DIY Photovoltaic > 350 Wp

Ver.4, 20/03/2022

As seen in Part A, even in the case of 100% self-consumption, a ***350 Wp plug-and-play*** *system produces relatively low savings (11.4% - 8.4%) compared to the annual consumption of a family of two (2000 -2700 kWh/year). For higher percentages, it is necessary to review the projects.*

By increasing the power of the system new problems arise for the installation of the panels (now fixed) which require at least 5 m^2 for each kWp, with the same exposure and without shadows.

Even the connection to the grid is complicated compared to the *plug-and-play* case, which is mobile by definition. With high powers, the strategies that can be used for the management of the energy produced also change:

1 Systems connected to the grid ('grid tie' or 'on grid'). Subject to constraints that vary by country and electricity distribution company. They manage any load: the necessary energy can always be supplied by the grid. Important: They don't work if there is no grid power:

- 1.1 The extra energy, beyond the self-consumption, is lost, both in the case that it is not fed into the grid (*inverter with limit*) and in the case that it is fed in (e.g. *plug-and-play*).
- 1.2 The extra energy, in addition to self-consumption, is fed into the grid (*on-grid* inverter) and is remunerated in various ways by the local operator (*in Italy: SSP contract with GSE*).
- 1.3 The extra energy, beyond the self-consumption, is stored in a local storage, to be used in the hours without production. (*In Italy: solar energy is available, simplifying, 6 hours in summer, 4 hours in winter*).

2 UPS (uninterruptible power source) systems, usually *off-grid*, can replace the grid in the event of a blackout. Load limited to the power of the inverter, which, in the presence of inductive loads (motors), must be sized for the starting point (at least triple the power).

- 2.1 UPS inverters manage three energy sources - Solar, Grid and Battery - with various strategies. The extra solar energy is stored in the battery or lost.

3 Independent systems, not connected to the grid (*off-grid*), always with loads limited to the power of the inverter:

- 3.1 Without storage: the energy produced is used immediately, for example, crop irrigation.
- 3.2 With storage, to ensure 24/7 services, e.g. street lighting and isolated houses.

We will mainly deal with on-grid and UPS systems, among which it is often difficult to choose.

For autonomous systems let's just say that they have the advantage, while complying with the standards, of not being subjected to the constraints of the distribution company, but must be sized for power peaks and equipped with adequate storage. However, it is advisable to provide other sources of energy and backup, for example, a wind/hydraulic turbine and/or a fuel generator, as it is not possible to use the grid in the event of low production, such as with cloudy skies for several days.

Note: some hybrid inverters manage two AC outputs (230V): the first for essential services (solar, battery) and the second for heavier loads (solar, grid).

Projects

- project B: module 800 / 1000 / 1200 Wp on grid
- project C: module 800Wp, with limit
- project D: adding storage to C (1200 Wh)
- project E: UPS hybrid inverter 6200W + storage, off-grid/grid tie.

The last version of this documet is in the repository https://github.com/msillano/DIY-photovoltaic-smart

Disclaimer

This article is for informational purposes, and is true and accurate to the best of the Author's knowledge, but may contain inadvertent errors or inaccuracies: it is provided "as is", without warranties of any kind, implicit or explicit.

The practical execution of the projects and the sizing calculations of the components and of the electrical connection cables must in any case always be carried out, verified and validated by specialized, competent and qualified technical personnel, in full compliance with all current electrical and safety regulations , which vary according to the country, therefore the Author is not responsible for direct or indirect accidental damages caused by the use of the information provided.

Note on WiFi

I don't want to use proprietary clouds, and therefore neither remote control WiFi APPs, apart from Tuya and the smartLife APP.

Already deciding to use Tuya and its cloud as the IOT environment of choice, and as the basis for the development of the TuyaDAEMON IOT framework was a difficult decision, justified by the high level of security, excellent performance, and the peculiar commercial position of Tuya as third-party service provider, a position that guarantees end users - see, for further information, 'why TuyaDAEMON' (in Italian, 'perché TuyaDAEMON').

The basic remote control and automation operations, where available, are therefore those native to Tuya and smartLife, including voice commands (Google or Alexa) sufficient in most cases - they are the best available on the market. If you want higher performance, such as integration with other devices, collected data processing, advanced logic, and custom user interface, then you can use TuyaDAEMON.

This leads to the preference for Tuya-compatible devices when choosing smart components.

Note on prices

I have tried to favor international suppliers for two reasons:

- ✔ Global availability, to be able to carry out these projects anywhere in the world.
- ✔ A good quality/price ratio, which can serve as a comparison.

The prices presented are for reference only: they are the amount I found or paid to the indicated supplier (inclusive of taxes and EU shipping, unless indicated otherwise - August-November 2022).

Prices can obviously vary (especially in this period and in the photovoltaic sector). In addition, *state subsidies have inflated prices, at least in Italy.*

Sometimes I refer to Italian products or to the UE-Italian regulatory situation, which I know best, but this is always clearly highlighted.

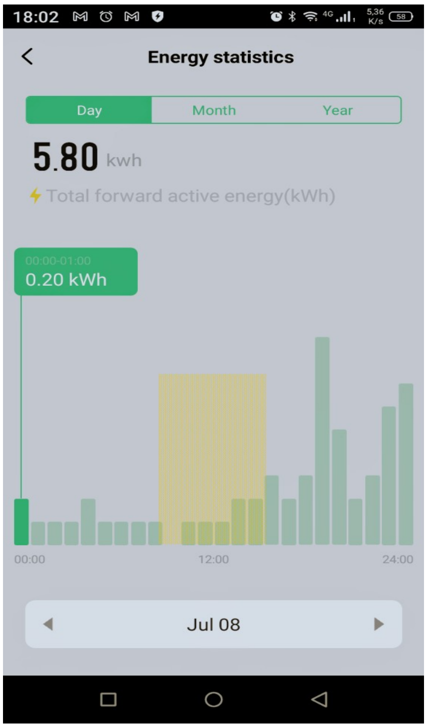
Before making important purchases, carefully select both the product and the supplier.

Analyses

Importance of storage

As starting data, let's consider a 1 kWp solar system 'on-grid': in optimal conditions, it will produce **1500 kWh/year** (Rome, see simulation), i.e. on average **125 kWh/month** and **4.1 kWh/day**.

Therefore simplifying a lot, during a summer day, from 9 to 15 (6 hours), **670 W** (4.1/6) are available. For 2 kWp we double this value.



In the figure, we have the consumption (**5.80 kWh**) for *8 July 2022* in *green* and the schematic PV production in *yellow*. Self-consumption is represented by the *yellow+green* area. Let's look at various scenarios:

A) *1 kWp solar system*

Solar: 4.1 kWh (equal to **69 %**)

Self-consumption: 0.7 kWh (equal to **12 %**)

If a battery stores the extra energy (yellow: 3.4 kWh) and gives it back over the following 18 hours, with 80% efficiency, we have *2.4 kWh*.

In total: 0.7 + 2.4 =3.1 kWh (**53 %**)

B) *2 kWp solar system*

(in the figure the yellow band would have double height):

Solar: 8.0 kWh (equal to **138 %**)

Self-consumption: 0.7 kWh (equal to **12 %**)

If a battery stores unused energy (7.3 kWh) and returns it over the following 18 hours, with 80% efficiency we have 5.8 kWh.

In total: 0.7 + 5.8 = 6.5 kWh **100%** + residual **0.7 kWh**

note: Consumption peaks exceeding the inverter capacity (1000 or 2000 W), which always absorbs power from the grid, are not considered in the estimations.

Conclusion:

On the day under review, the presence of a battery drives self-consumption **from 12% to 53% (1 kWp) or 100% (2 kWp)**.

Actual consumption in a 4 month interval

In the following table, we have:

kWh(month): consumption in the month, from the load-curves by the grid operator 'e-distribuzione'
avg24: average daily consumption = kWh(month)/30(31)
max24: maximum daily consumption in the month (from 'e-distribution' load curves)
min24: minimum daily consumption in the month (from 'e-distribution' load curves)
kWp (100%): power for a photovoltaic system (theoretical): 1 kWp = 125 kWh/month

month	kWh (month)	avg24	max24	min24	kWp (100%)
June 2022	175,45	5,85	21,63	1,22	1,4
July 2022	202,08	6,52	30,92	4,28	1,6
August 2022	320,63	10,32	16,81	5,39	2,6
Sept. 2022	170,33	5,67	7,6	2,58	1,4
average	217,1225	7,2			1,7

Let's do a **more detailed simulation** of self-consumption with storage:

1. for each month we use the PVGIS data (kWh **PVGIS/m**) multiplied by 0.8 (battery efficiency) to evaluate the available average daily solar energy (kWh **PV/d**)
2. from the daily consumption (the 'e-distribuzione' APP allows the CSV export of the data) we subtract the self-consumption (PV/d). What remains, added up, is kWh **pay/m**onth that must be provided by the grid
3. let's look at three cases: 1kWp, 2kWp, and 3kWp

month	energy grid	PVGIS/m	PV/d	pay/m	% saving	avg
PV system 1kWp						
June 2022	175,45	170,85	4,53	78,67	55,2%	**48,94%**
July 2022	202,08	186,41	4,8	135,22	33,1%	
August 2022	320,64	178,25	4,59	188,3	41,3%	
Sept. 2922	170,33	145,06	3,86	57,52	66,2%	
PV system 2kWp						
June 2022	175,45	341,7	9,06	36,74	79,1%	**79,44%**
July 2022	202,08	372,82	9,6	76,72	62,0%	
August 2022	320,64	356,5	9,18	74,76	76,7%	
Sept. 2922	170,33	290,12	7,72	0	100,0%	
PV system 3kWp						
June 2022	175,45	512,55	13,59	13,83	92,1%	**93,38%**
July 2022	202,08	559,23	14,4	34,09	83,1%	
August 2022	320,64	534,75	13,77	5,54	98,3%	
Sept. 2922	170,33	435,18	11,58	0	100,0%	

These values are an optimistic estimate for several reasons:

- The PVGIS considers the system losses equal to 14%. In a small plant, they can be greater.
- It is assumed that the batteries can accumulate all the daily energy (3.86...14.4 kWh)
- Consumption peaks have been neglected: i.e. consumption above 1000/2000/3000 Watts, which are always taken from the grid.

The estimate is instead pessimistic because:

- The data refer to habitual consumption, not optimized to increase self-consumption
- Each day is isolated, without calculating any remaining energy from the previous day.

It can be seen how the increase from 1000 to 2000 Wp brings the savings from 50% to 80% (+ 30 %), while the increase from 2000 WP to 3000 Wp brings an advantage of only 13%. This is also reflected in amortization (assumptions: consumption 2800 kWh/year, PV+storage cost 2000 €/kWp, energy cost: 41.51 c€/kWh):

1000 W (self-consumption = 2800 * 49% = 1370 kWh) amortization 5 years 5 months

2000 W (self-consumption = 2800 * 79% = 2200 kWh) amortization 6 years 3 months

3000 W (self-consumption = 2800 * 93% = 2600 kWh) amortization 7 years 9 months

(calculations with solar/payback-photovoltaic);

3 kWp is probably the right size for an 'on-grid' system, but I chose to build a 2 kWp system because:

- I believe that careful management of electrical devices can increase self-consumption
- Most important: I have no space for panels for 3 kWp!

note: Italy - exchange on site ('Scambio Sul Posto': SSP)

In Italy, the European 'Conto Energia' (remuneration by the operator) is now (2022) implemented through the 'Scambio sul Posto' (or SSP) contracts with GSE, whatever the supplier company is.

It would seem that the SSP could replace storage, but in reality, for the user, this is not exactly the case.

Let's simplify by considering the SSP as a virtual battery, with a yield between 99% and 60%, yield essentially determined by the spread between the energy purchase and sale prices (60% can be considered an extreme case: see article).

Let's consider July 8, 2022, with a consumption of 5.8 kWh (see above for details), and the worst case (60%) to highlight the problems:

2 kWp solar system with SSP, we have:

Solar production:	*8.0 kWh*	*(equal to 138 %)*
Self-consumption:	*0.7 kWh*	*(equal to 12 %)*

If we transfer the unconsumed energy (7.3 kWh) to the grid, this corresponds (from GSE calculations) to 4.4 kWh (at 60%) of consumption:

*In total 2 kWp + SPP gives: 0.7 + 4.4 = 5.1 kWh (equal to **87 %**)*

Be careful though:

- *The electricity bill will be reduced by self-consumption only: 5.8 -0.7 = 5.1 kWh.*
- *The bill must be paid immediately for the total (5.1 kWh) and will then be partially refunded by bank transfer from the GSE.*
- *Refunds will repay the value of 4.4 kWh, i.e. net we only pay for 5.1 – 4.4 = 0.7 kWh.*
- *However, we pay in full (i.e. on 5.1 kWh) both MTC (0.015 €/kWh) and taxes: VAT (10%) and excise duties (0.022 €/kWh), subsequently compensated only in part by the 'unit exchange fee annual flat rate' (5.08 c€/ kWh) calculated in the SSP.*
- *GSE management expenditure: up to 3 kWp, free; from 3 kWp to 20 kWp €30/year.*
- *Cost of production meter: about €20/year*
- *Any surplus kWh can be valued by GSE for a value close to the PUN (Unique National Price, variable: see intro), also taxed as 'other income'.*

Even in the SSP case, it can be seen how important it is to increase self-consumption, i.e. how appropriate the use of storage is.

But if high percentages of self-consumption must be reached, then the SSP becomes less attractive: the only advantage remains the summer/winter exchange, which cannot be managed with local batteries.

To comply with the regulatory constraints it is also necessary:

- ✔ *Use of devices (all) approved according to CEI 0-21 (with a protectionist effect)*
- ✔ *A qualified installer for installation*
- ✔ *A designer registered for the practice of connection to the national grid*

note: Thermal storage

An interesting possibility to increase self-consumption is to use a pre-existing electric storage water heater (the most common) as a (thermal) energy tank:

- The first rule is to use photovoltaic energy as much as possible to heat the water.
- An electric water heater has a high consumption (e.g. Ariston 80L, 1500W) to have rapid heating. *By reducing the supplied power (e.g. with a dimmer) a longer heating period is obtained, but a greater self-consumption of solar energy. It is also possible to think of dynamic modulation of the power, based on the availability of energy.*
- If other household appliances (dishwasher, washing machine...) use the hot water from the water heater instead of cold water, there is further saving: the household appliance consumes less electricity to bring the water to the required temperature, and so the energy produced in the hours of sunshine can be used to reduce consumption at different times.

The energy needed to heat an 80-liter boiler, from 15° to 60° is equal to **4.2 kWh**, an important fraction of daily consumption.

In formula: $$E = \frac{L * \Delta T}{860} \quad \text{[kWh]}$$

where *L* is liters and *ΔT* the temperature difference in °C.

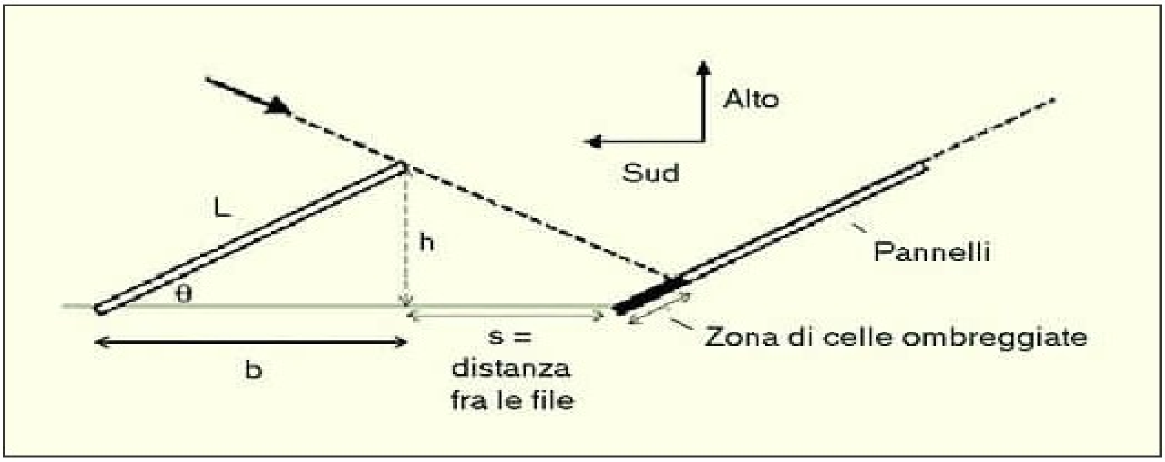
- ✔ This obviously applies to standard storage water heaters, not to heat pumps or gas water heaters.
- ✔ The boiler thermostat temperature is an important factor: in summer 40° and in winter 60° are usual values.
- ✔ If the water heater consumes 1300W, it will take 3h:38m to heat up to 60°.
- ✔ It is appropriate to give low priority to the water heater, i.e. turn it on only when there is photovoltaic energy available: there are various commercial solutions for this purpose.
- ✔ For a DIY 'modding' project of a standard storage water heater to make it 'smart' with tuyaDAEMON. See (under development).

Power Dimmer:

2000/4000W High Power Thyristor 2,71 / 6,86 €

Rows of solar panels

If the panels are not coplanar (case of the pitched roof) and if the panels are arranged in several rows, the problem of shadows arises between rows and the need for spacing increases the occupied surface (filling factor).



We have, in the flat case - see the figure with the side schematic view of 2 rows of photoelectric panels:

L: panel length
θ: panel angle (slope) $h = L \cdot \sin(\theta)$

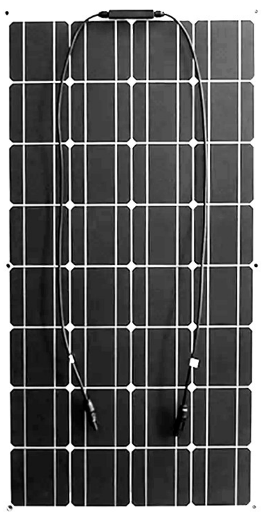
To have no shadows the distance between rows (*s*) must be greater than or equal to *d*, with *α*: minimum height of the sun (arrow in the figure):

$$d = h \cdot \cot(\alpha) = \frac{h}{\tan(\alpha)}$$

The formulas are more complex in the case of sloping terrain.

Installation of solar panels

For the reasons already seen in part A, also in these projects we use the flexible panels model RG-MN-100



- power 100 Wp,
- dimensions 1050 x 530 x 2.5 mm,
- weight 1,9 kg,
- open circuit voltage 19,2 V,
- short circuit current 6,87 A
- cables: 90 cm x 2.5 mm^2
- link for more information.

Based on the characteristics of the panels and the inverter (or controller) we can establish the number of series panels (called also *strings*: the voltages are added) and the number of strings (equal to each other) in parallel (the currents are added).
Note: in the temperature range -10°C.. + 70°C both Voc (21.31V… 16.5 V) and Icc (6.79 A… 6.96 A) vary.

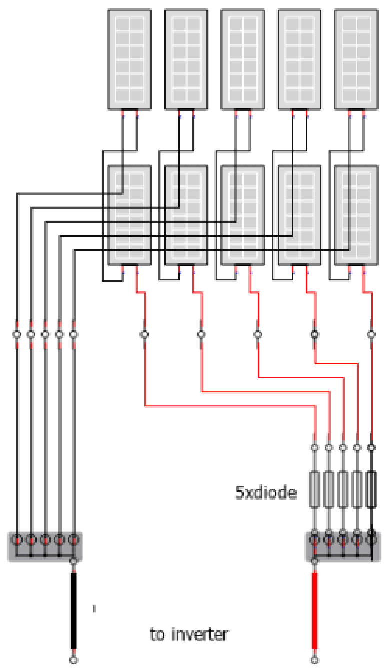
Examples:
With these panels, the 5P2S arrangement (1000 Wp) provides 38.46V (max 42.62V) and 34.35A (max 34.8A), compatible with the inverter chosen in project C (26-45V, max 40A).

8 connected 2P4S panels (800 Wp, for battery, project D)
- open circuit voltage. 76.8 V (max 85,24 V)
- short circuit current: 13.74 A (max 14 A)

For the project E, we have the range:
9 connected 9S panels (900 Wp):
- open circuit voltage. 172.8 V (max 191.79 V)
- short circuit current: 7.87 A (max 7 A)

60 connected 3P20S panels (6000 Wp):
- open circuit voltage. 384 V (max 426.2 V)
- short circuit current: 20,61 A (max 21 A)

Different connection schemes are possible, to make the connections as short and homogeneous as possible. Example: I have chosen the following scheme for *project C* (5P2S):



Each panel in one row is in series with the corresponding panel in the other row using panel terminals (90 cm).

5 black extension cords and 5 red extension cords, of variable length, 2.5 mm^2.

In the positive connections, there are 5 optional 10 A blocking diodes (the bypass diodes are already present in the junction box of the panels).

The extensions terminate in two watertight boxes
2 x 6 mounted on the structure of the panels from which two larger cables depart for the inverter.

Obviously, it is better to have cables as short as possible.

Only if the panels are very close to the inverter, can the junction boxes are omitted and the 10 cables sent directly to the inverter.

Panel mounting accessories

For the 10 extension cords

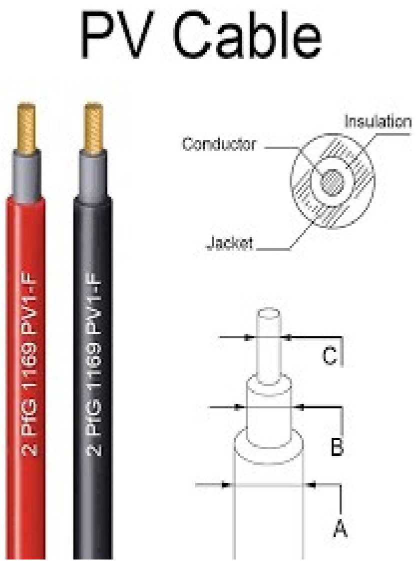
20 x PV connectors 8,94 €

For each string of 2 panels, one blocking diode (they could be replaced with fuses):

5 x diode 10A for PV 18,6 €

Cables for PV (e.g PV1-F), accessories

- in tinned copper (or aluminum for outdoors)
- double insulation in XLPE (no PVC)
- temperatures -40°/+90° (+120°)
- duration: 25 years
- section min > 0.25 mm²/A



PV cable (PV1-F)

for panel extensions (short, 7A):
1 x AWG13 – 2,5 mm², 10 m (black) 17.65 €
1 x AWG13 – 2,5 mm², 5 m (red) 10.53 €

from junction to inverter
diameter to be calculated case by case as a function of distance and current. Use

- 40V voltage (e.g.)
- 1.25 coefficient for the powers (1000 Wp => 1250W).
- loss < 1% (i.e. 0.4V).

See also the link.

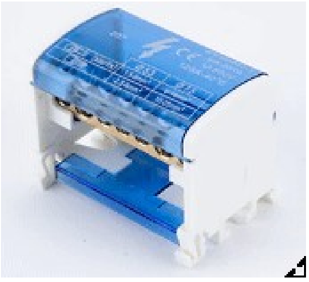
*Example: 5P2S (7*5 = 35A max):*
AWG7 - 10 mm², 4 m (red + black, indicative) 45,13 €

AWG	Diam mm	Sect. mm²	Resist. ohm/m	AWG	Diam mm	Sect. mm²	Resist. ohm/m
0000	11.7	107,0	0.000161	19	0,91	0,6530	0.0264
000	10.4	85.0	0.000203	20	0,81	0,5190	0.0333
00	9.26	67.4	0.000256	21	0,72	0,4120	0.0420
0	8.25	53.5	0.000323	22	0,64	0,3250	0.0530
1	7,35	42,4	0.000407	23	0,57	0,2590	0.0668
2	6,54	33,6	0.000513	24	0,51	0,2050	0.0842
3	5,83	26,7	0.000647	25	0,45	0,1630	0.106
4	5,19	21,2	0.000815	26	0,40	0,1280	0.134
5	4,62	16,8	0.00103	27	0,36	0,1020	0.169
6	4,11	13,3	0.00130	28	0,32	0,0804	0.213
7	3,67	10,6	0.00163	29	0,29	0,0646	0.268
8	3,26	8,35	0.00206	30	0,25	0,0503	0.339
9	2,91	6,62	0.00260	31	0,23	0,0415	0.427
10	2,59	5,27	0.00328	32	0,20	0,0314	0.538
11	2,30	4,15	0.00413	33	0,18	0,0254	0.679
12	2,05	3,31	0.00521	34	0,16	0,0201	0.856
13	1,83	2,63	0.00657	35	0,14	0,0154	1.08
14	1,63	2,08	0.00829	36	0,13	0,0133	1.36
15	1,45	1,65	0.0104	37	0,11	0,0095	1.72
16	1,29	1,31	0.0132	38	0,10	0,0078	2.16
17	1,15	1,04	0.0166	39	0,09	0,0064	2.73
18	1,02	0,82	0.0210	40	0,08	0,0050	3.44

The string parallel joint solutions

- Use mammoths or clamps
- Terminate the cables with cable lugs.
- Use a special Solar Connector 2T … 6T
- Use the DC field switchgear (see Project E)

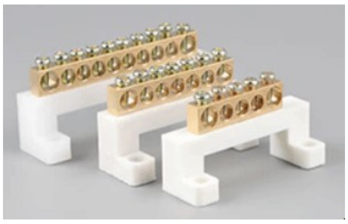
For instance:



DIN terminals 2x7 6,92 €

5 x 5,3 mm => 2.5...6 mm^2 cable

2 x 7,5 mm => 10...25 mm^2 cable



Bare terminal 7 fori 2,37 €

Cable lugs (20 pz):

SC4-6	(12AWG)	1,50 €
SC10-6	(7AWG)	2,50 €

If the cables do not reach the inverter box, always use waterproof junction boxes:

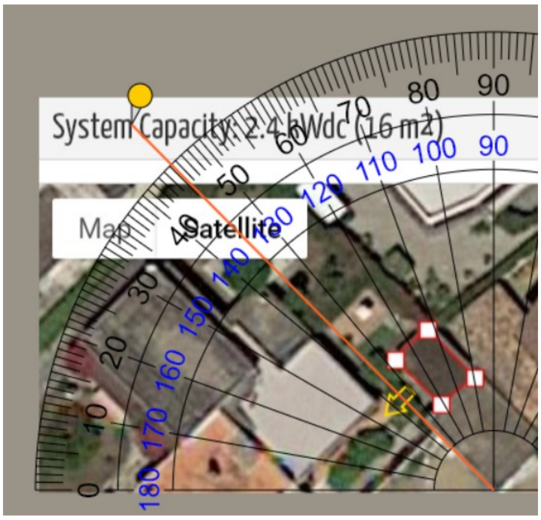
2 x 6 way junction box 10,32 €

Total mounting accessories for 5P2S panels: ***97 €***

note: it can be considered that the use of mini-inverters (such as those used in the plug-and-play project, or the ***SG-1200W-Mobile WIFI)*** *requires fewer accessories, simplifies assembly and ultimately reduces costs.*
Unfortunately, these inverters are not equipped with the 'LIMIT' function and are therefore not suitable for the C project.

DIY: Panel supports

A well-oriented pitched roof is the simplest case. There are many types of hardware to ensure, in various cases (tiles, corrugated, etc.), easy assembly of the solar panels in adherence to the groundwater (*in Italy it is required by standards*) without compromising the tightness of the roof. However, the costs of scaffolding, labor, etc. must be considered.



The case of terraces and flat roofs is more technically complicated: I found the space for the solar panels using the flat roof of a box (see satellite image from PVWATTS, plus protractor). It is not optimal (Azimuth 45°, shadows from buildings) but it is the only usable place available. Given the low height of the box, safety works (railings) are not necessary.

However, a structure is needed to position the solar panels at the right angle, robust enough and stable in the winds.

The type of system conditions the orientation of the panels.

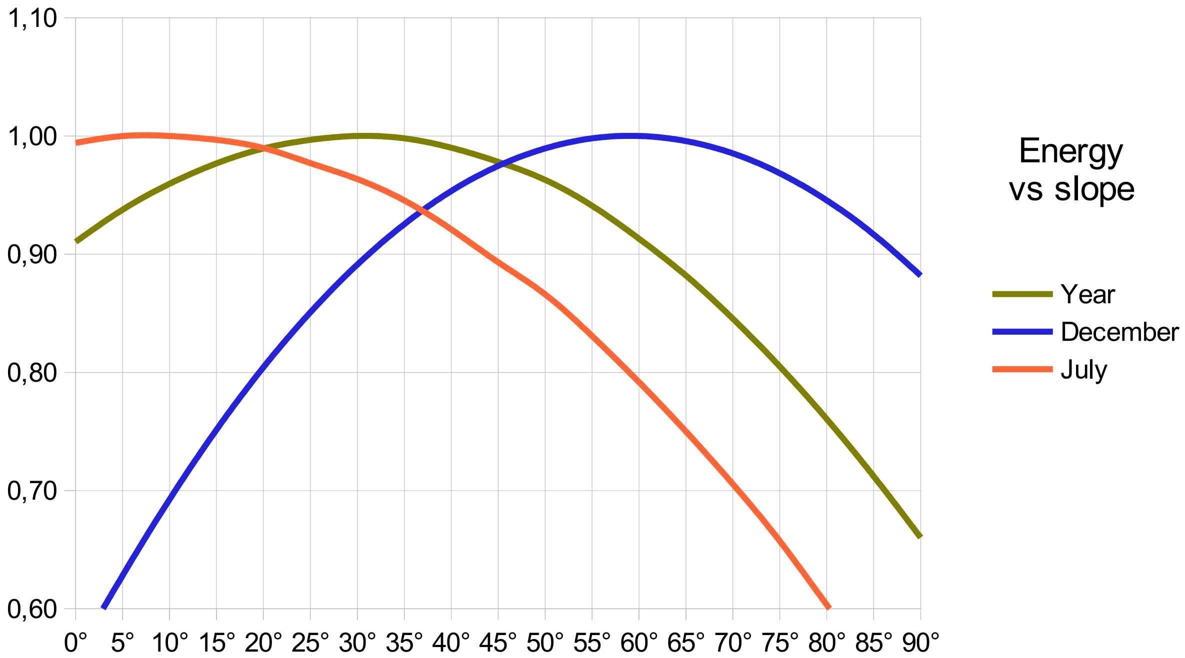
If the *energy fed into the grid is remunerated* in some way (*Italy: SSP*), the goal is to ***maximize the annual production***, and PVGIS automatically provides the optimal values of 'slope' and 'azimuth'.

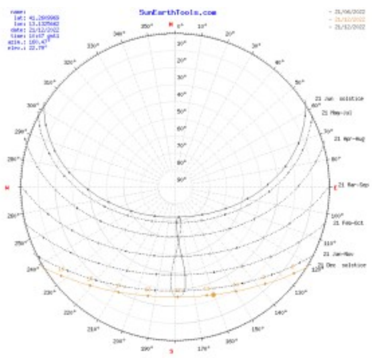
If, the *energy is not fed into the grid* ('limit' or 'off grid' inverter), due to storage limitations - summer energy cannot be accumulated for consumption in winter - the aim is to ***maximize winter production***: the optimal 'slope' must be found by trial and error with PVGIS.

In the present case, the azimuth is imposed by the existing roof (45°). By varying the slope (1 kWp):

Slope	Year		July		December		July/Dec
	kWh	%	kWh	%	kWh	%	
0°	1372	91%	197,29	99%	41,31	56%	4,78
5°	1413	94%	198,43	100%	46,35	63%	4,28
10°	1446	96%	**198,45**	**100%**	51,1	69%	3,88
15°	1472	98%	197,79	100%	55,45	75%	3,57
20°	1491	99%	196,42	99%	59,35	80%	3,31
25°	1502	100%	193,89	98%	62,78	85%	3,09
30°	**1507**	**100%**	191,21	96%	65,76	89%	2,91
35°	1504	100%	187,63	95%	68,28	93%	2,75
40°	1492	99%	182,78	92%	70,35	95%	2,60
45°	1474	98%	177,25	89%	71,92	97%	2,46
50°	1451	96%	171,86	87%	73,01	99%	2,35
55°	1418	94%	164,87	83%	73,64	100%	2,24
60°	1376	91%	157,12	79%	**73,79**	100%	2,13
65°	1329	88%	148,83	75%	73,47	100%	2,03
70°	1274	85%	139,99	71%	72,7	99%	1,93
75°	1213	80%	130,42	66%	71,46	97%	1,83
80°	1146	76%	119,73	60%	69,77	95%	1,72
85°	1073	71%	109,24	55%	67,64	92%	1,62
90°	995	66%	98,6	50%	65,07	88%	1,52

More immediate by looking at a graph:





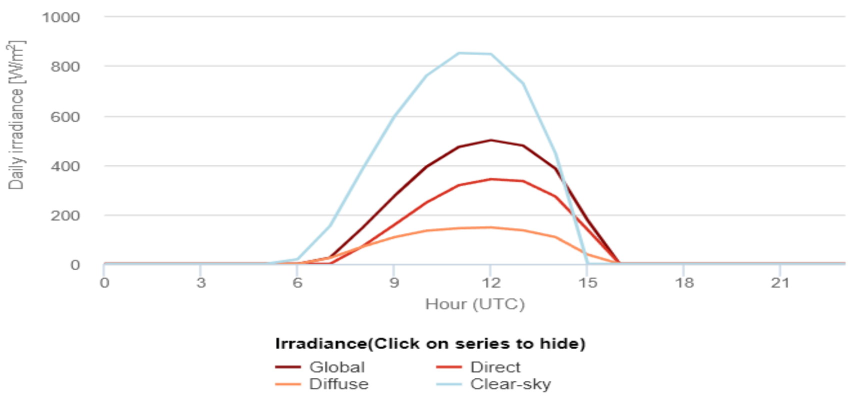
The [SunHeartTools]() site provides, for a given location, the height of the sun at each time.

December 21st at 12:00 = 25°.
December 21st at 14:00 = 20°.
December 21st at 15:00 = 12° .

Now let's calculate the [minimum distance between rows](), with a panel height of 105 cm:

slope	h	d@Sun 20°	d@Sun 12°
40°	67,5	185,4	317,5
45°	74,2	204,0	349,3
50°	80,4	221,0	378,4
55°	86,0	236,3	404,6
60°	90,9	249,8	427,8

The distances between rows are all greater than 2 meters, really high. *I can choose 50°*

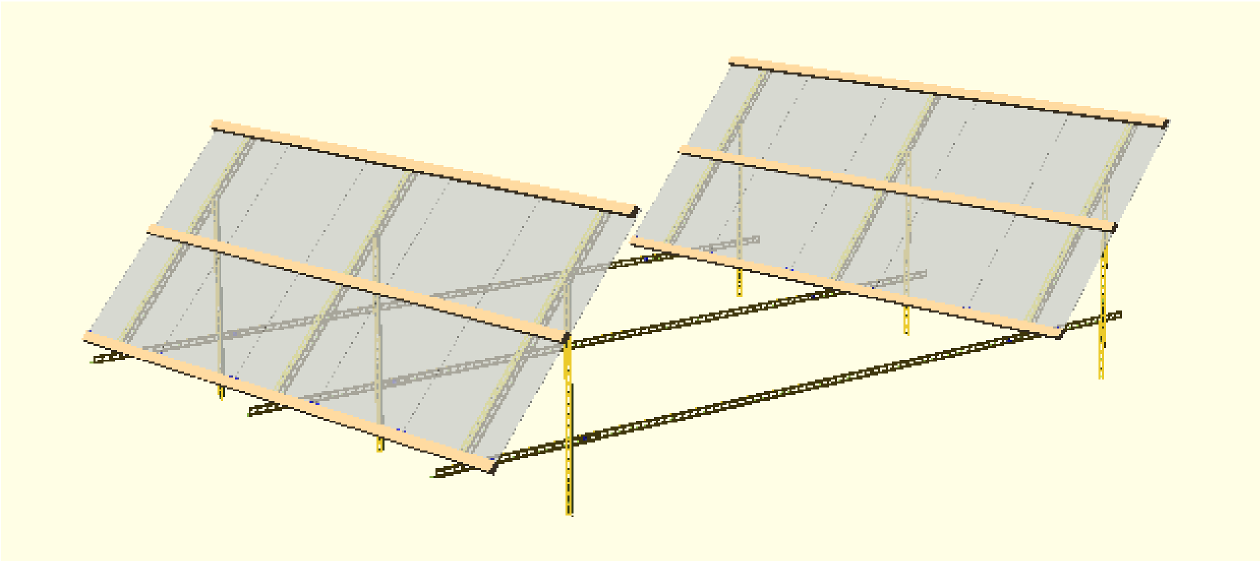


For verification, this is the irradiation of an (average) day in December, (from PVGIS, slope: 50°, Azimuth: 45°).

Clear-sky does not account for atmospheric absorptions for particles and clouds.

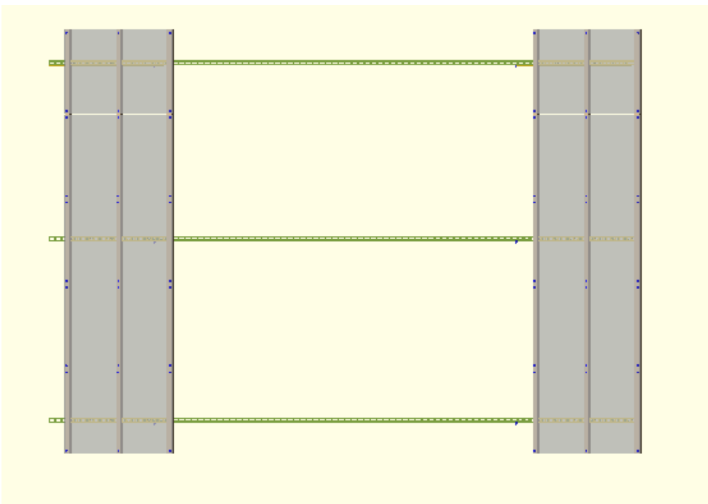
Solution 1: (without grid entry)

The fixed structure for rows of solar panels is made up of iron ribs and cross-currents to which the panels are fixed. Each rib has the support for each row of panels, with an (optional) leg that can be anchored as needed.
The basic values, for a system without feeding into the grid, are: 5x2 panels (1000 Wp), slope 50°, row distance 225 cm, 3 ribs.



Structure characteristics 5x2 (1000 W):

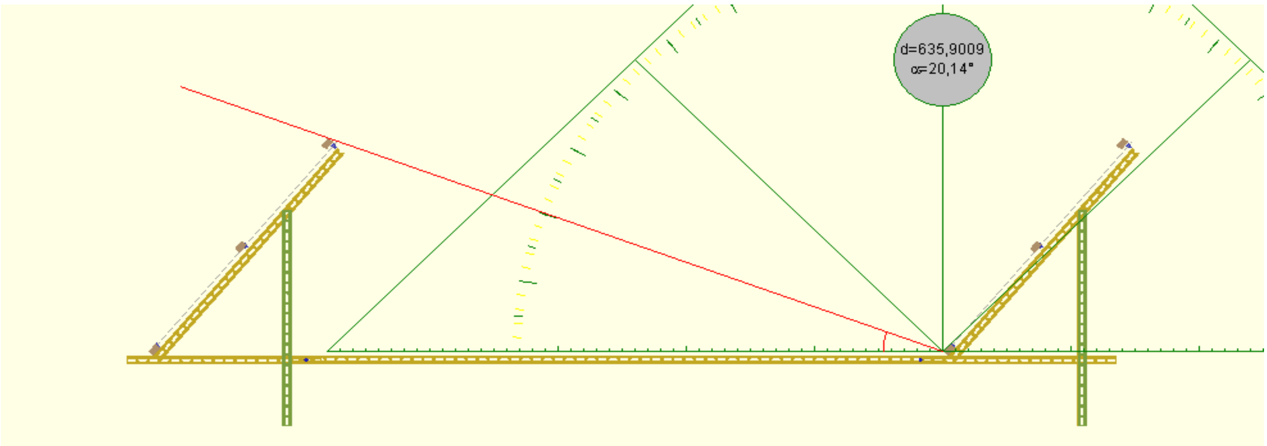
1. The structure is made up of L-shaped iron profiles, 35x35 mm perforated - shelf profiles - easily available everywhere.
2. Each rib is made up of two or more supports connected by spacers: the angle (slope) is defined in the design phase, the distance between rows in the assembly phase. The supports are fully welded for greater strength.
3. The ribs are connected to each other by 2 or 3 beams (wood, aluminum, galvanized steel sheet, etc.) bolted during assembly.
4. Without the vertical leg (`S_leg` = 0) the supports can simply be placed on the floor or fixed vertically on a wall (see example).



When assembling always add a safety system, e.g. lateral anchors to railings or walls or steel cables, to avoid movement and overturning.

All the supports have been calculated with the same parametric OpenSCAD project: the user can change many values in the file and both the drawings and the parts list is automatically updated. Download here.

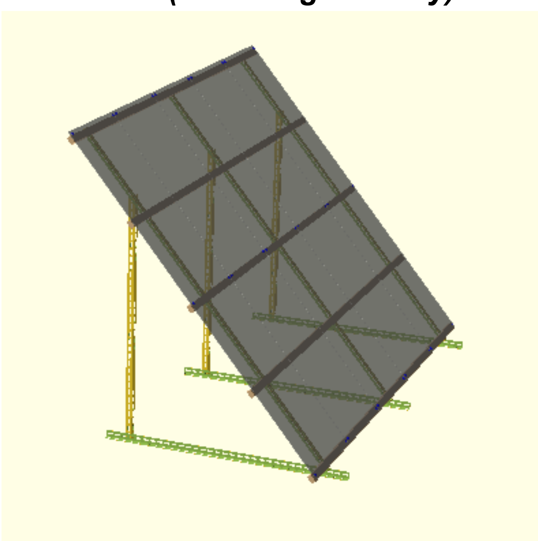
The entire structure for 1000 W requires 3 ribs with 2 supports each, 3 spacers and additionally 3 stringers for each row of 5 panels. *(Protractor is MB-ruler).*



The OpenSCAD parametric project also provides a complete parts list with the dimensions, and the total (net) of the L-profile needed:

Parameters: *string = 5x2* *PV panel = 1050x530 mm* *distance = 2250 mm* *feet = 250 mm*	ECHO: "Panels 5X2, slope: 50°" ECHO: "Footprint: 3702.43 x 2656 mm" ECHO: ECHO: "6 x supports:" ECHO: " base: 1052 mm" ECHO: " Hbar: 720 mm" ECHO: " Vbar: 840 mm" ECHO: ECHO: "3 x spacer: " ECHO: " length: 2411.86 mm" ECHO: ECHO: "6 x currents:" ECHO: " length: 2656 mm" ECHO: ECHO: "8/12 x bolts M8x15 " ECHO: "60 x wood screws M 4x30" ECHO: ECHO: "Total L: 22907.6 mm"

Solution 2: (without grid entry)



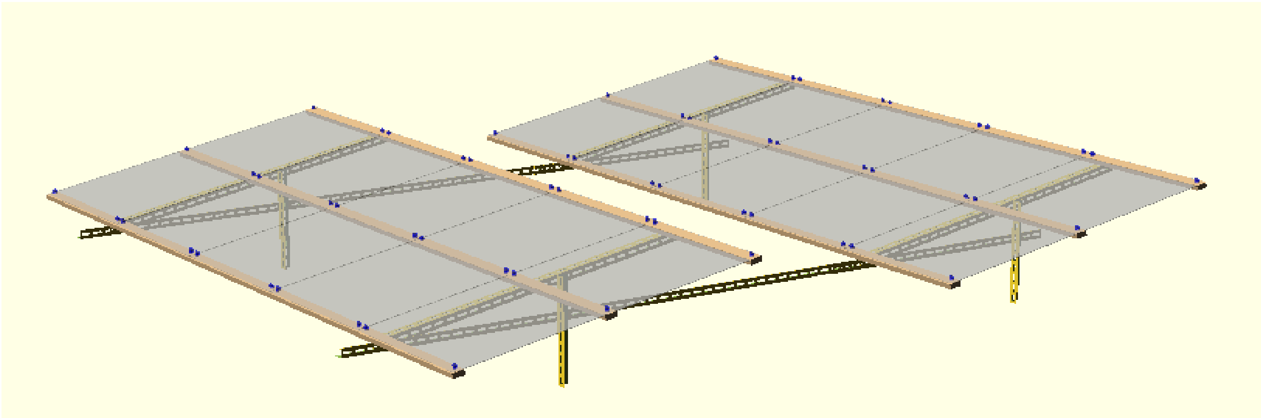
Alternative to solution 1, with the panels (2x5) located in the same plane.
The parameters are similar: slope 50°, but with 5x1 panels using the (virtual) size 2100x530, 3 ribs.

note: given the important dimensions, the structure can be strengthened:

- coupling the profiles to form a U.
- adding an intermediate vertical element
- adding a diagonal rear element
- adding a square plate, with holes at the corners, to each rib-beams joint

Parameters: *string = 5x1* *PV panel = 2100x530 mm* *slope = 50°* *feet = 0*	`ECHO: "Panels 5X1, slope: 50°"` `ECHO: "Footprint: 1451.14 x 2656 mm"` `ECHO:` `ECHO: "3 x supports:"` `ECHO: " base: 2102 mm"` `ECHO: " Hbar: 1320 mm"` `ECHO: " Vbar: 1323.18 mm"` `ECHO:` `ECHO: "5 x currents:"` `ECHO: " length: 2656 mm"` `ECHO:` `ECHO: "60 x wood screws M 4x30"` `ECHO:` `ECHO: "Total L: 14235.5 mm"`

Solution 3: (on grid)



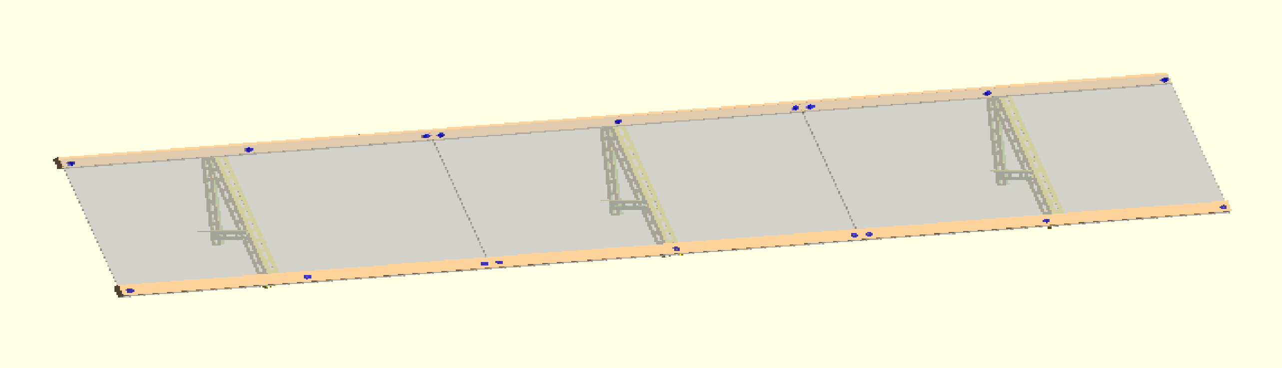
In this case, it is possible to use a very small slope (12°) with few losses compared to the annual maximum (97%) obtaining a compact structure adhering to the floor.

The basic values are: 5x2 panels (1000 Wp), slope 12°, rows distance 70 cm, 2 ribs.

Parameters: *string = 5x2* *PV panel = 1050x530 mm* *slope = 12°* *distance = 700 mm* *feet = 250 mm*	`ECHO: "Panels 5X2, slope: 12°"` `ECHO: "Footprint: 2861.94 x 2662 mm"` `ECHO: "4 x supports:"` `ECHO: " base: 1054 mm"` `ECHO: " Hbar: 840 mm"` `ECHO: " Vbar: 400 mm"` `ECHO:` `ECHO: "2 x spacer: "` `ECHO: " length: 1071.39 mm"` `ECHO:` `ECHO: "6 x currents:"` `ECHO: " length: 2662 mm"` `ECHO:` `ECHO: "8/12 x bolts M8x15 "` `ECHO: "60 x wood screws M 4x30"` `ECHO:` `ECHO: "Total L: 11318.8 mm"`

Solution 4: Plug and Play 300W

This example shows how, with the appropriate parameters, this OpenScad project can also define a horizontal support to be fixed with plugs for wall, slope 72° (S_slope = 18), Footprint: 507 x 3158



Construction notes

- However they are arranged, there is always a 1 mm gap in the joint of the triangular supports: if required insert a shim (washer) before welding.
- Use 2 or 3 M8x15 bolts to fix the horizontal spacers.
- Flexible panels can be directly fixed with screws if the currents are made of wood or aluminum.
- With rigid panels, a strong profile in aluminum or galvanized steel for PV can be used directly as a current.

- If there are height constraints, do not use the legs (S_leg = 0) and adequately ballast the profiles laid on the floor (20/100 Kg/m2).
- Otherwise (in the case of a terrace with balustrades) each leg can use an umbrella base (7,50 €) ballasted with water or sand, to which the vertical support is bolted.
- Pay attention to roof slopes and avoid standing water. Use an insulating sheet under the supports.

Note: for an example of industrial supports with all the mounting details see Cosmogas, manuale di installazione pannelli solari (in italian).

Lightning protection

There are two types of lightning-related problems

Direct damage, caused by lightning striking the panels.

Catastrophic, damages are very important, and the only solution is an adequate lightning protection system (LPS). Generally only in the case of isolated buildings or solar panels mounted directly on the ground.

Indirect damage, caused by the electromagnetic field of a nearby lightning strike.

Protection is provided by surge protectors (SPD) placed at strategic points: at the AC input, at the DC output for the inverter, and, if a cable exceeds 10m, at both ends of the cable (type 1 and type 2).

Usually, it is not advisable to connect the metal structures of solar panels to the ground: it seems that this increases the probability that they will be struck by lightning.

Support materials x 10 PV panels (1'000 W)

12 x Metal upright 3,5 x 3,5x200 cm grey/silver (7€) 84 €
6 x Wood 30x40 x 3000 mm (indicative: 12 €) 72 €
or:
6 x Aluminum 30x30x2 x 3000 (indicative: 20 €) 120 €
or:
6 x Galvanized profile for PV 41x21 x 3000 (indicative: 23 €) 138 €

..Screws and bolts, paint, welding, ballast and/or anchors, steel safety cable with clamps, wall plugs (indicative) 30 €

Structure cost for 10 PV panels: 200--280 €.

note: many of these materials are bulky and heavy: it is better to buy them on the spot. The prices and links provided are just an example. Find the best equivalent local offer.

Photovoltaic over 350W

Commercial example: [600W (800 ?) grid tie]

- 4 x panels 200Wp (1140x700 mm) 800 W (!) (2P2S)
- inverter 600 W(!) (note: model without WiFi)
- 2,5 m DC cable, 2,5 mm^2
- 5 m AC cable
- mounting accessories

Cost	**869 €**
Cost per kWp	**1.448 €**

Commercial example Italy: 1,5kWp photovoltaic kit WITH LIMIT – CEI 0-21

• 4 * monocrystalline photovoltaic panels 380/375Wp HANOVER Solar / MUNCHEN Solar (1760 x 1006 x 35 mm)

• Inverter Zucchetti CEI 0-21 1100Wp (!) ZCS 1100TL-V3

• 10mt red photovoltaic cable 4mmq

• 10mt black photovoltaic cable 4mmq

• 2 pairs of MC4 connectors

• Input sensor for LIMIT input

Cost	**1379 € + shipping**
Cost per kWp	**919 €**

Commercial example Italy: KFV30 photovoltaic kit 3 kW

- 410 Wp Monocrystalline Modules Hyundai HiE-S410VG; 25-year product and performance guarantee (number ??)
- Inverter AZZURRO ZCS-3000TLM-WS, 3 kW
- MC4 type male and female Amphenol fittings - 4 sq. mm
- Support and fastening structures

Cost: **4400 €**
with installation and paperwork 7400 €

Cost per kWp: **1467 €** (*2470 €*)

Commercial example Italy: 2000 Wp photovoltaic kit including installation

- 10* 200W CANADIAN panels
- AROS 2600 Wp inverter (certified)
- DC panel
- AC switchboard
- Inclined roof supports (screws, cables)
- installation
- drafting of an 'energy account' application

Cost: **5148 €**

Cost per kWp **2574 €**

Commercial example Italy: 1.5kWp hybrid photovoltaic KIT with 3kW 24V PWM inverter and 2 AGM 200Ah batteries (island**).**

- 4 x MUNCHEN Solar 375Wp photovoltaic panels
- 3kW inverter with PWM charge controller
- 2 * 12V 200Ah long-life AGM batteries. Total 4800Wh (useful 2400 Wh)

Cost: **2209 €**

Cost per kWp **1472 €**

note: as a starting point for a broader analysis of the photovoltaic kits available on the Italian market, see also *https://www.fotovoltaiconorditalia.it/idee/costo-kit-fotovoltaico-kilowatt.*

DIY project B: 800 / 1000 / 1200 Wp module

From the HW point of view, it is similar to plug-and-play, with the difference that, if a threshold is exceeded (*Italy 350 W*), the compensation mechanisms active in the various countries must be activated (*in Italy 'scambio il posto' or SSP*).

The energy produced is either consumed locally (*self-consumption*) or fed into the grid and accounted for by a meter.

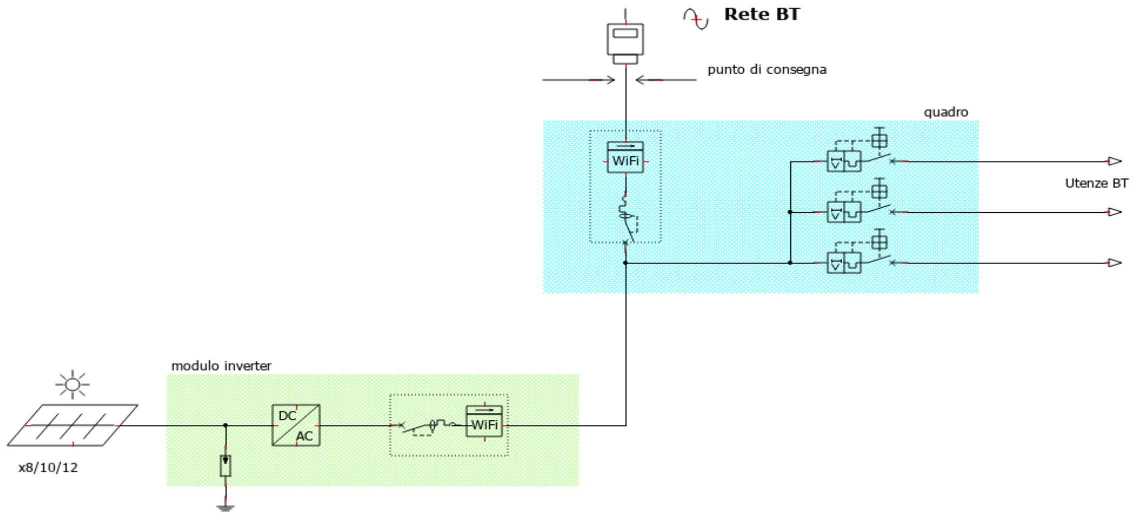
PROS:

- ✔ HW without storage, very simple and cheap.
- ✔ Can greatly reduce bills (Italy SSP analysis: see *above*)
- ✔ Compensates summer/winter, which is impossible with storage.

COS:

- ✗ Limited by contractual power (in Italy: 3.3 kW or 6.6 kW for homes).
- ✗ SSP is not as convenient for the user as self-consumption (see SSP analysis)
- ✗ Bureaucratic complexity and delays in updating meters (*Italy: over 3 months*)
- ✗ Numerous constraints on materials and inverters (certified) and on the installing company (authorized).

These projects send the extra energy to the grid: they must therefore be used with a 'Conto Energia' with the distributor. They must meet all the specifications required by the standards in force and by the counterparty (they vary depending on the country and the distributor company), and must also be installed by qualified firms. It doesn't seem very suitable for DIY. Here we present three hypotheses, substantially similar.



For safety it is necessary, in the DC circuit:

- surge protection (for lightning)
- panel switch. (if necessary)

In the AC circuit:

- a switch with protection to disconnect the inverter from the grid

DC protections: between the panels and the inverter (see diagram)

CHYT DC Surge protection 20-40 KA 600V 12 €

If the inverter is mounted on the panels, the protection can be inserted on the AC side

CHYT AC Surge protection 11,35 €

Watertight box DIN CHYT 8,04 €

2 modules

AC protections: between the inverter and the 220V bus (see diagram)

2P 63A TUYA APP WiFi Smart Energy Meter OPWT-63 € 33

This meter combines the functions of breacker, protection and power meter.

It can provide information about the energy produced by the inverter.

Measurements are accessible via WiFi (Tuya compatible).

Disconnector AC for a single module

EARU breaker DZ47 2P 10A 7,07 €

As an alternative to the OPWT -63 meter

Inverter on grid

Inverter SG-1200W-Mobile WIFI

Max input: 60V, startup 20 V (max 3 panels)

*Max input: 4*10A, 4*300W*

Output: 1150 W (220V, 5A)

WiFi smartLife compatible

Cost: 250.02 €

Very compact and easy to assemble, it includes the compatible Tuya WiFi function.

From the same series as the one used for the plug-and-play A2 project.

Works with both 4*2 panels (4P2S, 800W) and 4*3 panels (4P3S, 1200W)

Modular, up to 8 units (9,600 W) can be connected in series.

ZCS Zucchetti Azzurro 1Ph 1100TL-WS

Input 80V-450V. Max 10A (datasheet) (10 pannels in series)

Output 1000 W

With MOV disconnector and unloaders

Custom WiFi (not SmartLife compatible)

RS485 channel

CEI0-21 certificate (Italy): YES

Cost: 442,63 € + VAT + transport

The inverters of the Zucchetti Azzurro series are used by ENEL in commercial photovoltaic kits in Italy.

This inverter uses the connection of solar panels in series, saving connectors and diodes, but with high DC voltages and greater vulnerability to shadows.

Cost summary 800 / 1000 / 1200 Wp

item	PV [kWp]		
	800	1000	1200
8/10/12 PV panels RG-MN-100	692,8	866	1039,2
Inverter SG-1200W / ZCS 1100	250	480	250
Meter WiFi OPWT 63 (optional)	33	33	33
panels installation (see later)	180	200	220
Surge protector + box	20	20	20
Mounting accessories (variable)	50	40	50
Cost	1225,8	1639	1612,2
Cost per kWp	***1532,25***	***1639***	***1343,5***

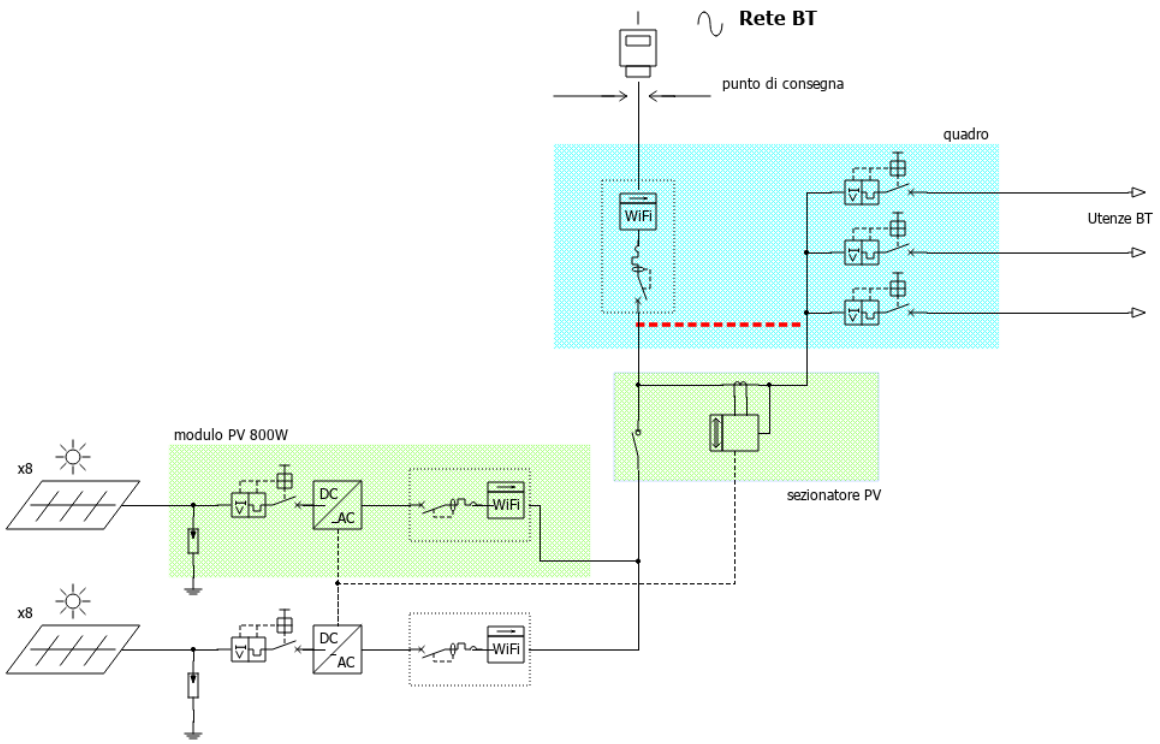
Feed-free systems

"*It is in response to the overwhelming clamor from our customers for a product that can control the amount of power that the grid tie inverters (GTI) can generate so that the amount of excess power produced by the solar panels are reduced to insignificant levels, if not eliminated --- because in some countries, the producer pays for the excess power it gives to the distribution grid. This is because the electric power meters (the one provided by the electricity provider in the area) are not aware of the direction of power flow. In other words it only adds even if power is exported to the grid, thus, the consumers will be charged for power even if it is given to the grid, and this is the problem*" (inverter GTN 1000 info).

note: 'Feed-free' inverters only produce for self-consumption. Excess energy is lost, but it is not fed into the grid: it is simply not produced.

DIY project C: 800W module

This design is for 800W, 'feed-free' modules, with batteries reachable at a later date (see below, D-storage project) and expandable up to 8kW using more modules.
It is a flexible and gradual modular approach, both in terms of performance and cost.



We have two contiguous elements: *house switchboard* (existing, modified) and *PV disconnector*, while the inverters can be located in a remote location, as close as possible to the solar panels.

1 – house switchboard

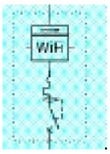
In the main switchboard, I replaced the existing main switch with the following device:

2P 63A TUYA APP WiFi Smart Energy Meter OPWT-63 (https://www.aliexpress.com/item/1005002361164427.html, € 33)

In addition to the measurement functions (V, I, W, kWh) visible on the display, this switch has adjustable protections for:

- Leakage (10-100 mA) (life saver)
- Overcurrent (1-63A)
- Overvoltage (250-300V) delay 0.5s
- Undervoltage (150-190 V) delay 0.5 s

It is Tuya compatible, so with the SmartLife APP you can both configure and read the data. In particular, this Meter provides the energy exchanged with the grid (on the bill) in real time.



In the diagram, the dotted box represents the OPWT-63 Energy Meter

Furthermore, the pre-existing direct connection between the main switch and the disconnectors (in red in the diagram) must be eliminated, in order to pass through the PV control unit

2 – sezionatore PV

The CA control unit consists of two devices - 5 modules - which can be inserted into the house switchboard if there is space available, or they can find their place in a new control unit placed near the existing switchboard.

This manual switch allows you to completely disconnect the AC 230V solar system. (50A => 10kW)
2 modules
EARU DZ47 2P 400Vwith 50A protection € 6,03

This DIN PowerMeter is an accessory included with the chosen inverter and measures the power absorbed by the loads using a current probe.
It can control up to 10 inverters via an RS485 link.
Must be set to the number of inverters present.
3 modules.

External watertight control unit for 5 DIN modules
CHYT 5way Plastic Waterproof Distribution Box € 11,95

2 – connection cables

From the control unit (see diagram) two connections reach the inverters, located near the solar panels:

• 220V bus, (3 poles), 5..50 A to connect the inverters

• RS485 connection, dashed in the diagram: a shielded twisted pair can be used up to a maximum of 100 m.

The characteristics of the cables vary according to the distance and the powers involved:

3-pole double sheath outdoor cable

Diameter to be calculated case by case as a function of distance and current. Use, in the link form:

- ✔ 230 V in EU as alternating voltage
- ✔ 1.25 as a coeff for the powers (ie 1250 W – 12500 W)
- ✔ loss < 1% (ie 2 V)

Values for short distances (< 5 m, indicative prices):

4 mm^2 : 25A	5 €/m
6 mm^2 : 32 A	6.50 €/m

Cable for RS485

For short distances (< 10 m):

twisted pair

For long distances (< 100 m)

shielded twisted pair (indicative price) 0.50 €/m

3 – DC control unit + inverter

A single box contains both the DC control unit and the inverter.

Construction site control box, 8 modules. 30,35 € + shipping

Requires a front closure panel.

Note: openings can be made or a fan added to improve cooling: in these cases use only indoors.

DC protections: between the panels and the inverter (see diagram)

CHYT DC Surge protection 20-40 KA 600V 12 €

2 modules

Per scollegare i pannelli solari:

EARU Breaker DC EACBDC (1000V)

2P protection 40A 9,78 €

2 modules

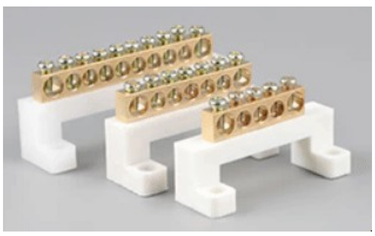
AC protections: between each inverter and the 220V bus (see diagram)

OP2P 63A TUYA APP WiFi Smart Energy Meter WT-63 € 33

This meter allows to connect/disconnect of the single inverter and offers all the necessary protections.

It also provides useful measurements to evaluate the performance of each inverter via WiFi (Tuya compatible).

2 modules



mass distributor
Bare clamp 7 holes 2,37 €

4- Inverter feed-free

There are many models of inverters with limiter available. Unfortunately, none are WiFi compatible with Tuya (for this reason I use the OP2P-63A Smart Energy Meter in each module).

In this project, I chose the GTN-1000LIM24 (192,65 €) inverter. It's not a recent model, but it has an excellent cost/performance ratio and some interesting features.

Note: of the same inverter there is also a version without display but with WiFI, the GTN-1000LIM24-W (234 €) model, which uses its own cloud and application (not compatible with Tuya - not tested).

Features:

Input power range: 200W-1100W
PV input range: 26 V – 45 V (pannels 5P2S)
Max Input protection current: 40 A
Battery mode (24 V) power range: 90W-650W
Battery + limit mode max output: 700 W
Efficiency: 88%

The LIMIT function uses an external sensor and controls, in an open loop, the AC output power, avoiding any extra energy input into the grid.

This inverter has four modes of operation:

1) PV: standard Inverter function, with MPPT for solar panels
2) PV + LIMIT: Operation with solar panel and with current limitation: it supplies only the power required by the loads.
3) BATT: Inverter function from the backup battery (from any DC source).
4) BATT + LIMIT: with battery and current limitation (max. 700 W).

In this project we are interested in mode 2: PV + LIMIT, and using this inverter the project is later expandable with storage batteries (using mode 4).

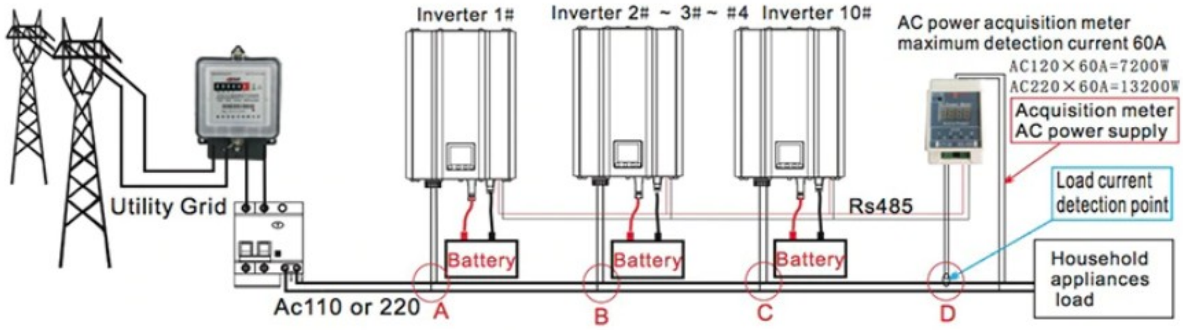
This inverter can be controlled via RS485, so it is possible to design a custom integration of the inverter in tuyaDAEMON and to use advanced management strategies (see also an example of remote control).

5- Modularity

The positive aspects of a modular approach are:

- Ability to achieve optimal sizing and adjust to changes.
- Reduction of the consequences of damage or failure, both in functional and cost terms.
- Possibility of modulating investments over time.
- Small-scale tests and checks before major investments.

These modules are expandable simply by using inverters in parallel and setting the inverter number in the probe. The inverters (A, B, C) must be connected 'before' the probe (D), and the domestic loads 'after' the probe: therefore you cannot use just any socket (characteristic of 'plug-and-play') but you must obtain a dedicated connection from the house switchboard (see diagram).



(*from GTN-1000LIM24 documentation*)

Each inverter can manage solar panels from 200 to 1100 Wp, so even the single module is scalable. Therefore, a continuous upgrade strategy from the *plug-and-play* module to a *200 Wp C-module* is possible, and then increase the power up to 1 kWp by adding pairs of panels.

It is recommended that the solar panels managed by an MPPT inverter all have the same exposure and no shade. More 800 Wp modules can therefore be used both to obtain greater powers and to manage groups of panels with different exposures. (note: some inverters contain multiple independent MPPTs for this purpose).

note: The choice of 800 Wp per module is due to the following criteria (it can be increased to 1 kWh):

- 700W limit in battery operation.
- Using 8 panels as 4P2S with inverter and then as 2P4S with battery controller.
- Positioning of panels in 4x2 or 8x1 rows
- Avoid excessive heating of the inverter.

Project C cost summary – inverter with limit (800 Wp)

una tantum			
house switchboard (modified)*		33	
PV AC box		18	
Cables 220 V +RS485 (5m)*		30	
	cost		**€ 81,00**
each module (800 Wp)			
PV DC box		85	
inverter		234	
8 x solar panels		693	
	cost		**€ 1.012,00**
	cost per 1 kWp		*€ 1.185,25*
flat roof installation			
Support*		200	
mounting accessories, cables*		97	
	cost		**€ 297,00**

(*) optional or variable

Energy storage

Analysis: choice of batteries

There are various battery technologies for PV storage::

- **Lead-acid batteries**: cheap (various types: AGM, GEL, tubular…)
  note: automotive batteries are NOT suitable for PV applications.
- **Lithium batteries**: In rapid development, also due to the demands in the locomotion sector. (various types: Lithium, LiFePO4...)
- **Supercapacitors**; New technology, high-end.

Example (Faam, from *https://www.iorisparmioenergia.com):*

Tecnologia	Pro	Cicli @DOD	Tensione nominale	Codice	Capacità nominale	Capacità utile prevista**		
						12 V*	24 V*	48 V*
GEL	• Misure compatte • Nessuna manutenzione • Prezzi economici	1000 @50%	12 V	FLG12-100	100 Ah	0,6 kWh	1,2 kWh	2,4 kWh
				FLG12-200	200 Ah	1,2 kWh	2,4 kWh	4,8 kWh
Tubolare GEL	• Nessuna manutenzione • Elevato nr. cicli di scarica • Lunga vita attesa	2000 @50%	12 V	FTG12-100	100 Ah	0,6 kWh	1,2 kWh	2,4 kWh
				FTG12-150	150 Ah	0,9 kWh	1,8 kWh	3,6 kWh
Litio Ferro Fosfato	• Elevata profondità di scarica • BMS integrato • 48V Compatibili con inverter ibridi serie VM III e serie MAX	3000@80%	12 V	ULT12-100	100 Ah	0,9 kWh	1,8 kWh	3,6 kWh
		6000 @80%	48 V	PYL-2.4	50 Ah	----	----	2,4 kWh
				BAT-5KWH-W	86 Ah	----	----	5,0 kWh
Super condesatore KiloWatt Labs Sirius	• Vita attesa di oltre 40 anni • Profondità di scarica al 99% • Compatibile con tutti i caricabatterie ed inverter • Altissima velocità di carica e scarica • T servizio da -30° a +80°C • Garanzia 10 anni	Oltre un milione @99%	12 V	SIR0.46-12	38 Ah	465 Wh	----	----
			12 V	SIR1.00-12	83 Ah	1,0 kWh	----	----
			24 V	SIR3.00-24	125 Ah	----	3,0 kWh	----
			48 V	SIR3.55-48	74 Ah	----	----	3,55 kWh
			48 V	SIR7.10-48	148 Ah	----	----	7,10 kWh

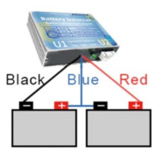
The most important parameters for a technical-economic assessment of storage are:

- **Depth of charge** (DOD): useful capacity compared to nominal.
- **Number of cycles**: that is the expected life of the battery. In solar applications a cycle equals one day.
  For l*ead acid batteries,* the number of cycle*s* is related to the *DOD*. Example (Prime AGM battery):

100% DOD	=>	300 Cycles	(less than one year)
80% DOD	=>	400 Cycles	(1.09 years)
50% DOD	=>	700 Cycles	(2 years)
30% DOD	=>	1700 Cycles	(4.65 years)
20% DOD	=>	2400 Cycles	(6.6 years)

- **Costs**: analyze the initial cost, the cost per kWh, the maintenance cost, the cost in 20 years (life of the system).

Always check the manufacturer's specifications before choosing a battery.
Note: beware of scams, especially mail order scams, they are very common with lithium batteries. Always check user comments, especially if you find offers at too low prices.



When using batteries (acid or lithium) in series to increase the voltage (for example 12+12 = 24V) it is advisable to use a device that guarantees the [balance of the charge]:
[Charge Battery Balancer] 16,99 €

Analysis: storage size

We try to establish rational criteria for evaluating the required storage.
We evaluate the solar energy (**E_{solar}**) expected for our system. Let's consider **2 kWp** (slope 50°, azimuth 45°): from PVGIS we get (we use a factor of 0.8 for storage losses

2900 kWh – average annual production	=>	6.4 kWh/day (annual average)
146 kWh – production month December	=>	3.8 kWh/day (December)
342 kWh – production month July	=>	8,8 kWh/day (July)

Let's consider consumption by dividing it into three categories:
- **Constant:** we have a fixed ceiling due to equipment that is always on or on standby: burglar alarm, WiFi, TV, etc...
- **Scheduleable:** these are the consumptions that can be moved to the daytime slot (self-consumption), or by changing habits or, better still, through automation. Examples: Water heater, washing machine, dishwasher, irrigation, etc.
- **Random:** these are consumptions that can take place at any time of the day or night and cannot, by their nature, be scheduled. Examples: lights, oven and kitchen appliances, refrigerator, air conditioning/heating, fans, TV, PCs, etc.

The energy required for storage (**$E_{from\text{-}storage}$**) is, considering an average of 5 hours of sunshine:

$$\mathbf{E_{from\text{-}storage} = 19/24\ E_{constant} + 19/24\ E_{random}}$$

The energy available for storage (**$E_{to\text{-}storage}$**) is, always considering 5 hours of sunshine and indicating with **E_{solar}** the energy produced in a day:

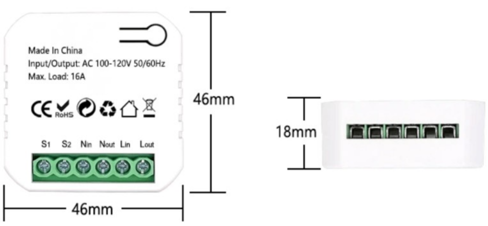
$$\mathbf{E_{to\text{-}storage} = E_{solar} - E_{schedulable} - 5/24\ E_{constant} - 5/24\ E_{random}}$$

A) This consumption can be evaluated a priori, using the plate data of the appliances and considering usage habits. To simplify the calculations, you can use online tools, such as the Trojan Battery Renewable Energy Sizing Calculator.

B) Or consumption can be evaluated experimentally, measuring actual consumption broken down by type for a period (e.g. one month, better if repeated: summer/winter).

For this purpose, I bought many smart sockets (8.82 €) for the main appliances. These sockets allow you to:

- know the instantaneous and historical consumption of household appliances
- evaluate the current ON/OFF status of the appliance
- suspend/resume operation of the appliance.
- later they will be used for automatic management.



Equivalent, but with a different form factor (14.73 €), this meter is suitable for fixed installation within existing outlets.

In all cases, TuyaDAEMON saves the data in a DB and therefore can be easily processed to obtain the desired synthesis.

DIY project D: adding storage

Battery choice

The following general criteria are found in the literature:

- *(a) useful battery capacity = from 0.1 to 0.15% of annual consumption*
- *(b) useful battery capacity = 1.5 × PV array power*
- *the reference value is the smaller value between (a) and (b).*

A quick alternative criterion for evaluating storage needs takes into consideration not consumption, but the energy produced and the self-consumption.

Starting data: PV 1kWp, slope 50°, production 1450 kWh/year. So the average daily production is ***3.9 kWh*** *(December 2.4 kWh, July 5.5 kWh).*
This table shows the extra energy (excluding self-consumption) available for storage:

Self-consumption	storage [kWh]		
	avg	December	July
0,00%	3,9	2,4	5,5
10,00%	3,51	2,16	4,95
20,00%	3,12	1,92	4,4
30,00%	2,73	1,68	3,85
40,00%	2,34	1,44	3,3
50,00%	**1,95**	1,2	2,75
60,00%	**1,56**	0,96	2,2
70,00%	**1,17**	0,72	1,65
80,00%	0,78	0,48	1,1
90,00%	0,39	0,24	0,55
100,00%	0	0	0

A reasonable value for self-consumption is between 50 and 70 percent, so there is energy available for 1..2 kWh of storage (average). Of course, the more storage the better, but it's still a major investment..

I choose to start with 1kWh of storage for each module (1000 Wp). If I can't reach 70% self-consumption I will increase the storage later: it is, therefore, important to use storage that allows the increase by adding batteries in parallel.

To have *1 kWh of useful storage*, the battery capacity varies according to the technology (24 V is imposed by the chosen inverter):

Lead batteries	(DOD 50%):	24V – 83 Ah
Lithium batteries	(DOD 80%):	24V – 52 Ah
Supercapacitors	(DOD 99%):	24V – 40 Ah

Examples (some prices are net because the VAT on batteries, in Italy, can be 22% or 10%):

2 x AGM Deep Cycle,12 V 100Ah (SLC 100-12S)
295 € + VAT + transport

output current: max: 60A
10 ÷12 Years of expected lifetime (?)
weight: 2x28 Kg

2x [AGM Deep Cycle,12 V 100Ah] Prime
324 € + VAT + transport

cycles: 700 (50% DOD)
weight: 2x33 Kg

[LiFePO4 24V 60 Ah] 519,63 €
discharge current 40A (960 W)
max 4 series/parallel (BMS limit)
cycles > 3000
weight: 14 Kg
Power adapter included

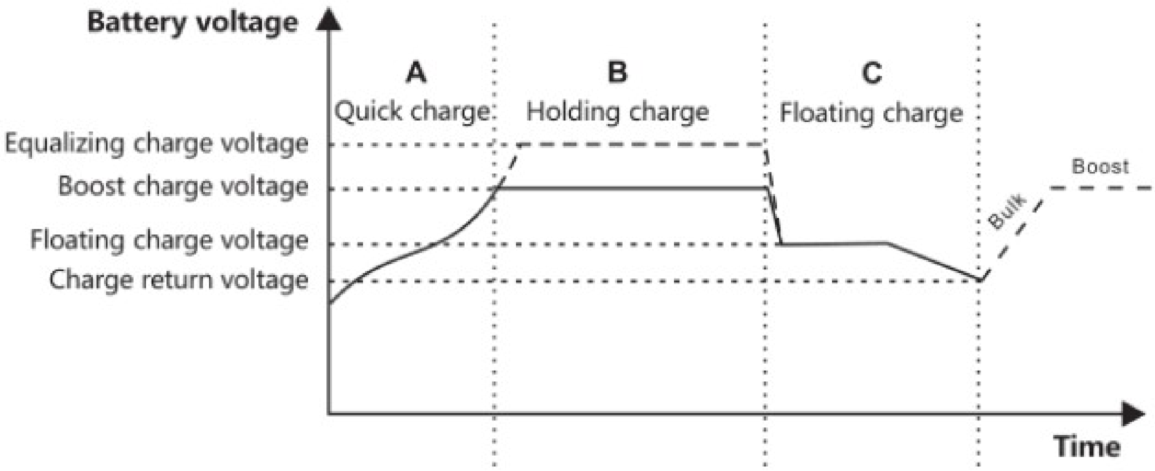
[LiFePO4 24V 54 Ah] 690 € + VAT +transport
Recommended/max charge current: 10,8A / 27A
cycles > 3000 (DOD = 80%)
max 2 series/parallel (BMS limit)
Bluetooth 4.0 monitoring via Android and IOS app.
weight: 14 Kg

2 x [supercapacitors Sirius] storage 500Wh 12V
1100 € + VAT + transport

Compatible with AGM charge
max charge/discharge: 40A / 40A
DOD = 99%
life > 40 anni.
weight: 2x11 Kg

The choice is exclusively based on subjective and economic considerations. Surely supercapacitors are the most convenient in the long run, but they are also a new solution with the highest initial cost.

The charging process of a battery is generally divided into 3 phases: *rapid*, *constant voltage*, and *maintenance*. [Equalizing charge] (for lead acid batteries only) once a month.



(from MC2440N10 documentation)

The values that identify each step depend on the battery voltage and technology and are generally modifiable by the user (always check the datasheets of the battery and the controller used):

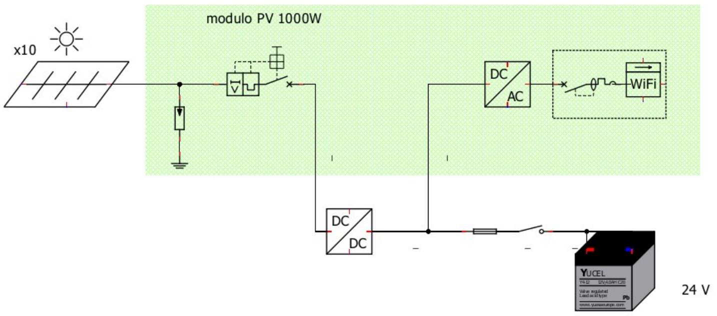
Lead-acid battery /BAT/ B1						
System Volt	12V system		24Vsystem		48Vsystem	
Float charging Volt	Default 14.4V	Adjustable range 13-15V	Default 28.8V	Adjustable range 26-30V	Default 57.6V	Adjustable range 52-60V
Discharge cut-off Volt	Default 10.7V	Adjustable range 9.5-11V	Default 21.4V	Adjustable range 19-22V	Default 42.8V	Adjustable range 38-44V
Discharge recovery Volt	Default 12.6V	Adjustable range 11.5-13V	Default 25.2V	Adjustable range 23-26V	Default 50.4V	Adjustable range 46-52V
Ternary lithium battery /LIT1/ B2						
System Volt	12V system 3 strings		24V system 7 strings		48V system 13 strings	
Float charging Volt	Default 12.6V	Unadjustable	Default 29.4V	Unadjustable	Default 54.6V	Unadjustable
Discharge cut-off Volt	Default 9V	Adjustable range 9-10.5V	Default 21V	Adjustable range 21-24.5V	Default 39V	Adjustable range 39-45.4V
Discharge recovery Volt	Default 10.5V	Adjustable range 10.5-11.7V	Default 24.5V	Adjustable range 24.5-27.3V	Default 45.4V	Adjustable range 45.5-50.7V
Lithium iron phosphate battery /LIT2/ B3						
System Volt	12V system 4 strings		24V system 8 strings		48V system 16 strings	
Float charging Volt	Default 14.6V	Unadjustable	Default 29.2V	Unadjustable	Default 58.4V	Unadjustable
Discharge cut-off Volt	Default 11.8V	Adjustable range 11.8-12.5V	Default 23.6V	Adjustable range 23.6-25V	Default 47.2V	Adjustable range 47.2-50V
Discharge recovery Volt	Default 12.5V	Adjustable range 12.5-13.5V	Default 25V	Adjustable range 25-27V	Default 50V	Adjustable range 50-54V

(from Demura controller)

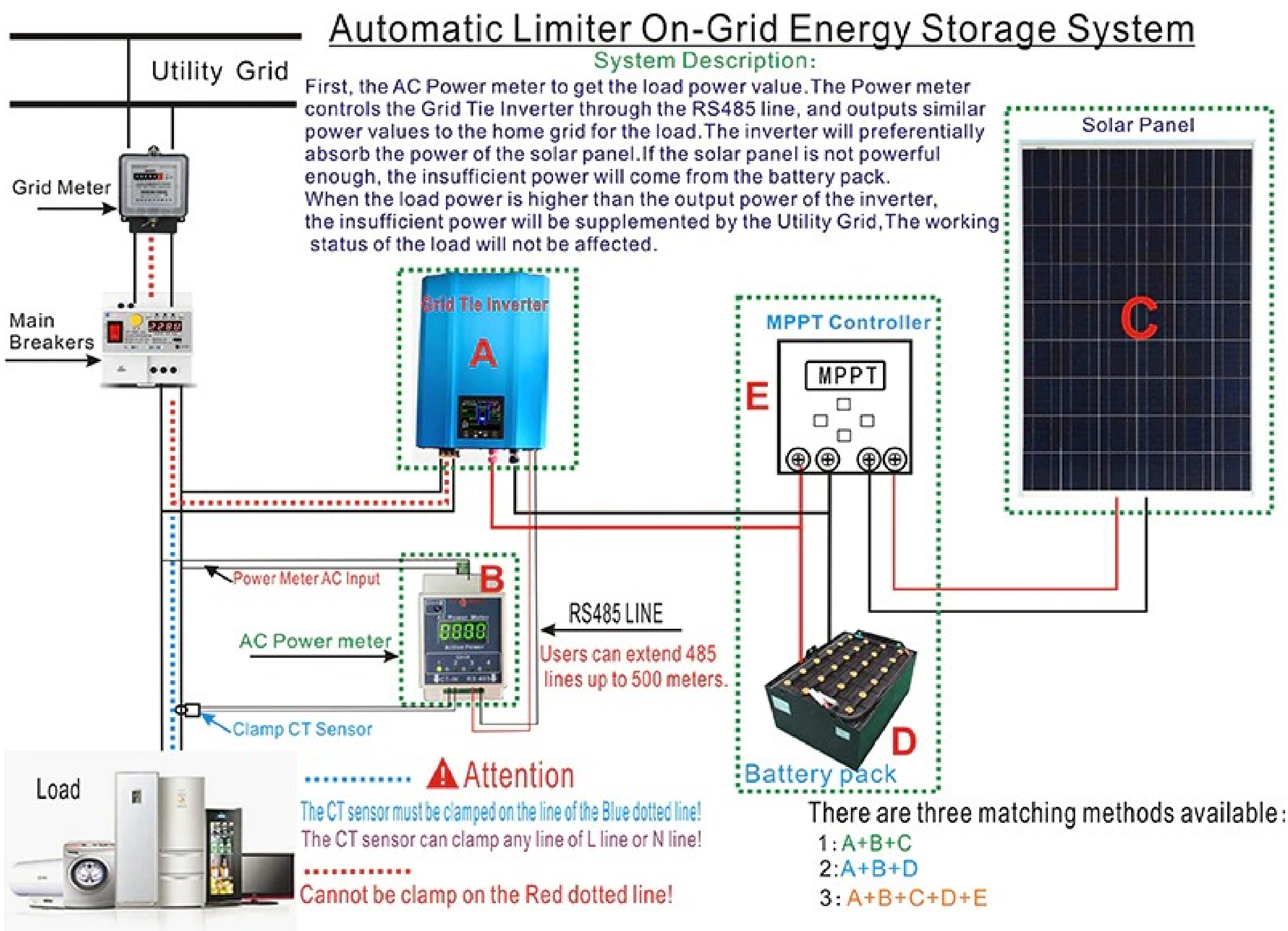
For the various types of lead-acid batteries see also here.

DIY project D: storage

The elements shown in the figure must be added to project C: the battery pack (with switch and fuse) and the DC/DC charge controller. The pre-existing inverter is no longer connected to the panels but is connected to the battery.



The scheme is substantially identical to that proposed by the manufacturer, apart from switches and protections (*often imposed by the standards in force*).
It may be advisable to wire the 8 solar panels differently: the controller accepts 26..92 V, and P2S4 reduces cables and currents (and therefore losses).



(*from GTN-1000LIM24 documentation*)

MPPT solar controller

This model was chosen, among the various controllers available, for its good price/performance ratio and for its well-documented communication interface.

Battery controller SRNE MC2440N10 103 €

MPPT: 26… 92 V, max 1320 Wp
battery 24V => 1100W
3-step charge
User manual.
TLL serial port, Modbus protocol.

12V-42V DC Circuit Breaker 100A 8,55 €
6M connections
It acts as a breaker and protection fuse for the batteries.

Cable lugs (10 pcs):

SC10-6	breaker (7AWG)	2,62 €
SC10-8	battery (7AWG)	2,93 €

Controller/battery/inverter cable recommended in the controller manual (10 mm2 - 7AWG)

AWG7 - 10 mm^2, 2 m (red + black) 25,67 €

Battery check

There are tools dedicated to checking batteries, for example, BMV 700 Precision Battery Monitor.

A simpler alternative that can be integrated into tuyaDAEMON (still to be evaluated, depending on the data available from the controller) is the following:

ATORCH tester for batteries, 240V, 100A 20,51 €

with Bluetooth

note: about the ATORCH and his Bluetooth protocol, see this project.

D project cost summary – storage (1200 Wh)

Lithium battery*	520	
Controller	103	
accessories, cables*	35	
costo		**658 €**

(*) optional or variabile

Off-grid system (UPS)

In stand-alone systems, the loads must be connected to the inverter (and not to the grid). Therefore the inverter must be sized for the total domestic load. In addition to complicating the installation, this makes simple modular extensions impossible with most inverters.

A big plus is that being isolated from the grid, contracts with local operators are not required, so it is well placed for DIY.

The priority, in many inverters, is user-definable and determines the automatic mode of operation (note: usually optional battery):

solar priority, then grid: battery only for backup. Functionality: self-consumption + UPS

solar priority, then battery, then grid: similar to *on-grid*, without UPS function.

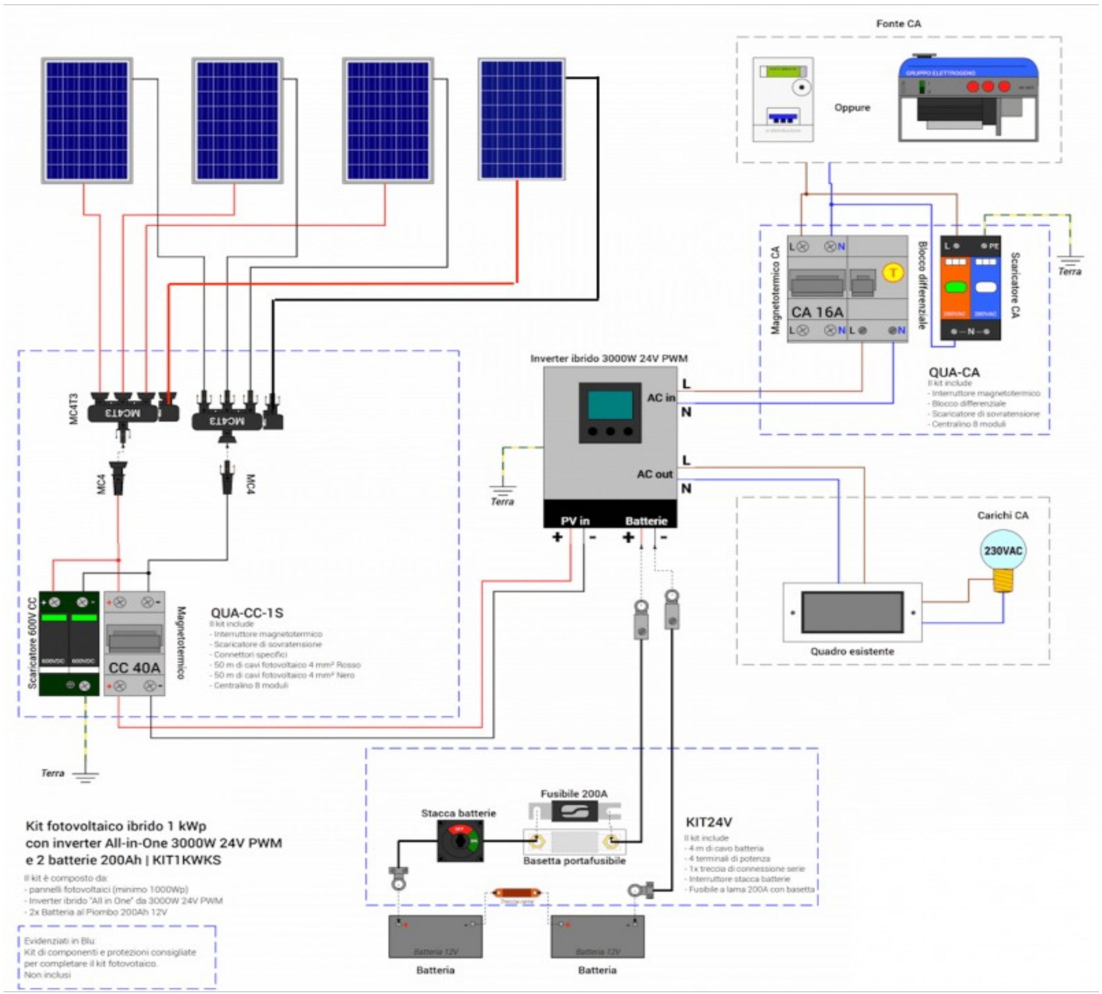
the batteries can be recharged by solar, grid, or both.

Esemple italy: inverter UPS 1000W Axpert VP-1000-12

off-grid UPS hybrid PWM inverter
input Max 55V Max 50A Max 600W => 3P2S
output 230VAC, 1000W
battery: 12V charge Max 50A
UPS 10/20ms transfert time

Cost 240 €

Italian commercial system: 1,5 kWp, 2.4 kWh storage, inverter 3kWh:



note:

- This 'off-grid' system uses a 'hybrid' PWM inverter (which includes the battery charger).
- Can operate as a UPS (grid priority) with 10/20ms intervention.
- AC loads are connected to the inverter and cannot exceed its power (3 kW).
- 2 x AGM 12V, 200A batteries for 4.8 kWh (useful 2.4 kWh)
- The inverter must be connected to the house control unit by 2 wires (AC in and AC out).
- Not parallelable (not expandable).
- Cost: €2209
- Cost per kWp €1472 (+ support + cables).

For DIY UPS projects this manual/automatic switch (ATS) (8 ms) may be useful:

switches to backup in the event of a mains voltage failure.
2 poles, 230V, 60/100/125 A 28,07 €

DIY Project E: 6200W MPPT (off-grid/grid tie)

This is an updated version (version 4) of the similar project ver. 3.

This 'island' project, which inevitably sacrifices modularity, has the following characteristics:

- Simplifications (and savings) using a single hybrid inverter
- Scalability of the panels (0.5 kWp… 6.5 kWp), mounted in one or more strings (S5..S20)
- Big storage: 48 V battery, min. 100 Ah.
- High initial investment

Goals

Better adherence to Italian safety standards which prescribe:

- UPS operation: with automatic switchover to the local generator only in case of mains failure.
- Off-grid (island) operation totally disconnected from the distribution network.
- Under no circumstances must voltage be fed into the grid in the absence of the grid.

'Smart' operation with the main commands and data sent via WiFi using compatible Tuya components. This, together with the remote commands of the inverter, allows to realize advanced IOT integrated control and management strategies (for example using TuyaDaemon).

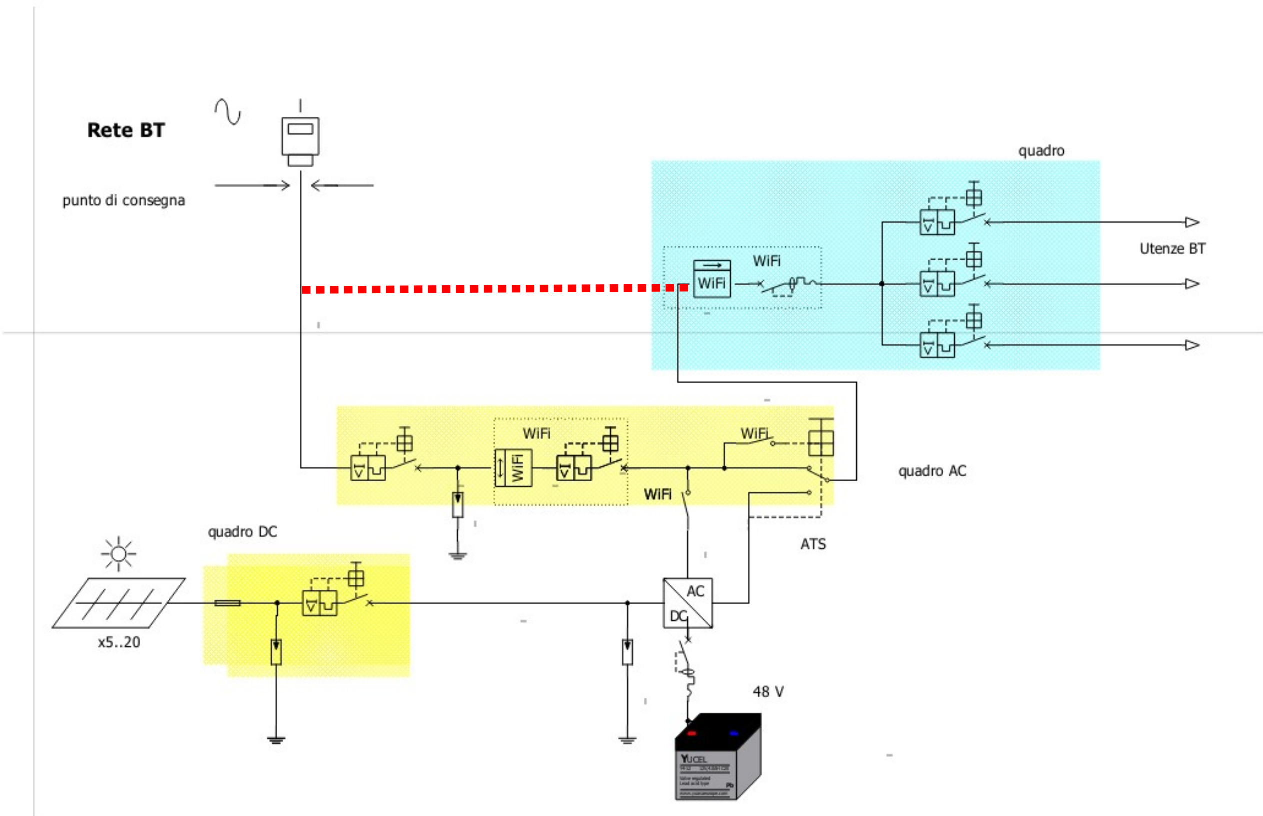
In this project it is advisable to position the inverter as close as possible to the house switchboard:

- ✔ The length of the double AC connections preceded by all the power (6 kW) is reduced
- ✔ Instead, the DC cables are lengthened, but they are at 90-450V and low current (7-14A).
- ✔ The batteries should also be placed close to the inverter.

WiFi performance in *smartLife APP*, in addition to the inverter and BMS remote options:

1. mains switch, also timed
2. ATS operating mode: *UPS* or *off-grid*, also timed
3. control of *grid → load* bypass, with complete disconnection of the inverter.
4. measurement of the energy exchanged with the grid (bidirectional)
5. measurement of the energy consumed by the loads
6. Definition of *protections*:
   - for the inverter: *overvoltage, undervoltage, overload*.
   - for the home network: *overvoltage, undervoltage, overload, leakage* (10-100 mA).

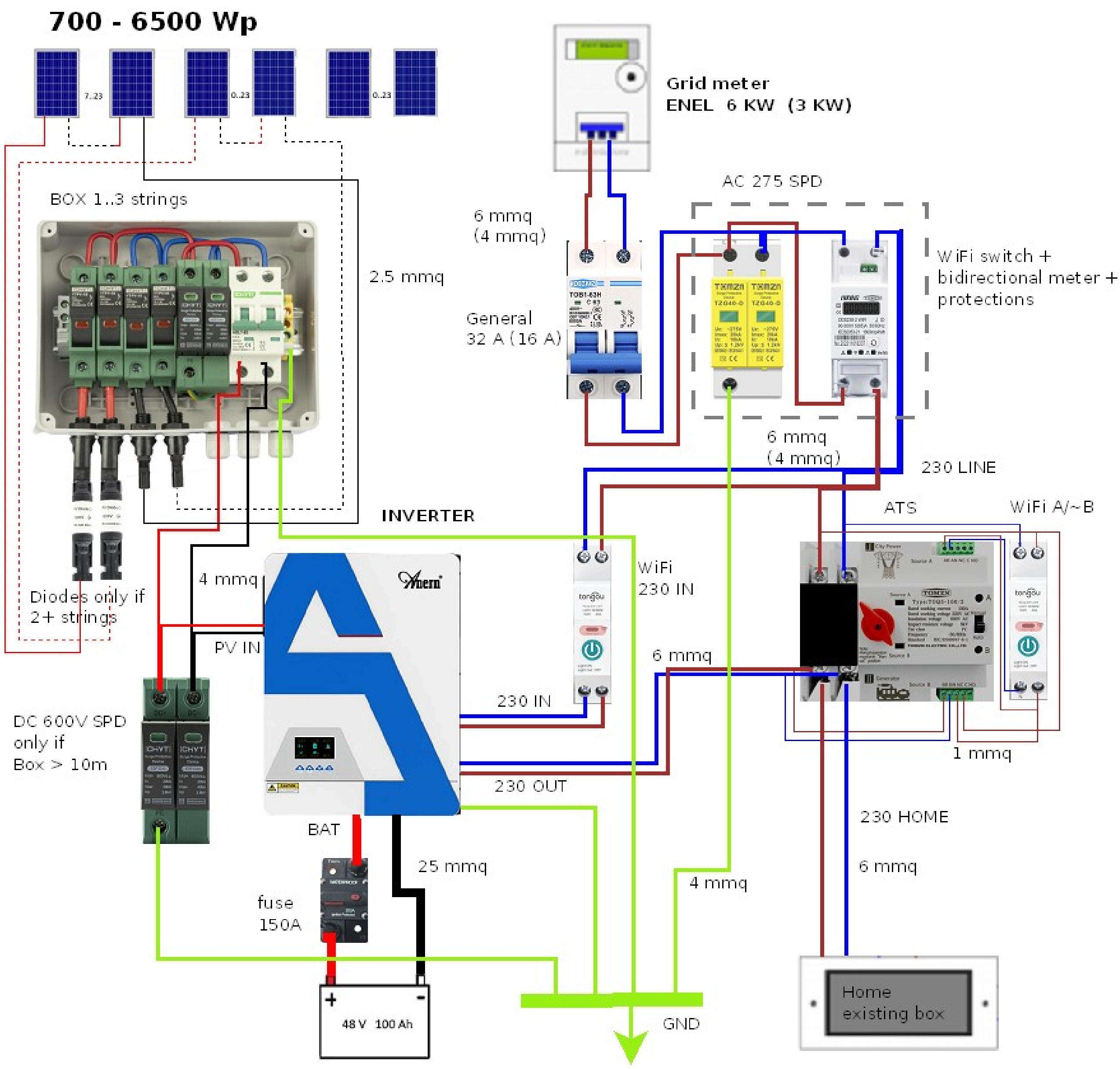
Unifilar circuit



(made with QelectroTech)

The total separation of the grid and photovoltaic circuits is evident in the diagram.

Detailed diagram



1. Home switchboard (existing)

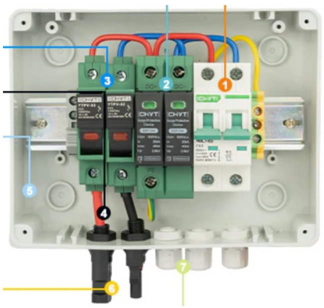
As usual, the existing switchboard must be modified by eliminating the red link.

As already indicated, I replaced the existing circuit breaker with:
OP2P 63A TUYA APP WiFi Smart Energy Meter WT-63 33 €

This meter allows you to measure consumption and connect/disconnect domestic loads. It offers protection and life saver function to appliances

2. DC box

It is advisable to use a complete DC field panel (with fuses, SPD, Breacker) for 1/2/3 string (with the chosen inverter, S7..S23):



1 string model (max 2,3 kWp)	51,07 €
2 string model (max 4,6 kWp)	52,81 €
+ 2 x diodes	
3 string model (max 6,5 kWp)	103,99 €
+ 3 x diodes	

I use the 2 string model because available space limits the number of panels.

If the box-inverter distance exceeds 10 metres, it is necessary to add a discharger (SPD) on the inverter side:

SPD DC 20-40 KA 600V 14,24 €

DC panel total ***52,81 €***

A connection (400V, 7-14-21A) is required between the DC control unit and the inverter, even a long one: the cable can be standard, since it works at low temperatures and, if in the sun, it can be inserted in raceways.

FS17 1 x 4 mm2, 3 x 10 m (red + black + mass) (indicative: 0.6 €/m) 18.00 €

For 4 mm^2 cable, the maximum free-air current is 55A. Applying the coefficients 0.90 (in a pipe) and 0.91 (in the sun) gives 45A, in any case, higher than Isc max (3P) = 20.9 A
Check for voltage losses in the connections to the inverter, max 21A

strings	3
length [m]	20,000
R (AWG12) [Ω]	0,104
Δ V	2,735

3. AC panel

The mains voltage comes from the distributor's counter, which can be (typically in Italy) 3 kW or 6 kW. In a new box find place:

1) Main switch

Guarantees disconnection from the network, with magneto-thermal protection.

2P 32A(16A) 400V ~ 50HZ/60HZ breacker AC MCB tipo C 7,61 €

2) SPD surge protector

Noise suppressor, especially useful if the meter is far away.

AC SPD 2P 275 V, 10-40 KA 9,97 €

3) WiFi switch + meter

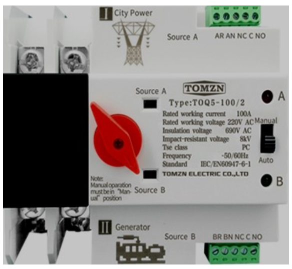
WiFi device with various functions:
- 230 network switch with timing and remote control
- Bidirectional active power (W), reactive (VA) and energy (Wh) meter
- Also measures: voltage, current, cosphi, frequency
- Store data locally, even without WiFi
- User-programmable protections (also in tripping and recovery times):
  overvoltage, undervoltage, overload

It allows a fine calibration of the protection levels for the inverter.
Allows you to exclude the grid by schedule.

TOMZN 1P + N 65A Tuya WIFI Smart bidirectional Energy Meter 32,61 €

The mains voltage, indicated `230 LINE` in the diagram, goes directly to two switches: `ATS` (home) and WiFi `230 IN` (inverter):

4) **ATS: Automatic Transfer Switch**



Basically it is a switch controlled by two voltages at 230: `AR-AN` and `BR-BN`.
Default priority is given to input A (the top one)
Manual mode: move the switch to 'Manual' and then rotate the red lever.
*This model is marked for **UPS** applications: grid priority in A.*

2P 63A 230V Mcb – ATS 20,98 €

The relay on the right (`WiFi A/~B`) has the purpose of changing, manually or via WiFi, the priority of the `ATS`: with the relay closed, the priority is of the input A (**UPS** mode) with the relay open, the priority is of the input B (**off-grid** mode).
If A and B are present at the same time, a priority change is equivalent to a manual switching of the ATS.

*If the relay is **closed**, `230 LINE` is directly connected to `AR-AN`, priority **A**.*
*If the relay is **open**, `230 LINE` is connected to `AR-AN` only when `BC-BNC` (dry contact) is closed, i.e. only when there is NOT `230 OUT`: priority **B**.*

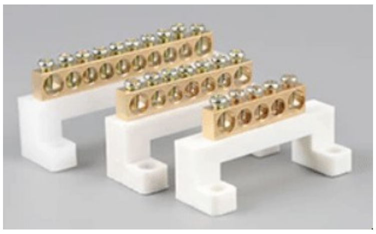
TUYA WIFI Smart Circuit Breaker DIN 40A 12,93 €
note: There are multiple versions, with various measurement functions that are not used here.

5) Switch for inverter (`230 IN`)
Allows you to disconnect the inverter from the grid, manually or via WiFi.
With this switch closed, in *off-grid* mode, the grid can supply power to the inverter when needed:

1. to charge the batteries
2. if required by the load (partial bypass)

TUYA WIFI Smart Circuit Breaker DIN 40A — 12,93 €
note: There are multiple versions, with various measurement functions that are not used here.

Also, as indicated in the diagram:

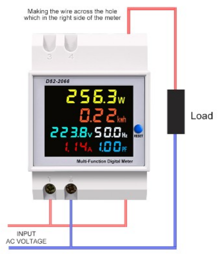


Bare clamp 7 holes — 2,37 €

To prolong the life of the contacts and to reduce interference, I also took some suppressors, to be mounted in parallel to the contacts or across the inductive load. The exact quantity and position will be defined with tests.

10 x RC Snubber — 8,16 €
0,22 µF/22 Ω/VDR 400 V

Extra



I added a panel meter to the `230 OUT` inverter output, to have immediate visual feedback on the energy produced.
The device is not WiFi, and is not shown in the diagrams.

Din Rail LCD/LED meter — 21,90 €

total AC panel total — ***107,66 €***

AC Cable

1 x AWG10 – 6 mm^2, 3 m (6.50 €/m) — ***19.50*** €

4. inverter

Many hybrid inverters can be used, such as Voltronic, Buffetti, etc. For my implementation I chose the following simple model:

Hybrid inverter AN-SCI02-PRO 6200W 605,82 €
PV: 90-450V, max 120A, max 6500W
Without Batt: ok, but PV > 360V
Battery: 48V, min 100Ah
note: also available 7200W 8200W 10200W
Interface: RS232, WiFi

PV to Inv: 97% max
PV to Bat: 98% max
Bat to Inv: 94% max
10/20 ms intervention

Priority: PV, (Bat,) grid.
Grid → *load* bypass even partial, possibility of *on-grid* mode.
See User manual. See also Anern.

5. solar panels

It is possible to use many combinations of panels, rigid or flexible, within the limits (450V, 120A, 6500W) of the chosen inverter. It is advisable not to push the inverter to the maximum.

Various types of panels can be used: for ease of handling I chose the usual 100W panels (19.2V, 6.87A). These must be placed in series, from 7 to 23 panels (2.3 kWp) per string, obtaining:

panels	7	23	*test*
V_{oc} standard	134,4	441,6	
V_{oc} Max (-10°)	149,2	490,3	< 500
V_{mp} Max (-10°)	126,8	416,7	< 450
V_{mp} min (70°)	92,9	305,4	> 90

Beware of high voltage: wire the panels at night.

Max 65 panels. When using multiple strings in parallel (over 2 kWp) make strings with the same number of panels (7..23), and use diodes.

diode 15A for PV 3,57 €

String connections.
Connections between each string and the DC box are short, PV cable (e.g. PV-1F) with high temperature and UV resistance should be used.

PV-IF AWG13- 2,5 mm^2, 2 m (red + black, indicative) 9,37 €

Check for voltage losses in string connections (each panel has 1.8m of cable):

panels	7	23
length [m]	16,6	45,4
R (AWG13) [Ω]	0,109	0,298
Δ V	0,954	2,610

Standard PV connectors can be used:

10 x PV connectors 4,18 €

6. Storage

The inverter must be able to obtain the peak value (6200 W) from the batteries, equal to 48V 130 A. At least 100Ah is therefore required. Here are several alternatives:

4 x AGM Deep Cycle, 12 V 100Ah (useful *2400 kWh*) 560 € + tax + shipping

or:

4 x LifePO4 12V 100 Ah (useful *3840 kWh*) 1455,16 €

or:

1 x LifePO4 48V 100 Ah (useful *4096 kWh*) 1290,10 €

1 x LifePO4 48V 100 Ah (useful *4096 kWh*) 1252,12 €

or

1 x Supercapacitors 48v 74 Ah scarica 120A (utile *3550 kWh*) 4279,90 €

For the choice of a battery, see the previous considerations. In this project the minimum size imposed is 48V 100Ah.

Furthermore, for the connection to the inverter:
2 x Cables AWG 6 – 16 mm^2 M8(M10), 40 cm red 17,28 €
1 x Cables AWG 6 – 16 mm^2 M8(M10), 80 cm black 13,15 €

Check for voltage losses in the connections to the inverter:

current [A]	120
length [m]	2,2
R (AWG6) [Ω]	0,003
Δ V	0,426

12V-48V DC Circuit Breaker 150A 8,55 €
Connections M6
It acts as a breaker and protection fuse for the batteries.

assembly 1 battery (48V) ***65,02 €***

To connect 4 x 12V batteries in series you also need:

3 x Charge Battery Balancer 60,97 €

3 x Cables AWG 6 – 16 mm^2 M8/10, 20cm red 29,22 €

accessories for 4 batteries (12V) ***90,19 €***

Project E – island (6200 W) cost summary

AC box		92,88	
AC cable (3m)*		19,5	
DC box		52,81	
DC cables (2m +10m)*		27,37	
	cost		**€ 798,38**
Storage (2400 Wh useful)			
4 x AGM 12V 100A batteries*		590 + tax	
accessories, cables (80 cm)*		129,17	
	cost		**€ 719,17**
PV (1 kWp)			
10 x pannels		866	
	cost		**€ 866,00**
Flat roof installation (1 kWp)			
Support structure*		200	
Mounting accessories*		43	
	cost		**€ 243,00**
	Total cost (1000 Wp)		***€ 2.626,55***
	Total cost (2000 Wp)		***€ 3.735,55***
	Total cost (3000 Wp)		***€ 4.758,55***

(*) opzional or variabile

note: optimization strategy

This is a blueprint for developing control algorithms.

Some consumption can be deferred over time and only be performed when solar energy is available, others not.

1. We equip the major appliances with IOT plug-meters, for example, the [plug-meters already seen]().
   In these conditions, consumption can be read and the system can be in 4 states:

Plug IOT	Appliance	Status	Power (W)
OFF	OFF	off	0
OFF	ON	wait	0
ON	OFF	ready	0
ON	ON	running	X

2. We divide the household appliances in the home network into two categories: ***interruptible*** and ***non-interruptible*** both based on the construction characteristics of the devices and based on our needs: water heater, dishwasher are interruptible, TV, oven, refrigerator are 'non-interruptible'.
   In reality, a high-class freezer, calibrated 1° or 2°C colder than required and with a safety system linked to the internal temperature, could be 'interruptible', i.e. powered only by photovoltaic energy (a few hours a day): but considering the reduced power typical of these appliances, probably more trouble than it's worth.

3. We give an interruptibility index, called ***marginality*** to all household appliances: 0 for non-interruptible, or a higher number the lower their priority: dishwasher 100; water heater 500 (each appliance has a unique value).

4. We give each IOT socket a 'default' value, valid in the absence of solar energy: 'ON' or 'OFF'.

5. There is a dynamic ***availability*** index stored, initialized to 0.

Algorithm for dynamic optimization:

A) If photovoltaic energy is available (not from storage):
   I) If there is unused photovoltaic energy, then the availability increases by one step by turning ON all the IOT sockets with *margin* < *availability*: some appliances will go into ready|running status.
   II) If the power absorbed by the grid is greater than the absorption of the 'running' appliance with the highest margin, then the availability decreases, turning OFF all the IOT sockets with *margin* > *availability*: some appliances will switch to the off|wait state.

B) If PV energy is NOT available
   I) All the IOT sockets are set to the 'default' state: ON or OFF depending on whether or not it is possible to power the device exclusively from the grid (or storage).

Problems:

1. stability: avoid the possibility of 'race'
2. push button remote control can be used to 'force' the 'ON' state of the IOT switches.

Addendum:

NOVEMBER 9, 2022

Essentially the brains of a PV plant, inverters' key function remains the conversion of DC power to AC. However, their design and configuration is continually evolving.

FEBRUARY 12, 2023

Since my last *National Electricity Service* bill (10.02.2023), the cost of electricity is **0,47 €/kWh** (includes energy costs/transport/system charges/taxes/VAT). This makes a photovoltaic system ever more urgent and convenient!