Solar PV System Installation and Maintenance

NTQF Level IV

Learning Guide -01

Unit of Competence	Calculating System Components
Module Title	Calculating System Components
LG Code	EIS PIM4 M02 LO1-LG01
TTLM Code	EIS PIM4 TTLM 0920v1

LO 1: Calculate Energy Demand

Instruction Sheet	Learning Guide:-01

This learning guide is developed to provide you the necessary information, knowledge, skills and attitude regarding the following content coverage and topics:

- Listing load demand in tabulated form.
- Calculating energy demand for each load.

This guide will also assist you to attain the learning outcome stated in the cover page. Specifically, upon completion of this Learning Guide, you will be able to:-

- List the load demand in tabulated form;
- Calculate energy demand for each load.

Learning Instructions:

1. Read the specific objectives of this Learning Guide.
2. Follow the instructions described below.
3. Read the information written in the information Sheets
4. Accomplish the Self-checks

Information Sheet 1	Listing load demand in a tabulated form.

1.1 Introduction

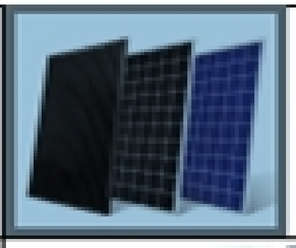
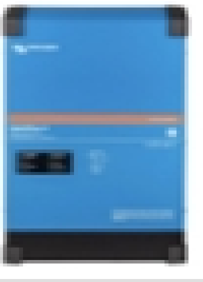
In this module, we will follow a particular sequence to calculate the system for an off-grid backup system. Please be aware that the process does not always need to be followed in the same sequence. For instance, the array size can be calculated before calculating the battery capacity etc. The first step should however always be to calculate the energy demand. In the structure below, the left-hand process is the process followed in this module. The right-hand process is an alternative process showing a different sequence. The results will be the same for both.

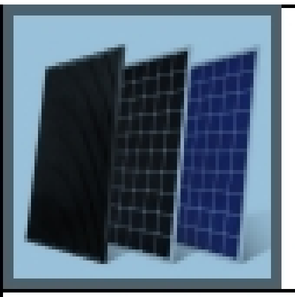
1.2 Definition of systems and components

Before starting to design a system, it is important to understand the terminology used for systems and for components of systems.

1.2.1

Components

Item	Description	Components Picture
Modules	A PV module is a device that produces DC electricity by making use of the light of the sun via the Photovoltaic Effect. Two broad categories of PV modules are silicon and thin-film.	
Charge Controller	A charge controller is a device that regulate the charging of batteries from PV modules	
Grid-tied inverter	A grid-tied inverter is a device that changes the DC power from PV modules into AC power to power AC loads. It also synchronises with the electricity grid and connects in parallel to the grid.	
Inverter Charger	An inverter charger is a bi-directional device. It can charge batteries from AC power (supplied by a grid or grid-tied inverter) and it can create AC power from batteries to power loads	
Hybrid inverter	A hybrid inverter is a combination of an inverter charger and either charge controller (DC coupled) or grid-tied inverter (AC coupled) all in one box. It is generally a lower-cost device that includes PV and battery connections but often lacks the flexibility of separate inverter chargers and	

Modules	A PV module is a device that produces DC electricity by making use of the light of the sun via the Photovoltaic Effect. Two broad categories of PV modules are silicon and thin-film.	
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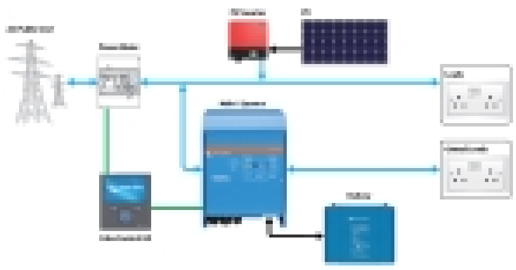
	charge controllers or grid-tied inverters.	
Battery	A battery is a device that can store DC energy and release it at a later stage. A battery have a certain voltage and capacity in Amp-hour (Ah)	
Battery Bank	A battery bank is a combination of series and parallel connected batteries that will have the desired voltage and Ah capacity	 https://www.lowtechmagazine.com/
Energy Storage Systems	An energy storage system is a system that stores energy capture from e.g. the sun or wind for later use. It normally consists of a device to get the energy into batteries (e.g. a charge controller or inverter charger) and release the energy later via an off-grid inverter or inverter charger.	

1.2.2 Systems

Grid-tied-As the **Name** suggests, a grid-tied system is tied to the municipal or national electricity grid, and can often feed power in to the grid where allowed. The grid can also power loads if the PV power is not sufficient. A grid-tied system can be with or without batteries and can be AC-coupled or DC coupled

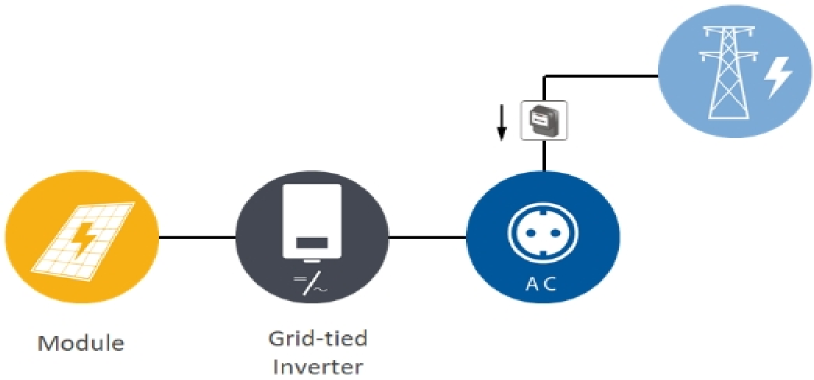


Figure 2: AC coupled Grid-tied system without batteries

Off-Grid -An off-grid system is not connected to the grid and all power has to come from PV modules, batteries, generators or other sources. The loads can be DC, AC or both

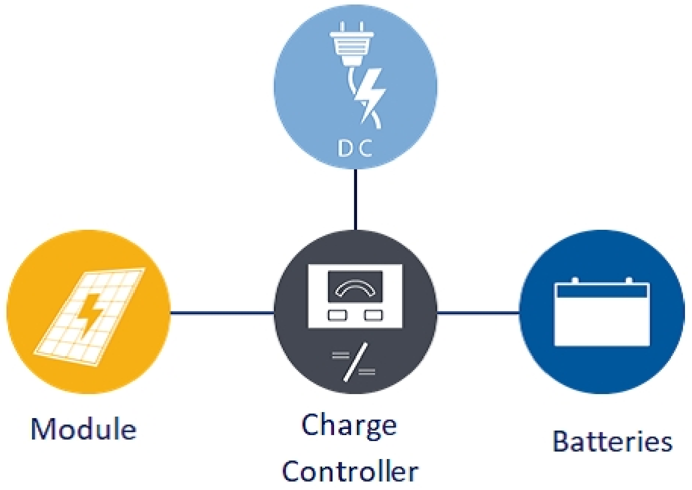


Figure 3: DC coupled off-grid system with DC loads

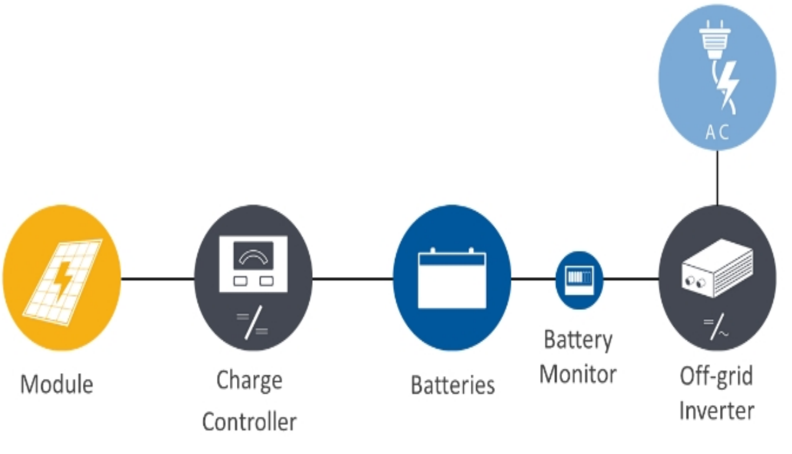


Figure 4: DC coupled off-grid system with AC loads

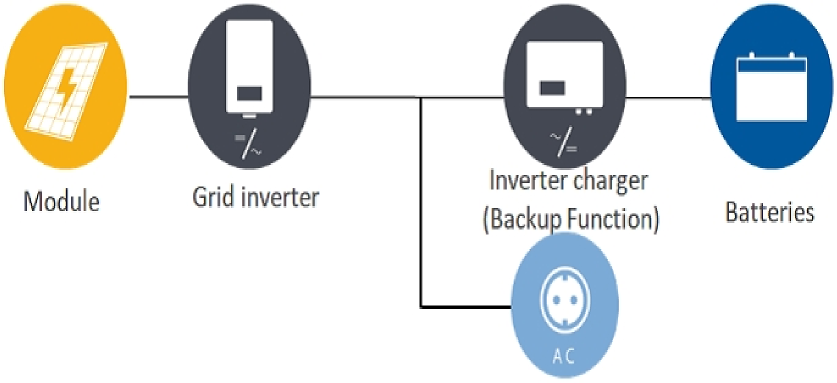


Figure 5: AC coupled off-grid backup system

AC-coupled In an AC-coupled system, power from the PV modules is inverted to AC immediately using a grid-tied inverter (also known as a PV inverter or string inverter). In order to store energy in batteries and use it later, an AC-coupled system use an inverter/charger (see below).

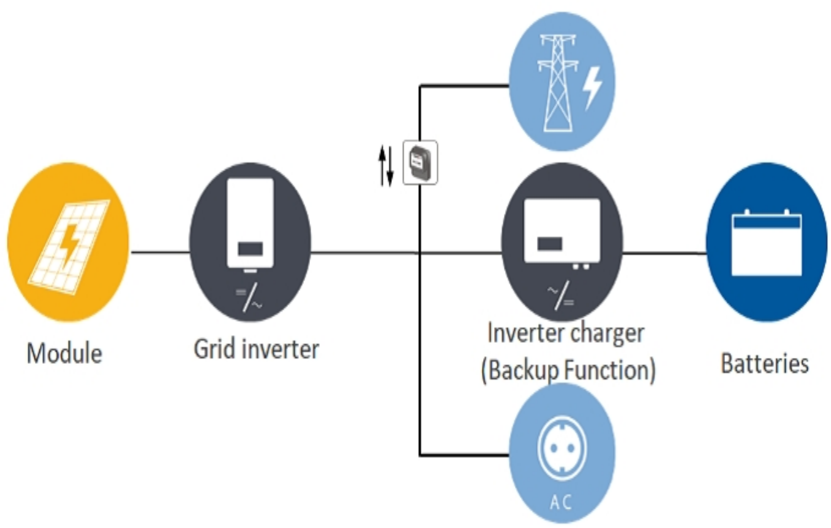


Figure 6: AC coupled grid-tied system with battery backup

DC-coupled -In a DC-coupled system, power from the PV modules are kept as DC but only changed to the correct voltage for charging batteries. In order to change the DC power to AC, a DC coupled system needs either an off-grid inverter (for off-grid systems) or an inverter/charger (for grid-tied systems).

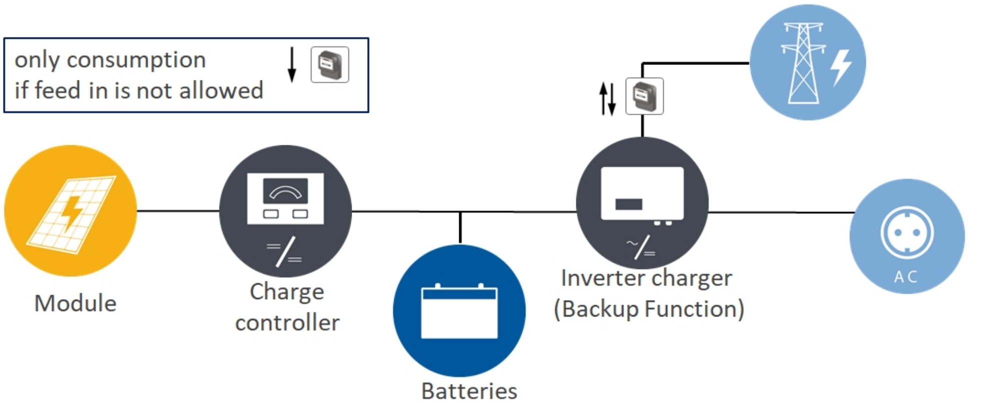


Figure 7: DC coupled grid-tied system with battery backup

Hybrid system A hybrid system have more than one source of power e.g. PV and wind or generators

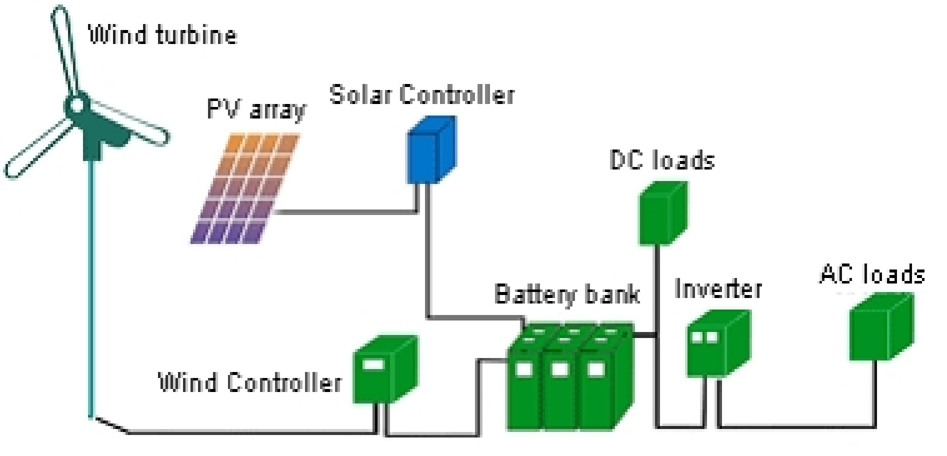


Figure 8: Hybrid System (PV and Wind) (https://www.mahaurja.com/)

1.2.3 Components

- Modules
- Charge controller
- Grid-tied inverter
- Off grid inverter
- Inverter charger
- Hybrid inverter
- Battery

- Battery bank
- Energy storage systems

1.3 Peak Demand

In order to design an off-grid PV system, it is important to understand the maximum load (or power) that needs to be supplied by the system. The maximum load is also called peak load or peak demand.

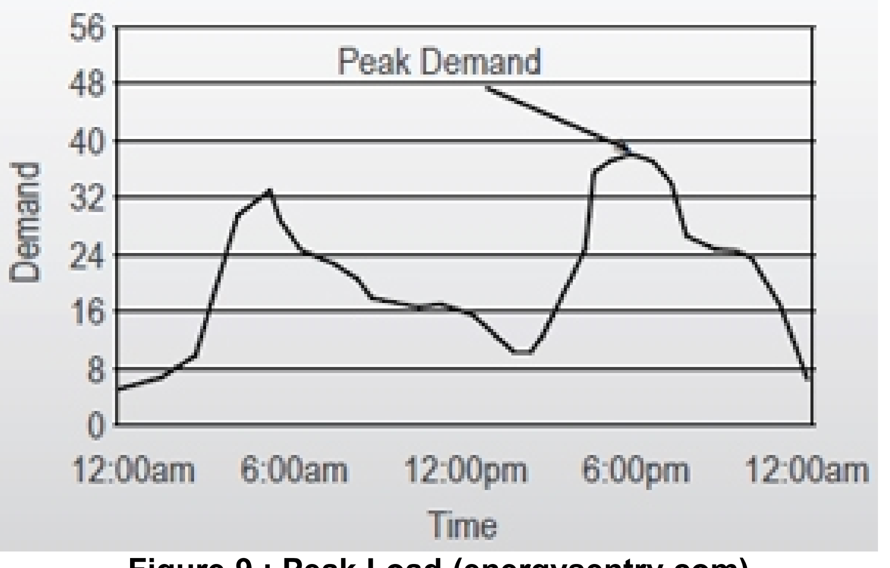


Figure 9 : Peak Load (energysentry.com)

In this module's calculations, we will use a practical example of a 5kW system designed for the Poly Technic College at Adama, Ethiopia.

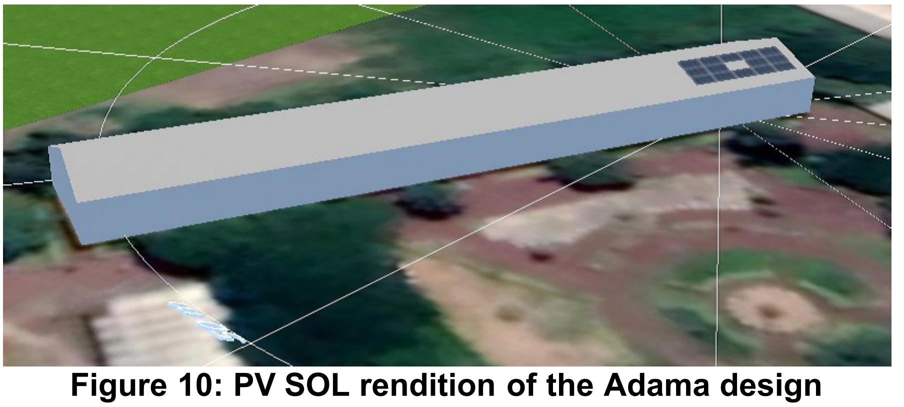


Figure 10: PV SOL rendition of the Adama design

1.4 Power and Energy

1.4.1 Energy

Energy is referred to as the ability to do work. Energy is measured in units called joules

(J) or in watt-hours as shown below. One kilojoules (kJ) is equal to 1000 joules and 1 mega joule (MJ) is equal to 1 million joules. Watt-hours (Wh) are a convenient way of measuring electrical energy. One watt-hour is equal to a constant 1 watt supply of power supplied over 1 hour (3600 seconds). If a light-bulb is rated at 40 watts, in 1 hour it will use 40Wh, and in 6 hours it will use 240Wh of energy. Electric power companies measure the amount of energy supplied to customers in kilowatt-hours (kWh) or thousands of watt-hours. One kilowatt-hour is equal to 3.6 mega joules.

Energy conversions

Watt-hours × 1000 = kilowatt-hours

Kilowatt-hours × 1000 = megawatt-hours

Mega joules ÷ 3.6 = kilowatt-hours (or peak sun hours)

Kilowatt-hours × 3.6 = mega joules

1.4.2 Power

Power is the rate at which energy is supplied (or energy per unit time). Power is measured in watts. One watt is equal to 1 joule supplied per second.

Power conversions

Watts ÷ 746 = horsepower

Watts × 1000 = kilowatt

Kilowatts × 1000 = megawatts

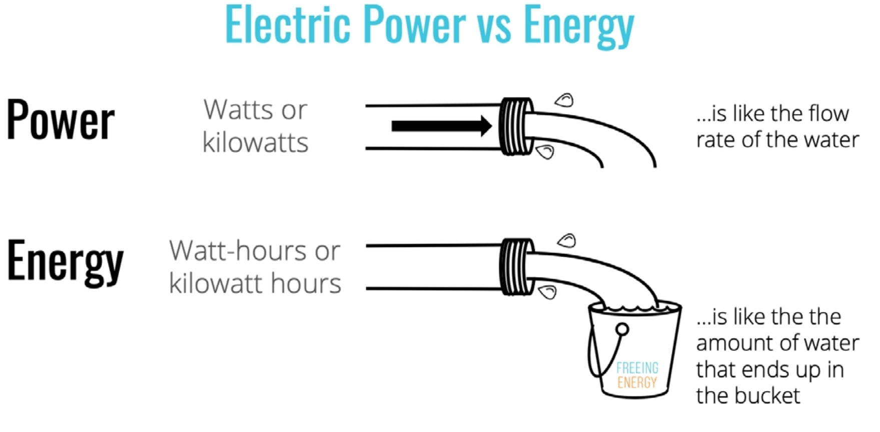


Figure 11: Power vs. Energy (freeingenergy.com)

1.5 Types of off-grid PV systems

There are two main types of off-grid PV systems considering the system design, i.e. DC coupled systems and AC coupled systems. The design of both systems starts with a load assessment and the selection of the PV generator size.

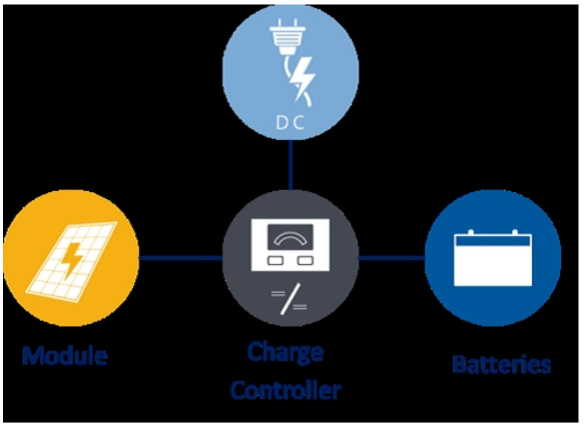
DC coupled system design then continues with the selection of the system voltage as most of the charge controllers only work in a 12 V, 24V or 48V range. Afterwards, all components have to match the system voltage and in many cases only certain, often more expensive modules can be used.

1.5.1 AC Coupled System

AC coupled off-grid system are designed like grid tied systems and thus the second step is the selection of an inverter. All other components then have to match the in and output values of the connected devices. Thus, the design is often a bit easier and standard components can be used.

1.5.2 DC Coupled Off-grid PV Systems

In a DC coupled system, the DC power from the PV modules are fed into a charge controller which charge the batteries at the correct voltage. In other words, the first inversion/conversion is from DC to DC. The battery power can than either be used directly or converted into AC electricity (via an off-grid inverter) to power the loads. See Figure 12 for examples of a DC coupled system, as presented already in Module 6, Level 3, LO2.



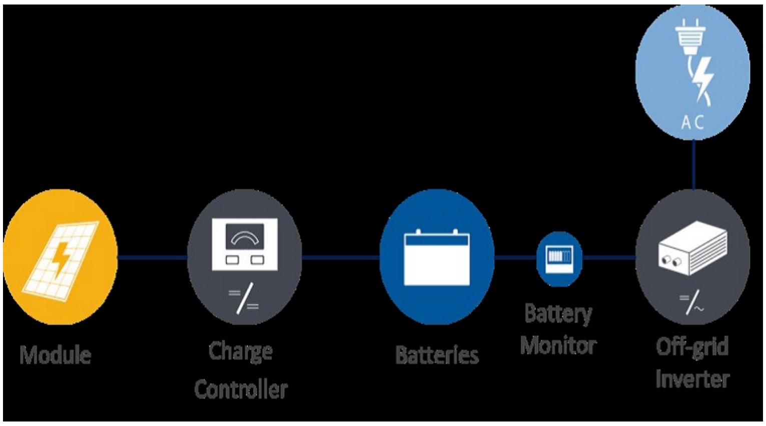


Figure 12: DC coupled off-grid system (left DC use, right AC use)

1.5.3 AC Coupled Off-grid PV system

In an AC coupled system, the DC power from the PV modules are inverted to AC and then, via a charger, converted to DC into the batteries. In other words, the first inversion is from DC to AC (see Figure 13).

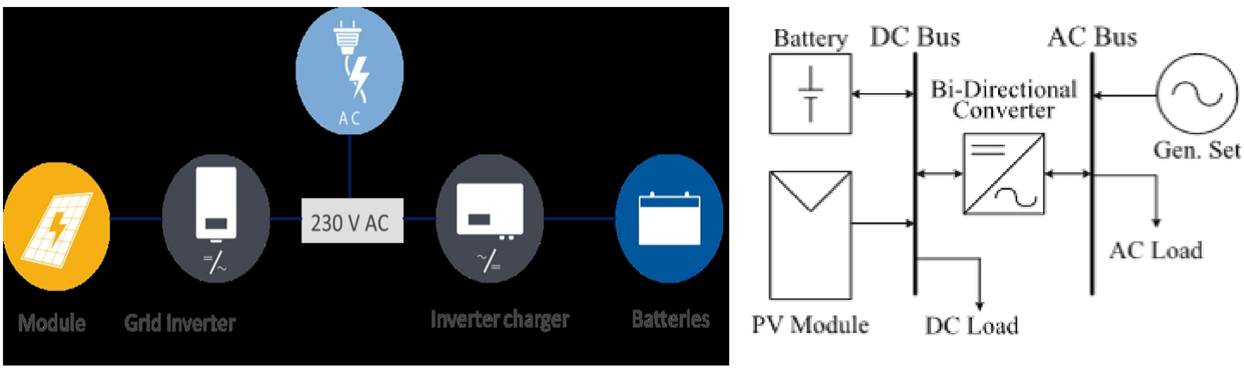


Figure 13: AC Coupled Off-Grid PV System

The DC from the PV modules is converted to AC by the PV inverter or Grid Inverter. The AC is then available for direct consumption on the loads. The AC can also be stored into batteries by the Inverter/Charger. The inverter charger can then invert the DC from the batteries to AC when needed. An inverter/charger is thus a bi-directional device.

1.5.4 Efficiency

When considering whether to use a DC coupled system or AC coupled system, one should understand how power is consumed. If most of the power is consumed during the day (when the sun is shining), an AC coupled system is more efficient as the PV power is directly changed to AC to use on the loads (see Figure 14).

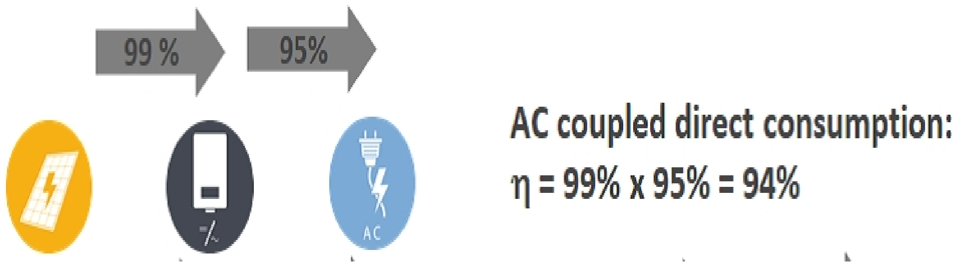


Figure 14: AC coupled efficiency for direct consumption

When most of the power is consumed at night, an AC coupled system is less efficient as the DC power is converted to AC, then back to DC to store into batteries. At night when the power is required, the DC is converted back to AC to be used by the loads. This process is much less efficient due to 3 power conversions as well as battery inefficiencies (see Figure 15).

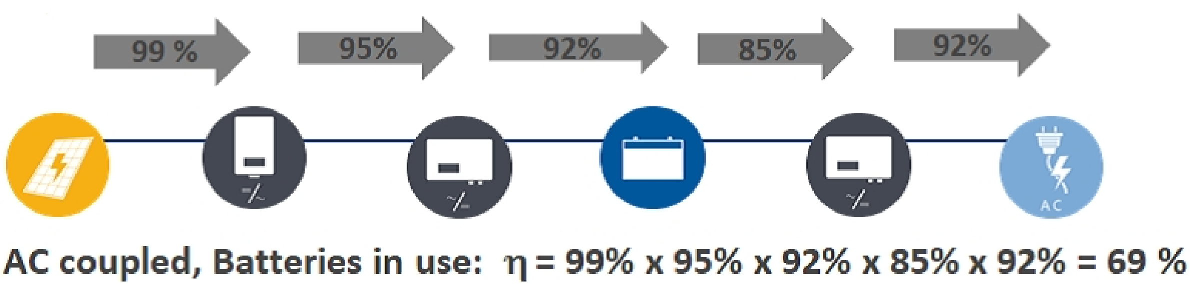


Figure 15: AC coupled efficiency when loads use power from batteries

A DC coupled system is less efficient than AC coupled systems when the direct consumption is high as the DC power from the modules is converted to DC via the charge controller, and then to AC via the off-grid inverter.

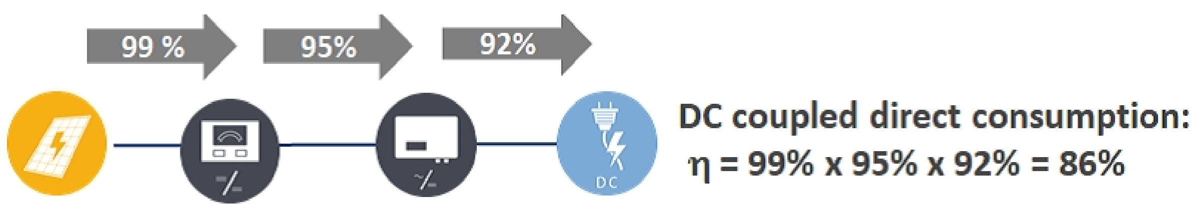


Figure 16: DC coupled system with direct consumption

DC Coupled systems are more efficient than AC coupled system when the direct consumption is low (more power used from batteries than directly) as seen in Figure 17.

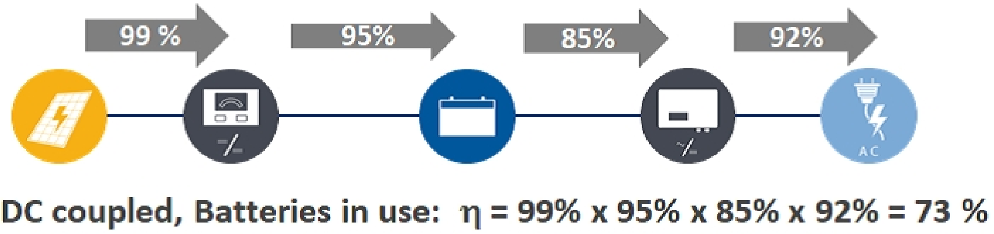


Figure 17: DC coupled system with high battery use

The efficiency figures above are general and can be different depending on the efficiency of specific equipment and batteries. In general, AC coupled systems are more efficient when the direct consumption is higher than about 30% - see Figure 18

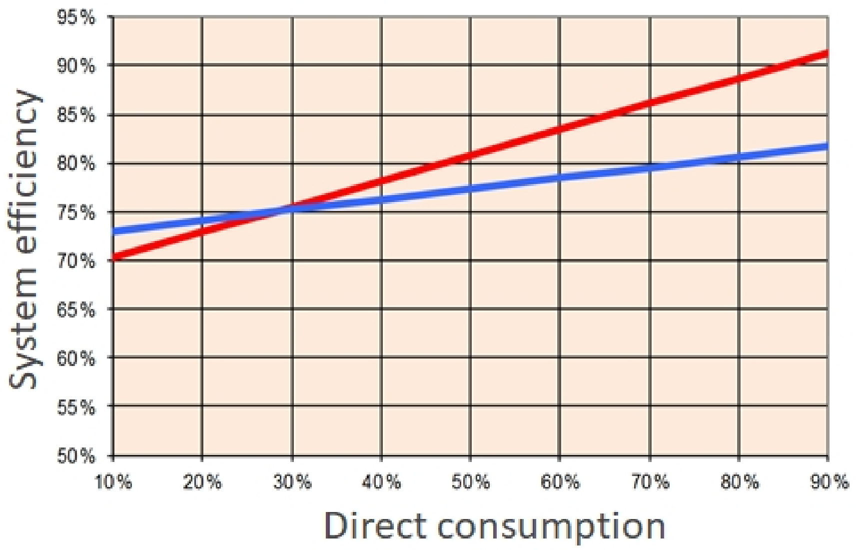


Figure 18: Efficiency vs. Direct consumption

1.6 Load demand table

In an off-grid PV system (see Figure 19), the inverter supplies the AC loads from the battery storage. The inverter needs to be able to supply the maximum AC load without overloading or tripping. As a consequence, the maximum load will determine the size of the inverter. In this section, we will determine the maximum load that needs to be supported by using a load demand table. The charge controller and inverter in Figure 19 can also be in one box which will make it a hybrid inverter as shown in Figure 20: Hybrid Inverter (https://www.cleanenergyreviews.info/). The Adama example makes use of such a hybrid inverter, **Name**ly the Phocos Anygrid PSW-H-5KW-230/48V.

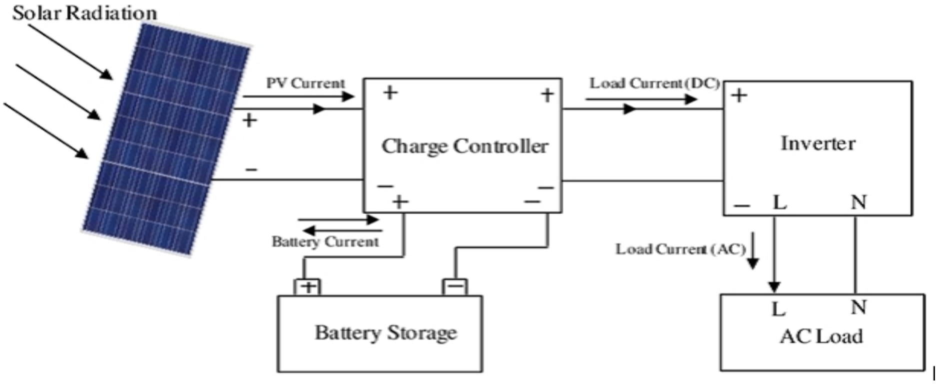


Figure 19: Off-grid PV System (researchgate.net)

Figure 20: Hybrid Inverter (https://www.cleanenergyreviews.info/)

Figure 21: Phocos Any grid Hybrid Inverter

The maximum load is measured in W or kW. It is normally the worst-case scenario i.e. the load when all the appliances (or consumers) are on at the same time, hence it is called peak load. One method to determine the maximum load is to list all the loads in a tabulated form (Table 1). The list can be compiled by interviewing the customer in order to determine the load types, quantities and usage patterns.

Table 1: Load Demand Table

1	2	3	4	5	6
Collected Information					Calculated Information
No	Power Consumer	AC or DC	Quantity	Power In Watt (W)	Total Power In Watt (W)
1	Lights	AC	20	18W	360W
2	Lights	AC	9	18W	162W
3	Computer	AC	3	250W	750W
4	Printer	AC	1	700W	700W
5	Projector	AC	1	300W	300W
6	Internet	AC	1	15W	15W
7	Router	AC	2	15W	15W
TOTAL					2317W

As can be seen in Table 1, the total power consumed by any type of consumer is the power consumed by 1 consumer (column 5) multiplied by the number of consumers (column 4). For example in row 1: 20 lights x 18W each = 360W. The maximum load is then the sum of all the power consumed. In this case, the inverter needs to be able to supply at least 2317 W without overloading.

1.7 DC Loads

Where DC loads are used we are interested in the energy as the energy is extracted directly from the battery. We therefore we need to add the number of hours used per load (Energy = power x time) as shown in LO2. Where AC and DC loads are used in the same system, only the maximum AC load will then be used to size the inverter.

Self-Check - 1	Written Test

Instruction: Follow the below selected instruction

The following are true or false items, write true if the statement is true and write false if the statement is false.

N°	**Questions and answers**
1	The inverter is selected according to the maximum load to AC consumers?
True or false:	
2	The maximum load (W) is the sum of all the consumer loads?
True or false:	

Note: the Satisfactory rating is as followed

Satisfactory	1 points
Not satisfactory	Below 1 points

Information Sheet 2	Calculating energy demand for each load

2.1 Introduction

In order to design an off-grid PV system, it is important to understand the maximum load that needs to be supplied by the system, as well as how much energy needs to be provided by the system. In the previous information sheet, we determined that the maximum load dictate the size of the inverter. In this section we will calculate the energy that is required per day. The energy demand will eventually dictate the size of the battery and the PV array. The unit for the energy is Watt-hours (Wh) or Kilowatt-hours (kWh).

2.2 Calculate energy demand

To calculate the energy demand, we can use and expand the load demand table. In this case it is important to determine how many hours per day each consumer is used in order to determine the total energy consumption per day.

Table 2: Energy Demand

1	2	3	4	5	6	7	8	9
Collected Information							Calculated Information	
No	Power Consumer	AC or DC	Quantity	Power in Watt (W)	Operation time (h)	Usage Time	Consumption (Wh/d)	Total Power in Watt (W)
1	Lights	AC	20	18W	4	Night	1440Wh/d	360W
2	Lights	AC	9	18W	12	Night	1944Wh/d	162W
3	Computer	AC	3	250W	8	Day	6000Wh/d	750W
4	Printer	AC	1	700W	1	Day	700Wh/d	700W
5	Projector	AC	1	300W	6	Day	1800Wh/d	300W
6	Internet	AC	1	15W	24	Day/ night	360Wh/d	15W
7	Router	AC	2	15W	24	Day/ night	720Wh/d	15W
TOTAL							12964Wh/d	2317W
Total day								1795W
Total night								567W

As can be seen in Table 2, the energy consumed by all consumers is 12964Wh per day. This is the minimum energy the battery needs to be able to supply in one day, not accounting for system losses. The PV array also needs to be able to charge the battery in order to supply the energy. It can thus be seen that the energy consumption eventually influences (among other factors) the size of the battery and the PV array.

2.3 DC Loads

Where AC and DC loads are used in the same system, one should distinguish between AC and DC energy consumption (see example in Figure 22). When calculating the battery size, the DC loads will have fewer losses than the AC loads due to the extra inverter losses for AC loads.

Column A Lamp or Appliance list below	Column B Voltage volts	Column C Power watts	Column D Daily Use hours	Column E Daily Energy Use (DC) watt hours	Column F Daily Energy Use (AC) watt hours
DC Appliances					
Lamps (6 x 3 W LED)	12	18	2	36	
Lamps (6 x 10W fluorescent)	12	60	2	120	
Sitting room lamps (2 x 15W fluor.)	12	30	3	90	
Security light (6W LED)	12	6	10	60	
Water pump	12	40	1.5	60	
				0	
AC Appliances		154			
Colour television	240	80	3		240
CD Player/music system	240	15	2		30
Laptop computer	240	25	3		75
Cell phone chargers (3 x 3W)	240	9	6		54
					0
		129			
BOX G: Total Daily DC Energy Demand				366	Watt-hours
BOX H: Total Daily AC Energy Demand					399

Figure 22 : Example of AC and DC loads (Hankins, 2010)

Self-Check - 2	Written Test

Instruction: Follow the below selected instruction

The following are true or false items, write true if the statement is true and write false if the statement is false.

N°	Questions and answers
1	Energy is measured in W
True or false:	

For each of the following question choose the best answer and circle the letter of your choice.

N°	Questions and answers
1	The daily energy demand determines the size of:
A – The inverter	B – The battery
C – The battery and PV array	D – None of the above

Note: the **Satisfactory** rating is as followed

Satisfactory	3 points
Not satisfactory	Below points

Solar PV System Installation and Maintenance

NTQF Level IV

Learning Guide -02

Unit of Competence	**Calculating System Components**
Module Title	**Calculating System Components**
LG Code	**EIS PIM4 M02 LO1-LG02**
TTLM Code	**EIS PIM4 TTLM 0920v1**

LO 2: Determine battery capacity

Instruction Sheet	Learning Guide:- 02

This learning guide is developed to provide you the necessary information, knowledge, skills and attitude regarding the following content coverage and topics:

- Determining Maximum Depth of Discharge;
- Calculating Battery capacity.

This guide will also assist you to attain the learning outcome stated in the cover page. Specifically, upon completion of this Learning Guide, you will be able to:-

- Determine Maximum Depth of Discharge;
- Calculate Battery capacity

Learning Instructions:

1. Read the specific objectives of this Learning Guide.
2. Follow the instructions described below.
3. Read the information written in the information Sheets
4. Accomplish the Self-checks

1. Determining Maximum Depth of Discharge

1.1 Introduction

The next step in the design process is to determine the battery capacity:

3) Sizing the Battery

$$C_{10} = \frac{E \times A}{DOD \times V_{System}}$$

E-Daily energy consumption [Wh/d]

A-Days of Autonomy [d])

DOD-Depth of Discharge [%], V-System Voltage[V])

Conversion of the different capacities	
C10	'= C1 / 0.61
C10	'= C5 / 0.88
C10	'= C10
C10	'= C20 / 1.09
C10	'= C100 / 1.25
C10	'= C120 / 1.28

Select the Battery

Based on 12V, 24V e 48V system, determine best battery configuration i.e. either series, parallel or both. For choice of battery capacity, all must be converted to C_{10} capacity, as per table:

Figure 23: Design step 2

In order to calculate the size battery required, it is important to understand the term ''Depth of Discharge'' or DoD and how to determine it.

1.2 Battery overview .

1.2.1 Energy Storage

Stated simply, a battery is like a tank for electric energy. The solar array produces an electric charge as long as the sun is shining. The charge travels through wires into the battery where it is converted to stored chemical energy. Over the course of several days, a battery may 'fill' with stored energy. It can be compared to a water tank that fills with water collected from the rooftop during rain. And just like a water tank, the battery has a limited capacity. When it is fully charged, it cannot take up any more energy without overflowing -or in case of the battery- without damage.

The same limit applies for discharging: it is impossible to remove more energy from the battery than is put in by charging. And if an appliance, e.g. a light, is left on by accident all night, all electricity will drain from the battery. This can be compared to an open tap of a water tank. The water will flow out and if you forget to close the tap overnight, all water will be gone the next morning.

Figure 24 Water tank as battery equivalent (www.menschenfuermenschen.de)

Figure 25 Example of a Battery (Alibaba.com)

1.2.2 Principle of Operation

Batteries are groups of 'electrochemical cells', devices that convert chemical energy into electrical energy. These groups of cells are connected in series. Battery cells should not be confused with solar cells, which operate according to completely different principles.

Battery cells are composed of two 'electrodes' (also called plates) immersed in an 'electrolyte' solution. When a circuit is formed between the electrodes, a current flows. This current is caused by reversible chemical reactions between the electrodes and the electrolyte within the cell.

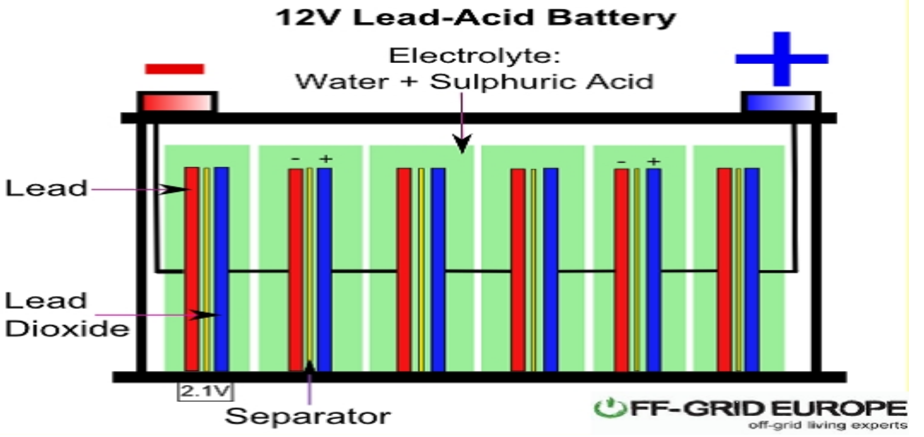


Figure 26: Connection of 6 cells to a 12V battery (off-grid Europe, 2017)

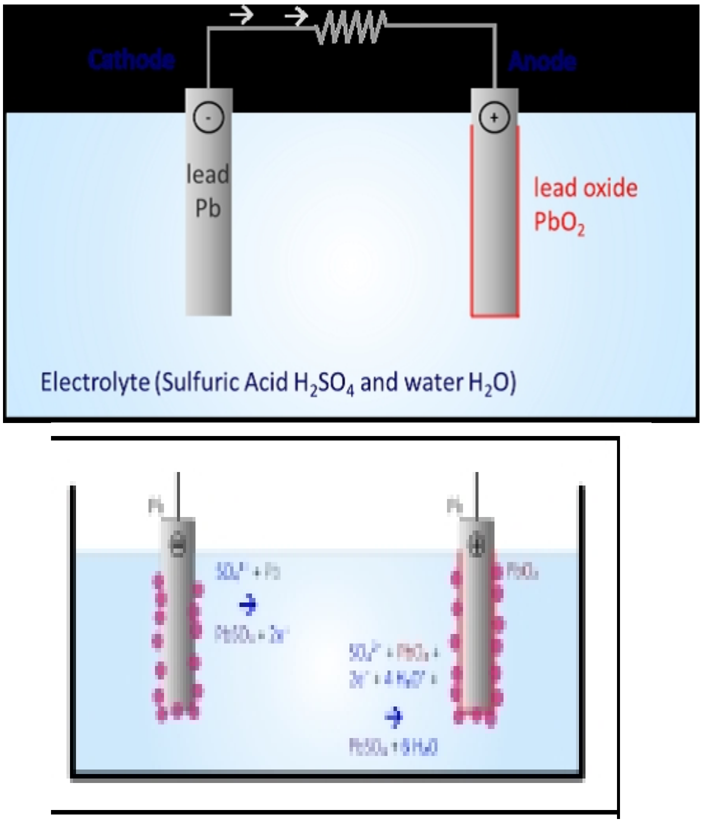


Figure 27: Chemical reaction and electron flow in a battery

Some cells can only be used once – these are called ‘primary batteries’ (i.e. dry cells). Other batteries can be recharged over and over again; these are called ‘secondary batteries’ (or accumulators). Because ordinary dry cells cannot be recharged, this chapter is concerned with rechargeable secondary batteries only.

As a battery is charged, electric energy is stored as chemical energy within the cells. When the battery is being discharged (i.e. when it is connected in circuit with a load), stored chemical energy is being removed from the battery and converted to electrical energy. The most common types of rechargeable battery systems on the world market today are lead-acid, lithium ion, nickel metal hydride and nickel cadmium.

Deep discharge or deep cycle batteries are preferred for solar electric systems because most of their stored energy can be delivered without causing damage to the cells or shortening their life. Shallow discharge batteries, made for automotive purposes, are designed to supply a large amount of power for a short duration. Taking too much energy out of these batteries before recharging them is likely to damage the plates inside.

It is advisable to only use deep cycle batteries in solar systems. If only shallow discharge batteries are available, they should be managed very carefully and never discharged deeply to avoid damage and system failure. In general, car batteries will have a much shorter lifetime when used in solar systems.

1.2.3 Rated Storage Capacity

The amount of energy that a battery can store is called its capacity. A water tank, for example, with a capacity of 8000 liters can hold at most 8000 liters. Similarly, a battery can only store a fixed amount of electrical energy. Battery capacity, typically marked on the casing by the manufacturer, is measured in amp-hours (Ah). This indicates the amount of energy that can be drawn from the battery before it is completely discharged. Logically, that would mean that a battery of 100Ah capacity gives a current of 1 amp for 100 hours, or 2 A for 50 hours, and 4 A for 25 hours:

1 A x 100h = 100 Ah

2 A x 50 h = 100 Ah

4 A x 25h = 100 Ah

However, batteries do not follow this logic. The rate at which a battery is discharged affects the capacity of the battery. For example, a battery discharged at a rate of 1 amp might provide that current for 100 hours, giving it a capacity of 100Ah at that rate of discharge; but the same battery discharged at the rate of 4 amps might only deliver that current for 20 hours thus giving it a real capacity of 80Ah.

On battery datasheets this is indicated by C-rates: C100 indicates the capacity of a battery being discharged over 100 hours (at the rate of 1 amp in the above example), C20 indicates the capacity of a battery being discharged over 20 hours (at the rate of 4 amps in the above example).

Thus, the battery in the example has the following capacities: 100Ah at C100 and 80Ah at C20. So when choosing a battery you should be aware of the C-rate to which the rated storage capacity relates.

1.2.4 Charge and Discharge

'Charge current' is the electric current supplied to and stored in a battery. As a water tank will take more or less time to fill depending on the rate at which water enters it, the amount of time required to completely charge a battery depends upon the rate of the current at which it is being charged. 'Discharge' is the state when battery energy is being consumed by a connected load (i.e.

appliances). The discharge current is the rate at which current is drawn from the battery. The amount of energy removed from a battery over a period of time can be calculated by multiplying the discharge current by the amount of time the load is used. For example, a lamp drawing 1.2 amps for 4 hours uses 4.8 amp-hours of energy from the battery (1.2A × 4 hours = 4.8Ah).

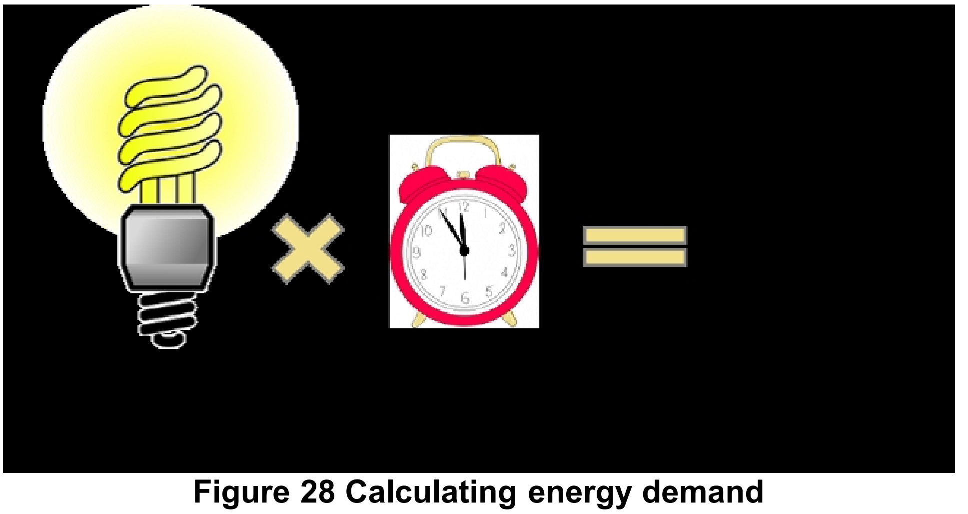


Figure 28 Calculating energy demand

But unlike a water tank, a battery can never be fully discharged. Some of the energy always has to remain in the battery, for lead solar batteries usually min. 20%, otherwise the battery will be damaged permanently and can never be charged again. This state is called "deep discharge". Because batteries also discharge themselves over time, they have to be checked and charged frequently when not in use in order to prevent permanent damage.

1.2.5 State of Charge

Just as one needs to monitor the amount of fuel left in a car's petrol tank, one needs to keep track of how much energy remains in the battery. The 'state of charge' (SoC) is a measure of the energy remaining in the battery. It tells you whether a battery is fully charged, half-charged or completely discharged. The cells of a fully charged battery have a 100 per cent state of charge, while those of a battery with one-quarter of its capacity removed are at a 75 per cent state of charge.

1.2.6 Cycles and Cycle Life

Typically, batteries in PV systems are charged each day by the PV array and then discharged by the load each night (though this is not always the case in larger systems where some loads are also powered during the day). Each charge period together with the following discharge period is called a 'cycle'. For example, in one cycle a 100Ah battery might be charged up to 95 per cent state of charge (12.68V) during the day, and then discharged by lights and television to 75 per cent state of charge that evening. The 'rated cycle life' of a battery (this should be specified by the manufacturer) is the number of cycles a battery is expected to last before its capacity drops to 80 per cent of its original rated capacity. Note that, in off-grid systems, this is typically the number of days the battery will last because each 'day' is more or less the same as one 'cycle'.

1.2.7 Depth of Discharge

Note also that the cycle life is determined by the average depth of discharge per cycle – a battery cycled at 30 per cent will last longer than a battery cycled at 70 per cent – as well as by average battery temperature. The actual cycle life of a battery is greatly shortened by such mistreatment as deep discharge, high temperature and high discharge rates.

'Depth of discharge' (DoD) is another term that manufacturers use to express how much batteries are discharged in a cycle before they are charged again, , in other words, how much was taken out of a battery already. When 20 Ah were already taken from a 100 Ah battery, the DoD is 20%.

A battery at 20 per cent DoD is the same as an 80 per cent state of charge battery. A battery at 75 per cent DoD is at a 25 per cent state of charge. Shallow cycle batteries should not be discharged below 20 per cent DoD (80 per cent state of charge) on a regular basis. Even deep cycle batteries should not regularly be discharged below 60 per cent DoD (40 per cent state of charge). Remember, batteries last much longer when they are maintained in a high state of charge.

1.2.8 Solar Batteries

The following paragraph is taken/adapted from (Dobelmann & Klauss-Vorreiter, 2009) chapter 5. Although the solar battery may look like the battery used in automobiles, inside it is very different. Batteries used for vehicles are designed to provide large amounts of power for a short time while solar batteries are designed to provide a small amount of power continuously for many hours. To provide this kind of power, the solar batteries have thicker lead plates in the inside than car batteries. Car batteries should not be used in solar systems to avoid early system failure.

The type of battery best suited for most solar systems is called a deep discharge battery. It is called that because it is especially designed to deliver a high percentage of its power without any damage. You can regularly use 80% of the power stored in a deep discharge battery without damage (compared to the allowable rate of 10% for a car battery). Therefore the use of a deep cycle battery would necessitate a correspondingly much smaller battery capacity.

1.3 Determining Depth of Discharge

Determining the Depth of Discharge is often a compromise exercise between lifetime and upfront capital layout. If a battery is discharged deeply, the battery size can be much smaller but the lifetime (cycles) will be much less. If a battery is not discharged deeply, a much bigger and more expensive battery is required, but it will last longer (more cycles). Battery cycles vs. Depth of Discharge information can be found on the battery datasheet, normally in a graph format.

In Figure 29 it can be seen that if a particular battery (Moll OPzS Solar range) is discharged to only 20%, it should last around 7500 cycles (green lines), while if it is discharged to 80%, is should last around only 1500 cycles (red line).

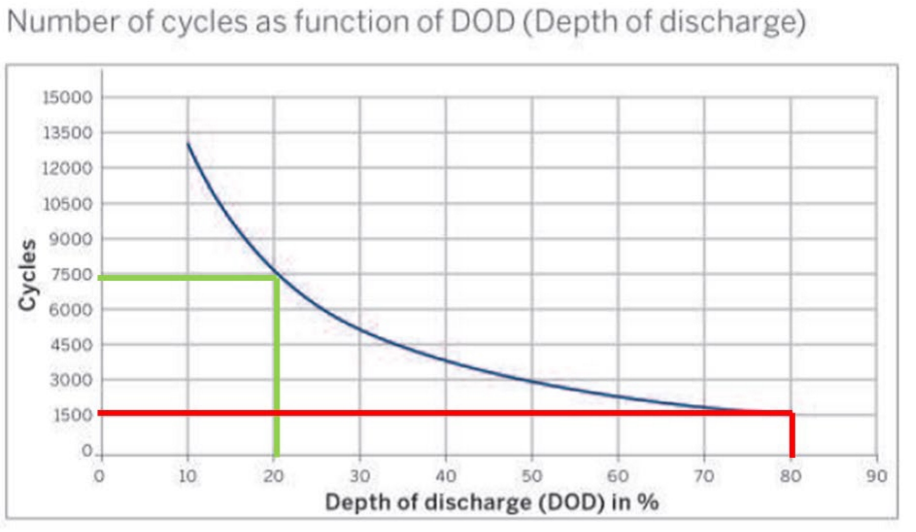


Figure 29 : Cycles vs. DoD

If a battery is only discharged 20%, one would need battery with about 4xtimes higher capacity (and higher price) to get the same energy out as when it is discharged to 80%. The bigger battery will however last much longer.

In order to determine the optimal depth of discharge, it is advisable to not only look at the upfront cost but rather the lifetime cost of the batteries. As an example, let's assume we require 150Ah of energy for an application and we have 50Ah batteries available. We can set up a table (Table 3) to determine the lifetime cost of batteries for more than one DoD scenario, assuming the battery discharge curve in Figure 29:

Table 3: Comparing Price per Cycle

DoD	Battery available	Energy per Cycle	Energy Required	Batteries required	Price per Battery	Total Price	Cycles	Price per Cycle
20%	50Ah	10Ah	150Ah	15	$100	$1500	7500	20c
80%	50Ah	40Ah	150Ah	4	$100	$400	1500	27c

As can be seen, the initial capital required will be much less if the battery is discharged to 80% ($400 vs. $1500), but the price per cycle is about 35% more expensive (27c vs. 20c) compared to a 20% discharge. Furthermore, the batteries at 80% discharge will have to be replaces much more often (with added labor cost).

It can therefore be seen that it important to look at the lifetime cost of batteries to determine the optimal solution. For instance, if we use the same example, it can be seen (Table 4) that a good compromise may be a DoD of 50%. It will give a good price per cycle at a reasonable cost while also maintaining a reasonable number of cycles.

Table 4: Cycle price vs. Cost

DoD	Battery available	Energy per Cycle	Energy Required	Batteries required	Price per Battery	Total Price	Cycles	Price per Cycle
20%	50Ah	10Ah	150Ah	15	$100	$1500	7500	20c
50%	50Ah	25Ah	150Ah	6	$100	$600	3000	20c
80%	50Ah	40Ah	150Ah	4	$100	$400	1500	27c

Self-Check - 1	Written Test

Instruction: Follow the below selected instruction

N°	**Questions and answers**
1	Deep cycle batteries are preferred for solar systems
True or false:	
2	The capacity of a battery is the same, regardless of the rate of discharge
True or false:	
3	The 'rated cycle life' of a battery is the number of cycles a battery is expected to last before its capacity drops to 80 per cent of its original rated capacity.
True or false:	
4	The best battery is:
A – The cheapest battery	B – The battery with the most cycles
C – The one that can be discharged deepest	D – A compromise between cost, discharge depth and cycles

Note: the **Satisfactory** rating is as followed

Satisfactory	2points
Not satisfactory	Below 2 points

Information Sheet 2	Calculating Battery capacity

2.1 Introduction

The capacity of a battery that is required for an application is a function of the energy consumption that the battery needs to supply, the efficiency of the battery, the system voltage, for how long the battery needs to supply energy (autonomy) and the Depth of Discharge.

2.2 Calculate battery size

2.2.1 Energy Consumption

In Learning Outcome 1, we dealt with the calculation of energy consumption using load tables (page 17).

2.2.2 System efficiency

Storing energy into a battery (converting from electrical energy to chemical energy) and retrieving energy from a battery (converting from chemical energy to electrical energy) imply certain losses. Depending on what type of battery is used, the efficiency of batteries can be more than 90% for lithium-ion down to 70% or less with lead-acid batteries. When calculating battery size for off-grid systems, one will normally increase the size of the battery to make up for losses.

2.2.3 System Voltage

The following paragraph is/are adapted from (Hankins, 2010) Chapter 4.

System Voltage ‘System voltage’ is the nominal voltage at which the batteries, charge regulator and solar array operate. Also, system appliances often operate at the system voltage. Most small off-grid PV systems (especially solar home systems below 100Wp) use 12V DC as their system voltage. If there is a need for AC power, an inverter is used to convert 12V DC electricity from the battery to the desired AC voltage. Sometimes 24 and 48V DC system voltage is used. In such cases, batteries and solar modules are wired in series or series-parallel so that they are 24 or 48V, and 24 or 48V charge regulators and inverters must be selected. Such systems have less voltage drop in wire runs, so they are often selected to save on cable costs (48V DC systems are common in off-grid telecom systems). However, note that 24 or 48V DC appliances are not readily available, so 12V DC system voltage is usually preferred for DC loads.

From the formulas P=IV and V=IR, it can be derived that $P=I^2R$. It is therefore clear that there is a squared (I^2) relationship between power losses and current i.e. the higher the current, the higher the losses will be. The selection of the system voltage should aim to reduce the current (in order to reduce losses). There are various ways to determine the system voltage: The 1-ohm rule: This rule states that the moment the load resistance goes below 1 ohm, the next voltage should be selected:

System voltage	12 V	24 V	48 V
Load resistance	1ohm	1ohm	1ohm
Limiting PV power to (1Ω-rule):	144 W	576 W	2304 W

The current limit rule i.e. keeping the current below e.g. 100A:

System voltage	12 V	24 V	48 V
Current	83A	83A	83A
Limiting PV power to:	1000 W	2000 W	4000 W

In practice though, it will largely depend on the available charge controller voltage and power, as well as the available inverter voltage. It is important to size connectors and wires properly to limit losses.

2.2.4 Autonomy

Autonomy is the reserve storage factor, or the number of days of storage needed. This varies with site and is higher for sites with cloudy weather. In sunny areas, depending on the application, this number may be as low as one to two days only. The higher the days of autonomy, the higher the cost of the battery bank and it will increase the risk that, during cloudy weather or winter periods, batteries will not be fully charged and will be damaged by cycling in a low state of charge. For larger systems, a diesel generator may be more cost effective than large battery banks to cater for days of prolonged rain.

2.2.5 Depth of Discharge

This is the deepest depth of discharge that is ordinarily allowed with the battery. Shallow cycle batteries, for example, should not be cycled below 20 per cent depth of discharge, while deep discharge batteries can regularly handle 50 per cent discharges. Lithium-ion batteries can generally handle much deeper discharges of up to 90%.

2.2.6 Calculation formula

For the calculation of the battery, we will use the Adama design as example. The following formula can be used to calculate the battery size:

$$C_{10} = \frac{E * A}{DoD * Vsyst}$$

Where:

- DoD = Depth of Discharge e.g. 50%
- E = Energy consumption (daily) e.g. 5 kWh/day
- A = Autonomy days e.g. = 2 days
- Vsyst = System Voltage DC e.g. 48 V

For the Adama design, we determined that the daily energy consumption is 12964Wh/d

(see Table 2). The Phocos Any grid inverter is a 48V inverter, therefore the battery voltage needs to be 48V. We decided on only 1 day of autonomy to reduce battery costs. There is grid power available to use in case of days without sunshine. We also decided on a 50% DoD since we will be using lead acid batteries (Hoppecke Sun Power). The required battery is therefore:

$$C_{10} = \frac{12964Wh/day * 1days}{50\% * 48V} = 540.17Ah$$

Note that Lithium-ion batteries are normally specified in Wh, therefore we omit the system voltage from the equation to get to the Wh rating. From Figure 30, we see that the 7 OpzS solar power 730 battery gives us 546 Ah at C10. This is higher than the 540Ah we require. This battery is a 2V battery and we need 48V. To determine the number of batteries is

series:

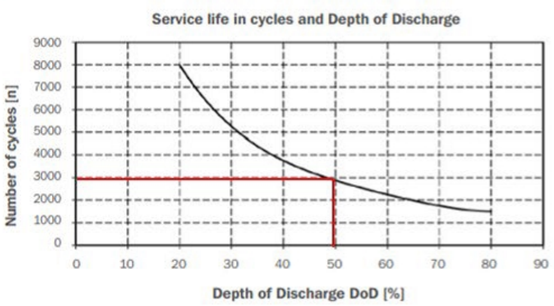
$$n_{series} = \frac{V_{System}}{V_{selected\ battery}} = \frac{48V}{2V} = 24$$

To determine the number of batteries in parallel:

$$n_{parallel} = \frac{C_{10,required}}{C_{10,selected\ battery}} = \frac{540.17Ah}{546Ah} = 0.99 = 1$$

We therefore need one series string of 24 x 2V cells to get a 546Ah, 48V battery.

Type	C_{100}/1.85 V Ah	C_{50}/1.85 V Ah	C_{24}/1.83 V Ah	C_{10}/1.80 V Ah	C_5/1.77 V Ah	max. Weight kg	Weight electrolyte kg (1.24 kg/l)	max.* Length L mm	max.* Width W mm	max.* Height H mm	Fig.
4 OPzS solar.power 280	280	265	245	213	182	17.1	4.5	105	208	420	A
5 OPzS solar.power 350	350	330	307	266	227	20.7	5.6	126	208	420	A
6 OPzS solar.power 420	420	395	370	320	273	24.6	6.7	147	208	420	A
5 OPzS solar.power 520	520	490	454	390	345	29.1	8.5	126	208	535	A
6 OPzS solar.power 620	620	585	542	468	414	34.1	10.1	147	208	535	A
7 OPzS solar.power 730	730	685	634	546	483	39.2	11.7	168	208	535	A
6 OPzS solar.power 910	910	860	797	686	590	46.1	13.3	147	208	710	A
7 OPzS solar.power 1070	1070	1002	930	801	691	59.1	16.7	215	193	710	B
8 OPzS solar.power 1220	1220	1145	1063	915	790	63.1	17.3	215	193	710	B
9 OPzS solar.power 1370	1370	1283	1192	1026	887	72.4	20.5	215	235	710	B
10 OPzS solar.power 1520	1520	1425	1325	1140	985	76.4	21.1	215	235	710	B
11 OPzS solar.power 1670	1670	1572	1459	1256	1086	86.6	25.2	215	277	710	B
12 OPzS solar.power 1820	1820	1715	1591	1370	1185	90.6	25.8	215	277	710	B
12 OPzS solar.power 2170	2170	2010	1843	1610	1400	110.4	32.7	215	277	855	B
14 OPzS solar.power 2540	2540	2349	2163	1881	1632	142.3	46.2	215	400	815	C
16 OPzS solar.power 2900	2900	2685	2472	2150	1865	150.9	45.9	215	400	815	C
18 OPzS solar.power 3250	3250	3015	2765	2412	2097	179.1	56.4	215	490	815	D
20 OPzS solar.power 3610	3610	3350	3072	2680	2330	187.3	55.7	215	490	815	D
22 OPzS solar.power 3980	3980	3685	3388	2952	2562	212.5	67.0	215	580	815	D
24 OPzS solar.power 4340	4340	4020	3696	3220	2795	221.2	66.4	215	580	815	D
26 OPzS solar.power 4700	4700	4355	4004	3488	3028	229.6	65.4	215	580	815	D



C_{100}, C_{50}, C_{24}, C_{10} and C_5 =
Capacity at 100 h, 50 h, 24 h, 10 h and 5 h discharge

* according to DIN 40736-1 data to be understood as maximum values

Figure 30: Battery selection

At a dept of discharge of 50%, we can expect around 3000 cycles.

Figure 31: Hoppecke batteries

Self-Check - 2	Written Test

Instruction: Follow the below selected instruction

N°	**Questions and answers**
1	Batteries should be fully discharged
True or false:	
2	Autonomy refers to how long a battery can supply the load without getting charged
True or false:	
3	Lithium-ion batteries can be discharged deeper than lead-acid batteries without problems
True or false	

N°	**Questions and answers**
4	Calculate the C10 capacity of a battery when the consumption is 850Wh/day, the autonomy is 3 days, the DoD is 50% and the system voltage is 24V

Note: the **Satisfactory** rating is as followed

Satisfactory	2 points
Not satisfactory	Below 2 points

Solar PV System Installation and Maintenance

NTQF Level IV

Learning Guide -03

Unit of Competence	**Calculating System Components**
Module Title	**Calculating System Components**
LG Code	**EIS PIM4 M02 LO1-LG03**
TTLM Code	**EIS PIM4 TTLM 0920v1**

LO 3: Calculate array size

Instruction Sheet	Learning Guide:- 03

This learning guide is developed to provide you the necessary information, knowledge, skills and attitude regarding the following content coverage and topics:

- Determining minimum solar insolation;
- Calculating array size;
- Adjusting array size based on the environmental factors.

This guide will also assist you to attain the learning outcome stated in the cover page. Specifically, upon completion of this Learning Guide, you will be able to:-

- Determine minimum solar insolation;
- Calculate array size;
- Adjust array size based on the environmental factors.

Learning Instructions:

1. Read the specific objectives of this Learning Guide.
2. Follow the instructions described below.
3. Read the information written in the information Sheets
4. Accomplish the Self-checks

Information Sheet 1	Determining minimum solar insolation

1.1 Introduction

Step 3 in the design process is to calculate the array size:

2) PV generator

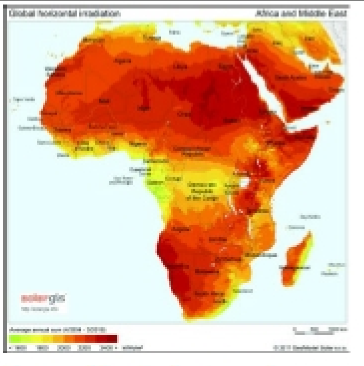
Calculate solar irradiation for the location of the planned solar system

Sizing the PV Generator

$$P_{PV} = \frac{E}{G \times h} = \frac{\text{Daily Energy Consumption } [\frac{Wh}{d}]}{\text{Sun Hours } [h] \times \text{ System Efficiency}}$$

Number of Modules

$$n = \frac{Power_{PV}}{Power_{Mod}} = \frac{P_{PV}}{P_{Mod}}$$



Sourcre: https://solargis.com/

Figure 32: Design Step3

In order to determine the size of the PV generator required, one needs to determine the available solar energy at the specific location, taking into consideration the location, mounting angle and azimuth.

1.2 Background

The following paragraphs are taken/adapted from (Hankins, 2010) chapter 2.

Sunshine reaches the earth as a type of energy called radiation. Radiation is composed of millions of high-energy particles called photons. Each unit of solar radiation, or photon, carries a fixed amount of energy. Depending on the amount of energy that it carries, solar radiation falls into different categories including infrared (i.e. heat), visible (radiation that we can see) and ultraviolet (very high energy radiation). The solar spectrum describes all of these groups of radiation energy that are constantly arriving from the sun, and categorizes them according to their wavelength.

Different solar cells and solar energy collecting devices make use of different parts of the solar spectrum. Solar energy arrives at the edge of the Earth's atmosphere at a constant rate of about 1350 watts per square meter (W/m^2): this is called the 'solar constant'. However, not all this energy reaches the Earth's surface. The atmosphere absorbs and reflects much of it, and by the time it reaches the Earth's surface, it is reduced to a maximum of about $1000W/m^2$ (see Figure 33). This means that when the sun is directly overhead on a sunny day, solar radiation is arriving at the rate of about 1000W/m2. Northern countries (i.e. Europe) have lower annual solar radiation levels than countries nearer the Equator – mainly because they have shorter days in winter.

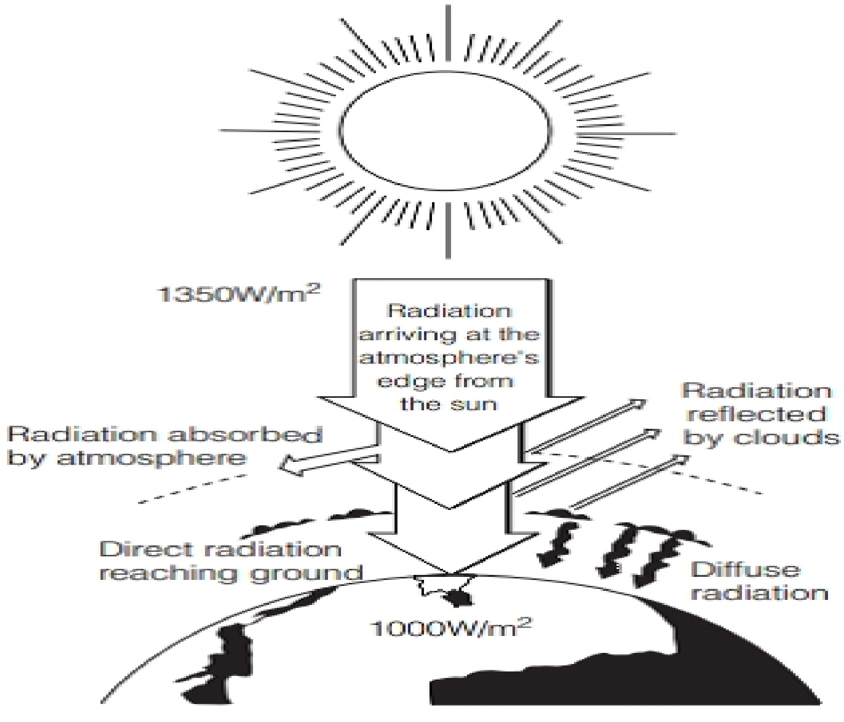


Figure 33: Absorption and reflection of solar radiation by the Earth's atmosphere

1.2.1 Direct and Diffuse Radiation

Solar radiation can be divided into two types: direct and diffuse. Direct radiation comes in a straight beam and can be focused with a lens or mirror. Diffuse radiation is radiation reflected by the atmosphere or radiation scattered and reflected by clouds, smog or dust. Clouds and dust absorb and scatter radiation, reducing the amount that reaches the ground. On a sunny day, most radiation reaching the ground is direct, but on a cloudy day up to 100 per cent of the radiation is diffuse. Together, direct radiation and diffuse radiation are known as global radiation. Radiation received on a surface in cloudy weather can be as little as one tenth of that received in full sun (see Figure 34).

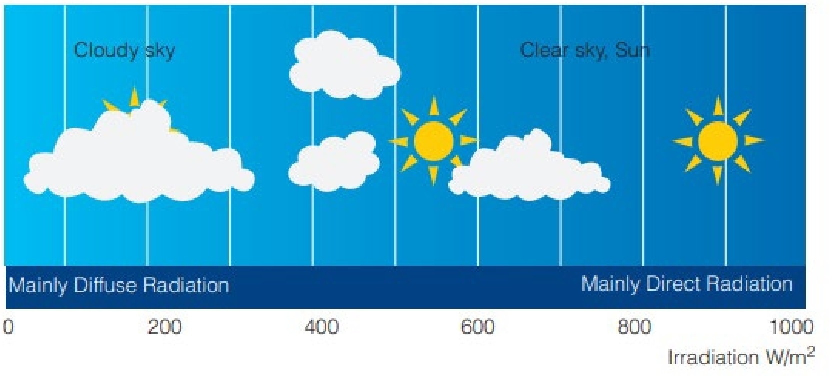


Figure 34: Direct and diffuse radiation

Therefore, solar systems must be designed to guarantee enough power in cloudy periods and months with lower solar radiation levels. At the same time, system users must economize energy-use when it is cloudy. Annual and even monthly solar radiation is predictable.

Factors that affect the amount of solar radiation an area receives include the area's latitude, cloudy periods, humidity and atmospheric clarity. At high-intensity solar regions near the Equator, solar radiation is especially affected by cloudy periods. Long cloudy periods significantly reduce the amount of solar energy available. High humidity absorbs and hence reduces radiation.

Atmospheric clarity, reduced by smoke, smog and dust, also affects incoming solar radiation. The total amount of solar energy that a location receives may vary from season to season, but is quite constant from year to year.

1.2.2 Solar Irradiance

Solar irradiance refers to the solar radiation actually striking a surface, or the power received per unit area from the sun. This is measured in watts per square meter (W/m2) or kilowatts per square meter (kW/m2). If a solar module is facing the sun directly (i.e. if the module is perpendicular to the sun's rays) irradiance will be much higher than if the module is at a large angle to the sun. Figure 35 shows the changes in the amount of power received on a flat surface over the course of a clear day.

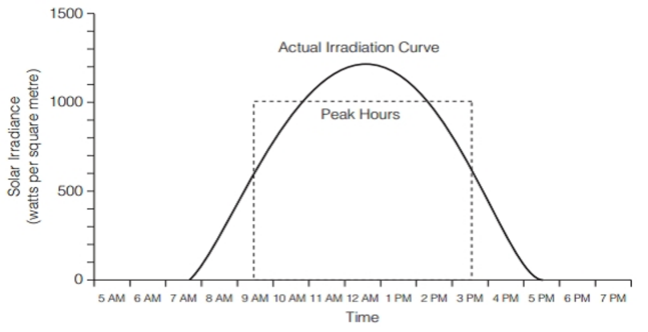


Figure 35 : Solar irradiance received over time

In the morning and late afternoon, less power is received because the flat surface is not at an optimum angle to the sun and because there is less energy in the solar beam. At noon, the amount of power received is highest. The actual amount of power received at a given time varies with passing clouds and the amount of dust in the atmosphere. The angle at which the solar beam strikes the surface is called the solar incident angle. The closer the solar incident angle is to 90°, the more energy is received on the surface (see Figure 36). If a solar module is turned to face the sun throughout the day, its energy output increases. This practice is called tracking

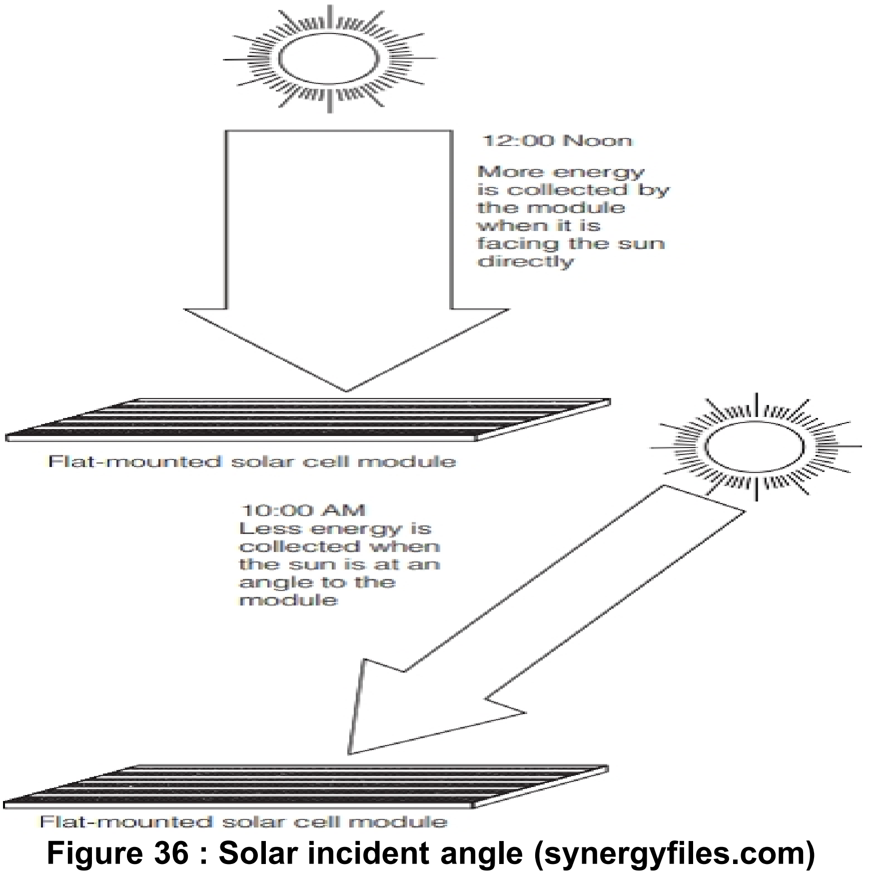


Figure 36 : Solar incident angle (synergyfiles.com)

1.2.3 Insulation

Insulation (a short way of saying incident solar radiation) is a measure of the solar energy received on a specified area over a specified period of time. Meteorological site that receives 6 peak sun hours a day receives the same amount of energy that would have been received if the sun had shone for 6 hours at 1000W/m2. In reality, irradiance changes throughout the day.

At a good solar energy site, irradiance is above 1000W/m2 for about 3 hours, between 800 and 1000W/m2 for 2 hours, between 600 and 800W/m2 for 2 hours and between 400 and 600W/m2 for 2 hours and between 200 and 400W/m2 for 2 hours. Still, the energy is equivalent to 6 hours of irradiance at 1000W/m2 (Figure 35). For example, during October a site in Arusha, Tanzania, would be expected to receive 6.3kWh/m2/day and 6.3 peak sun hours per day.

Method	Abbreviation	Definition
Kilowatt-hours per square metre per day	$kWh/m^2/day$	Quantity of solar energy, in kilowatt-hours, falling on a square metre in a day.
Daily peak sun hours	PSH	Number of hours per day during which solar irradiance averages $1000W/m^2$ at the site.

Figure 37 : Insolation Measurement

Peak sun hours are useful because they simplify calculations. Figure 38 shows the mean daily insolation in peak sun hours for each month at four sites around the world. Note that the total amount of energy available per day changes considerably from month to month, even in Equatorial countries. On a sunny October day, Arusha, Tanzania, receives more than 6 peak sun hours of insolation. However, on a cloudy day in July the same site might receive only 4.3 peak sun hours.

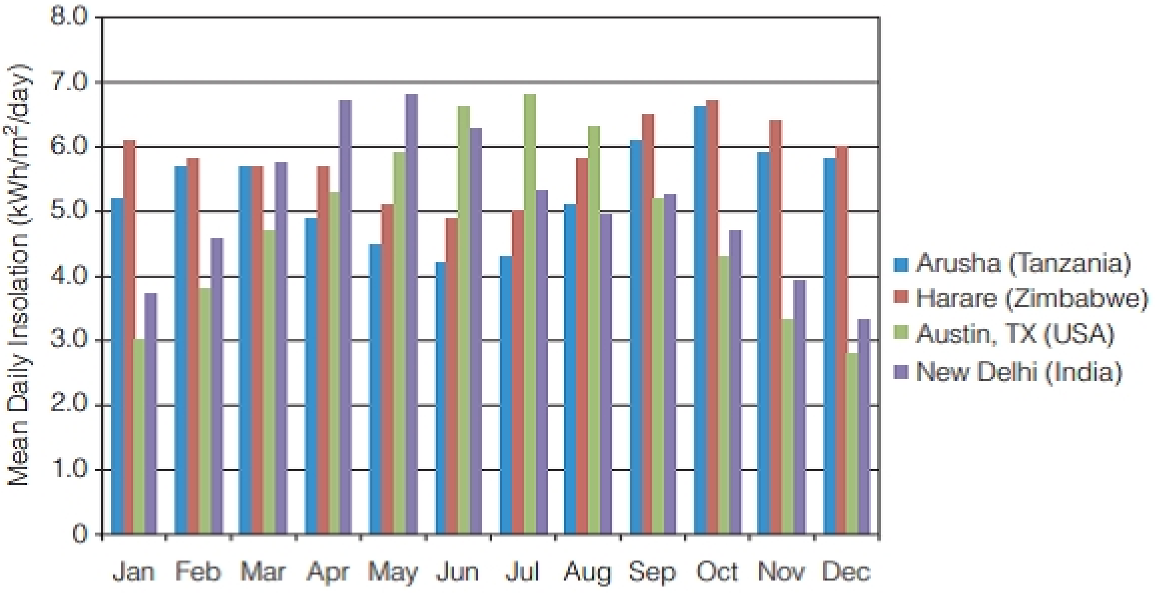


Figure 38: Mean daily insolation in four cities

1.3 Source of data

When planning a solar electric system, you will need to estimate your site's monthly mean daily insolation in kWh/m2 or peak sun hours. As a general rule, tropical locations receive between 3 and 8 peak sun hours per day. In the winter, northern climates receive less than 2 peak sun hours per day. The exact amount of insolation depends on the location and time of year.

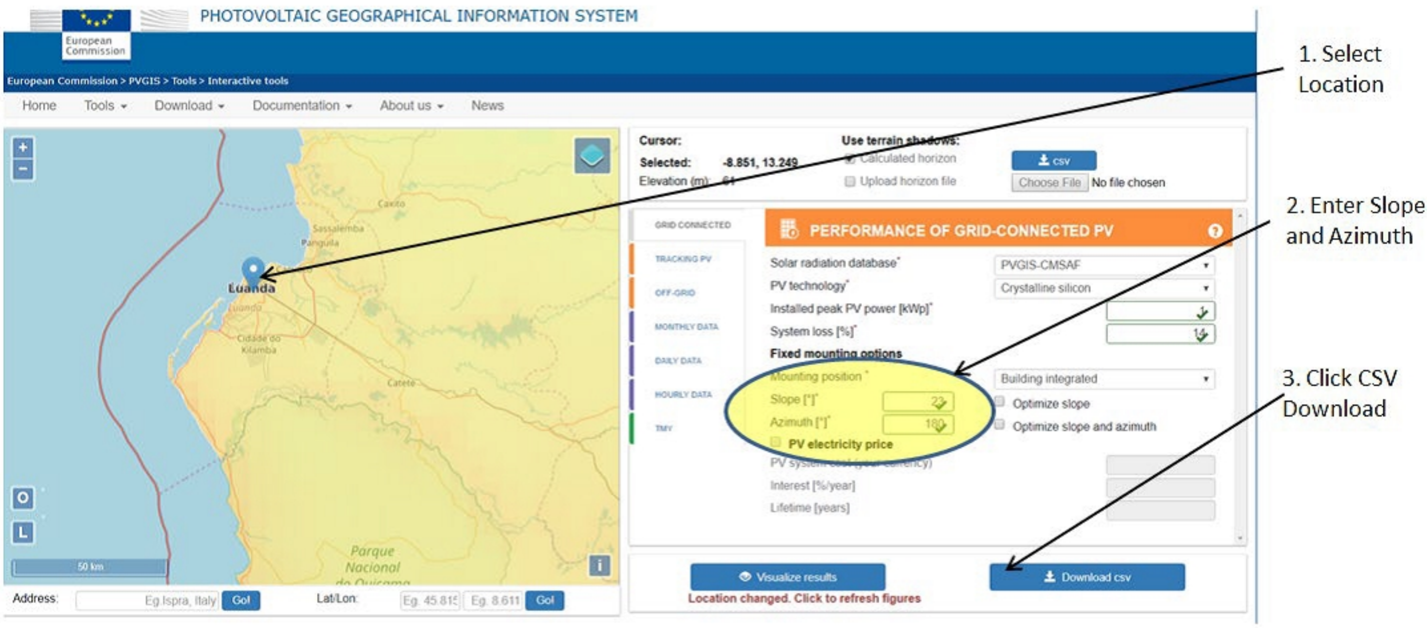
While it is difficult to accurately estimate how much solar energy a site will receive on any given day, it is possible to predict insolation fairly accurately on a monthly or annual basis. Solar insolation is measured using a device called a pyranometer. For small systems, however, it is not necessary to buy or install an expensive pyranometer. Monthly daily insolation information is collected and kept by national and international agencies around the world. Insolation data for your site may be kept at a nearby meteorological station or at a government meteorological district office. It is also be available online. Two online sources that can be used is: PVGIS and Power Data Access Viewer (previously RETSCREEN)

Table 5: Insolation Sources

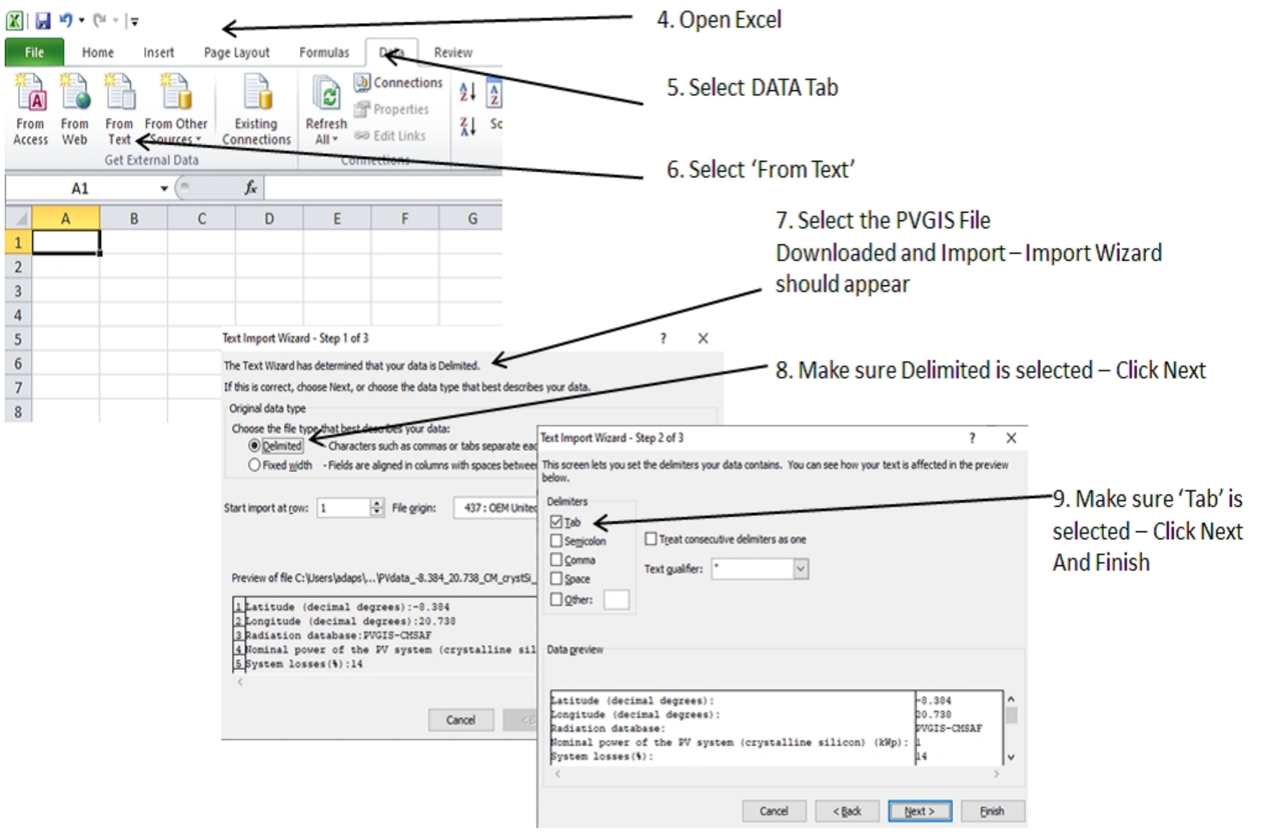
Source	Link	Notes
Power Data Access Viewer	https://power.larc.nasa.gov/data-access-viewer/	Maintained by NASA
PVGIS	https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html	Maintained by the European Commission

1.3.1 Getting Insolation data from PVGIS The following procedure can be followed to get the insolation data from PVGIS:

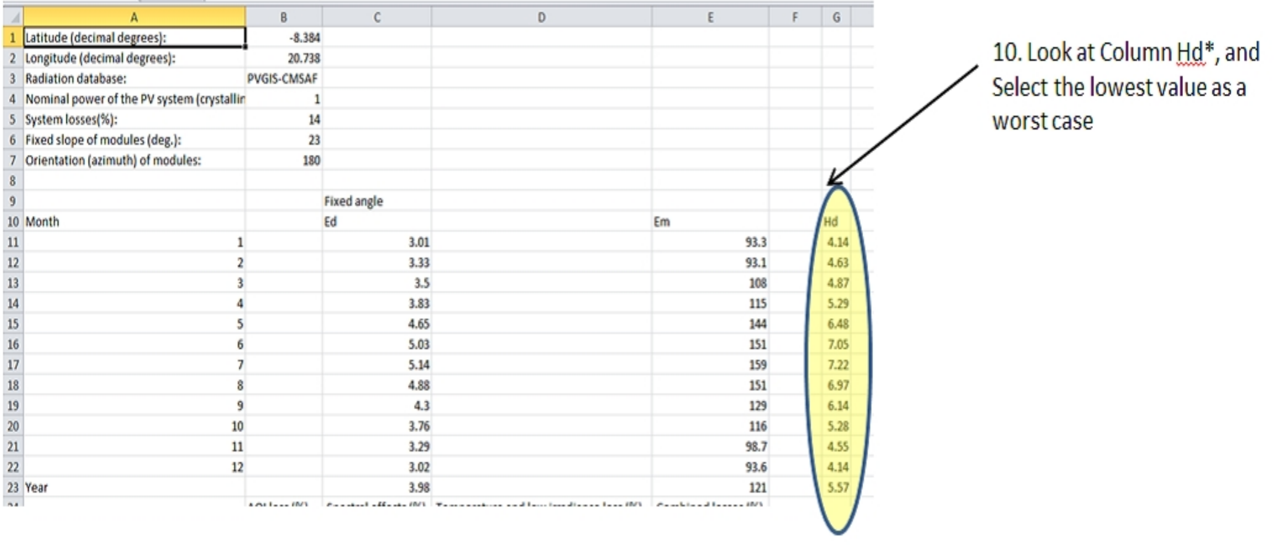
- Step 1 – Select location
- Step 2 – Select Slope and Azimuth
- Step 3 – Click Download data



- Step 4 – Open Excel
- Step 5 – Select DATA tab
- Step 6 – Select 'From Text'
- Step 7 – Select PVGIS file downloaded
- Step 8 – Make sure 'Delimited' is selected
- Step 9 – Make sure 'TAB' is selected



- Step 10 – Look at the Hd* column to get average daily insolation per month. Hd is the average daily sum of global irradiation per square meter received by the modules (kWh/m2) .

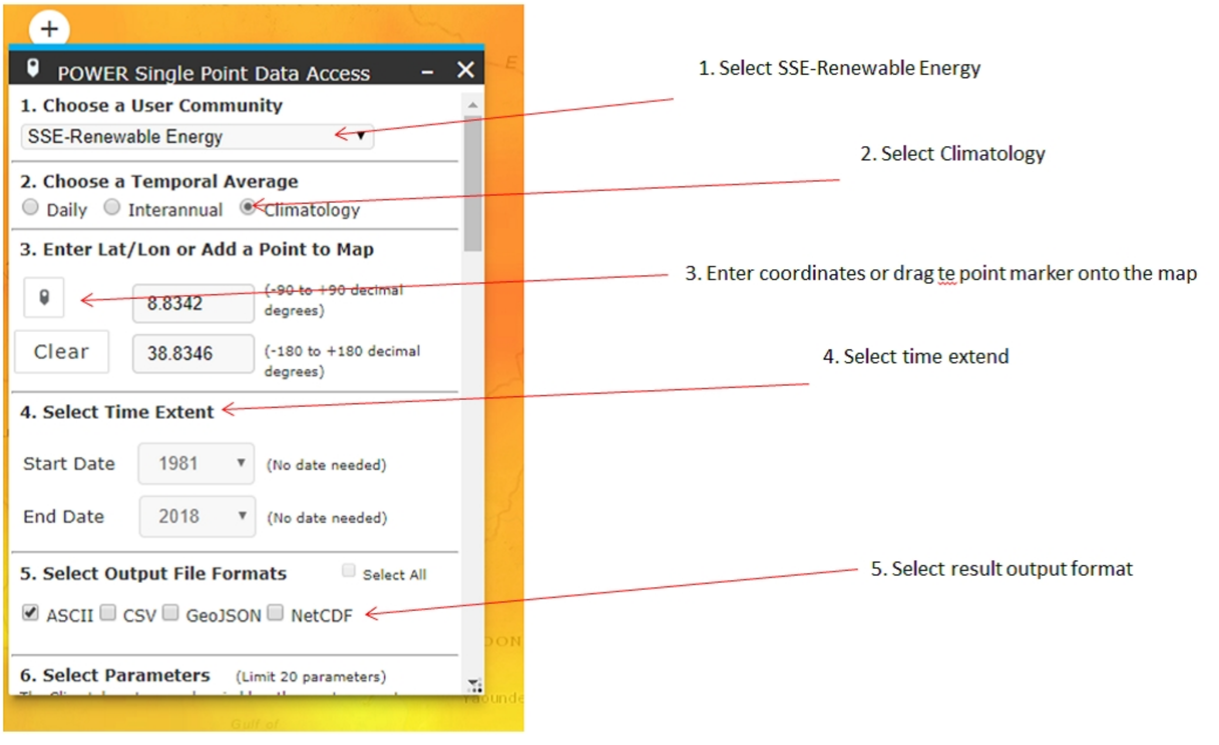


	A	B	C	D	E	F	G
1	Latitude (decimal degrees):	-8.384					
2	Longitude (decimal degrees):	20.738					
3	Radiation database:	PVGIS-CMSAF					
4	Nominal power of the PV system (crystallin	1					
5	System losses(%):	14					
6	Fixed slope of modules (deg.):	23					
7	Orientation (azimuth) of modules:	180					
8							
9			Fixed angle				
10	Month		Ed		Em		Hd
11	1		3.01		93.3		4.14
12	2		3.33		93.1		4.63
13	3		3.5		108		4.87
14	4		3.83		115		5.29
15	5		4.65		144		6.48
16	6		5.03		151		7.05
17	7		5.14		159		7.22
18	8		4.88		151		6.97
19	9		4.3		129		6.14
20	10		3.76		116		5.28
21	11		3.29		98.7		4.55
22	12		3.02		93.6		4.14
23	Year		3.98		121		5.57

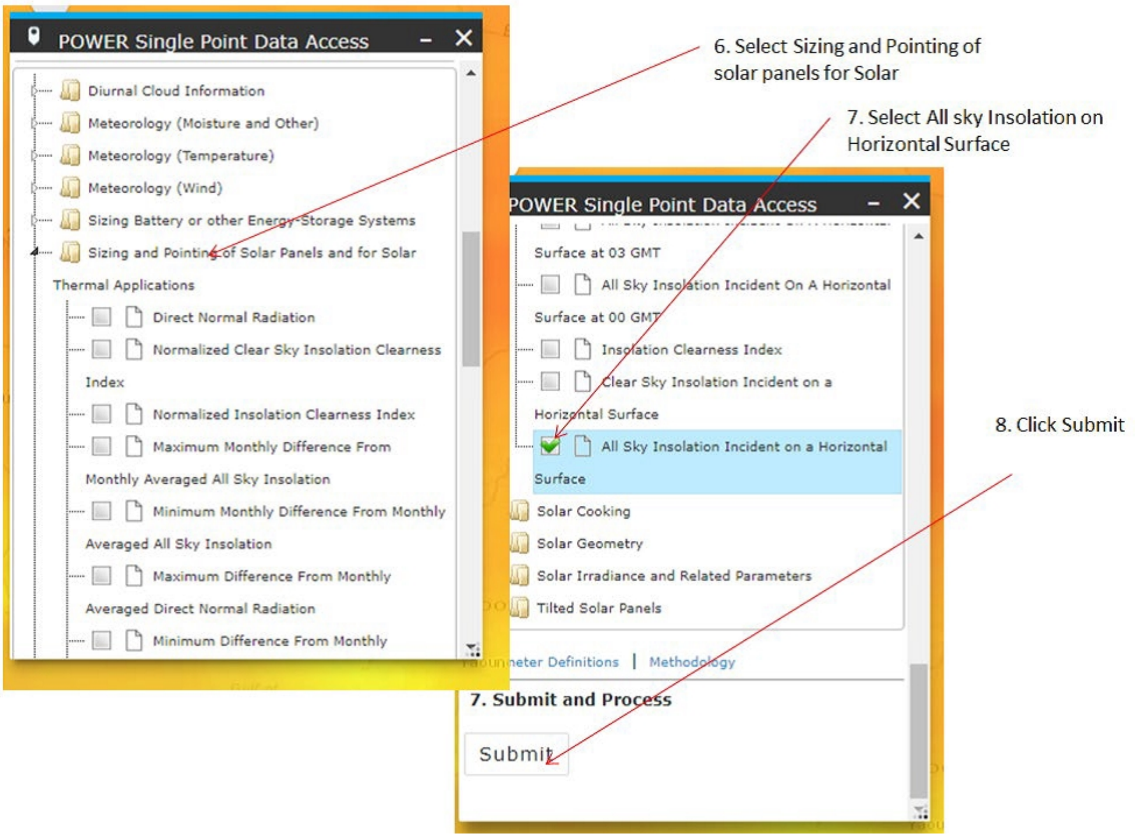
1.3.2 Getting Insolation Data from Power Data Access Viewer

The following procedure can be followed to get the insolation data from RETSCREEN:

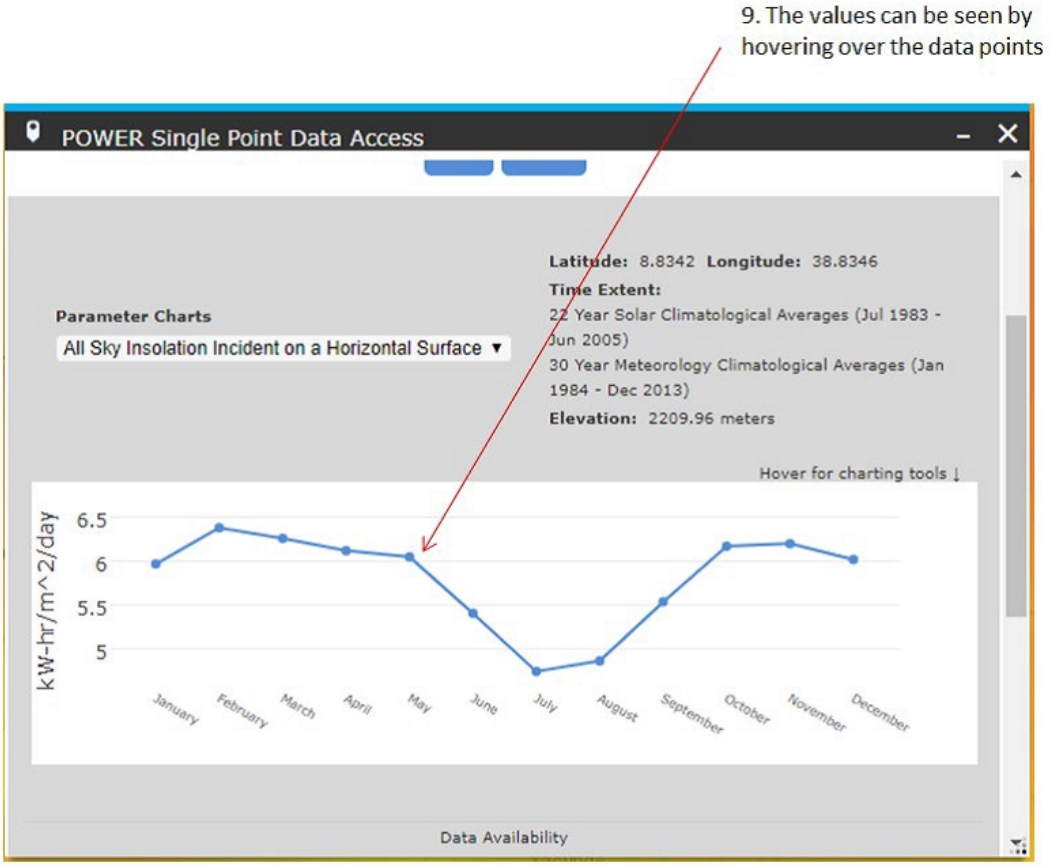
- Step 1 – Select SSE-Renewable Energy from Power single point Data Access Menu
- Select Climatology
- Enter coordinates or drag point marker onto the map
- Select time extend
- Select result format



- Select Sizing and Pointing of solar panels for solar
- Select All sky insolation on horizontal surface
- Click Submit



- The values can be seen by hovering with the mouse over the monthly data points



1.3.3 Interpreting Insolation Data

It is quite important to understand the insolation data received from the various sources. One important distinction between PVGIS and Power Data Access Viewer is that PVGIS calculate the insolation on the module plane (in other words, based on the slope and azimuth entered), while Power Data Access Viewer give insolation on a horizontal plane (in other words 0 degree slope). To explain the difference, Figure 39 shows a graph of PVGIS data for a specific point at North 30 degree angle, PVGIS data at 0 degree angle and Power Data Access Viewer data (no option to specify slope). As expected, there is a very good correlation between PVGIS at 0 degrees and Power Access Data Viewer as both are on the horizontal plane, but there is a significant difference for PVGIS at 30 degree angle.

This means that if any source that provide data that is not measured on the module slope and azimuth, needs to be compensated for when sizing the array.

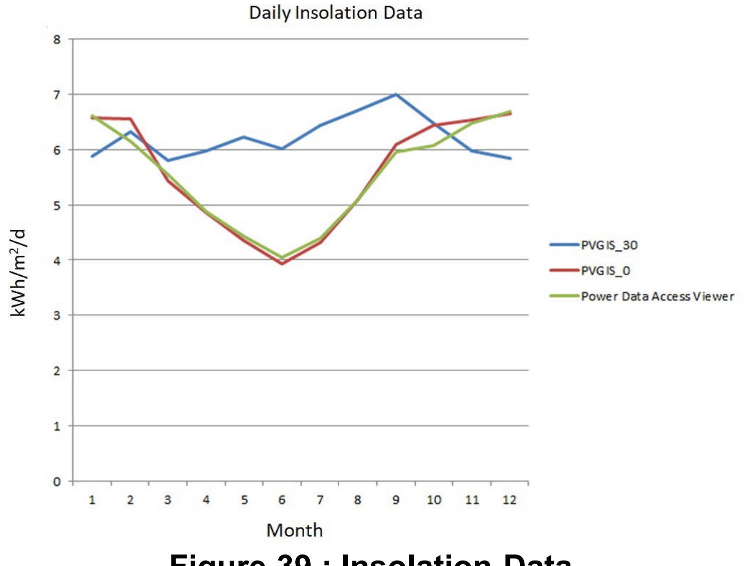


Figure 39 : Insolation Data

1.4 Calculating minimum solar insolation

For an off-grid PV system, one usually designs according to the worst case scenario, i.e. the month with the lowest insolation. If the system will work for the worst month, it will work for all the other months as well.

In rare cases where the system is used only for portions of the year (e.g. only summer months), then the insolation for that period can be used.

The insolation based on the Adama design can be tabled as shown in Table 6. The Adama design roof is sloped at 20 degrees East-South-East

Table 6: Average Daily Insolation data per month for Adama

J	F	M	A	M	J	J	A	S	O	N	D	ø
7.31 kW/ m^2*d	7.61 kWh/ m^2*d	7.3 kWh/ m^2*d	6.28 kWh/ m^2*d	5.83 kWh/ m^2*d	5.68 kWh/ m^2*d	5.35 kW/ m^2*d	5.57 kWh/ m^2*d	6.15 kWh/ m^2*d	7.14 kWh/ m^2*d	7.2 kWh/ m^2*d	7.3 kWh/ m^2*d	6.56 kWh/ m^2*d

As can be seen, in this case the worst month is June with an average daily insolation of 5.35kWh/m2/d or 5.35 peak sun hours per day.

Self-Check - 1	Written Test

Instruction: Follow the below selected instruction

The following are true or false items, write true if the statement is true and write false if the statement is false.

N°	**Questions and answers**
1	Solar energy arrives at the edge of the Earth's atmosphere at a constant rate of about 1350 watts per square metre (W/m2)
True or false:	
2	Insolation is measured in kWh/m2/day and is also referred to as 'sun hours'
True or false:	
3	We normally use the average insolation of the best month in the year to design the PV Array?
True or false:	

Note: the **Satisfactory** rating is as followed

Satisfactory	2 points
Not satisfactory	Below 2 points

Information Sheet 2	Calculating array size

2.1 Introduction

In order to calculate the size of the PV array required for a specific location, two pieces of information is required:

- Daily energy consumption, i.e. how much energy do we need to supply by the array; (Covered in LO1, Information Sheet 2)
- Insolation, in other words how much energy can we get from the sun. Covered in LO3, information sheet 1)

Once we get these two values, we can calculate the size of the array. It is also important to compensate for system losses.

2.2 System losses and efficiency

Energy is always lost due to inefficiencies in cables, modules, batteries, charge controllers and inverters. The extra amount of energy lost must be estimated and added to the daily energy demand. As a general rule, the loss for DC loads is about 20% and for AC loads about 35%.

One can attempt to calculate all losses as shown in Table 7.

Table 7: Table to calculate losses

Efficiencies [η]	Efficiency	Efficiency Range	Project Efficiency
Deviation MPP / Type of the CC	η_{cc}	0,9-0,95	0.95
Line Losses between Battery and Generator	$\eta_{cable-bat}$	0.97	0.95
Line Losses between Battery and Inverter	$\eta_{cable-inverter}$	0.97	0.95
Battery Charge and Discharge	η_{bat}	0.8-0.9	0.95
Efficiency of the Charge Controller	η_{cc}	0.9-0.98	0.95
Efficiency of the Inverter	η_{inv}	0.85-0.95	0.90
Influence of the Ambient Temperature	η_{Temp}	0.9-0.95	0.95
Insolation	η_{Insol}	0.9-1.1	1.00

The total efficiency will be the product of all individual efficiencies e.g.
$\eta Total = \eta 1 \times \eta 2 x \ldots \eta x$.
In practice though, an assumed efficiency of 65% (35% losses) is often used.

2.3 Calculating array size

To calculate the array size, the following formula can be used:

$$P_{PV} = \frac{E}{G \times \eta} = \frac{\text{Energy Consumption in } [\frac{Wh}{d}]}{\text{Peak Sun Hours in}[h] \times \text{System Efficieny}}$$

Where:
E = Energy consumption (Wh/d or kWh/d)
G = Insolation (kwh/m²/day), also peak sun hours
η = System efficiency

As an example, let's use the Adama design to calculate the PV array size with a daily energy consumption of 12964Wh (See Table 2), worst case peak sun hours of 5.35 (see Table 6) and 65% system efficiency:

$$P_{PV} = \frac{E}{G \times \eta} = \frac{12964 \, [\frac{Wh}{d}]}{5.35[h] \times 0.65} = 3728Wp$$

2.3.1 Determining number of Modules

Once the array size has been determined, the number of modules required can be calculated as follows:

$$n = \frac{P_{PV}}{P_{mod}}$$

Where:

n= the number of modules required
P_{PV} = the calculated PV array power
P_{mod} = the module power at STC

The number of modules (n) is usually rounded up.

For the Adama example, the calculated number of Phaesun PN6M72-350 E modules is:

$$n = \frac{P_{PV}}{P_{mod}} = \frac{3728\text{Wp}}{350\text{Wp}} = 10.65 \text{ modules} = 11 \text{ modules}$$

In practice, the number of modules is often increased to compensate for module degradation. Modules degrade in the region of 20% over 25 Years. For the Adama example, we selected 14 modules. Total PV Size = 14 modules a 350Wp = 4900Wp

Self-Check - 2	**Written Test**

Instruction: Follow the below selected instruction

The following are true or false items, write true if the statement is true and write false if the statement is false.

N°	**Questions and answers**
1	As a general rule, the loss for DC loads is about 20% and for AC loads about 35%
True or false:	
2	The number of modules required is calculated by dividing the Calculated PV array (kWp) size into the module size (Wp)
True or false:	

Answer all the questions listed below. Use the Answer sheet provided in the next page:

N°	**Questions and answers**
1	Calculate the PV array size with a daily energy consumption of 1750Wh, worst case peak sun hours of 5.25 and 65% system efficiency: 3points

Note: the **Satisfactory** rating is as followed

Satisfactory	3 points
Not satisfactory	Below 3 points

Information Sheet 3	Adjusting array size based on the environmental factors

3.1 Introduction

It is important to consider the local environmental conditions when designing a solar system as it can have a profound influence on the size of a system required.

3.2 Environmental factors

3.2.1 Insolation

Insolation (kwh/m2/day) values differ from place to place and also from month to month. It is therefore important to get the insolation values for the specific location. Information sheet 2 deals with getting insolation values.

Most of the environmental conditions like cloud cover, particles in the air, location etc. are already accommodated for in the insolation value for a site.

If the insolation data source provide insolation data for the horizontal plane and not the actual module plane (see Figure 40), it is important to compensate for the difference as it will affect the size of the PV Generator.

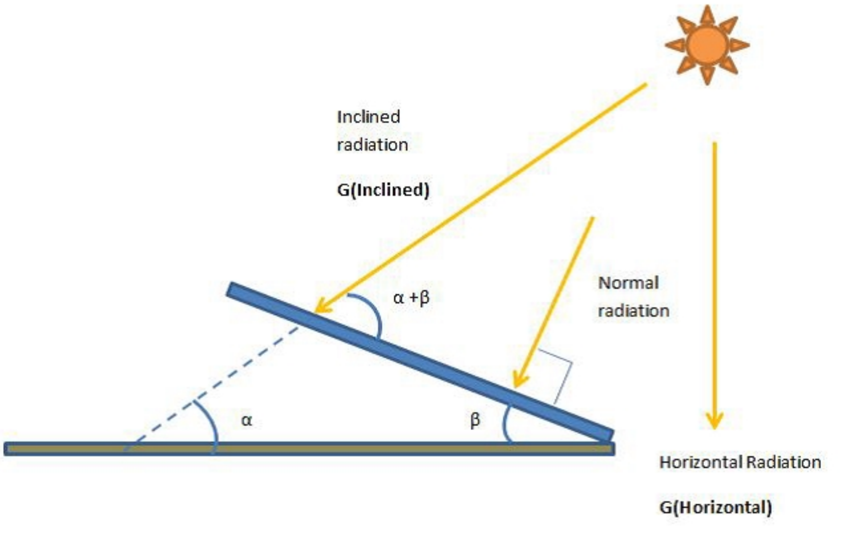


Figure 40 : Insolation planes

As we look at the average insolation for the 'worst' month (see 2.3 above) when we size the PV Generator, there can be a significant difference between worst month for the module plane and worst month for the horizontal plane as can be seen in Figure 41. If the horizontal plane insolation is used, the net effect will be a generator that is significantly oversized.

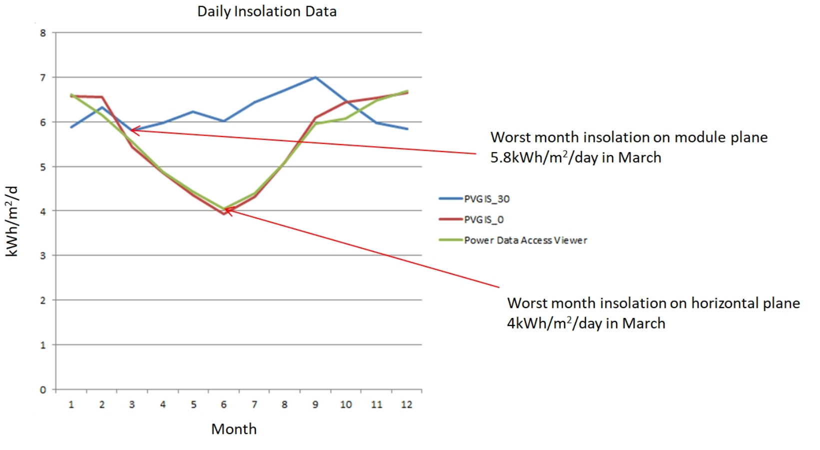


Figure 41 : Insolation difference between horizontal- and module planes

3.2.2 Temperature

Temperature does have an effect on the output of PV systems. Crystalline PV modules have a negative temperature coefficient for power which means that as the temperature rises, the power decreases. This is one of the parameters considered when calculating the PV array size and is encapsulated in the efficiency factor used in Table 7of information sheet 2.

3.2.3 Shading

Shading in PV systems should be avoided as far as possible. If it is unavoidable, the effects of shading should be considered when sizing a system. The effect of shading can also be reduced by planning strings to ensure that shaded strings are kept on separate charge controllers/MPPT trackers where possible.

3.2.4 Dust

In areas with a lot of dust, PV array sizes may needs to be increased to compensate for the loss of power due to dust. The effect of dust can also be mitigated by regular cleaning of the modules.

Self-Check - 3	Written Test

Instruction: Follow the below selected instruction

The following are true or false items, write true if the statement is true and write false if the statement is false.

N°	Questions and answers
1	Insolation (kwh/m2/day) values differ from place to place and also from month to month
True or false:	
2	Temperature has no effect on the output of a PV system
True or false:	

For each of the following question choose the best answer and circle the letter of your choice.

N°	Questions and answers
1	The best angle for a PV module is:
A –0 Degrees	B – 30 Degrees
C – 90 Degrees	D – It depends on location
2	PV Modules should preferably:
A – Only Face North	B – Face the equator
C – Only Face South	D – Always face East

Note: the Satisfactory rating is as followed

Satisfactory	3 points
Not satisfactory	Below 3 points

Solar PV System Installation and Maintenance

NTQF Level IV

Learning Guide -04

Unit of Competence	**Calculating System Components**
Module Title	**Calculating System Components**
LG Code	**EIS PIM4 M02 LO1-LG04**
TTLM Code	**EIS PIM4 TTLM 0920v1**

LO 4: Determine peak AC load and Inverter size

Instruction Sheet	Learning Guide:- 10

This learning guide is developed to provide you the necessary information, knowledge, skills and attitude regarding the following content coverage and topics:

- Determining peak ac load demand;
- Calculating inverter size.

This guide will also assist you to attain the learning outcome stated in the cover page. Specifically, upon completion of this Learning Guide, you will be able to:-

- Determine peak ac load demand;
- Calculate inverter size.

Learning Instructions:

1. Read the specific objectives of this Learning Guide.
2. Follow the instructions described below.
3. Read the information written in the information Sheets
4. Accomplish the Self-checks

Information Sheet 1	Determining peak ac load demand

1 Determining peak ac load demand

1.1 Introduction

Step 4 in the design process is to calculate the peak AC load in order to size the inverter:

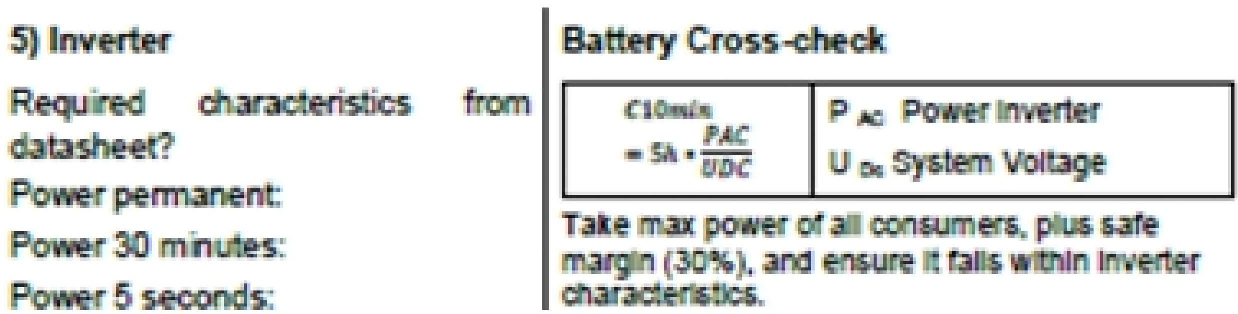


Figure 42: Design Step 4

The peak AC load is important to consider when selecting the Inverter in an off-grid PV system with AC loads. Inverters can normally supply a maximum load on a continuous basis and a higher load for short periods of time. This is to ensure that the inverter does not overload and trip when certain equipment (e.g. inductive motors) are switched on. When motors switch on, the peak current can be multiples of the normal operating current.

1.2 Ways of determining the peak load

1.2.1 Load Table

The peak load can be determined by setting up a load table as described in LO1, Information Sheet 1. This load table lists all the equipment and their power ratings. The table is separated between AC and DC loads, as only the AC loads are considered when selecting the inverter. Usually, the manufacturer indicates the power rating on the appliance itself. With better information about your appliance, you can accurately predict your demand.

1.2.2 Measurement

Sometimes it is difficult to get the correct power requirements of equipment. Another option is to measure individual equipment power consumption, or even to measure all the equipment simultaneously over a period of time with a data logger. Be careful with inductive loads that can have a very high start-up current. A peak-hold meter can be very handy to determine the peak currents drawn when switching on motors.

Load profile meters can connect in series for smaller loads, or with current transformers (CT's) for bigger loads. The CT clips over the live wire to the load(s). The CT is connected to a device that translates the current to a power value and possibly even transmits it wirelessly to a smart phone or computer. See Figure 43: CT Connection

Figure 43: CT Connection

Figure 44: Load profile meter

The load profile meter needs to be installed long enough to get a representative sample of the load. From the meter, the load profile can then be extracted (see Figure 45) and the peak load can be determined.

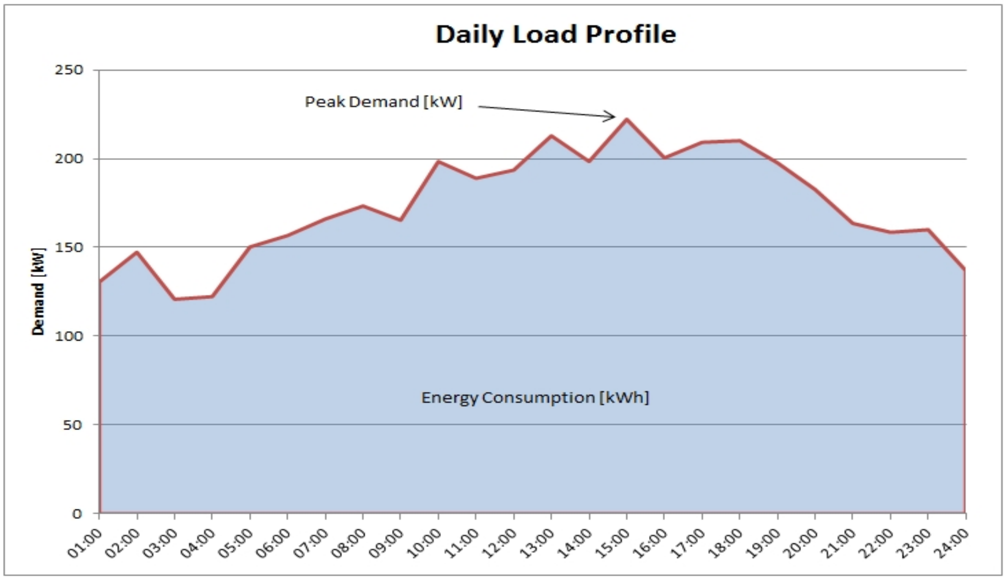


Figure 45: Load Profile Measured

Self-Check - 1	Written Test

Instruction: Follow the below selected instruction

The following are true or false items, write true if the statement is true and write false if the statement is false.

N°	**Questions and answers**
1	A load table list all the equipment and their power ratings
True or false:	
2	A distinction between DC loads and AC loads needs to be made as only AC loads are used to size the inverter?
True or false:	

Note: the **Satisfactory** rating is as followed

Satisfactory	1 points
Not satisfactory	Below 1 points

Information Sheet 2	Calculating inverter size

2.1 Introduction

The inverter is sized according to the peak load of all the AC consumers. The inverter DC input voltage must also match the battery voltage. Some inverters can work with different battery voltages.

2.2 Selecting inverter

Always select an inverter designed for solar systems. Many inverters are not designed for solar use and perform poorly in PV systems because of poor efficiency or wave shape. It is also important to consult the inverter datasheet. Depending on the size of the PV system a simpler or more complex inverter with more programming options can be used. Some inverters come with integrated charge controllers and some allow other sources of power to charge the battery as well e.g. a diesel generator. These are called hybrid inverters.

2.2.1 Matching the peak load

The first step in selecting the inverter is to match the peak load with the inverter continuous power rating. Most inverters will also have a peak power that is higher than the continuous power rating, but only available for a short period of time. This is to cater for higher start-up currents of some appliances. When selecting the inverter power rating, allow for a safety margin e.g. 30%. This will leave room for a bit of expansion in future.

SINE WAVE INVERTERS

Steca
A KATEK Brand

	500-12	550-24	1100-24	1500-48
Inverter type		PI 550-24	PI 1100-24	PI 1500-48
Number of inverters / Steca PA Link1		1 / 0	1 / 0	1 / 0
Characterisation of the operating performance				
System voltage	12 V	24 V	24 V	48 V
Continuous power	450 VA	450 VA	900 VA	900 VA
Power 30 min.	500 VA	550 VA	1100 VA	1500 VA
Power 5 sec.	500 VA	1000 VA	1400 VA	2800 VA
Max. efficiency	93 %	93 %	94 %	94 %
Own consumption standby	0.5 W	0.5 W	0.7 W	0.7 W
Own consumption ON	6.0 W	6.0 W	10.0 W	10.0 W
DC input side				
Battery voltage	10.5 V ... 16 V	21 V ... 32 V	21 V ... 32 V	42 V ... 64 V
Reconnection voltage (LVR)	12.5 V	25.0 V	25.0 V	50.0 V
Deep discharge protection (LVD)	10.5 V	21.0 V	21.0 V	42.0 V
AC output side				
Output voltage	230 V AC ± 10 %			
Output frequency	50 Hz			
Load detection (standby)	adjustable: 2 W ... 50 W			
Safety				
Protection class	II (double insulated)			
Electrical protection	reverse polarity battery, reverse polarity AC, over voltage, over current, over temperature			
Operating conditions				
Ambient temperature	-20 °C ... +50 °C			
Fitting and construction				
Cable length battery / AC	1.5 m / 1.5 m			
Cable cross-section battery / AC	16 mm² / 1.5 mm²			
Degree of protection	IP 20			
Dimensions (X x Y x Z)	212 x 395 x 130 mm			
Weight	6,6 kg	6,6 kg	9 kg	9 kg

- Deep discharge protection (LVD) adjustable via charge controller together with compatible parallel switch box
- Dimensions and weight per inverter

Figure 46: Inverter Datasheet (StecaSolarix)

Figure 47: Off-grid inverter Victron Phoenix

2.2.2 Matching the Battery Voltage

The inverter also needs to match the battery voltage. For instance the 500-12 model inverter on the datasheet in Figure 46 have a battery voltage of 10.5V-16V and will be suitable for a 12V battery while the 550-24 model have a battery voltage of 21V-32V and will be suitable for a 24V battery.

2.2.3 Surge Capabilities

Some equipment draws a large current for a short period when it turns on e.g. a pressure pump motor or a refrigerator compressor. The inverter must be able to handle these surges without tripping. The datasheet in Figure 46 shows the continuous power for the first inverter as 450VA while allowing 500VA for 30 minutes only. For the second inverter, the continuous power is also 450VA, but the 30min power is higher at 550VA and it allows 1000VA for 5 seconds. The second inverter will therefore be able to handle loads with higher surge currents better for a short period of time (5s).

2.2.4 Waveform

The waveform of an inverter refers to how pure the AC output waveform is. The ideal output waveform is a sinusoidal waveform but many cheaper inverters have a square waveform (worst case) or a modified sine wave (a bit better). These inverters are generally cheaper but may not work with some appliances.

Modified sine wave inverters are very affordable, all-purpose inverters. Using a more basic form of technology than pure sine wave inverters, they produce power which is perfectly adequate for powering simple electronics. Use modified sine wave inverters to provide power for your less sensitive appliances like phone chargers, heaters and air conditioners. Modified inverters are best suited for resistive loads which don't have a start-up surge.

Pure sine wave inverters use more sophisticated technology to protect even the most sensitive electronics. Pure sine wave inverters produce power which equals – or is better than – the power in your home. Appliances which may not function properly or which may be permanently damaged without pure, smooth power will be safe with pure sine inverters. Use these inverters for televisions, laptops, digital microwaves, fridges and other sensitive electronic equipment. Pure Sine inverters can power just about any AC appliance without risk of damage.

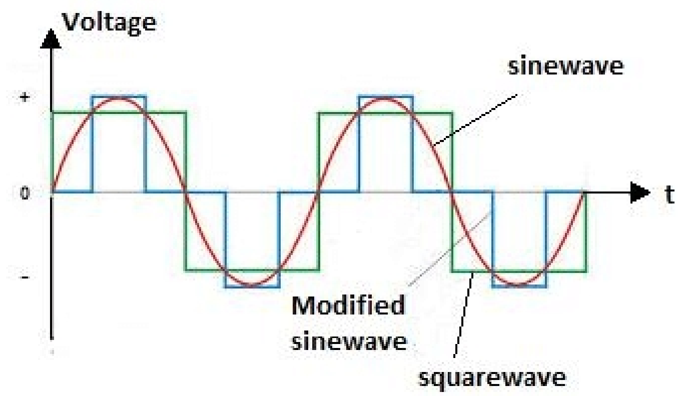


Figure 48: Inverter waveforms

2.2.5 Stand-by Mode

Many inverters still consume power from the battery when there are no appliances on. Some inverters automatically detect the load and will shut themselves down to prevent battery drain. The inverter in Figure 49 has automatic load detection and will switch on when a load is switched on.

Especially the cheaper and simpler inverters often don't have automatic load detection and continue to consume power. In small solar system, this self-consumption of the inverter can make quite a difference with regards to the amount of energy available, so system users should be advised to switch off the inverter at night or when not in use.

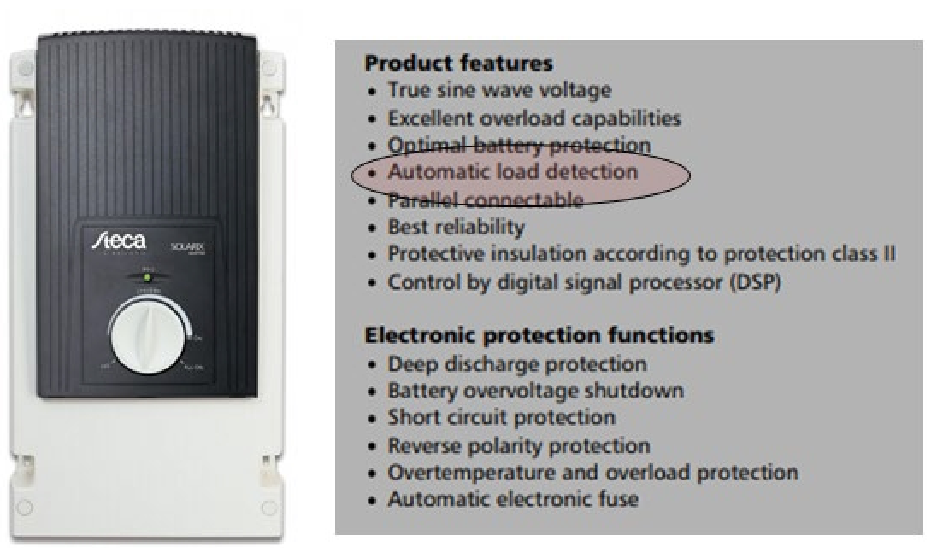


Figure 49: Automatic Load Detection

2.3 Adama Design

For the Adama Design, the peak load was calculated using a load table (see Table 1). The Calculated load was 2317W. If we apply a safety margin to it, the required peak load is:

Peak Load = 2317W x 1.3 = 3012W.

From Figure 50 we can see that the Phocos Any grid PSW K-5kW inverter's rated power is 5000W while it can handle surges of 2 x rated power (10000W) for 5 seconds.

There is normally a minimum size battery specified for an inverter:

$C10min = 5h \cdot \frac{PAC}{UDC}$	P_{AC} Power Inverter U_{DC} System Voltage

In the case of Adama, the minimum is:

$$C10min = 5h \cdot \frac{5000W}{48V} = 521Ah$$

The selected battery of 541Ah is larger than 521Ah therefore ok.

PSW-H (3 kW/5 kW)
Any-Grid™ Hybrid Inverter Charger
phocos

Technical Data

Type	PSW-H-3KW-120/24V	PSW-H-3KW-230/24V	PSW-H-5KW-230/48V
Output Waveform	Pure Sine Wave		
System Voltage	24 VDC		48 VDC
Rated Power	3000 VA / 3000 W		5000 VA / 5000 W
Max. Charge Current (PV)	80 A		
Max. Charge Current (AC)	80 A		
Max. Total Charge Current	80 A		
Max. AC Input Current	40 A	30 A	40 A
Float Charge	27.6 VDC (adjustable)		55.2 VDC (adjustable)
Boost Charge	28.8 VDC (adjustable)		57.6 VDC (adjustable)
Equalization Charge	29.6 VDC (adjustable)		59.2 VDC (adjustable)
Deep-Discharge Protection	22 VDC (adjustable)		44 VDC (adjustable)
Reconnect Level	25.6 VDC (adjustable)		51.2 VDC (adjustable)
Overvoltage Protection	33 VDC		66 VDC
Undervoltage Protection	18.8 VDC		37.5 VDC
Max. PV Panel Voltage	250 VDC	450 VDC	
PV Panel MPP Voltage	90 – 230 V	90 – 430 V	120 – 430 V
Max. Usable PV Power	2400 W	4000 W (2400 W for battery charging)	4800 W
Max. PV Array Power	3000 Wp	5000 Wp	6000 Wp
AC Frequency	50 / 60 Hz auto recognition		
AC Output Voltage	110 – 120 VAC ±5% (adjustable)	220 – 240 VAC ±5% (adjustable)	
Surge Power	2x rated power for 5 seconds		
Extensibility	Up to 9 units in parallel or 3-phase		
Inverter Efficiency (from Battery)	> 90 % peak	> 91 % peak	> 93 % peak
Inverter Efficiency (from PV)	> 96 % peak		

Figure 50: Phocos inverter datasheet

Self-Check - 2	**Written Test**

Instruction: Follow the below selected instruction

The following are true or false items, write true if the statement is true and write false if the statement is false.

N°	**Questions and answers**
1	Always allow for a safety margin when sizing the inverter.
True or false:	
2	A pure sine wave inverter is suitable for all loads
True or false:	

For each of the following question choose the best answer and circle the letter of your choice.

N°	An AC inverter is NOT selected according to the following criteria
1	Question
A – The Battery Voltage	B – The AC peak load
C – The PV Array Voltage	D – The inverter surge capability

Note: the Satisfactory rating is as followed

Satisfactory	2 points
Not satisfactory	Below 2 points

Solar PV System Installation and Maintenance

NTQF Level IV

Learning Guide -05

Unit of Competence	Calculating System Components
Module Title	Calculating System Components
LG Code	EIS PIM4 M02 LO1-LG05
TTLM Code	EIS PIM4 TTLM 0920v1

LO 5: Calculate the size of the

charge Controller/regulator

Instruction Sheet	Learning Guide:- 05

This learning guide is developed to provide you the necessary information, knowledge, skills and attitude regarding the following content coverage and topics:

- Determining size of the charge controller/regulator;
- Doing tasks and calculations on
  - ✓ System losses;
  - ✓ Wire voltage drop;
  - ✓ Site assessment data;
- Recording and documenting calculations in a standard way.

This guide will also assist you to attain the learning outcome stated in the cover page. Specifically, upon completion of this Learning Guide, you will be able to:-

- Determine size of the charge controller/regulator;
- Do tasks and calculations on o System losses;
  - ✓ Wire voltage drop;
  - ✓ Site assessment data;
- Record and documenting calculations in a standard way.

Learning Instructions:

1. Read the specific objectives of this Learning Guide.
2. Follow the instructions described below.
3. Read the information written in the information Sheets
4. Accomplish the Self-checks

Information Sheet 1	Determining size of the charge controller/regulator

1.1 Introduction

Step 5 in the design process is to calculate the charge controller size:

Charge Controller (CC)

From the Charge Controller datasheet, extract the following information::

Type:	....
System Voltage:	
Max. Module Voltage: $V_{max\,CC}$	
Min. Startup Voltage $V_{min\,CC}$	
Max. CC current (permanent):	
Max. CC current (peak load):	
P_{PV} max	

Does the controller fit the modules?

Determine temperature range:

Minimum module temperature Tmin:................................

Maximum module temperature Tmax:...............................

Max/Min Voltage @ Tmin/Tmax

Number of modules per string		Module	String
V_{OC} @ STC			
ΔV_{OC} @ T_{min} = α_{VOC}X(T_{min}-25°)			
V_{OC} @ T_{min} (V_{OC} @ STC+ΔV_{OC} @ T_{min})			
Is $V_{OC,\,Tmin}$<V_{maxCC}?			
V_{MPP}@ STC			
ΔV_{MPP} @ T_{max} = α_{VOC}X(T_{max}-25°)			
V_{MPP} @ T_{max} (V_{MPP} @ STC+ΔV_{MPP} @ T_{min})			
Is $V_{MPP,\,Tmax}$>V_{minCC}?			

Figure 51: Design Step 5

1.1.1 Types of Charge Controllers

The following was adapted from (Solar4RVs) .There are two main types of charge controllers; PWM and MPPT. PWM and MPPT charge controllers are both widely used to charge batteries with solar power. The PWM controller is in essence a switch that connects a solar array to the battery. The result is that the voltage of the array will be pulled down to near that of the battery.

The MPPT controller is more sophisticated (and more expensive): it will adjust its input voltage to harvest the maximum power from the solar array and then transform this power to supply the varying voltage requirement of the battery plus load. Thus, it essentially decouples the array and battery voltages so that there can be, for example, a 12V battery on one side of the MPPT charge controller and panels wired in series to produce 36V on the other. It is generally accepted that MPPT will outperform PWM in a cold to temperate climate, while both controllers will show approximately the same performance in a subtropical to tropical climate.

The best panel match for a PWM controller:

- A panel with a voltage that is just sufficiently above that required for charging the battery and taking temperature into account, typically, a panel with a Vmp (maximum power voltage) of around 18V to charge a 12V battery.
- These are frequently referred to as a 12V panel even though they have a Vmp of around 18V.

To match a panel to an MPPT controller it is advisable to check the following:

The best panel match for an MPPT controller:

- The panel open circuit voltage (Voc) must be under the permitted voltage.
- The Voc must be above the “start voltage” for the controller to “kick-in”
- The maximum panel short circuit current (Isc) must be within the range specified
- The maximum array wattage must match the MPPT controller.

A PWM is a good low-cost option:

- Suitable for smaller systems
- Where the efficiency of the system is not critical, e.g. trickle charging.
- For solar panels with a maximum power voltage (Vmp) of up to 18V for charging a

12V

- battery (36V for 24V battery, etc.)
- The MPPT controller is best:
- For larger systems where the additional 20%* or more energy harvesting is worthwhile
- When the solar array voltage is substantially higher than the battery voltage e.g. using house panels, for charging 12V batteries

1.1.2 Function of a Charge Controller

The following paragraph is adapted from (Hankins, 2010) chapter 5. The success of any off-grid PV system depends, to a large extent, on the long-term performance of the batteries. For a system to operate well and have a long lifetime, the batteries must be charged properly and kept in a high state of charge. Over several months, the energy entering the batteries during the day (i.e. the solar charge) must be roughly equivalent to the energy being discharged from the batteries at night by the load. Any off-grid PV system must be managed so that:

- Batteries are not damaged by deep discharges from over-use of the load;
- Batteries are not damaged through overcharging from the modules.

Solar electric systems use charge controllers (also called charge regulators) to manage the electrical power produced by the modules, to protect the batteries and to act as a connection point for all the system components (in systems without inverters). The charge controller has a number of primary functions.

- It provides a central point for connecting the load, the module and the battery.
- It manages the system so that the optimum charge is provided to the batteries.
- It ensures that components (especially batteries and lights) are protected from damage due to overcharge, deep discharge and changing voltage levels.
- It enables the end-user to monitor the system and identify potential system problems.

The main factors to consider when selecting the charge controller are the following:

- Charge controller PV input voltage range
- Charge controller PV input current range
- Charge controller output voltage
- Charge controller power rating
- Protective devices and other features

SmartSolar Charge Controller
MPPT 150/35

SmartSolar Charge Controller	MPPT 150/35
Battery voltage	12 / 24 / 48V Auto Select (software tool needed to select 36V)
Rated charge current	35A
Nominal PV power 1a, b)	12V: 500W / 24V: 1000W / 36V: 1500W / 48V: 2000W
Max. PV short circuit current 2)	40A
Maximum PV open circuit voltage	150V absolute maximum coldest conditions 145V start-up and operating maximum
Maximum efficiency	98%
Self-consumption	12V: 20mA 24V: 15mA 48V: 10mA
Charge voltage 'absorption'	Default setting: 14,4 / 28,8 / 43,2 / 57,6V (adjustable)
Charge voltage 'float'	Default setting: 13,8 / 27,6 / 41,4 / 55,2V (adjustable)
Charge algorithm	multi-stage adaptive (eight pre-programmed algorithms)
Temperature compensation	-16 mV / -32 mV / -64 mV / °C
Protection	Battery reverse polarity (fuse, not user accessible) PV reverse polarity Output short circuit Over-temperature
Operating temperature	-30 to +60°C (full rated output up to 40°C)
Humidity	95%, non-condensing
Data communication port	VE.Direct See the data communication white paper on our website
ENCLOSURE	
Colour	Blue (RAL 5012)
Power terminals	16 mm² / AWG6
Protection category	IP43 (electronic components), IP22 (connection area)
Weight	1,25 kg
Dimensions (h x w x d)	130 x 186 x 70 mm
STANDARDS	
Safety	EN/IEC 62109-1, UL 1741, CSA C22.2

1a) If more PV power is connected, the controller will limit input power.
1b) The PV voltage must exceed Vbat + 5V for the controller to start.
Thereafter the minimum PV voltage is Vbat + 1V.
2) A higher short circuit current may damage the controller in case of reverse polarity connection of the PV array.

Figure 52 : Typical Charge Controller datasheet

1.2 PV Input Voltage Range

The PV input voltage range is the maximum voltage that can be on the input of the inverter from the PV modules. Exceeding this voltage may damage the device or cause the device protection to switch off the device.

PV Module voltage is affected by temperature (see Figure 54). Module voltages (and other parameters) are specified at standard test conditions (STC). One of the STC conditions is a temperature of 25˚C. Any deviation from 25˚C will affect the module voltage. Colder temperatures will increase the voltage while warmer temperatures will decrease the voltage. In Figure 53, it can be seen how the voltage (and also the current and power) is affected by temperature on a Jinko 260Wp polycrystalline module.

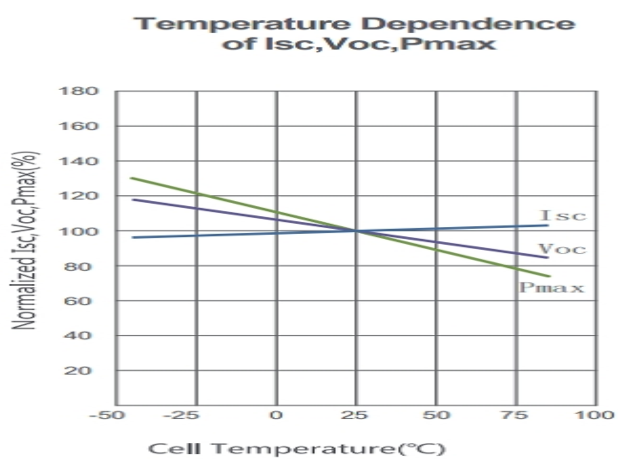


Figure 53: Temperature Dependence Jinko module

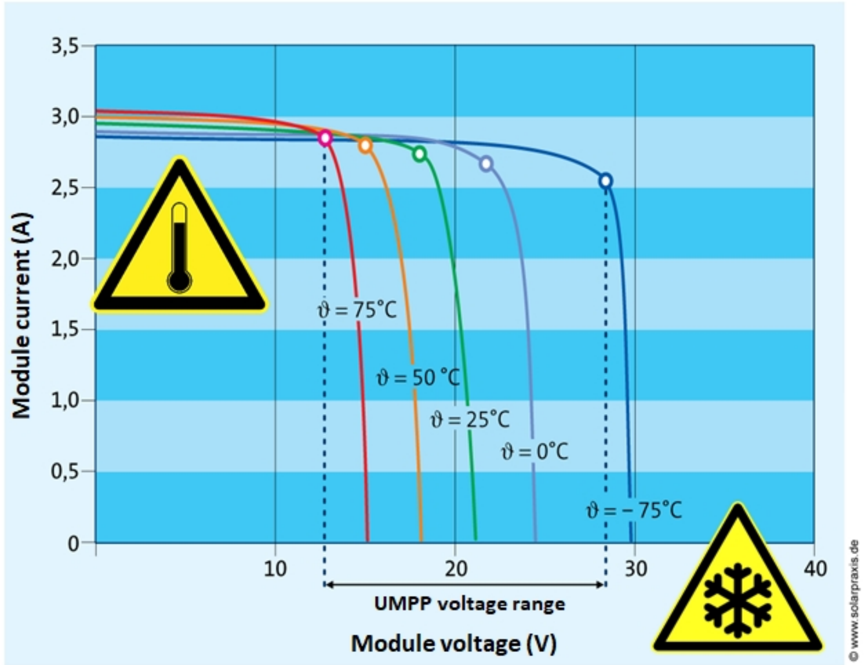


Figure 54: Temperature effect on PV Voltage

It is important to consider the input voltage at the site's coldest temperature as it will provide the highest voltage to the charge controller. We also consider the Open Circuit voltage as it is the highest voltage from a PV Module. The steps to determine the maximum input voltage is the following:

- Determine the minimum temperature for the area
- PV modules have a negative temperature coefficient, i.e. when the temperature drops, the module voltage rise. The coldest temperatures normally occur early morning when the sun just start to rise.
- Determine the Open Circuit Voltage of the string connected to the Charge Controller
- The Open Circuit voltage is the highest voltage obtainable from a module. Therefore to get the maximum input voltage, we consider open circuit voltage at the coldest temperatures.
- Get the module temperature coefficient
- The module temperature coefficient for voltage describes how much the module

voltage change per 1 degree change in temperature. This value can be found on the module datasheet and is specified either as a percentage or an absolute voltage e.g. -0.4%/˚C or 120mV/˚C. As can be seen in Figure 55, there are normally three temperature coefficients given i.e. coefficients for Power, Voltage and Current. The one of interest is the coefficient for voltage

TEMPERATURE CHARACTERISTICS

Specification	Data
Temperature Coefficient (Pmax)	-0.41 % / °C
Temperature Coefficient (Voc)	-0.31 % / °C
Temperature Coefficient (Isc)	0.05 % / °C

Figure 55 : Temperature coefficients

- Determine the maximum input voltage
- Here we determine maximum input voltage by calculating the change in voltage form the minimum temperature to STC temperature (25˚C), multiply the change in temperature with the temperature coefficient for voltage, and add it to the open circuit voltage e.g. If the open circuit voltage is 120V@STC, the temperature coefficient is -0.3%/˚C and the minimum temperature is -5˚C then

ΔT = -5˚C - 25˚C = -30˚C

Change in voltage = ΔT x αVocx Voc

= -30˚C x -0.3%/˚C x 120V

= 10.8V

Voc @ -5˚C = 120V + Change in voltage

= 120V + 10.8V

= 130.8V The maximum input voltage is therefore 130.8V.

- Select Charge Controller with an input voltage higher than the maximum calculated

1.3 Input Current Range

The input current range of the charge controller must be higher than the short circuit current of the PV string(s).

1.4 Charge Controller Output Voltage

The charge controller output voltage must match the battery voltage. Some charge controllers can work with multiple battery voltages. That means they are e.g. suitable for 24 V and 48 V systems. These voltages can be auto-detected or may need to be set-up by the installer.

1.5 Charge controller power rating

As a general rule, the Charge Controller Power must be 1.2 x the PV Power e.g. if the PV Power is 900Wp, then the Charge Controller power rating must be at least 900Wp x 1.2 = 1080W.

1.6 Protective Devices and other features

Charge Controllers may have some protective devices build-in e.g. reverse voltage protection, short-circuit protection etc. Important features to consider include: overcharge protection, low-voltage disconnect, solar charge and low-voltage warning lamps, voltage and current meters, and load timers.

- Features: low-voltage disconnect (LVD) and high-voltage disconnect (HVD) are important features of charge controllers. Make sure you know the rated values of the unit you want to purchase.
- Displays: simple charge controllers use one or more diodes to inform users about solar charge and state of charge. More elaborate charge controllers have liquid crystal displays of the amp-hour meter. Select the display appropriate to customer needs.
- Protective features: the better the controller, the more protective features it has.

Check which type of short-circuit and reverse polarity protection it has.

- Charging type: be sure that the charging method your controller uses matches the needs of your modules and batteries. This is even more important when using Lithium-ion batteries as the charge controller needs to communicate with the Battery Management System in Lithium-ion batteries.

1.7 Adama Design

For the Adama Design we used a DC Coupled hybrid inverter (PhocusAnygrid PSW-H-5KW-230/48V – see Figure 56); in other words, the charge controllers are built into the device. With this hybrid, we use 14 x Phaesun PN6M72-350 E modules (See Figure 57).From the module datasheet, we require the following information

Table 8: Module required information

Available Modules	Phaesun PN6M72-350 E
V_{OC}	47.2 V
V_{MPP}	38.6 V
I_{SC}	9.56 A
I_{MPP}	9.08 A
α_{VOC} and α_{VMPP}	-0.3 %/K
α_{ISC} and α_{IMPP}	0.04 %/K

From the hybrid inverter datasheet, we need the following information:

Table 9: Hybrid charge controller data

Charge Controller Type	Phocos Anygrid PSW-H-5KW-230/48V
Nominal Power Rating	5000 W
V System System Voltage	48 V
Voc max MAX Open-Circuit Voltage Modules (at minimum Temperature)	450 V
Voc min MAX Open-Circuit Voltage Modules (at minimum Temperature)	120 V
Vmpp min Input	120 V
Vmpp max Input	430 V
max. Current Modules	22.5 A
max. Current Charge Controller (permanent)	22.5 A
max. Current Charge Controller (peak load)	22.5 A

PSW-H (3 kW/5 kW)

Any-Grid™ Hybrid Inverter Charger

phocos

Technical Data

Type	PSW-H-3KW-120/24V	PSW-H-3KW-230/24V	PSW-H-5KW-230/48V
Output Waveform	Pure Sine Wave		
System Voltage	24 VDC		48 VDC
Rated Power	3000 VA / 3000 W		5000 VA / 5000 W
Max. Charge Current (PV)	80 A		
Max. Charge Current (AC)	80 A		
Max. Total Charge Current	80 A		
Max. AC Input Current	40 A	30 A	40 A
Float Charge	27.6 VDC (adjustable)		55.2 VDC (adjustable)
Boost Charge	28.8 VDC (adjustable)		57.6 VDC (adjustable)
Equalization Charge	29.6 VDC (adjustable)		59.2 VDC (adjustable)
Deep-Discharge Protection	22 VDC (adjustable)		44 VDC (adjustable)
Reconnect Level	25.6 VDC (adjustable)		51.2 VDC (adjustable)
Overvoltage Protection	33 VDC		66 VDC
Undervoltage Protection	18.8 VDC		37.5 VDC
Max. PV Panel Voltage	250 VDC	450 VDC	
PV Panel MPP Voltage	90 ~ 230 V	90 ~ 430 V	120 ~ 430 V
Max. Usable PV Power	2400 W	4000 W (2400 W for battery charging)	4800 W
Max. PV Array Power	3000 Wp	5000 Wp	6000 Wp
AC Frequency	50 / 60 Hz auto recognition		
AC Output Voltage	110 ~ 120 VAC ±5% (adjustable)	220 ~ 240 VAC ±5% (adjustable)	
Surge Power	2x rated power for 5 seconds		
Extensibility	Up to 9 units in parallel or 3-phase		
Inverter Efficiency (from Battery)	> 90 % peak	> 91 % peak	> 93 % peak
Inverter Efficiency (from PV)	> 96 % peak		
Idle Self-Consumption	< 40 W on, < 14 W Green Mode		
Grounding	Galvanically isolated battery allows positive or negative battery grounding		
Ambient Temperature	-10 to +50 °C		
Storage Temperature & Humidity	-15 to +60 °C, 5-95 % (non-condensing)		
Max. Altitude	4,000 m above sea level, 1 % power de-rating per 100m above 1,000 m above sea level		
Battery Type	Lead acid (gel, AGM, flooded), Lithium		
Datalogger	60 days		
Max. Wire Cross Section	Battery: 50 mm^2 (AWG 0), PV: 16 mm^2 (AWG 4), AC: 10 mm^2 (AWG 7)		
Dimensions (WxHxD)	478 x 295 x 143 mm / 18.8 x 11.6 x 5.6 in	478 x 309 x 143 mm / 18.8 x 12.2 x 5.6 in	
Weight	12 kg / 27 lbs	11 kg / 24 lbs	11.8 kg / 26 lbs
Ingress Protection	IP21		
Certificates	CE compliant, RoHS compliant, UL compliant	CE compliant, RoHS compliant	
Warranty	2 years		

Figure 56: Phocos Hybrid datasheet

Technical Data		Technische Daten				PN6M72-350 E	PN6M72-360 E
Nominal voltage		Systemspannung				24	
Power		Nennleistung		Pmp	W	350	360
Voltage at max. power		Spannung bei Max. Leistung		Vmp	V	38,6	38,4
Current at max. power		Strom bei Maximalleistung		Imp	A	9,08	9,37
Open circuit voltage		Leerlaufspannung		Voc	V	47,2	46,9
Short circuit current		Kurzschlußstrom		Isc	A	9,56	9,72
Cell		Zellen				72 mono	
Cell dimension		Zellabmessung			mm	156 x 156	
Cell efficiency		Zellen Wirkungsgrad			%	20,0	20,5
Module efficiency		Modul Wirkungsgrad			%	18,0	18,5
Max. tolerance		Max. Leistungstoleranz			%	-0/+5	
Max. system voltage		Max. Systemspannung			V	1000	
Operating module temp.		Min. Betriebstemperatur			°C	-40...+85	
Front		Vorderseite				tempered glass | gehärtetes Glas	
Glass thickness		Frontglas Dicke			mm	3,2	
Backside color		Rückseite Farbe				white | Weiß	
Frame		Rahmen				clear anodized aluminium | silber eloxiertes Aluminium	
Frame color		Rahmenfarbe				silver | Silber	
By-Pass Diodes		By-Pass Dioden				3	
Junction box protection		Anschlussdose Schutzklasse				IP67	
Module cable	cross section	Modulkabel	Querschnitt		mm²	4,0	
	length		Länge	l	mm	1000	
	connector		Stecker			Standard4	
Dimension		Abmessung		X x Y x Z	mm	1956 x 992 x 40	
Mounting holes pitch		Befestigungslöcher		x1 / y / x2	mm	1176 / 942 / 1676	
Weight		Gewicht			kg	24,0	
Temperature coefficient	Power	Temperaturkoeffizient	Leistung		%/K	-0,410	
	Voc		Voc		%/K	-0,300	
	Isc		Isc		%/K	0,040	
Pallet	dimension	Paletten	Abmessung	L x W x H	mm	2025 x 1110 x 1200	
	weight		Gewicht		kg	687	
	module quantity		Anzahl Module		pcs. /Stk.	27	
Container	quantity paletts/ modules	Container	Anzahl Paletten/ Module	20 ft	pcs. / Stk.	10 / 270	
				40 ft		22 / 594	
NOCT		NOCT			°C	45	
Static / dynamic load		Statische / dynamische Last			kN/m²	5,4 / 2,4	
Hail impact		Hagelschlag				Ø 25 mm, 23 m/s	
Certificates		Zertifikate				IEC61215 (design qualification) | IEC61730 (safety)	
Article Number		Artikelnummer				310363	310364

Figure 57: Phaesun module datasheet

1.7.1 String design

To calculate a preliminary maximum and minimum number of modules:

$$\text{Number of maximum modules in a string } n\ max = \frac{\text{Charge Controller Voc}}{\text{Module VOC}}$$

$$n\ max(\text{Phocos Anygrid}) = \frac{450\ V}{47.2\ V} = 9.5$$

$$\text{Number of minimum modules in a string } n\ min = \frac{\text{Charge Controller min Vmp}}{\text{Module Vmp}}$$

$$n\ min(\text{Phocos Anygrid}) = \frac{120\ V}{38.6\ V} = 3.1$$

Since we need 14 modules, we cannot have one string as it is over the maximum number allowed. We therefore can use two strings of 7 modules each in parallel as 7 is higher than the minimum and lower than the maximum allowed. We should however still check the current: Current for 2 modules = 2 x Impp = 2 x 9.08A = 18.16A The Phocos hybrid can handle 22.5A (see Table 9), therefore we can use 2 strings of 7.

1.7.2 Charge Controller Dimensioning

Power of the PV-Generators	4900 Wp
Nominal Power Rating CC	6000 W

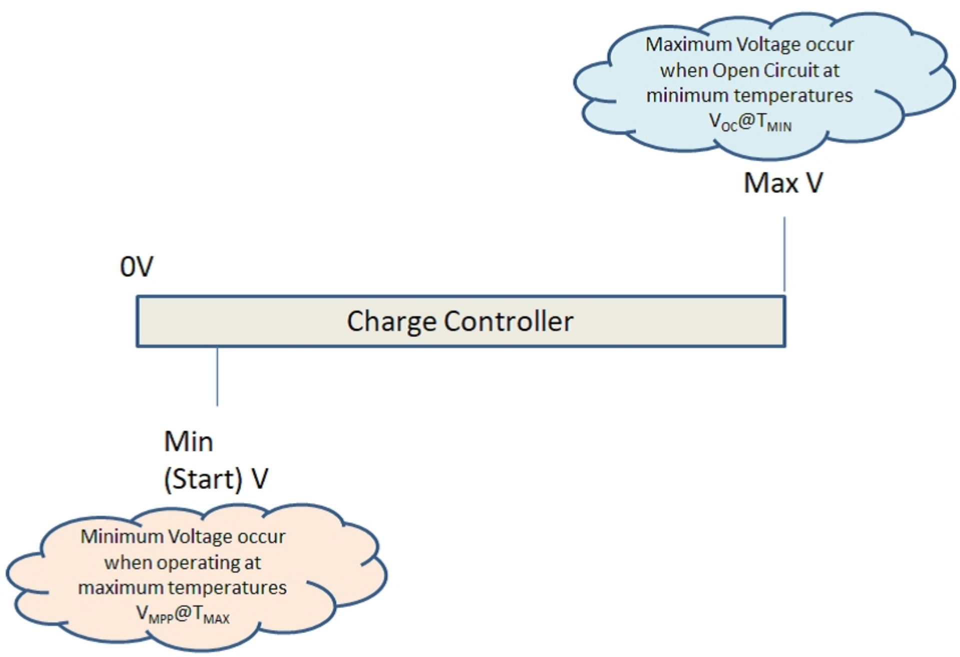
$$\text{Power Ratio} = \frac{4900W}{6000W} = 0.82$$

The power ratio of the PV generator peak power and the charge controller nominal powe to 1.2. In other words, the PV generator power can be up to 20% bigger than the nominal the CC.

1.7.3 Ambient Temperature

Minimum Temperature Modules T_{min}	5 °C
Maximum Temperature Modules T_{max} (50 degrees > ambient)	85 °C
Insolation, if it's sharply higher as according to STC G	1,000 W/m²*d

Comment: In case G_{max}>1000 W/m², the calculated I_{MPP}, T_{max} of the System (T_{max}) has to be by the percentage of the increase of the Radiation G, if G_{max} is 1200 W/m² IMPP has to be by 20%.

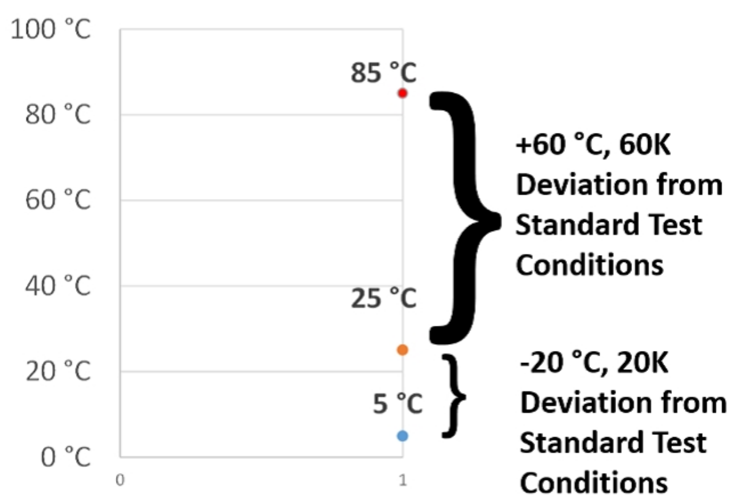


1.7.4 Maximum Voltage

We need to determine if the maximum voltage (i.e. the voltage when it is cold and the system is open circuit) is below the charge controller maximum voltage:

Is $V_{OC, Tmin} < V_{maxCC}$? Tmin= 5 °C, αVOC = - 0.3 %/K, VOC = 47.2 V

- The highest voltage is created with the open circuit voltage VOC at the lowest temperatures (winter)!
- With every °C difference to the Standard Test Condition (STC) 25°C the voltage increases. The temperature co-efficient tells you how much it increases. Now you only have to calculate how many °C you have less than STC at your location and what is the voltage increase per °C. Below you see one calculation path but you can use your own one. Actually, all can be calculated with the "rule of proportion".
- Why check this? To avoid overvoltage on the CC



Number of Modules per String	7	
V_{OC} at STC (25°)	47.2 V	
Δ $V_{OC, module}$ per 1 K (V_{OC}· $α_{VOC}$)	47.2V x -0.3 %/K = -0.142V/K	
Δ T_{min}=T_{min}-T_{STC}	16°-25° = -9°C	
	Module	String
Δ V_{OC} at T_{min} (Δ V_{OC}·Δ T_{min})	-0.142V/K x -9°C = 1.27 V	1.27 V x 7 modules = 8.89V
V_{OC} at T_{min} (Δ V_{OC}+$V_{OC, STC}$)	1.27V + 47.2V = 48.47V	48.47V x 7 = 339.29V

We can see that the maximum system voltage (per string) is 339.29V. This is less than the charge controller maximum input voltage of 450V.

1.7.5 Minimum Voltage

We need to determine if the minimum voltage (i.e. the voltage when it is hot and the system is in operation) is above the charge controller minimum voltage:

Is VMPP, Tmax>VminCC?

- The lowest voltage is created with the operational voltage VMPP at the highest temperatures (summer).
- With every °C difference to the Standard Test Condition 25°C the Voltage decreases. The temperature co-efficient tells you how much. Now you only have to calculate how many °C you have more and what the Voltage increase per °C is. Below you see one calculation path but you can use your own one. Actually all can be calculated with the "rule of proportion"
- Why check this? To avoid CC not starting up

Number of Modules per String	7	
V_{MPP} at STC (25°)	38.6V	
D $V_{MPP, module}$ per 1 K (V_{MPP}· $α_{MPP}$)	38.6V x -0.3%/K = -0.1158V/K	
Δ T_{max}=T_{max}-T_{STC}	85°-25° = 60°	
	Module	String
Δ V_{MPP} at T_{max} (Δ V_{MPP}·Δ T_{max})	60° x -0.1158V/K = -6.948V	7 x -6.948V = 48.64V
V_{MPP} at T_{max} (Δ V_{MPP}+$V_{MPP, STC}$)	38.6V-6.948V = 31.65V	7 x 31.65V = 221.56V

The minimum voltage per string is 221.56V which is higher than the charge controller minimum voltage of 120V.

1.7.6 Maximum Current

We need to ensure that we do not exceed the charge controller maximum current i.e:

Is IMPP, Tmax<ImaxCC?

- The highest current is created with the operating current IMPP at the highest temperatures (summer)

Number of Modules per String	2 strings of 7 modules each	
IMPP at STC (25°)	9.08A	
$\Delta I_{MPP, module}$ per 1 K ($I_{MPP} \cdot \alpha I_{MPP}$)	9.08A x 0.04%/K = 3.632mA/K	
$\Delta T_{max} = T_{max} - T_{SCT}$	85°-25° = 60°	
	Module/String	Array
ΔI_{MPP} at T_{max} ($\Delta I_{MPP} \cdot \Delta T_{max}$)	3.632mA/K x 60° = 0.218A	2 x 0.218A = 0.439A
I_{MPP} at T_{max} ($\Delta I_{MPP} + I_{MPP, STC}$)	0.218A + 9.08A = 9.3A	2 x 9.3A = 18.6A

We see that the actual maximum current of 18.6A is lower than the charge controller maximum input current.

Self-Check - 1	Written Test

Instruction: Follow the below selected instruction

The following are true or false items, write true if the statement is true and write false if the statement is false.

N°	**Questions and answers**
1	The Charge Controller input voltage should not be exceeded
True or false:	
2	The input current range of the charge controller must be higher than the short circuit current of the PV string(s) connected to it
True or false:	
3	The Charge Controller output voltage does not need to match the battery voltage
True or false:	
4	The Charge Controller charging type should match the battery type
True or false:	

Note: the **Satisfactory** rating is as followed

Satisfactory	2 points
Not satisfactory	Below 2points

Information Sheet 2	Doing tasks and calculations

2.1 Introduction

When designing an off-grid PV system, it is important to perform a number of steps to ensure that the system performs optimally and according to the client's requirements. There are many factors that cause losses in a PV system that needs to be considered.

2.2 Doing tasks according to standard calculations for:

2.2.1 System losses

Not all energy produced by the modules is available for use in the system, as some is lost in the cables, batteries, charge regulators and inverter. There are concerns about mainly two types of efficiency:

- General System Efficiency: the efficiency of cables, the battery and the charge controller. This can be taken to be 80 per cent (meaning 20 per cent of the energy is lost).
- Inverter Efficiency: a good inverter, one designed for use in off-grid PV systems for example, will be about 85 per cent efficient under average loads. Because of the extra losses in the inverter, AC energy in a system will suffer higher losses than DC energy, e.g. 80 per cent general efficiency multiplied by 85 per cent inverter efficiency equals about 65 per cent overall efficiency. This means that about 35 per cent of the electricity fed by the PV array into the battery that is converted into AC electricity by the inverter will be lost (the sum of battery and inverter efficiency).

System losses are considered when sizing the PV System. In Learning Outcome 3 we used the following formula to calculate the size of the PV Array:

$$P_{PV} = \frac{E}{G \times \eta} = \frac{\text{Energy Consumption in } [\frac{Wh}{d}]}{\text{Peak Sun Hours in}[h] \times \text{System Efficieny}}$$

Note that 'System Efficiency' is below the line in calculating the array size. This means that the array size is increased to compensate for the losses in the system.

In practice, efficiency figures of 80% for DC load systems and 65% for AC load systems can be assumed. One can however attempt to calculate the efficiency for each system by obtaining the efficiencies in all the sub-sections. A table like Table 10 below for an AC load system can be created:

Table 10: Efficiency Table

Efficiencies [η]	Efficiency	Efficiency Range	Project Efficiency
Deviation MPP / Type of the CC	η_{cc}	0,9-0,95	0.95
Line Losses between Battery and Generator	$\eta_{cable\text{-}bat}$	0.97	0.95
Line Losses between Battery and Inverter	$\eta_{cable\text{-}inverter}$	0.97	0.95
Battery Charge and Discharge	η_{bat}	0.8-0.9	0.95
Efficiceny of the Charge Controller	η_{cc}	0.9-0.98	0.95
Efficiceny of the Inverter	η_{inv}	0.85-0.95	0.90
Influence of the Ambient Temperature	η_{Temp}	0.9-0.95	0.95
Insolation	η_{Ind}	0.9-1.1	1.00

In this case, the total efficiency will be:

$$\eta_{system} = \eta_{CC} \times \eta_{cable\text{-}bat} \times \eta_{cable\text{-}inverter} \times \eta_{bat} \times \eta_{CC} \times \eta_{inv} \times \eta_{Temp} \times \eta_{Ind}$$

$$= 0.95 \times 0.95 \times 0.95 \times 0.95 \times 0.95 \times 0.9 \times 0.95 \times 1$$

$$= 0.66 \text{ or } 66\%$$

2.2.2 Wire voltage drop

Voltage drop is the loss of voltage (and hence power) due to resistance in long cable runs. If the wire's cross-section area is too small for a given current, an unacceptable voltage drop will occur over its length. Resistance in the cable converts electrical energy to heat and causes a consequent voltage drop. When the voltage drop is too large in, for example, the cables from the PV module or array, the battery or battery bank will not be charged properly; in distribution circuits it will affect performance of lamps and appliances, and may damage them. The voltage drop also wastes expensive energy from the PV array and battery.

Voltage drop occurs in all wire runs. However, voltage drops of more than 5 per cent are always unacceptable. Correctly selected cable sizes will avoid unacceptable voltage drops. Review every circuit in an extra-low-voltage system for voltage drop.

To calculate the voltage drop in the wire, the resistance of the wire and the current through the wire is required:

Vdrop= I x Rwire

Cable Size	Resistance in ohms per metre (Ω/m)
2.5mm^2	0.0074
4.0mm^2	0.0046
6.0mm^2	0.0031
10.0mm^2	0.0018
16.0mm^2	0.0012
25.0mm^2	0.00073
35.0mm^2	0.00049

Figure 58: Cable Resistance

The resistance of the wire depends on the length of the wire and the type of wire material (e.g. copper or aluminum). Each type of wire has a wire resistance factor (K) in ohms per meter e.g. a 2.5mm2 copper cable in Figure 58 has a K value of 0.0074 ohms per meter. Always consult the wire specification sheet.

Therefore, the voltage drop can be calculated by:

Vdrop = I(A) x length of wire(m) x K(Ω/m)

The length of the wire is the length to the load and back (i.e. 2 x the distance).

The different voltage drops can be calculated using a table as shown in Figure 59:

Voltage Drop Calculation

Column A	Column B	Column C	Column D	Column E	Column F	Column G
Cable run (list circuits)	Distance of cable (m)	Maximum current (A)	K Value of wire (ohms/m)	Total resist-ance (ohms)	Voltage drop (V)	Voltage drop (%)

Figure 59: Voltage Drop Calculation

- List each wire run together with its one way distance. 1 Measure the actual length of required wire run (i.e. bends, extra distance around objects, not just the straight line distance). Write these in Columns A and B
- Find the maximum current passing through each wire. To do this, add the power in watts of all the lamps and appliances on each wire run, and divide by the voltage. Write this on the worksheet in Column C.
- Find the K value of the intended cable from the cable datasheet. Write it in column D.
- Calculate the resistance in Column E by multiplying the K value x the total cable length.
- Calculate the voltage drop by multiplying the resistance (column E) with the current (Column C).
- Calculate the percentage voltage drop (Column G).

  The suggested maximum voltage drops are shown in Figure 60: Suggested maximum voltage drops

Battery to charge controller	<1%
Battery to inverter	<1%
Solar module to charge controller	<3%
Charge controller to loads	<5%
Inverter to loads	<5%

Figure 60: Suggested maximum voltage drops

2.2.3 Site assessment data

When designing an off- grid PV system, the specific site conditions are important to correctly size the system. The site factors to consider are the following:

- Task 1 – Obtain Site Insolation;
- Insolation data encapsulates most environmental weather conditions e.g. cloud cover, rainfall, temperature, moisture and dust particles etc.;
- Normally the insolation for the worst month of the year will be used;
- If insolation data on the module plane is used, the tilt and orientation of the modules will be accounted for already.
- This insolation value will determine the size of the PV Array – see Learning Outcome 3
- Task 2 - Mounting location and surface;
- Determine where the PV module(s) will be mounted;
- If on an existing roof, look at the roof structure to determine if it is strong enough;
- Is the orientation and angle good enough for solar?
- If no suitable roof space are available, look at other mounting possibilities e.g. free-standing structures or pole mounted;
- Will the modules be protected from animals, theft and not accessible to small children?
- Shading objects;
- Are there any objects that can shade the PV modules?

- Small trees can grow quickly and be problematic in the future;
- Arrange string layouts to minimize the effect of shading.
- Task 3 - Site layout
- Look at where batteries can be safely stored. Specifically make sure that there is enough ventilation, that it is not too hot or cold and that it is out of the way of small children and pets;
- Where will the Charge controller(s) and inverter be located?
- What is the distance between the modules and the charge controller?
- Size the cabling according to the distances and loads to prevent excessive losses and voltage drops.

Self-Check - 2	Written Test

Instruction: Follow the below selected instruction

The following are true or false items, write true if the statement is true and write false if the statement is false.

N°	**Questions and answers**
1	The higher the system losses, the smaller the PV array should be
True or false:	
2	For an AC load system, losses of about 65% is typical
True or false:	

Answer all the questions listed below. Use the Answer sheet provided in the next page:

N°	**Questions and answers**
1	Calculate the voltage drop over a 20m cable with a resistance of 0.0074Ω/m and a current of 5A (5)

Note: the **Satisfactory** rating is as followed

Satisfactory	4 points
Not satisfactory	Below 4 points

Information Sheet 3	Recording and documenting calculations in a standard way

3.1 Introduction

When designing off-grid PV systems, it is good practice to follow a standardized procedure. This ensures that:

- We do not skip steps or forget some critical steps;
- That the results will be repeatable;
- That knowledge will be retained when persons leave the company.

The design process can be standardized with forms that guides the process, done on spread sheets with automatic checks and calculations or even embedded in customized software. The advantage of spread sheets and software is that manual calculation mistakes can be prevented and certain sanity checks can be build-in.

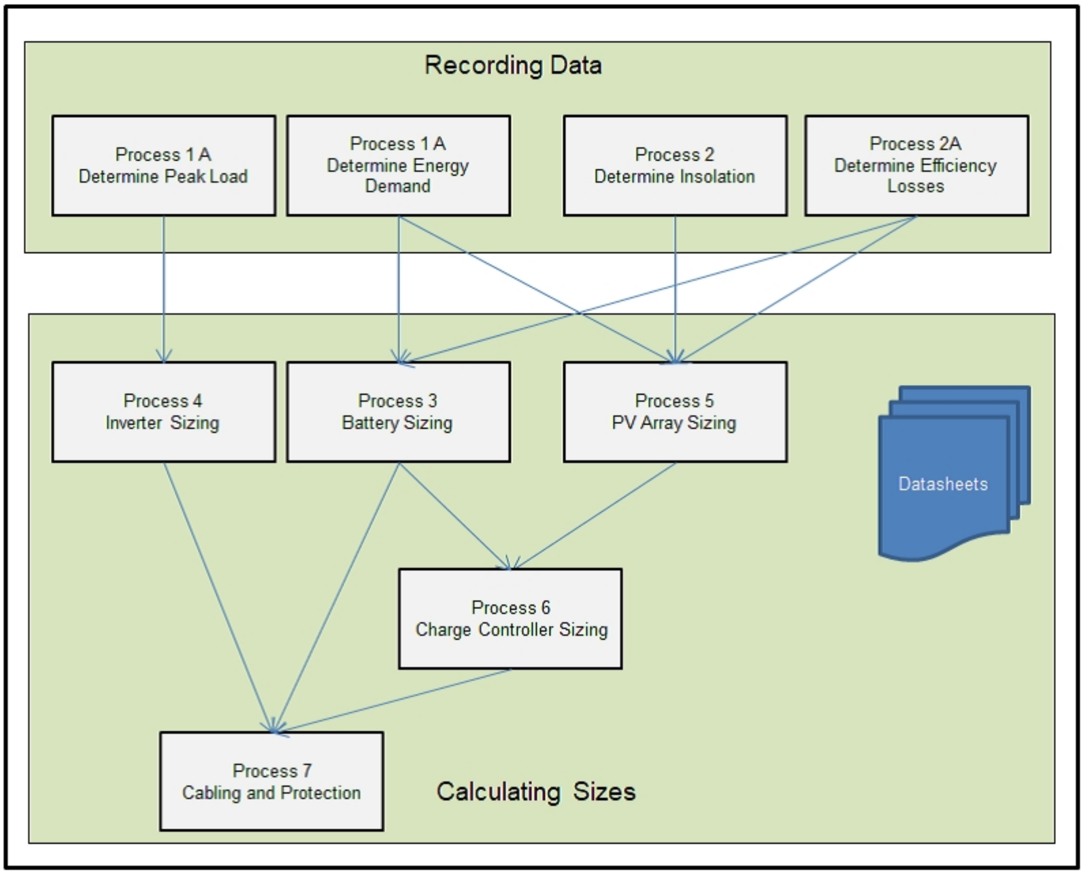


Figure 61 : Off-Grid Design Process

Figure 61 shows a typical design process. Each of the blocks can be standardized in order to streamline the design process and ensures quality and consistent designs.

3.2 Charge Controller Sizing Process

In order to size the charge controller, a standardized process can be established to record the relevant data, process the data and cross-check the data.

3.2.1 Input Data

The following data is required before the charge controller can be sized (Table 11).

Table 11: Input Parameters

Parameter	Description	Source	Value
1	PV Generator Power	Calculated based on Insolation, Energy consumption and system losses	kWp
2	Battery Voltage (System Voltage)	Determined based on Energy Consumption	V
3	Module Power rating	From module datasheet	kWp
4	Module V_{oc}	From module datasheet	V
5	Module I_{sc}	From module datasheet	A
6	Temperature Coefficient V	From module datasheet	%/°C
7	Minimum Site Temperature	Environmental data for the site	°c
9	CC max input Voltage	From CC datasheet	V
10	CC max input current	From CC datasheet	I
11	CC Power rating	From CC datasheet	W
12	CC Output Voltage	From CC datasheet	V

This data gets calculated from prior processes e.g. Battery sizing and Array sizing, as well as data sources like module and Charge Controller data sheets as well as environmental data like minimum temperatures.

3.2.2 Derived Data

From the input data, other parameters can be derived as shown in (Table 12) below. Here some standard calculations will be made like:

- Calculating the number of modules;
- Calculating the maximum Voltage (Voc) at the minimum site temperature;
- Determining the number of modules per string and the number of parallel strings. This can be an iterative process to match the modules to a charge controller.
- Determining the maximum array current.

Table 12: Derived Parameters

Parameter	Description	Calculation	Value
13	No of Modules	PV power(1)/Module power(3) rounded up	#
14	Number of modules per string	Based on an iterative process to fit within the CC input voltage range and current range	#
15	Number of strings in parallel		#
16	String Max Voltage	Calculate the maximum voltage by adjusting module V_{oc}(4) x number of modules(14) with the temperature coefficient for voltage of the module(6) using minimum site temperature(7)	V
17	Array Max Current	Number of parallel strings(15) x Module short circuit current(5)	I

3.2.3 Cross-checking the data

The derived parameters need to be cross-checked against the Charge Controller parameters (Table 13) according to certain rules:

- Check that the Charge Controller output voltage match the system voltage;
- Check that the Charge Controller power rating is higher than the PV Generator power;
- Check that the Maximum string voltage (Voc at minimum temperatures) does not exceed the Charge Controller input voltage;
- Check that the maximum array current does not exceed the Charge Controller maximum input current.

Table 13: Parameter Cross-check

Parameter	Desired Result	Description	Check
18	Charge controller output voltage(12) should match System Voltage(2)	Is 12 = 2?	If not, select a different CC
19	The Charge controller power rating(11) should be at least 1.2 times the PV power(1)	Is 11 >= (1 x 1.2)?	If not, select a bigger CC
20	The maximum string voltage (16) should be lower than the Charge Controller maximum input voltage(9)	Is 16 < 9?	If not, reduce the number of modules per string or select a different CC
21	The maximum array current (17) should be lower than the Charge Controller maximum input current (10)	String Max Voltage	If not, reduce the number of strings or select a different CC

3.2.4 Automating the Design Process

As noted previously, the design process can be automated to a certain extend using spread sheets (Figure 62) or even customized software. The advantage of an automated process is that it speeds up design and ensures quality control.

	Project ID: SRI Angola						
	Selected Components	Type	Number	Type		Properties	Total Prize
	PV-Generator	IBC Sol 95	2	P		95.00 Wp	
	Battery	Exide Solar 100Ah, 12V	1	C10		100 Ah	
	Charge Controller	Steca PR1010 LCD 12/24V 10/10A	1	V		95 V	
	Inverter	Steca PI 500	1	P		450 W	
	Cable	SOLAR Cable calculated leangth	20				
	Fuse K1		1	I		100 A	
	Fuse K2		2	I		20 A	
	System Voltage		12 V				
A	Consumption and electrial Power						
A1	Estimated Consumption of the						
	Existing Consumers	Power in Watt	Amount	Operation Hours per day	Usage Time	Consumption [Energy]	Total Power in Watt
		[W]	[qty.]	[h/d]		[Wh/d]	[W]
1	Illumination	15	2	3.0	night	90.00	30.00
2	55" led tv	60	1	3.0	night	180.00	60.00
3	decoder	45	1	3.0	night	135.00	45.00
4	Laptop	65	1	2.0	day	130.00	65.00
5	Charge Controller	0.15	1	4.0	Day/night	0.60	0.15
6	Inverter standby	0.5	1	20.0	Day/night	10.00	0.50
7	Inverter ON	6	1	4.0	Day/night	24.00	6.00
8						0.00	0.00
9						0.00	0.00
10						0.00	0.00
11						0.00	0.00
Total:						569.60 Wh/d	206.65 W
A2	Measured Total Consumption		Actual measured daily consumption, when provided				
A3	Energy Consumption [E]	569.60 Wh/d					
A4	Total Power in Watt [W]	206.65 W	Relevant for Inverter Dimensioning				
A5	Total Power per Day in Watt [W]	71.65 W	Relevant for Battery Dimensioning				
A6	Total Power per Night in Watt [W]	141.65 W	Relevant for Battery Dimensioning				
B	Climate / Insolation	January	February	March	April	May	June
		5.76 kW/m²*d	6.17 kWh/m²*d	5.92 kWh/m²*d	5.93 kWh/m²*d	5.98 kWh/m²*d	5.71 kWh/m²*d
		July	August	September	October	November	December
		5.71 kW/m²*d	6.48 kWh/m²*d	7.06 kWh/m²*d	7.02 kWh/m²*d	5.98 kWh/m²*d	5.40 kWh/m²*d

Figure 62: Spread Sheet example

Self-Check - 3	Written Test

Instruction: Follow the below selected instruction

The following are true or false items, write true if the statement is true and write false if the statement is false.

N°	When the temperature goes up, the array open circuit voltage goes up
1	Question
True or false:	
2	The Charge Controller input current should be lower than the array short circuit current
True or false:	

For each of the following question choose the best answer and circle the letter of your choice

N°	Which of the following parameters is NOT required to size the Charge Controller
1	Question
A – The PV Array Size	B – The PV String Voltage
C – The PV Array Current	D – The AC Load

Note: the **Satisfactory** rating is as followed

Satisfactory	3 points
Not satisfactory	Below 3 points

Solar PV System Installation and Maintenance

NTQF Level IV

Learning Guide -06

Unit of Competence	**Calculating System Components**
Module Title	**Calculating System Components**
LG Code	**EIS PIM4 M02 LO6-LG06**
TTLM Code	**EIS PIM4 TTLM 0920v1**

LO 6: Balance of System

Instruction Sheet	Learning Guide:- 06

This learning guide is developed to provide you the necessary information, knowledge, skills and attitude regarding the following content coverage and topics:

- Determining and calculating size of wires and protection devices, low voltage disconnectors, Kilowatt Hour meter and battery meter;
- Detecting and documenting technical problems;
- Completing and reporting the work.

This guide will also assist you to attain the learning outcome stated in the cover page. Specifically, upon completion of this Learning Guide, you will be able to:-

- Determine and calculate size of wires and protection devices, low voltage disconnectors, Kilowatt Hour meter and battery meter;
- Detect and document technical problems;
- Complete and reporting the work.

Learning Instructions:

1. Read the specific objectives of this Learning Guide.
2. Follow the instructions described below.
3. Read the information written in the information Sheets
4. Accomplish the Self-checks

Information Sheet 1	Determining and calculating size of wires and protection devices, low voltage disconnectors, Kilowatt Hour meter and battery me

1.1 Introduction

The last step in the design process is to determine the balance of system (BOS):

Cabling	Fuses
$A = \frac{L \times P}{0.03 \times U^2 \times k}$ L – Length of cable, P – Power U – System Voltage, K – electrical conductivity: K_{Copper} = 56 m / (Ohm x mm²) $K_{Aluminium}$ = 34 m / Ω · mm²	$I_{max,\,Battery} = \frac{P_{max\ Inverter}}{System\ Voltage}$ $I_{SC,\,module} = No\ of\ strings \cdot Isc,\ Module$ Recommended to increase size by 20%

Figure 63: Design Step 6

In an electrical system, voltage drops can be excessive if the wires are not sized correctly. This is due to the resistance of the wires being too high. There is always a compromise between wire size and cost. Thicker wires are more expensive, but the more losses mean bigger batteries and panels. Furthermore, cables should be kept as short as possible (specifically cables carrying high current). Power losses in cables can be calculated using the power formula:

$P = I^2 R$

Where

- P= power loss in cable;
- I = the current flowing in the cable
- R= the resistance of the cable

Figure 64 indicates that the power loss (with a linear increase in current) is not linear.

The higher the current the higher the losses, therefore it is important to keep the resistance as low as possible where high currents are flowing.

Protection devices need to be of the correct size and type to ensure that is protects the system adequately. For the low voltage DC system, the typical points of protection/disconnection are (refer to Figure 65):

- Fuses between the PV modules and the combiner box (F1)
- A DC Disconnect switch between the combiner box and the charge controller (S1)
- A Fuse between the Charge Controller and the batteries (F2);
- Between the batteries and the inverter (F3);

The protection and disconnection on the AC side is normally governed by specific standards and needs to be implemented by qualified electricians.

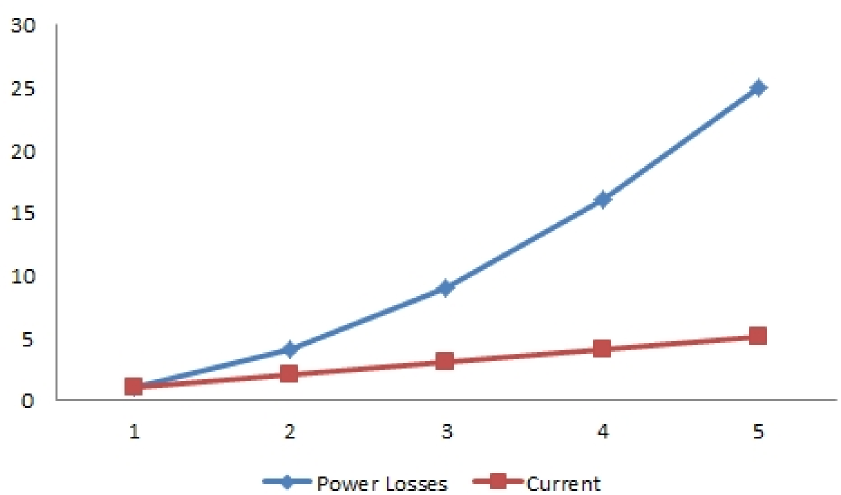


Figure 64: Power losses vs. current increase

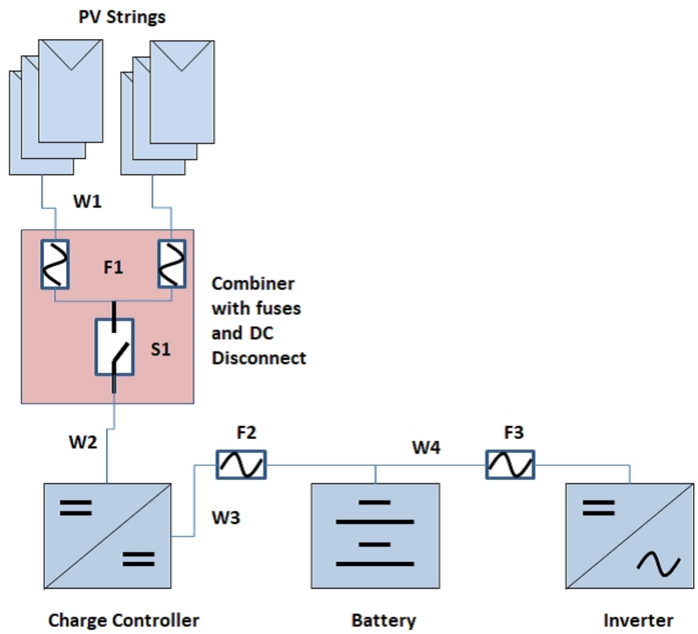


Figure 65 - Protection and Wiring

The selection of the correct cables, fuses and accessories for electrical distribution systems can only be discussed in general terms here. National wiring codes and regulations as well as equipment manuals need to be complied with.

1.2 Calculate cable sizes

The following paragraph(s) are adapted from (Dobelmann &Klauss-Vorreiter, 2009) chapter 6. The formula that can be used for cable sizing is the following:

$$A = \frac{L \times P}{\rho_{loss} \times V^2 \times K}$$

Where

A = cross section of cable in mm2

L = length of cable (conductor positive and negative) one way length x 2

P = Power of the cable

ɲloss = Loss factor (0.01 for 1%, 0.02 for 2% etc.)

V = system voltage

κ = Kappa – electric conductivity

K_{Cu} = 56 m / Ω · mm² for copper

K_{Alu} = 34 m / Ω · mm² for aluminum

In practice, one can make use of tables supplied by wire manufacturers to 'lookup' the size of wires. These tables are often specified per system voltage e.g. 12V, 24V etc. In Figure 66 below, we can select the wire suitable for an appliance that consumes 30Wand is 3m away from the battery. It can be seen that a 1.5mm2 will be suitable.

In fact, 1.5mm2 will be suitable up to 8m after which the next size (2.5mm2) will have to be used.

The Watts or Amperes listed on an appliance is its electricity use while in normal, continuous operation. For example, a refrigerator may show a power requirement of 60 Watts at 12Volts. That means when it is running continuously, it will need to receive 5 Amperes of current from the battery.

Electric motors, however, require extra current to start, several times the Amperes it uses when running. To prevent a large voltage drop, wires running to appliances with motors (refrigerators, washers and pumps for example) should be sized for at least twice as many Watts or Amperes as the appliance normally requires when running.

Load		Wire Length In Meters														
Watts	Amperes	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		Standard Size Wire Needed (Square Millimeters)														
5	0.42	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
10	0.83	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
15	1.25	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
20	1.67	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	2.5	2.5	2.5
25	2.08	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	2.5	2.5	2.5	2.5	2.5	2.5
30	2.50	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	2.5	2.5	2.5	2.5	2.5	4	4
35	2.92	1.5	1.5	1.5	1.5	1.5	1.5	2.5	2.5	2.5	2.5	2.5	4	4	4	4
40	3.33	1.5	1.5	1.5	1.5	1.5	1.5	2.5	2.5	2.5	2.5	4	4	4	4	4

Figure 66: Using a wire table

1.2.1 Type of wire

It is important to use the correct wire suitable for the application. The wire from the PV modules is exposed to the elements and needs to be PV rated wire. PV rated wire normally have the following properties:

- Mechanical stability to withstand compression, tension and bending;
- Weather stability including UV and ozone stability, heat and cold stability;
- Ground and short circuit insulation – single cable with double insulation.

Figure 67 - PV1-F Cable

PV cable has different voltage and temperature ranges. Figure 68 show a selection of PV cables available with their temperature and voltage ranges and size.

Module Cables for Outdoors	Producer	Nominal Voltage in U/U⁰	Temperature Range	Cross section diameters (mm²)				
Lapptherm Solar Plus	Lapp-Kabel	900/1500 V	-50°C – 120 °C	2,5	4	6	10	
Flex-Sol	Multi-C	600/1000 V	-40°C – 90 °C	2,5	4	6		
Radox 125	Huber+Suhner	600/1000 V	-25°C – 125 °C	2,5	4	6		
Siemens-Solar leitung	Siemens AG	1800/3000 V	-40°C – 120 °C	2,5	4	6		
Solar-Kabel*C	Solar-Kabel GmbH	1800/3000 V	-25°C – 90 °C	2,5	4	6		
Solarflex 101	Helukabel GmbH	600/1500 V	-30°C – 125 °C	2,5	4	6	10	16
TECSUN S1ZZ-F Solarleitung	Pirelli Kabel und Systeme GmbH	900/1800 V	-40°C – 120 °C	2,5	4	6	10	
Titanex 11 H07RN-F	ConCab-Kabel	450/750 V	-35°C – 85 °C	2,5	4	6		

Figure 68: PV Cable comparison

Although the size of the wire is the most basic specification, there are several different types of wire available in standard sizes. Typically, wire is classified as multi-stranded or solid. For house wiring, solid copper wire is often used. It consists of a single solid copper conductor inside an insulating sleeve (figure Figure 69b). Solid wires are usually cheaper but are stiff and if bent back and forth enough times they will break.

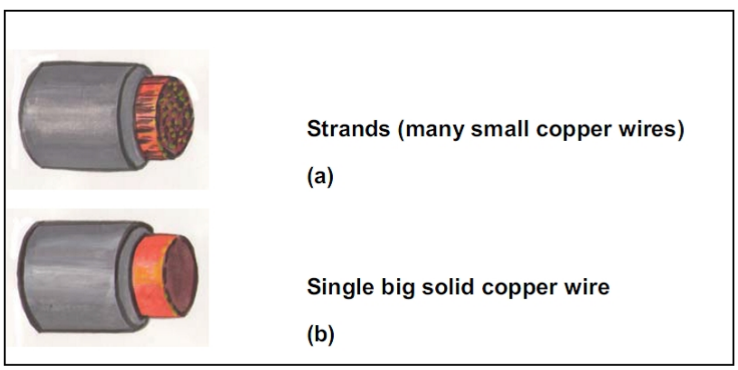


Figure 69: Conductor types

Often wire is made up of many small wires all bunched together inside the insulating sleeve. It is called stranded wire because it is made up of many small strands of wire (Figure 69a).Though each strand is very small, enough strands are bunched together to make the total wire area equal to that of a solid wire. For example, if each strand is , 0.1 mm2 in size, then 25 strands will be used in a 2.5 mm2 wire. The main advantage of stranded wire is its flexibility. Electrically, there is no difference between equal sizes of stranded and solid wire. Solid wire is cheaper and good for permanent installations. Stranded wire is usually best for any application where the wire is not permanently fixed in place.

1.3 Fuses and circuit breakers

Fuses are sized according to the current through the fuse and the voltage over the fuse. Temperature can also de-rate fuses. Fuses are devices placed in circuits to prevent accidental damage to appliances, modules and charge-controller circuitry from high current normally associated with short circuits. The very high current that batteries will deliver under short circuit conditions can cause fires, extensive damage or even explosions! Ideally, in a system, there should be a fuse on each of the battery, solar array and load circuits.

When a short circuit occurs or there is an overload, the fuse 'blows' (i.e. a strip of wire inside melts). This opens the circuit so that current cannot flow. Once a fuse has blown, the cause of the high current should always be investigated and repaired before replacing the fuse with a new one of the same rating. Miniature circuit breakers (MCBs) are small switches that automatically break the circuit when there is a short circuit or overload. Unlike fuses, they can be switched back on once the wiring problem has been corrected.

DC-rated fuses and circuit breakers should be used in DC circuits, and AC-rated fuses and circuit breakers should be used in AC circuits. They also need to be correctly rated for the circuit voltage.

As a minimum safety precaution, all small systems (less than 100Wp) require at least one fuse: the main battery fuse. Larger systems should have a fuse to protect each major circuit, the battery and the module/array. If there are loads that need to be protected independently, then fuses should be included in the circuit of that load.

Some charge controllers contain in-built electronic load and circuit protection. Look for these charge controllers that have circuitry to protect loads and PV arrays. Such charge controllers not only avoid the problem of including multiple fuses, they also avoid the common (and very dangerous!) practice of consumers replacing blown fuses with the wrong-sized fuse wire (or pieces of copper /tools – see Figure 70). In all cases, when planning fuse protection, choose the main battery fuse first and follow these

suggestions:

- The fuse should be DC rated.
- It should be on the positive cable(s) from the battery, as near as possible to the battery's positive terminal in unearthed and in negative earthed-systems, which most systems are.
- Its rating in amperes (A) should be less than the thermal rating (current rating) of the battery cables. A 30A fuse protecting a cable designed to take 20A means that if 29A flows in the cable the fuse will not blow – but the cable, which is designed to take a maximum of 20A, will overheat and become a fire hazard. However, a 15A fuse would provide full protection.
- Its 'breaking capacity' (in kA) should be greater than the battery short circuit current. This means that the fuse needs to be able to blow (i.e. not arc) if there is a short circuit – short-circuit currents can be very high.

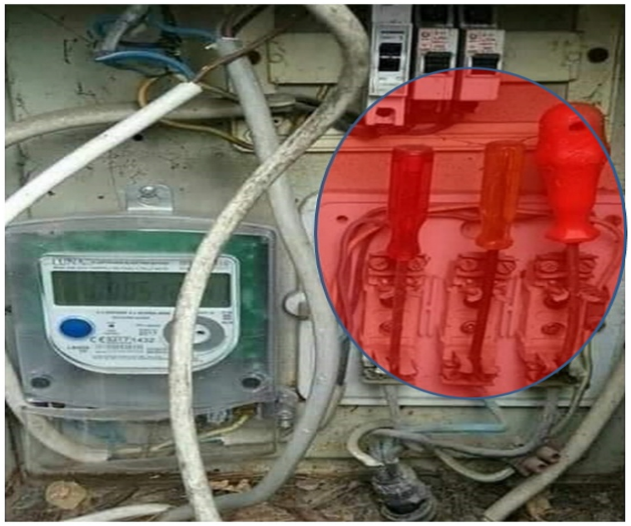


Figure 70: Dangerous fuse 'replacement'

Other fuses (often located in the charge controller) are important but do not protect against battery short circuit from faults in cables between the battery and the charge controller. Refer to the inverter manual when placing fuses on inverter circuits. It should specify fuse size and type (as well as recommended cable size from battery to inverter).

Figure 71: Battery DC-rated fuses

1.3.1 Battery Fuse Calculation

Fuses are rated in amps. They are sized to 'blow' very quickly when the current is about 20 % greater than the maximum expected current in the circuit. If, for example, there is a short circuit in one of the appliances, the circuit draws much more than the rated current (i.e. more than 20 per cent higher), so the fuse rapidly heats up, 'blows' very quickly and opens the circuit.

To size the battery fuse calculate the power of the loads (W) and divide it by the system voltage to get current (A). Take this current and multiply with 1.2 to get the fuse current rating.

1.3.2 PV Fuse calculation

PV Fuses are often use when there are multiple strings combined. An earth fault in one string can cause the other string currents to also flow into the earth fault. PV strings are normally calculated empirically as follows:

- VP,fuse ≥ VOC,array x 1.2
- Inom,fuse ≥ ISC module x 1.4

As an example, if there are a string of 4 modules (VOC = 36V), and the Short circuit current ISC = 10A:

- VP,fuse ≥ VOC,array x 1.2 ≥ (4 modules x 36V) x 1.2 ≥ 172.8V
- Inom,fuse ≥ ISC module x 1.4 ≥ 10A x 1.4 ≥ 14A

  From the fuse datasheet (Figure 72), the closest suitable fuse will be the PV-15A10F fuse.

10 x 38 PV Fuses (1000V DC)

A range of UL 2579 fast-acting 600V DC Midget fuses specifically designed to protect solar power systems in extreme ambient temperature, high cycling and low-level fault current conditions (reverse current, multi-array fault).

Product Code	Rated Current	Rated Voltage	Breaking Capacity	Dimensions	Class
PV-2A10F	2A	600V DC	30kA	10 x 38mm	gPV
PV-6A10F	6A	600V DC	30kA	10 x 38mm	gPV
PV-8A10F	8A	600V DC	30kA	10 x 38mm	gPV
PV-10A10F	10A	600V DC	30kA	10 x 38mm	gPV
PV-12A10F	12A	600V DC	30kA	10 x 38mm	gPV
PV-15A10F	15A	600V DC	30kA	10 x 38mm	gPV
PV-20A10F	20A	600V DC	30kA	10 x 38mm	gPV
PV-25A10F	25A	600V DC	30kA	10 x 38mm	gPV

Figure 72: PV Fuse selection

1.4 Switches

Switches are used to turn appliances and other loads on and off. They also serve the important purpose of disconnecting modules, batteries and loads during servicing and emergencies. Always select the right type and size of switch for the purpose.

Switches and disconnects need to be properly rated for the circuit in which they are being installed – in terms of current and voltage. A switch or disconnect in a 12V DC circuit needs to be rated for 12V DC and the maximum current expected in that circuit, while a switch or disconnect in a 230V AC circuit needs to be rated for 230V AC and the maximum current expected in that circuit. Many switches and disconnects are rated for both DC and AC current/voltage, though the values for AC and DC may be different.

When 230V AC switches must be used to turn lights or small appliances on and off (e.g. because suitable 12V DC switches are not available, which is often the case) always make sure that their nominal current rating is twice the maximum expected DC current.

Only use the proper DC-type switches of the correct voltage and current rating on main switches that control high current DC appliances, PV array or battery circuits.

Improperly used AC switches may burn up or arc, and may cause dangerous short circuits or fires!

1.5 Meter selection

Some manufacturers may have built-in meters in their inverters and charge controllers while others may have external devices that communicate with the devices and report the state of charge, power consumption etc. either to the internet or to a local display unit. Figure 73 shows the use of an ammeter and voltmeter connected between the load and the charge controller. In this case, the ammeter will act as a rev counter (the higher the current, the higher the motor revolutions) while the voltmeter will report the battery voltage (fuel gage).

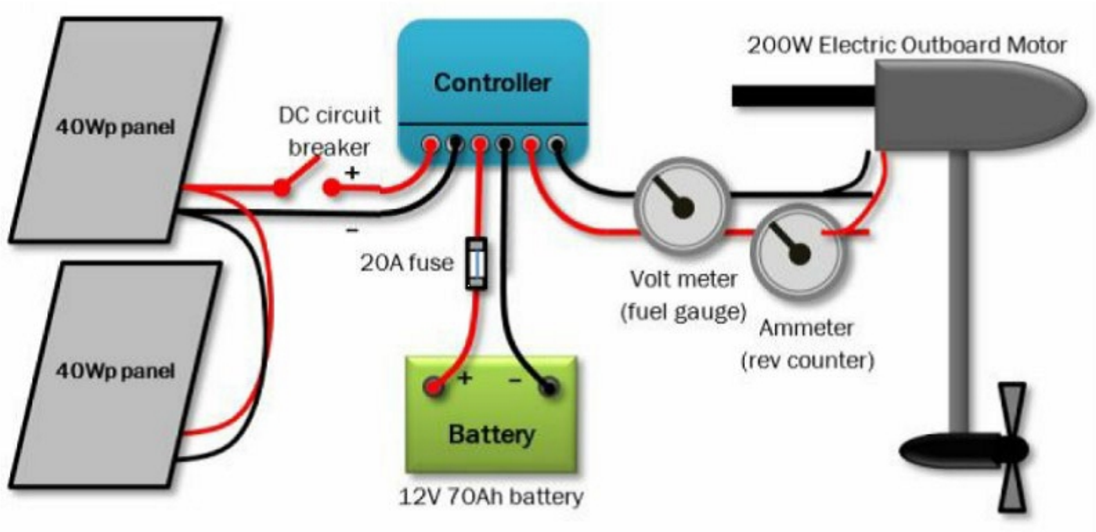


Figure 73: Adding meters to an Off-Grid system (Boxwell, 2017)

In Figure 74 a Charge Controller with built-in meter can be seen.

Figure 74: Charge Controller Integrated Meter

Figure 75 shows a separate display unit that can communicate with charge controllers and inverters. It may also provide remote access via the internet.

Figure 75: Separate Display Unit

In larger systems, it is often advisable to include a battery monitor (Figure 76 and Figure 77) device between the charge controller and the inverter. While the charge controller controls the charging of the battery, the battery monitor protects the battery to make sure it is not discharged too deeply.

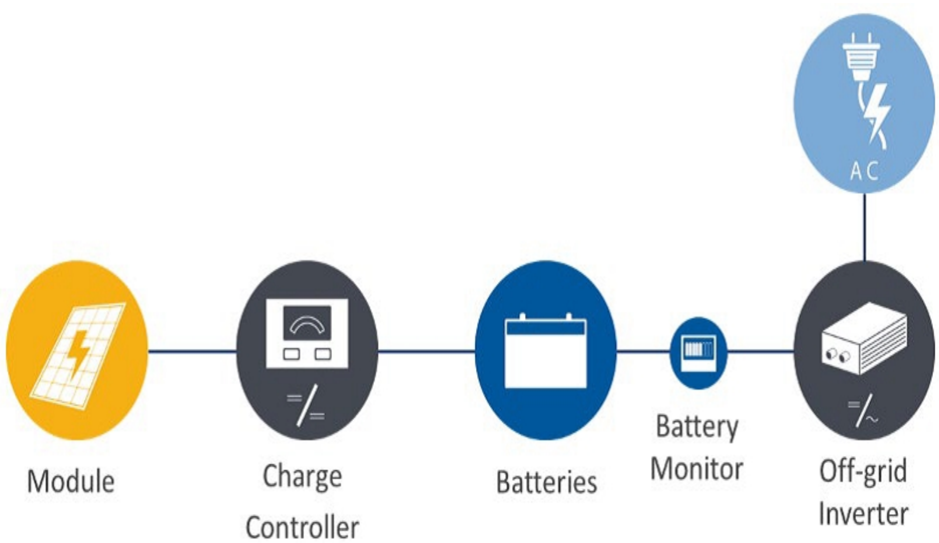


Figure 76: System with battery monitor

Figure 77: Battery Monitor

1.5.1 Adama design

In reference to the Adama design Figure 78, we need to calculate the following

Cabling	L Single Distance	LF Loss Factor	P_{max} Affiliated Power	K Conductivity	U_{SYS} System Voltage
A1 Single Cable Length between Modules and combiner box (Vmpp, String) per string	5 m	1.0%	4900 W/2 strings 2450W per string	56	270.2 V
A2 Single Cable Length between combiner box and charge Controller (Vmpp, String)	5 m	1.0%	4900 W	56	270.2 V
A3 Single Cable Length between Charge Controller and Battery (PPV)	3.00 m	0.50%	4900 W	56	48 V
Material of the Cables	Cu				

Required cable diameters $A = \frac{L \times P}{0.03 \times U^2 \times k}$

A1 $= \frac{2 \times 5\ m \times 2450W}{0.001 \times 270.2^2 \times 56} = 0.6\ mm^2$, selected diameter 4 mm^2 DC cable

$$A2 = \frac{2 \times 5\ m \times 5000W}{0.001 \times 270.2^2 \times 56} = 1.2\ mm^2$$, selected diameter 4 mm^2 DC cable

$$A3 = \frac{2 \times 3\ m \times 4900}{0.005 \times 48^2 \times 56} = 45.6\ mm^2$$, selected diameter 50 mm^2 DC cable

Double Check Inverter battery terminal size to fit cable size:

Any-Grid model	PSW-H-5KW-230/48V	PSW-H-5KW-120/48V	PSW-H-3KW-230/24V	PSW-H-3KW-120/24V
Battery cable cross-section	35 ~ 50 mm^2, AWG 0 ~ AWG 2			

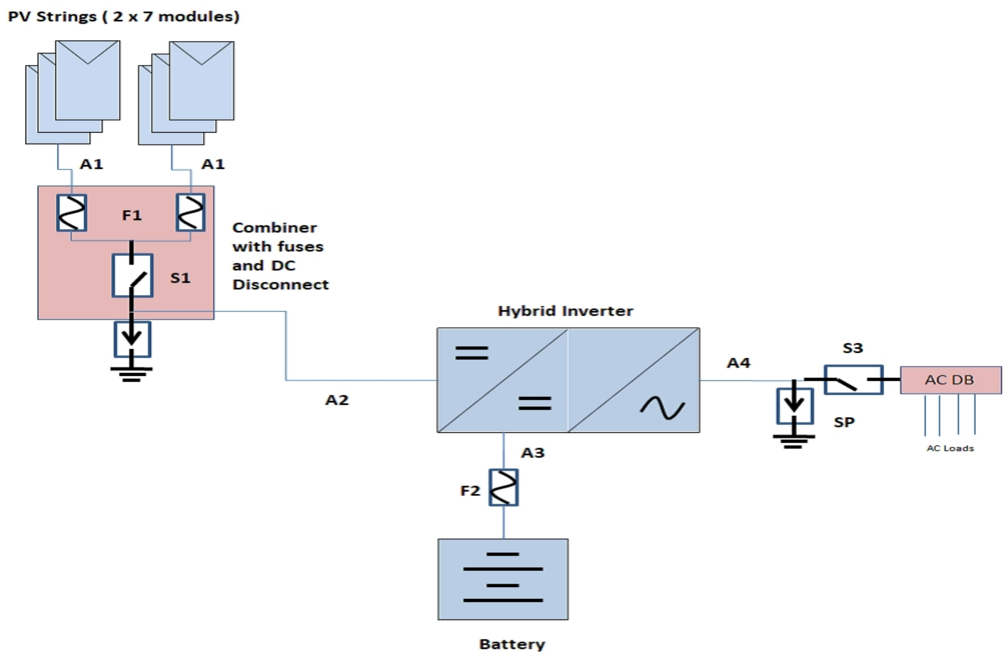


Figure 78: Adama Design

- F2 Fuses from charge controller to Battery

  ICC= 80A (max capacity of CC)

  Add safety margin of 20 %: F2=ICC 1.20 = 80A * 1.20 = 96A

  FuseF2=100A

- F1 Fuses from string to combiner box

ISC, Module=9.56 A

F1=ISC String = Isc module

F1=ISC String = 9.56A

Add safety margin of 20 %: F1=ISC String * 1.20 = 9.56 * 1.20 = 11.47 A

FuseF1=15A

Self-Check - 1	Written Test

Instruction: Follow the below selected instruction

The following are true or false items, write true if the statement is true and write false if the statement is false.

N°	**Questions and answers**
1	A linear increase in current causes a non-linear higher increase in losses
True or false:	
2	PV Fuses are normally rated at 1.4 x the string short circuit current
True or false:	

Answer all the questions listed below. Use the Answer sheet provided in the next page:

N°	**Questions and answers**
1	Calculate the required cable size for the following: • One way cable length of 30m • Power of 2000W • Acceptable loss of 2% • Voltage of 48V • Copper cable 5points

Note: the **Satisfactory** rating is as followed

Satisfactory	4 points
Not satisfactory	Below 4 points

Information Sheet 2	Detecting and documenting technical problems

2.1 Introduction

The following paragraph(s) are adapted from (Louie, 2018) chapter 7.

PV systems have many advantages; there is however some considerations to take into account:

- The energy produced by PV arrays is variable and uncertain. PV array power production is driven by sunlight, which varies throughout the day and year.
- Cloud coverage is difficult to forecast, and production might be severely limited during rainy seasons. This adds uncertainty to the design process, leading to arrays that are larger than needed and consequentially more expensive, or smaller than needed causing the system to be unreliable.
- In certain locations, particularly those with perennial cloud coverage or at polar latitudes, the solar resource is inadequate for a PV array to be an economic and practical solution.
- Although PV array prices have fallen globally to much less than US$0,30/W, energy storage, charge controllers, and other components are needed, increasing the cost and complexity.
- PV arrays have low power density, and so a large amount of roof space or land is needed. For example, a 5 kW system requires approximately 40 m² of surface area for the PV array. Further, the PV array must be tilted and oriented in a specific way to maximize power production. This often necessitates custom made racking structures. From this it is clear that technical problems should be detected and documented before the system is procured and installed.

2.2 Understanding The Environment

To detect technical problems early, it is imperative to understand the environment where the system to be designed will operate. The environment have many aspects:

- The Location.
- Access to the site;
- Weather conditions;
- Installation environment;
- Mounting modules;
- Shading;
- Appliances to be used (e.g. loads with high startup currents)
- Appliance Voltage and consumption;
- Health and safety;
- Security concerns.
- Users.
- Who will use the system?
- How will the system be used?
- What are the exact needs?
- How to protect users from danger?
- Affordability
- Regulatory environment
- Are there specific regulations that need to be adhered to?
- Maintainability.

A good design needs to address all aspects mentioned above. Only by proper understanding of the environment will it be possible to address all the factors. It is also important to document any concerns and constraints before a system is procured and installed.

2.3 Documenting Technical Problems

There are a number of stages in the development of a PV system in which mistakes can occur:

- Site selection
- Design and planning of the system
- Selection of components
- Mechanical failures
- Electrical failures
- Physical installation of the components
- Mechanical failures
- Electrical failures
- Safety (personnel safety as well as safety of installation from e.g. external exposures)
- Service, including inspection & maintenance (insufficient)

This document deals mainly with the design and planning of the system. A good design process will prevent most technical issues. Most technical issues can be avoided if a semi-automated process is designed and followed (as explained in LO5). Apart from following the process, the final design should be peer reviewed where possible. One of the outputs of the design should also include proper instructions to the installers of the system.

The following paragraph(s) are adapted from (Assoc. Prof. Theocharis Tsoutsos, 2011) chapter 4 Most common failures are not encountered because of bad practices in one specific step, but are a combination or accumulation of suboptimal actions in different stage or simply due to wrong or inadequate communication between the designers and the installers.

The design and planning stages include all decisions taken on the appropriate size of the system as well as the selection of the different components. It is important to take into account basic structural load and wind load calculations.

Moreover, emphasis should be put on the sizing, including the size and selection of an appropriate inverter, cables, power optimizer and switch devices as well as combiner boxes and transformers. This task normally ends with a modeling exercise on the future performance of the PV system and therefore also includes knowledge about software and simulation tools for yield modeling.

For residential systems, it is of critical importance to respect the building and safety codes, including measures on ventilation of the building, access for fire departments, maximum load, etc. When the roof is not appropriate for the installation of a PV system, this should be simply acknowledged.

Moreover, the choice of components is critical; especially when it comes to PV systems in sub-optimal locations, such as west-facing roofs or flat roofs where mounting the modules is not an option because of load limitations. Taking into account the latest innovations is critical, e.g. specialized products targeted for east-west facing roofs, light-weight flexible PV modules, etc.

It has to be acknowledged that without sufficient training, the likelihood of mistakes during this step can be significant.

2.3.1 Common Mistakes

Common mistakes to be encountered in this stage are then as listed in Figure 79:
Orientating a system North or West facing (northern hemisphere) may result in a system where the yield is insufficient for the planned consumption. A common mistake is also to disregard the hemisphere where the system is located i.e. facing array south in southern hemisphere and north in northern hemisphere.

Moreover, it is clear that any last minute changes in one of the design stages affects the entire configuration of the PV system design and can have a detrimental impact on the performance or safety of the final installation

PARAMETER	FAILURE / IMPROPER PRACTICE
1. Site selection	
Orientation	- north / west facing installations
Inclination	- different azimuths or inclinations in the same string - array not tilted at an angle of latitude (for throughout the year best performance)
Shading	- place the system in area surrounded by trees and/or buildings - seasonal shading is not taken into account
Corrosion	- modules are located in areas exposed to salt water
Biodiversity (for large ground-mounted systems)	- potential impact to wildlife is neglected because of inadequate EIA
2. Design and planning of the system	
Structural load	- age and condition of the roof is not considered - not use of specified hardware leading to stability problems - no respect to the building codes
Wind load	- inadequate mounting - system not mounted on concrete bases
Location	- no respect to the building and safety codes (eg overload the roof, no access for fire departments) - BOS are not sited in weather resistant or rain-tight enclosures
Equipment	- inappropriate inverter, undersized cables, power optimiser and switch devices as well as combiner boxes and transformers
Lightning/grounding	- no lightning protection, earthing and surge protection - PV system installed in an exposed location - allow copper (equipment grounding conductor) to come in contact with the aluminum rails and module frames
Electrical connections	- improper polarity - incorrect circuit protection - mismatch: e.g. inverter mismatch or generation meter not well fitted to inverter output - lengths of electrical wiring are not minimized - electrical codes for grid connection not taken into account

Figure 79: Common Mistakes

Self-Check - 2	Written Test

Instruction: Follow the below selected instruction

The following are true or false items, write true if the statement is true and write false if the statement is false

N°	**Questions and answers**
1	A common mistake is the wrong orientation of the array
True or false:	
2	One should not worry too much about wind loading when selecting the mounting position of modules
True or false:	
3	Lightning protection is only applicable to large systems
True or false:	

Note: the **Satisfactory** rating is as followed

Satisfactory	2 points
Not satisfactory	Below 2point

Information Sheet 3	Completing and reporting the work

3.1 Introduction

No job is done till the paperwork is finished. It could not be truer for a PV design. Module 8 "Compiling and Producing Solar PV Installation Detailed Report" described this topic in detail. A good design should document every step of the design and should consist of (at least) the following information:

- Project background;
- Client information;
- Site information;
- Design parameters as obtained from the client and site information;
- Technical design of the system including PV Array, Charge Controller(s), Batteries, Inverter, wiring and protection;
- Installation and mounting system;
- Technical constraints and concerns;
- Installation Documents including:
- Single line diagram;
- Wiring diagram;
- Installation manuals of all equipment;
- Commissioning procedure;
- Bill of material;
- Costing information;

In terms of this Learning Guide (Calculating System Components), the Bill of Materials (BOM) will be considered.

3.2 Bill of Materials

The Bill of Material includes should include the following components:

- PV Generator
- PV modules;
- Mounting structure;
- Charge Controller(s)
- Batteries
- Inverter
- Wiring
- Protection devices
- Earthing
- Fixtures and fittings
- Cable trays and trunking;
- Conduit;

Nuts and bolts;

- Cable ties;

Figure 80 shows a sample of a typical BOM

Component	Size	Description	Numbers/Amount
Solar module	80Wp	Monocrystalline	4
Battery	350Ah	6V Traction	2
Charge controller	30A	PWM with LVD	1
Inverter	250W	Sine wave	1
AC circuit cables	$2.5mm^2$	Twin flat	30m
DC circuit cables (all sizes and types)	• $2.5mm^2$ • $4.0mm^2$ • $6.0mm^2$	Twin flat, multi-strand cable	• 80m • 30m • 20m
Conduit	standard	For exposed cables	30m
Switches	5A	DC rated switches	20
Sockets	240V AC, 5A	Switched	4
Fuses	50A	Main battery fuse DC rated	1
Junction boxes	Standard DC		40
Connector strips	Standard DC	Standard	4 boxes
Earthing		Earth rod	1
Bolts, screws, nuts, etc.		Various boxes	

Figure 80: Bill of Material

The BOM for the Adama Design is shown in Table 14:

Table 14: Adama BOM

Pos.	Item no.	Description	Quantity	Unit
1	310363	Phaesun PN6M72-350E Modules	14	Pcs
2	340026	Battery OPzS Hoppecke sun | power V L 2-730	24	Pcs
3	321728	Inverter / Hybrid Charger Phocos PSW-H-5KW230/48V	1	Pcs
4	161103	Module Support Structure PN-ASS 03	4	
5		Middle Clamp Included In 4	16	Pcs
6		End Clamp Included In 4	24	Pcs
7	390003	Corrugated Sheet Roof Screw Fitting 160mm	20	bar
8	704230	SOLARFLEX® - X PV1-F 25mm²	35	m
9	704232	SOLARFLEX® - X PV1-F 50mm²	100	m
10	303588	Cable Solarflex-X 1x 4 black 4mm²	25	m
11	390900	PV Standard4 Connector 4-6 mm² Set WM	5	Pcs
13	500090	Connection Box GCB 5-1 200V/50A gland	1	Pcs
14	108010	Battery Rack Kunstmann	1	Pcs

Pos.	Item no.	Description	Quantity	Unit
		1E.B560.R2		
15		Fuse 100 Amp DC	1	Pcs
18		Fuse 15 Amp DC	4	Pcs

3.3 Design Calculations

The design calculations should also be documented. If a semi-automated spread sheet or customized software is used or, the calculations can be extracted fairly easily in a standard format. Alternatively, a template can be set-up to guide the final report. Figure 81 shows the output of a typical design template – in this case the template used for the Adama design.

	Inverter	Phocos Anyware [illegible] 48V	2	P		[illegible] W	
	Cable	SOLAR-Cable calculated length	4mm2 - 20m				
	Cable	Other Cable	16mm2 - 8m				
	Fuse [illegible]		2	1		250 A	
	Fuse [illegible]		2	1		50 A	
	System Voltage		48 V				
A	Consumption and electrical Power						
A1	Estimated Consumption of the Costumers						
	Existing Consumers	Power in Watt	Amount	Operation Hours per day	Usage Time	Consumption (Energy)	Total Power in Watt
		[W]	[pcs]	[h/d]		[Wh/d]	[W]
1	Lights	14	20		Day/night	[illegible]	[illegible]
2	Lights	14			Day/night	[illegible]	[illegible]
3	Computer	250			Day/night	[illegible]	[illegible]
4	Printer	700			Day/night	[illegible]	[illegible]
5	Projector	500			Day/night	[illegible]	[illegible]
6	Internet	15			Day/night	[illegible]	[illegible]
7	Router	15			Day/night	[illegible]	[illegible]
10						0,00	0,00
11						0,00	0,00
Total						12884,00 Wh/d	2527,00 W
A2	Measured Total Consumption		Actual measured daily consumption, when provided				
A3	Energy Consumption [E]	12884,00 Wh/d					
A4	Total Power in Watt [W]	2527,00 W	Relevant for Inverter Dimensioning				
A5	Total Power per Day in Watt [W]	2527,00 W	Relevant for Battery Dimensioning				
A6	Total Power per Night in Watt [W]	2527,00 W	Relevant for Battery Dimensioning				
B	Climate / Insolation	January	February	March	April	May	June
		[illegible]					
		July	August	September	October	November	December
		[illegible]					
		minimum	average				
B	Insolation minimum / average	[illegible] kWh/m²*d	[illegible]	We will use the minimum value for the modules			
C	PV-Generator	[illegible]				P_{PV} Power of the PV Generator	
						E Consumption	
C1	Efficiencies [%]	Efficiency	Range of Efficiency	Project Efficiency		G Radiation horizontal	
	Deviation MPP / Type of the CC	[illegible]	[illegible]	[illegible]	η_{sys}	System efficiency PV [illegible]	
	Line losses between Battery and Generator	[illegible]	[illegible]	[illegible]			
	Line losses between Battery and Inverter	[illegible]	[illegible]	[illegible]			
	Battery Charge and Discharge	[illegible]	[illegible]	[illegible]			
	Efficiency of the Charge Controller	[illegible]	[illegible]	[illegible]			
	Efficiency of the Inverter	[illegible]	[illegible]	[illegible]			
	Influence of the Ambient Temperature	[illegible]	[illegible]	[illegible]			
	Insulation	[illegible]	[illegible]	[illegible]			
		Calculated as product of all efficiencies		Total Efficiency			
C2	System Efficiency [%] selected	[illegible]		[illegible]	We will use the [illegible]		
C3	PV-Generator [illegible]	[illegible] Wp		Calculation based on minimum radiation!			
C4	Number of Modules						
	Selected Type of Modules	Phaesun [illegible]					
	Module Power Pnom	[illegible] Wp					
	Needed Number of the Modules [illegible]	[illegible]					
C4	Selected Number of Modules	[illegible]					
C5	Power of the PV-Generators	[illegible] Wp					

D	**System Voltage**	**48 V**
E	**Battery Dimensioning**	**[=E*A/(DOD*V)]**
	Consumption [E]	12964 Wh/d
	Autonomous Days [A]	1,00 d
	Voltage of the Battery-Bank [V]	48 V
	max. Depth of Discharge of the Battery in %	50,00%
E1	**Required Electrical Capacity [C10]**	**540,17 Ah**
	Required Electrical Capacity [C100]	**675,21 Ah**
a	Voltage of the selected Batteries [V]	2 V
b	Capacity of the selected Batteries [Ah] C10	686 Ah
c	Voltage of the required Battery-Bank [V]	48 V
d	Number of Batteries series-connected	24,00
e	Number of Batteries parallel-connected	0,79
f	Number of Batteries	18,90
E2	**Selected Batteries**	
	Selected Type of Batteries	**Hoppecke sun power VL7-730**
c	Voltage of the Battery-Bank [V]	48 V
a	Voltage of the selected Batteries [V]	2 V
g	Number of Batteries series-connected	24
h	Number of Batteries parallel-connected	1
i	Capacity of the selected Batteries [Ah] C10	546 Ah
j	Number of Batteries	24,00
	Total Capacity C10 actual	**546,000 Ah**
	Total Capacity C10 desired	**540,17 Ah**
	actual C10 >C10 desired	**ok**
F	**Configuration of the Modules**	
F1	**U, I and α of the Modules (s. Datasheet)**	
	Selected Type of Modules	**Phaesun PN6M72-350 E**
k	V_{OC}	47,20 V
l	V_{MPP}	38,60 V
m	I_{SC}	9,56 A
n	I_{MPP}	9,08 A
o	α_{VOC}	-0,30 %/K
p	α_{VMPP}	-0,30 %/K
q	α_{ISC}	0,040 %/K
r	α_{IMPP}	0,040 %/K
F2	**Module Installation**	
	Number of Modules	14
rr	Number of Strings	2
s	Number of Modules per String	7

G	**Charge Controller Dimensioning**	
	Charge Controller Type	Phocus Anygrid PSW-H-5KW-230/48V
	Nominal Power Rating	5000 W
	V System System Voltage	48 V
	Voc max MAX Open-Circuit Voltage Modules (at minimum Temperature)	450 V
	Voc min MAX Open-Circuit Voltage Modules (at minimum Temperature)	120 V
	Vmpp min Input	120 V
	Vmpp max Input	430 V
	max. Current Modules	26 A
	max. Current Charge Controller (permanent)	26 A
	max. Current Charge Controller (peak load)	26 A
	Number of Charge Controllers	1
	Number of Modules each Subsystem	14
G0	**Power Check**	
t	Power of the PV-Generation	4900 Wp
u	Nominal Power Rating	5000 W
	Ratio PPV/PCC has to be bellow 1.2.	0,98
	Ratio check	ok
	In other words, the PV generator power can be up to 20% bigger thant the nominal power of the CC.	
G1	**Ambient Temperature**	
t	Minimum Temperature Modules	5,00 °C
u	Maximum Temperature Modules	85,00 °C
	Insolation, if it's chargely higher as according to STC	1000 W/m²*d
G2	**Maximum System Voltage, Voc at Tmin**	
k	V_{oc} Module at STC (25°)	47,20 V
v	V_{oc} at T_{min} = α_{voc}x(T_{min}-25°)xV$_{oc}$	2,83 V
s	Number of Modules per String	7
w	V_{oc} String at STC (25°)	330,40 V
x	V_{oc} at T_{min} = α_{voc}x(T_{min}-25°)xV$_{oc,string}$	19,82 V
	$V_{OC,\,Tmin}$ each String (T_{min})	**350,22 V**
	Voc max (at minimum Temperature)	450,00 V
	Is $V_{OC,\,Tmin,\,String}$<max$V_{OC,\,CC}$	ok
	Voc min (at minimum Temperature)	120,00 V
	Is $V_{OC,\,Tmin,\,String}$>min$V_{OC,\,CC}$	ok
	Minimum System Voltage, Vmpp at Tmax	
	V_{MPP} each String at STC (25°)	270,20 V
	V_{MPP} at T_{max} = α_{Vmpp}x(T_{max}-25°)xV$_{MPP,String}$	-48,64 V
	$V_{MPP,\,Tmin}$ for String (Tmin)	**221,56 V**
	V_{min} Charge Controller	120,00 V
	actual $V_{MPP,\,Tmax}$<V_{minCC}	ok
G3	**Maximum System Current, Impp at Tmax**	
n	I_{MPP} Module at STC (25°)	9,08 A
y	I_{MPP} at T_{max} = α_{Impp}x(T_{max}-25°)xI$_{MPP}$	0,22 A
rr	Amount of strings in parallel	2
z	I_{MPP} System at STC (25°)	18,16 A
aa	I_{MPP} at T_{max} = α_{Impp}x(T_{max}-25°)xI$_{MPP,String}$	0,44 A
bb	I_{MPP}, T_{max} of the System (T_{max})	18,60 A
	I_{MPP}, T_{max} of the System (T_{max}) and G_{max}	**18,60 A**
	I_{max} Charge Controller	26,00 A
	Actual $I_{MPP,\,Tmax}$<I_{maxCC}	ok

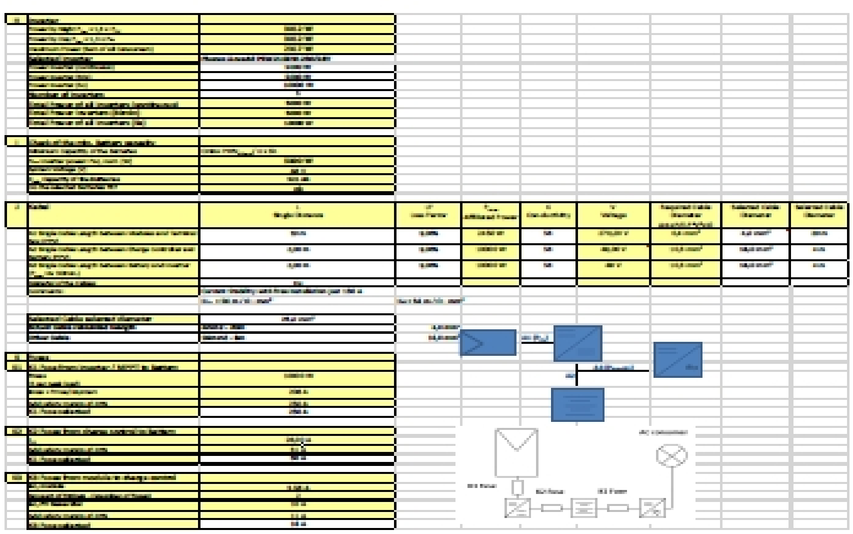


Figure 81: Typical Design Template - Adama

Self-Check - 3	Written Test

Instruction: Follow the below selected instruction

The following are true or false items, write true if the statement is true and write false if the statement is false.

N°	**Questions and answers**
1	The Bill of Materials should include all material required
True or false:	
2	A design template helps to structure the design process and avoid mistakes
True or false:	

Note: the **Satisfactory** rating is as followed

Satisfactory	1 points
Not satisfactory	Below 1 points

List of reference materials

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