populated with the photovoltaic panel type (monocrystalline, polycrystalline, amorphous, hybrid), this characteristic being read from the manufacturer's technical documentation.

The *Panel Power* field will be populated with its power, given in [Wp].

The *Panel Length* and *Panel Width* fields will be populated with the dimensions of a single photovoltaic panel, taken

from the manufacturer's technical documentation and given in [m]. The value in the *Panel Area* field is given by the length multiply by width, in [m²], in according with:

$$S_{PV} = L_{PV} \cdot l_{PV} \text{ [m}^2\text{]} \quad (33)$$

The *Conversion Efficiency* field is populated with the photovoltaic panel efficiency value, as it is also known in the specialized literature, and the efficiency value is taken from the manufacturer's technical documentation. The efficiency of the photovoltaic panel also plays an essential role in determining the amount of electricity ultimately produced by the entire photovoltaic system.

Number of panels required in the system: the calculation of electricity production is made by the value of electricity produced by 1 mp of photovoltaic panel, but in direct relation to the intensity of solar radiation in a certain area.

The total area of photovoltaic panels must be dimensioned so that it **covers the value of electricity needs:**

$$S_{total} = \frac{E_{nec}}{E_{mp} \cdot \frac{\sigma_{PV}}{\sigma_{standard}}} \quad (34)$$

where:

S_{total} = total area producing electricity;

E_{nec} = estimated energy consumption (electricity requirements)

E_{mp} = electricity produced by 1 mp of PV;

$\frac{\sigma_{PV}}{\sigma_{standard}}$ = ratio of PV yield and correction coefficient (0,202)

After identifying the total area needed to cover the estimated energy consumption, the number of photovoltaic panels will be given by the ratio between the total area and the area of a single panel:

$$N_{PV} = \frac{S_{total}}{S_{PV}}; \quad (35)$$

where:

N_{PV} = number of photovoltaic panels

S_{total} = total area producing electricity;

S_{PV} = the surface of a single photovoltaic panel.

Total power installed represents the power of all photovoltaic panels, in kWh and is given by the sum of the installed power of all photovoltaic panels:

$$P_{i total} = \sum_{i=1}^n P_{PV i}; \quad (36)$$

The required area represents the minimum area available for the installation of all photovoltaic panels. In order to activate the component responsible for economic calculation, regarding the design and operation of the photovoltaic system, the user must activate, with a left click, the checkbox assimilated to economic data. The economic calculation was made taking into account the annual inflation rate, reported to the annual consumer price index, according to data of the National Institute of Statistics. This index is determined as the ratio, expressed as a percentage, between the average price index of the current year and the average index of the previous year (or other year chosen as reference period).

As from 1992 onwards, the average price index of a given year shall be determined as the simple arithmetic average of the monthly indices for that year, calculated against the same base (October 1990=100). The annual inflation rate is calculated by subtracting 100 from the annual consumer price index, as presented on the website of the National Institute of Statistics (INS). After activating the checkbox assimilated to economic data, numerical values of materials, workmanship, etc., including the selling price of one kWh, can be entered. The calculation, the payback period and the level of return on investment are made according to the numerical values entered here.

The calculation of electricity production, separately on the 2 components (production of photovoltaic panels and production of photovoltaic system) was done in 2 ways:

1. In the first case, the **real mode** of electricity production was taken into account, with the decrease in time of the efficiency of photovoltaic panels, according to the manufacturer's technical documentation.
2. In second case, the **ideal mode** of production was taken into account; the decrease in the efficiency of photovoltaic panels over time (without degradation of photovoltaic cells over time) was not taken into account.

4.2 Electrical dimensioning module

The module dedicated to the electrical dimensioning of the photovoltaic system is accessed by pressing the "*Electric*" button in the menu bar, after the entire photovoltaic system has been dimensioned, as shown in figure no 3.

Figure 3. Electrical dimensioning of the photovoltaic system

The window that opens after accessing the "*Electric*" button is shown in figure no. 3, 4 and 5 and has the following input data, taken from the photovoltaic system sizing window:

- The value of the installed power of the photovoltaic system (P_i);
- Number of photovoltaic panels in the system (Nr_{PV});
- Maximum power value of the dimensioned system (P_{max}).

After presenting the values specific to the photovoltaic system, values that represent input data for dimensioning the values of the maximum, minimum voltages and current of the inverter, the section of direct current conductors and the section of alternating current conductors, the user must establish the number of strings and the number of photovoltaic panels connected in series, in a string.

The number of strings and the number of photovoltaic panels linked in series determine the value of the system voltage and current, values that represent input data for the inverter and must be within the range of values with which it works.

Below are presented the values of the electrical dimensioning of the photovoltaic system, on the 3 cases presented at the beginning of the application.

Figure 4. Electrical dimensioning of the photovoltaic system

Figure 5. Electrical dimensioning of the photovoltaic system

When the user presses the "Calculator" button, the graphical application calculates, after the steps presented in the numerical calculation section, the specific values of the photovoltaic generator, the sizing of the inverter and conductors.

The results obtained with the help of the **Cool-PV** application can be compared with the results obtained by analytical calculation.

4. CONCLUSION

Analyzing the results obtained by numerical calculation, as well as with the help of the Cool-PV application, **the most efficient solution** (table no. 6) is given by placing the photovoltaic panels on **6 rows, 25 pieces in turn**, thus having input on all MPPT channels of the inverter (the inverter has 6 MPPT).

	Case 1 (6x25)	Case 2 (5x30)	Case 3 (3*50)
V_{maxDC} [V]	1.399	1.678	2.797
V_{minDC} [V]	926	1.112	1.853
I_{maxDC} [A]	73,3	61,1	36,6
U_{PV} [V]	791,2	949,5	1.582,5
ΔU [V]	15,8	19	31,6
I_{nom} [A]	18,7	18,7	18,7
I_{calc} [A]	56,6	56,6	56,6
S [mmp]	6	6	6
ΔU [V]	4,6	4,6	4,6

Table 6. The final result for PV system management

The **Construction installations** field is no longer a field that is reduced to lighting, utility supply and household or industrial waste disposal.

Another important factor governing construction installations is the level of technology and automation.

In order to ensure optimal living conditions, to ensure conditions according to the norms in force in buildings with special functions, to avoid tragedies and disasters, construction installations are designed, executed and maintained in operation with the help of multiple instruments of a high technological level.

The latest technologies are used in all fields of activity and there are no longer procedures that are not computer-assisted or automated.

That is why specialists in this field must be very good specialists, well anchored in the IT area and very good connoisseurs of automation algorithms.

These specialists can be trained and perfected if simulators are increasingly used.

Also, all stages of design, execution and testing of installations and apparatus in the field of installations can be executed only with the help of simulation systems.

The simulation and dimensioning software of photovoltaic systems is not only a tool to support students, electricians, technicians and installation engineers, but a way to train new specialists, to educate their skills, to improve them, to accustom them to use all the tools in the field of modelling and simulation to obtain maximum efficiency in design and execution.

Finally, we can quote Paulo Coelho who said that “the great mystery that the Divinity revealed to the world was fire. Not just the one capable of warming up, but the one who turns wheat into bread”; and this is precisely the role of modern man: the transformation of wheat into bread.

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