Short-Course

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 M01 0120 LO1-LG05
TTLM Code	EIS PIM4 TTLM 0120v1

LO 1: Calculate Energy Demand – 05

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:

- 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 Sheet 1 (page: 3), Sheet 2 (page: 17)
4. Accomplish the Self-Check 1 (page: 16), Self-Check 2 (page: 19)

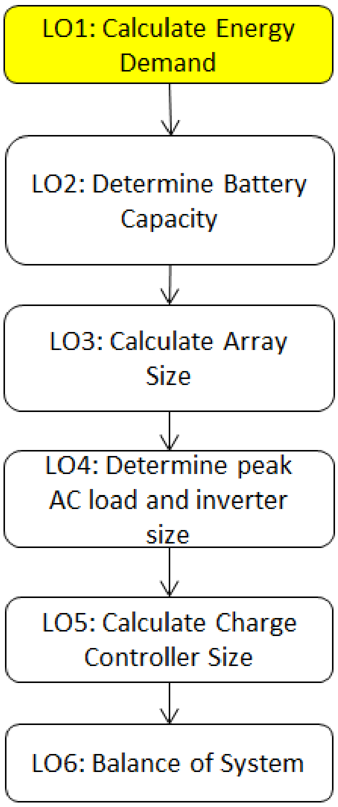
LO 1: Calculate Energy Demand

Information Sheet 1	Listing load demand in a tabulated form.

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) Site survey A Consumption B Climate data
2) PV generator C Design PV Generator D Selection of System Voltage
3) Battery sizing (BAT) E Battery Dimensioning based on consumption
4) Charge Controller (CC) F Configuration of the Modules (G Charge Controller Dimensioning
5) Inverter (INV) H Select an Inverter based on the Loads I Cross-Check Battery/Inverter matching
6) Balance of System (BoS) J Calculate Cabling diameters and length K Calculate the Fuses L Mounting System

1) Site survey

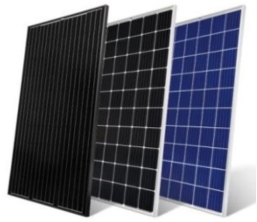
Daily Energy Consumption	
Maximum load	

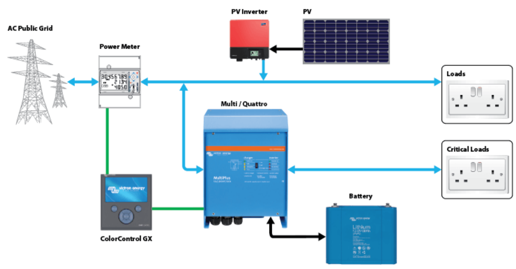
Figure 1: sequence of system design (left Module 01. right: DGS/GREEN approach)

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

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	

	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.

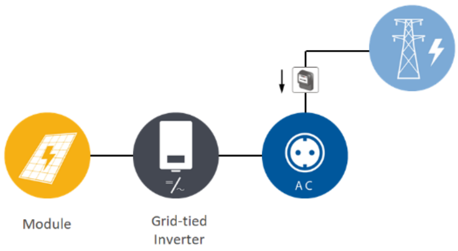


Figure 2: AC coupled Grid-tied system without batteries

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

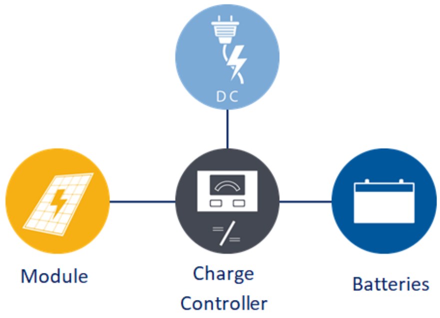


Figure 3: DC coupled off-grid system with DC loads

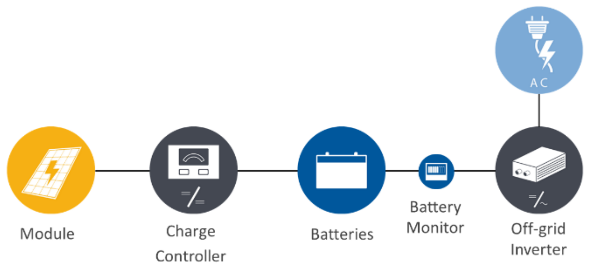


Figure 4: DC coupled off-grid system with AC loads

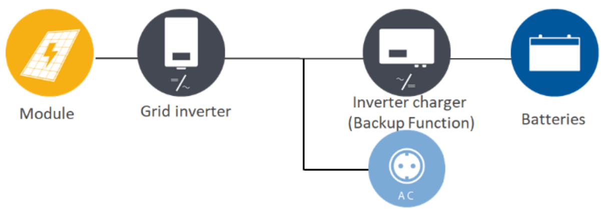


Figure 5: AC coupled off-grid backup system

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).

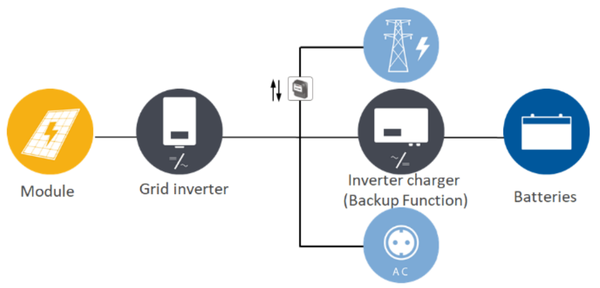


Figure 6: AC coupled grid-tied system with battery backup

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.

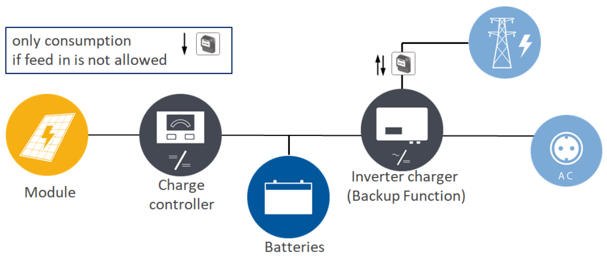


Figure 7: DC coupled grid-tied system with battery backup

Hybrid system

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

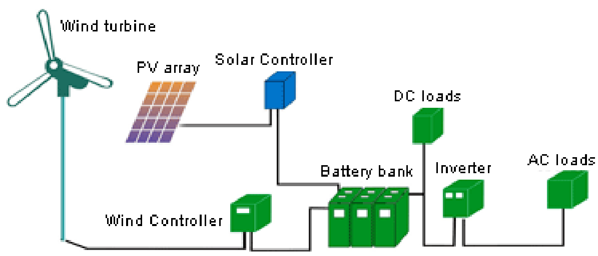


Figure 8: Hybrid System (PV and Wind) (https://www.mahaurja.com/)

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.*

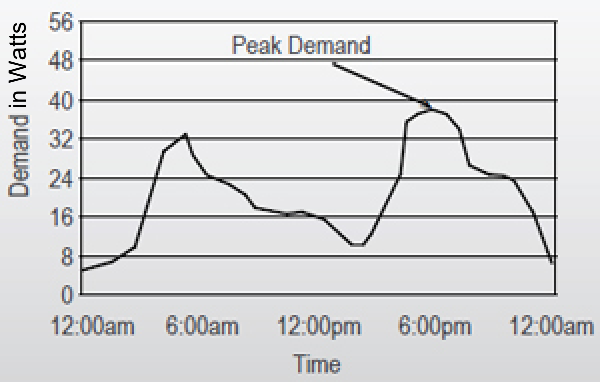


Figure 9 : Peak Load (energysentry.com)

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

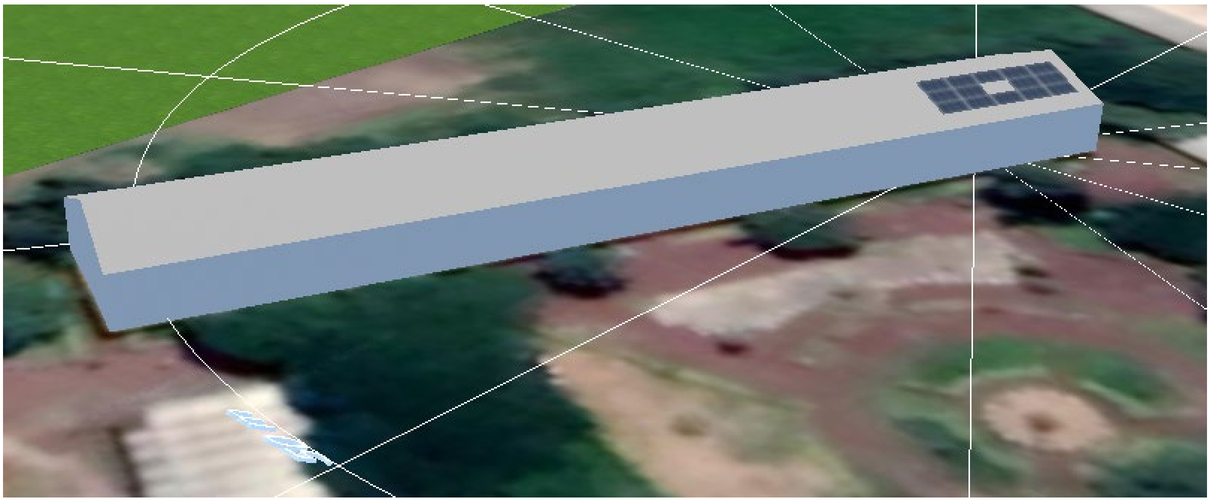


Figure 10: PV SOL rendition of the Adama design

1.4 Power and Energy

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

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 kilojoule (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

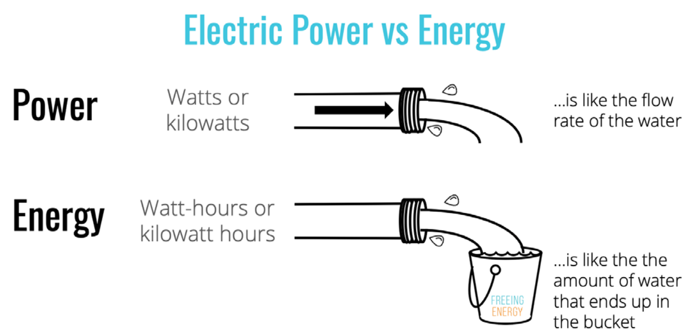


Figure 11: Power vs. Energy (freeingenergy.com)

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.

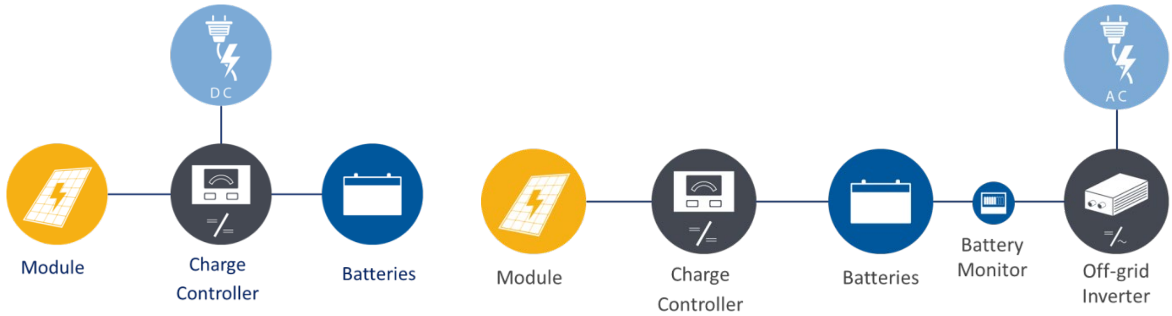


Figure 12: DC coupled off-grid system (left DC use, right AC use)

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).

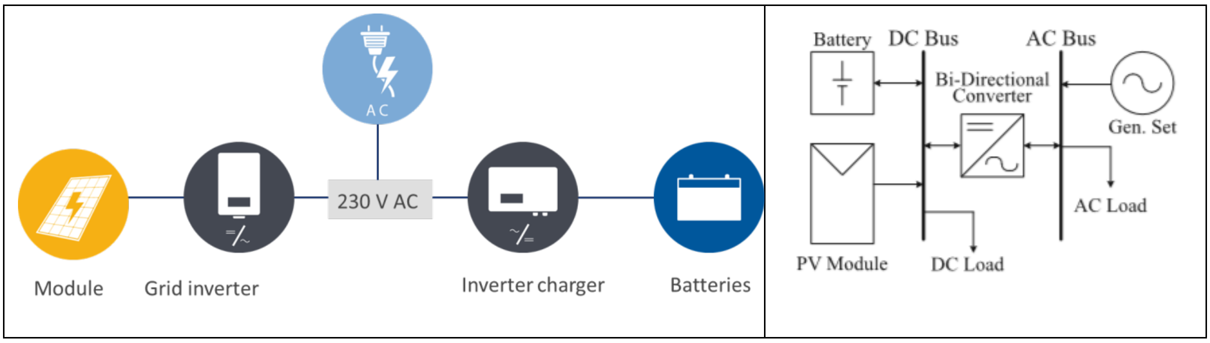


Figure 13: AC Coupled Off-Grid PV System

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).

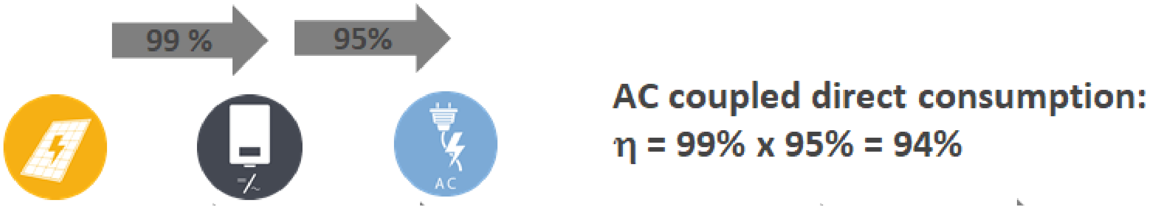


Figure 14: AC coupled efficiency for direct consumption

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).

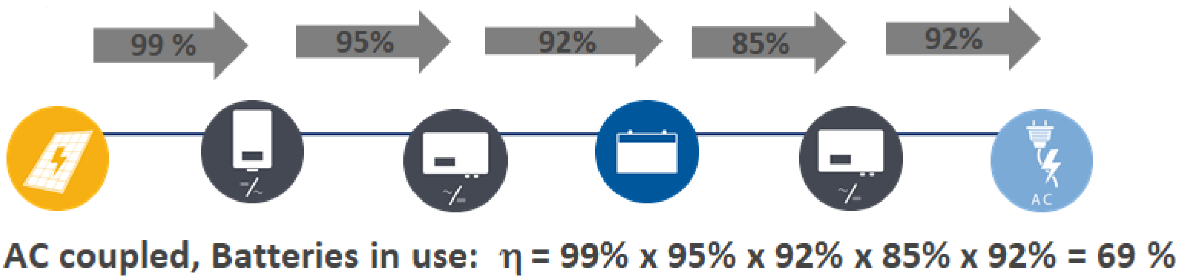


Figure 15: AC coupled efficiency when loads use power from batteries

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.

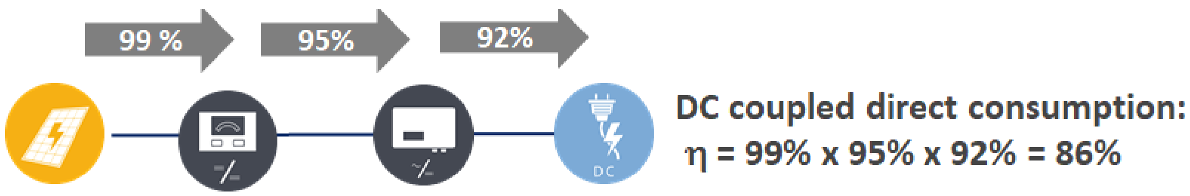


Figure 16: DC coupled system with direct consumption

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.

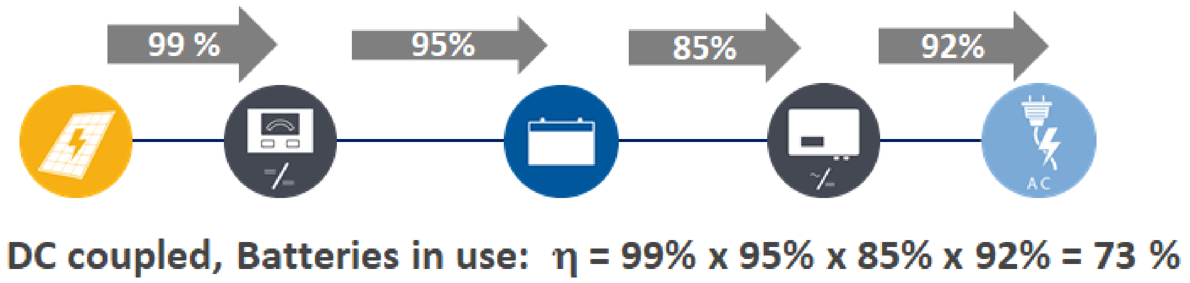


Figure 17: DC coupled system with high battery use

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

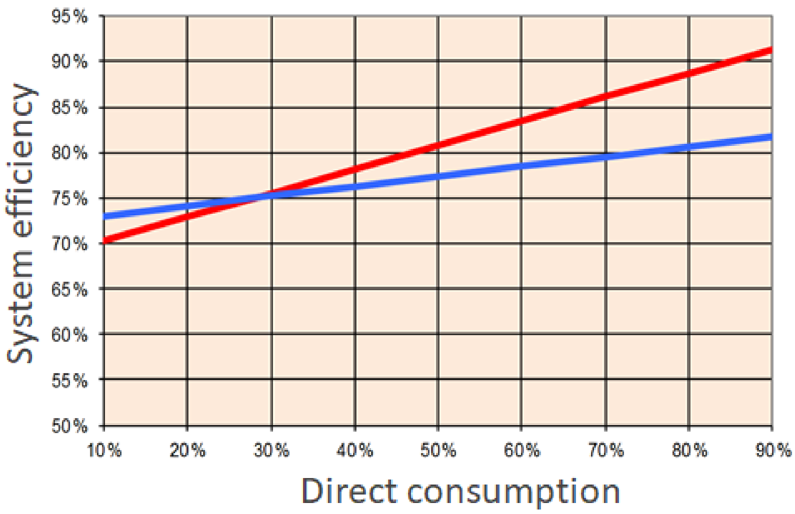


Figure 18: Efficiency vs. Direct consumption

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, namely the Phocos Anygrid PSW-H-5KW-230/48V.

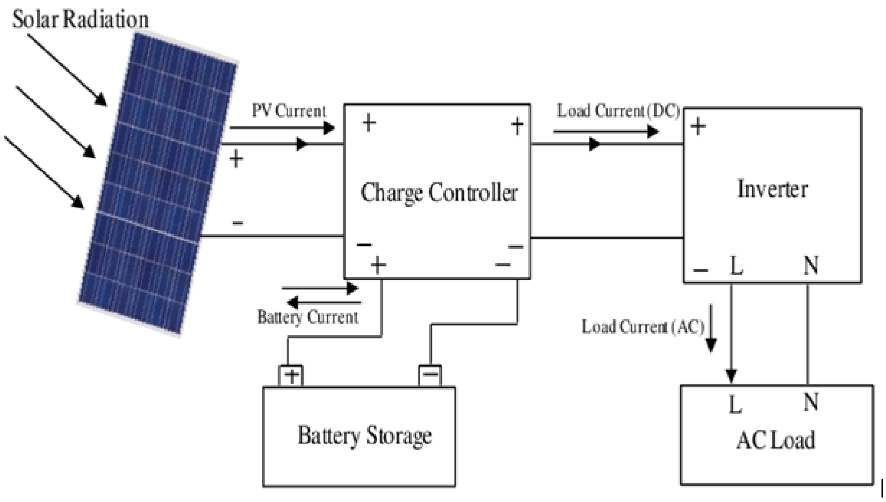


Figure 19: Off-grid PV System (researchgate.net)

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

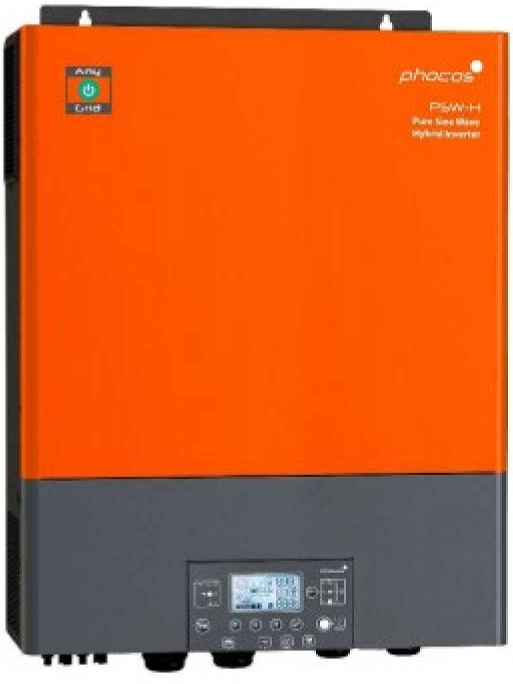


Figure 21: Phocos Anygrid Hybrid Inverter

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	2 points
Unsatisfactory	Below 2 points

Answer Sheet

Score = ___________

Rating: ____________

Name

Date

Information Sheet 2	Calculating energy demand for each load

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	2 points
Unsatisfactory	Below 2 points

Answer Sheet

Score = ___________

Rating: ____________

Name

Date