Short-Course

Solar PV System Installation and Maintenance

NTQF Level IV

Learning Guide -10

Unit of Competence	**Calculating System Components**
Module Title	**Calculating System Components**
LG Code	**EIS PIM4 M01 0120 LO6-LG10**
TTLM Code	**EIS PIM4 TTLM 0120v1**

LO 6: Balance of System-10

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 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 Sheet 1 (page: 107), Sheet 2 (page: 123), Sheet 3 (page: 129)
4. Accomplish the Self-Check 1 (page: 121), Self-Check 2 (page: 128), Self-Check 3 (page: 136)

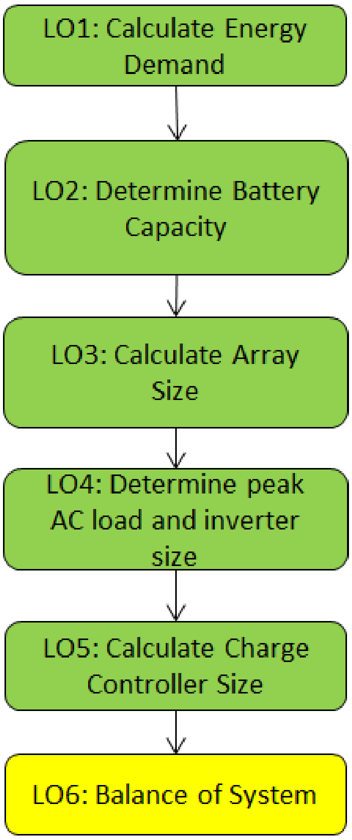
LO 6:- Balance of System

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

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

1.1 Introduction

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



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

Cabling

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

L – Length of cable, **P –** Power
U – System Voltage, **K –** electrical conductivity:

K_{Copper} = 56 m / (Ohm x mm²)
$K_{Alumímium}$ = 34 m / Ω · mm²

Fuses

$$I_{max,\,Battery} = \frac{P_{\max inverter}}{System\ Voltage}$$

$$I_{SC,\,module} = No\ of\ strings * Isc,\ Module$$

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 losses will be lower (smaller battery, panels etc.). Thinner wires will be cheaper but 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.

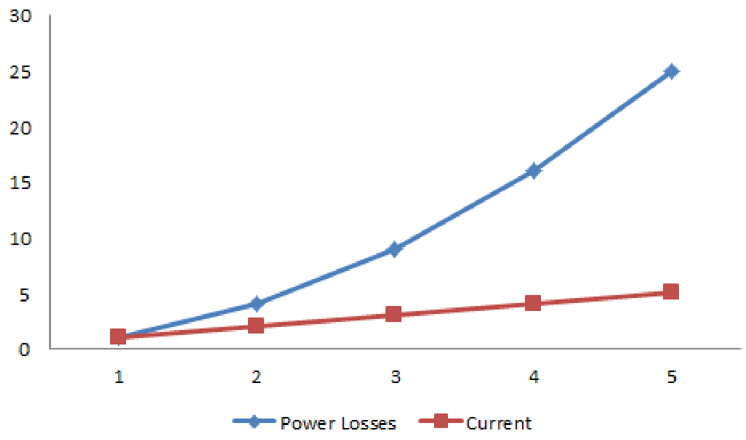


Figure 64: Power losses vs. current increase

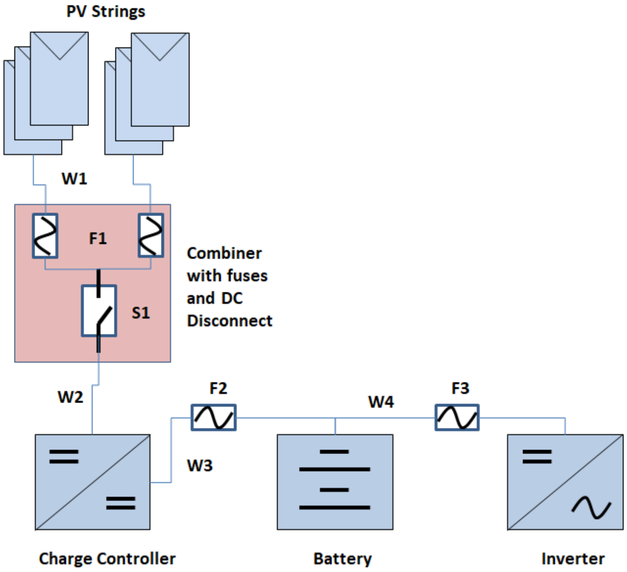


Figure 65 - Protection and Wiring

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:

$$A=\frac{L\ x\ P}{ɲ_{loss}\ x\ V^{2} x\ K}$$

Where

A = cross section of cable in mm^2
L = length of cable (conductor positive and negative) one way length x 2
P = Power of the cable
$ɲ_{loss}$ = 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 aluminium

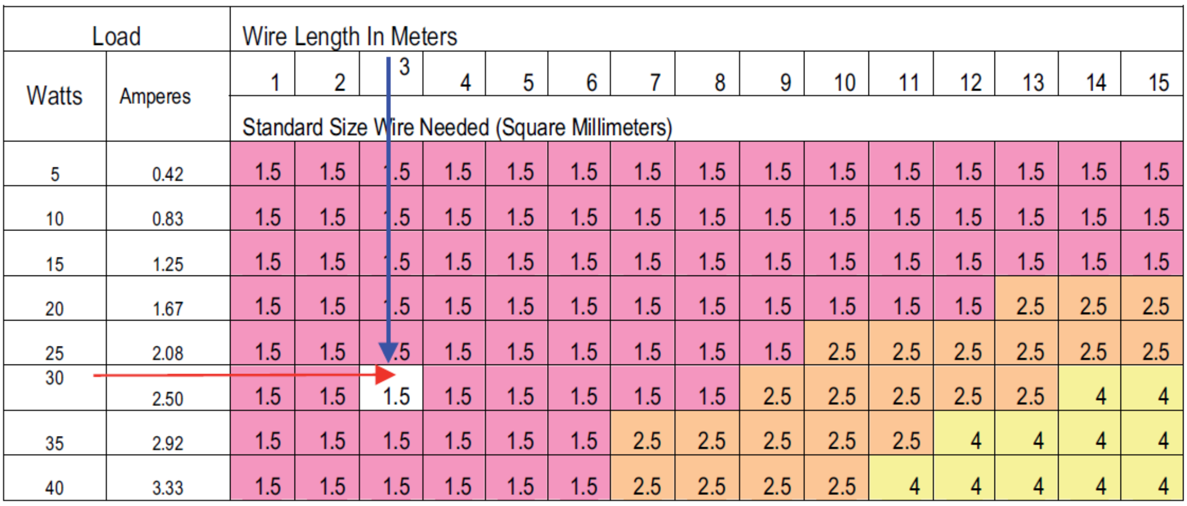
In practice, one can make use of tables supplied by wire manufacturers to ‘lookup’ the size of wires. These tables are often specified per system voltage e.g. 12V, 24V etc.

In Figure 66 below, we can select the wire suitable for an appliance that consumes 30W and is 3m away from the battery. It can be seen that a $1.5mm^2$ will be suitable.

In fact, 1.5mm^2 will be suitable up to 8m after which the next size (2.5mm^2) 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/U^0	Temperature Range	Cross section diameters (mm^2)				
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.

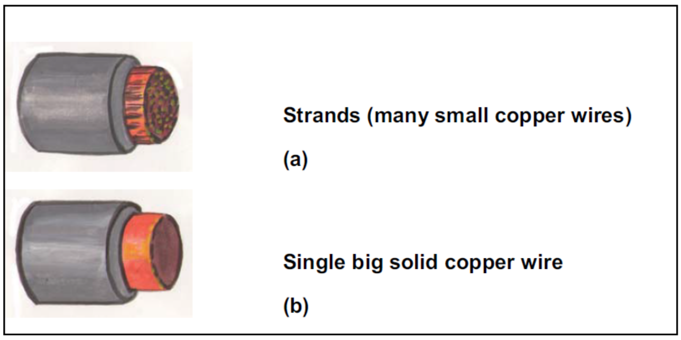


Figure 69: Conductor types

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 mm^2 in size, then 25 strands will be used in a 2.5 mm^2 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

The following paragraph(s) are taken/adapted from (Hankins, 2010) chapter 7.

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.

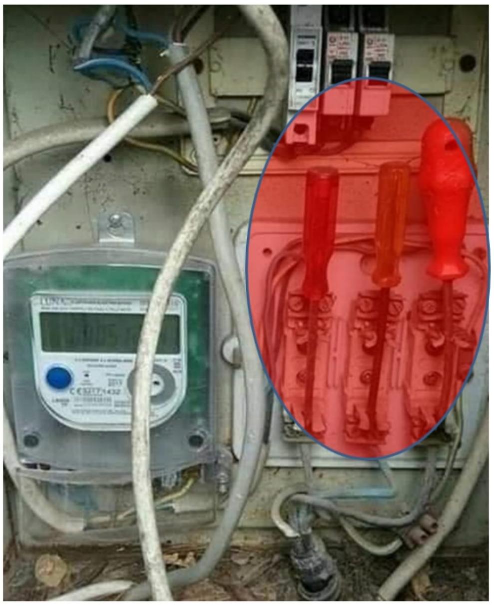


Figure 70: Dangerous fuse 'replacement'

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

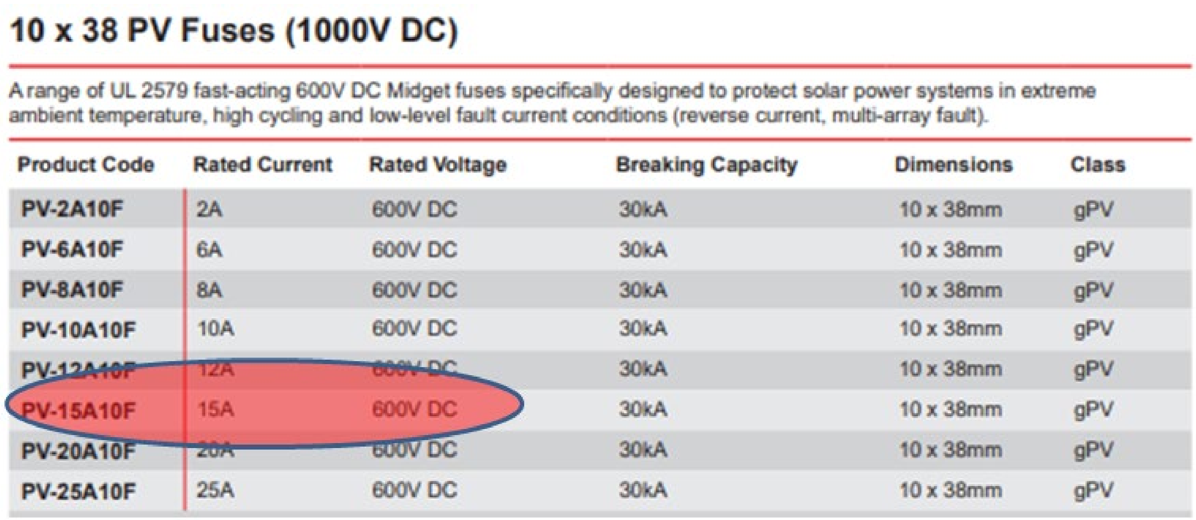
PV Fuses are often use when there are multiple strings combined. An earth fault in one string can cause the other string currents to also flow into the earth fault. PV strings are normally calculated empirically as follows:

- $V_{P,fuse} \geq V_{OC,array} \times 1.2$
- $I_{nom,fuse} \geq I_{SC\ module} \times 1.4$

As an example, if there are a string of 4 modules (V_{OC} = 36V), and the Short circuit current I_{SC} = 10A:

- $V_{P,fuse} \geq V_{OC,array} \times 1.2 \geq (4\ \text{modules} \times 36V) \times 1.2 \geq 172.8V$
- $I_{nom,fuse} \geq I_{SC\ module} \times 1.4 \geq 10A \times 1.4 \geq 14A$

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).

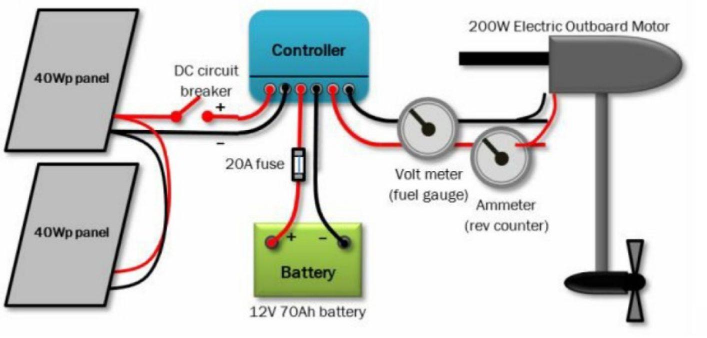


Figure 73: Adding meters to an Off-Grid system (Boxwell, 2017)

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.

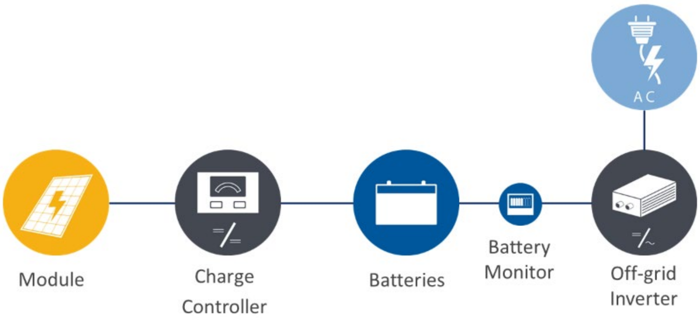


Figure 76: System with battery monitor

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 mm² 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 mm², AWG 0 ~ AWG 2			

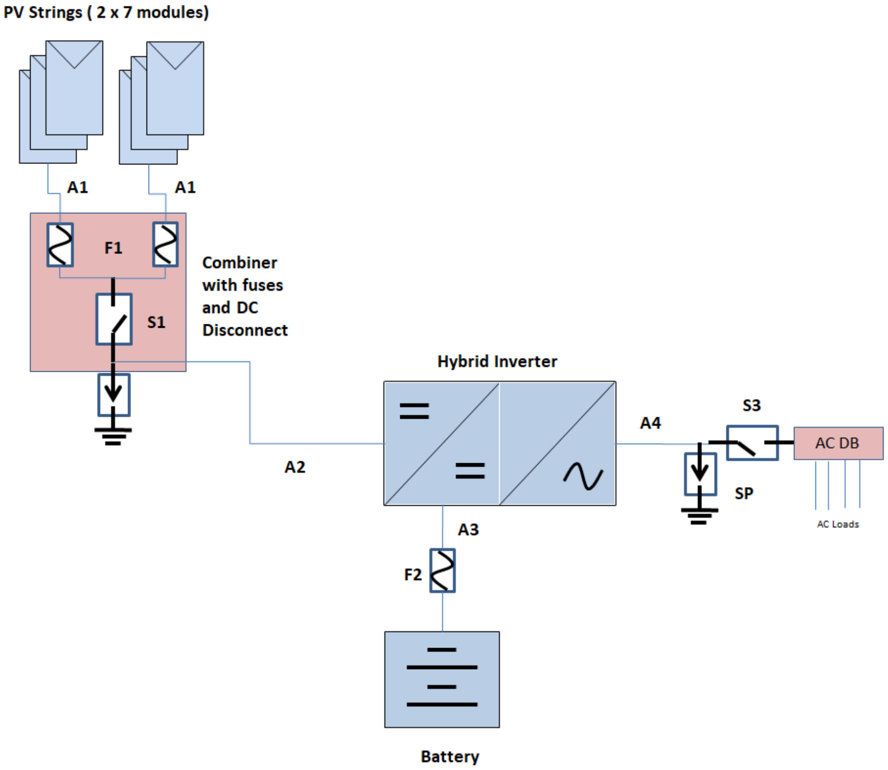


Figure 78: Adama Design

- F2 Fuses from charge controller to Battery

I$_{CC}$= 80A (max capacity of CC)
Add safety margin of 20 %: F2=I$_{CC}$ 1.20 = 80A * 1.20 = 96A
Fuse$_{F2}$=100A

- F1 Fuses from string to combiner box

$I_{SC,\ Module}$=9.56 A

F1=I_{SC} String = Isc module

F1=I_{SC} String = 9.56A

Add safety margin of 20 %: F1=I_{SC} String * 1.20 = 9.56 * 1.20 = 11.47 A

Fuse$_{F1}$=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

Note: the satisfactory rating is as followed

Satisfactory	5 points
Unsatisfactory	Below 4 points

Answer Sheet

Score = ___________

Rating: ____________

Name

Date

Information Sheet 2	**Detecting and documenting technical problems**

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 m^2 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 stages 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 optimiser and switch devices as well as combiner boxes and transformers. This task normally ends with a modelling exercise on the future performance of the PV system and therefore also includes knowledge about software and simulation tools for yield modelling.

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. specialised 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 - 4	**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	3 points
Unsatisfactory	Below 3 points

Answer Sheet

Score = ____________

Rating: _____________

Name

Date

Information Sheet 3	Completing and reporting the work

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.

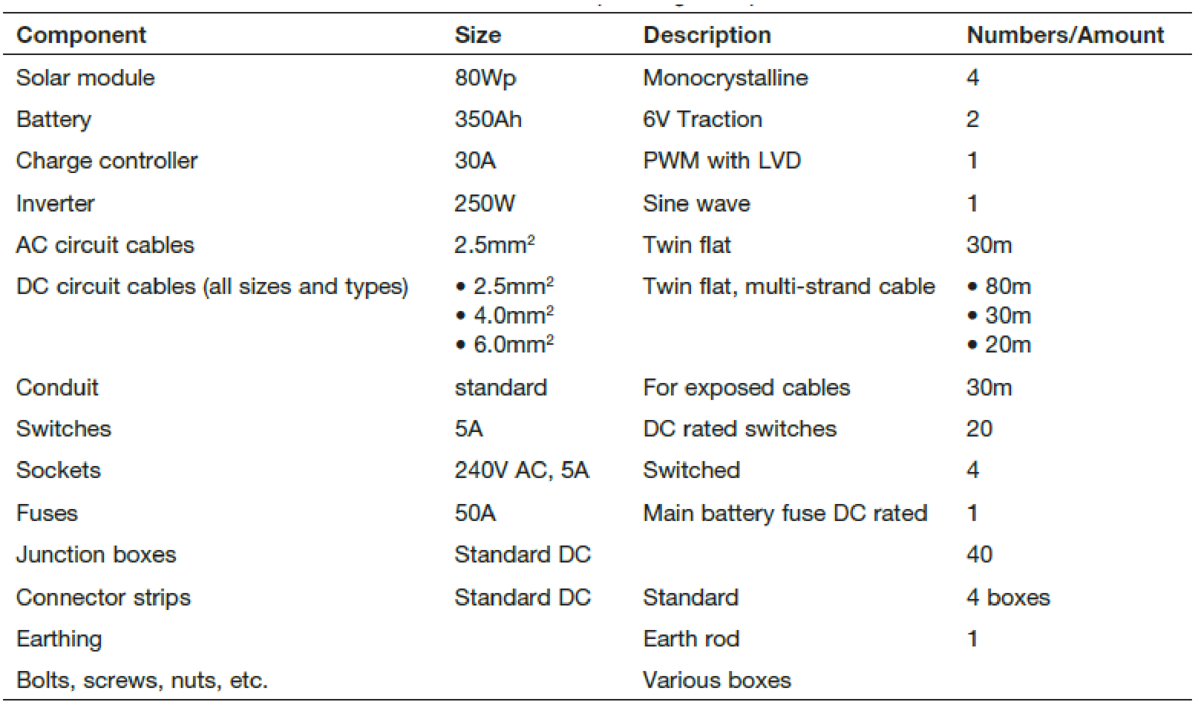
3.2 Bill of Materials

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;
- Etc.

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	2.5mm²	Twin flat	30m
DC circuit cables (all sizes and types)	• 2.5mm² • 4.0mm² • 6.0mm²	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:

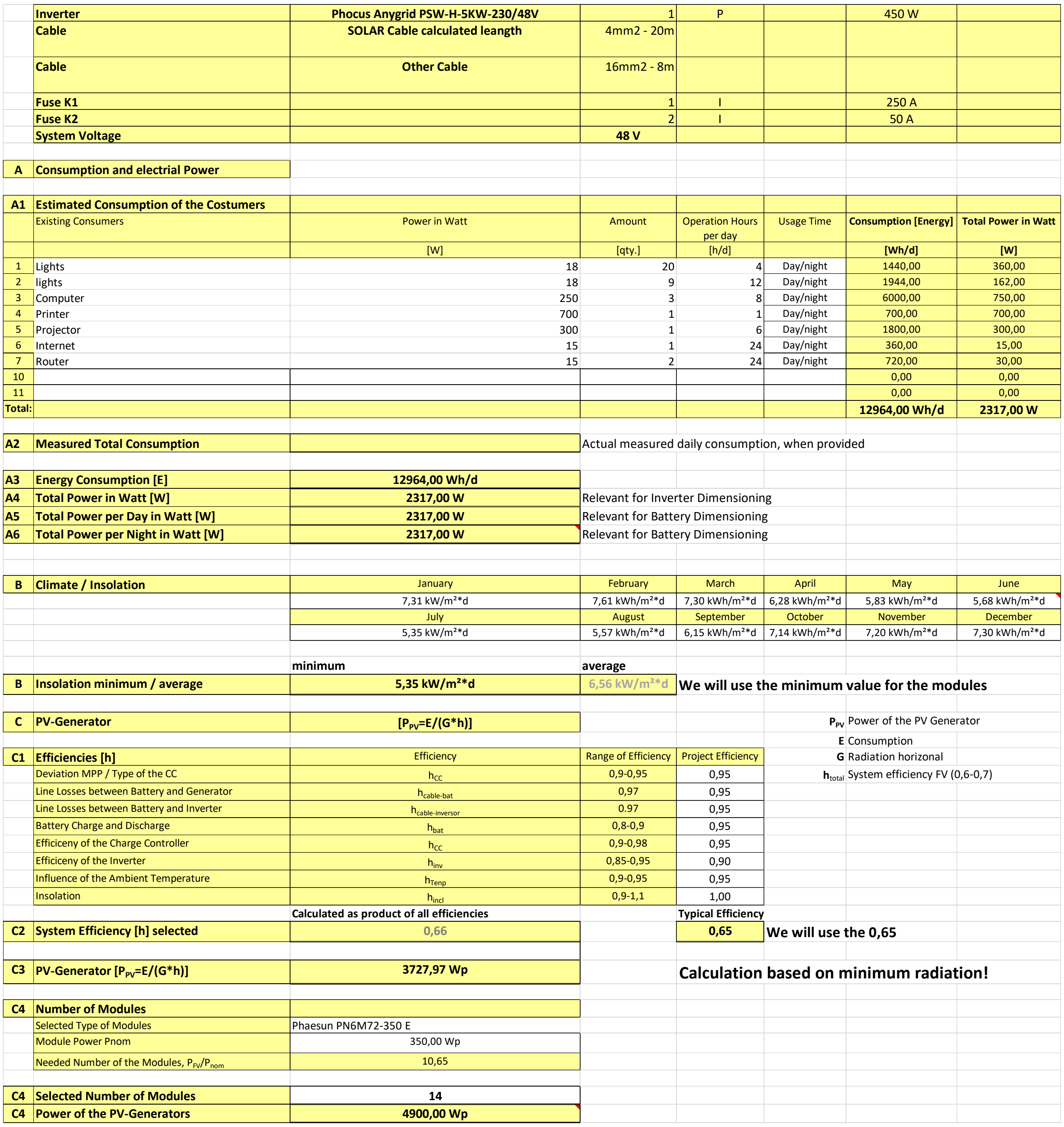
Table 14: Adama BOM

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

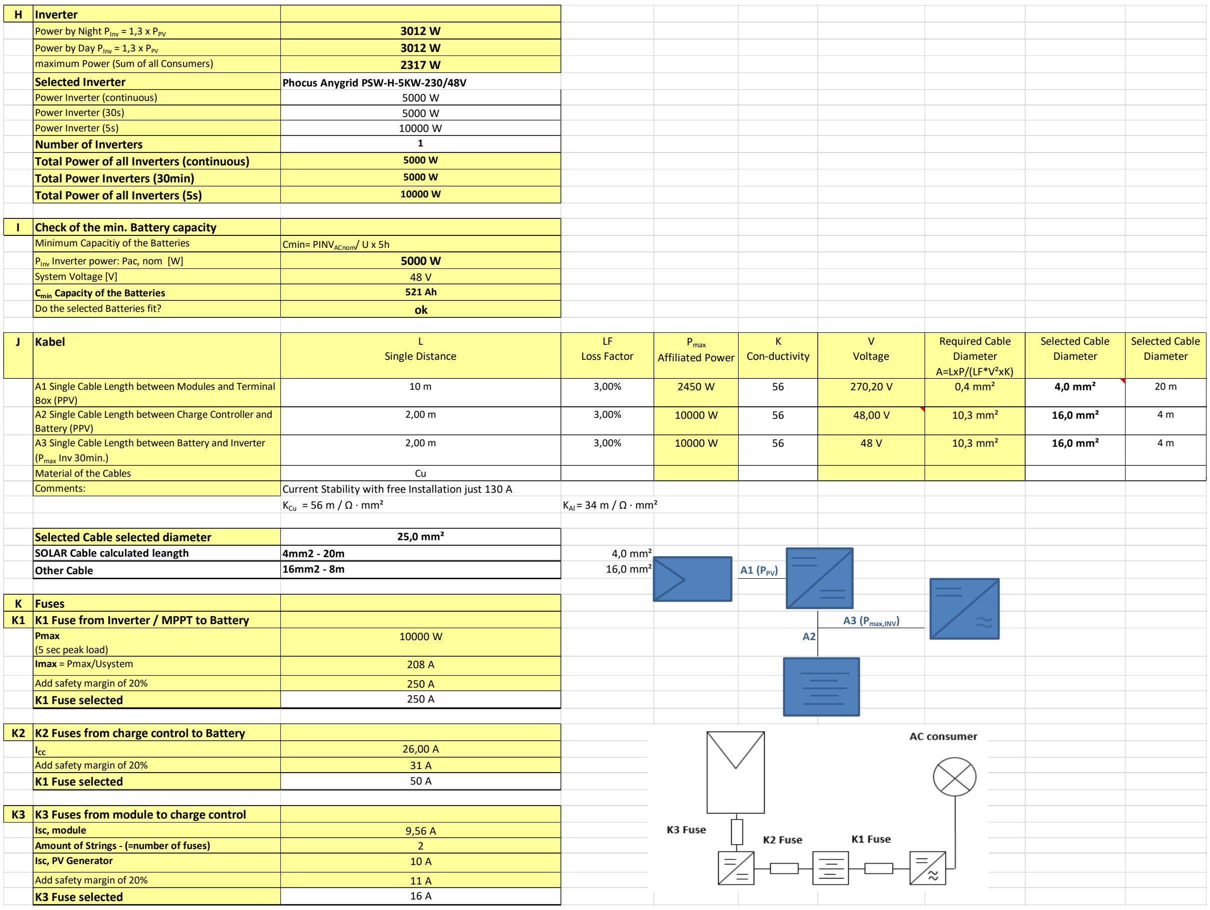
The design calculations should also be documented. If a semi-automated spread sheet or customised software is used or, the calculations can be extracted fairly easily in a standard format. Alternatively, a template can be set-up to guide the final report. Figure 81 shows the output of a typical design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



	Inverter	**Phocus Anygrid PSW-H-5KW-230/48V**	1	P		450 W	
	Cable	**SOLAR Cable calculated leangth**	4mm2 - 20m				
	Cable	**Other Cable**	16mm2 - 8m				
	Fuse K1		1	I		250 A	
	Fuse K2		2	I		50 A	
	System Voltage		**48 V**				
A	**Consumption and electrial 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]	[qty.]	[h/d]		**[Wh/d]**	**[W]**
1	Lights	18	20	4	Day/night	1440,00	360,00
2	lights	18	9	12	Day/night	1944,00	162,00
3	Computer	250	3	8	Day/night	6000,00	750,00
4	Printer	700	1	1	Day/night	700,00	700,00
5	Projector	300	1	6	Day/night	1800,00	300,00
6	Internet	15	1	24	Day/night	360,00	15,00
7	Router	15	2	24	Day/night	720,00	30,00
10						0,00	0,00
11						0,00	0,00
Total:						**12964,00 Wh/d**	**2317,00 W**
A2	**Measured Total Consumption**		Actual measured daily consumption, when provided				
A3	**Energy Consumption [E]**	**12964,00 Wh/d**					
A4	**Total Power in Watt [W]**	**2317,00 W**	Relevant for Inverter Dimensioning				
A5	**Total Power per Day in Watt [W]**	**2317,00 W**	Relevant for Battery Dimensioning				
A6	**Total Power per Night in Watt [W]**	**2317,00 W**	Relevant for Battery Dimensioning				
B	**Climate / Insolation**	January	February	March	April	May	June
		7,31 kW/m²*d	7,61 kWh/m²*d	7,30 kWh/m²*d	6,28 kWh/m²*d	5,83 kWh/m²*d	5,68 kWh/m²*d
		July	August	September	October	November	December
		5,35 kW/m²*d	5,57 kWh/m²*d	6,15 kWh/m²*d	7,14 kWh/m²*d	7,20 kWh/m²*d	7,30 kWh/m²*d
		minimum	**average**				
B	**Insolation minimum / average**	**5,35 kW/m²*d**	**6,56 kW/m²*d**	**We will use the minimum value for the modules**			
C	**PV-Generator**	**[P_{PV}=E/(G*h)]**			**P_{PV}**	Power of the PV Generator	
					E	Consumption	
C1	**Efficiencies [h]**	Efficiency	Range of Efficiency	Project Efficiency	**G**	Radiation horizonal	
	Deviation MPP / Type of the CC	h_{CC}	0,9-0,95	0,95	**h_{total}**	System efficiency FV (0,6-0,7)	
	Line Losses between Battery and Generator	$h_{cable-bat}$	0,97	0,95			
	Line Losses between Battery and Inverter	$h_{cable-inversor}$	0.97	0,95			
	Battery Charge and Discharge	h_{bat}	0,8-0,9	0,95			
	Efficiceny of the Charge Controller	h_{CC}	0,9-0,98	0,95			
	Efficiceny of the Inverter	h_{inv}	0,85-0,95	0,90			
	Influence of the Ambient Temperature	h_{Tenp}	0,9-0,95	0,95			
	Insolation	h_{incl}	0,9-1,1	1,00			
		Calculated as product of all efficiencies		**Typical Efficiency**			
C2	**System Efficiency [h] selected**	**0,66**		**0,65**	**We will use the 0,65**		
C3	**PV-Generator [P_{PV}=E/(G*h)]**	**3727,97 Wp**		**Calculation based on minimum radiation!**			
C4	**Number of Modules**						
	Selected Type of Modules	Phaesun PN6M72-350 E					
	Module Power Pnom	350,00 Wp					
	Needed Number of the Modules, P_{FV}/P_{nom}	10,65					
C4	**Selected Number of Modules**	**14**					
C4	**Power of the PV-Generators**	**4900,00 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-Generators	4900 Wp
u	Nominal Power Rating	5000 W
	Ratio PPV/PCC has to be below 1.2.	0,98
	Ratio check	**ok**
	In other words, the PV generator power can be upt 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 sharply 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 $T_{min} = \alpha_{VOC} x (T_{min}-25°) x V_{OC}$	2,83 V
s	Number of Modules per String	7
w	V_{OC} String at STC (25°)	330,40 V
x	V_{OC} at $T_{min} = \alpha_{VOC} x (T_{min}-25°) x V_{OC,String}$	19,82 V
	$V_{OC, Tmin}$ each String (T_{min})	**350,22 V**
	Voc max (at minimum Temperature)	450,00 V
	Is $V_{OC, Tmin, String} < maxV_{OC, CC}$	**ok**
	Voc min (at minimum Temperature)	120,00 V
	Is $V_{OC, Tmin, String} > minV_{OC, CC}$	**ok**
	Minimum System Voltage, Vmpp at Tmax	
	V_{MPP} each String at STC (25°)	270,20 V
	V_{MPP} at $T_{min} = \alpha_{MPP} x (T_{min}-25°) x V_{MPP,String}$	-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 $T_{max} = \alpha_{MPP} x (T_{max}-25°) x I_{MPP}$	0,22 A
rr	Amount of strings in parallel	2
z	I_{MPP} System at STC (25°)	18,16 A
aa	I_{MPP} at $T_{max} = \alpha_{MPP} x (T_{max}-25°) x I_{MPP,String}$	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**



H	Inverter	
	Power by Night P_{Inv} = 1,3 x P_{PV}	**3012 W**
	Power by Day P_{Inv} = 1,3 x P_{PV}	**3012 W**
	maximum Power (Sum of all Consumers)	**2317 W**
	Selected Inverter	**Phocus Anygrid PSW-H-5KW-230/48V**
	Power Inverter (continuous)	5000 W
	Power Inverter (30s)	5000 W
	Power Inverter (5s)	10000 W
	Number of Inverters	**1**
	Total Power of all Inverters (continuous)	**5000 W**
	Total Power Inverters (30min)	**5000 W**
	Total Power of all Inverters (5s)	**10000 W**

I	Check of the min. Battery capacity	
	Minimum Capacitiy of the Batteries	Cmin= $PINV_{ACnom}$/ U x 5h
	P_{Inv} Inverter power: Pac, nom [W]	**5000 W**
	System Voltage [V]	48 V
	C_{min} Capacity of the Batteries	**521 Ah**
	Do the selected Batteries fit?	**ok**

J	Kabel	L Single Distance	LF Loss Factor	P_{max} Affiliated Power	K Con-ductivity	V Voltage	Required Cable Diameter A=LxP/(LF*V²xK)	Selected Cable Diameter	Selected Cable Diameter
	A1 Single Cable Length between Modules and Terminal Box (PPV)	10 m	3,00%	2450 W	56	270,20 V	0,4 mm²	**4,0 mm²**	20 m
	A2 Single Cable Length between Charge Controller and Battery (PPV)	2,00 m	3,00%	10000 W	56	48,00 V	10,3 mm²	**16,0 mm²**	4 m
	A3 Single Cable Length between Battery and Inverter (P_{max} Inv 30min.)	2,00 m	3,00%	10000 W	56	48 V	10,3 mm²	**16,0 mm²**	4 m
	Material of the Cables	Cu							
	Comments:	Current Stability with free Installation just 130 A							
		K_{Cu} = 56 m / Ω · mm²	K_{Al} = 34 m / Ω · mm²						

Selected Cable selected diameter	**25,0 mm²**
SOLAR Cable calculated leangth	**4mm2 - 20m**
Other Cable	**16mm2 - 8m**

4,0 mm²
16,0 mm²

K	Fuses	
K1	**K1 Fuse from Inverter / MPPT to Battery**	
	Pmax (5 sec peak load)	10000 W
	Imax = Pmax/Usystem	208 A
	Add safety margin of 20%	250 A
	K1 Fuse selected	250 A

K2	K2 Fuses from charge control to Battery	
	I_{CC}	26,00 A
	Add safety margin of 20%	31 A
	K1 Fuse selected	50 A

K3	K3 Fuses from module to charge control	
	Isc, module	9,56 A
	Amount of Strings - (=number of fuses)	2
	Isc, PV Generator	10 A
	Add safety margin of 20%	11 A
	K3 Fuse selected	16 A

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	2 points
Unsatisfactory	Below 2 points

Answer Sheet

Score = ____________

Rating: _____________

Name

Date

LAP Test	**Practical Demonstration**

Name:		Date:	
Time started:		Time finished:	

Instructions:

Task 1:

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