Short-Course

Solar PV System Installation and Maintenance

NTQF Level III

Learning Guide -12

Unit of Competence	Determining PV system Customer Requirements
Module Title	Determining PV system Customer Requirements
LG Code	EIS PIM3 M06 0120 LO2-LG12
TTLM Code	EIS PIM3 TTLM 0120v1

LO 2: - Recommend options for simple solar home and institution system-12

Instruction Sheet	Learning Guide -12

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

- Gathering information for system recommendation
- Approving recommendation to the customer requirement.

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: -

- Gather information for system recommendation
- Approve recommendation to the customer requirement.
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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: 49), Sheet 2 (page: 66),
4. Accomplish the Self-Check 1 (page: 65), Self-Check 2 (page: 71),
5. Perform the LAP test (page: 44)

LO2. Recommend options for simple solar home and institution system

Information Sheet 1	Gathering information for system recommendation

1 Gathering information for system recommendation

The main source for this chapter is chapter 12 of Mayfield's Book "PV Design and Installation for Dummies". Some paragraphs are taken from [Mayfield, 2010, chapter 12, page 203], some are adapted for Africa by the authors and some are added by the authors.

In this chapter we show how to read and evaluate the data form site surveys. We show how to perform a load analysis, what are the important parameters to size the PV generator, the Inverter, the charge controller and the batteries and how to select the appropriate system for the client, AC or DC-coupled, ground, roof or pole mounted, hybrid or stand alone.

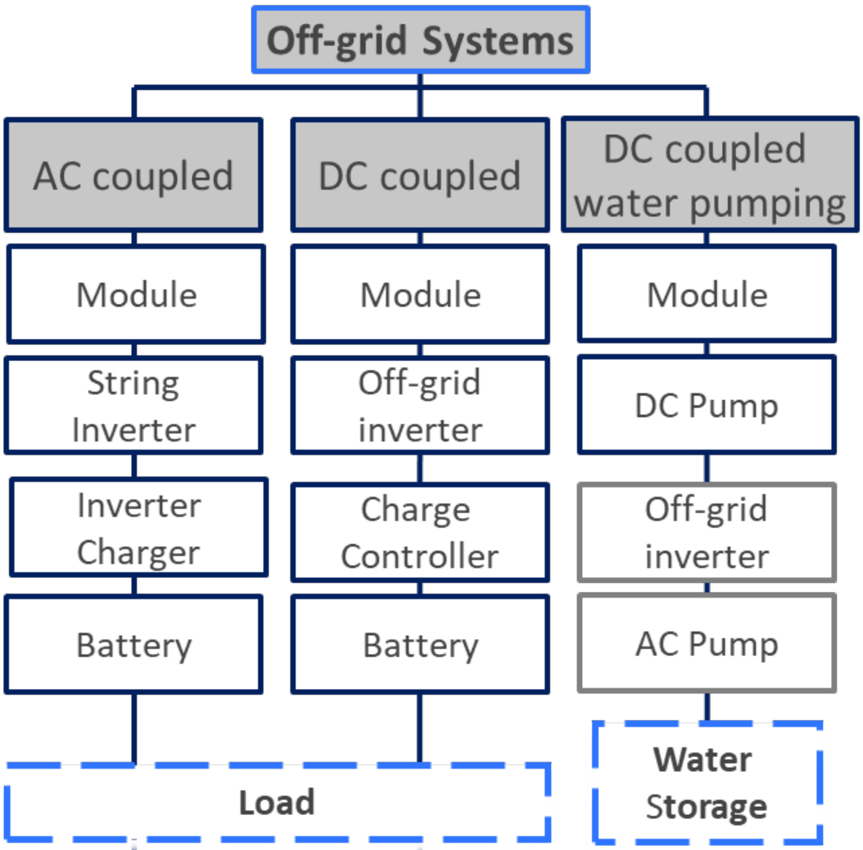


Table 14: Types of off-grid PV systems

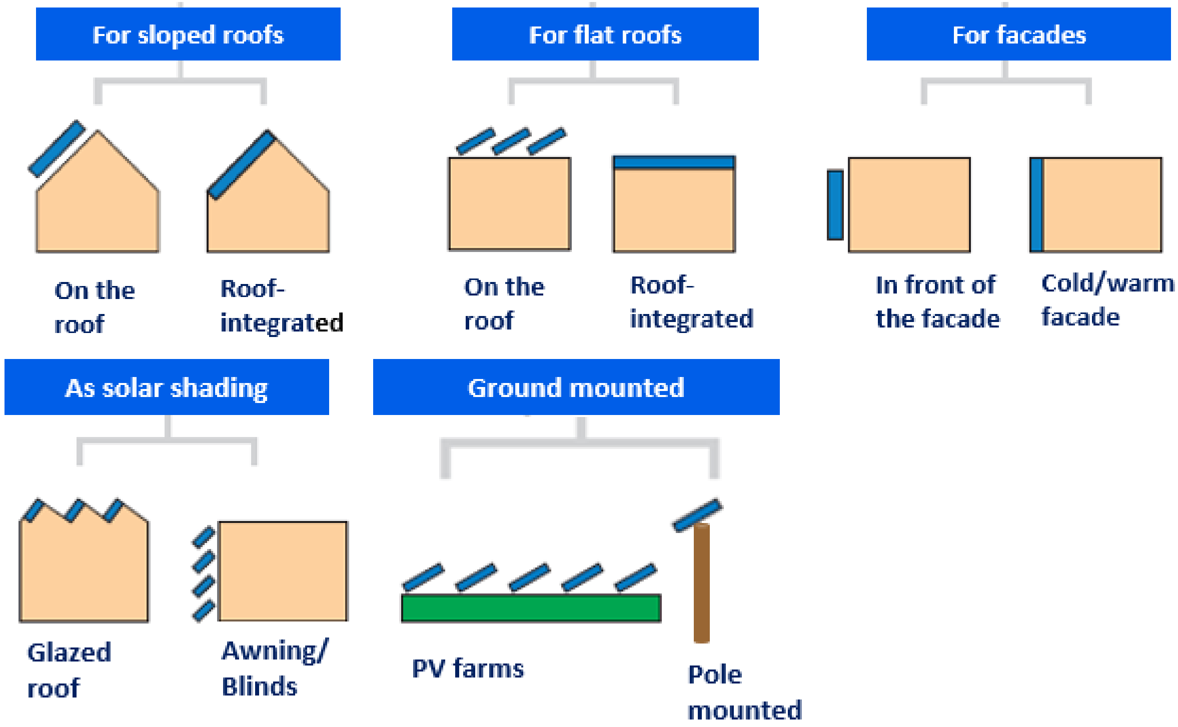


Table 15: Types of PV mounting systems

1.1 Performing a load analysis

A load is any piece of electrical equipment people want to use in their homes and offices as described in chapter 3.2 Loads/consumptions. When sizing a battery-based system, you need to establish exactly what loads your client wants to run and how long they plan to run those loads. This information serves as the basis for all of your other calculations throughout the design process.

For utility-interactive, battery-based systems, the battery bank provides power for essential loads (loads that the client wants to have on regardless of the utility availability). In this scenario, you have two load centres: the main distribution panel (MDP) and the backup subpanel. Any of the loads connected to the backup sub-panel will always be available, whereas the essential loads connected to the MDP will only be powered when the grid is present.

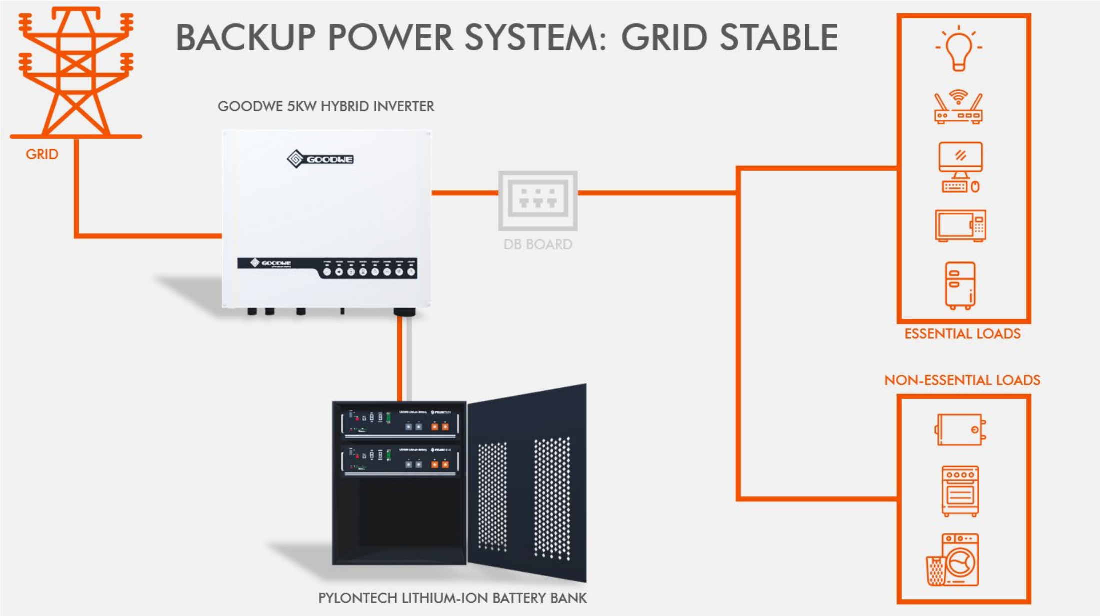


Table 16: Back up system for essential loads (Sinetech, 2020)

For stand-alone, battery-based systems, the battery bank is designed to power all the electrical loads the client wants to run.

1.1.1 Evaluating the loads that the battery bank must serve

After determining your client's budget and available space, your next task when sizing any battery-based system is to evaluate the loads the batteries will be serving. When I say loads, I mean all the loads — everything from the barely-there energy drain (think small cell phone chargers) all the way up to the electrical hogs (think air-conditioning units). When using batteries to power loads, you have to generate and store every watt-hour (Wh) used, which means you also need to find out whether a more efficient alternative exists. For example, compact fluorescent light bulbs (CFLs) produce the same amount of light as incandescent lights, but they use a lot less power. If you can convince your client to replace her incandescent bulbs with CFLs, her battery bank will be able to deliver power for more loads due to the reduced power requirements. Ultimately, the less energy your client consumes, the less expensive the system will be to install and maintain.

If the client has no access to electricity so far you should even consider to offer him a complete DC system with decent DC devices. This only makes sense, if DC loads are available locally, if the customer has the budget to invest in DC loads and if the customer does not intend to use AC loads or to connect to the grid. People from rural areas often rely on their relatives who work and live in the City. In this case they usually get the old devices (computer, TV, fridges) from the relatives, which are always AC devices. Make sure that this is not the case, as it would be very frustrating for the client if he would have a DC system and then not be able to operate those AC loads.

Following are some points to consider about the common loads powered entirely or partially by battery banks:

Well Pumps

In many situations, a well pump is the sole source of water for a home. Well pumps can be large electrical loads with the potential to cause problems for the inverters and batteries in a battery-based system. With advancements in inverter technologies, however, inverters are much better at running these large pumps.

Look at the well pump's power draw and try to determine the energy consumption (see the next section for details). If the pump is being replaced or hasn't been installed, try to work with the pump supplier to get the most energy-efficient version available.

DC pumps are especially interesting as you can run them directly with a solar module.

The American company, SHURflo, is one company which offers great solutions for remote water pumping. One can use these pumps by only connecting the solar module with the pump, in case both have the same voltage. If not, a pump controller could be needed. In any case no extra battery is needed. The water is pumped when the sun is shining and stored in a tank. This can either operate automatically using water level sensors or purely manually using a person to switch on and off the system.

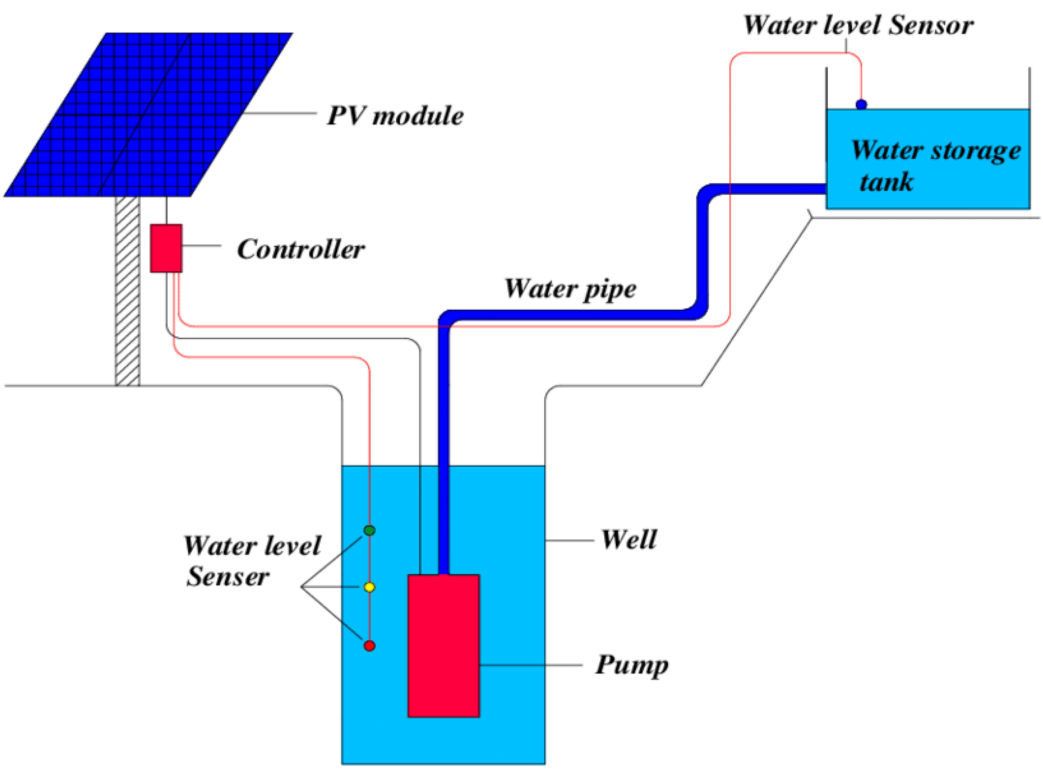


Table 17: Principle of solar water pumping using a submersible pump

Refrigeration and lighting

Refrigeration and lighting will be present in most homes or offices, so you need to be able to account for them accurately. In the next section, I show you how to account for the energy consumed by these appliances and how to make sure you design the battery system to handle these loads.

Phantom loads

The small loads that are on 24/7 are the so-called phantom loads. Many televisions and entertainment centers draw power even when they're "off," and chargers for small electronic devices and digital clocks incorporated in microwaves and stoves can cause major problems. If these small loads are always present, then the inverter can never turn off and must always supply power. Therefore, the inverter requires a small amount of power to produce a low level of power, causing it to operate at its worst efficiency level.

The solution to phantom loads? When no major loads are running, allow the inverter to go to sleep by unplugging the phantom loads. By removing these small loads, the inverter can go to sleep and wake up (and operate more efficiently) when the larger loads are turned on.

Loads one should not operate with PV systems

One type of load that should never be placed on a battery bank is anything that uses electricity to generate heat (these are called resistive loads). That rules out water heating, space heating, and electric stoves (incandescent lights also fall into this category). In a stand-alone, battery-based system, petroleum-based fuels generally support resistive loads, with propane being one of the most common in off-grid applications. For people connected to the grid with a utility-interactive, battery-based system, these loads can still be present; you can't just back them up with the batteries.

Back-up systems

In back-up systems, also called utility-interactive, battery-based system, loads served by the batteries should generally be kept to a minimum; the batteries should only supply power to loads that are truly necessary (which means you need to have a frank conversation with your client to help her evaluate what's really necessary in her daily life). This is because the utility grid is the primary power source, and the batteries are merely the backup power source.

When talking about utility-interactive, battery-based systems, people often refer to loads the battery bank needs to back up when the grid fails as critical or essential loads, see Table 16.

Typical and Essential Loads

Only the customer can decide which loads are critical or essential for him. Sometimes it is an electric fence, sometimes light, sometimes TV. Typical essential loads in Ethiopia are light, internet, mobile phone charger, computers, TV and printers.

You must be careful though; if you make it too easy to pull power from the battery bank, the system owner will do exactly that and then be disappointed in the lack of time that the batteries back up those "few" loads.

For a stand-alone battery-based system, a load is just a plain old load, not a backup load or a critical load. People who live in off-grid homes typically have major lifestyle differences from people who live in homes that are on the grid. They have to evaluate the necessity of anything that requires electricity to run because they don't have unlimited access to electricity. This doesn't mean that your client can't lead a "normal" life (whatever that means anymore); she just has to become selective in her electrical consumption.

DC Loads

Some clients with stand-alone systems may want to run some loads straight from the DC electricity stored in the battery bank. Nowadays, you can find almost any load you need for rural areas as DC loads, where by the most common loads are lamps and fridges. giz published 2016 a catalogue of DC-Appliances under the title "Photovoltaics for Productive Use Applications"

Table 18: Typical DC Loads from the company SolarWorks

These DC loads are nice in the sense that they can pull power directly from the battery bank without the help of an inverter, which increases the overall efficiency of the system because the loads use the same type of electricity produced by the PV array and stored in the batteries. However, DC loads are found in special locations and must be matched to the voltage available from the batteries and the clients need to have the budget to invest in those loads as described above.

Keep DC loads separate on your list of loads. When you have to account for system efficiencies, you'll use the DC loads in your calculations.

1.1.2 Calculating the energy required during an outage for utility-interactive systems

For a utility-interactive, battery-based system, you need to know how much energy your client will need to use over a very short period of time. After all, most people experience power outages that are measured in hours (or a few days at the most). On top of the short duration, typically only a few loads need to be backed up during an outage. If, however, your client insists on powering the entire house/office or a number of major loads, you need to incorporate a generator into the system design

When designing a back-up system, look at the loads the client wants to run during an outage and estimate how much energy they'll consume during the specific amount of time required. You can do this by multiplying the total drawn watts for a load by the number of hours it needs to run during a utility outage to find the total energy consumption during the outage. Generally, 24 hours is enough, except for those clients who want to have multiple days of backup.

1.1.3 Determining the average daily energy consumption for stand-alone systems

After you've identified all the loads (both AC and DC), you need to evaluate how much energy each load consumes in order to begin the process of sizing all the required components. Going through the load analysis may seem like a real pain, but if you don't take the time to estimate each load's energy consumption, the installed system will be either grossly under- or oversized for your client's needs. Both situations result in a waste of time and money.

To determine the amount of energy consumed by each AC load in kilowatt- hours (kWh), you need to know the number of watts the load draws, the amount of time it runs each day, and the number of days it's used each week. Certain loads may only run a few times a week, whereas others may run daily. By averaging out the loads over a week's time, you can establish a consistent pattern of energy consumption. Use the following equation:

$$\text{Energy (in watt-hours)} = (\text{Watts} \times \text{Hours per day} \times \text{Days per week}) \div 7 \text{ days per week}$$

When estimating weekly energy consumption, include all the watts drawn. For example, if you're looking at lighting, don't just calculate the energy based off of one light — look at all the lights that will be on at the same time. Please also consider the usage time, is the load being used in the night or in the day only, or even permanently.

The source to calculate the energy and the power you need is the consumption table from the site survey.

1.1.4 Example, family house in Adama

The Kebebe family (2 adults and 4 kids) lives in the Adama region in a town house without electricity. They called the PV Installer Dave and ask him if he could deliver a solar system for their house. They know about Dave as he installed a system for Mr. Kebebe's brother. Dave explained to him that one cannot sell a PV system as if it were a TV, as the system has to be adapted to the requirement of the individual family and they agreed that Dave comes for a site survey.

Table 19: The house of the Kebebe family in Adama

During the site visit, Dave discussed the electricity use with the Kebebe's and documented the power consumption as part of his site survey, see raw 1 to 7.

Table 20: Electricity consumption overview of the Kebebe family

1	2	3	4	5	6	7	8	9
Collected Information							Calculated Information	
No.	Technical device	AC or DC	Quantity	Power [W]	Operation time [h]	Usage Time	Consumption [Wh/d]	Total Power in Watt
1	Illumination	AC	4	3	6	night	72	12
2	19" led tv	AC	1	15	7	night	105	15
3	decoder	AC						
4	Laptop	AC	1	65	2	Day	130	65
6	Charge Controller	DC	1	0.15	24	Night/day	3.6	0.15
7	Inverter standby							
8	Inverter ON							
TOTAL							**310.6Wh/d**	**92.15W**
Total day								**92.15W**
Total night								**27.15W**

As a first step Dave has to calculate the total consumption of the Kebebe family and note his results in column 8 and 9.

The Kebebes use 4 lamps that draw 3 W for 6 hours. They run 7 days a week, thus you can determine the average daily energy value by multiplying the number of lamps, the power drawn and the number of hours to get

4 lamps x 3 W × 6 hrs. = 72 Wh, or 0.72 kWh

So, the operation of the lamps consumes 0.72 kWh every day. The overall electricity consumption is 310.6Wh/d with a max. power of 92.15W.

The Kebebe family only uses AC loads, as they already got all devices from their relatives, thus, it was easy to evaluate the overall energy consumption. Sometimes the clients have not yet purchased their devices, then you could estimate loads using typical devices. See some examples below.

Table 21: Performance of typical 12V lamps (Hankins, 2010)

Table 6.1 *Performance of typical 12V lamps*

Lamp type	Rated watts (W)	Light output lumens (lm)	Efficacy (lm/W)	Lifetime (Hours)	Light colour (K)
Incandescent Globe	15	135	9	1000	2700–3000K
Incandescent Globe	25	225	9	1000	2700–3000K
Halogen Globe	20	350	18	2000	2700–3000K
Batten-type Fluorescent (with ballast)	6	240	40	5000	4100–6300K
Batten-type Fluorescent (with ballast)	8	340	42	5000	4100–6300K
Batten-type Fluorescent (with ballast)	13	715	55	5000	4100–6300K
PL-type Fluorescent (with ballast)	7	315	45	10,000	4100–6300K
LED Lamp	3	180	30–100	>50,000	Depends on lamp type

Table 22: Approximate power and energy requirements for common off-grid appliances (Hankins, 2010)

Table 6.3 *Approximate power and energy requirements for common off-grid appliances*

Appliance	Typical daily usage time	Power rating (W)	Typical daily energy use (Wh)	Notes
Sewing machine	2 hours	80	50	Motor is engaged only 25% of time
14in colour television	2 hours	80	160	More efficient versions available!
14in black-and-white television	2 hours	24	48	
Radio	3 hours	3–30	9–90	Power draw depends on volume setting
Music system	2 hours	10–40	20–80	Power draw depends on volume setting
Electric iron	30 minutes	300	150	Not recommended for PV systems
Soldering iron	10 minutes	200	45	
Electric drill	5 minutes	150	30	
Computer and monitor	2 hours	80–150	160–300	
Laptop computer	2 hours	25–40	50–80	
Fan	continuous	60	1440	
Water pump	3 hours	450	1000	
DC Refrigerator	continuous	100–150	300–450	Actual energy use depends on ambient temperature. Refer to datasheets

1.1.5 Autonomy days

The number of days your client wants their battery bank to sustain their electrical lifestyle is known as the days of autonomy. In other words, it's the number of days the client expects their battery bank to provide her with her average daily energy requirements without needing to be recharged by the PV array and the charge controller, generator, or utility. This number is completely up to the system owner but you (as the system designer) should offer suggestions that will keep your client satisfied. The local climate usually plays a major role in this decision, as does the available budget for the project. As you can imagine, the more days of autonomy, the more batteries you need and the higher the system cost climbs.

Off-grid system for telecommunication towers usually need up to 5 days to secure the ongoing performance, as usually technicians come max. one per year for maintenance purposes. Households can sometime deal with 1 ore 2 autonomy days as they life with their system and could decide to use less loads during days with less sunlight.

1.2 Determining the PV generators' capacity

The relevant values to size the PV generator are:

- The energy consumption of the customer
- The insolation or sunshine hours and
- The usage time of the PV system (permanently, seasonally, selected days only…)

1.2.1 Introduction

When the battery-based system you're sizing is of the stand-alone variety, the PV array needs to produce an amount of energy equal to your client's average daily energy consumption (as calculated in the earlier section). If it doesn't, the battery bank will never be able to recharge fully. In addition, the array should be able to help recharge the battery bank after there has been little to no charging by any source (such as the PV array or a generator) and the battery bank has dipped into the reserve supplied by your client's desired days of autonomy, see 1.1.5.

In reality, the amount of energy consumed isn't a constant value; it changes throughout the year. Depending on the size of the house and the location, people may have a different energy consumption in the different seasons. Some houses use fans or air conditioners, but only in the warm months. In some regions the days are much shorter in winter and the families need less light at night. You have to consider all those facts while evaluating the electricity consumption and determining the PV generator.

The advantage of most of the regions in Africa is that the high energy consumption related to hot summers correlates with high solar resources. In Europe usually high consumption is related to winter. This situation presents a problem for the PV system designer. If you design the PV array around the scenario of high consumption and low solar resource, you'll end up with a PV array that's very large. Come summertime, when the energy consumption is reduced and the solar resource is increased, the PV array will be oversized and have the batteries charged very early in the day, which is bad because the PV array will be underutilized those times of the year, and the initial system cost will be outrageous.

To determine the appropriate array size in watts, you need to evaluate the information about the site you gathered during the site survey and make some assumptions regarding the operation of the system. These values will help you estimate the array size needed based off of the total energy consumption you calculated in the very beginning of the process.

The power of the PV generator is calculated as follows:

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

You need to know the:

- Energy consumption (to be calculated based on the data collected during the site survey).
- the solar irradiation in the respective region; the “fuel” which is available in peak sun hours and (to be researched using tools like PVGis or PV Sol)
- the system efficiency (to be calculated)

The approach is simple, you calculate how many modules you need to produce enough electricity to fuel your hour loads.

The Energy consumption is the electricity you need.

The peak sun hours is the electricity the sun is sending.

And you simply divide these 2 values by each other. To ensure that you really have enough electricity you multiply the PSU with the system efficiency. Meaning you say that you can never use 100% of the solar electricity which arrives on the PV modules, but only less, typically 65%.

1.2.2 PV Generator for the Kebebe Family

Dave investigated the weather conditions in Adama and found the following information:

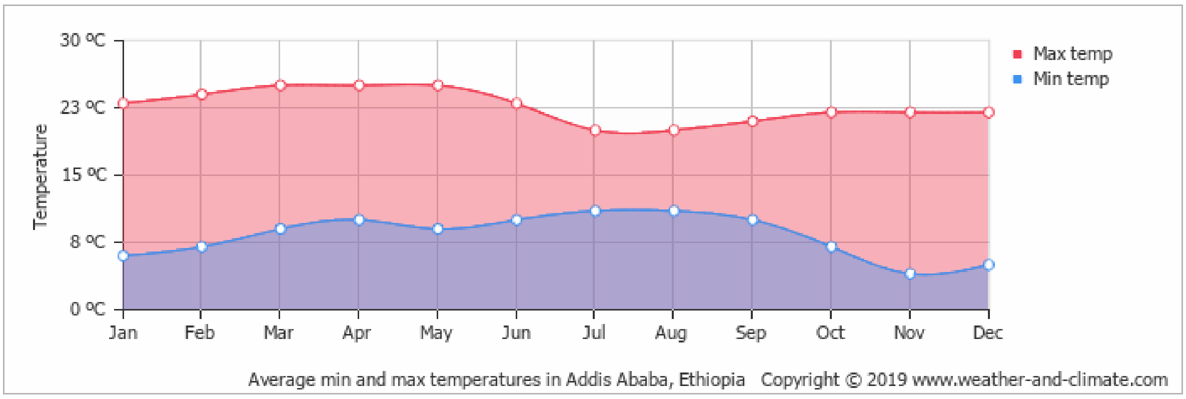


Table 23: Average max and min Temperature in Addis Ababa

Table 24: Average sun hours in Addis Ababa

Furthermore, he checked the average peak sun hours with the PV GIS tool.

Peak Sun Hours: Mekele Optimal (Slope: 11 degrees, Azimuth 12 degrees)

J	F	M	A	M	J	J	A	S	O	N	D	Ø
6.96	7.43	7.35	6.56	6.24	6.13	**5.63**	5.75	6.23	7.05	6.93	6.93	6.6

He decided to design the system based on the minimum peak sun hours 5.63 h, as the yearly changes are not that high.

$$P_{PV} = \frac{E}{G \times h} = \frac{180.6\ \frac{Wh}{d}}{5.63 \times 0.65} = \mathbf{84.87Wp}$$

Dave always works with a system efficiency of 65%, as this is a proven value. How to calculate the system efficiency is explain in module 1 level 4.

1.3 System Voltage

For any battery-based system you install, you need to look at battery bank nominal voltages of 12, 24, or 48 V_{DC}. The basis for the selection of the battery bank voltage is the system voltage, which depends on the PV array capacity and needed power. The table below shows suggested system voltages for different inverter power.

Table 25: System Voltages of PV systems

System voltage*	**12 V**	**24 V**	**48 V**
Limiting power generator/inverter	**Up to 1 kW**	**1-5 kW**	**5 kW & over**

According to Hankins, 2010 “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. This means batteries are configured at 12V DC and the charge regulators and modules are rated at 12V DC. Lights are normally 12V DC in such small systems. 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.

MPPT charge controllers accept electricity from the array at a range of voltages (i.e. from 15 to over 100V) and deliver it to the battery at 12 or 24V. Many charge regulators and inverters can operate at either 12 or 24V DC. They sense the system voltage and adjust to it automatically.

Even though an inverter is used to convert power from DC to AC on the distribution side, the system voltage will still be between 12V and 48V."

1.4 Determining the battery bank's capacity

The relevant values to size the battery banks are:

- System voltage
- Autonomy days
- The energy consumption of the customer

After you know what your client's electrical lifestyle is on an average day, you need to translate that into the amount of energy stored in her battery bank (also known as the battery bank's capacity). For any battery-based system — whether utility-interactive or stand-alone — when you size the battery bank, you take the view that no other source of power exists (at least for a certain amount of time) and that the battery bank is the primary source of energy (the PV array, a generator, or the utility merely replenishes the battery bank when it discharges). Consequently, you need to size the battery bank to run the electrical loads your client wants, when she wants — which means you need to establish some criteria that you expect the battery bank to follow. All of the following dictate the battery bank capacity you're looking for:

- The efficiency of the inverter
- The number of days you expect the battery bank to last without recharging
- The batteries' operating temperature and voltage
- How much of the battery bank your client is willing to use
- The voltage at which you want the battery to operate

When you buy batteries to make up the entire battery bank, you have a few options. The most common battery type for battery-based PV systems is a 6 V nominal battery (This battery has three individual cells in it that are all wired internally to deliver 6 V across the terminals.). You then take these batteries and wire them in a series-parallel arrangement to achieve the voltage and capacity characteristics you're after. Other options include 12 V nominal batteries as well as individual 2 V cells in their own plastic cases; these cells look like batteries, but because there's only one cell, technically they're cells and not batteries. (Batteries also come in 4 V and 8 V nominal arrangements, although these are less common.)

1.5 Making sure the inverter fits

The relevant value to size the inverter is:

- Maximum power of all consumers per day.
- Capacity of the battery

You must discuss which load is relevant to design the inverter and select an inverter with a continuous power which is higher than the relevant max power of the loads.

$P_{INV,\ continuous} > P_{loads}$

To ensure that the loads do not harm the inverter we even include a safety margin of 30% in this calculation.

$P_{INV,\ continuous} > (1{,}3xP_{loads})$

The Mekele family you should design the inverter based on the power P_{loads}= 92.15W.

$P_{INV,\ continuous} = P_{loads}$= 92.15Wx1,3=120 W

You should suggest to the Mekele family an inverter with a load of 120W. Off-grid inverter loads are usually given for continuous 30s and 5 s operation. This means you can operate higher loads for a short time so that short peaks do not destroy your inverter. It is important that your customer understands that a 120W inverter could not operate a 500W boiler. Cheap ones will break, better quality ones with overload protection will switch off. However, these overloads should be avoided.

All inverters are rated by their maximum continuous power output, which is measured in watts or kilowatts (More often than not, this number is incorporated into the inverter's model number, giving you a quick idea of the inverter's rating.). This value is the AC power output. Inverters limit their power output, so you can use this value to figure out the maximum power input coming into the inverter from the PV array.

During the detailed design process, you also have to consider that the module ratings fit to the inverter and that the battery bank is big enough to ensure inverter stability.

1.6 Calculating required charge controller

The relevant value to size the charge controller is:

- The system voltage (Series and Shunt charge controller)
- The output of the PV generator and
- The Capacity of the battery
- The temperature variation of the modules

There are 2 main types of Charge Controllers, PWM and MPPT Controller. The right Charge Controller is chosen considering budget, climate zone, module availability and required power. PWM charge controllers work on system voltages and can operate systems with 12, 24 or 48 V modules. MPPT chargers are preferable when using solar panels with more than 36 cells in a 12V system or 72 cells in a 24V system or when using 60 cell modules as they work on system voltages.

Depending on the energy demand, the budget of the customer and the availability of material, especially modules, you would suggest either a simple system with PWM charge controller or a more complex system with the MPPT charge controller.

The Charge Controller is the “brain“of a PV off-grid solar system. It controls how much energy from the Module is forwarded to the battery to optimize the charging process. It also protects the battery from deep discharge by showing you how much energy is in the battery. And it monitors the discharge, but only of the DC loads.

The figure below shows the tasks a charge controller takes over in a DC coupled off-grid system. The arrows in the picture show where the charge controller has an impact.

The charge controller is the “brain” of the system that interprets the needs of the battery so it has many tasks. All the programming regarding the charging is done at the charge controller, such as nightlight function e.g. In general, the main task of the charge controller is charging the battery and keeping it “healthy “.

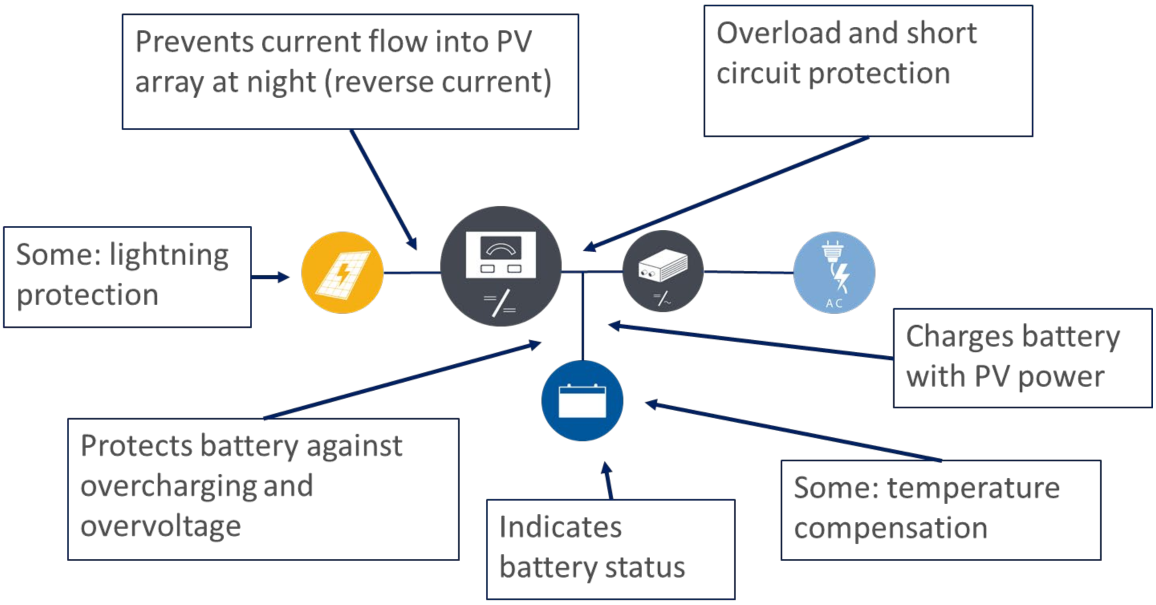


Table 26: Functions of a charge controller in an off-grid system

Self-Check - 1	Written Test

Instruction: Follow the below selected instruction

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

N°	Questions and answers
1	**Please list 5 typical DC loads:**
2	**When should a PV installer suggest his customer to use DC loads?**
2	**Please list min. 4 functions of a charge controller in a PV system.**

Note: the satisfactory rating is as followed

Satisfactory	6 points
Unsatisfactory	Below 3 points

Answer Sheet

Score = ___________

Rating: ____________

Name

Date

Information Sheet 2	Approving recommendation to the customer requirement

2 Approving recommendation to the customer requirement

If your client wants to buy an off-grid PV system you have to decide which type and size of system he needs. The main criteria are how many Watt the consumers wants to operate and how much time he wants to use them. Also, you can vary the capacity of the battery, the power of the inverter and the power of the modules to adjust them to the requirements of the customer.

Other important points are the budget of the customer and the available space.

Customers usually have different reasons why to invest in a PV system and you have to understand where your customer is coming from. Here are 6 reasons for buying a SHS:

- **Financial Savings.** With an off-grid solar system one is independent from rising electricity costs; the power of the sun is free!
- **Security.** When the public grid breaks down one still has energy.
- **Independence.** Even when one lives in remote areas without a connection to the public grid you have electricity from your off-grid solar system.
- **Mobility.** When one travels a lot and needs electricity wherever a small portable SHS is comfortable.
- **No disposable batteries.** With an off-grid solar system one can operate directly radios or lamps at home or charge small rechargeable batteries to run these mobile devices. No more money to spend on disposable batteries and saving the environment.
- **Flexibility.** One can start with a small off-grid solar system but systems can be upgraded if you need to provide more electricity.
- **Green energy.** Using the renewable energy of the sun without affecting the environment.

Once you have evaluated the site survey and prepared all input data for the system design, you have to decide if you want to suggest to the client a DC or an AC coupled system and what components you would suggest.

The main source for the description of DC and AC coupled systems is chapter 4 of Louie's Book "Off-Grid Electrical Systems in Developing Countries". Some paragraphs are taken from [Louie, 2018, chapter 4, page 88], some are adapted for Africa by the authors and some are added by the authors.

2.1 System coupling (AC/DC)

There are two types of coupling: AC and DC-coupled systems. The type of coupling depends on how the energy sources are connected, independent of whether the load is AC or DC.

2.1.1 DC Coupling

DC coupled Systems were the first off-grid systems in use. They can run DC loads, as shown in Table 27: Basic DC-coupled system, only DC electricity useTable 27: Basic DC-coupled system, only DC electricity use, but also operate AC loads as shown in figure Table 28: Basic DC-coupled system, with AC conversion. To run AC loads the DC electricity has to be converted to AC using an inverter.

The term DC coupled refers to the connection of the PV system. As the term implies, DC-coupled systems are connected to the DC side of the PV system.

In DC-coupled systems, the energy sources are connected in parallel at a DC bus. In most off-grid systems, there is a single DC bus. DC-coupled systems almost always include a battery. AC components must include an inverter or rectifier to be integrated into a DC-coupled system. The battery sets the DC bus voltage. Although the problem with forming and maintaining the frequency of the AC bus is eliminated (unless multiple inverters are connected in parallel), the battery must be protected from being over- or undercharged. For this reason, a system with a DC bus should have charge controllers or diversion loads and diversion load controllers. A charge controller limits the current supplied by a source; a diversion load provides a parallel path for the current, reducing the current into the battery. The DC-coupled architecture issued in smaller capacity mini-grids and in solar lanterns and solar home systems.

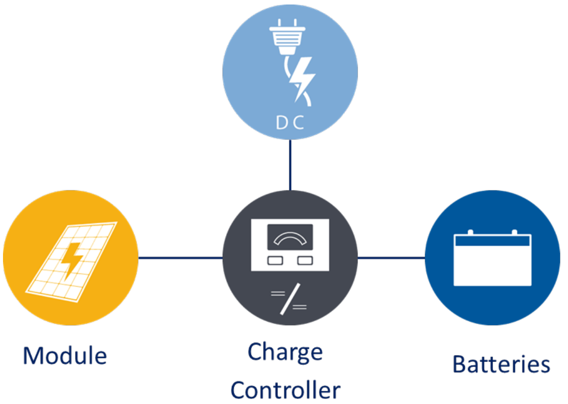


Table 27: Basic DC-coupled system, only DC electricity use

In order to run AC devices, one has to add an inverter or work with an inverter charger. The simplest and most used option is to connect an inverter to the battery. Or, with or often even without, a battery monitor. The main problem with these solutions is that without battery monitor there is no link between the charge controller and the inverter, hence the electricity drawn by the inverter out of the battery can't be monitored by the charge controller.

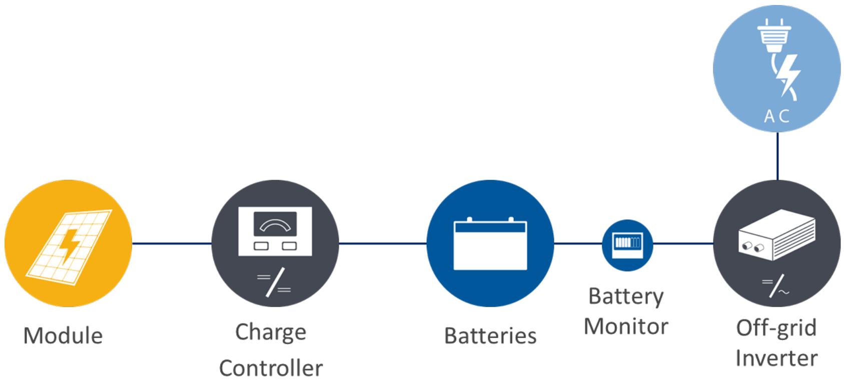
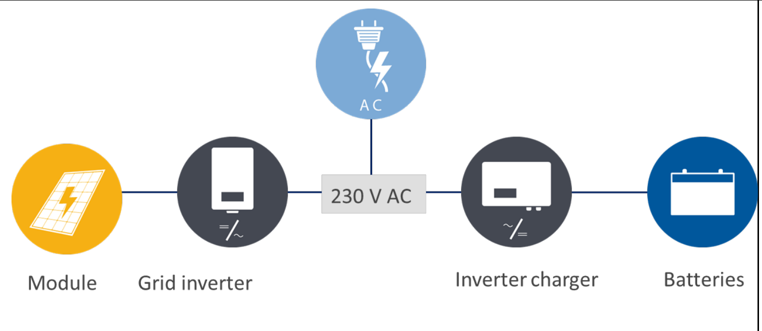


Table 28: Basic DC-coupled system, with AC conversion

2.1.2 AC Coupling

The central feature of an AC-coupled system is the AC bus. Note that the schematics shown in Table 29: Typical AC-coupled system is intended to be illustrative only— it is possible, for example, for an AC-coupled system to have somewhat different components. The schematics show the high-level connection of the components, with the arrows indicating the possible flow of power. For clarity, the distribution and end-use systems are not shown. Do not confuse the schematics with circuit models, even though at times the same symbols are used in both. In electrical terms, a bus is simply a node in the system where various components are connected. National grids can have thousands of buses; mini-grids often have just one. The AC Bus is often just a copper bar inside the circuit breaker box with several cables and switches or circuit breakers attached. All the components connected to the AC bus are in parallel, and so they operate at the same voltage frequency and magnitude. This means that the voltage output by the generators must be synchronized.

DC components cannot be used unless they are connected to the AC bus through a rectifier or an inverter. The voltage frequency and magnitude at the AC bus should be approximately constant. Certain sensitive loads cannot tolerate deviations beyond a few percent without damage or malfunction. Other loads such as heaters and incandescent lights are more robust and can tolerate variation in the voltage and frequency. Control of the AC bus voltage frequency and magnitude is an important aspect in consideration of AC-coupled systems. Normally, one component is controlled so that it resembles a voltage source. This component is said to be “forming” the AC bus. The other sources must be able to synchronize to the AC bus voltage and are controlled as current sources to inject power into the bus. For reasons discussed in Louie’s Book “Off-Grid Electrical Systems in Developing Countries”, only energy conversion technologies capable of adjusting their power output on demand and that have a voltage control system can be used to form the AC bus. This functionality is usually found in conventional- and biomass-fueled internal combustion engines and certain MHP systems. Inverters are also capable of forming the AC bus. One reason why WECSs and PV modules cannot be used to form the AC bus is that they are only capable of producing power when there is sufficient wind speed or sunlight. However, they can be integrated into the system as long as some other source forms the AC bus voltage. AC-coupled systems can be easily expanded by connecting additional load and generation to the AC bus.



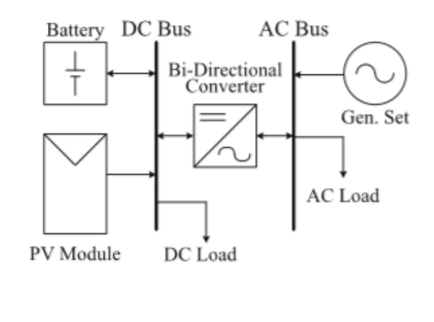


Table 29: Typical AC-coupled system

The main advantage of AC coupled systems is the use of components, especially modules, which are used in grid-tied systems. A disadvantage is, that you either need 2 inverters or expensive inverter chargers, such as SMA's sunny island. In the last years MPP charge controllers are more and more available for DC coupled systems. They also operate with standard modules. Hence, the advantage to use standard modules is now also available with some DC-coupled systems.

2.2 Component selection

When selecting the components, you have to decide if you want to offer an AC or DC coupled system. The size of the system, the operation time, the budget of the client and the availability of material are main points which should influence your decision. Please see below a matrix which should help you to select the right system for your client.

Table 30: Choosing the Right System AC or DC

Requirements	AC Coupling	DC Coupling
Installation	++ standard	- specific
Distance	+ Up to 1 km (230 V)	-- Up to 50 m (24 V)
Expandability	++ No limit	0 Very limited
Costs	+ Standard product, modular, but 2 inverters	+ for small SHS no yet standard products, but less components
Loads to be supplied	++ All	+ Small loads only (household level)

Table 31: Efficiency of DC and AC coupled Systems shows you the efficiency of the DC and AC coupled system.

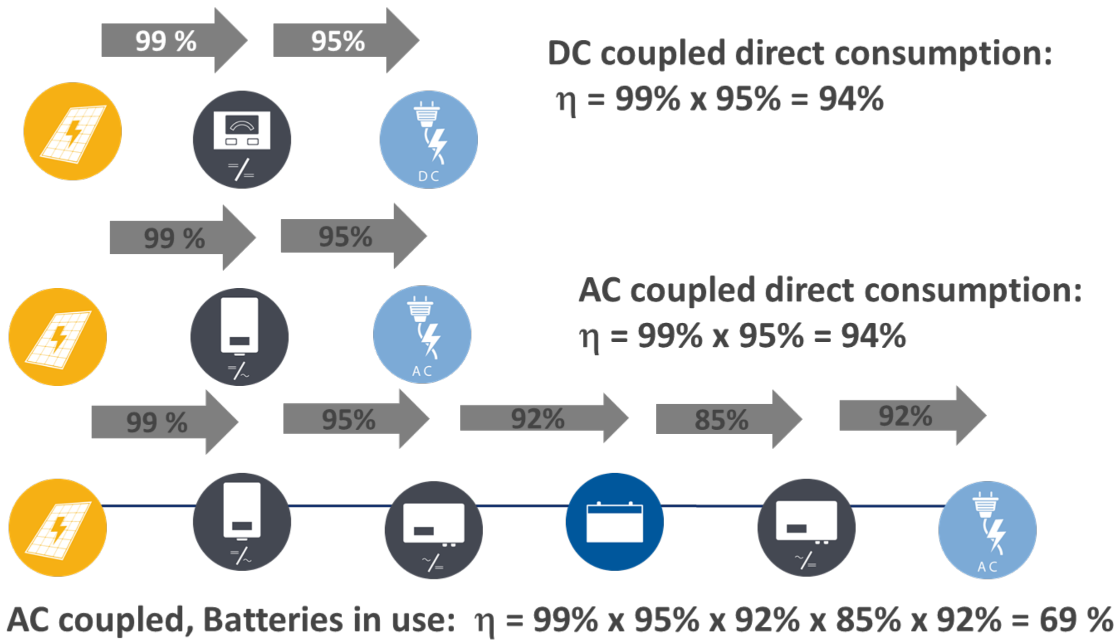


Table 31: Efficiency of DC and AC coupled Systems

The selection of the right system and the right components depend on a lot of different factors. The main questions to be answered are listed again below:

- What is the budget of the client?
- What is the total consumption of the client?
- Does the client already have loads (electrician devices) he wants to use?
- What is the total power of the loads?
- When will the electricity be used?
- Which components are available in my region and how are the warranty terms?
- Is there a second electricity source (diesel generator, wind turbine) to be integrated?
- How many days of autonomy have to be served?

With the years a solar installer learns what system to offer to which client. It is suggested to consult experienced installers when you implement your first projects. Usually you also can ask wholesalers and manufacturers to review you design or even to assist with the design.

Self-Check - 2	Written Test

Instruction: Follow the below selected instruction

A	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 typical reason to buy an off-grid PV system is to become independent and to have access to electricity:**
	True or false:
2	**DC coupled system can also run AC loads.**
	True or false:

Note: the satisfactory rating is as followed

Satisfactory	2 points
Unsatisfactory	Below 1points

Answer Sheet

Score = ____________

Rating: _____________

Name

Date

LAP Test	Practical Demonstration

Name:		Date:	
Time started:		Time finished:	

Instructions: Given necessary materials, tools and measuring instruments you are required to perform the following tasks within 2 hour.

Task 1:

Evaluate the site survey form you completed at the end of LO1. Evaluate the date and suggest a suitable system for the selected house based on the site survey. Evaluate the loads, determined the daily energy consumption and the needed autonomy days, suggest the type of system and suggest the size of the battery bank an the inverter.