Design Of A Small Scale Off-Grid Solar Energy Plant

Marias Gonzalez, Gerard

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Abstract

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Author: Marias Gonzalez, Gerard
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This report is the culmination of a ten-month design study on the feasibility of an off-grid photovoltaic installation in a cottage in Finland. The purpose was to calculate, size, and choose each of the components that made up the system considering numerous factors that could affect the operation and performance of each of them.

Much information was obtained from the simulation tool available on the Photovoltaic Geographical Information System (PVGIS) website. A range of simulations was performed for three different tilt angles and four different arrangements. Thus, the optimum inclination and orientation were found.

It has been noticed that the best performance was obtained with all the panels being faced to the South and between 45°-50° of tilt angle, being considered that the lower the inclination -in the months of April, May, June, July, and August- the more irradiation will be obtained, whereas for the other months -September, October, February, and March- a higher inclination would mean more irradiation being captured by the panels.

With the known irradiation and consumption, the corresponding calculations were made, choosing the most unfavorable case to obtain the correct dimensioning of each component of the system. Hence, concluding with the choice of the following elements: 10 photovoltaic panels (340 W each), 3 batteries with 3552 Wh nominal capacity each, 1 MPPT charge controller with a maximum open-circuit voltage of 250 V, and an inverter of 5000 W.

Finally, this thesis could be helpful to any person without previous knowledge interested in carrying out a solar installation not connected to the grid.

Language: English
Key words: Solar, Off-Grid, Cottage, PVGIS, Tilt angle, Irradiation, Photovoltaic.

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1 Introduction

Photovoltaic solar energy directly transforms sunlight into electricity using technology based on the photovoltaic effect. When the sun's radiation strikes one side of a photoelectric cell (which makes up the panels), a difference in electrical potential is produced between the two sides, causing electrons to jump from one place to another, thus generating electrical current (Solar Joinder, 2018).

In the initial stages of photovoltaic technology, this type of energy was used to provide electricity to satellites. It was in the 1950s (Oni, 2017), when photovoltaic panels accelerated their development until they became, today, an alternative to the use of fossil fuels.

The electrical energy generated by photovoltaic solar panels is inexhaustible and does not pollute, and therefore contributes to sustainable development, as well as favoring the development of local employment. It can also be used in two different ways: it can be sold to the electricity network or consumed in isolated places where there is no conventional electricity network.

The cost of installing and maintaining solar panels, which have an average useful life of over 30 years, has fallen significantly in recent years as photovoltaic technology has developed. It requires an initial investment and small operating costs, but once the photovoltaic system is installed, the fuel is free and for life.

One of the strongest points of photovoltaic solar energy is that it uses the most abundant and inexhaustible renewable energy resource on the planet, the sun. Numerous studies have shown that there is 10,000 times more solar energy reaching the Earth's surface than the annual global demand for fossil fuels (Student Energy, 2020).

The aim of this thesis is to go deeper into this field and design an off-grid photovoltaic installation in order to demonstrate that this type of energy is very useful and still has a lot of potential in the future.

1.1 Aims and objectives

The aim of this study is to design a small scale off-grid solar photovoltaic (PV) and battery storage plant in an isolated cottage house on an island located 25 km away from Vaasa. This thesis is based on real-life, because the customer wants to carry out the studied installation at his cottage located on the west coast of Finland.

To meet this aim, the following objectives have been established:

- To introduce the readers how a photovoltaic off-grid system work, how each of the components relates to each other, why there should be an earth connection in the system, the operation of each part of the equipment (i.e., how solar panels convert solar radiation into electricity, how the inverters transform the current from direct to alternating current, so on).
- To identify the power demands of the location and select the most appropriate hardware such as solar panels (PV panels), batteries, BMS (commonly included in the newest batteries), charge controller, inverter, and Automatic Backup Generator.
- To compare different brands and types of each of the parts of the equipment to show the advantages and disadvantages of each one and then choose the one that seems to be more convenient.
- To determine the solar energy resource and optimum equipment location allowing for annual variation and cloud cover.
- Dimensioning the solar photovoltaic array and the battery storage that will be necessary to achieve the desired consumption based on real solar irradiation data taken during 2019 from a solar installation located in Meteoria.

2 Background information and research

This section explains the general system to be installed, each of its components and their respective function and operation, but without going into detail on comparisons since this task belongs to section 5.

2.1 Complete off-grid system introduction

This section comprehends essential information to understand how a solar energy complete off-grid system works and also to acknowledge the kinds of relations between components and why are connected among which.

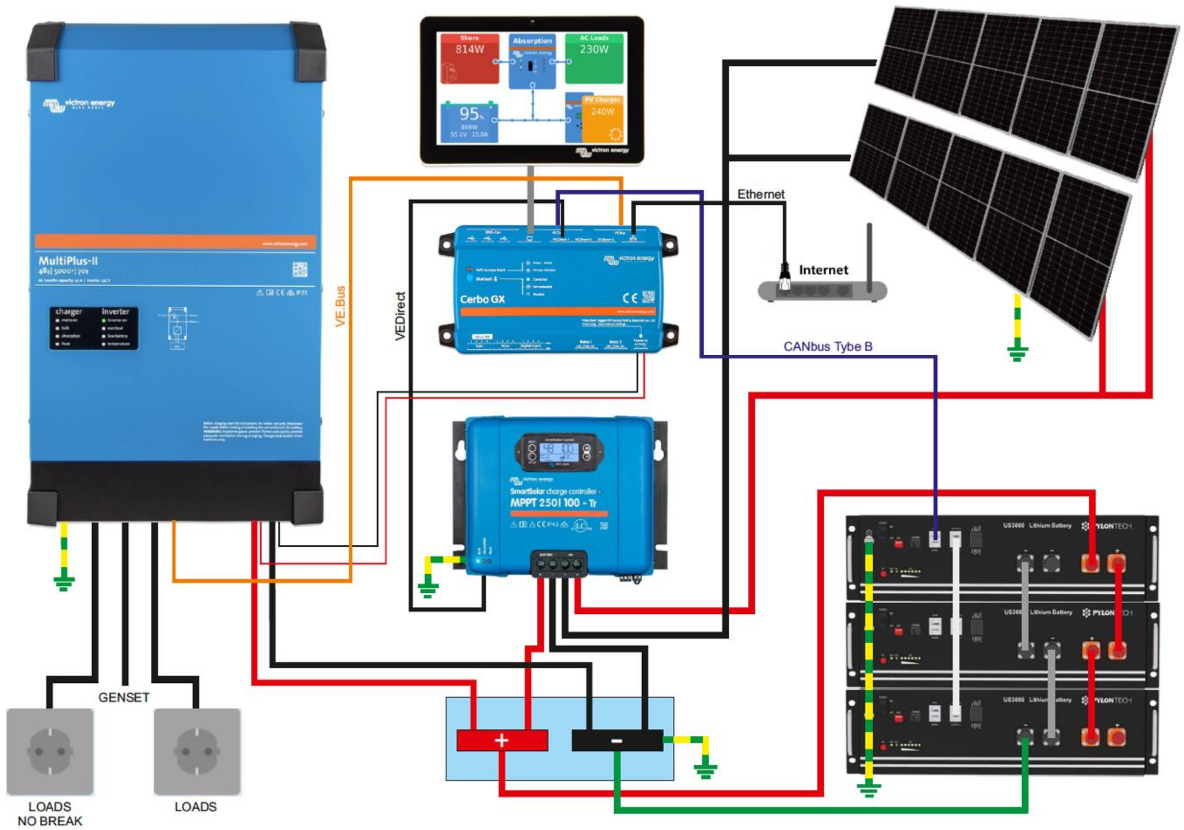

Figure 1. Overall picture of an off-grid PV system (Victronenergy.com, 2020)

As can be seen in the picture above, the PV panels are directly wired to an MPPT charge controller (which can be connected between a PV panel and a battery of different voltages each) and it to the batteries. This connection is extremely necessary when people talk about an off-grid system because the released voltage of the panels cannot be fully transmitted to the battery. That is because every battery has a voltage capacity, and if this voltage is exceeded it can be very harmful to them, they can even lose its functionality. The MPPT charge controller manages the energy that enters the battery from the solar array to ensure that the battery does not overcharge during the day.

The batteries, apart from having the connection mentioned in the upper paragraph, are also connected to the inverter, which will be in charge of converting DC to AC, to expand the uses of the energy obtained. In the system that appears in Figure 1, the inverter is not simply an inverter but it is an inverter charger, which, when the voltage of the batteries drops to the minimum, will activate the charger function, which consists of giving the order to the automatic backup generator (GENSET), so that it feeds the batteries again and at the same time, supplies energy to the house.

The inverter, batteries, and charge controller are all connected to a system monitoring device called Cerbo GX. This communications center allows control of the system at all times and from anywhere, as well as maximizing performance. Simply by connecting through the Victron Remote Management (VRM) portal, through the VictronConnect application thanks to the Bluetooth function it incorporates, or directly through the GX Touch 50 standalone multi-function display which appears in the figure above. Of course, the device is connected to the Internet via an Ethernet cable.

More information about how each component work is provided in the sections below.

2.2 Grounding

Electricity will always be directed to where it meets the least resistance, so humans can interact with its path to direct electricity to a safe place when it produces an overload. The way to do this is with a grounding system.

In every house, every electrical element is connected by a bare copper wire. Somewhere, this wire is connected to a copper pipe that is buried in the ground. This is exactly where the electrical current will be directed in the event of a short circuit or even a lightning strike.

The above example was given because the same thing must happen with a photovoltaic system, i.e. every element must be connected between each other and to an earth connection, including the panel supports and the combination box. A very common mistake is not to tie the photovoltaic system's grounding to the same grounding point of the house because if lightning strikes one system and not the other, a dangerous electrical differential between both systems will be generated (How to Ground Solar Panels Correctly, 2012). This connection is crucial and is called bonding.

To ensure that the electric current finds its way to the desired point, the earth must have good conductivity to facilitate the choice of the right path. Even if the earth has good conductivity, it is advisable to have several copper pipes buried in the earth, provided that both, the grounding pipes, and all the equipment are well connected. This is usually done because it reduces the electrical potential accumulated in the cable in case of a lightning discharge. In addition to burying several tubes deeply, the area should be slightly moistened and the tubes covered with rock salt.

Each grounding pipe must be buried between 2 and 2.5 meters deep, 2 meters being the minimum allowed. It tends to happen that the soil gets wetter the deeper it goes, due to the decrease in temperature that is equivalent to the reduction of evaporation, which is interesting to increase the conductivity of the grounding. For the outside ground wire, it is very common to use bare copper wire, but it must be thick enough to support powerful electrical loads. One recommendation would be that the cable used for outdoor equipment should have a minimum of 6 AWG (Advanced Power Inc., 2020).

The two most popular grounding methods are the use of lock washers and approved mechanical connectors. The latter can be mounted on a module with a slot for a copper wire that joins the components and connects them to the ground. The lock washers are used in conjunction with clamping and screw connections in the rack system. The washer fits over the bolt, and when tightened to the prescribed torque value, passes through the oxidized or coated surfaces, providing a solid bond between the metal parts (Smalley, 2015).

Figure 2. Bonding washers in conjunction with hold-down clamps and bolted joints (Smalley, 2015)

This section should be carefully designed before starting to install the system to make the installer's job much easier and to prevent any damage to the system. There are many ways to do this, the important thing is that the system is allowed and if possible, coded according to the requirements of the city where the installation will take place.

2.3 PV Panels

Photovoltaic (PV) panels are a type of solar panel designed to harness photovoltaic solar energy. This is a renewable and sustainable technology that is used to convert solar energy into electricity. It can be used to generate electricity in both domestic and commercial applications and it is responsible for directly transforming the energy from solar radiation into electricity, in direct current (DC) form.

As it is known, the sun is a powerful energy source that could meet global energy demands of Earth for an entire year with only an hour of sunlight. Nevertheless, solar energy technology by today's standards is only able to use 0.001% of the energy given off by the sun (Oni, B., 2017).

The PV panel is designed to withstand the conditions that occur outdoors and to be able to form part of the 'skin' of the building. They have a nice future overview because they present unique advantages and have a large potential to become a renewable and green energy source. A point to bear in mind is that its useful life is considered to be 25 years approximately (Solar Energy Technologies Office, 2013).

A few years ago, in 2009, the average cost of installing a solar panel was $8.50 per watt. Today, this price has changed in several ways. The first is that efficiency cannot be compared to that of a few years ago, as it is considerably higher. The second is that the manufacturing processes have been streamlined and drastically improved.

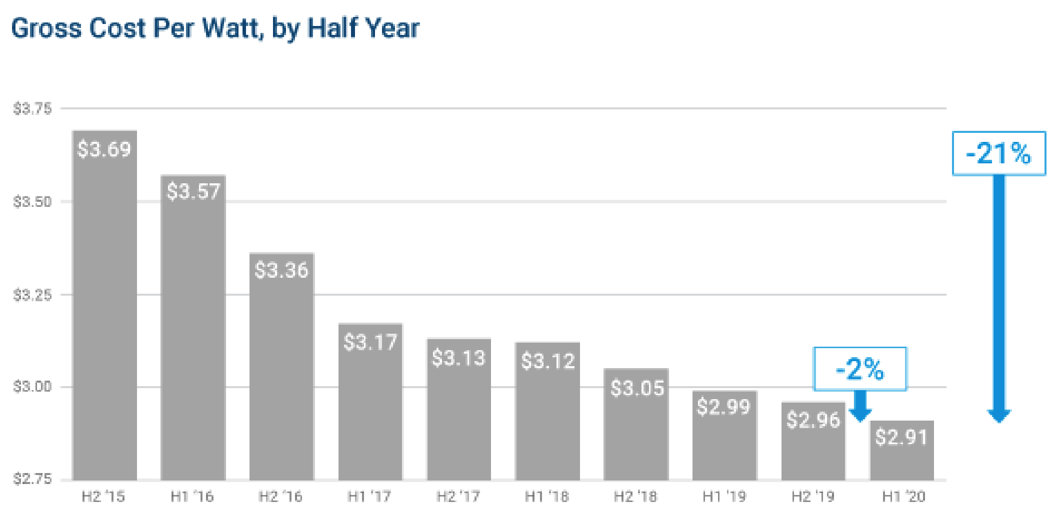

Figure 3. Price in $/Watt from the first half of 2015 to the first half of 2020 (Matasci, 2017)

Both of the factors mentioned above imply that the price of solar energy has fallen by 65% from 2009, and 21% from 2015, which means that the current price is $2.91 per Watt (Matasci, 2017) as it is shown in Figure 3. This decrease is one of the main reasons why many people are increasingly interested in installing solar panels.

Richard Swanson, the founder of one of the world's largest solar energy companies, SunPower, established the Swanson's Law, which explains why prices have dropped so much. This is because the price of solar photovoltaic modules decreases by 20% for every doubling of the world's solar capacity.

2.3.1 Historical background

The photoelectric effect was first noticed by a French physicist, Edmund Bequerel, in 1839, who found out that certain materials would produce small amounts of electric current when they are exposed to light. In 1905, Albert Einstein defined the nature of light and the photoelectric effect on which photovoltaic technology is based (Science Mission Directorate, 2020).

The first photovoltaic module was built by Bell Laboratories in 1954, it was just a curiosity because its high price. In 1960s, the space industry began to make the first serious use of the technology to provide power aboard spacecraft. Through the space programs, technology has grown up in terms of reliability and reasonable prices. Thanks to the energy crisis in the 1970s, photovoltaic technology won recognition as a source of power for non-space applications (Renewable Energy World, 2010)

2.3.2 How it works?

Photovoltaics is the direct conversion from light into electricity at an atomic level. Some materials have a property known as the photoelectric effect; the material absorbs light photons and releases electrons. A panel is divided into cells, which are responsible for converting the energy of light into direct current (DC) electricity, which happens when the free released electrons are captured (Knier, 2008). The use of a PV inverter is commonly used due to the need to stabilize the current, transforming from DC into alternating current (AC) before using it in a local grid. Figure 4 illustrates PV cell’s energy transformation.

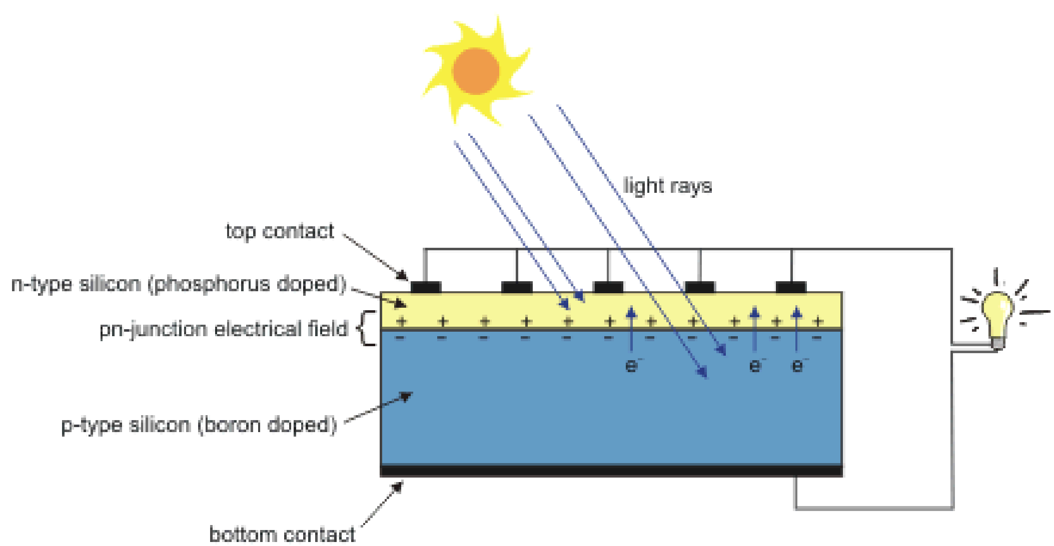

Figure 4. Diagram illustrating the operation of a PV cell (Lighting Research Center, 2006).

Photovoltaic cells are made of specially treated semiconductor material that shares both metal and insulation properties to convert sunlight into electricity. The light that is absorbed by a semiconductor is transferred as energy to the electrons. This allows the electrons to flow freely through the material as an electric current. The direction of the electron flow is controlled by the positively and negatively charged electric fields in the photovoltaic cells. By extracting the current from the PV cell, the power produced by the solar cell can be used extrinsically (Knier, 2008).

Silicon is one of the most widely used semiconductor materials in solar cell manufacturing. In fact, approximately ninety percent of solar panels sold today use silicon as a semiconductor material. The marketability of silicon contributes to the crystalline structure of the atom being able to provide solar cells with higher efficiency, which will mean lower cost and longer product life. The silicon is usually doped with phosphorus, which helps to produce n-type silicon. This will be doped with boron resulting in p-type silicon to increase the conductivity of its crystalline network. This increase in conductivity will help speed up the mobility of electrons through the positive-negative junction and create the flow of current and voltage in the photovoltaic cell, thus producing energy. Other semiconductor materials used in solar cells include thin-film photovoltaics, organic photovoltaics, and concentrated photovoltaics (Solar Energy Technologies Office, 2013).

The set of electrically connected photovoltaic cells is usually called a photovoltaic module, also known as a solar panel. An ordinary solar panel consists of approximately 40 PV cells. Solar panels can also be connected to form a solar array. The electrical energy produced is directly proportional to the increase in the area of the solar panel or array. According to the National Renewable Energy Laboratory (NREL), a set of 10-20 solar panels is required to provide enough electricity to power an everyday home (Solar Research, 2018).

The amount of electrical energy obtained by a photovoltaic cell depends on the intensity, the wavelength of the light source, and on various performance characteristics of the photovoltaic cell. The most important parameters in terms of PV cell performance would be the maximum current and voltage, efficiency, characteristic and parasitic resistance, temperature, diode ideality factor, and bandgap energy (Alternative Energy Tutorials, 2019). Of all factors, temperature and solar irradiation have the greatest influence on the performance of photovoltaic cells.

Figure 5 shows a graph showing the current and voltage (I-V) characteristics of a photovoltaic cell operating under normal conditions. The I-V characteristic curves of the photovoltaic cell are important for determining the relationship between current and voltage at the current temperature and solar irradiation conditions. The information provided by the I-V characteristic curves provides the information needed to design a solar cell to operate as close as possible to the optimum peak power point (MPP) of the photovoltaic cell.

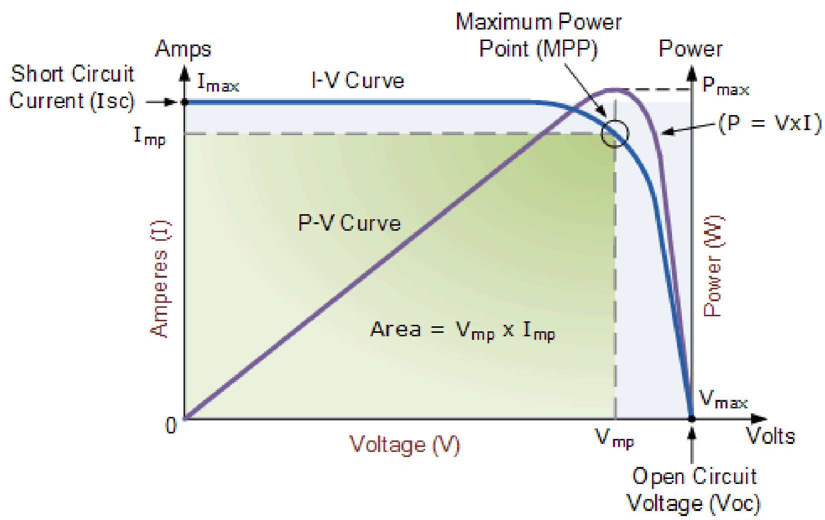

Figure 5. I-V characteristic curve of a PV cell (Alternative Energy Tutorials, 2019)

The efficiency of each photovoltaic cell will determine the total efficiency produced by the solar panel. The cell efficiency of the solar panel is defined as the ratio of the electrical energy produced by the photovoltaic cell to the amount of sunlight captured by the photovoltaic cell (Office of Solar Energy Technologies, 2013). In other words, the efficiency of a solar panel determines the amount of energy captured by the photovoltaic cell that will later be converted into electrical energy.

Efficiency tests on solar panels are conducted under Standard Test Conditions (STC), an industry-wide standard, to compare, qualify, and determine the efficiency and performance of solar panels. These conditions would be, a clear, sunny day in which incident light hits a surface facing the sun at a 37-degree tilt with the sun at a 41.81-degree angle over the horizon. The standard test conditions are shown in Table 1 below.

Table 1. STC specifications

Standard Testing Conditions (STC)	
Cell Temperature	25°C
Solar Irradiance	1000 W/m^2
Air Mass	1.5

It is important to note that the STC is not a precise enough standard to estimate the true global performance and yield due to the Earth's climatic and geographic conditions. Regular deviations in lamp spectrum, module temperature, environment, and solar irradiation are examples of drawbacks that cause manufacturers' panels not to strictly comply with the STC, resulting in incorrect output data. Today, the typical efficiency of photovoltaic panels available on the market is 7-17%, although the most efficient ones can reach 22.2%. The efficiency values of panels and cells vary with each manufacturer and type of panel.

2.3.3 Types of panels

About 90% of the photovoltaic panels are made out of a variant of silicon. The quality of their solar cell depends basically on the purity of these silicon derivatives. Depending on this composition, commercialized solar panels can be classified into three different groups (Fraunhofer Institute for Solar Energy, 2019):

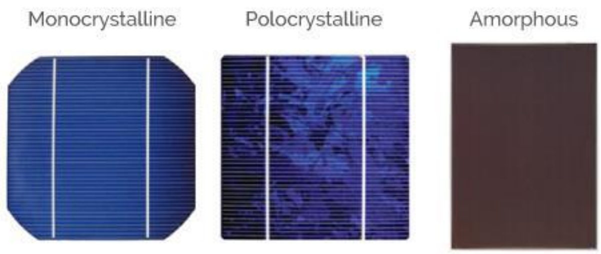

Figure 6. Types of PV cells (Energy Informative, 2019)

- Monocrystalline Solar Panels (Mono-Si)

Monocrystalline solar cells are made out of the highest-grade silicon, created using a process called Czochralski in their manufacturing. This makes them the most efficient cells with an efficiency rate of about 15-20% (Table 2). These kinds of panels have a high-power output, occupy less space, and last longest but that also means they are the most expensive ones. Another advantage of taking care of is that they tend to be slightly less affected by high temperatures compared to polycrystalline panels. They are characteristic of a dark colour and round shaped solar cell corners (GreenMatch, 2020).

- Polycrystalline Solar Panels (Poly-Si)

Polycrystalline solar cells are at an intermediate level. They are made by melting raw silicon, which is a faster and cheaper process than that used for monocrystalline panels. It also has lower efficiency (13-17%), lower space efficiency (Table 2), and a shorter lifespan since they are affected by hot temperatures to a greater degree. These panels can be quickly distinguished because this type of solar panels has squares, its angles are not cut, and it has a blue, speckled look.

- Thin-Film Solar Cells (TFSC)

Thin-film solar cells (TFSC) are created by depositing a photovoltaic material, such as silicon, cadmium or copper, onto a substrate. There are different types depending on the materials used in the process (amorphous silicon, copper indium gallium selenide, cadmium telluride, so on). An interesting advantage of this kind of panels is that they can be made flexible, which opens up many new potential applications, and is less affected by high temperatures. Another advantage is that these types of solar panels are the easiest to produce and economies of scale make them cheaper than the alternatives due to less material being needed for its production. The main issue is that they take up a lot of space, generally making them unsuitable for residential installations.

Furthermore, they carry the shortest warranties because their lifespan is shorter than the mono and polycrystalline solar panels. Their aspect is dark and mainly homogenous. These kinds of cells are commonly used for photovoltaic power stations, integrated into smaller power systems or buildings.

There are some different types of thin-film panels:

- **Amorphous Silicon Solar Cell** (A-Si) are the cheapest and the most used in spite of its low efficiency (approximately 7%).
- **Cadmium telluride cells (CdTe)** are cheap to manufacture but they have around 11% of efficiency. Furthermore, the materials needed are rare.
- **Gallium arsenide cells** have nice temperature resistance and can reach an efficiency of around 32%. The materials used to manufacture are also rare, thus are more expensive than the other types. Actually, is not available in the market.
- **CIS cells** (Copper and indium selenide alloy) have module efficiencies around 12% (Table 2) and the output is constant.

Here is a table that summarizes the information previously commented and adds some important details to take under consideration when comparing the different solar panel types:

Table 2. Different solar panel types characteristics (Energy Informative, 2020)

	Monocrystalline	Polycristalline	Amorphous	CdTe	CIS/CIGS
Typical module efficiency	15-20%	13-17%	6-8%	9-11%	10-12%
Best research cell efficiency	25%	20.4%	13.4%	18.7%	20.4%
Area required for 1 kWp	6-9 m^2	8-9 m^2	13-20 m^2	11-13 m^2	9-11 m^2
Typical length of warranty	25 years	25 years	10-25 years		
Average price	0.189$/Watt	0.165$/Watt	0.213$/Watt		

- Bifacial panels

Bifacial modules are characterized by their ability to produce solar energy on both sides of the panel, which means that the solar cells are exposed to the sun from both the front and the back.

When bifacial modules are installed on a highly reflective surface, some manufacturers ensure an increase of up to 30% in production with the energy obtained from the back of the panel alone. There are many designs of bifacial modules, some are double glazed, and others use transparent backing sheets. Most use monocrystalline cells, but there are always exceptions, and polycrystalline cells are also used.

The only thing that does not vary when making these modules is that the energy is produced from both sides. There are frameless double glass modules that expose the backside of the cells but they are not bifacial. True bifacial modules have contacts/collector bars on both the front and back of their cells.

- PERC Technology

As in all sectors, studies and tests are constantly being carried out to improve the operation and performance of almost everything today. In the area of photovoltaic cells, PERC cell technology has recently been making a name for itself.

The acronym PERC stands for Passivated Emitter Rear Cell, Passivated Emitter Rear Contact, or even Passivated Emitter and Rear Cell, depending on the source of information, one or the other is found. The meaning of this acronym would be to place a reflective layer (Dielectric Layer) to make the most of the radiation.

The standard photovoltaic cell consists of three layers with different electrical properties:

- **Emitting layer:** this is the silicon layer on the upper surface of the cell, i.e. the area most exposed to radiation.
- **Base Layer:** The intermediate layer of silicon that is in contact with the emitting layer and the aluminum layer.
- **Back Surface Field:** The lower surface of the aluminum layer. This is the deepest area of the cell.

Light is known as an electromagnetic wave that can have a wide range of different wavelengths. Given the spectrum of visible light, the look has to be at both ends. A large part of the blue light or "short" wavelength is absorbed by the atmosphere. However, the remaining amount reaches the cell with low energy, so it can only penetrate the upper layer of the cell (emitter) generating electrons in it and therefore electric current (Tegio, R. 2018).

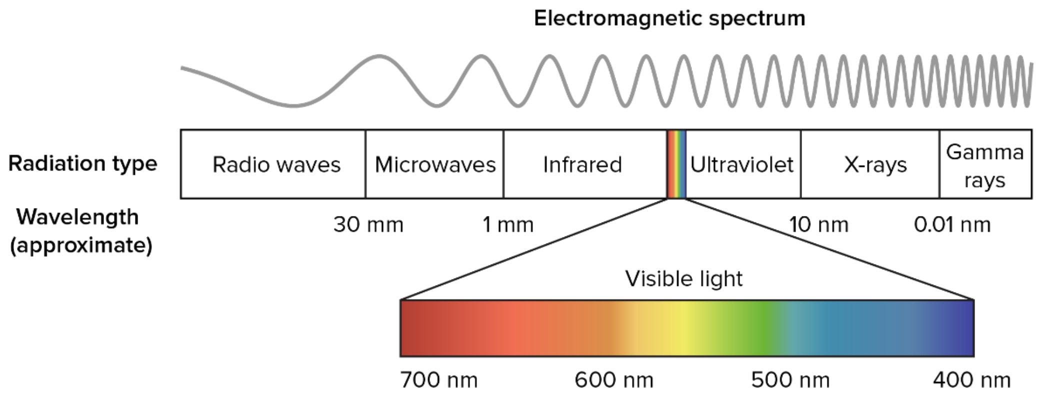

Figure 7. Different wavelengths that compose light (Khan academy, 2020)

Red light with a longer wavelength is not absorbed by the atmosphere and reaches the cell with a higher level of energy; it can thus penetrate the cell and reach the base layer where it will also generate current. But these are not the only wavelengths that reach our cell. Infrared light, with a higher energy level than red light, can penetrate even below the base layer, reaching the lower layer (BSF), thus losing this energy.

<u>PERC photovoltaic cell operation</u>

If is placed a passive dielectric material between the aluminum layer and the silicon base layer, it can be achieved that these electrons from the infrared light do not penetrate to the aluminum layer, but are reflected and allow to generate a current between the base layer and the emitter. This use of infrared light gives the PERC cell a higher "sensitivity" to long wavelengths.

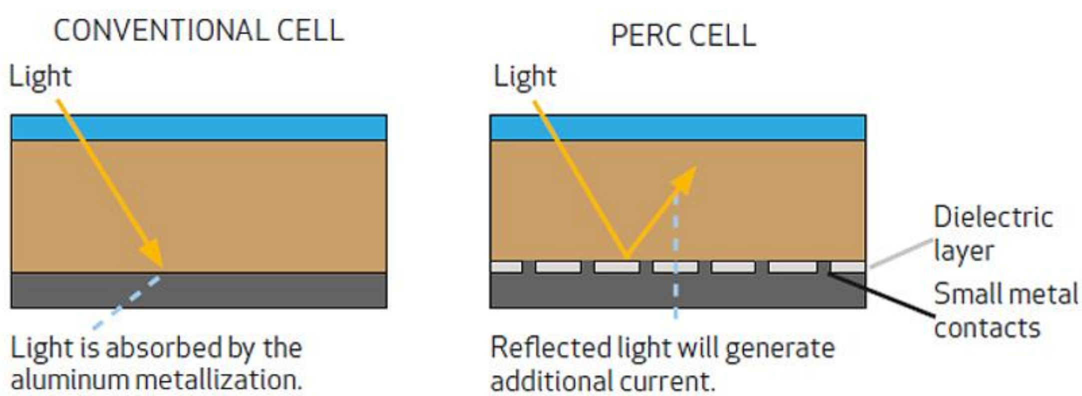

Figure 8. Difference between conventional cell and PERC cell (Tegio, R. 2018)

Generally, these wavelengths (Figure 8) are more present when the sun is at a certain angle, i.e. during the first and last hours of the day or during cloudy days with low radiation. This allows modules with PERC technology to have a higher efficiency than other conventional modules (both monocrystalline and polycrystalline).

The thing is not over. Wavelengths longer than the infrared cannot penetrate the photovoltaic cells, well, rather they cannot generate energy, but these waves arrive directly at the lower aluminum layer in conventional cells, being absorbed by it and increasing the temperature of the module. And this increase in temperature could harm production. However, in the PERC cells, these waves are reflected sending them out of the panel and thus achieving a lower temperature.

Finally, the passivation of the dielectric material prevents the electrons from "escaping" into the aluminum layer, thus allowing better circulation between the silicon base and emitter layers. In summary, PERC technology offers two significant advantages:

- Higher production with low irradiance.
- Lower temperature coefficient.

In order to demonstrate the improvement in performance with PERC cells, a comparative chart is provided below (Figure 9).

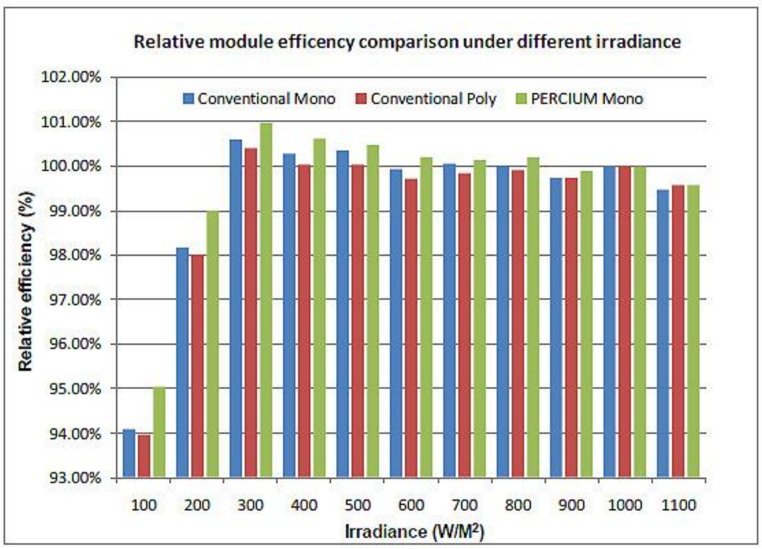

Figure 9. Efficiency comparison with different irradiance values (JA Solar, 2017)

The graph shows a comparison of the efficiency according to different irradiation values. As can be noticed, the difference in efficiency between PERC and mono/poly is higher the lower the efficiency. Likewise, the improvement in efficiency is remarkable.

<u>What is Half-Cut or Half-Cell technology?</u>

It is another innovation in solar panels. It consists of the use of solar cells cut in half, placing the connection box in the center of the solar panel. Thus, unlike conventional solar modules, the solar panel is cut in two halves, with 50% capacity each.

Half-Cell solar panels, or panels made up of halves of solar cells, also allow the options of photovoltaic installations to be expanded (Pickerel, 2018).

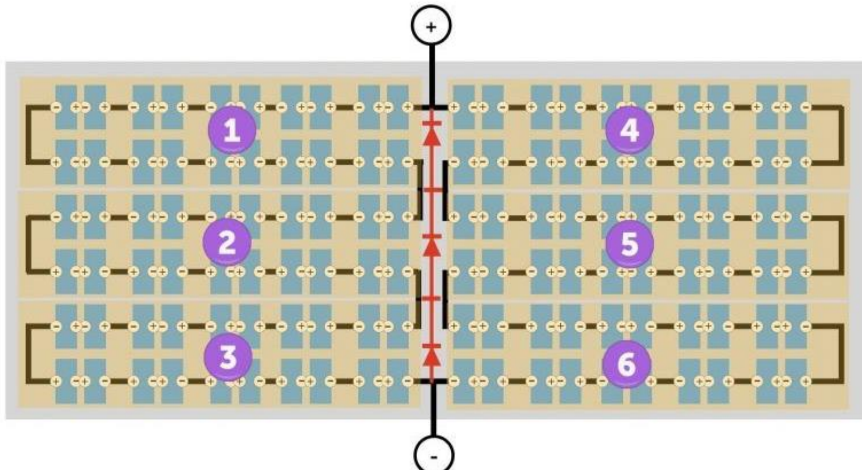

Figure 10. Internal wiring scheme of solar panel with Half-Cell technology (Pickerel, 2018)

As it is shown in Figure 10, HC solar panels divide the current flow into two parts joined in series and there are 6 separate rows of cells connected in parallel. This reduces the internal resistance of the panels (lower current losses when transported along the conductive tracks) and ensures continuous production when the panel is partially shaded since partial shading of one half of the solar panel will not affect the total panel.

2.4 Batteries/storage capacity and technology

Nowadays in the market there are some different kind of batteries but this project will be focused in four options: AGM, Lithium Iron Phosphate, Nickel Manganese Cobalt, and Lithium Titanite batteries.

2.4.1 AGM (Absorbed Glass Mat)

Absorbed Glass Mat is also called starved electrolyte. This peculiar technology was originally invented in 1980, and developed and introduced in 1985 for the use of military aircraft as they needed high power, low weight, and reliability (Clarios, 2020).

The technology used in AGM batteries can be seen in Figure 11 is that the separation between the positive and negative plate is covered by a glass mat, the function of which is to absorb, retain the battery acid, and control the flow of it. The plates are installed by means of strong compression in each of the cells, fitting them into the plastic box and maintaining a certain pressure. After that compression, the mat it is welded in place because the plates and mats are tight so they are close to becoming immune to vibration (BatteryStuff, 2020).

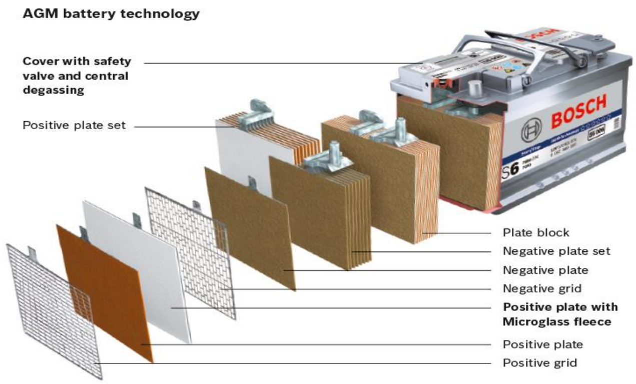

Figure 11. AGM battery structure (Bosch Start Stop, 2018)

To achieve longer life, it must be internally well compressed, because this, limits the separation of the material contained in the plates throughout the cycles. This requirement also causes a reduction in internal resistance and a significant improvement in pulse output power. Normally, a rigid container is used to compress the battery to the end of its life.

2.4.2 LiFePO4 (Lithium Iron Phosphate)

In 1996, the University of Texas (and other contributors) discovered phosphate as a good cathodic material for rechargeable lithium batteries since combining it with lithium offers good electrochemical performance with low resistance (Battery University, 2020). This good performance is made possible by the nanoscale phosphate cathode material. Its main virtues are high current capacity and long cycle time, as well as good thermal stability, greater safety, and tolerance in case of abuse.

Lithium phosphate is more tolerant of working under full load conditions and does not stress as much as other lithium-ion systems if kept at high voltage for a long time. As with most batteries, cold temperatures reduce performance and high storage temperatures shorten battery life. One of the characteristics of Li-Phosphate is that it has a higher self-discharge rate than other Li-Ion batteries, which usually causes balance problems with battery aging. In this type of battery, there is no tolerance to humidity, and cold temperatures will decrease its performance (How Does a Lithium-ion Battery Work, 2020).

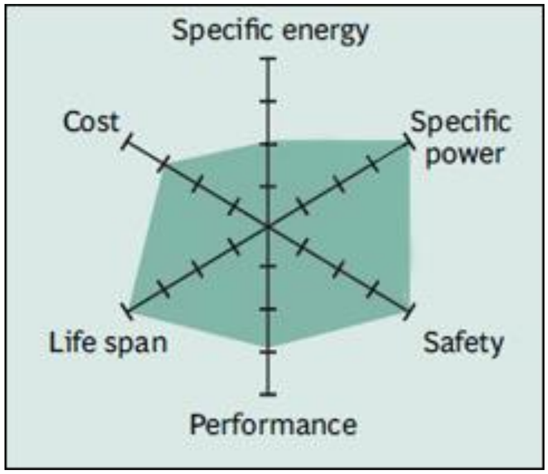

Figure 12. Lithium Iron Phosphate atributes (Battery University, 2020)

Figure 12 summarizes the attributes of the Li-Phosphate. The strengths of this kind of battery are its life span, safety, and the specific power. A common use for this kind of battery is to replace the lead-acid vehicle starter battery.

2.4.3 NMC (Nickel Manganese Cobalt)

NMC is one of the most successful lithium-ion systems is the combination of nickel-manganese-cobalt cathodes (NMC), these systems can be adapted to serve as Energy Cells or Power Cells. The silicon added to the graphite has the disadvantage that the anode grows and shrinks with loading and unloading, making the cell mechanically unstable.

What makes NMC different than the others is its material combination. A good example to explain this combination would be table salt in which the main ingredients are sodium and chloride, which, independently, are toxic materials, but when mixed serve as seasoning salt and food preservative (Targray, 2020).

Nickel has high specific energy but little stability; manganese, on the other hand, has low specific energy, which it achieves with its spinel-shaped structure, also achieving a low internal resistance. The combination of the metals enhances the strengths of each.

This type of battery is usually chosen for power tools, bicycles, and other electric trains. The most commonly used cathode combination is 1-1-1, i.e. one-third nickel, one-third manganese, and one-third cobalt. This combination reduces the cost since there is a significant reduction in the use of the raw material, in this case, speaking of cobalt. Obviously, this is not the only possible combination, NCM (5-3-2), 5 parts nickel, 3 parts cobalt, and 2 parts manganese are also very common (The Netherlands, 2016).

As mentioned above, the cost of cobalt has been high these recent years, i.e., in 2018 its price was 90$/kg (Historical, 2020). So many battery manufacturers tried to stay as far away from cobalt systems as possible. Therefore, manufacturers tend to opt for nickel-based systems, because, they have a higher energy density, lower cost, and longer life than cobalt-based cells, even though they have a slightly lower voltage. Figure 13 shows the characteristics of the NMC.

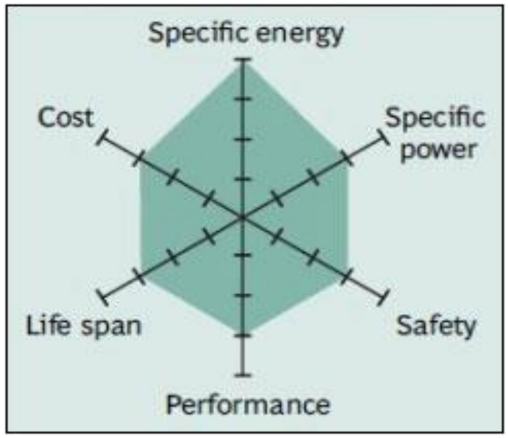

Figure 13. Nickel Manganese Cobalt atributes (Battery University, 2020)

As shown in the picture above, the NMC has a good overall performance and excels in the specific energy field. This battery is usually the preferred candidate for the electric vehicle as it has the lowest self-heating rate.

2.4.4 LTO (Lithium Titanite)

In essence, the LTO is a rechargeable battery based on lithium-ion battery technology, or rather, it is a succession of them. Li-titanate oxide is a substitute for the graphite anode, commonly used in many types of batteries. If the nominal cell voltage is 2.40V, LTO releases a high discharge current that is 10 times the capacity of most lithium batteries. Instead of using carbon particles on its surface, it uses lithium-titanate nanocrystals (Global World Logistic, 2020).

The production of lithium titanate batteries has many scientific advantages due to the required nanotechnology. This means a good impact since, exceptionally, new technologies have a positive influence on the product and its reliability. LTOs have many advantages, e.g. long life, high charging and discharging speed, increased safety, good low-temperature performance, and a high potential for integration with energy storage solutions. (InvestorIntel, 2020) To demonstrate this, Figure 14 shows the characteristics of LTO.

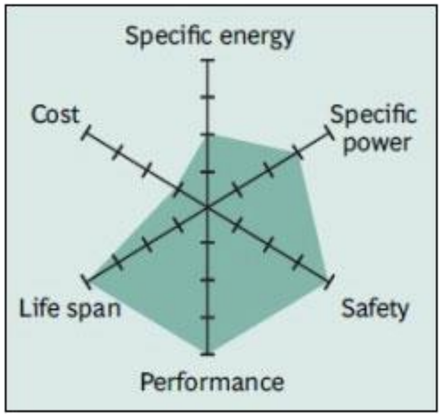

Figure 14. Lithium Titanite atributes (Battery University, 2020)

As it has been said and can be seen above, LTO has three strengths, which are, safety, low-temperature performance, and life span. Nowadays, a lot of companies are trying to improve the specific energy and lower cost.

2.5 Battery Management System

A Battery Management System or BMS is essentially the brain of a battery pack. It measures and reports crucial information for the operation of the battery, and also protects the battery from damaging a wide range of operating conditions.

First of all, its components must be known, as well as its main functions. The single most important function of a BMS performance is self-protection or what would be the same, protection of the circuit. Lithium-Ion batteries sell-off with critical design issues: If you overcharge them, you can damage them, and cause overheating, and even explosions or flames. So, it is important to have a BMS to provide overvoltage protection.

Every battery protection circuit has two electronic switches called MOSFETs, which are semiconductors used to switch electronic signals to ON or OFF in a circuit. A BMS typically has a discharge MOSFET and a charge MOSFET. At the lithium-ion protector chip detects that the voltage across the cells exceeds a certain limit, it will discontinue the charge by opening the charge MOSFET. Once the charge is going back down to the same level, then the switch will be closed again. Similarly, when the cell drains to a certain voltage, the protector, will cut-off the discharge by opening the discharge MOSFET (A Look Inside Battery-Management Systems, 2015).

The second most important function performed by BMS is Energy Management, for example, most laptops are not only able to tell how much charge is left in the battery, but also what your rated consumption is how much time have left to use the device before the batteries new recharge. So, in practical terms, the battery management is very important for portable electronic devices (Electric Vehicle, 2019).

The coulomb count is very important in a BMS since it tracks the available capacity. A good example would be a shelf where there are five pots, two are removed and three remain. If you put four more pots in, there will be a total of seven. If the shelf holds ten pots, it will be 70% full. This is the information that the BMS communicates electronically (Battery Management Systems, 2020).

BMS for certain applications include an embedded charger consisting of a control device, an inductor, which is an energy storage device and a discharger. The control device manages the charging algorithm, for Lithium-Ion cells the ideal charging algorithm would be constant current and voltage (Engineering.com, 2019).

A battery pack usually consist of several individual cells which work together in combination. The ideal would be that all the cells of the battery pack should be kept at the same state of charge. If the cells are unbalanced, individual cells will be stressed and lead a premature charge termination, and a reduction in the overall cycle life of the battery. The cell balancers of the BMS, extend the life of the battery by preventing these imbalances of charge in individual cells from occurring.

2.6 Charge Controllers

As it is explained in the chapters above, batteries are rated according to their voltage capacity, and exceeding this voltage can be the trigger to cause permanent damage to the battery and even loss of functionality over time.

Charge controllers are only necessary in specific cases. They can be dispensed with when someone wants to install a solar array with a grid-connected battery in their home. There will be no need to control the charge because when the battery is full, the remaining energy will be automatically redirected to the grid, thus avoiding the dreaded overcharge. However, charge controllers are necessary if someone is trying to install an off-grid solar system, from rooftop systems to smaller installations on boats or recreational vehicles.

Therefore, solar charge controller is responsible for managing the energy that enters the battery bank from the solar array. It is a very important component both to ensure that the deep cycle batteries are not overcharged during the day, and that power is not returned to the solar panels at night and drains the batteries (Marsh, 2019).

Apart from their main function, managing the energy, some charge controllers are manufactured with different "extras", to increase their scope of work, such as lighting and charge control. Solar charge controllers can be found in two different technologies, PWM and MPPT.

2.6.1 PWM

A PWM type solar charge controller is electronically quite simple. It basically acts as a contactor to allow or not the passage of current from the solar panel to the battery. Depending on the voltage at which it detects the battery and the charge it admits, the regulator detects its status: discharged or charged either partially or totally.

In this way the regulator closes the circuit and allows the current to flow from the panels to the battery, opening it when the battery is reaching its full charge. This makes the panel work at a voltage equivalent to the battery voltage, always lower than the one the panel can offer, so that this charge is possible. This fact causes that the panel is not always offering its maximum power since we make it work at a lower voltage, so we lose efficiency and we do not take advantage of the power that the solar panels can offer in the installation.

2.6.2 MPPT

Maximum Power Point Tracking (MPPT) is an electronic system that manages the photovoltaic modules in such a way that maximum power can be extracted from them. The MPPT is not a solar tracker, it is a fully electronic system that varies the electrical point of operation of the panels and thus allows the panel to deliver the maximum removable power. The additional power extracted is converted into an increased battery charge current (What is Maximum Power Point Tracking, 2020).

To understand the operation of an MPPT, first, the operation of a traditional charge controller has to be considered. When a normal RC is charging a discharged battery, what it does is simply close a circuit that allows the panels to be connected to the battery. This "forces" the panels to work at the operating voltage of the battery, which normally does not match the ideal maximum power voltage of the panel. The Power/Voltage/Intensity curve for a 75W panel type in STC 25ºC conditions and 1000W/m^2 irradiance is the one shown in Figure 15.

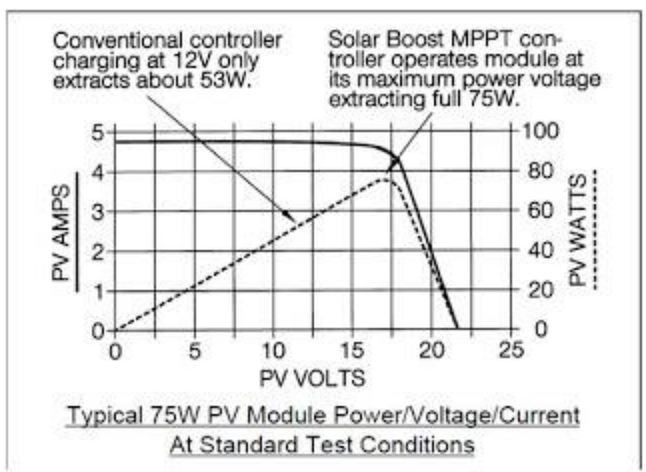

Figure 15. MPPT Charge Controller Data at STC (V. 2018)

As can be seen above, the traditional charge regulator connects the battery with the module and therefore forces the module to work at 12 V. This fact of making the 75W module work at 12V, which causes the module to artificially deliver only about 53W.

The charge regulators that incorporate MPPT, what they do is to calculate at all times the voltage at which the module is likely to produce the maximum power for the conditions of the moment. In the figure above the maximum power voltage (Vmp) is 17 V, and what the charge regulator with MPPT does is to make the battery voltage independent of that of the module, allowing the photovoltaic module to operate at 17 V independently of the battery voltage, achieving an increase in the battery charge current (Marsh, 2019).

2.7 Solar Inverter

A solar inverter is a common inverter but it uses solar energy. The function of this inverter helps to convert DC to AC using solar energy. DC flows in one direction in the circuit and helps to supply current when there is no electricity. Direct current is used for small devices where there is energy already stored in their battery. As for AC (alternative current), it is the energy supplied back and forth within the circuit, and normally alternating current is used for household appliances. A solar inverter helps many DC powered appliances to run on AC power so that the consumer can make good use of it.

It is an essential component in a solar energy system. The main function of the inverter, as it is said above, is to change the variable direct current output of the solar panels into alternating current by means of various electrical and electronic components integrated and connected in the circuitry that assists in the conversion process.

The energy from the converted alternating current is used to run appliances such as air conditioning, TV, refrigerator, microwave, induction, etc. In some exceptional applications, we can use the Direct Current energy, for example, to charge the battery of a cell phone. But, most commonly, the energy obtained from a solar system is used to power AC loads.

There are many kinds of solar inverters, but this thesis will be focused on Off-grid inverters because they are the most suitable for remote or rural areas where the power grid is situated far away from the solar inverter.

2.8 Automatic Backup Generator

Nowadays, when it comes to installing solar energy in a house, many people need to be sure that the energy will be available when they need it. If you want to ensure this availability, whether the batteries are part of the solar array or not, adding a generator can be very helpful.

Generators fulfill three main objectives for Off-Grid systems, which are:

1. **Backup Charging**. Producing power regardless of the weather.

2. **Battery equalizing**. Certain batteries require a planned overcharge several times a year to increase performance and life.

3. **Running Loads that Exceed the Inverter Capacity**.

Like batteries, generators add a layer of complexity to the solar system and may require maintenance and have a shorter life than the solar array itself. The life expectancy of the generator can increase depending on the manufacturer and of course if you have a good warranty (a minimum of two years is usually recommended).

Another consideration is the sizing of the generator and its AC voltage output. In off-grid systems, the generator size should be the one required to supply the full load capacity of the inverter, with the addition of any additional loads required. Most generators in-home systems are about 2,500 watts. In terms of AC voltage, some generators only produce 120 V and others are field configurable or are 120/240 V with a switch (Wholesale Solar, 2019).

Combining a generator with your off-grid solar array will provide additional system capacity and potentially allow you to consider a smaller battery bank because the generator can compensate for the shortfall when solar power is limited. Or, adding a generator to your off-grid solar array can provide backup power while maximizing your solar production.

3 Practical Section

3.1 Location and Climate

Vaasa is located on the west coast of Finland, also known as Ostrobothnia. Further south, on an island called Långgrund (Figure 16), is the cottage on which this thesis is based. Being a little isolated and surrounded by water, it will be a very cold place during the winter and a little bit warm during the summer, although not too much.

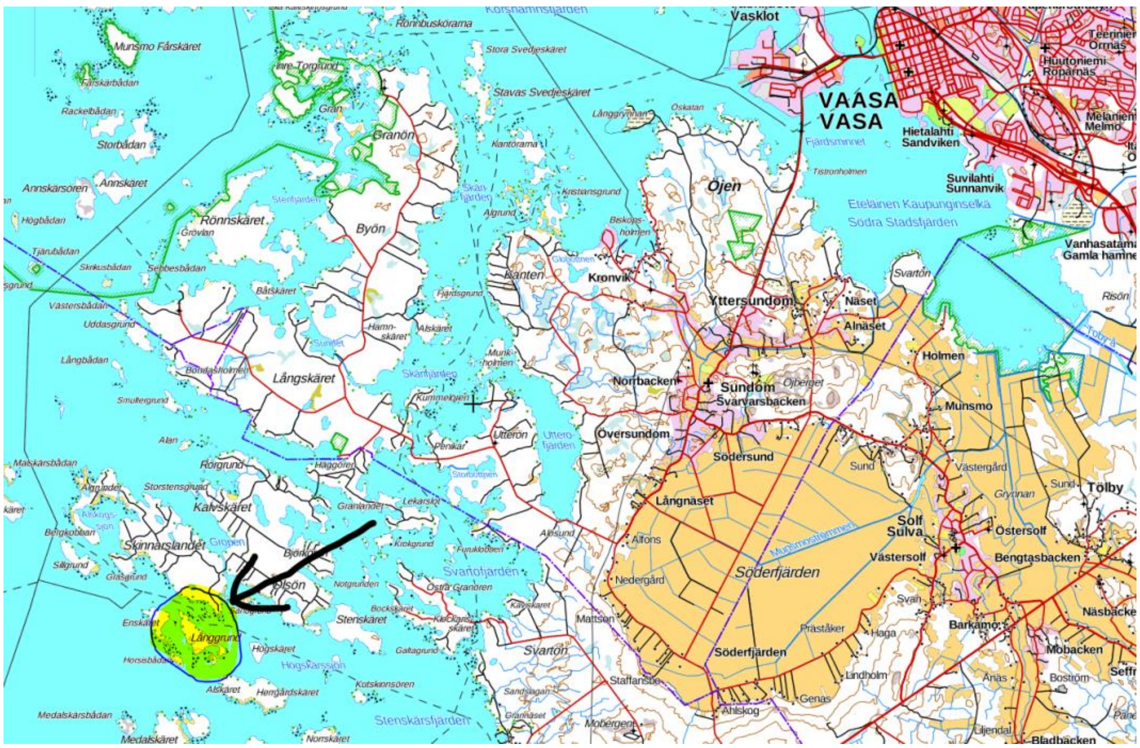

Figure 16. Cottage location (Maanmittauslaitos, 2020)

According to different sources consulted, the temperature varies between -10ºC and 20ºC, although there are exceptions of minimum temperatures of -20ºC and a maximum of 22ºC as can be seen in Figure 17.

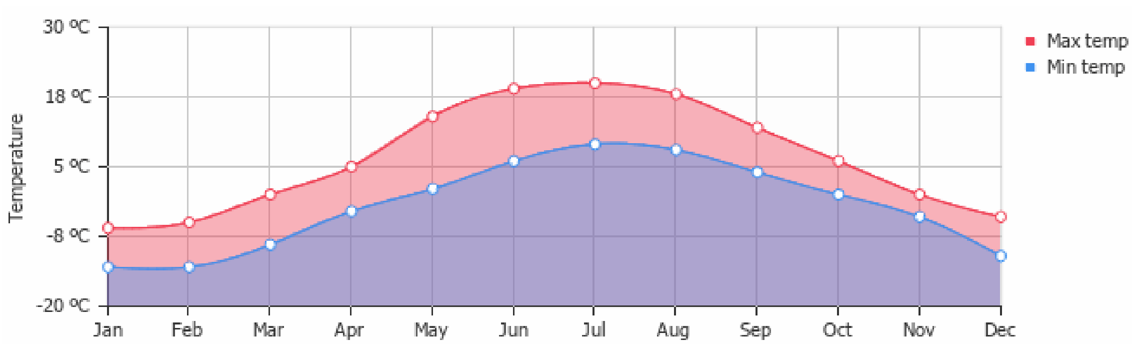

Figure 17. Monthly average temperature in Vaasa (Weather Spark, 2020)

Clouds

The climate of Vaasa can be described as cloudy/overcast for most of the year. On average, it is cloudy for almost 50% of the day. On most days it is 45% to 75% cloudy (PVGIS, 2020). The cloudiest time of the year is usually between winter and spring, in detail between October and March, which will mean more opposition when it comes to generating energy.

Precipitation

Rainfall in Vaasa is in the form of rain for an average of almost 10 months of the year, which means that it will also be cloudy. Besides rain, Finland is known for its huge snowfalls, which are common for about 6 months on average during the year (Weather statistics for Vaasa, 2020).

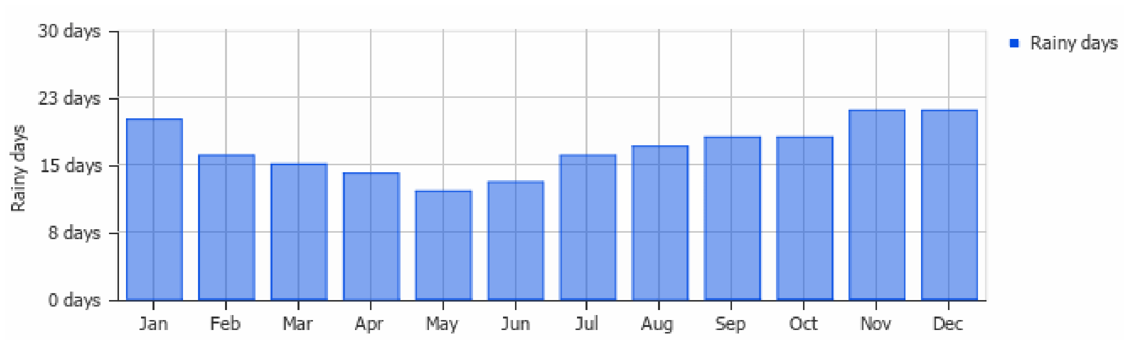

Figure 18. Rainy days per month in Vaasa (Weather statistics for Vaasa, 2020)

As it is shown in the picture above, rainy days are a common thing in Vaasa. This data, together with the previous ones, gives meaning to why the photovoltaic installation will not be used during January, November, and December.

Wind

According to Weather-and-climate.com, the wind in Vaasa, Finland, blows from the south for almost 11 months of the year, and the wind that comes from the north during the last month of the year. This means that the wind will most likely have an impact on the facility since it is located on an island. But fortunately, at the exact location of the panels, there is a huge arrangement of trees, which will protect the installation to a great extent.

3.2 Sunshine

Thanks to WeatherSpark.com, several factors are considered in this section, for example, the length of the day throughout the seasons, absorption by the clouds, and the elevation of the Sun. Once these factors have been evaluated, the following graph is generated (Figure 19) which shows the total daily incident solar energy reaching one square meter of the earth's surface (although in the figure, the units are in kWh, actually the correct representation would be in kWh/m^2).

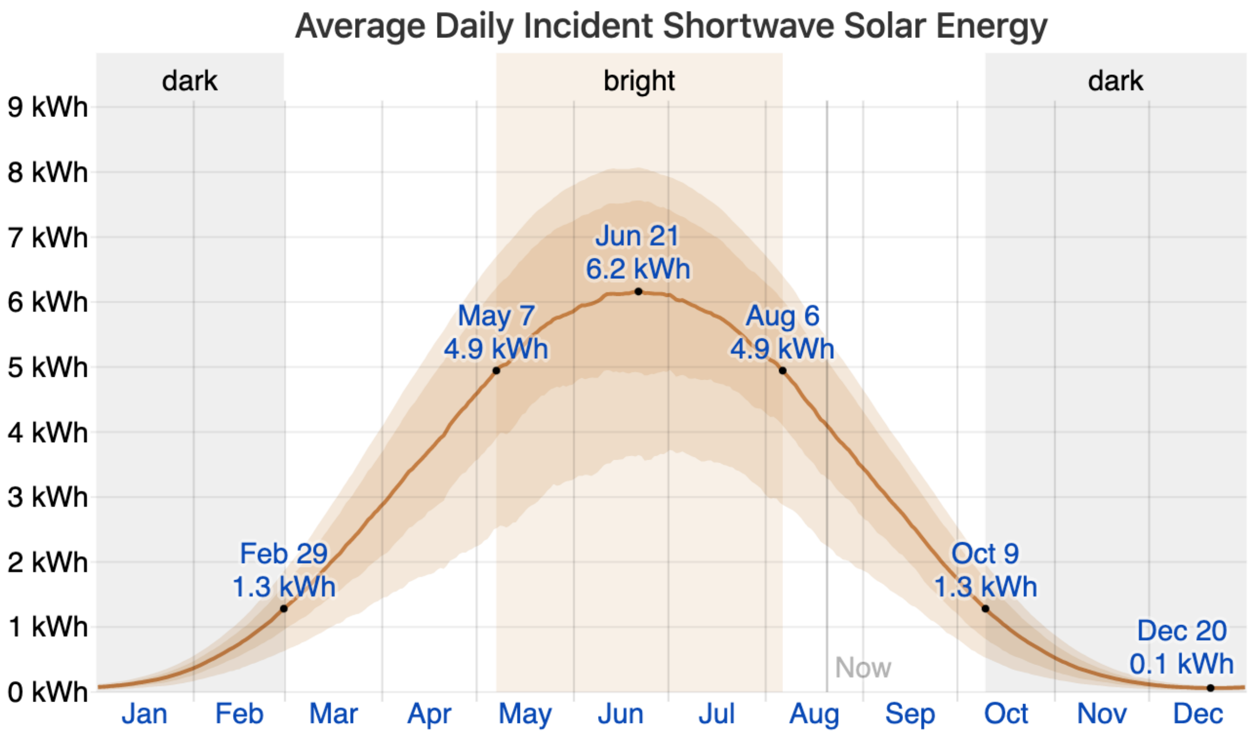

Figure 19. Average Daily Solar Energy in Vaasa (WeatherSpark.com, 2020)

As shown in the illustration, the period with the most solar energy of the year lasts 3 months, exactly from May 7 to August 6, with a daily average of incident solar energy above 4.9 kWh/m^2. The peak of solar energy is June 21, with an average of 6.2 kWh/m^2.

3.3 Comparison of energy input with different facing directions of Solar panels

In this section, the energy input has been studied according to the different proposed arrangements of the solar panels. First and foremost, the azimuth must be explained. It is the angle between a body and the line that comprises both the North and the South (in this case the South has been used as a reference), measured in a clockwise direction, with positive directions following that direction and negative directions going in a counter-clockwise direction. For example, an eastbound body has an azimuth of -90°, and a westbound body of 90° (PhotoPills, 2020).

The arrangements are as follows:

- 10 Panels to the South (0° azimuth)
- 10 Panels Southwest (45° azimuth)
- Option 1: 3 SE panels (-45° azimuth), 4 S panels (0° azimuth), and 3 SW panels (45° azimuth)
- Option 2: 3 panels SW (45° azimuth), 4 S (0° azimuth), and 3 W (90° azimuth)

Thanks to the PVGIS source, it has been possible to carry out the simulation and obtain the different irradiation data, with which the following graph has been generated (Figure 20). The panel used for this example is monocrystalline, with a rated maximum power of 340 W and dimensions of 1690 mm x 997 mm x 36 mm.

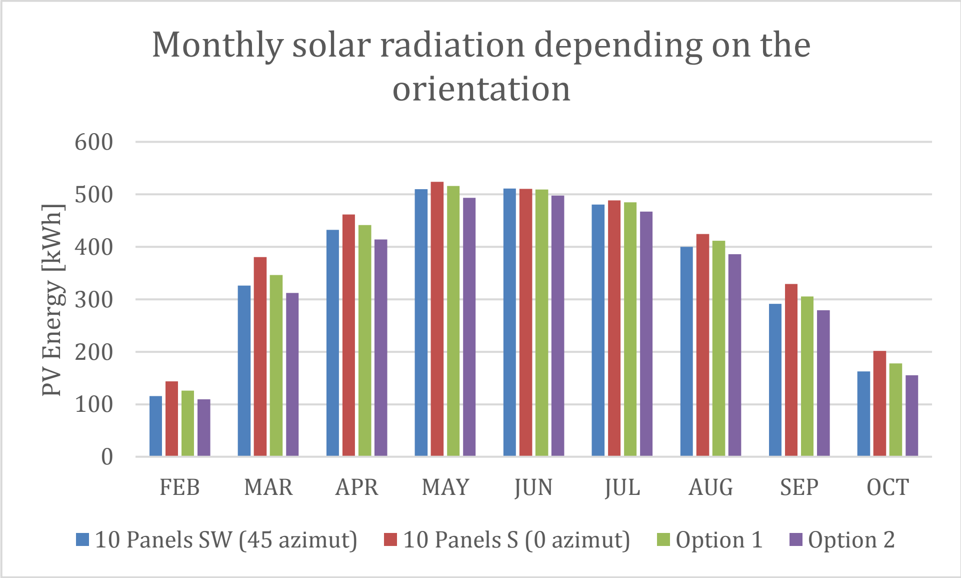

Figure 20. Hypothetical Monthly PV Energy (Author own, 2020)

As can be appreciated, the best disposition is 10 panels faced to the South. Although in June and July the difference is minimum, in the other months it is considerably higher, that is why this option is the chosen one.

4 Dimensioning calculations

4.1 Basic notions about isolated photovoltaic systems

Firstly, before going into the development of the calculation of a standard off-grid photovoltaic system, the equipment that makes up this type of system will be briefly defined because some points are necessary to understand the calculus done. The full explanation of each component is provided in Section 5 of this project. Its fundamental elements are:

- Photovoltaic modules

They will be in charge of power generation. They can be of various types, including those most commonly used for this type of installation are the panels with monocrystalline and polycrystalline technology. Monocrystalline and polycrystalline solar panels, with serial connections of their cells, they are around 12-18 volts for 36 cell connections and the 24-34 volts for 72 cells. It is important to always look at the I-V curve that is provided by each manufacturer in their datasheets and on the influence of temperature on the current and voltage of the module (Figure 21).

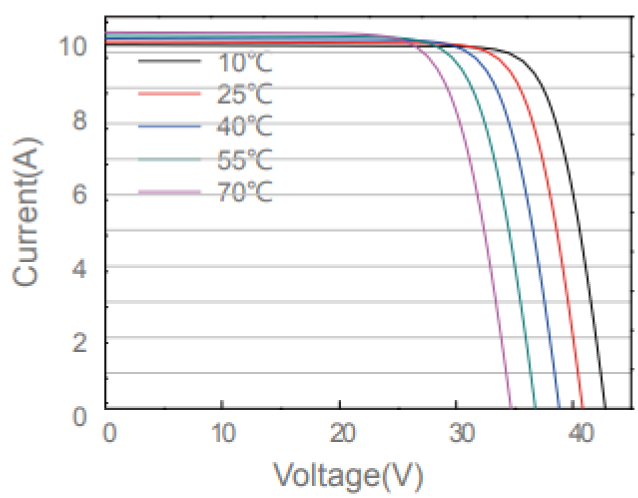

Figure 21. Current-Voltage Curve of JAM60S10-330/PR (Annex I)

An increase in temperature causes a slight increase in the current and to a greater extent, decreases the output voltage of the module.

- Charge controllers

It is in charge of controlling the charge of the batteries, as well as the discharge and avoiding excessive charges or discharges. Simply, a controller can be understood as a switch, closed, and connected in series between panels and battery for the charging process and open when the battery is fully charged.

The maximum input and output currents of the appropriate regulator for each application will depend on the maximum current that the photovoltaic generation system can produce for the input and the maximum current of the loads for the output. To consider possible irradiance peaks or temperature changes, it is recommended that, when choosing the regulator, it should be one with 15-25% more than the short-circuit current that can reach it from the photovoltaic generation system (I_{input}) or that which can consume the system's load (I_{output}). The choice of the regulator will be that which supports the greater of the two calculated currents.

- Batteries

They are in charge of accumulating the electrical energy generated by the photovoltaic generation system to have it available during the hours of the day when the sun is not shining. The most recommended for this type of installation are stationary lead-acid batteries, with glasses of 2V each, which will be arranged in series and/or parallel to complete the 12, 24, or 48 V_{cc} that is appropriate in each case. The criteria that we can use when choosing the voltage level of the photovoltaic module that we need for our photovoltaic system could be summarized, in a generic way, in the following table:

Table 3. Needed operating voltage depending on the power demanded (Author own, 2020)

Power demanded by the loads (W)	Operating voltage (V)
Less than 1500	12
1500 – 5000	24 / 48
Greater than 5000	120 / 300

This type of battery can remain charged for long periods and can withstand deep discharges sporadically. To define the necessary size of the batteries it is necessary to consider a couple of parameters:

- Maximum **depth of discharge (DOD)**, what is the maximum level of discharge allowed to the battery before the regulator is disconnected, to protect the life of the battery. The maximum depths of discharge that are usually considered for a daily cycle (maximum daily depth of discharge) are around 15-20%.
- In the case of the **seasonal cycle**, which is the maximum number of days that a battery can be discharged without receiving sufficient solar radiation, they are around 4-10 days and depth of discharge of approximately 70%. In photovoltaic installations, we are not looking for aggressive discharges, but rather progressive ones, for this reason, the batteries to be used are usually with a 100-hour discharge (C100), since the more intense the discharge of a battery is, the less energy it is capable of supplying. Besides, they are usually specified with times of unloading of 100 hours because when speaking of times of autonomy of 5 or more days the unload would take place in, for example, 24 x 5 = 120h, and by defect, the 100 hours are chosen then.

- Inverter

If the loads to be supplied are at 230Vac, we will need equipment that transforms the direct current from the regulator into alternating current to supply the loads. This is the function of the inverter. When sizing the inverter, we will consider the power demanded by the sum of all the AC loads in an instant. In this way, the chosen inverter whose power is 20% higher than the demanded by the loads, assuming that it works at the same time.

4.2 Procedure for the Calculation of an Off-grid Photovoltaic System

First, a fundamental concept must be introduced, that of "Peak Sun Hours" or HPS [hours]. It can be defined as the number of hours in which we have a hypothetical constant solar irradiance of 1000 W/m^2. That is, one peak solar hour "HPS" is equivalent to 1kWh/m^2 or, in other words, 3.6 MJ/m^2. In other words, it is a way to count the energy received from the sun by grouping it in packages, each "package" being of 1 hour receiving 1000 Watts/m^2.

At this point, an important note must be made:

Irradiance: This is the magnitude that describes the radiation or intensity of solar illumination that reaches us measured as an instantaneous power per unit area, W/m^2, or equivalent units.

Irradiation: This is the amount of irradiation received in a given time, i.e. the power received per unit of time and per unit of area. It is usually measured in Wh/m^2 or, in the case of one day, in Wh/m^2/day or equivalent units.

To calculate the HPS value, the value of the incident radiation must be divided by the value of the irradiance power under standard measurement conditions (STC), since it is under these conditions that the electrical characteristics of the photovoltaic modules are met. This value of irradiance in standard measurement conditions is 1000 watts/m^2. That is, if you have the data of solar irradiation for a given day and divide it by 1000, you get the HSP. For example, if is given irradiation of 3,800 Wh/m^2, to pass it to HSP, it is divided by 1,000W/m^2, to obtain 3.8 HPS. Once this has been said, the respective system calculations can begin.

4.2.1 Consumption estimation

Here, the data provided by the consumer is always essential and must always be as realistic as possible to avoid sizing deviations. If the installation is to be carried out for a house used daily throughout the year, the average value for the whole year should be chosen. If the installation is carried out for occasional use, for example in summer, the values for the summer months should be chosen. In this case:

Table 4. Energy consumers (Author own, 2020)

Load	Power [kW]	Total Energy Needed/day [kWh/day]	Total Energy Needed [kWh/day] * 20% Security Parameter
Coffee maker	1	0.4	0.48
Water heater (Dish/Hand wash)	2	1.5	1.8
Water heater (Shower)	2	3	3.6
Water maker (Pumps)	0.78	2	2.4
LED-lights	0.025	0.1	0.12
Fridge	0.04	0.96	1.152
Kitchen fan	0.26	0.2	0.24
Air Conditioner	0.7-5.2	0.5-1.5	0.6-1.8
Kitchen Induction	1.7	3	3.6
TOTAL	**8.5**	**11.66/12.66**	**13.992/15.192**

With the data from this "Consumption Table", the average daily consumption of the installation is obtained, to which 20% has been applied as a recommended safety margin. An important point is there will be performance losses in the battery and inverter in the installation and this influences the final energy requirement. Generally, for good sizing, battery efficiency will be assumed as 95%, the inverter 90%, and the conductors 100%.

Therefore, to calculate the average daily consumption (L_{md}) it is considered the following expression:

$$L_{md} = \frac{L_{md,DC} + \frac{L_{md,AC}}{\eta_{inv}}}{\eta_{bat} * \eta_{con}} = \frac{\frac{15.192}{0.9}}{0.95} = 17.768\ kWh/day$$

Where (L_{md}) is the average daily power consumption, ($L_{md,DC}$) is the average daily power consumption of DC loads, and ($L_{md,AC}$) is that of AC loads.

As expected, the real average daily consumption is slightly higher than the nominal one, since, as mentioned, the losses that can occur in some of the elements of the installation and the safety margin of 20% have been considered.

Table 5. Monthly consumption (Author own)

Month	Consumption [kWh]
February	1
March	1
April	3.798
May	3.798
June	9.115
July	15.192
August	9.115
September	3.798
October	3.798

Once the consumption has been calculated, the global solar radiation data on Låggrund has to be found exactly where the house is located, using, for example, PVGIS, which is a free online application.

Apart from this data, the data provided by Hans, from an installation in Vaasa, has been considered to corroborate the calculations. Combining both data, the "Radiation Table" (Wh/m^2/day) will be obtained according to the inclinations to be studied. These inclinations refer to the tilt angle and this is measured concerning the horizontal, i.e. an angle of 0° would correspond to the panel parallel to the floor, while one of 90° would correspond to the panel perpendicular to the floor.

Table 6. Radiation table (Author own, 2020)

Month	45 degrees	50 degrees	60 degrees
February	1410	1453	1511
March	3592	3655	3712
April	4431	4427	4339
May	5130	5055	4815
June	5960	5826	5454
July	5363	5259	4964
August	4213	4181	4046
September	3736	3777	3788
October	2096	2156	2236

The optimum slope for the installation is calculated, for which the criterion of the Critical Month must be applied, so it must be prepared from the table of radiations, the "Table of Quotients" Consumption / Radiation which is shown below:

Table 7. Table of Quotients (Author own, 2020)

Month	45 degrees	50 degrees	60 degrees
February	830	805	774
March	326	320	315
April	1002	1003	1024
May	866	879	923
June	1789	1830	1955
July	3313	3380	3580
August	2531	2550	2635
September	1189	1176	1173
October	2120	2060	1987

For each inclination, the highest value of all the quotients of each column must be recognized, since they will correspond to the time of the year when the ratio between energy consumption and available irradiation will be the highest, so that the energy supply will have to be guaranteed, especially at that time, even if this means over-sizing for the other months. These values have been marked with the shaded cells.

What usually happens is that the maximum values coincide with the months with more solar radiation. In this case, however, consumption is not constant throughout the year, which means that the maximum values do not coincide in the same month. This does not affect the calculation as the maximum ratios in the second table must be chosen. Once these values are known, the lowest of them is chosen to avoid excessive over-sizing, which in this case corresponds to the value of 3313.40 and 45º of inclination.

4.2.2 Calculation of the total number of modules required

$$N_T = \frac{L_{mdcrit}}{P_{MPP} * HPS_{crit} * PR} = \frac{15192}{340 * 5.36 * 0.9} = 9.25 \equiv 10$$

The explanation of this equation is simple, to know how many panels we need to generate the energy that the system demands every day, we must divide that energy by the one generated by each panel because the daily energy that each panel can give is obtained from the equation:

$$E_P = P_{MPP} * HPS_{crit} * PR$$

So, a total of 10 panels will be needed to cover the demands of the system, although this number could change, Being (L_{mdcrit}) the average monthly daily consumption for the critical month, "Table of Consumption", (in this case, 15.192 kWh/day).

(P_{MPP}) the peak power of the module under standard measurement conditions (STC). In this case, the model used is JAM60S10 320-340/MR with 340 W of peak power in STC.

(HPS_{crit}) are the peak hours of sunshine of the critical month calculated from the "Radiation Table", i.e.: Irradiation of the critical month (July 45º) / 1000 W/m2 = 5.36 HPS.

(PR) the overall operating factor which varies between 0.65 and 0.90. For this calculus, 0.90 will be taken by default.

Regarding the connection between the modules calculated in this section, how many panels are in series and how many in parallel will be detailed when the charge controller has been chosen, in Section 5.3.

4.2.3 Calculation of the batteries

Now, turning to the calculation of the batteries, remember that the two important parameters for the dimensioning of the battery are the maximum depth of discharge (seasonal and daily) and the number of days of autonomy as a general rule, these parameters will be taken:

Maximum Seasonal Discharge Depth ($P_{Dmax,e}$) = 70% = 0.7

Maximum Daily Discharge Depth ($P_{Dmax,d}$) = 30% = 0.3

Number of Autonomy days (N) = 1

The required nominal capacity of the batteries is calculated as a function of the seasonal and daily depth of discharge. The largest of these will be selected, as otherwise a seasonal or daily insufficiency may be incurred.

The nominal capacity of the battery as a function of the maximum daily discharge (C_{nd}):

$$C_{nd}(Wh) = \frac{L_{md}}{P_{Dmax,d} * F_{CT}} = \frac{15192}{0.3 * 1} = 50640\ Wh$$

$$C_{nd}(Ah) = \frac{C_{nd}(Wh)}{V_{BAT}} = \frac{101280}{48} = 1055\ Ah$$

The explanation of the two equations is simple, there is a need to generate a daily energy Lmd with the batteries but allowing only a 15% of maximum daily discharge and assuming a Temperature Correction Factor (FCT = 1). Once the energy in Wh of the battery is known, it will be divided by the voltage of the battery (48V in this case) and the minimum capacity needed for the accumulation system according to the maximum daily discharge will be obtained.

The nominal capacity of the battery in the function of the maximum seasonal discharge (C_{ne}):

$$C_{ne}(Wh) = \frac{L_{md} * N}{P_{Dmax,e} * F_{CT}} = \frac{15192 * 1}{0.7 * 1} = 21702.85\ Wh$$

$$C_{ne}(Ah) = \frac{C_{ne}(Wh)}{V_{BAT}} = \frac{21702.85}{48} = 452.14\ Ah$$

The explanation is similar to the previous one, there is a need to generate a daily L_{md} energy with the batteries but that can have it during 1 day without sun, without allowing a greater discharge of 70% and supposing a Temperature Correction Factor (TFC= 1). Once the energy in Wh of the battery is known, it is divided by the battery voltage (48V in this case) and the minimum capacity that is needed for the accumulation system according to the autonomy days will be obtained.

Therefore, the highest nominal capacity of the batteries has to be chosen, and that would be at least C=1055 Ah.

4.2.4 Calculation of the charge controller

To achieve this, the maximum current that the regulator can withstand must be calculated, at its input but also at its output.

To calculate the input current to the regulator, the product of the short circuit current of a module has to be made, in this case the one of the JAM60S10 320-340/PR is of I_{sc}=10.46 A, and it is multiplied by the number of branches (the current of each branch in parallel will be approximately the same) in parallel calculated previously:

$$I_{input} = 1.25 * I_{SC} * N_P = 1.25 * 10.46 * 5 = 65.375\ A$$

Being,

(NP) the number of panels for each parallel branch, in this case, 5 (chosen in Section 5.3).

1.25 is a safety factor to avoid occasional damage to the controller.

For the calculation of the output current evaluation of the powers of the DC loads and the AC loads have to be made:

$$I_{output} = \frac{1,25 * \left(P_{DC} + \frac{P_{AC}}{\eta_{inv}}\right)}{V_{BAT}} = \frac{1.25 * \left(\frac{3500}{0.95}\right)}{48} = 95.94\ A$$

Being,

(P_{DC}), Power of DC loads.

(P_{AC}), Power of alternating loads.

(η_{inv}), inverter efficiency, around 90-95%.

Therefore, the regulator should withstand a current of at least 65.375 A at its input and 95.94 A at its output.

4.2.5 Calculation of the inverter

Finally, for the calculation of the inverter, only the sum of the powers of the AC loads should be calculated. In this case, it would be the coffee maker (1kW), the heating (3kW), and the fridge (40W), and apply a safety margin of 20%. So:

$$P_{inv} = 1,2 * P_{AC} = 1,2 * 4040 = 4848\ W$$

Therefore, an inverter of approximately 5000 W will be needed.

4.2.6 Cable Calculation

This is the last section of calculation, where you can find the procedure followed to clarify when choosing the type of wiring to be used in the installation. First of all, the data obtained on Copper and Aluminium are shown (Notes, E. 2020).

$$\rho_{Cu@20°C} = 0.018\ \Omega \cdot mm^2/m \qquad \alpha_{Cu} = 0.0039 \frac{1}{°C}$$

$$\rho_{Al@20°C} = 0.027\ \Omega \cdot mm^2/m \qquad \alpha_{Al} = 0.0043 \frac{1}{°C}$$

Once these values are known, a resistivity calculation table is made according to the temperature to which the system will be exposed, and it is obtained from the following equation:

$$\rho = \rho_{20°C} \cdot (1 + \alpha \cdot (T - 20°C)$$

Now, assuming the length (120 m) and section (35 mm^2) of the cables, the resistance of both kinds of the cable must be calculated using:

$$R = \rho \cdot \frac{l}{A}$$

Once this calculation has been made, there is a need to go to the datasheet of the panel to be used in the installation (Annex 1) and note the Open Circuit Voltage (41.55 V) and the Open Circuit Temperature Coefficient (-0.272%/°C), also bearing in mind that the number of panels in series is 5. Therefore, it is possible to calculate both the Open Circuit voltage and the Voltage of the Panels according to the temperature to which they will be exposed from the following formulas:

$$V_{OC@T_2} = 41.55\ V \cdot \left(1 + (T_2 - 25°C) \cdot \frac{-0.272\%/°C}{100}\right)$$

$$V_{MAX@T_2} = 5 \cdot V_{OC@T_2}$$

Finally, to calculate the maximum total power of the system under a certain temperature (T_2), the current in the cable, and the voltage drop in both Copper and Aluminum cables, you should look at the Panel Datasheet in Annex 1, and note the values of maximum power per panel (340 W), the total number of panels (10), the temperature coefficient of P_{max} (-0.35%/°C), and make use of the following equations:

$$P_{MAX@T_2} = 10 \cdot 340\ W \cdot \left(1 + (T_2 - 25°C) \cdot \frac{-0.35\%/°C}{100}\right)$$

$$I_{Cable@T_2} = \frac{P_{MAX@T_2}}{V_{MAX@T_2}}$$

$$\Delta V_{T_2} = \frac{I_{Cable@T_2}}{R}$$

All calculations have been made in Microsoft Excel to speed up the process. They can be found in Annex 2. The following table (Table 8) has been generated from the data obtained:

Table 8. Data obtained from the above calculations (Author own, 2020)

Temperature	**25**	**20**	**15**	**10**	**5**	**0**	**-5**	**-10**
Voltage from panels (V)	207.75	210.57	213.41	216.22	219.05	221.87	224.71	227.52
Voltage Drop Cu (V)	1.02	1.01	0.99	0.98	0.96	0.94	0.93	0.91
Voltage Drop Al (V)	1.54	1.52	1.49	1.46	1.43	1.41	1.38	1.35

As can be deduced, not all the results are in this table as it would otherwise take up a lot of space and this has been considered unnecessary (other calculations can be found in Annex 2). Only the transcendent data are shown, which are, the maximum voltage of the panels, the voltage drops with both copper and aluminum cabling.

Two conclusions are drawn from this section, one is that the wiring to be used in the installation will be copper because it has a lower voltage drop than aluminum. The second is that the charge controller used must have a maximum voltage higher than 227.52 V, which in this case, has a capacity of up to 250 V (Annex 1).

5 Components choice

In this section, each component of the system will be chosen and compared among all the possible options presented in the previous sections.

5.1 PV Panels

After defining in detail, the different types of solar panels, now 7 essential points will be highlighted to choose the photovoltaic panel that best suits the needs of this project, considering the technical characteristics of the photovoltaic panel.

1.- Number of cells and voltage. The cells that a photovoltaic panel has are important to know if you are going to use a photovoltaic battery to store energy or if you want to carry out a photovoltaic self-consumption project. For self-consumption installations, the panels are usually 36 cells (12 V) or 72 cells (24 V). Depending on the capacity of the battery, one will be chosen with more cells or another with fewer cells.

2.- Output power. It is the data that determines the capacity that the panel has to obtain electrical energy through the solar energy it receives. This parameter has been measured under certain conditions which rarely occur on the surface where the photovoltaic panels are to be installed. However, this value serves to compare two panels with the same dimensions.

3.- Output power at nominal operating temperature. Good solar panels, apart from detailing the output power in certain unused parameters (see point 2) in their technical data sheet, also indicate the output power at more common temperatures. This data is much more functional since it determines the power value in normal conditions.

4.- Tolerance. Due to different issues such as the elements that form the photovoltaic panel, the output power may vary. This data can be indicated in % or W. For example, if you have a 100W panel and this one has a tolerance of +/- 5%, it means that this panel, depending on different factors, can produce from 95W to 105W.

Many manufacturers have their photovoltaic panels only with positive tolerance (that is, they can never worsen their power, only improve it) so the buyer is sure that he will get a minimum of W and already knows what he is paying for each Wp as a minimum.

5.-Efficiency. It is the parameter of the power generated by the photovoltaic panel in the square meter when it receives irradiation of 100 W/m2. Currently, this parameter is highly exalted in high-performance photovoltaic panels which are generally the most expensive. The higher the efficiency figure, the greater the power of that solar panel. The following shows the efficiency that each type of photovoltaic panel usually has (Energy News, 2018):

- Monocrystalline photovoltaic panels have an efficiency of between 15% and 21%
- Polycrystalline photovoltaic panels are between 13% and 17%
- Thin-film panels are between 7% and 13%

6.- Power temperature coefficient. As it has been already explained, some photovoltaic panels work much worse in high-temperature conditions, such as polycrystalline photovoltaic panels. Well, the power temperature coefficient determines the output power that is wasted in the photovoltaic panel for each degree above 25ºC.

7.- Nominal Operating Cell Temperature (NOCT). This data is the temperature that the cell of the module has in a usual ambient temperature (20ºC) with irradiation of 800W in a square meter. In other words, the less the cells of the module overheat, the better the photovoltaic panel will work. In general terms, the lower the NOCT, the more efficient the panel.

After explaining all the types of photovoltaic panels and all the important elements that have to be considered from the photovoltaic panel's datasheet, the conclusion reached is that monocrystalline modules have higher efficiency, since the internal structure of the cells is more uniform and, therefore, presents less resistance to electronic displacement.

Also, within monocrystalline modules, the split cell increases efficiency because it improves module response when there are shading conditions.

Besides, n-type monocrystalline cells have an electronic structure that makes better use of the light received, which increases their efficiency. By having many more cells separated by several strings, if there is an area of the module that is shaded, it will not affect the production of the rest of the cells, avoiding chain errors and increasing the efficiency of the module. This means an increase in watts of about 1.5% per module.

Having said that, despite the cost of the mono panels, as the installation to be carried out does not require many units, the solar panel chosen for this project will be the 340W PERC Half-Cell Module Mono - JAM60S10 340/MR with 120 solar cells, which has numerous advantages mentioned above over other panels.

Figure 22. JAM60S10 340/MR (Anon, 2020)

5.2 Batteries/storage capacity, technology

The choice of a suitable battery is crucial for the realization of this project. To this end, in-depth research has been carried out on each type of battery. As mentioned in section 5.2, from the beginning, the batteries were chosen that met requirements such as location, climate, capacity, life span, so on. The batteries chosen were 3 Lithium-Ion (Lithium-Iron Phosphate, Lithium-Nickel Manganese Cobalt, and Lithium Titanate), and the remaining battery was an Absorbed Glass Mat.

Firstly, to make the most practical comparisons, different real batteries have been chosen from two of the battery types mentioned above. This is because in section 2.4, the characteristics of each one have been exposed, and it has been considered to discard both LTO and AGM. Then, these are the chosen batteries:

- **$LiFePo_4$:** Pylontech US2000B, BYD B-Box LV
- **NMC:** Tesla Powerwall I, LG Chem RESU HV, GNB Li-Ion

Figure 23 obtained from the Lithium Ion Battery Test Centre and its numerous studies comparing batteries have made it possible to carry out this section much more easily.

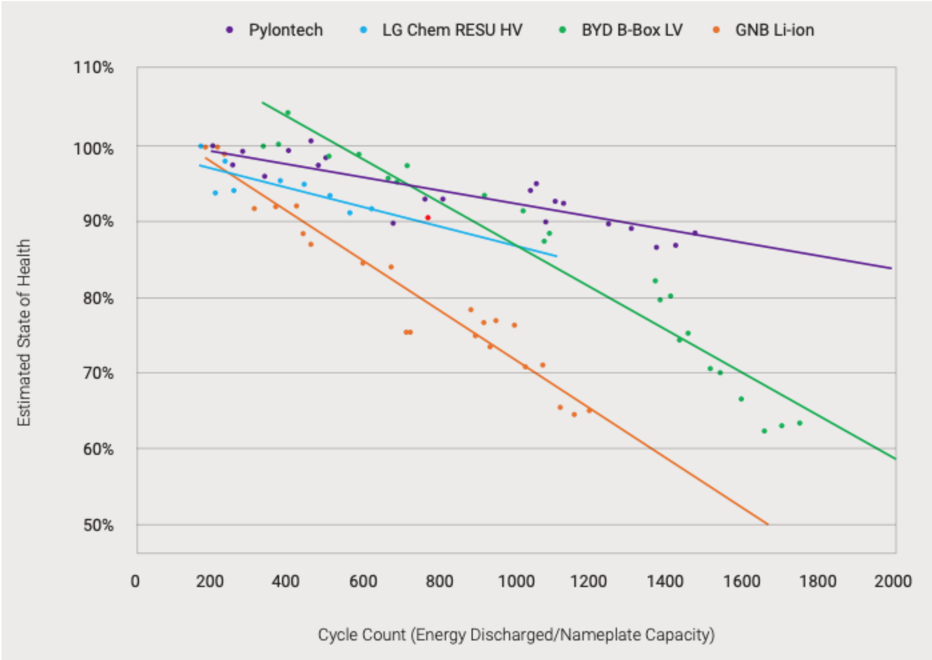

Figure 23. Capacity fade of the batteries (Batterytestcentre.com, 2020)

It should be noted that Figure 23 includes adjustment lines that are determined by simple linear regression. While a linear regression appears to provide a good fit for some of the capability test data collected so far, it may not be appropriate to extrapolate linearly into the future. Even so, with the current data, it can be seen that the trend for the Pylontech US2000B is the longest-lasting, reaching 60% State Of Health (SOH) with 4,460 cycles (Batterytestcentre.com, 2020).

In addition, the Pylontech battery has one of the highest efficiencies among the mentioned batteries, although it does not have the highest, it has a 92% efficiency. Because of the two factors mentioned in this section, the choice is the one mentioned, but a little more powerful.

Figure 24. Pylontech US3000 Lithium Battery (Annex 1)

5.3 Charge controllers

Pulse Width Modulation solar charge controllers, also known as PWM, are the standard ones. They are simpler than MPPT controllers, and consequently cheaper. The operation of PWM controllers consists of slowly reducing the amount of energy supplied to the battery as it approaches its maximum capacity. When the battery is full, PWM controllers maintain a "dripping" state, which means that they constantly and gradually supply the minimum amount of energy required to keep the battery full without exceeding its limit.

An important point is that with a PWM controller, your solar panel system and your home battery need to have the same voltages. However, in large scale, solar panel systems designed to power the entire house, the panel voltage, and the battery voltage are usually not the same. Because of this requirement, the most common uses of PWM controllers are usually small-scale systems, that is, with low-voltage panels, and a low-capacity battery.

Maximum Power Point Tracking solar charge controllers, also known as MPPT, are the most expensive and complex controllers on the market today. In terms of protection, it is very similar to the PWM, as the protection is of the switch type and decreases the energy reaching the battery as it reaches its maximum capacity.

One of the main advantages of MPPT charge controllers is that they can be connected between a solar panel and a battery of different voltages each, i.e. it is the perfect component for large scale installations. Another advantage is that MPPT controllers channel their input to achieve the maximum possible power in the solar array. Besides, they also can vary their output power to match that of the battery to which they are connected. These power variations, even if they are minimal, are significant and this qualifies this type of controllers as more efficient and intelligent than PWM controllers because they do not waste power they use it rationally.

Having said that, the chosen charge controller is the MPPT because, although it is more expensive, it is the one that best fits the system to be installed since with this type of charge controller, as explained above, you can connect a solar panel and a battery of different voltages, which is ideal for off-grid installations.

The following example is presented in Figure 25 to justify the taken decision:

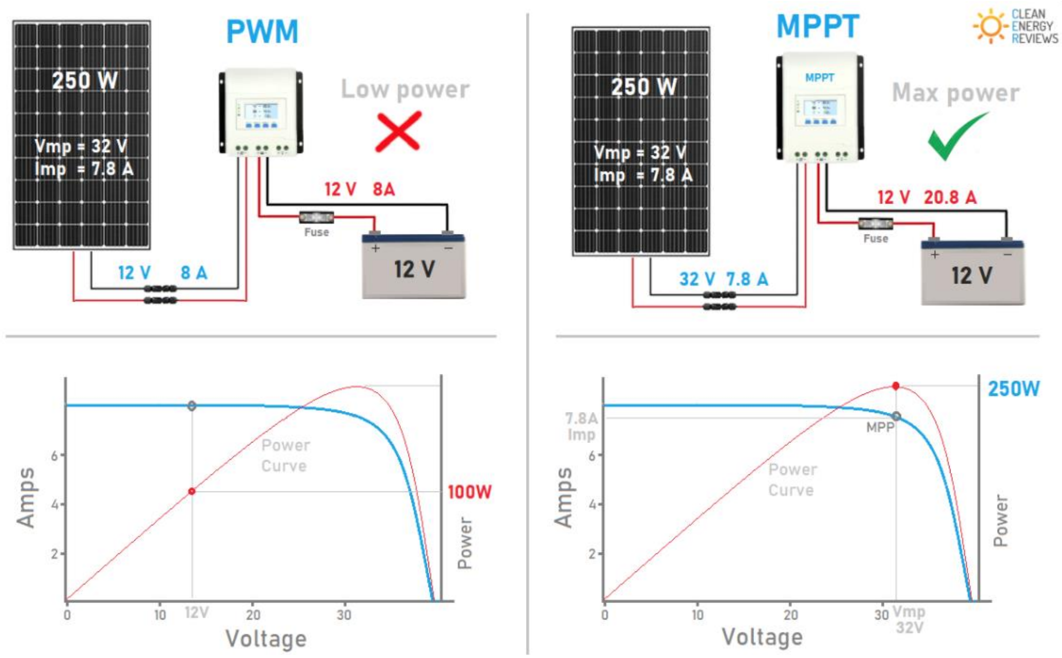

Figure 25. Comparison between PWM and MPPT (Clean Energy Reviews, 2020)

In both cases a 24 V solar panel with a V_{mp} = 32 V is available. This panel is connected to a 12V battery using a PWM charge controller in the first case, and an MPPT in the second case.

As can be seen, with the PWM, the voltage of each panel must decrease to equal that of the battery, which means a considerable reduction of the output energy. On the other hand, with an MPPT, the panel works at maximum power, generating consequently more energy.

Once the decision is clear, the component proposed below (Figure 26) is chosen for this project.

Figure 26. SmartSolar Charge Controller MPPT 250/100-Tr (Victronenergy.com, 2020)

After having chosen the charge controller for the system, it is time to determine the number of panels that will go in series and parallel. Since the MPPT cannot take more than 250 V DC and the voltage of each panel in the open circuit is 41.36 V (Annex 1), the maximum number of panels in series will be 5. Knowing that 10 panels are needed to supply the system, then, the final scheme will be 2 series in parallel with 5 panels per series, which will keep the voltage below 250 V and double the current.

5.4 Solar inverter

This is the section in which you have the least choice because, according to the calculations made in section 4.2.5, the conclusion is that the inverter should have a power of 5 kW.

Once this is known, as the last component to choose, an inverter of the same brand as the load controller, Victron MultiPlus-II 48I | 5000 | 70, is chosen, shown in Figure 27.

Figure 27. Victron MultiPlus-II | 48I | 5000 | 70 (Victronenergy.com, 2020)

6 Discussion

With respect to the initial aims and objectives, it can be said that they have been successfully achieved. Starting with the basic introduction of the operation and components of an off-grid solar photovoltaic system, how to install it safely with grounding, explaining the process of energy conversion, and the function of each of the components both one by one and together.

The objective of estimating the demand that the cabin will have during each of the months of operation, which are all but January, November, and December, has also been achieved. It should be noted that the demand is not the same for every month, as the house will consume much more during the holiday months of June, July, and August, but it will also produce more energy because in Finland days can have up to 20 hours of sunlight. As for the data that Hans provided for the realization of this project, they have been useful but not used for the calculations since irradiation data were missing in certain months.

Concerning the components of the installation, they have been carefully selected after making the calculations, but above all following the advice of the project tutor, who in this case is the client who invests. Apart from this consideration, throughout the project, it is possible to observe the study and comparison of each of the components to ensure at all times that it has been an appropriate choice.

It should be noted that there is a possibility of increasing the production of photovoltaic solar energy without changing any other component, that is, adding 5 more panels, which means, one more branch in parallel. This will not affect the voltage, only the power, and the current. In this case, the cable would need to be dimensioned for this current. This option is suggested because if one more panel per branch is added, the branch's open-circuit voltage would rise to more than 250 V during cold days, and this would require another MPPT.

It is also important to take in account that the PV-power of 3.4 kW is obtained only during a short period of the coolest and sunniest days. Nearly not every day. Normally the PV-power is much lower.

Another example can be found in the choice of batteries. In terms of quality, performance, and durability, Pylontech batteries are exceptional, but in terms of price they leave a lot to be desired, so a cheaper option should be recommended. But due to the customer's purpose, which is to make the installation last and work as well as possible, it must be said that Pylontech is one of the best batteries in these areas.

About the limitations of the project, it should be noted that it has been a pity that the visits necessary to acquire the practical knowledge of how to install the panels and equipment were not possible. It has only been possible to make three visits to the cottage, mainly due to the situation of Covid-19.

7 Conclusion

Although solar panel technology is constantly evolving, the choice of components has been based entirely on studies and comparisons of current components. This does not rule out the possibility that another study will be necessary for the next few years to cover all the new possibilities that have appeared to obtain solar energy as efficiently as possible.

In the realization of this project, different possible arrangements for the solar panels have been studied, considering shadows, hours of sunshine, irradiation, temperature, wind, rainfall, and clouds.

The results of this report suggest that the optimum panel inclination (tilt angle) would be between 45 and 50 degrees, considering that the lower the inclination, the months of April, May, June, July, and August will get more irradiation, whereas for the months of September, October, February and March, a higher inclination will make the panels capture more irradiation. All irradiation data can be found in Table 6. Besides, as far as the optimum orientation is concerned, after comparing different layouts in section 3.3, the best one is that of all south-facing panels.

When making the calculations, it was considered that consumption is not constant throughout the year, i.e. depending on the month, it will be higher or lower. February and March have 1 kWh/day, April, May, September, and October, 3.8 kWh/day, June and August, 9.1 kWh/day, and finally, July is at the top of the list with 15.2 kWh/day. However, it should be borne in mind that the numbers obtained are estimations of consumption as this is a hypothetical case and at no time are real consumption values available.

Once both consumption and irradiation were known, the worst case was chosen, which corresponded to the greatest difference between consumption/radiation, which was during July. With this data, the dimensioning of each of the components of the installation was carried out, obtaining the following results: 10 photovoltaic panels (340 W each), 3 batteries with 3552 Wh nominal capacity each, 1 MPPT charge controller with a maximum open-circuit voltage of 250 V, and an inverter of 5000 W.

Panels with a total of 3.4 kW are expected to have enough energy to almost fully charge the batteries (about 10 kW) during the months of work. It should be noted that the most challenging months will be February and October due to the irradiation shortage.

The installation studied, to prevent the wear of the whole system components, must be disconnected during the months of January, November, and December due to the extremely low temperatures suffered in the area and the few hours of sunlight.

It is worth mentioning the good performance of the installation since it has been carried out by the Sponsor of this project, and consequently, very good results have been obtained in terms of energy production.

This thesis could help any person interested in carrying out a solar installation not connected to the grid, since it provides from basic notions of the whole to the whole calculation process for the correct dimensioning, considering many essential factors that without previous knowledge can be overlooked.

Finally, the realization of this thesis has given way to familiarize oneself with the world of renewable energies, and specifically to get to know solar energy and its full potential, which is no small thing.

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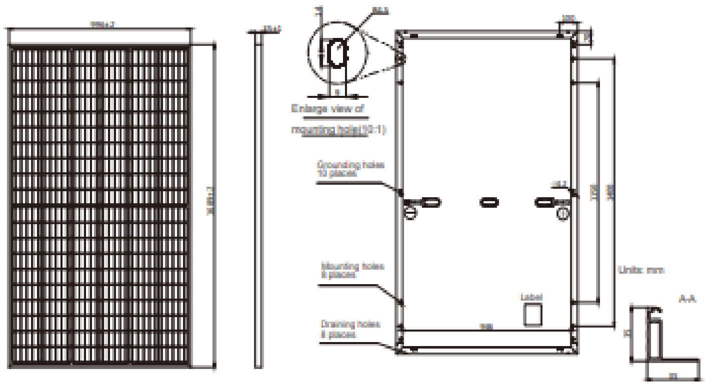
APPENDIX 1: Chosen Equipment Datasheet

JA SOLAR

JAM60S10 320-340/PR Series

MECHANICAL DIAGRAMS



Remark: customized frame color and cable length available upon request

SPECIFICATIONS

Cell	Mono
Weight	18.7kg±3%
Dimensions	1689±2mm×996±2mm×35±1mm
Cable Cross Section Size	4mm²
No. of cells	120(6×20)
Junction Box	IP68, 3 diodes
Connector	QC 4.10-35
Cable Length (Including Connector)	Portrait:300mm(+)/400mm(-); Landscape:1000mm(+)/1000mm(-)
Packaging Configuration	30 Per Pallet

ELECTRICAL PARAMETERS AT STC

TYPE	JAM60S10 -320/PR	JAM60S10 -325/PR	JAM60S10 -330/PR	JAM60S10 -335/PR	JAM60S10 -340/PR
Rated Maximum Power(Pmax) [W]	320	325	330	335	340
Open Circuit Voltage(Voc) [V]	40.27	40.56	40.84	41.12	41.36
Maximum Power Voltage(Vmp) [V]	33.62	33.87	34.13	34.36	34.63
Short Circuit Current(Isc) [A]	10.16	10.23	10.30	10.38	10.46
Maximum Power Current(Imp) [A]	9.52	9.60	9.67	9.75	9.82
Module Efficiency [%]	19.0	19.3	19.6	19.9	20.2
Power Tolerance	0~+5W				
Temperature Coefficient of Isc(α_Isc)	+0.051%/℃				
Temperature Coefficient of Voc(β_Voc)	-0.289%/℃				
Temperature Coefficient of Pmax(γ_Pmp)	-0.350%/℃				
STC	Irradiance 1000W/m², cell temperature 25℃, AM1.5G				

Remark: Electrical data in this catalog do not refer to a single module and they are not part of the offer.They only serve for comparison among different module types.

ELECTRICAL PARAMETERS AT NOCT

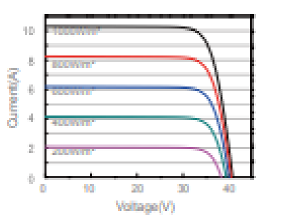
TYPE	JAM60S10 -320/PR	JAM60S10 -325/PR	JAM60S10 -330/PR	JAM60S10 -335/PR	JAM60S10 -340/PR
Rated Max Power(Pmax) [W]	237	241	244	248	252
Open Circuit Voltage(Voc) [V]	37.15	37.38	37.65	37.93	38.18
Max Power Voltage(Vmp) [V]	33.31	33.54	33.82	34.10	34.38
Short Circuit Current(Isc) [A]	8.14	8.20	8.25	8.30	8.36
Max Power Current(Imp) [A]	7.11	7.17	7.22	7.27	7.32
NOCT	Irradiance 800W/m², ambient temperature 20℃, wind speed 1m/s, AM1.5G				

OPERATING CONDITIONS

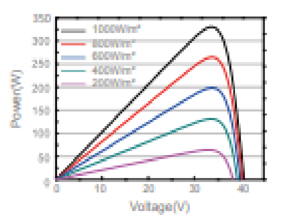
Maximum System Voltage	1000V/1500V DC(IEC)
Operating Temperature	-40℃~+85℃
Maximum Series Fuse	20A
Maximum Static Load,Front	5400Pa
Maximum Static Load,Back	2400Pa
NOCT	45±2℃
Application Class	Class A

CHARACTERISTICS

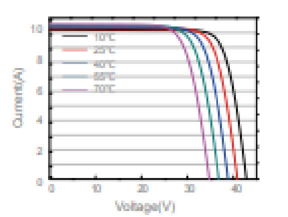
Current-Voltage Curve JAM60S10-330/PR



Power-Voltage Curve JAM60S10-330/PR



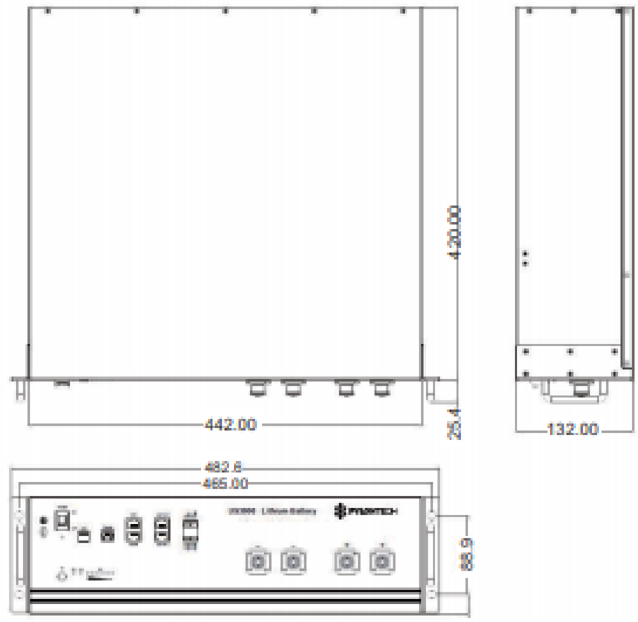
Current-Voltage Curve JAM60S10-330/PR



Rechargeable Li-ion Battery
US3000 Product Manual

Information Version: 2.1

2.2 Specifications



Basic Parameters	US3000
Nominal Voltage (V)	48
Nominal Capacity (Wh)	3552
Usable Capacity (Wh)	3200
Dimension (mm)	442*420*132
Weight (Kg)	32
Discharge Voltage (V)	45 ~ 53.5
Charge Voltage (V)	52.5 ~ 53.5
Recommend Charge/Discharge Current (A)	37
Max. Charge/Discharge Current (A)	74
Peak Charge/Discharge Current (A)	100A@15sec
Communication	RS485, CAN
Configuration (max. in 1 battery group)	8pcs
Working Temperature	0℃~50℃ Charge
	-10℃~50℃ Discharge
Shelf Temperature	-20℃~60℃
Protective class	IP20
Cooling type	Natural Cooling
IP rating of enclosure	IP20
Humidity	5%~ 85%
Certification	IEC62619/ CE / UN38.3
Design life	10+ Years (25℃/77℉)
Cycle Life	>6,000 25℃
Reference to standards	IEC62619, IEC62040, IEC62477-, IEC61000-6-2,IEC61000-3, UN38.3

MultiPlus-II Inverter/Charger

MultiPlus-II 24/3000/70-32, 48/3000/35-32 & 48/5000/70-50

► Victron online product page

https://ve3.nl/6H

A MultiPlus, plus ESS (Energy Storage System) functionality

The MultiPlus-II is a multifunctional inverter/charger with all the features of the MultiPlus, plus an external current sensor option which extends the PowerControl and PowerAssist function to 50A resp. 100A.
The MultiPlus-II is ideally suited for professional marine, yachting, vehicle and land based off-grid applications.
It also has built-in anti-islanding functionality, and an increasingly long list of country approvals for ESS application.
Several system configurations are possible. For more detailed information see the ESS Design and configuration manual.

PowerControl and PowerAssist - Boosting the capacity of the grid or a generator

A maximum grid or generator current can be set. The MultiPlus-II will then take account of other AC loads and use whatever is extra for battery charging, thus preventing the generator or grid from being overloaded (PowerControl function).
PowerAssist takes the principle of PowerControl to a further dimension. Where peak power is so often required only for a limited period, the MultiPlus-II will compensate insufficient generator, shore or grid power with power from the battery. When the load reduces, the spare power is used to recharge the battery.

Solar energy: AC power available even during a grid failure

The MultiPlus-II can be used in off grid as well as grid connected PV and other alternative energy systems. It is compatible with both solar charger controllers and grid-tie inverters.

Two AC Outputs

The main output has no break functionality. The MultiPlus-II takes over the supply to the connected loads in the event of a grid failure or when shore/generator power is disconnected. This happens so fast (less than 20 milliseconds) that computers and other electronic equipment will continue to operate without disruption.
The second output is live only when AC is available on the input of the MultiPlus-II. Loads that should not discharge the battery, like a water heater for example, can be connected to this output.

Virtually unlimited power thanks to parallel and three phase operation

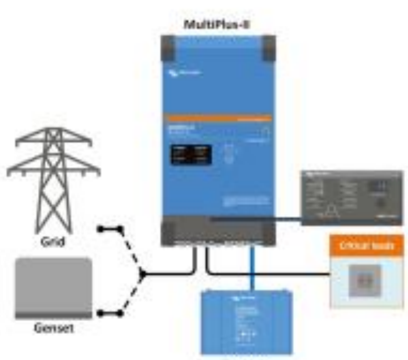
Up to 6 Multis can operate in parallel to achieve higher power output. Six 48/5000/70 units, for example, will provide 25 kW / 30 kVA output power with 420 Amps charging capacity.
In addition to parallel connection, three units of the same model can be configured for three phase output. But that's not all: up to 6 sets of three units can be parallel connected for a 75 kW / 90 kVA inverter and more than 1200 Amps charging capacity.

On-site system configuring, monitoring and control

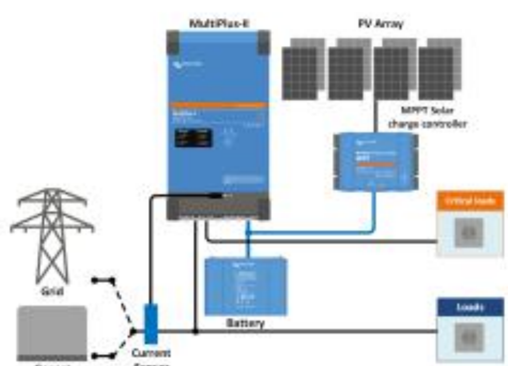
Settings can be changed in a matter of minutes with VEConfigure software (computer or laptop and MK3-USB interface needed).
Several monitoring and control options are available: Color Control GX, Venus GX, Octo GX, CANvu GX, laptop, computer, Bluetooth (with the optional VE.Bus Smart dongle), Battery Monitor, Digital Multi Control Panel.

Remote configuring and monitoring

Install a Color Control GX or other GX product to connect to the internet.
Operational data can be stored and displayed on our VRM (Victron Remote Management) website, free of charge.
When connected to the internet, systems can be accessed remotely, and settings can be changed.



Standard marine, mobile or off-grid application
Loads that should shut down when AC input power is not available can be connected to a second output (not shown). These loads will be taken into account by the PowerControl and PowerAssist function in order to limit AC input current to a safe value when AC power is available.



Grid parallel topology with MPPT solar charge controller
The MultiPlus-II will use data from the external AC current sensor (must be ordered separately) or power meter to optimise self-consumption and, if required, to prevent grid feed. In case of a power outage, the MultiPlus-II will continue to supply the critical loads

Color Control Panel (CCGX)
Provides intuitive system control and monitoring
Besides system monitoring and control the CCGX enables access to our free remote monitoring website: the VRM Online Portal

VRM Portal
Our free remote monitoring website (VRM) will display all your system data in a comprehensive graphical format. System settings can be changed remotely via the portal. Alarms can be received by e-mail.

VRM app
Monitor and manage your Victron Energy system from your smart phone and tablet. Available for both iOS and Android.

VE.Bus Smart Dongle
Measures battery voltage and temperature and allows monitoring and control with a smart phone or other Bluetooth enabled device.

MultiPlus-II	24/3000/70-32	48/3000/35-32	48/5000/70-50
PowerControl & PowerAssist	Yes		
Transfer switch	32A		50A
Maximum AC input current	32A		50A
INVERTER			
DC Input voltage range	19 – 33V	38 – 66V	
Output	Output voltage: 230 VAC ± 2% Frequency: 50 Hz ± 0,1% (1)		
Cont. output power at 25°C (3)	3000VA		5000VA
Cont. output power at 25°C	2400W		4000W
Cont. output power at 40°C	2200W		3700W
Cont. output power at 65°C	1700W		3000W
Maximum apparent feed-in power	2500VA		4000VA
Peak power	5500W		9000W
Maximum efficiency	94%	95%	96%
Zero load power	13W	11W	18W
Zero load power in AES mode	9W	7W	12W
Zero load power in Search mode	3W	2W	2W
CHARGER			
AC Input	Input voltage range: 187-265 VAC Input frequency: 45 – 65 Hz		
Charge voltage 'absorption'	28,8V	57,6V	
Charge voltage 'float'	27,6V	55,2V	
Storage mode	26,4V	52,8V	
Maximum battery charge current (4)	70A	35A	70A
Battery temperature sensor	Yes		
GENERAL			
Auxiliary output	Yes (32A)		
External AC current sensor (optional)	50A		100A
Programmable relay (5)	Yes		
Protection (2)	a – g		
VE.Bus communication port	For parallel and three phase operation, remote monitoring and system integration		
General purpose com. port	Yes, 2x		
Remote on-off	Yes		
Operating temperature range	-40 to +65°C (fan assisted cooling)		
Humidity (non-condensing)	max 95%		
ENCLOSURE			
Material & Colour	Steel, blue RAL 5012		
Protection category	IP22		
Battery-connection	M8 bolts		
230 V AC-connection	Screw terminals 13 mm² (6 AWG)		
Weight	18 kg		29 kg
Dimensions (hxwxd) mm	506 x 275 x 147		565 x 323 x 148
STANDARDS			
Safety	EN-IEC 60335-1, EN-IEC 60335-2-29, EN-IEC 62109-1, EN-IEC 62109-2		
Emission, Immunity	EN 55014-1, EN 55014-2 EN-IEC 61000-3-2, EN-IEC 61000-3-3 IEC 61000-6-1, IEC 61000-6-2, IEC 61000-6-3		
Uninterruptible power supply	Please consult the certificates on our website.		
Anti-islanding	Please consult the certificates on our website.		

1) Can be adjusted to 60 Hz
2) Protection key:
a) output short circuit
b) overload
c) battery voltage too high
d) battery voltage too low
e) temperature too high
f) 230 VAC on inverter output
g) input voltage ripple too high

3) Non-linear load, crest factor 3:1
4) At 25°C ambient
5) Programmable relay which can be set for general alarm, DC under voltage or genset start/stop function. AC rating: 230V / 4A, DC rating: 4A up to 35VDC and 1A up to 60VDC

Connection Area

Current sensor 100A:50mA
To implement PowerControl and PowerAssist and to optimize self-consumption with external current sensing.
Maximum current: 50A resp. 100A.
Length of connection cable: 1 m.

Digital Multi Control Panel
A convenient and low-cost solution for remote monitoring, with a rotary knob to set PowerControl and PowerAssist levels.

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SmartSolar Charge Controllers with screw- or MC4 PV connection
MPPT 250/60 up to MPPT 250/100

SmartSolar Charge Controller
MPPT 250/100-Tr
with optional pluggable display

SmartSolar Charge Controller
MPPT 250/100-MC4
without display

Bluetooth sensing:
Smart Battery Sense

Bluetooth sensing:
BMV-712 Smart Battery Monitor

Bluetooth Smart built-in
The wireless solution to set-up, monitor, update and synchronise SmartSolar Charge Controllers.

Ultra-fast Maximum Power Point Tracking (MPPT)
Especially in case of a clouded sky, when light intensity is changing continuously, an ultra-fast MPPT controller will improve energy harvest by up to 30% compared to PWM charge controllers and by up to 10% compared to slower MPPT controllers.

Advanced Maximum Power Point Detection in case of partial shading conditions
If partial shading occurs, two or more maximum power points (MPP) may be present on the power-voltage curve.
Conventional MPPTs tend to lock to a local MPP, which may not be the optimum MPP.
The innovative SmartSolar algorithm will always maximize energy harvest by locking to the optimum MPP.

Outstanding conversion efficiency
No cooling fan. Maximum efficiency exceeds 99%.

Flexible charge algorithm
Fully programmable charge algorithm (see the software page on our website), and eight pre-programmed algorithms, selectable with a rotary switch (see manual for details).

Extensive electronic protection
Over-temperature protection and power derating when temperature is high.
PV short circuit and PV reverse polarity protection.
PV reverse current protection.

Internal temperature sensor
Compensates absorption and float charge voltage for temperature.

Optional external battery voltage and temperature sensing via Bluetooth
A Smart Battery Sense or a BMV-712 Smart Battery Monitor can be used to communicate battery voltage and temperature to one or more SmartSolar Charge Controllers.

Fully discharged battery recovery function
Will initiate charging even if the battery has been discharged to zero volts.
Will reconnect to a fully discharged Li-ion battery with integrated disconnect function.

VE.Direct
For a wired data connection to a Color Control GX, other GX products, PC or other devices

Remote on-off
To connect for example to a VE.BUS BMS.

Programmable relay
Can be programmed (a.o. with a smartphone) to trip on an alarm, or other events.

Optional: SmartSolar pluggable LCD display
Simply remove the rubber seal that protects the plug on the front of the controller, and plug-in the display.

SmartSolar pluggable display

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SmartSolar Charge Controller	250/60	250/70	250/85	250/100
Battery voltage	12 / 24 / 48V Auto Select (software tool needed to select 36V)			
Rated charge current	60A	70A	85A	100A
Nominal PV power, 12V 1a,b)	860W	1000W	1200W	1450W
Nominal PV power, 24V 1a,b)	1720W	2000W	2400W	2900W
Nominal PV power, 36V 1a,b)	2580W	3000W	3600W	4350W
Nominal PV power, 48V 1a,b)	3440W	4000W	4900W	5800W
Max. PV short circuit current 2)	35A (max 30A per MC4 conn.)		70A (max 30A per MC4 conn.)	
Maximum PV open circuit voltage	250V absolute maximum coldest conditions 245V start-up and operating maximum			
Maximum efficiency	99%			
Self-consumption	Less than 35mA @ 12V / 20mA @ 48V			
Charge voltage 'absorption'	Default setting: 14,4 / 28,8 / 43,2 / 57,6V (adjustable with: rotary switch, display, VE.Direct or Bluetooth)			
Charge voltage 'float'	Default setting: 13,8 / 27,6 / 41,4 / 55,2V (adjustable: rotary switch, display, VE.Direct or Bluetooth)			
Charge voltage 'equalization'	Default setting: 16,2V / 32,4V / 48,6V / 64,8V (adjustable)			
Charge algorithm	multi-stage adaptive (eight preprogrammed algorithms) or user defined algorithm			
Temperature compensation	-16 mV / -32 mV / -64 mV / °C			
Protection	PV reverse polarity / Output short circuit / Over temperature			
Operating temperature	-30 to +60°C (full rated output up to 40°C)			
Humidity	95%, non-condensing			
Maximum altitude	5000m (full rated output up to 2000m)			
Environmental condition	Indoor, unconditioned			
Pollution degree	PD3			
Data communication port	VE.Direct or Bluetooth			
Remote on/off	Yes (2 pole connector)			
Programmable relay	DPST AC rating: 240VAC / 4A DC rating: 4A up to 35VDC, 1A up to 60VDC			
Parallel operation	Yes			
ENCLOSURE				
Colour	Blue (RAL 5012)			
PV terminals 3)	35 mm^2 / AWG2 (Tr models) Two pairs of MC4 connectors (MC4 models)		35 mm^2 / AWG2 (Tr models) Three pairs of MC4 connectors (MC4 models)	
Battery terminals	35mm^2 / AWG2			
Protection category	IP43 (electronic components), IP22 (connection area)			
Weight	3 kg		4,5 kg	
Dimensions (h x w x d) in mm	Tr models: 185 x 250 x 95 mm MC4 models: 215 x 250 x 95 mm		Tr models: 216 x 295 x 103 MC4 models: 246 x 295 x 103	
STANDARDS				
Safety	EN/IEC 62109-1, UL 1741, CSA C22.2			

1a) If more PV power is connected, the controller will limit input power.
1b) The PV voltage must exceed Vbat + 5V for the controller to start. Thereafter the minimum PV voltage is Vbat + 1V.
2) A PV array with a higher short circuit current may damage the controller.
3) MC4 models: several splitter pairs may be needed to parallel the strings of solar panels
Maximum current per MC4 connector: 30A (the MC4 connectors are parallel connected to one MPPT tracker)

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1. Introduction

1.1. What is the Cerbo GX?

The Cerbo GX sits at the heart of your energy installation. All the other system-components - such as inverter/chargers, solar chargers, and batteries - are connected to it. The Cerbo GX ensures that they all work in harmony.

There is an optional touch screen accessory for the Cerbo GX called the GX Touch.

Monitoring of the system can be done either with the Cerbo GX in front of you - or from anywhere in the world using an internet connection and the VRM Portal.

The Cerbo GX also provides Remote firmware updates and allows settings to be Changed Remotely.

The Cerbo GX is part of the GX product family. GX products are Victron's state-of-the-art monitoring solution that run our Venus OS operating system.

All the information in this manual refers to the latest software. You can check your device has the latest version in the Firmware menu [29] when the GX device is connected to the internet. For installations without internet, you can find the latest version in Victron Professional.

1.2. What's in the box?

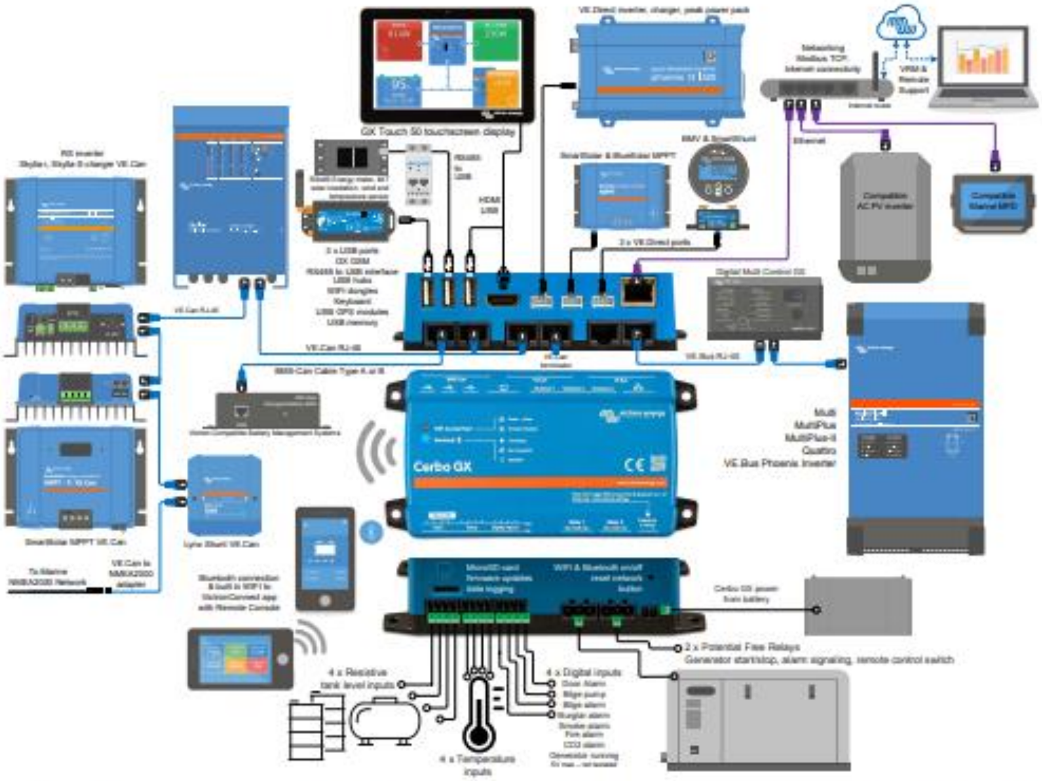
- Cerbo GX device
- Power cable with inline fuse and M8 terminal eyes for battery or DC busbar-attachment.
- VE.Can terminators (2 pcs)
- Terminal Blocks for all the connectors on each side.
- Watch this Video for an unboxing and overview of the interfaces.

https://www.youtube.com/embed/3wheKaU2_qw

X

2. Installation

2.1. Overview of connections



On the Cerbo GX, the USB socket closest to the HDMI connector can only be used to power a GX Touch. That USB port can **not** be used for any data related functions such as VE.Direct to USB cables, USB-sticks, USB-GPS-es, or other common USB usages. It's a power port only, no data.

2.2. Power

The device is powered by using the *Power in V+* connector. It accepts 8 to 70 V DC. The device will not power itself from any of the other connections (eg network). The supplied DC power cable includes an inline 3.15 A slow blow fuse.

If the DC voltage exceeds 60V, the Cerbo GX is classified as a "built-in product". Installation should be in such a way the user cannot touch the terminals.

Powering in systems with VE.Bus BMS

When the Cerbo GX is used in an installation with a VE.Bus BMS, connect the *Power in V+* on the Cerbo GX to the terminal labelled '*Load disconnect*' on the VE.Bus BMS. Connect both negative leads to the negative stub of a common Battery.

A Cautionary word about Powering from the AC-out terminal of a VE.Bus Inverter, Multi or Quattro:

If you power the Cerbo GX from an AC adaptor connected to the AC-out port of any VE.Bus product (Inverter, Multi or Quattro), then a deadlock will occur after the VE.Bus products are powered-down for any reason (after any operational fault or during a black start). The VE.Bus devices will not boot-up until the Cerbo GX has power …but the Cerbo GX will not boot-up until *it* has power. This deadlock can be rectified by briefly unplugging the Cerbo GX VE.Bus cable at which point you will observe the VE.Bus products will immediately begin to boot-up.

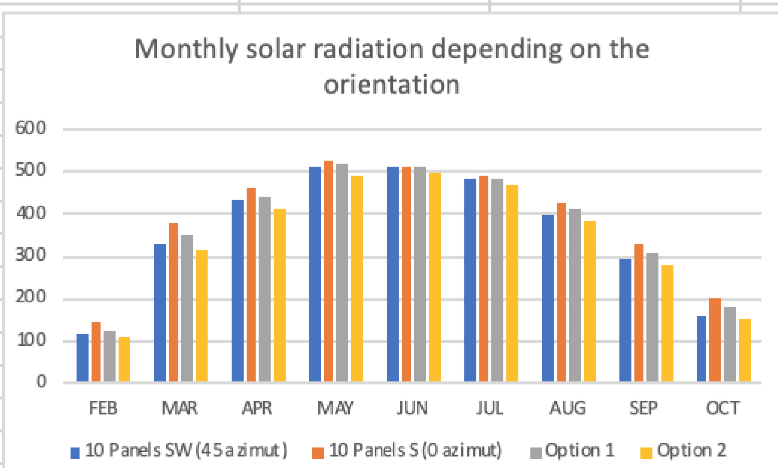
Or a modification can be done to the RJ45 cabling. See FAQ Q20 [67]for more information about this.

APPENDIX 2: Excel Data

	10 Panels SW (45 azimut)	10 Panels S (0 azimut)	Option 1	Option 2
FEB	115,29	143,45	125,76	109,48
MAR	326,05	380,32	346,53	311,98
APR	432,63	461,83	441,61	413,8
MAY	510	524	516,19	493,5
JUN	511,33	510,29	509,18	497,64
JUL	480,85	488,59	485,09	467,07
AUG	400,15	424,64	411,39	385,69
SEP	291,62	329,01	305,4	278,85
OCT	162,7	201,62	178,05	155,19

	3 Panels SE (-45 azimut)	4 Panels S (0 azimut)	3 Panels SW (45 azimut)	TOTAL
FEB	33,79	57,38	34,59	125,76
MAR	96,58	152,13	97,82	346,53
APR	127,09	184,73	129,79	441,61
MAY	153,59	209,6	153	516,19
JUN	151,66	204,12	153,4	509,18
JUL	145,4	195,44	144,25	485,09
AUG	121,5	169,85	120,04	411,39
SEP	86,31	131,61	87,48	305,4
OCT	48,59	80,65	48,81	178,05

	4 Panels S (0 azimut)	3 Panels SW (45 azimut)	3 Panels W (90 azimut)	TOTAL
FEB	57,38	34,59	17,51	109,48
MAR	152,13	97,82	62,03	311,98
APR	184,73	129,79	99,28	413,8
MAY	209,6	153	130,9	493,5
JUN	204,12	153,4	140,12	497,64
JUL	195,44	144,25	127,38	467,07
AUG	169,85	120,04	95,8	385,69
SEP	131,61	87,48	59,76	278,85
OCT	80,65	48,81	25,73	155,19



Temperature t2:	25	Celsius				
Resistivity Cu @ 20C:	0,018	Ohm mm2/m		Temp-coeff Cu:	0,0039	1/C
Resistivity Al @ 20C:	0,027	Ohm mm2/m		Temp-coeff Al:	0,0043	1/C
Resistivity Cu @ t2:	0,018351	Ohm mm2/m		rho2 = rho1 x (1 + Temp-coeff x (t2 - t1))		
Resistivity Al @ t2:	0,0275805	Ohm mm2/m		rho2 = rho1 x (1 + Temp-coeff x (t2 - t1))		
Length in meters	120	m		(60+60m)		
Cross sectional area in mm2	35	mm2				
Resistance Cu	0,062917714	Ohm		R = rho x l/A		
Resistance Al	0,094561714	Ohm		R = rho x l/A		
Open Circuit Voltage @ 25C:	41,55	V				
Number of panels in series:	5					
Temp coeff of Voc:	-0,272	%/C				
Open Circuit Voltage @ t2:	41,55	V				
Voltage from panels:	207,75	V	Max voltage is important for the MPPT			
Pmax per panel @ 25C:	340	W				
Number of panels in total:	10					
Temp coeff of Pmax:	-0,35	%/C				
Pmax in total @ t2	3400	W				
Current in the cable:	16,37	A				
Voltage drop in the Cu-cable:	1,029700258	V	0,49564	%		
Voltage drop in the Al-cable:	1,547580402	V	0,74492	%		

Temperature	25	20	15	10	5	0	-5	-10
Voltge from panels	207,75	210,5754	213,401	216,226	219,0516	221,877	224,702	227,528
Voltage_Drop_cu	1,029700258	1,013891326	0,99783	0,98153	0,964988852	0,94823	0,93125	0,91407
Voltage_Drop_al	1,547580402	1,520836988	1,49369	1,46616	1,438258743	1,41	1,3814	1,35246
R_Cu	6,29E-02	0,061714286	0,06051	0,05931	0,058104	0,0569	0,0557	0,05449
R_Al	9,46E-02	0,092571429	0,09058	0,08859	0,086600571	0,08461	0,08262	0,08063

2016	30 degrees		[kWh/m^2]	[Wh/m^2]	[Wh/m^2/day]	40 degrees		[kWh/m^2]	[Wh/m^2]	[Wh/m^2/day]
		January	10,91	10910	351,9354839		January	12,43	12430	400,9677419
		February	34,49	34490	1231,785714		February	38,04	38040	1358,571429
		March	101,37	101370	3270		March	108,68	108680	3505,806452
		April	128,56	128560	4285,333333		April	132,27	132270	4409
		May	160,45	160450	5175,806452		May	160,45	160450	5175,806452
		June	184,47	184470	6149		June	181,78	181780	6059,333333
		July	170,15	170150	5488,709677		July	168,5	168500	5435,483871
		August	128,96	128960	4160		August	130,81	130810	4219,677419
		September	104,23	104230	3474,333333		September	110,13	110130	3671
		October	56,92	56920	1836,129032		October	62,67	62670	2021,612903
		November	19,08	19080	636		November	21,79	21790	726,3333333
		December	9,9	9900	319,3548387		December	11,87	11870	382,9032258

	45 degrees		[kWh/m^2]	[Wh/m^2]	[Wh/m^2/day]	50 degrees		[kWh/m^2]	[Wh/m^2]	[Wh/m^2/day]
		January	13,07	13070	421,6129032		January	13,64	13640	440
		February	39,47	39470	1409,642857		February	40,67	40670	1452,5
		March	111,34	111340	3591,612903		March	113,3	113300	3654,83871
		April	132,94	132940	4431,333333		April	132,82	132820	4427,333333
		May	159,04	159040	5130,322581		May	156,7	156700	5054,83871
		June	178,81	178810	5960,333333		June	174,79	174790	5826,333333
		July	166,24	166240	5362,580645		July	163,02	163020	5258,709677
		August	130,6	130600	4212,903226		August	129,62	129620	4181,290323
		September	112,07	112070	3735,666667		September	113,31	113310	3777
		October	64,97	64970	2095,806452		October	66,85	66850	2156,451613
		November	22,94	22940	764,6666667		November	23,94	23940	798
		December	12,74	12740	410,9677419		December	13,53	13530	436,4516129

	60 degrees		[kWh/m^2]	[Wh/m^2]	[Wh/m^2/day]
		January	14,51	14510	468,0645161
		February	42,31	42310	1511,071429
		March	115,08	115080	3712,258065
		April	130,18	130180	4339,333333
		May	149,27	149270	4815,16129
		June	163,63	163630	5454,333333
		July	153,88	153880	4963,870968
		August	125,43	125430	4046,129032
		September	113,64	113640	3788
		October	69,31	69310	2235,806452
		November	25,48	25480	849,3333333
		December	14,81	14810	477,7419355

Month	30 degrees	40 degrees	45 degrees	50 degrees	60 degrees
January					
February	1231,785714	1358,571429	1409,642857	1452,5	1511,071429
March	3270	3505,806452	3591,612903	3654,83871	3712,258065
April	4285,333333	4409	4431,333333	4427,333333	4339,333333
May	5175,806452	5175,806452	5130,322581	5054,83871	4815,16129
June	6149	6059,333333	5960,333333	5826,333333	5454,333333
July	5488,709677	5435,483871	5362,580645	5258,709677	4963,870968
August	4160	4219,677419	4212,903226	4181,290323	4046,129032
September	3474,333333	3671	3735,666667	3777	3788
October	1836,129032	2021,612903	2095,806452	2156,451613	2235,806452
November					
December					

Month	30 degrees	40 degrees	45 degrees	50 degrees	60 degrees
January					
February	949,5082056	860,8974241	829,707069	805,2259162	774,0141341
March	357,6729796	333,6152921	325,6449609	320,0115617	315,0617826
April	1036,583369	1007,508565	1002,430855	1003,33653	1023,683806
May	858,2440833	858,2440833	865,8530128	878,7827898	922,524708
June	1733,786409	1759,443167	1788,667183	1829,804788	1954,602328
July	3237,267427	3268,967671	3313,408642	3378,855678	3579,549341
August	2562,753036	2526,508918	2530,571452	2549,703993	2634,877075
September	1278,548958	1210,053191	1189,106433	1176,09353	1172,678264
October	2419,277287	2197,307534	2119,52075	2059,914183	1986,802239
November					
December					

October [Wh	February	March	April	May	June	July	August	September	
2157,5	1270,357	190	0	6082,903	3012	XX	4904,737	3750	
2018.10.12	750		2019.4.23	6740	2019.3.4	2930		2019.6.13	9050
2018.10.13	1910		2019.4.24	8020	2019.3.5	1040		2019.6.14	2730
2018.10.14	1430		2019.4.25	7960	2019.3.6	4720		2019.6.15	3380
2018.10.15	4260		2019.4.26	6870	2019.3.7	1860		2019.6.16	5170
2018.10.16	770		2019.4.27	7180	2019.3.8	980		2019.6.17	9460
2018.10.17	3980		2019.4.28	7680	2019.3.9	920		2019.6.18	6660
2018.10.18	130		2019.4.29	8300	2019.3.10	2500		2019.6.19	9150
2018.10.19	2210		2019.4.30	7700	2019.3.11	2070		2019.6.20	9230
2018.10.20	4200		2019.5.1	8140	2019.3.12	1520		2019.6.21	4620
2018.10.21	1560		2019.5.2	3440	2019.3.13	5250		2019.6.22	8170
2018.10.22	310		2019.5.3	4000	2019.3.14	2320		2019.6.23	6580
2018.10.23	3530		2019.5.4	3390	2019.3.15	1680		2019.6.24	9270
2018.10.24	3060		2019.5.5	6800	2019.3.16	1190		2019.6.25	9300
2018.10.25	3040		2019.5.6	8770	2019.3.17	930		2019.6.26	5440
2018.10.26	360		2019.5.7	3980	2019.3.18	770		2019.6.27	1820
2018.10.27	1810		2019.5.8	2640	2019.3.19	1150		2019.6.28	5980
2018.10.28	2850		2019.5.9	7020	2019.3.20	1020		2019.6.29	7640
2018.10.29	3370		2019.5.10	6000	2019.3.21	2850		2019.6.30	3780
2018.10.30	3350		2019.5.11	6230	2019.3.22	4720		2019.8.13	2310
2018.10.31	270		2019.5.12	6080	2019.3.23	6530		2019.8.14	3200
2019.2.1	120		2019.5.13	2960	2019.3.24	4640		2019.8.15	5610
2019.2.2	150		2019.5.14	9080	2019.3.25	6960		2019.8.16	2170
2019.2.3	20		2019.5.15	9110	2019.3.26	5080		2019.8.17	6920
2019.2.4	40		2019.5.16	8970	2019.3.27	6210		2019.8.18	4910
2019.2.5	820		2019.5.17	8760	2019.3.28	2760		2019.8.19	1250
2019.2.6	240		2019.5.18	8600	2019.3.29	2650		2019.8.20	4550
2019.2.7	840		2019.5.19	8310	2019.3.30	4020		2019.8.21	5370
2019.2.8	670		2019.5.20	5800	2019.3.31	4450		2019.8.22	6490
2019.2.9	320		2019.5.21	5530	2019.4.1	5540		2019.8.23	7490
2019.2.10	270		2019.5.22	8080	2019.4.2	4280		2019.8.24	3930
2019.2.11	550		2019.5.23	6510	2019.4.3	6840		2019.8.25	7240
2019.2.12	1180		2019.5.24	1800	2019.4.4	6420		2019.8.26	3560
2019.2.13	3260		2019.5.25	2720	2019.4.5	1220		2019.8.27	4900
2019.2.14	1830		2019.5.26	3750	2019.4.6	1300		2019.8.28	6830
2019.2.15	800		2019.5.27	4760	2019.4.7	6880		2019.8.29	6090
2019.2.16	440		2019.5.28	9320	2019.4.8	1320		2019.8.30	5570
2019.2.17	1050		2019.5.29	3670	2019.4.9	1300		2019.8.31	4800
2019.2.18	3850		2019.5.30	7440	2019.4.10	1710		2019.9.1	2910
2019.2.19	380		2019.5.31	6910	2019.4.11	7130		2019.9.2	5750
2019.2.20	660		2019.6.1	7860	2019.4.12	7420		2019.9.3	920
2019.2.21	1440		2019.6.2	5650	2019.4.13	7830		2019.9.4	6120
2019.2.22	3680		2019.6.3	9560	2019.4.14	7530		2019.9.5	3510
2019.2.23	3110		2019.6.4	2340	2019.4.15	7710		2019.9.6	2850
2019.2.24	1240		2019.6.5	9190	2019.4.16	7580		2019.9.7	6690
2019.2.25	1730		2019.6.6	7150	2019.4.17	7720		2019.9.8	1590
2019.2.26	2930		2019.6.7	8570	2019.4.18	8000		2019.9.9	4950
2019.2.27	2850		2019.6.8	5480	2019.4.19	7700		2019.9.10	2760
2019.2.28	1100		2019.6.9	8200	2019.4.20	4550		2019.9.11	4590
2019.3.1	930		2019.6.10	9030	2019.4.21	7530		2019.9.12	2360
2019.3.2	3870		2019.6.11	8430	2019.4.22	4280			
2019.3.3	1090		2019.6.12	8900					