Abstract:

Off-grid photovoltaic (PV) solar systems represent a promising solution for decentralized energy generation, particularly in areas where access to the traditional grid is limited or non-existent. This abstract delves into the key aspects of off-grid PV solar systems, encompassing their components, functioning, advantages, challenges, and potential applications. Off-grid PV solar systems comprise solar panels, charge controllers, batteries, and inverters, all working in tandem to capture solar energy, store it efficiently, and convert it into usable electricity. The solar panels harness sunlight and convert it into direct current (DC), which is then regulated and stored in batteries through charge controllers. Inverters convert the stored DC electricity into alternating current (AC), enabling the powering of appliances and devices. The advantages of off-grid PV solar systems are manifold. They offer energy independence, enabling users to generate electricity autonomously, thereby mitigating reliance on centralized power grids and reducing utility bills. Additionally, off-grid PV solar systems are environmentally friendly, producing clean energy without emitting greenhouse gases or pollutants. They are also versatile and can be deployed in remote locations, providing electricity to off-grid communities, rural areas, and disaster-stricken regions.

However, off-grid PV solar systems also present challenges. The initial installation costs can be high, although they are often offset by long-term savings on utility bills. Additionally, the need for proper system sizing, maintenance, and battery management is crucial to ensure optimal performance and longevity. Furthermore, intermittency and variability in solar radiation can affect energy generation, necessitating appropriate system design and backup solutions.

Despite these challenges, off-grid PV solar systems hold immense potential for various applications. They are particularly well-suited for remote cabins, off-grid homes, RVs, boats, telecommunications infrastructure, and humanitarian projects in underserved regions. Moreover, advancements in solar technology, battery storage, and energy management systems continue to enhance the efficiency, reliability, and affordability of off-grid PV solar solutions.

In conclusion, off-grid PV solar systems offer a sustainable, reliable, and decentralized approach to electricity generation, with the potential to empower individuals, communities, and industries worldwide. By harnessing the abundant energy of the sun, these systems pave the way towards a cleaner, more resilient energy future

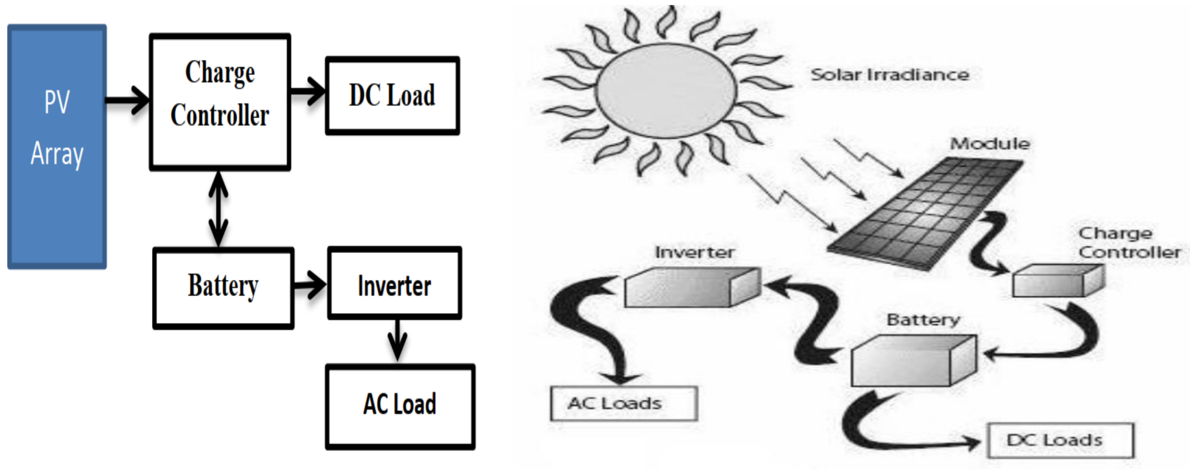


Figure1. Off grid system equipment.

1-System Sizing:

System sizing is the process of evaluating the adequate voltage and current ratings for each component of the photovoltaic system to meet the electric demand at the facility and at the same time calculating the total price of the entire system from the design phase to the fully functional system including, shipment, and labor.

1-1-Residence Device

As a first step, the electrical devices available at the residence are itemized with their power ratings and time of operation during the day to obtain the average energy demand in Watt-hour per day as shown below in Table 1. The total average energy consumption is used to determine the equipment sizes and ratings starting with the solar array and ending with system wiring and cost estimate as explained below.

1-2-Sizing of the Solar Array

Before sizing the array, the total daily energy in Watt-hours (E), the average sun hour per day Tmin, and the DC-voltage of the system (VDC) must be determined. Once these factors are made available we move to the sizing process. To avoid under sizing, losses must be considered by dividing the total power demand in Wh.day-1 by the product of efficiencies of all components in the system to get the required energy E_r. To avoid under sizing we begin by dividing the total average energy demand per day by the efficiencies of the system components to obtain the daily energy requirement from the solar array:

$$E_r = \frac{\text{daily average energy consuption}}{\text{product of component's efficiencies}} = \frac{E}{\eta_{overall}} \quad (1)$$

To obtain the peak power, the previous result is divided by the average sun hours per day for the geographical location T_{min}.

$$P_p = \frac{\text{daily energy requirement}}{\text{minimum peak sun} - \text{hours per day}} = \frac{E_r}{T_{min}} \quad (2)$$

The total current needed can be calculated by dividing the peak power by the DC- voltage of the system.

$$I_{DC} = \frac{Peak\ power}{System\ DC\ Voltage} = \frac{P_p}{V_{DC}}$$

Modules must be connected in series and parallel according to the need to meet the desired voltage and current in accordance with: First, the number of parallel modules which equals the whole modules current divided by the rated current of one module Ir.

$$N_p = \frac{\text{whole module current}}{\text{rated current of one module}} = \frac{I_{DC}}{I_r}$$

Second, the number of series modules which equals the DC voltage of the system divided by the rated voltage of each module V_r.

$$N_s = \frac{system\ DC\ voltage}{module\ rated\ voltage} = \frac{V_{DC}}{V_r}$$

Finally, the total number of modules Nm equals the series modules multiplied by the parallel ones:

$$N_m = N_s * N_p$$

1-3-Sizing of the Battery Bank

The amount of rough energy storage required is equal to the multiplication of the total power demand and the number of autonomy days $E_{rough}=E\times D$. For safety, the result obtained is divided by the maximum allowable level of discharge (MDOD):

$$E_{safe} = \frac{\text{energy storage required}}{\text{maximum depth of discharge}} = \frac{E_{roug\ h}}{MDOD}$$

At this moment, we need to make a decision regarding the rated voltage of each battery V_b to be used in the battery bank. The capacity of the battery bank needed in ampere-hours can be evaluated by dividing the safe energy storage required by the DC voltage of one of the batteries selected:

$$C = \frac{E_{safe}}{V_b}$$

According to the number obtained for the capacity of the battery bank, another decision has to be made regarding the capacity C_b of each of the batteries of that bank. The battery bank is composed of batteries The total number of batteries is obtained by dividing the capacity C of the battery bank in ampere-hours by the capacity of one of the battery C_b selected in ampere-hours:

$$N_{battries} = \frac{C}{C_b}$$

The connection of the battery bank can be then easily figured out. The number of batteries in series equals the DC voltage of the system divided by the voltage rating of one of the batteries selected:

$$N_s = \frac{V_{DC}}{V_b}$$

Then number of parallel paths N_p is obtained by dividing the total number of batteries by the number of batteries connected in series:

$$N_p = \frac{N_{battries}}{N_s}$$

1-4-Sizing of the Voltage Controller

According to its function it controls the flow of current. A good voltage regulator must be able to withstand the maximum current produced by the array as well as the maximum load current. Sizing of the voltage regulator can be obtained by multiplying the short circuit current of the modules connected in parallel by a safety factor F_{safe}. The result gives the rated current of the voltage regulator

I:

$$I = I_{SC} * N_p * F_{safe}$$

The factor of safety is employed to make sure that the regulator handles maximum current produced by the array that could exceed the tabulated value. And to handle a load current more than that planned due to addition of equipment, for instance. In other words, this safety factor allows the system to expand slightly. The number of controller equals the Array short current Amps divided by the Amps for each controller:

$$N_{controller} = \frac{I}{Amps\ each\ controller}$$

1-5-Sizing of the Inverter

When sizing the inverter, the actual power drawn from the appliances that will run at the same time must be determined as a first step.

2-Problem and calculations

Portable charging Station:

Goal: the 3d printing machine have 200w heating mat, total machine has 12 heating mats – so total

machine required power 3KW. Voltage :440v

Machine running timings are flexible, we can run the machine day or night.

expected run time is 4hrs a day.

During the machine usage we cannot charge the panels because total portable charging station should be taken into the workshop so we cannot produce current during the machine working.

The total setup is movable.

Space available is 1.5 m x.1.5 m * 2 times. we can accommodate 2 panels

Required:

Which pv panel should be used? how much watt?

Which battery is used? how much Ah?

Which invertor is used?

which PV controller?

all this information in PV Syst required.

2-1-Manual calculation

Load name	Qty	Voltage	Current(A)	Power(W)	Use h/day	Use day/week	Divide by7	W.h Ac
3D printing	1	440	6.81	3000	4	7	7	12000

AC Total Connected Watts: **3000**	AC Average Daily Load: **12000**

2-1-1. Panel calculation

Specifications	
Cell type:	N type Mono-crystalline
Module type:	Glass/Foil
Manufacturer number:	JKM445N-54HL4R-V
Maximum Power (Pmax):	445 Wp
Glass front:	3,2 mm Low iron, tempered glass with Anti-Reflection Coating
Glass back:	1.6 mm / 2 mm highly transparent glass, White mesh
Frame:	Black anodized Aluminium Alloy
Connector:	MC4 compatible
Cable length:	each 1200mm +/-
Product Warranty:	15 years
Performance Warranty:	30 years linear warranty
Dimensions (L x W x H):	1762 mm x 1134 mm x 30 mm
Weight:	22 kg

Figure2: Panel specifications

SPECIFICATIONS										
Module Type	JKM425N-54HL4R JKM425N-54HL4R-V		JKM430N-54HL4R JKM430N-54HL4R-V		JKM435N-54HL4R JKM435N-54HL4R-V		JKM440N-54HL4R JKM440N-54HL4R-V		JKM445N-54HL4R JKM445N-54HL4R-V	
	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT
Maximum Power (Pmax)	425Wp	320Wp	430Wp	323Wp	435Wp	327Wp	440Wp	331Wp	445Wp	335Wp
Maximum Power Voltage (Vmp)	32.18V	29.99V	32.38V	30.10V	32.59V	30.33V	32.81V	30.56V	33.02V	30.76V
Maximum Power Current (Imp)	13.21A	10.67A	13.28A	10.73A	13.35A	10.78A	13.41A	10.83A	13.48A	10.89A
Open-circuit Voltage (Voc)	38.75V	36.81V	38.95V	37.00V	39.16V	37.20V	39.38V	37.41V	39.59V	37.61V
Short-circuit Current (Isc)	13.66A	11.03A	13.73A	11.09A	13.80A	11.14A	13.86A	11.19A	13.93A	11.25A
Module Efficiency STC (%)	21.27%		21.52%		21.77%		22.02%		22.27%	
Operating Temperature(℃)	-40℃~+85℃									
Maximum system voltage	1000/1500VDC (IEC)									
Maximum series fuse rating	25A									
Power tolerance	0~+3%									
Temperature coefficients of Pmax	-0.29%/℃									
Temperature coefficients of Voc	-0.25%/℃									
Temperature coefficients of Isc	0.045%/℃									
Nominal operating cell temperature (NOCT)	45±2℃									

*STC: Irradiance 1000W/m^2 Cell Temperature 25°C AM=1.5

NOCT: Irradiance 800W/m^2 Ambient Temperature 20°C AM=1.5 Wind Speed 1m/s

Figure3: Panel specifications

$\mathbf{I} = \frac{P}{\sqrt{3}*440}$ =3.95 A

$\boldsymbol{E_r} = \frac{E}{\gamma overal}$=$\frac{3000}{0.8}$=3750 wh/day

$P_p = \frac{\boldsymbol{E_r}}{T_{min}} = \frac{\mathbf{3750}}{3.5}$=1071 wp

$Idc = \frac{Pp}{Vdc}$=$\frac{1071}{48}$= 22.31 A

Np=$\frac{Idc}{Ir}$=$\frac{22.31}{13.48}$=1.65   1 to 2 panel is required

Ns=$\frac{Vdc}{Vr}$=$\frac{48}{33.02}$=1.45   1 to 2 panel is required

Between 2 to 4 panels, we must select for this project. If we select 4 panels we have below calculations:

2-2-Batteries:

Lead-Acid

Lead-acid batteries have been in use for decades and are one of the most common types of battery used in automotive and industrial applications. They have a low energy density (meaning they cannot hold much energy per kg of weight), but remain both cost-effective and reliable and thus have become a common choice for use in a home solar setup.

Lead-acid batteries come in both flooded and sealed varieties and can be classified as either shallow cycle or deep cycle depending on the intended function and safe depth of discharge (DOD). Recent technological advancements have improved the lifespan of these batteries and lead-acid continues to be a viable option for many homeowners.

Figure4: batteries specifications

Electrical characteristics

Nominal Voltage		12 V
Capacity (25°C)	20HR(10.5V)	150Ah
	5HR(10.2V)	115.6Ah
	1HR(9.6V)	87.3Ah
Dimension	Length	485±2mm
	Width	172±1mm
	Height	240±2mm
	Total Height	240±2mm
Approx. Weight		44kg (70.4lbs)±4%
Terminal type		T11
Internal resistance (Fully charged, 25°C)		Approx. 4.2mΩ
Capacity affected by temperature (10HR)	40°C	103%
	25°C	100%
	0°C	88%
	-15°C	70%
Self-discharge (25°C)	3 month	Remaining Capacity: 94%
	6 month	Remaining Capacity: 88%
	12 month	Remaining Capacity: 75%
Nominal operating Temperature		25°C±3°C(77°F±5°F)
Operating temperature range	Discharge	-15°C～55°C(5°F～131°F)
	Charge	-10°C～55°C(14°F～131°F)

Dimensions

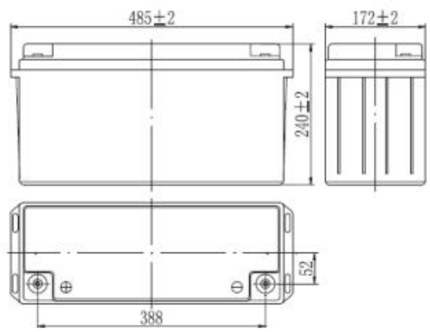


Figure5: battery specifications

Manufacturer model	Enjoysolar GEL 150Ah 12V
EAN Code	4260558571773
Article number	4112150
Capacity	150Ah
Dimension	485* 172* 240mm
Approx. Weight	44kg (96.8lbs)±4%
Terminal type	T11
Internal resistance	Approx. 4.2mΩ
Nominal operating temperature	25°C±3°C(77°F±5°F)
Float charging voltage(25°C)	13.50 to 13.80V Temperature compensation: -18mV/°C
Cyclic charging voltage(25°C)	14.10 to 14.40V Temperature compensation: -30mV/°C
Maximum charging current	30A
Terminal material	Copper
Maximum discharge current	1500 A(5 sec.)

Figure6: battery specifications

The amount of energy storage for 1 days :12000wh

Esafe=$\frac{12000}{0.75}$=16000

The capacity of the battery bank=$\frac{16000}{12}$=1333.3Ah

Nbatteries=$\frac{1333.3}{150}$=8.89

The number of series battery=48/12=4

The number of paralle= 8.89/4=2.22

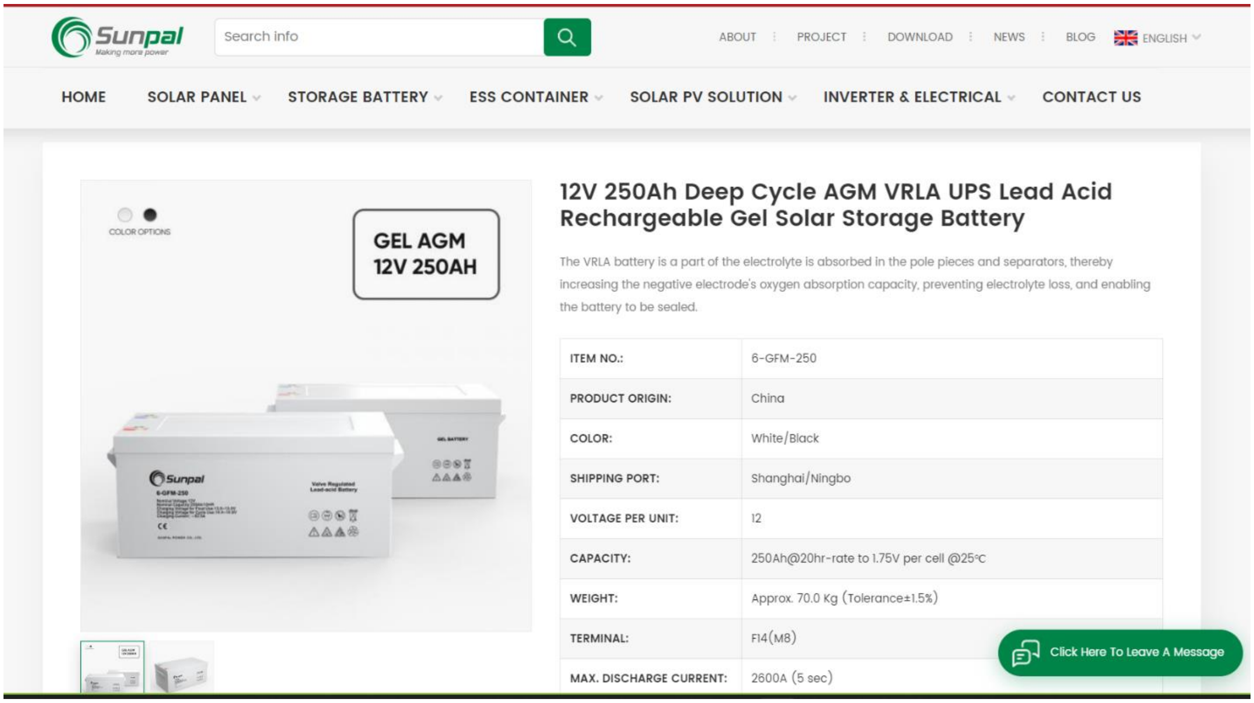


Figure7: 250Ah bateery specifications

Calculation with 250Ah battery

The amount of energy storage for 1 days :12000wh

Esafe=$\frac{12000}{0.75}$=16000

The capacity of the battery bank=$\frac{16000}{12}$=1333.3Ah

Nbatteries=$\frac{1333.3}{250}$=5.33

The number of series battery=48/12=4

The number of paralle= 5.33/4=1.33

2-3-charge controller:

$I = I_{sc} * N_p * F_{safe}$=13.93*2*1.25=34.825

2-4-Inverter sizing

3000 to 3500 w

3-PVsyst simulation

According to 4 simulations result that has been sent. This project can establish with 4 panels, but it cannot support all of your requirements. In Fig. 8 suggested PV power is 9190 Wp for this reason PVsyst offer 8 panels.

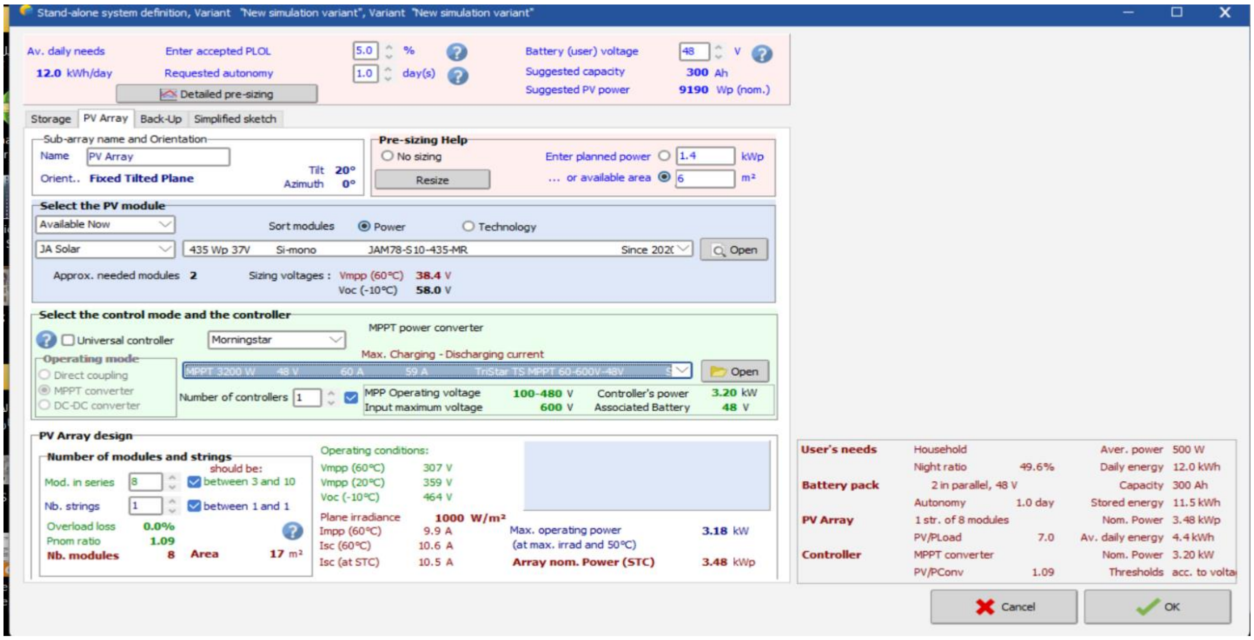


Figure 8. simulation for full load with 8 panel.

In the Fig. 9. you can see simulation with 4 panels that is acceptable with pvsyst.

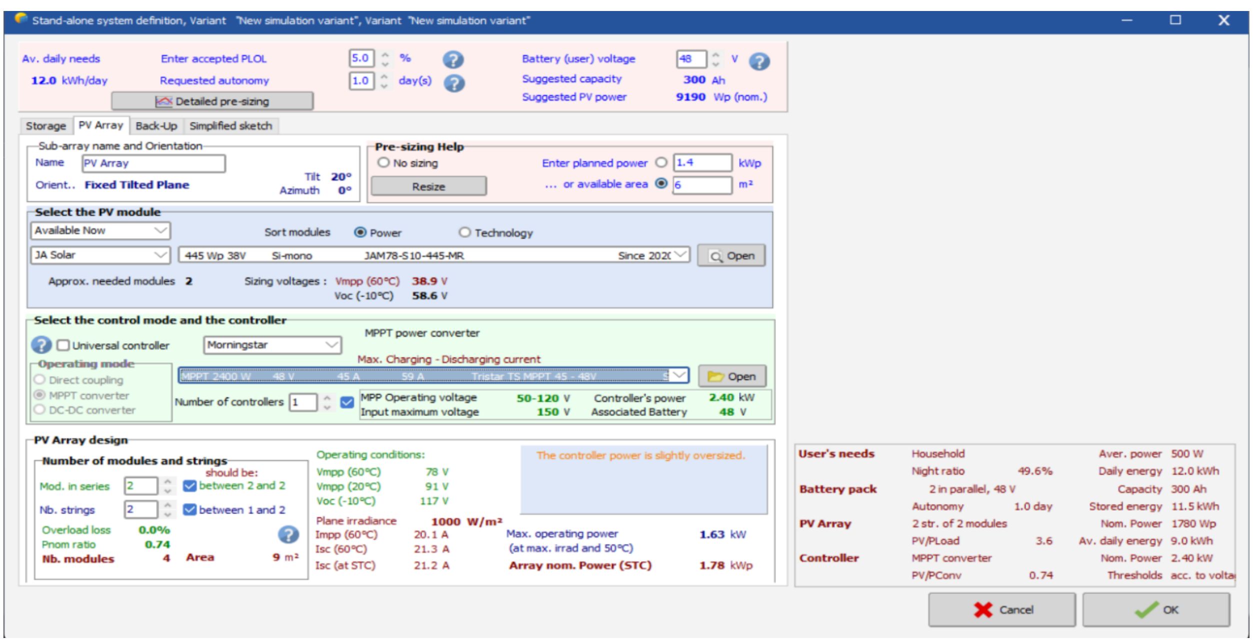


Figure 9. Simulation with 4 panels

For battery calculation, Lead acid technology has been selected. Each battery has 150Ah capacity, Voltage is 12v and the catalogue attached with the report. Totally 8 batteries have been offered by the software. In manual calculation the number of batteries with 250Ah also calculated.Fig.10 shows simulation with pvsyst software.

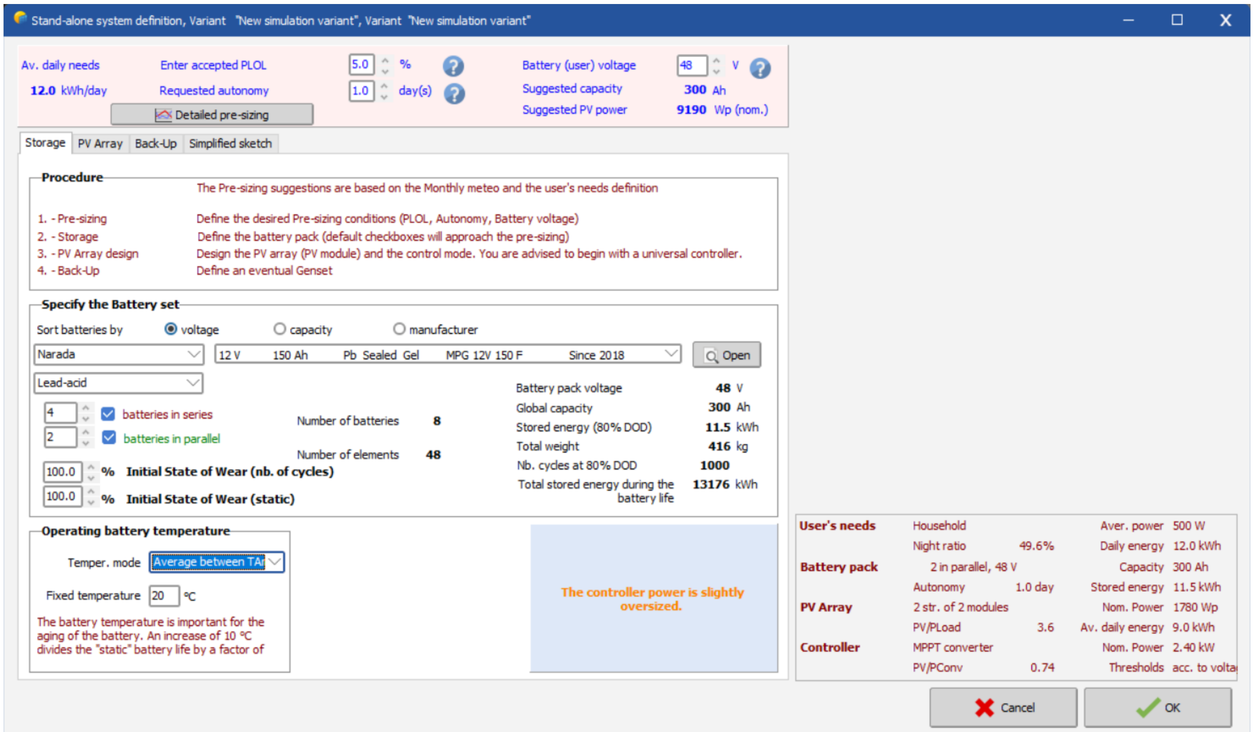


Figure10. Selecting Battery

All of loss calculated in the project, but wind and snow must calculate in the structure simulations. If you haven't all of information, Pvsyst allow you to select in by experience and this software set by default 3%.

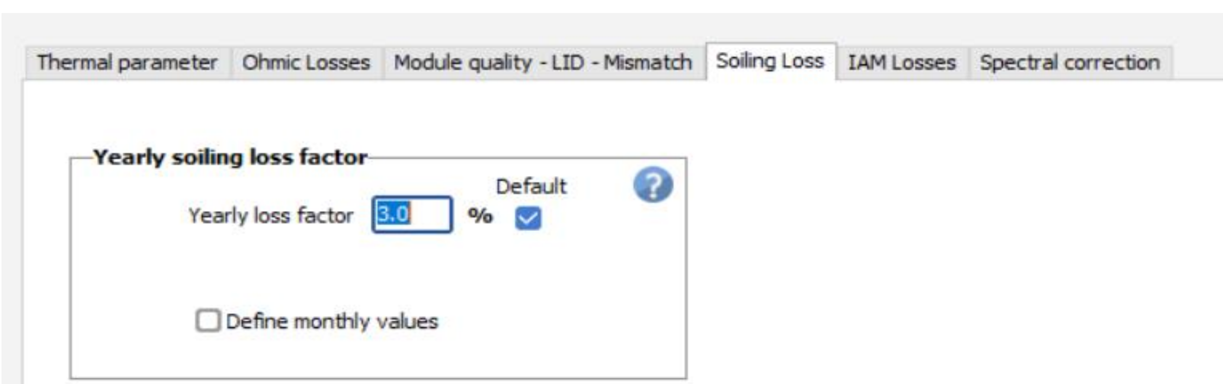


Figure11. Soiling Loss

For the simulation of the project at first the climate data and location must be added to the software. For this reason pvsyst use meteonorm database.Fig.14,Fig.15, Fig.16, respectively show the selecting the location for the project.

Project summary

Geographical Site	Situation		Project settings	
Planegg	Latitude	48.11 °N	Albedo	0.20
Germany	Longitude	11.43 °E		
	Altitude	552 m		
	Time zone	UTC+1		

Meteo data
Planegg
NASA-SSE satellite data 1983-2005 - Synthetic

System summary

Stand alone system — **Stand alone system with batteries**

PV Field Orientation		User's needs	
Fixed plane		Daily household consumers	
Tilt/Azimuth	20 / 0 °	Constant over the year	
		Average	12.0 kWh/Day

System information

PV Array		Battery pack	
Nb. of modules	4 units	Technology	Lead-acid, sealed, Gel
Pnom total	1740 Wp	Nb. of units	8 units
		Voltage	48 V
		Capacity	300 Ah

Results summary

Available Energy	1925 kWh/year	Specific production	1106 kWh/kWp/year	Perf. Ratio PR	78.38 %
Used Energy	1774 kWh/year			Solar Fraction SF	40.49 %

Figure12. project summery and system summery.

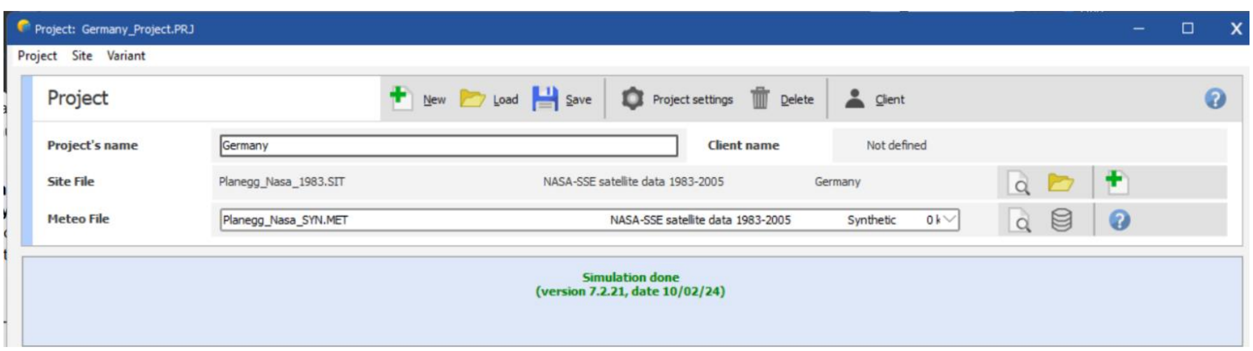


Figure13. Selecting the location

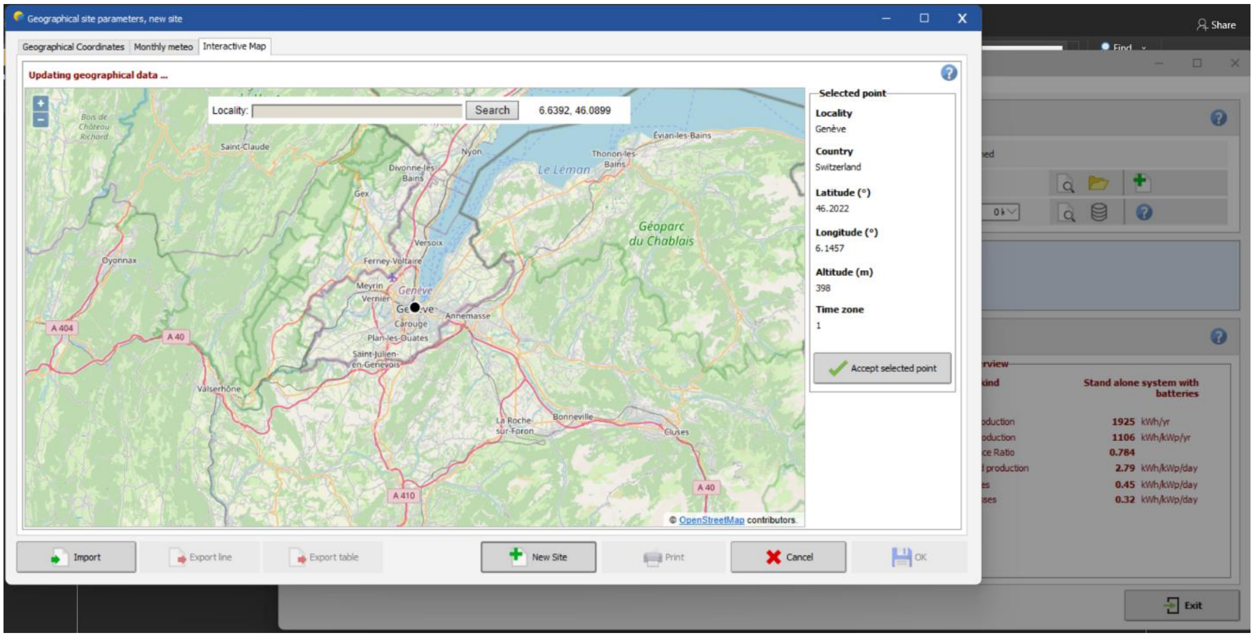


Figure14.choosing the location

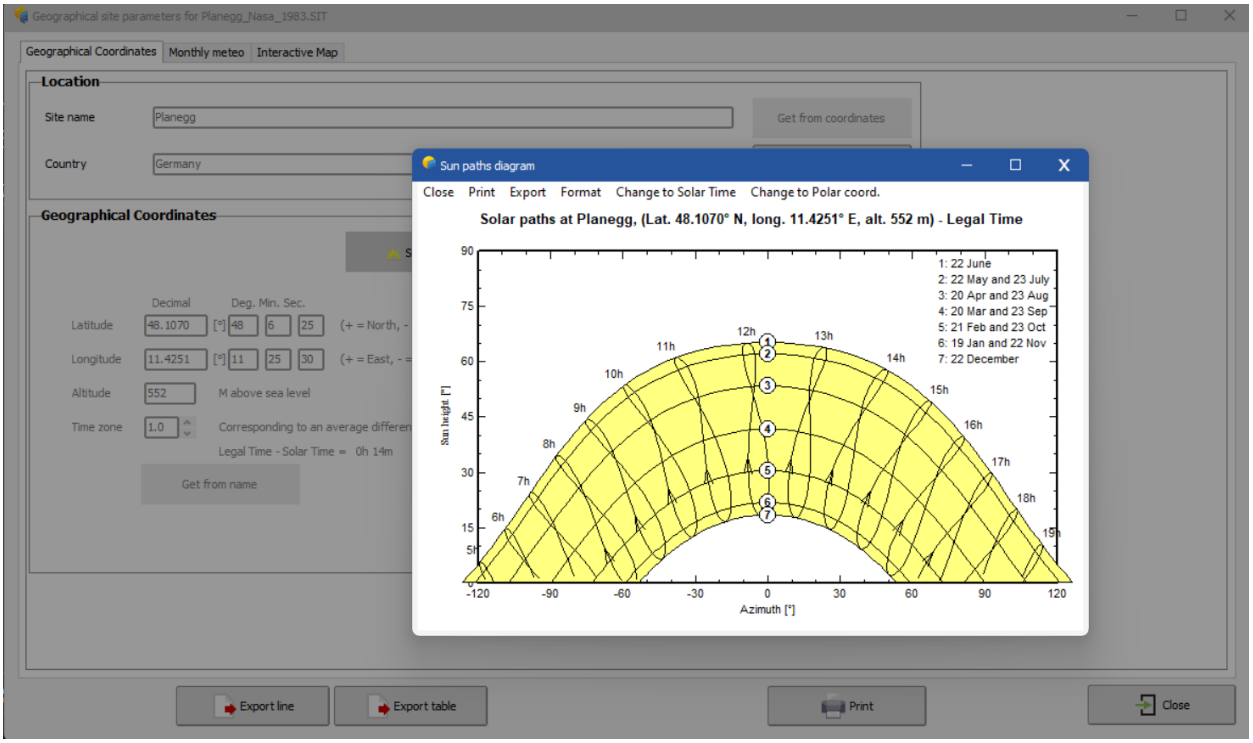


Figure15.Import data from metenoorm database

Meteonorm is unique combination of reliable data sources and sophisticated tools. From the below site you can achieve more information.

https://meteonorm.com/en/

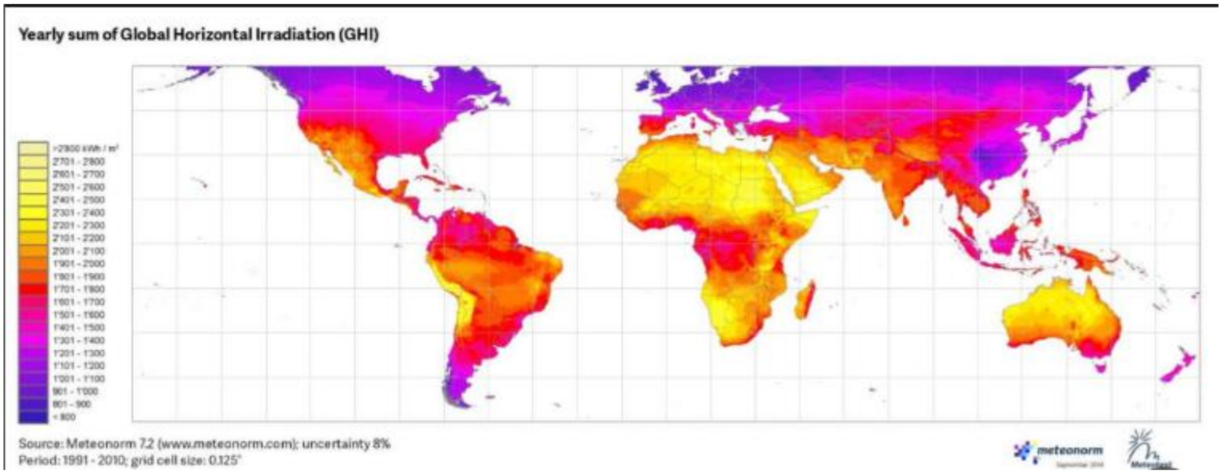


Figure16.Import data from metenoorm database

One section of the results shows the equipment characterustics.in Fig. 17 all of information about the PV, Battery, controller have been calculated.

PV Array Characteristics

PV module

Manufacturer	JA Solar
Model	JAM78-S10-435-MR
(Original PVsyst database)	
Unit Nom. Power	435 Wp
Number of PV modules	4 units
Nominal (STC)	1740 Wp
Modules	2 Strings x 2 In series
At operating cond. (50°C)	
Pmpp	1590 Wp
U mpp	80 V
I mpp	20 A

Controller

Manufacturer	Morningstar
Model	Tristar TS MPPT 45 - 48V
Technology	MPPT converter
Temp coeff.	-5.0 mV/°C/Elem.
Converter	
Maxi and EURO efficiencies	98.5 / 97.7 %

Total PV power

Nominal (STC)	1.74 kWp
Total	4 modules
Module area	8.7 m²

Battery

Manufacturer	Narada
Model	MPG 12V 150 F
Technology	Lead-acid, sealed, Gel
Nb. of units	2 in parallel x 4 in series
Discharging min. SOC	21.4 %
Stored energy	11.7 kWh
Battery Pack Characteristics	
Voltage	48 V
Nominal Capacity	300 Ah (C10)
Temperature	Average between fixed 20 °C and External

Battery Management control

Threshold commands as	Battery voltage
Charging	55.2 / 49.7 V
Corresp. SOC	0.92 / 0.56
Discharging	47.0 / 49.0 V
Corresp. SOC	0.20 / 0.42

Figure17.simulation results for main equipments

Figure18,Figure 19 and Figure 20 consumer information has been shown.

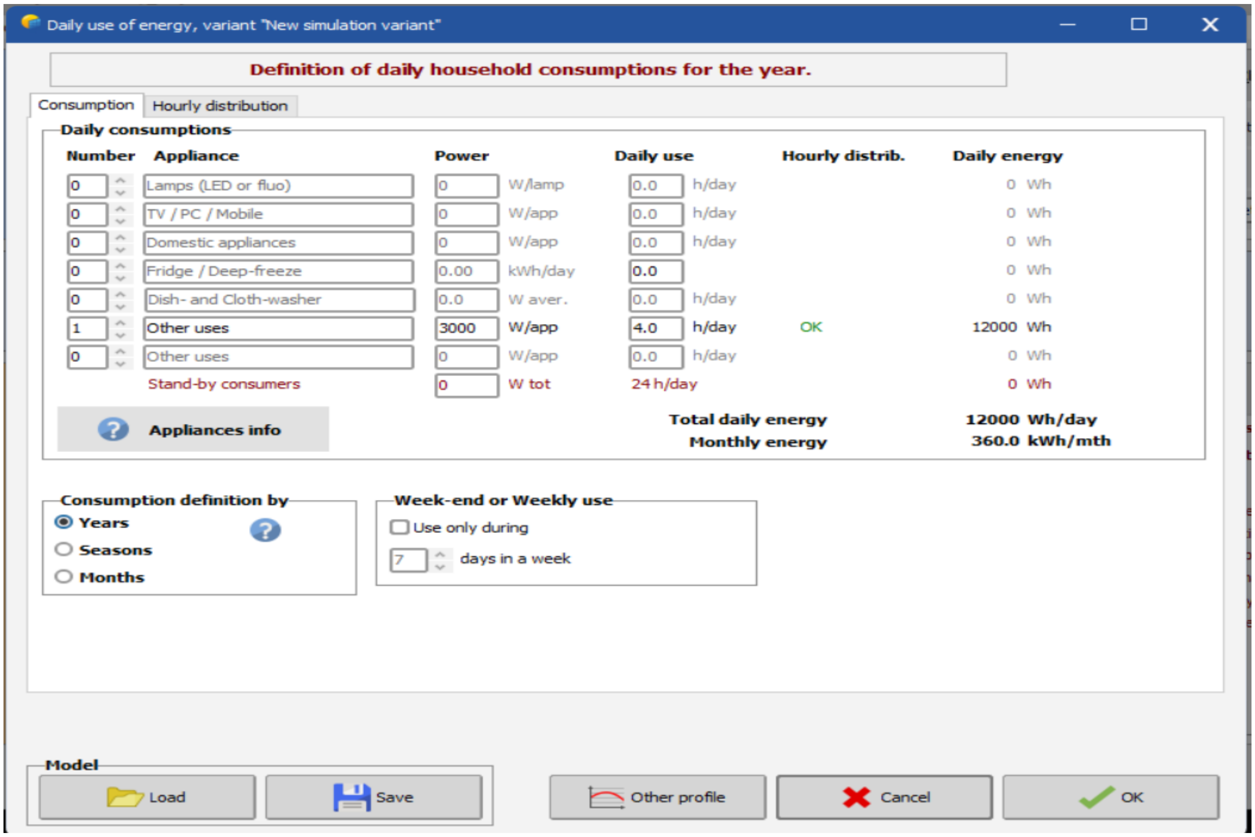


Figure18.Importing consumer information in pvsyst

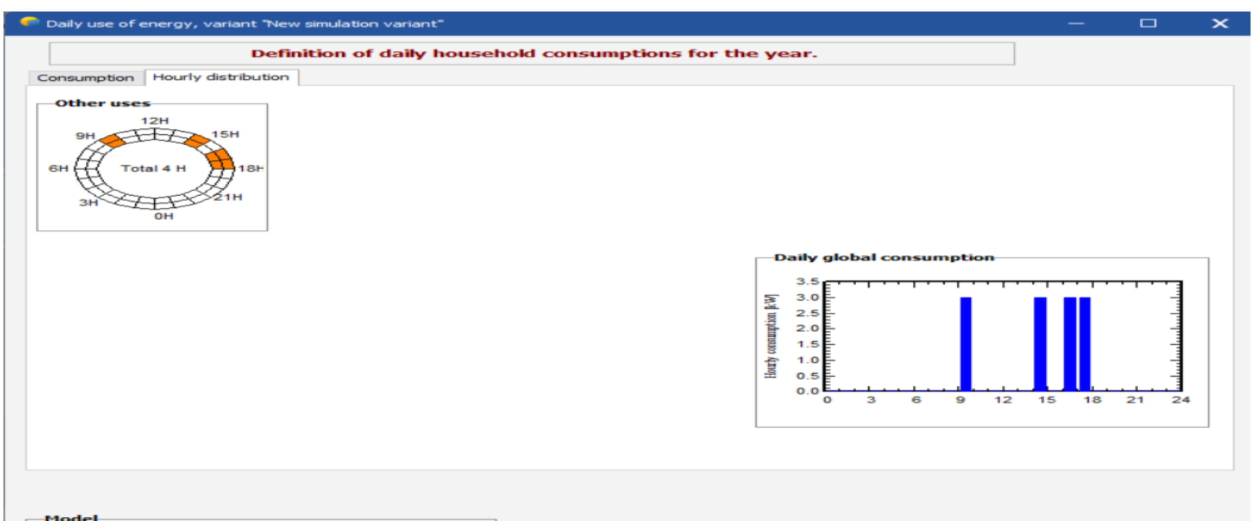
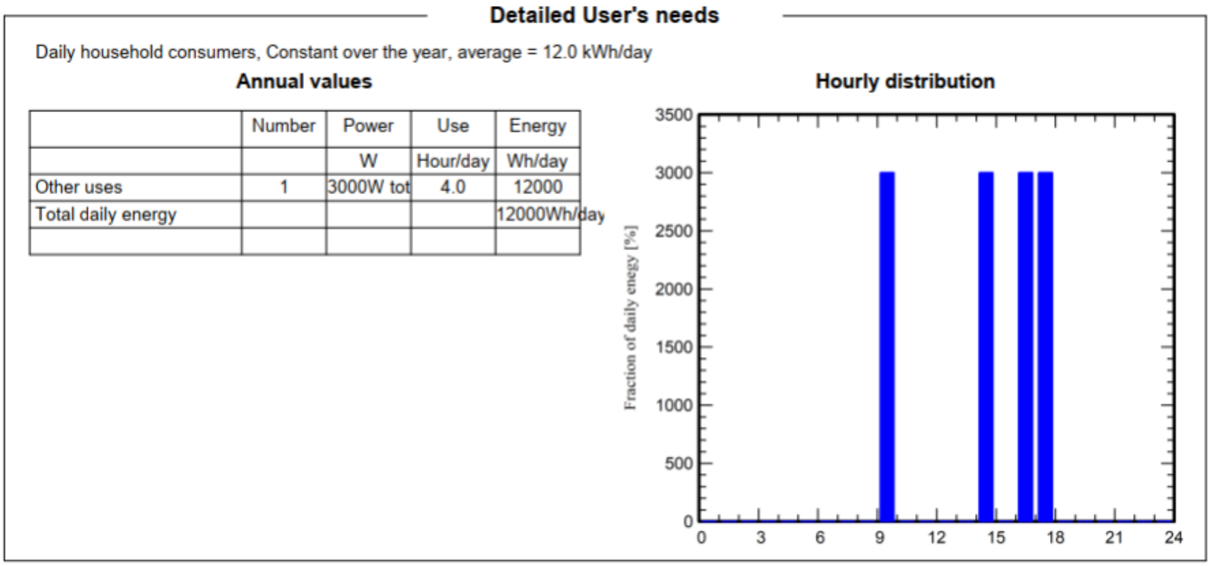


Figure18.Definition of Daily consumptions for the year



	Number	Power	Use	Energy
		W	Hour/day	Wh/day
Other uses	1	3000W tot	4.0	12000
Total daily energy				12000Wh/day

Figure19.Definition of Daily consumptions for the year in the PVsyst result

In the Fig.20 Main results have been studied and shows that specific production is 1106 kwh/kwp/year, Performance ration is 78.38% that is acceptable.

The Performance Ratio is the ratio of the energy effectively produced (used), with respect to the energy which would be produced if the system was continuously working at its nominal STC efficiency. The PR is defined in the norm IEC EN 61724.

In usual Grid-connected systems, the available energy is E_Grid. In stand-alone systems, it is the PV energy effectively delivered to the user, i.e. E_User - E_BackUp. In pumping systems, this is E_PmpOp.

The energy potentially produced at STC conditions is indeed equal to GlobInc * PnomPV, where PnomPV is the STC installed power (manufacturer's nameplate value). This equivalence is explained by the fact that at STC (1000 W/m², 25°C) each kWh/m² of incident irradiation will produce 1 kWh of electricity.

Namely, the PR is not dependent on the PV module efficiency. As an example an amorphous module and a crystalline high-efficiency module will lead to comparable PR. Only the low-light performance and temperature dependency will induce differences.

A tracking system will have a similar PR than a fixed sheds arrangement. Even sometimes slightly lower because the array temperature (related to GlobInc) may be higher.

Main results

System Production			
Available Energy	1925 kWh/year	Specific production	1106 kWh/kWp/year
Used Energy	1774 kWh/year	Performance Ratio PR	78.38 %
Excess (unused)	0 kWh/year	Solar Fraction SF	40.49 %
Loss of Load		**Battery aging (State of Wear)**	
Time Fraction	24.9 %	Cycles SOW	89.7 %
Missing Energy	2606 kWh/year	Static SOW	91.8 %
		Battery lifetime	9.7 years

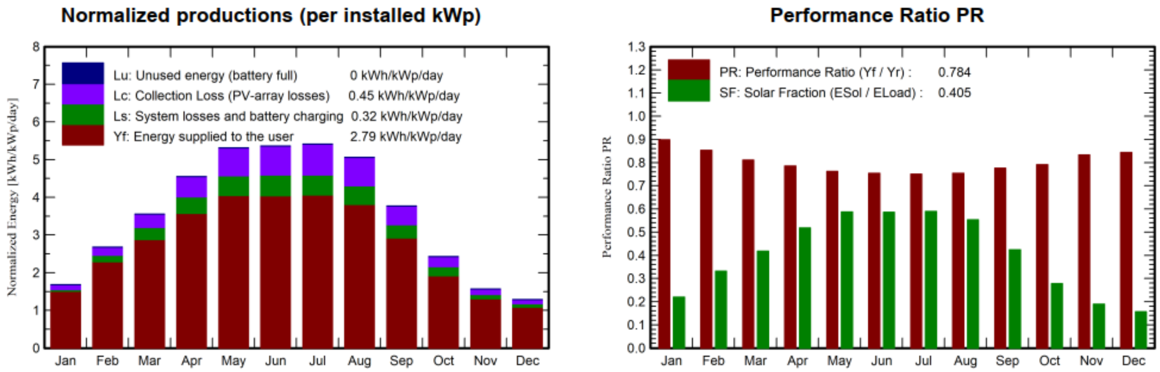


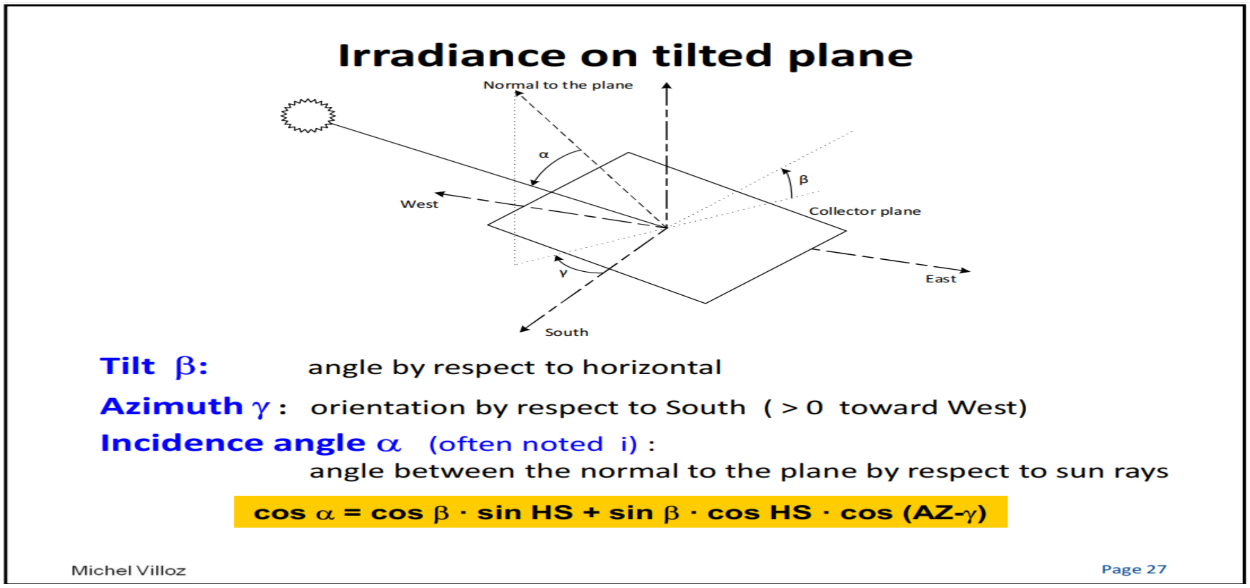
Figure20.Main result

4- conclusion:

According to my calculations this system need approximately 4.5 to 5 kw panels for working 4 hours continuously. Because of lack of space and the 445w panel we have close to 2 kw panel and for this reason we need 8*150AH lead acid AGM battery.. For working more time, we need more panels with more power. Also the output of Inverter is 220 v and you need add small transformer for converting to 440V. The DC system voltage is 48 V and all of equipment must work in this voltage. All of information are in the Pvsyst results that attached to the report.

Attachment

1.How much efficiency reduces if we keep plates flat? Tilt angle zero



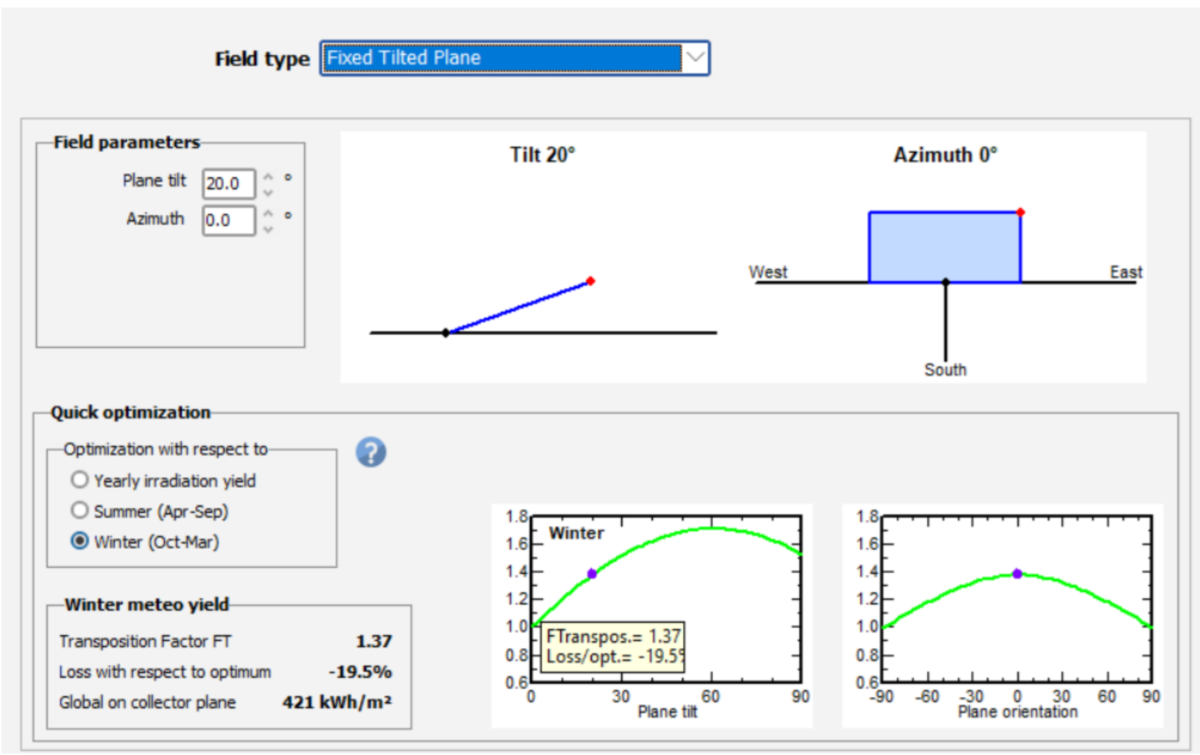


Figure1: Global on collector plane with 20 tilt : 421kwh/m2

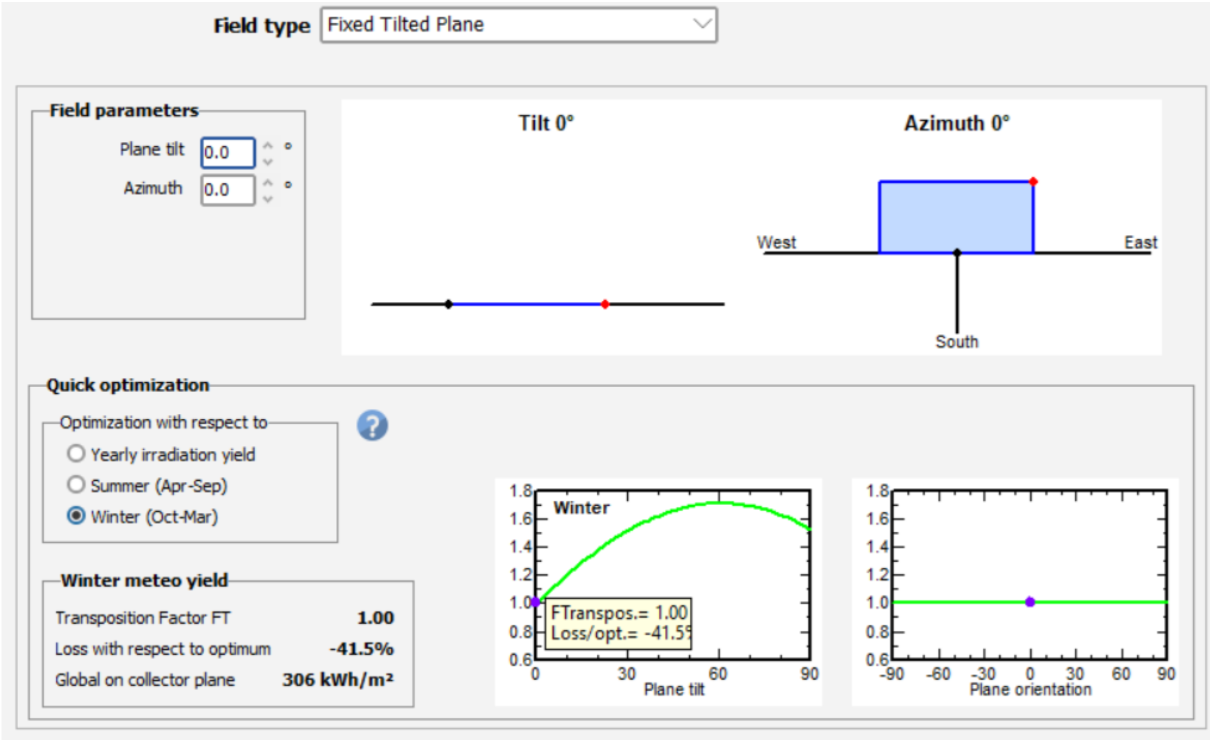


Figure 2 :Global on collector plane with 20 tilt : 306kwh/m2

Difference between to tilt is : 421-306=115 kw/m2

2. Why we have so much unsed power? What happens to this unsed power.

The 2 panels for your project is enough, But PVsyst shows that you need more than 2 panels. In figure 3 you can see the Pvsyst simulation. According to manual calculation 2 panel is ok. I will add it in the report.

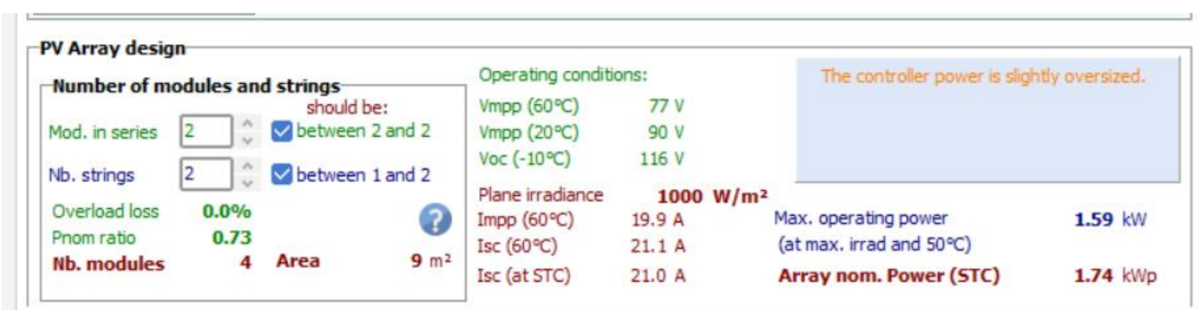
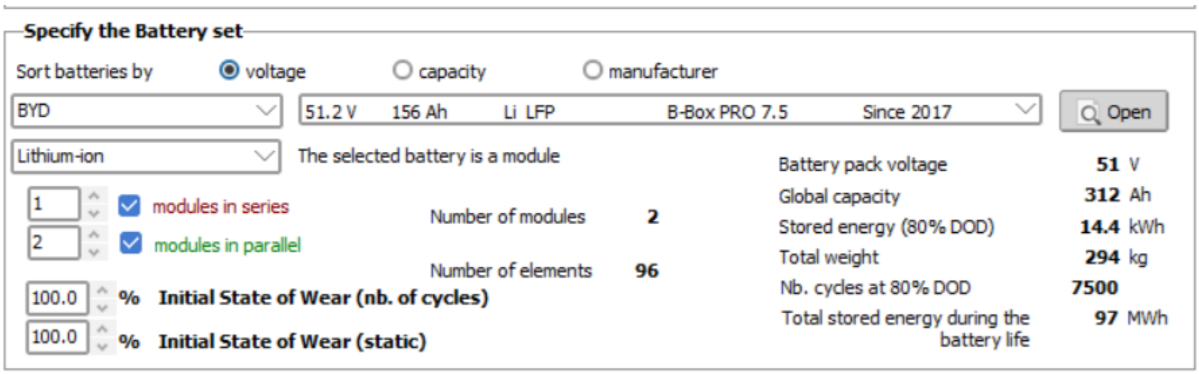


Figure3. PV Array Design

3. can be replace 635w with 445w panels i, because 445w panels are small fit(1762mmX 1134mm)exactly in door, i know power is less but we have so much unused power also so i think its not a such a big problem.

Yes. You can use 445w

4. Do we need 312 Ah Battery, how many the machine can run with such battery .



I sent you all information about battery. The capacity of each battery can be 156Ah , Global capacity is 312 Ah

5. we need AC output with 440V, where I can see that in your simulation file.

It depends on your charge controller and its output

6.why we selected hourly distribution different , usually we run machine 4 hours continuously , because if we stop the machine we need to re heat it takes more energy.

Because of calculation in bad conditions. Its possible to simulate continuedly.

7. if we use 4x 445w panels how much power we can produce per day?

I can send you new simulation with PVsyst

8.MPPT invertor which type and which brand?

In the report I will attach the information.

9.battery which brand and type , please send me the cost?

In the report I will attach the information.