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# INDUSTRIAL PLANTS II

## Chapter nine (part 2):
## Solar photovoltaic systems

**DOUBLE DEGREE MASTER IN**

**“PRODUCTION ENGINEERING AND MANAGEMENT”**

**CAMPUS OF PORDENONE**

**UNIVERSITY OF TRIESTE**

## Dimensioning of a photovoltaic plant

The dimensioning of a photovoltaic plant aims to maximize the conversion of solar radiation into electricity annually available. It is necessary, in the design phase of installation, choose the right solar module, considering the availability of free space on which to install the photovoltaic generator, the availability of solar energy and the energy gain estimate. You must define the best trade regime of the energy produced: net metering or total sale of energy. This aspect has a fundamental role in the identification of the tax incentive rate and the success of the investment.

## Dimensioning of a photovoltaic plant

The design principle usually used for a photovoltaic generator is to maximize the collection of solar radiation annual available. In some cases, the design criterion may be to optimize energy production during certain periods of the year. The electricity that a photovoltaic plant can produce in a year depends mainly on the availability of solar radiation, the orientation and inclination of the modules, and the yield of the photovoltaic plant.

Dimensioning of a photovoltaic plant

Since solar radiation is variable in time, to determine the electrical power that a plant can produce in a fixed time interval, you considering the solar radiation relative to that time interval, assuming that the performance of the modules are proportional to irradiation. The values of the average solar radiation in Italy can be inferred from: UNI 10349, the European solar atlas that is based on data recorded by the CNR-IFA (Institute of Physics) in the decade from 1966 to 1975 and that shows maps of isoradiative Italian and European territory on horizontal surface tilted and database ENEA.

Dimensioning of a photovoltaic plant

The values of the radiation have a meaning probabilistic, i.e. an expected value and certainly not. Starting from the average annual radiation $E_{ma}$ to obtain the expected produced energy per year $E_p$ we have:

$$E_p = E_{ma} \cdot \eta_{BOS} \qquad (\mathrm{kWh/kWp})$$

where:

$\eta_{BOS}$ = total performance of all photovoltaic system components downstream of the panels (inverter, connections, losses due to the temperature effect, shading losses, losses due to reflection).

This performance, in a system properly designed and installed, can be between 0.75 and 0.85.

Dimensioning of a photovoltaic plant

Instead taking into account the average daily radiation $E_{mg}$, to obtain the expected produced energy per year $E_p$ using the relationship:

$$E_p = E_{mg} \cdot 365 \cdot \eta_{BOS} \qquad \text{(kWh/kWp)}$$

## Dimensioning of a photovoltaic plant

For the dimensioning of a photovoltaic plant are need to know:

- the weather features of the site, or the annual insolation, and possibly the season;
- the characteristics of the load to be supplied, especially indispensable for stand-alone systems to an appropriate dimensioning of the storage unit;
- the requirements of service continuity.

## Dimensioning of a photovoltaic plant

The basic criterion for the design of a photovoltaic system is the energy balance between the energy collected by the solar radiation and the energy absorbed by the user. Established the necessary power to users is estimated, according to the area available, the photovoltaic capacity installed.

It is important to size the field of generation according to a layout that allows to avoid mutual shading between the modules. If these are arranged in parallel rows is good, in first approximation, that the distance between the rows is at least two times the length of the photovoltaic module.

## Dimensioning of a photovoltaic plant

The analysis of the components of the system, in their peculiarities to the type of plant to be built, is one of the most important parts of the project. On the basis of this study, we start at the proper stage of design, in accordance with the technical regulations of reference, in order to obtain a plant corresponding to the so-called "rule of art".

## Dimensioning of a photovoltaic plant

You should try sizing the photovoltaic plant in the two solutions:

a) plant stand-alone

You identifies a daily load $C_e$ (kWh/day).

The system is isolated from the network and then the sizing is carried out on winter period.

You must have the value of the average sunshine $h_{eq}$ equal to the value of statistical sunshine average for climate in December $h_{eq,dicembre}$ (Table), corresponding to the hours of sunshine equivalents related to kWh/m$^2$ day.

| Band climatic | Average value in December (kWh/m$^2$ day) | Average value in July (kWh/m$^2$ day) | Average value in the year (kWh/m$^2$ day) |
|---|---|---|---|
| North (Milan) | 1,3 | 5,6 | 3,6 |
| Center (Rome) | 2,7 | 6,4 | 4,7 |
| South (Trapani) | 3,5 | 7,1 | 5,4 |
| Alpine resorts | 3,3 | 5,4 | 4,4 |

Dimensioning of a photovoltaic plant

You should try sizing the photovoltaic plant in the two solutions:

a) plant stand-alone

For systems connected to the network are assumed instead $h_{eq}$ nnual averages relating to the different climatic zones.

The power to be installed P is equal to:

$$P = \frac{C_e}{h_{eq}} \cdot \frac{1}{\eta_{ib}}$$

where:

$\eta_{i,b}$ = performance of the inverter and batteries

<u>Dimensioning of a photovoltaic plant</u>

You should try sizing the photovoltaic plant in the two solutions:

a) plant stand-alone

Nota la potenza di picco del modulo $W_p$, è possibile definire il numero di moduli che devono essere utilizzati n:

$$n = \frac{P}{W_p}$$

Referring to business forms, with a given conversion efficiency and specific surface area, you can check the voltage supplied.

Dimensioning of a photovoltaic plant

You should try sizing the photovoltaic plant in the two solutions:

a) plant stand-alone

The modules are formed from a number of cells electrically connected together in series, so as to form a single component. A series connection of several modules constitutes itself a string, which, connected in parallel with the other strings, the generic form subfield; the union of subfields is the generic photovoltaic field.

The photovoltaic field, along with the control system and power conditioning, constitutes the photovoltaic plant.

Dimensioning of a photovoltaic plant

You should try sizing the photovoltaic plant in the two solutions:

a) plant stand-alone

In this case, must be dimensioned the batteries; therefore, assuming to have an autonomy of 4 days in complete absence of insolation, the storage capacity of the request C is equal to:

$$C = \frac{C_e \cdot n_{giorni,acc}}{\eta_{i,acc}}$$

where:

$n_{giorni,acc}$ = number of days of storage;

$\eta_{i,acc}$ = performance of the inverter and the storage system, that is, its energy yield during the discharge process as to ensure adequate service life of the batteries, you can not download more than 80%. The average yield is 0.65.

Dimensioning of a photovoltaic plant

You should try sizing the photovoltaic plant in the two solutions:

a) plant stand-alone

Whereas an operating voltage of the installation of a certain tension $V_{impianto}$ e you can determine the ampere hour of batteries $A_h$:

$$Ah = \frac{C}{V_{impianto}}$$

With this dimensioning the range is greater than 4 days (usually 5 or 6), whereby the battery capacity increases if the charge takes place in a long time, exceeding 10 hours to which refers the plate data on which is calculated the yield value of 0.65.

Even in cloudy weather, the generator receives a share widespread, however, that is converted into electrical energy.

Dimensioning of a photovoltaic plant

You should try sizing the photovoltaic plant in the two solutions:

a) plant stand-alone

The amount of energy generated in a year $E_{el,annua}$ (kWh), ssuming the average annual $h_{eq}$, is:

$$E_{el,annua} = n \cdot W_p \cdot h_{eq} \cdot \eta_{ib} \cdot 365$$

Assuming, therefore, to have a daily load in December $C_e$ of 3,4 kWh/giorno and assuming a $h_{eq}$ middle of December of 2,7 kWh/m$^2$ day, the power to be installed is:

$$P = \frac{C_e}{h_{eq}} \cdot \frac{1}{\eta_{ib}} = \frac{3,4}{2,7} \cdot \frac{1}{0,8} = 1,57 \;\; kW_p$$

Dimensioning of a photovoltaic plant

You should try sizing the photovoltaic plant in the two solutions:

a) plant stand-alone

Assuming to use modules of peak power unitary $W_p$ equal to 60 $W_p$, the number of modules to be used are :

$$n = \frac{P}{W_p} = \frac{1.570}{60} = 26 \quad \text{modules}$$

The modules have a conversion efficiency of 13% and a surface area of 0.45 $m^2$, must be inclined at an angle equal to the latitude of the site and provide a voltage of 16 V, obtaining a photovoltaic field voltage of 24 V to charge the battery.

Dimensioning of a photovoltaic plant

You should try sizing the photovoltaic plant in the two solutions:

a) plant stand-alone

The storage capacity per 4 day of autonomy is:

$$C = \frac{C_e \cdot n_{giorni,acc}}{\eta_{i,acc}} = \frac{3,4 \cdot 4}{0,65} = 21 \ kWh$$

Considering an operating voltage of 24 V system (12 elements of 2 V), you will determine the ampere hour of the batteries $A_h$:

$$Ah = \frac{C}{V_{impianto}} = \frac{21000}{24} = 875 \ Ah$$

The amount of energy generated in a year $E_{el,annua}$ (kWh), assuming the average annual of $h_{eq}$ equal to 4,7 kWh/m$^2$ day is:

$$E_{el,annua} = n \cdot W_p \cdot h_{eq} \cdot \eta_{ib} \cdot 365 = 26 \cdot 60 \cdot 4,7 \cdot 0,65 \cdot 365 = 2.140 \ kWh$$

## Dimensioning of a photovoltaic plant

You should try sizing the photovoltaic plant in the two solutions:

b) plant grid connected

In this plant, the group of batteries is not necessary.

It gives energy to the grid during production hours and is taken when you have insufficient sunlight, like a battery infinite capacity.

It is based on the number of hours equivalent average annual $h_{eq}$, whose values are given in Table

| Band climatic | Average value in December ($kWh/m^2$ day) | Average value in July ($kWh/m^2$ day) | Average value in the year ($kWh/m^2$ day) |
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Dimensioning of a photovoltaic plant

You should try sizing the photovoltaic plant in the two solutions:

b) plant grid connected

You can consider the average daily load $C_e$ (kWh/giorno), which allows you to determine the power to install P which is:

$$P = \frac{C_e}{h_{eq}} \cdot \frac{1}{\eta_{isi}}$$

where:

$\eta_{isi}$ = performance of the inverter, system of power conditioning and interfacing to the network and various losses such as those caused by the heating of the modules (mean value 0.85).

Dimensioning of a photovoltaic plant

You should try sizing the photovoltaic plant in the two solutions:

b) plant grid connected

Note the peak power of module $W_p$, you can define the number of modules that have to be used n:

$$n = \frac{P}{W_p}$$

The modules must provide a certain tension and must occur as the n modules are connected in m strings that are connected in parallel, while the modules are connected in series.

The amount of energy generated in a year $E_{el,annua}$ (kWh), assuming the average annual of $h_{eq}$, is:

$$E_{el,annua} = n \cdot W_p \cdot h_{eq} \cdot \eta_{isi} \cdot 365$$

Dimensioning of a photovoltaic plant

You should try sizing the photovoltaic plant in the two solutions:

b) plant grid connected

Assuming, therefore, to have a daily load $C_e$ of 8,5 kWh/day and assuming a $h_{eq}$ annual average of 4,7 kWh/m$^2$ day, the power to be installed is:

$$P = \frac{C_e}{h_{eq}} \cdot \frac{1}{\eta_{ib}} = \frac{3,4}{4,7} \cdot \frac{1}{0,85} = 0,85\ kW_p$$

Assuming to use modules of peak power unitary $W_p$ equal to 60 Wp, he number of modules to be used are:

$$n = \frac{P}{W_p} = \frac{850}{60} = 14 \ \text{mod}\,ules$$

Dimensioning of a photovoltaic plant

You should try sizing the photovoltaic plant in the two solutions:

b) plant grid connected

The modules provide 16 V and per connect to the network at 220 V the 36 modules are connected in 3 strings of 12 modules each. The strings are connected in parallel, while the modules 12 are connected together in series.

The amount of energy generated in a year $E_{el,annua}$ (kWh), assuming the average annual heq of $h_{eq}$ equal to 4,7 kWh/m$^2$ day is:

$$E_{el,annua} = n \cdot W_p \cdot h_{eq} \cdot \eta_{ib} \cdot 365 = 14 \cdot 60 \cdot 4{,}7 \cdot 0{,}65 \cdot 365 = 936\, k\mathrm{Wh}$$

Dimensioning of a photovoltaic plant of a reality industrial

The purpose of the project is to provide technical guidance for the construction of a photovoltaic plant with a rated power of 125 kWp, intended to operate in parallel with the electricity distribution network.

This plant will be located in the town of Treviso for which they derived their climate data and solar radiation according to UNI 10349.

The photovoltaic system will be installed on the roof of an industrial building with a pitched asbestos roof. This coverage allows you to carry the load of the solar modules monocrystalline silicon, so it is expected the use of solar modules in thin film (amorphous silicon).

Dimensioning of a photovoltaic plant of a reality industrial

The plant will have a fully automatic operation; In fact, during the hours of the day, when you reach a minimum threshold of irradiation on the surface of the modules, the system will automatically begin to chase the optimum operating point of the field, changing the voltage (current) on the side continues to extract the maximum power of plant.

It is interesting but consider that the Fourth Energy Account you can turn this into an investment cost, since the installation of the system, contextual remediation of asbestos, to receive an award for all the energy produced, with an increase of incentive in c€/kWh. In this way, in the face of increased spending, you also has a higher income and a new roof is no longer a cost-repayable, but a productive investment that can pay off the costs and generate a profit.

Dimensioning of a photovoltaic plant of a reality industrial

The photovoltaic modules expected to be tested and verified by accredited laboratories and the inverters will be certified Enel DK 5940. At the final testing the tester shall verify compliance with the following two conditions (valid for power plants exceeding 50 kWp and less than 1,000 kWp):

$$P_{CC} > 0{,}85 \cdot P_{nom} \cdot \frac{I}{I_{STC}}$$

where:

$P_{CC}$ = current power measured at the output of the photovoltaic generator, with accuracy better than ± 2% (kW);

$P_{nom}$ = rated power of the photovoltaic generator (kW);

I = irradiation measured on the surface of the modules, with accuracy better than ± 3% ($W/m^2$);

$I_{STC}$ = irradiation in standard test conditions of 1000 $W/m^2$.

Dimensioning of a photovoltaic plant of a reality industrial

This condition must be verified for I > 600 W/m$^2$:

$$P_{CA} > 0{,}9 \cdot P_{CC}$$

where:

$P_{CA}$ = active power into alternating current measured at the output of the conversion assembly with accuracy better than ± 2%.

This condition will be checked for PCA > 90% of the rated power of the group conversion.

Dimensioning of a photovoltaic plant of a reality industrial

Will not be admitted the parallel of strings are not perfectly identical to each other for exposure and/or brand and/or model and/or number of modules used. Each module will be equipped with by-pass diode.

The photovoltaic array will be exposed, with an azimuthal orientation at 0° to the south and have an inclination to the horizontal of 13° (tilt). Such exposure is the most suitable in order to maximize the energy producible.

Dimensioning of a photovoltaic plant of a reality industrial

The plant will be installed in an industrial building is not subject to constraints on the landscape and building integrated with a pitched roof building under redevelopment. He was elected a reduction factor of the shadows of 0.95, thus ensuring that the energy losses resulting from the effects of shading does not exceed 5% annually and factor of albedo corresponding to that of the asphalt aged.

It defines factor of albedo of the portion of the global radiation incident on a horizontal surface that is reflected

Dimensioning of a photovoltaic plant of a reality industrial

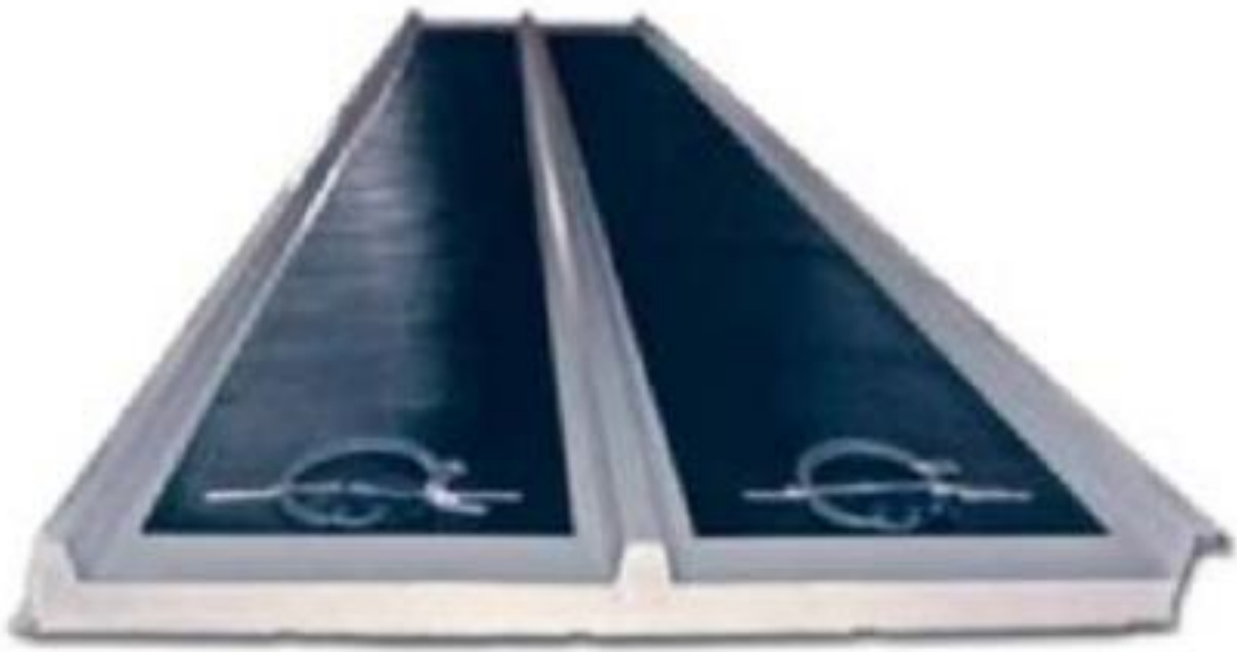
The photovoltaic plant will consist of 1088 modules with silicon cells triple junction amorphous, of which:

- 680 modules divided into 40 strings each having 17 modules of the nominal power of 144 Wp, had VOC voltage of 46.2 V, the short circuit current ISC of 5.3 A, voltage at maximum power VMP of 33 V, the current at maximum power IMP of 4.36 A, having dimensions of 5486 x 394 mm, weight of 7.7 kg and degree of efficiency of 6.66%;
- 408 smaller modules divided into 12 strings of 34 modules of the nominal power of 68 Wp, had VOC voltage of 23.1 V, the short circuit current ISC of 5.1 A, voltage at maximum power VMP of 16.5 V, the current IMP at maximum power of 4.13 a, having dimensions of 2849 x 394 mm, weight of 3.9 kg and degree of efficiency of 6.66%;

for a total area of the plant of 1928 $m^2$.

Dimensioning of a photovoltaic plant of a reality industrial

The photovoltaic plant will consist of 1088 modules with silicon cells triple junction amorphous



Dimensioning of a photovoltaic plant of a reality industrial

Photovoltaic modules convert sunlight directly into electricity through a technology called "triple junction". Each solar cell is composed of three different overlapping sub compartments, each of which absorbs a part of the solar spectrum, which allows an increase in efficiency especially at low levels of radiation and scattered light, so that does not require exposure to South oriented either perpendicular to the inclination of the solar rays.
These panels are not affected by the decrease of performance at high summer temperatures, typical of crystalline silicon panels, and are guaranteed to maintain peak power of at least 80% for 20 years and certified IEC 61646. In the presence of shadows, the panels, thanks to the by-pass very narrow adopted in the triple junction, have a very low loss of efficiency compared to that of crystalline panels in the same conditions.

Dimensioning of a photovoltaic plant of a reality industrial

The total power to be achieved will be equal to:

$$(680 \times 144) + (408 \times 68) = 125664 \ W_p$$

with a voltage VMP at 25°C of 561 V, a current at maximum power:

- 4.36 x 40 = 174.4 A of inverter 1;
- 4.13 x 12 = 49.56 A of inverter 2

Dimensioning of a photovoltaic plant of a reality industrial

The voltage values to the various operating temperatures (minimum, maximum and operating) fall within the range of acceptability admitted by the inverter. The modules will be provided with by-pass diodes. Each string of modules will be equipped with a blocking diode to isolate each string from the other in the event of accidental shading, faults etc. The modules are glued on each sheet-metal mechanically fastened to the existing roof.
The plant has panels that do not just fit inside the building envelope, but replace part of the architectural elements such as the roof so as to be classified as "innovative" as to access the specific rate expected for the reference year and depending on the field of power considered.

Dimensioning of a photovoltaic plant of a reality industrial

The conversion assembly consists of two static converters (inverters). Each DC/AC inverter used is fit for the transfer of power from the PV array to the network of the distributor, in accordance with regulatory requirements and technical safety standards. The values of the voltage and input current of this device are compatible with those of the respective photovoltaic field, while the values of the voltage and output frequency are compatible with those of the network to which is connected the plant.

Dimensioning of a photovoltaic plant of a reality industrial

The characteristics of the two inverters are:

- power indicative of the photovoltaic field: minimum 80 kWp, maximum 125 kWp, rated AC 100 kW, maximum open circuit voltage 800 VCC, MPPT range 330-700 VCC, maximum input current ACC 320, operating voltage 400 VCA, operating range 340-460 VCA, frequency range from 49.7 to 50.3 Hz, rated current 145 ACA, maximum current 182 ACA, maximum yield 96.1%, dimensions 800 x 800 x 1900 mm and weight of 720 kg;

Dimensioning of a photovoltaic plant of a reality industrial

The characteristics of the two inverters are:

- power indicative of the photovoltaic field: minimum 20 kWp, maximum 30 kWp, rated AC 25 kW, maximum open circuit voltage 800 VDC, MPPT range 330-700 VDC, maximum input current ACC 80, operating voltage 400 VAC, operating range 340-460 VAC, frequency range from 49.7 to 50.3 Hz, rated current 36 ACA, maximum current 46 ACA, maximum yield 96.1%, dimensions 555 x 720 x 1200 mm and weight of 300 kg.

Dimensioning of a photovoltaic plant of a reality industrial

As for the electrical panels, will be installed on the side of a framework DC (direct current) of each converter for isolation and protection of the strings and a framework of parallel on the AC (alternating current), within a cassette downstream of static converters for measurement, the connection and control of the output from the inverter sizes. Within this framework, it will be added to the system interface to the network and the counter output of the distributing company for electricity distribution ENEL S.p.A.

Dimensioning of a photovoltaic plant of a reality industrial

The electrical wiring will occur by means of cables with insulated copper having as requirements:

- section of souls in copper at 1 mm x 1.5 A;
- FG7 whether outdoors or in conduits in underground tracks;
- type N07V-K if within ducts of buildings.

Furthermore, the cables will be in accordance with CEI 20-13, CEI 20-22 and CEI 20-37, marking IMQ, staining of souls according UNEL and degree of isolation of 4 kV.

Dimensioning of a photovoltaic plant of a reality industrial

To ensure the safety of those who work on the plant during the verification or adjustment or maintenance, the conductors will have the following colors:

- protective conductors: yellow-green (required);
- neutral conductors: light blue (required);
- phase conductors: gray / brown;
- conductor circuits for DC: clearly signed with indication of the positive "+" and negative "-".

Dimensioning of a photovoltaic plant of a reality industrial

You notice that the sections of the conductors of the photovoltaic plants are definitely over-sized for the current and the limited distances. With these sections, the potential drop is contained within 2% of the measured value from any module posed to the conversion assembly.

The system control and monitoring of the system allows, by means of a PC and a specific software to interrogate the system at any instant in order to verify the functionality of the inverters installed with the opportunity to view the magnitudes techniques (voltage, current , power, etc.) of each inverter. You can read in the event log of all electrical converter of the days previous to the current one.

# Solar photovoltaic systems

<u>Dimensioning of a photovoltaic plant of a reality industrial</u>

The photovoltaic array will be managed as IT system, ie with no pole earthed. The strings will be constituted by the series of individual modules and individually disconnectors, equipped with blocking diode and protection against overvoltage. Will be provided the electrical isolation between the current system and the network or security-sensitive current only in the case of single-phase systems. May be different technical solutions provided that they comply with applicable regulations and the good rule of art. For safety, if the user network or part of it is deemed unfit to bear the larger current capacity available for the contribution of the photovoltaic system, the network itself or the affected part must be appropriately protected. The support structure will be regularly connected to the earth system already in the building.

Dimensioning of a photovoltaic plant of a reality industrial

According to UNI 8477-2 and UNI 10349, calculated on the irradiation modules exposed to 0° with respect to the South and inclined relative to the horizontal of 13° with a factor of albedo selected and aged asphalt is equal to 1495 kWh/m$^2$. The power to the STC conditions (irradiation of the modules of 1000 W/m$^2$ at 25°C temperature) results to be:

$$P_{STC} = P_{MODULO} \cdot N_{MODULI} = 144 \cdot 680 + 68 \cdot 408 = 125.664 \ \ W_p$$

Considering an efficiency of Balance of System (BOS) of 85%, which takes into account the losses due to many factors such as higher temperatures, dusty surfaces of the modules, differences in performance between the modules, losses due to the power conversion system on the side CA, will be equal to:

$$P_{CA} = P_{STC} \cdot 0{,}85 = 106.814 \ \ W_p$$

Dimensioning of a photovoltaic plant of a reality industrial

The energy can be produced on an annual basis by the photovoltaic plant E (kWh/year) is given by:

$$E = \left( I \cdot A \cdot K_{OMBRE} \cdot R_{MODULI} \cdot R_{BOS} \right)$$

where:

I = average annual radiation = 1415 kWh/m$^2$;

A = total area of the modules = 1927 m$^2$;

$K_{OMBRE}$ = reduction factor of the shadows = 0,95;

$R_{MODULI}$ = performance of conversion of the modules = 6,66%;

$R_{BOS}$ = performance of the BOS = 85%.

This energy can be produced on an annual basis if there are no interruptions of service is equal to:

$$E = \left( 1415 \cdot 1927 \cdot 0{,}95 \cdot 0{,}0666 \cdot 0{,}85 \right) = 146.640 \;\; kWh / anno$$

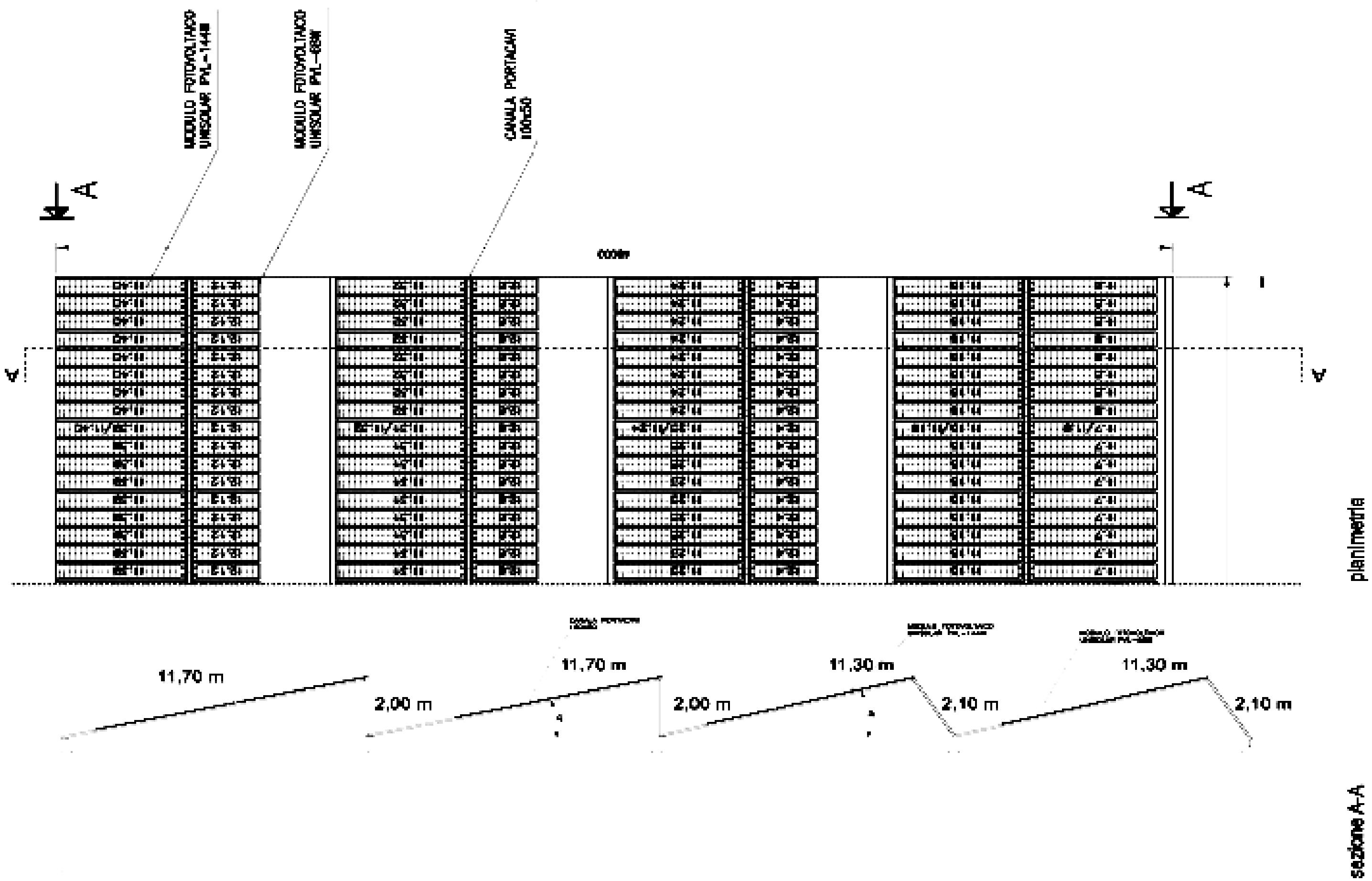
Dimensioning of a photovoltaic plant of a reality industrial

The meters of energy produced will be:

- un misuratore dell'energia totale prodotta dal sistema fotovoltaico, fornito e posato a cura dell'installatore dell'impianto, sul quadro della CA del sistema, oppure direttamente integrato nell'inverter;
- un contattore di energia di tipo elettromeccanico con visualizzazione della quantità di energia ceduta alla rete elettrica esterna e sarà posto a cura del Distributore di Energia Elettrica.

Dimensioning of a photovoltaic plant of a reality industrial

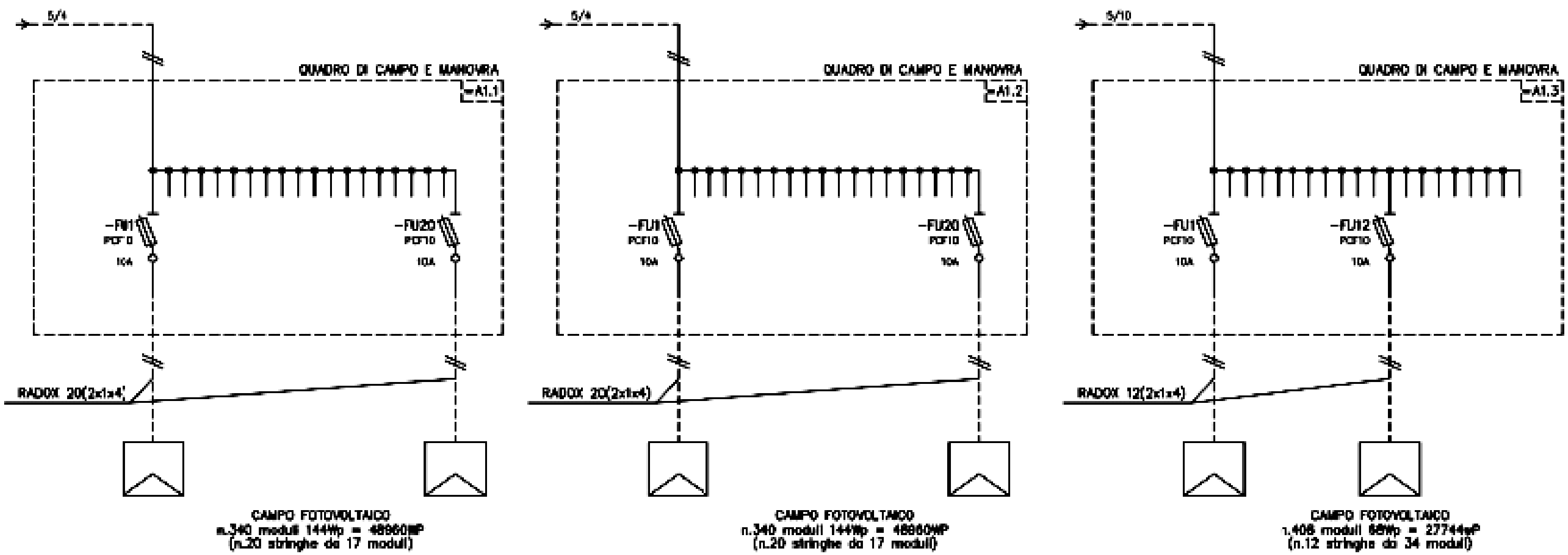
The figure shows the layout of the plant on the roof



# Solar photovoltaic systems

<u>Dimensioning of a photovoltaic plant of a reality industrial</u>

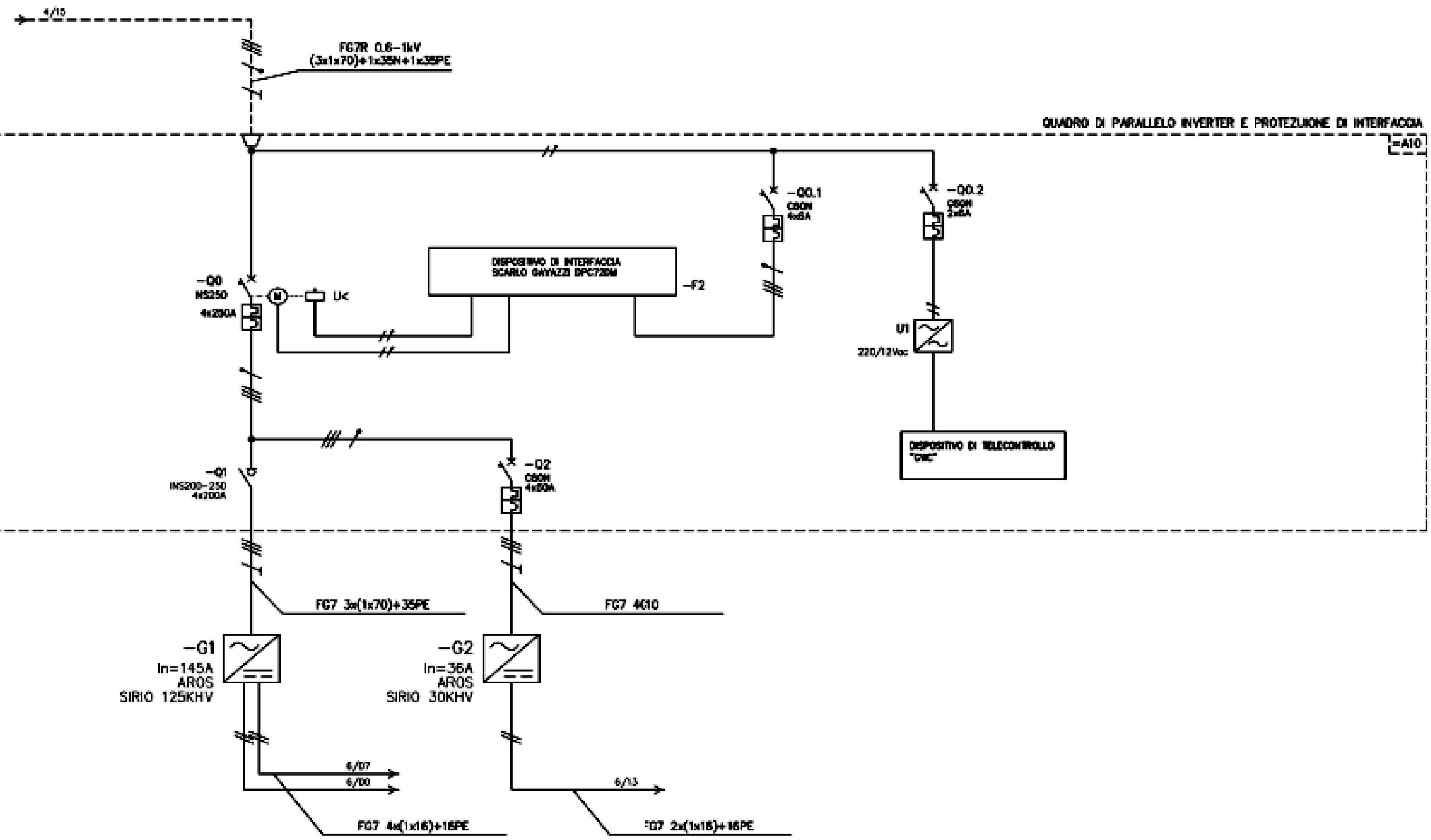
The figure shows the single line diagram of the system



# Solar photovoltaic systems

<u>Dimensioning of a photovoltaic plant of a reality industrial</u>

The figure shows the single line diagram of the system



Dimensioning of a photovoltaic plant of a reality industrial

The analysis of economic feasibility aims to show the benefits achievable by operation of a photovoltaic system. The revenues that are obtained with the connection of the plant to the grid during the useful life of the plant, estimated at 25 years, consist of:

- energy produced by the plant and rewarded by the Electricity Services Operator (GSE) with an incentive to the level of architectural integration and the power class of the facility;
- energy, which is injected into the network of the local electrical distributor in dedicated withdrawal regime, is priced by GSE, which recognizes the user producer market price refers to the area where the plant is located.

Dimensioning of a photovoltaic plant of a reality industrial

The installation of a photovoltaic system requires a high initial investment, whereas the operating costs are limited, including maintenance costs, since in most cases the system has no moving parts. These costs are estimated at around 1% per annum of the cost of the system and includes an insurance policy against theft and bad weather conditions that could damage the system, and must be taken every 10 years the charges for the replacement inverter.

Dimensioning of a photovoltaic plant of a reality industrial

A photovoltaic plant is made up of different components, although in the initial investment for the higher cost is due to the photovoltaic modules that account for over 70% of the total. The inverter comprised of automatic and protection accounts for about 10%, while the complementary at 100 is the remainder part covering the costs of planning, transport and installation. In the preliminary phase of the project, the budget can be drawn considering the average costs offered by the market, or on the basis of a first analysis you want to identify the magnitude of the planned spending.

To the values of 2012 the plant involves an investment of around 3,700 €/kWp.

Dimensioning of a photovoltaic plant of a reality industrial

The analysis of the investment should carefully consider the following aspects:

- installation cost per kW, which depends substantially on the type of structure and the complexity of installation;
- maintenance costs, for which it is generally considered the 1% of the initial investment for each year of operation;
- manufacturability of energy in kWh/year, which depends on the geographical location, the orientation of the panels;
- remuneration of the energy produced per kWh, which is obtained as the sum of two factors: the incentive rate to which you are entitled and the sale of the energy fed into the grid.

Dimensioning of a photovoltaic plant of a reality industrial

The economic fattibility is done by the cost-benefit analysis, which consists of a comparison between the initial investment and the amount of the discounted cash flow that is assumed to be positive over the life of the plant (25 years). If the evaluation were to prevail, the period for the investment, the same is not convenient.

To represent in a simplified way, the feasibility aims to determine the gross profit $U_{L,i}$, the many years of a particular investment, the difference from the revenues $R_i$ and costs operational $C_i$ of year j-th due to the photovoltaic plant.

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To the values of 2012 has an incentive tariff of 0.38 €/kWh, an average resale price of the energy produced by 0.079 €/kWh, estimated annual energy inflation and inflation of 2.5%.

The first year of operation is estimated manufacturability electricity plant 139,608 kWh with a remuneration based on the Energy Account of € 53,051.00 and revenues on electricity sales of € 11,029.00, resulting in a total revenue of € 64,080.00.

In the first twenty years of operation is estimated producibility of 2,589,809 kWh of electric power plant with a remuneration based on the energy account of € 984,127.00 and revenues on electricity sales of € 259,602.00, which involves a total revenue of € 1,243,729.00.

# Solar photovoltaic systems

Dimensioning of a photovoltaic plant of a reality industrial

A photovoltaic system with an output of 126 kWp saves about 0.67 kg of $CO_2$ per kWh produced, compared with a conventional thermal power plant fuel oil, thus avoiding during the entire life of the system, entering about 1,750 tons of carbon dioxide.

Dimensioning of a photovoltaic plant of a reality industrial

Operating costs are an important aspect for the evaluation of the profitability and refer to the costs generated by the operation of the system with the exception of depreciation and lease payments, which are not computable. In this case the operating costs consist of the following items:

- cost of connection and metering of electricity fed into the grid;
- cost due to the insurance policy is another fixed operating expense amounting to € 1414.00 and is applicable over the entire life of the system;
- costs due to routine maintenance and repairs (every 10 years to replace inverter) system;

Dimensioning of a photovoltaic plant of a reality industrial

Operating costs are an important aspect for the evaluation of the profitability and refer to the costs generated by the operation of the system with the exception of depreciation and lease payments, which are not computable. In this case the operating costs consist of the following items:

- IRAP: regional tax on productive activities, is proportional to turnover and not applicable to the profit for the year, which is worth 3.9% in 2012,
- IRAS: corporate income tax, to apply to taxable income in 2012 and is currently 27.5%.

Dimensioning of a photovoltaic plant of a reality industrial

Operating costs in the first 10 years in the case of bank loan on a straight line are shown in table

| OPERATING COSTS (value in €) | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Measurement costs (Aeeg) | | 175 | 176 | 177 | 178 | 179 | 180 | 181 | 182 | 183 | 184 |
| Insurance policy | | 1414 | 1414 | 1414 | 1414 | 1414 | 1414 | 1414 | 1414 | 1414 | 1414 |
| Various costs (rent, supervision ect.) | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Ordinary maintenance | | 471 | 483 | 495 | 507 | 520 | 533 | 546 | 560 | 574 | 588 |
| Straordinar maintenance | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 25000 |
| | | | | | | | | | | | |
| Interest due to mutual | | 19325 | 17828 | 16243 | 14568 | 12799 | 10932 | 8965 | 6892 | 4709 | 2413 |
| **TOTAL COSTS** | | **21385** | **19900** | **18329** | **16667** | **14912** | **13059** | **11106** | **9047** | **6880** | **29600** |

Dimensioning of a photovoltaic plant of a reality industrial

As for the tax amortization was considered a depreciation factor of 9%, while the rate of VAT is 10% of the plant.

# Solar photovoltaic systems

<u>Dimensioning of a photovoltaic plant of a reality industrial</u>

Operating income in the first 10 years are shown in table

| OPERATING REVENUES (value in €) | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Energy saving | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Remuneration Energy Account | | 53051 | 52627 | 52206 | 51788 | 51374 | 50971 | 50555 | 50151 | 49750 | 49351 |
| Selling electric energy | | 11029 | 11214 | 11403 | 11594 | 11789 | 11987 | 12189 | 12393 | 12602 | 12813 |
| TOTAL REVENUES | | **64080** | **63841** | **63841** | **63382** | **63163** | **62958** | **62744** | **62544** | **62351** | **62165** |

Dimensioning of a photovoltaic plant of a reality industrial

It is then determined cash flow $F_j$ of year j-th defined by:

$$F_j = R_j - C_j - A_j - \check{Q}i_j - Im_j + \acute{A}_j - Qc_j$$

where:

$R_j$ = sum of revenues to the j-th year;

$C_j$ = sum of costs to the j-th year;

$A_j$ = depreciation at j-th year;

$I_{mj}$ = mposed on the j-th year related to the difference Rj – Cj – Aj;

$U_{Lj}$ = profit before taxes = Rj – Cj – Aj;

$U_{nj}$ = net profit a year j-th = ULj – Imj;

$F_j$ = cash flow year j-th = Unj + Aj;

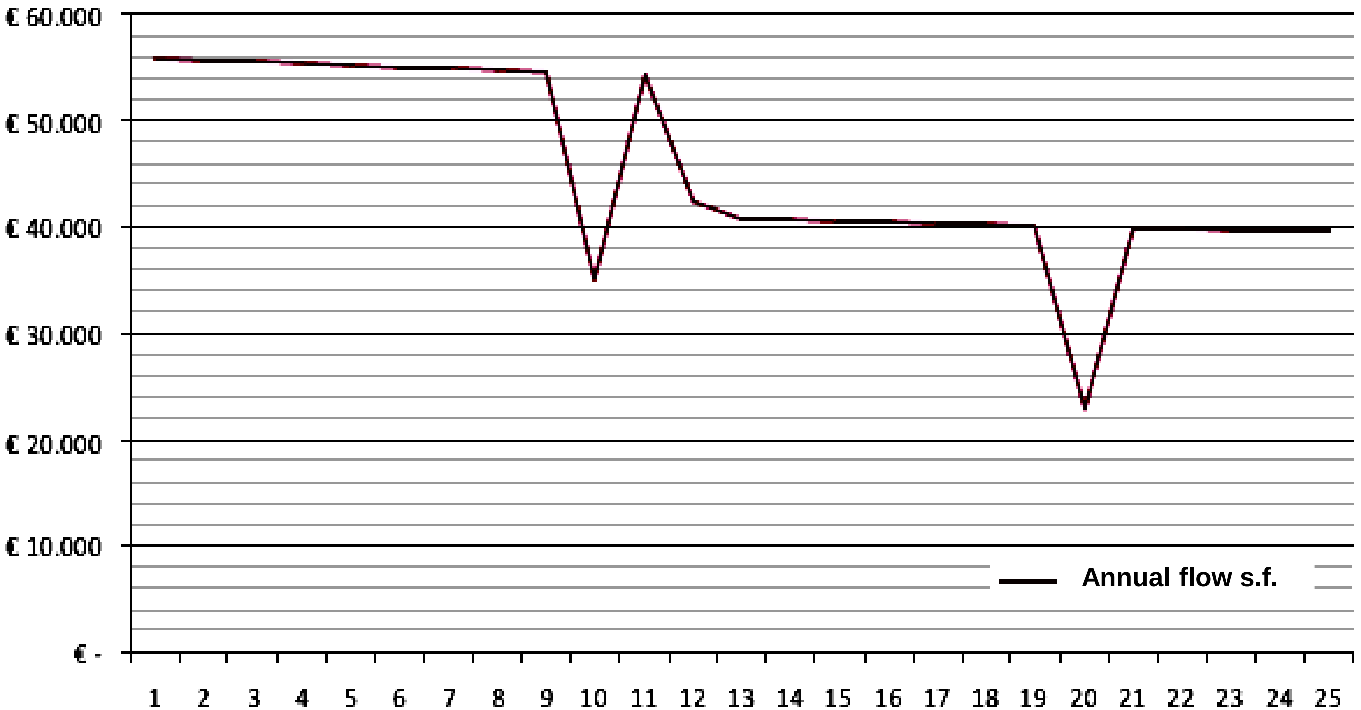
$Q_{ij}$ = interest portion of the mortgage to the j-th year;

$I_{mj}$ = imposed at j-th year on the difference Rj – Cj – Aj – Qij;

$Q_{cj}$ = principal amount of the mortgage to the j-th year.

Dimensioning of a photovoltaic plant of a reality industrial

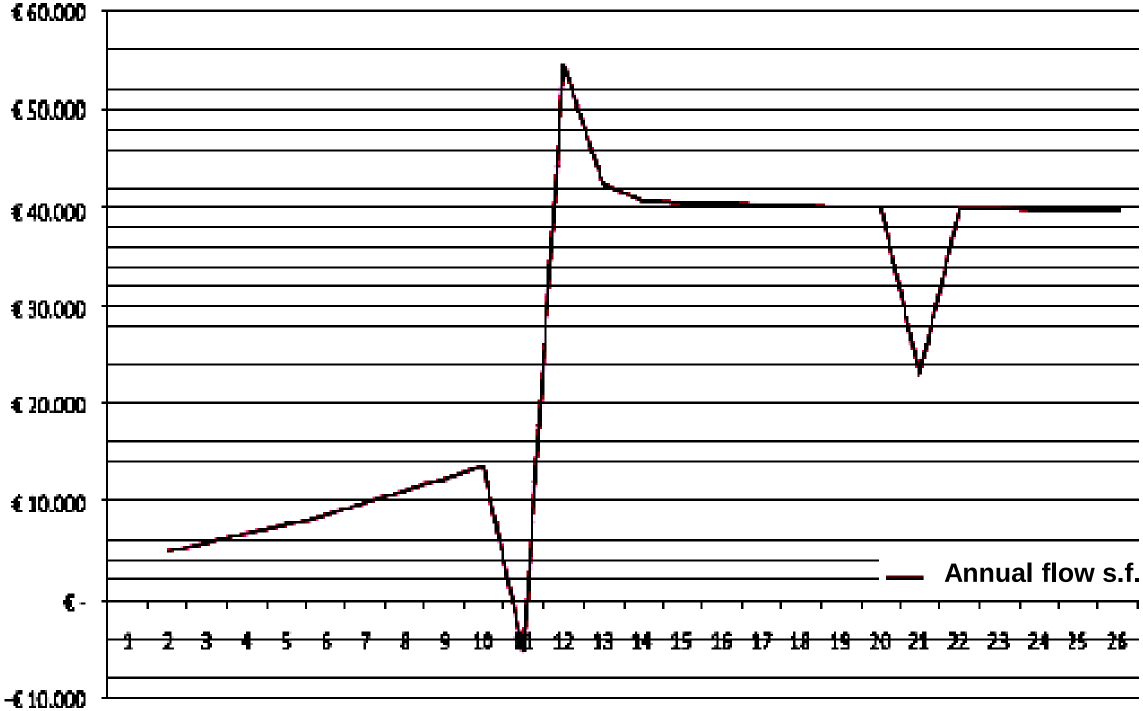
In the case of investment without bank loan, the cash flows are reported yearly in the figure, where the cash flows decrease slightly due to the poor performance of the modules and around the tenth year there will be a significant decrease in cash flows due to the exchange rate inverter.



# Solar photovoltaic systems

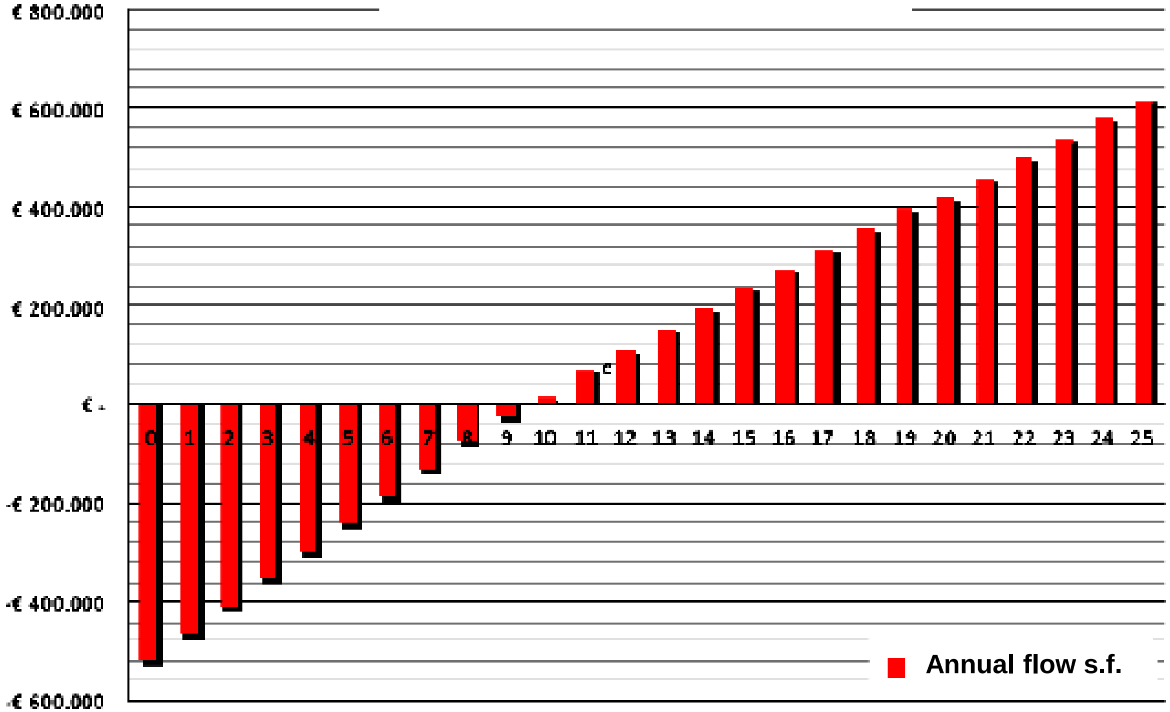
Dimensioning of a photovoltaic plant of a reality industrial

In the case of investment with bank loan, the cash flows are reported in the annual figure, where after having paid off the mortgage in the tenth year and have replaced the drive, unlike the previous graph, the cash flows are much higher.



Dimensioning of a photovoltaic plant of a reality industrial

By cash flows was visible that the payback period is less in the case of the investment with equity (9.4 years), although the financial risk to which they expose the entrepreneur is significantly greater than investment with bank financing (figure).



Dimensioning of a photovoltaic plant of a reality industrial

The use of the bank loan reduces the risk to which the farmer is exposed, but lengthens the payback time of 10.8 years (Figure).