HERE COMES THE SUN...

An introductory framework to understand the basics of electricity and photovoltaic systems for community networks

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APC RHIZOMATICA Sida

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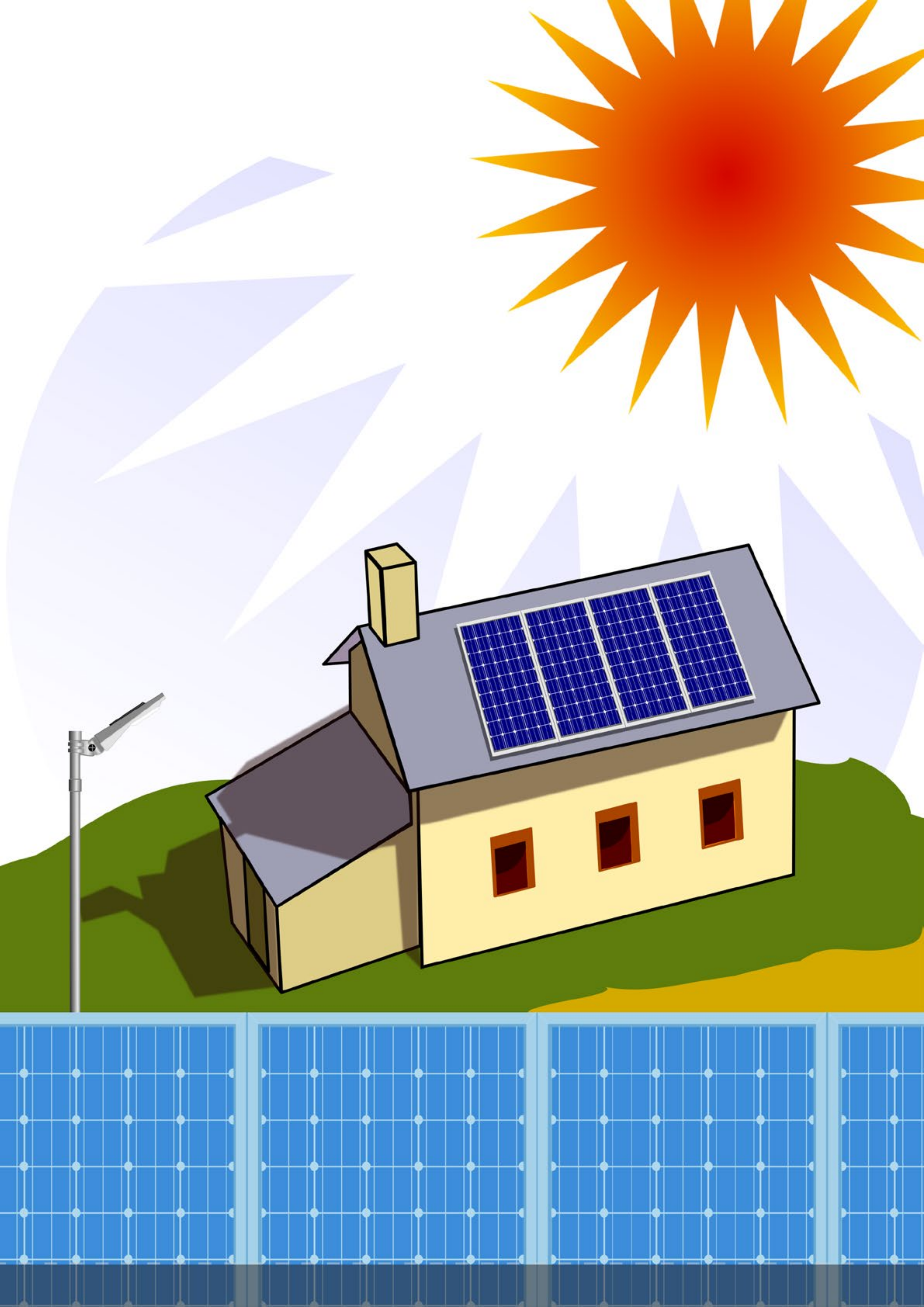

CONTENTS

INTRODUCTION TO LOCNET COMMUNITIES OF PRACTICE

This manual is the result of one of the projects undertaken by the communities of practice (CoPs) with the support of the Local Networks (LocNet) initiative. LocNet is a collective effort headed by Rhizomatica and the Association for Progressive Communications (APC) that works with partners in Africa, Asia and Latin America and the Caribbean. Its goal is to support the development of bottom-up approaches for the construction of communications infrastructures known as community networks (CNs).[1] APC and Rhizomatica want to contribute to an ecosystem that permits the emergence and growth of such networks. To achieve its goals, LocNet adopts various strategies related to exchange among peers and institutional strengthening, training and tutoring, policy and promotion, technological innovation and sustainability, and gender and women's participation.

In recent years, LocNet has provided advice, financial resources and forums to support various CNs and other partners. The purpose of the CoPs is to increase collaboration among community networks worldwide through online collaborative spaces created in relation to different topics of interest for CN professionals.

The approach of CoPs includes activities seeking to enhance support on key issues of interest for the CN community, bringing together the different lines of work in technology and innovation from previous years. In this sense, a CoP is a group of people who share a common concern, a set of problems or interest in an issue and who join forces to pursue both individual and collective goals. CoPs are often centred on exchanging best practices and creating new knowledge to drive advances in a given area, and one of their crucial components is constant interaction.

1. These initiatives are best understood as a collective undertaking by local communities to connect in a meaningful way and construct relevant digital networks. Since 2017, the LocNet initiative has accompanied and supported their efforts.

PHOTOVOLTAIC SYSTEMS, A FOUNDATIONAL TECHNOLOGY

Electricity is as important for telecommunications as sunlight is to a tomato plant. Anyone who designs and operates communications infrastructure must guarantee a reliable power supply. Too often, supposed connectivity "solutions" take for granted a general supply of power anywhere on our planet. But 13% of the world's population lacks access to electricity and a much higher percentage experiences unstable or deficient service, especially in rural areas. Also, power consumption varies substantially and qualitatively, while affordable electricity is inextricably linked to income. In other words: while flowers, people and everything on earth share a free and abundant supply of sunlight, electricity is not available to all. Thus, using sunlight to generate electricity is of vital importance to produce a more democratic supply and more inclusive infrastructure.

Photovoltaic systems are already part of this inclusive infrastructure constructed and used by a growing number of community networks. In the year 2019, the LocNet Technology, Innovation and Sustainability Team (WP4) mapped the "foundational technologies" (tools and skill sets essential for collectively created and maintained community networks), with representatives of the CN ecosystem. In this map, priority was given to photovoltaic systems (classified as "passive infrastructure").

Some community networks in Africa, Asia and Latin America had already had success in creating autonomous power supplies for local telecommunications and other infrastructure. Solar energy, especially photovoltaic systems, were key in proposals for BOSCO (Uganda), Abradig (Brazil), and the Pathardi community network and the Servelots network (both in India). With the format of the above-mentioned "communities of practice", LocNet launched a practical experiment to bring collaborations between CN professionals and other relevant professionals to the forefront. And after consulting the CN ecosystem on possible CoP issues, it became evident that solar energy is clearly a priority for many CN professionals.

The group of 17 participants in the CoP for passive infrastructure began exploring priorities and possible methodologies for learning exchanges.[2] In

2. It took us some time to define the interaction collectively and without hierarchies, defining as priorities inclusion by gender, race/ethnicity, different abilities, and different levels of knowledge, validating empirical knowledge and promoting an environment free of prejudice. Our aim was and is to use this approach to incentivise and share community-centred dynamics for the design and production of technology that incorporates the localised nature of technology practices from the outset. This specific project will address appropriation, innovation, and implementation of technologies that are key in participative and sustainable organisation of community networks.

the first session, they focused on the need to better understand electricity and its key concepts. Regarding photovoltaic energy, the CN professionals wanted to establish a general framework of components and orientation to plan the local deployment of such systems. They recognised that it was an enormous task that would be difficult to address globally from zero. Therefore, they agreed to conduct a series of online exchanges with professionals with experience in photovoltaic energy, especially Elektra Wagenrad and Hiure Queiroz. These meetings were followed by two inclusive online sessions in which they presented the basics of electricity and photovoltaic practices. And although these sessions were conducted online (in English), the participants also recommended recording the lessons in a written document and translating it into several languages.

The resulting work was directed by Jose Manuel Ramos Rodríguez, a professor of communication and social change with extensive experience in writing manuals and instructional texts for local communities in Latin America. His editorial work is accompanied by more than 30 illustrations by Khushalsingh Kanheyasingh Rajput, who has previously worked on visual translation of know-how and experience with and for the CN ecosystem. Elektra Wagenrad and Michael Jensen have kindly added a highly practical conclusion to the introductory material, with which it covers a wide range of different expertise and skills and will be useful for both beginners and people looking for practical ideas.

This initial approach to an introductory framework on the basics of electricity and photovoltaic systems will have its voids and shortcomings. In fact, it should end with the phrase "to be continued," because it is expected to become a collectively managed resource, maintained, expanded and translated by a diverse and active community of practice within the CN ecosystem – a kind of intercultural technological landscaping. We hope it will form part of a series of approaches that produce tangible results and benefits for CNs and a conduit for continued work on the emerging methodology of LocNet CoPs.

We hope you enjoy the following pages, give us feedback, share your comments and ideas, and join LocNet's CoP on Solar Energy for new undertakings and co-creations: https://t.me/+qO4cZ3ZJPSsyYzhi

NOTES ON CONTRIBUTORS

José Manuel Ramos Rodríguez is a researcher and activist in training and accompaniment for processes of communal and Indigenous education and communication.

Hiure Queiroz has worked daily in a rural community network (https://portalsemporteiras.github.io).Through this experience he has contributed to several open source projects to help develop new tools and devices for community networks. In an attempt to generate movement on this issue, he has produced documentation, guides and tutorials with coolab (https://coolab.org).

Elektra Wagenrad has been developing wireless mesh technology for community networks and systems powered by solar energy and has participated in the development of http://villagetelco.org and http://freifunk.net. She has developed three types of Freifunk-OpenMPPTs, open solar software/hardware controllers with maximum power point tracking. She is the author of "Mesh" and co-author of "Wireless Networking in the Developing World".

Khushalsingh Kanheyasingh Rajput works autonomously under the name Korelgraphics. He has worked for more than 20 years in the field of creative graphics, animation, illustration, publication and web development. At present, Khushalsingh works with the Indian Institute of Technology Bombay (IIT Bombay), where he promotes the use of open source software.

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1.

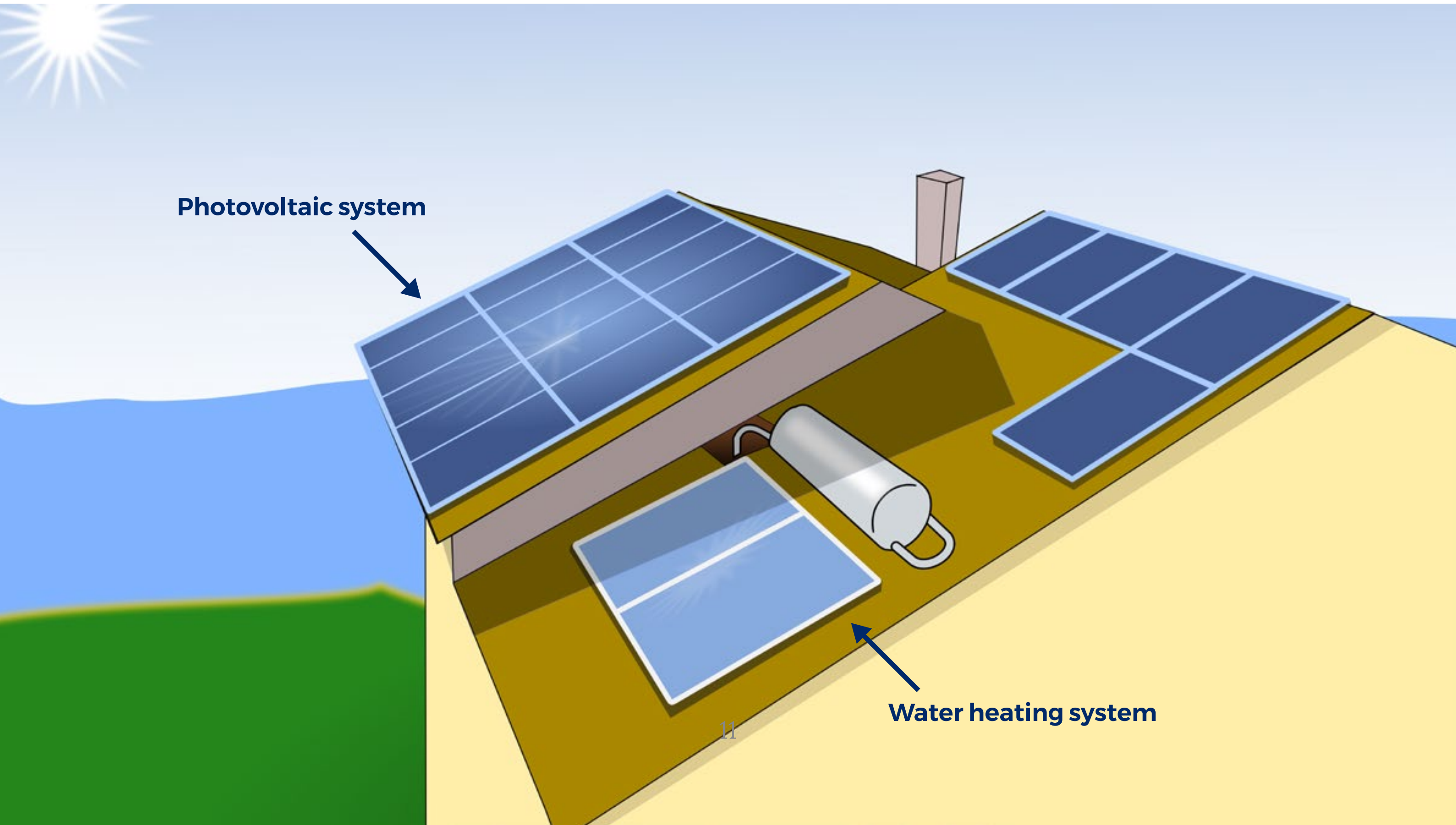
INTRODUCTION TO ELECTRICITY AND PHOTOVOLTAIC SYSTEMS

INTRODUCTION TO ELECTRICITY AND PHOTOVOLTAIC SYSTEMS

1.1 BASIC CONCEPTS ON ELECTRICITY

In this first section, we present some basic concepts related to electricity that are necessary to better understand the functioning of the solar panels from which we can generate it. Readers may already be familiar with some of these concepts, but it is important to form a joint vision that can be shared with members of the group or collective interested in starting or maintaining a process using this technology.

First, we must distinguish systems that use sunlight to produce electricity from those used to heat water. The former, which provide electricity, are called ***photovoltaic***. Although there are similarities between the two, they function differently. The illustration below shows both types of systems for use of solar energy.



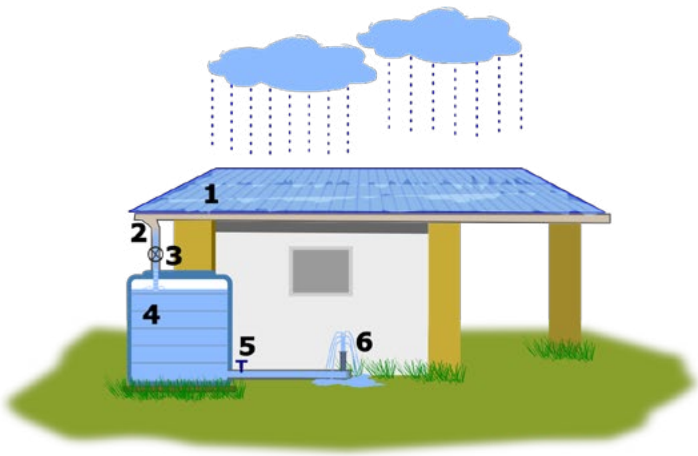
Photovoltaic systems are those capable of converting sunlight into electricity. The term *photovoltaic* is a composite of two words: photo (or light) and voltaic. The second word comes from the name of the 18th century Italian scientist Volta, who was a pioneer in studies of electricity. As a result, the word voltage is associated with electrical phenomena.

The term *photovoltaic* describes the basic feature of these systems: generation of electricity from sunlight.

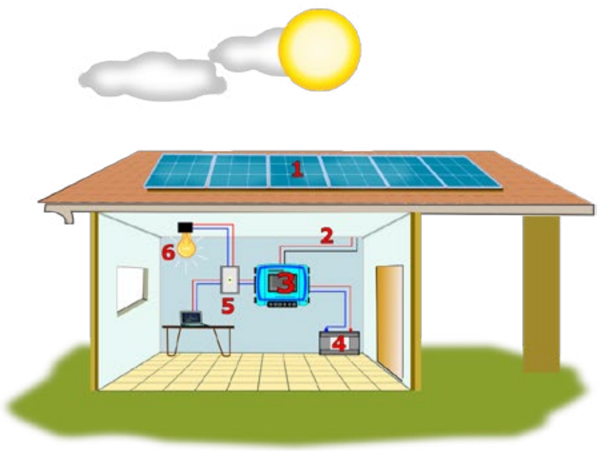
Before discussing concepts related to electricity and its basic properties, it is advisable to have an overview of photovoltaic systems and their primary components.

We recur to an easily understandable analogy: rainwater collection systems. Similar to the way they gather rainwater for use in homes or on crops, photovoltaic systems "collect" sunlight and convert it into electricity. This analogy should not be taken literally, since we are logically dealing with different things. However, the "parts" or components of the two systems are similar and the analogy is helpful to understand the functioning of photovoltaic systems.

See the illustration below:



Water collection system



Photovoltaic System

In the above figure we see six components in both systems. Below, we describe the general functions they perform:

	Water collection system	**Photovoltaic System**
1	The rooftop collects rainwater.	Photovoltaic panels receive sunlight.
2	The piping carries the water collected.	Wires conduct the power produced by the panels.
3	A valve regulates the quantity of water to be stored in a:	A load controller regulates the power stored in a:
4	Tank	Battery
5	A valve regulates the tank's water output.	A variable resistance controls the flow of electricity.
6	A sprinkler allows us to water our yard with the water collected.	We have electricity to power a light bulb.

We must insist that this is merely an analogy that helps to understand the essential parts of a photovoltaic system and the functions they perform in simple terms.

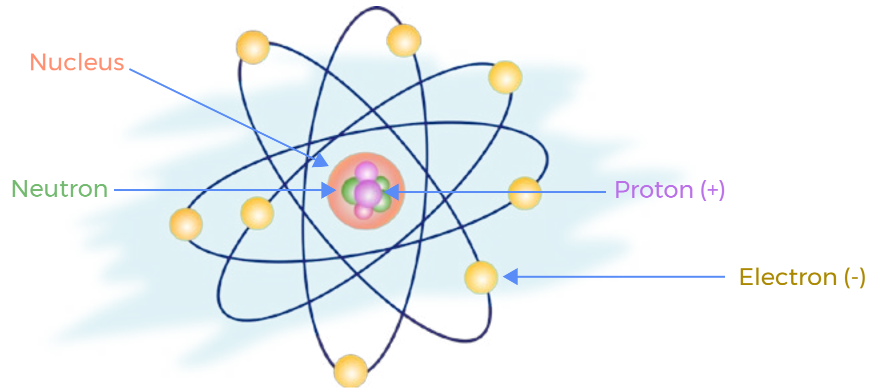
Continuing with our analogy, it is clear that what circulates through the water collection system is, precisely, water. But in the case of the photovoltaic system, what circulates through the system? ... If we answer that what circulates is "electricity," we will be correct.

But what is electricity? Surely we can say what we use electricity for, that it makes light bulbs and domestic appliances work, or that it is dangerous if we make a mistake and receive an electric shock. Or we think of thunder and lightning bolts in a storm as a form of electricity. But what is electricity? Where does it come from and why does it exist?

ELECTRICITY

Properly speaking, electricity is not something invented by humans. It is something found in everything that exists, and science has merely studied it and put its properties to use. We will start by saying that all matter that surrounds us, solids, liquids and gases, is made up of tiny molecules, which in turn are combinations of atoms. Atoms are extremely small particles formed by protons and neutrons (which are found in the nucleus of the atom), and electrons surrounding the nucleus.

The graphic representation that has been used for the atom is as follows:

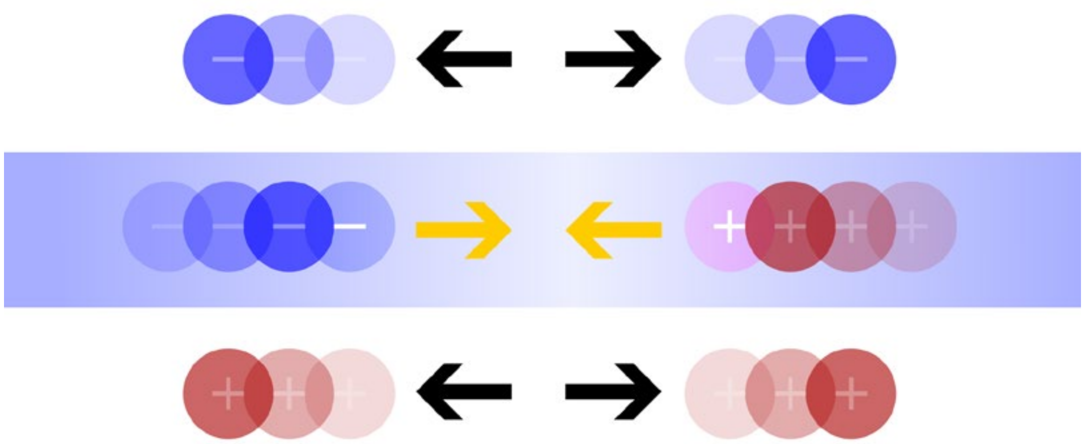


- In the nucleus of the atom we find:
    - protons, which have a positive charge (+)
    - neutrons, which have no charge.

- Electrons move around the nucleus and have a negative charge (-).

Scientists assure us that this is merely a representation to help us understand the atom. In fact, the nucleus is much smaller and electrons do not necessarily follow an orbital trajectory. But this representation is sufficient to describe the composition of the atom.

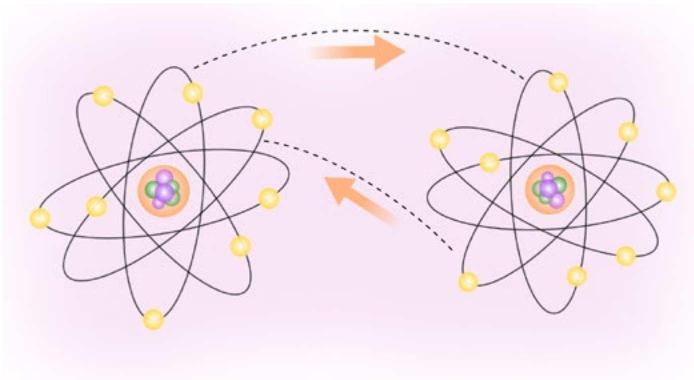
Furthermore, electrons are negative and are attracted by positively charged protons. There will always be attraction from a source with an excess of electrons to a source with a deficiency of electrons, which has a positive charge.



Opposite charges attract, like charges repel.

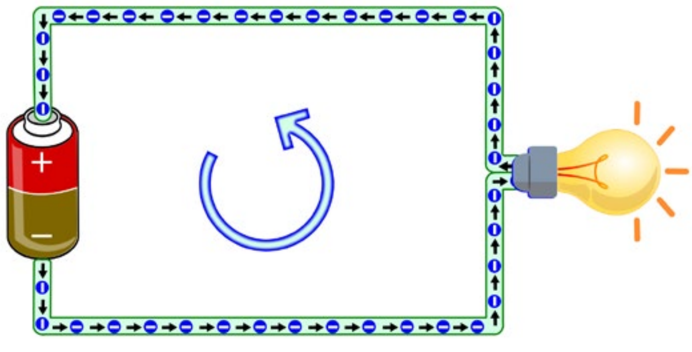
Electrons revolve around the nucleus due to the balance of two forces: the inherent force of the electron, which keeps it constantly in motion, and the force of attraction that the nucleus exercises on the electron. The electrons that are at the farthest points from the nucleus can break off from the atom – if they are subject to an external force like friction, a chemical reaction, heat, pressure, a magnetic field, or light. This kind of electrons are known as free electrons. The movement of free electrons from one atom to another produces what is known as an electron stream. When electrons flow through a body from end to end, an electric current is produced. This is the basis of electricity.

Flow of free electrons



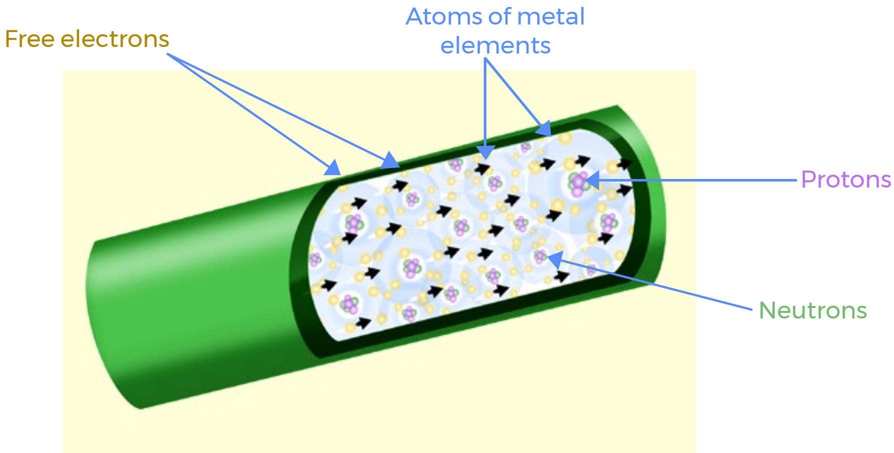
Now we will see a very simple example:

Electric circuit

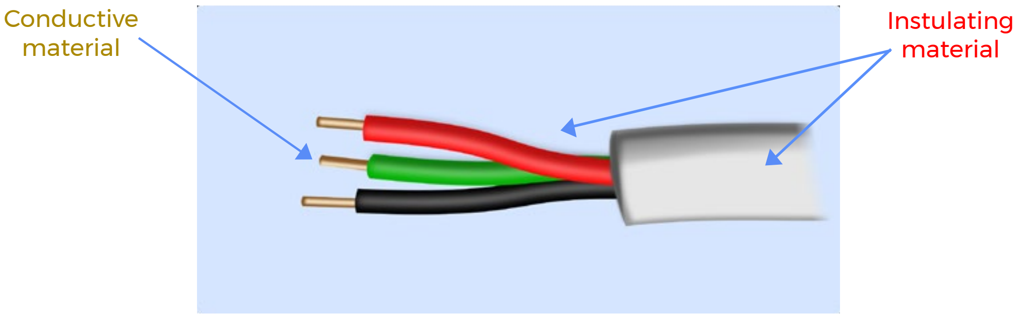


We have a very simple electric circuit, formed by a battery, a wire and a light bulb. As we see in the illustration, there is a flow of electrons which are attracted by the positive charge in the battery. As they pass through the light bulb, a very thin filament becomes incandescent and produces light.

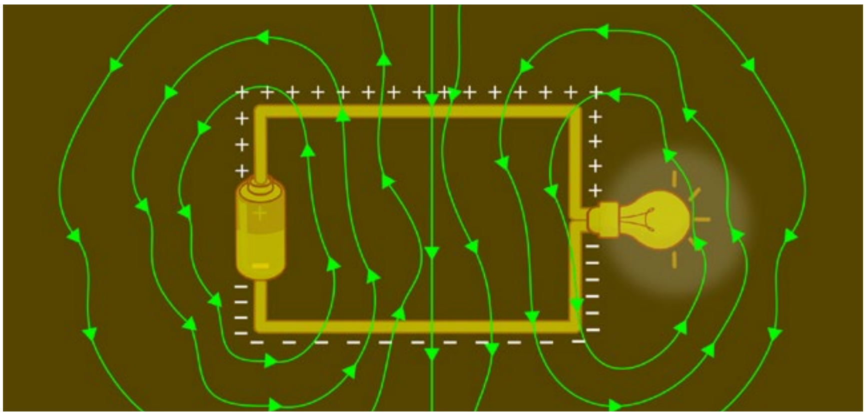
As we have explained, free electrons flow through the wire. Thus, we can imagine the inside of the wire if we could enlarge the image thousands and thousands of times.



There are materials that allow electrons to flow more easily. Such elements are called conductors. Copper, for example, is a material capable of favouring the flow. The electric wires we are familiar with are made from a conductive material surrounded by an insulating material which does not favour the flow.

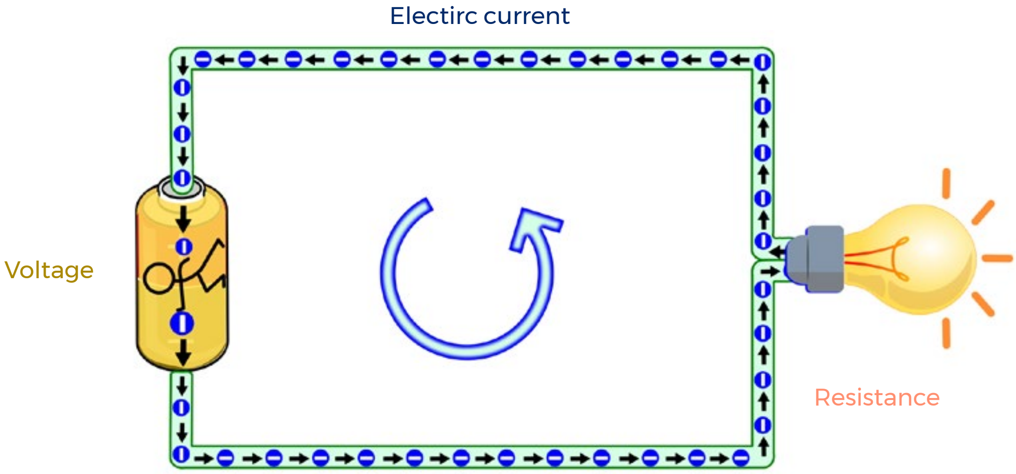


The phenomenon that occurs is actually considerably more complex than electrons flowing through a wire. Instead, what is known as an "electrical field" is produced, which can be represented as follows:



The study of this electrical field is highly complex and requires in-depth knowledge of physics and mathematics. For now, bear in mind that the field exists and it also involves the force of magnetism, for which reason it is also called an ***electromagnetic field***.

Now, we will see the same simple circuit, distinguishing three elements: voltage, current and resistance:

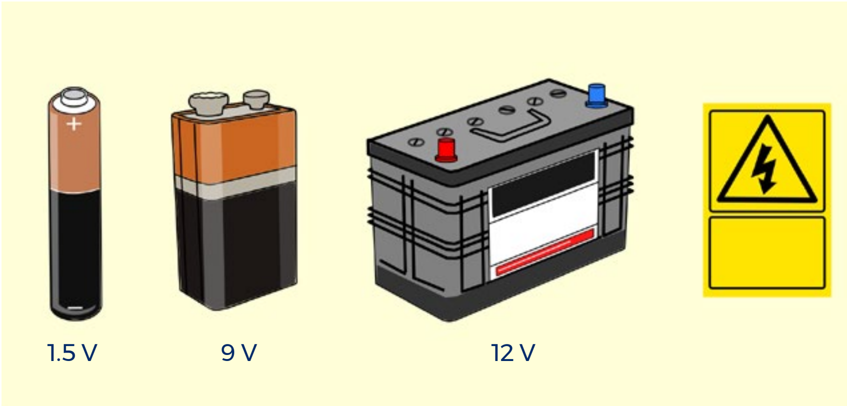


As we see in this illustration, voltage is the force that "pushes" and "pulls" the electrons. Current is the number of electrons that actually flow in the circuit, and the filament that lights up offers a certain resistance to that flow.

Now let's examine each of these concepts in somewhat greater detail. We should note that these are also quite complex phenomena, a full understanding of which is beyond the scope of this lesson. However, below we present some general, albeit fundamental ideas about them.

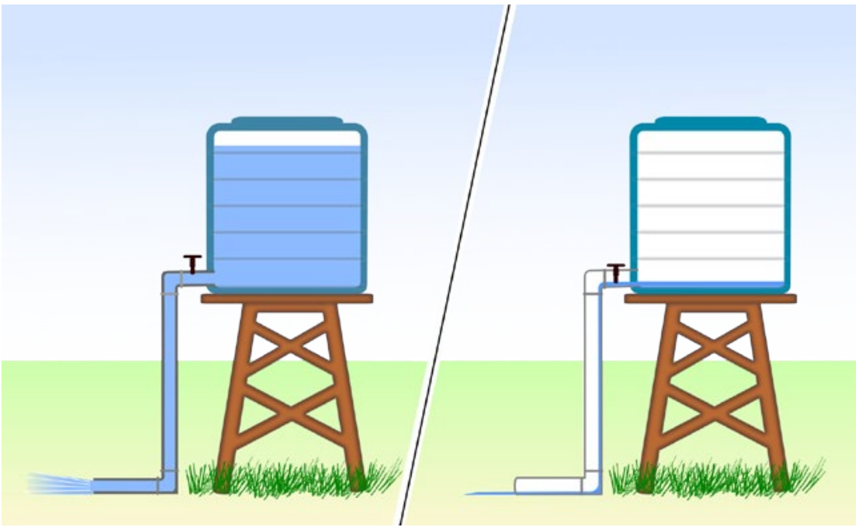
VOLTAGE

As we have seen, voltage is the force or pressure with which electrons move in an electrical field. Surely we are familiar with the term "voltage" and we know, for example, that it is an important feature of batteries for domestic use. We are also familiar with the expression "high voltage", which warns us of the danger of suffering a powerful discharge.



But, what is voltage?

Again we will use the analogy of a water storage system. If we have a storage tank, for example, when it has different amounts of water we can observe the following:



A B

As we can see, in the case of tank A, the water leaving the tank exits with greater pressure than in the case of tank B, which is nearly empty.

Something similar occurs when there is greater or lesser force moving the flow of electrons. Remember that this motion comes from the force of attraction between opposing charges and the force with which charges of equal polarity repel one another.

Voltage, also known as tension or potential difference, is the pressure that an electrical power supply source exercises on the electrons in a closed electric circuit. The unit of measurement used for voltage is, precisely, the volt (V) and its definition involves two concepts which it is useful to know, even if only superficially.

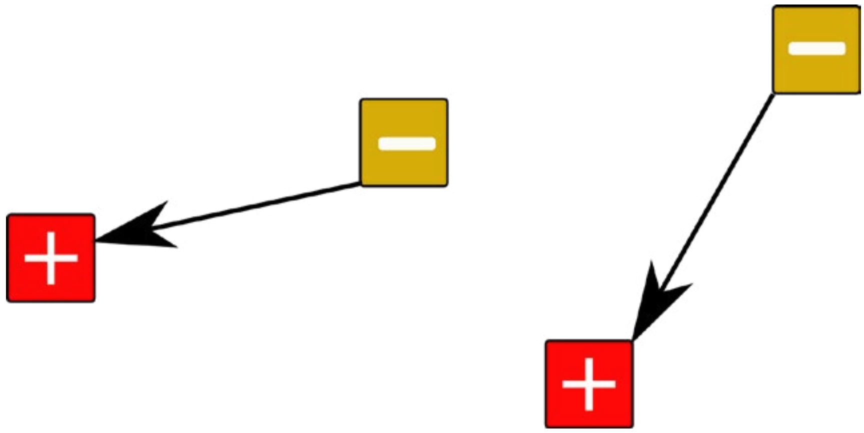
The motion produced involves an *expenditure of energy or work* and the motion of a given *number* of particles. Scientists have established a means of measuring both these things, which are interrelated. Thus, the measurement known as *joule* is defined as the quantity of work necessary to move a charge of one *coulomb* (which measures the quantity of charge a circuit can transport in a period of time). A coulomb is equal to the charge of a vast number of electrons (6.4×10^{18}).

To simplify these complex measurements, we have the unit known as a ***volt*** (V). One volt is equal to the difference in potential recorded between two points on a given conductor when, to move a one-coulomb charge from one point to another, it is necessary to perform the work of one joule.

Another way to define the volt is as the difference in potential between two points such that the work of 1 joule is needed to move the charge of 1 coulomb from one point to the other.

For the time being, it will suffice to make clear that:

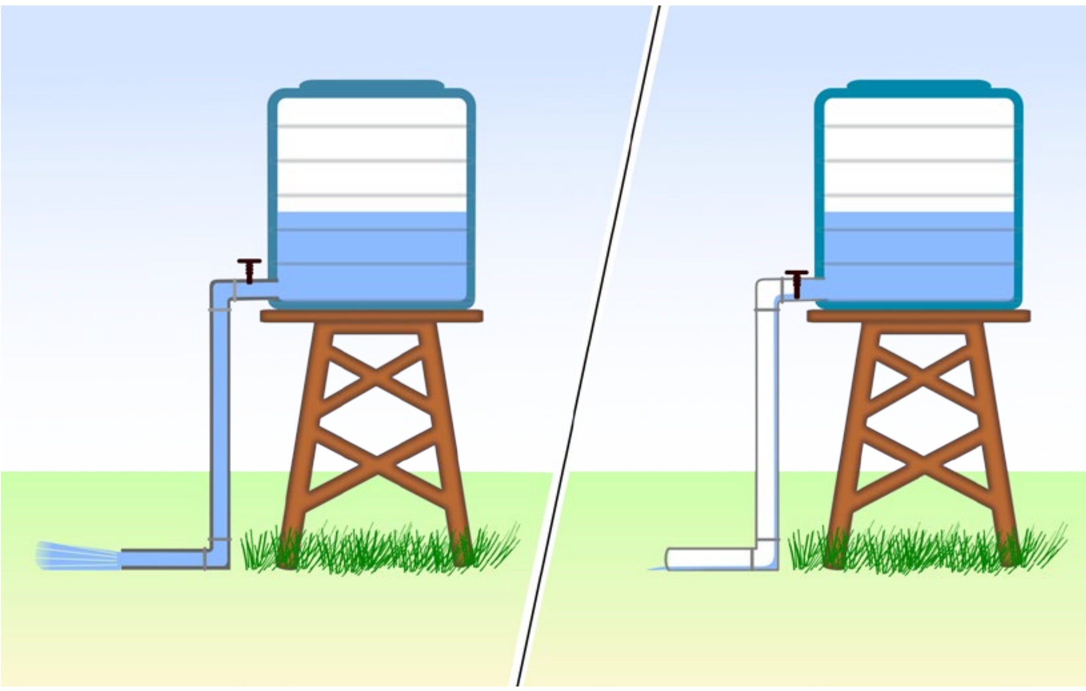
Voltage measures the force or pressure with which electrons are conducted in an electrical field and that force comes from the difference in potential between two sources. The greater the difference, the higher the voltage.



Lower voltage **Higher voltage**

ELECTRIC CURRENT

The number of electrons that flow through the field in a given time is what we call *electric current*. Returning to our analogy of the water storage tank, we can imagine that there is a valve that allows more or less water to pass; in other words, the quantity of water that passes may be greater or lesser.

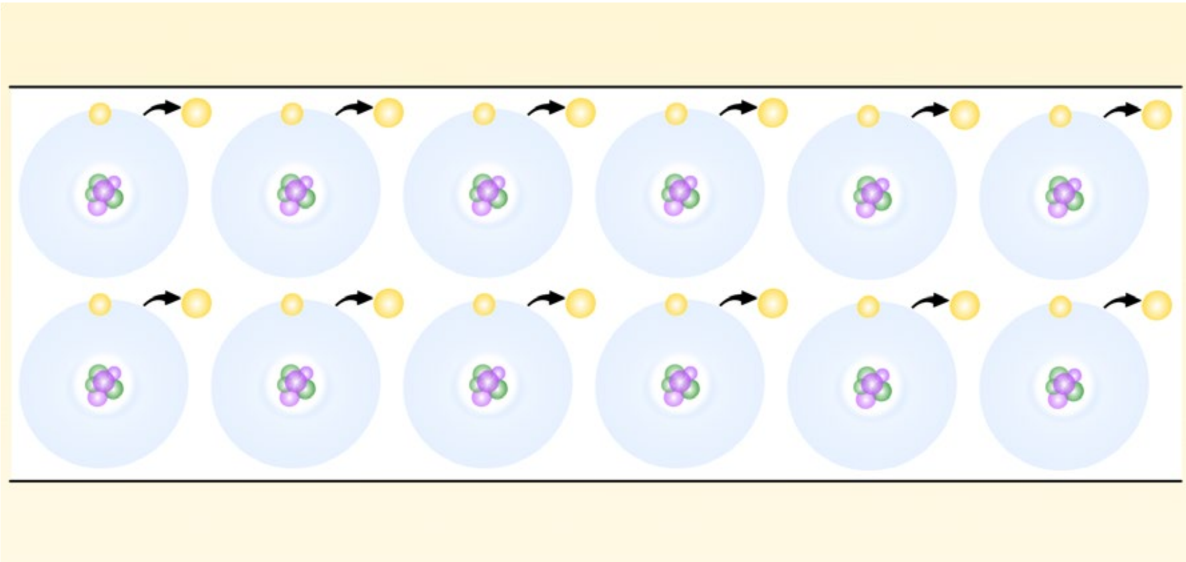


The same thing happens in an electric circuit; the current can be greater or lesser depending on the number of electrons flowing.

The unit of measurement of this current is the ampere (amp), which is defined as follows:

1 ampere = 6.24 x 10^{18}
electrons flowing per second at a given point.

We can imagine what is happening in the wire based on the illustration below:



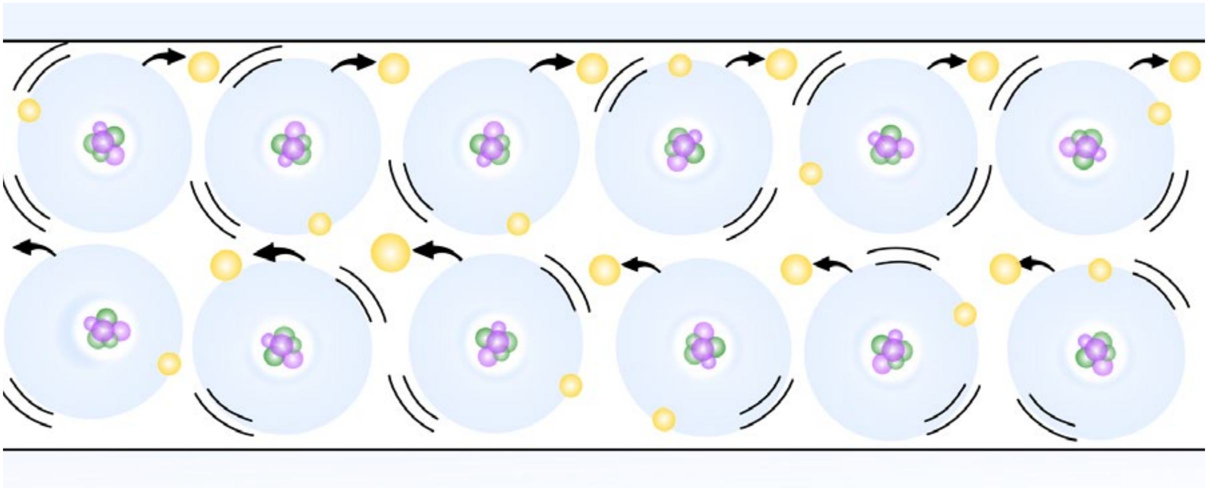
If we think of the circles as atoms and the small blue points as electrons, we see that one of the electrons breaks free and affects the atom adjacent to it, which in turn releases electrons toward the adjacent atom, and so on successively.

RESISTANCE

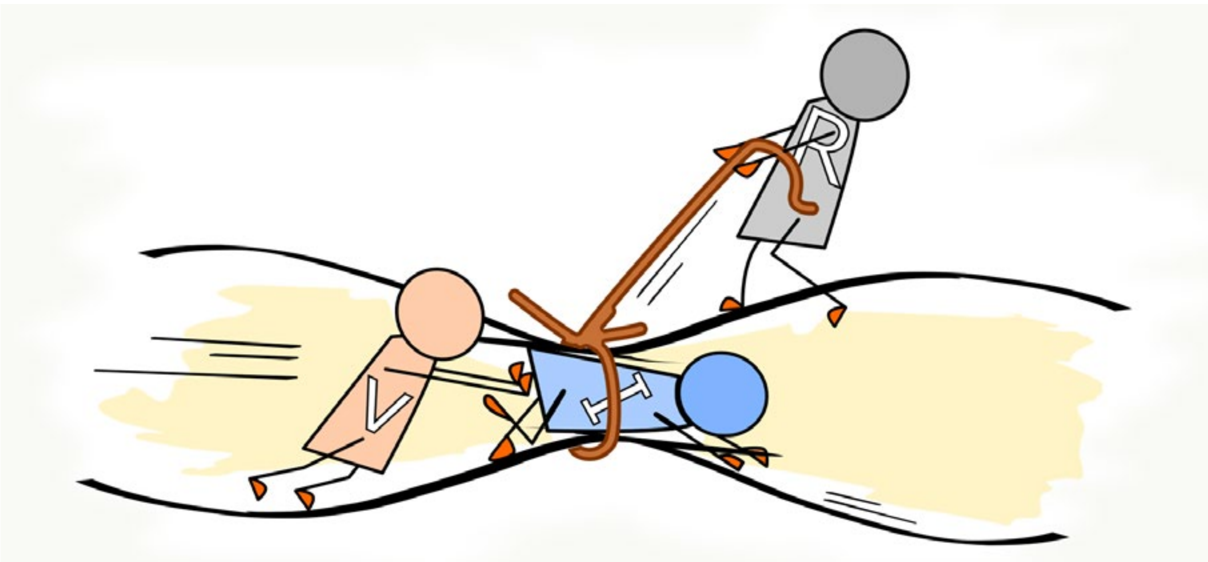
The third element we see in our diagram of the simple electric circuit is resistance, which, in this case, is a filament that heats up to produce light. Resistance is the force which, to a greater or lesser extent, opposes or blocks the passing of electrons. Returning to our water storage tank, the valve that allows more or less water through would be the resistance that is limiting the passage of current.

Resistance is defined as the capacity of a material to facilitate or block the flow of electric current. It is measured in ohms and the symbol used to represent it is the Greek letter omega: Ω.

Returning to our previous illustration, we would see some atoms that impede the passage of electrons and interrupt the flow, thereby creating resistance.



The drawing below provides a simple illustration of the concepts of voltage, amperage and resistance:



In summary:

Property of electricity	Measured by:	Simplified as:	Task in a circuit:
Voltage	Joule/coulomb	Volt (V)	Pressure the flow of electrons creates
Current	Coulomb/second	Ampere (A)	Number of electrons flowing
Resistance		Ohm (Ω)	Inhibits the flow of electrons

ELECTRICAL POWER

Electrical power is the ratio by unit of time with which electricity is transferred through an electric circuit, in other words, the quantity of electricity delivered or absorbed by an element at a given time. Measuring it is important to estimate the quantity of energy that a photovoltaic system can provide and the energy that different devices consume.

The unit of measurement of this power is the *watt*, which is equal to one joule per second. We can calculate the power of a circuit using the measurements of voltage and current we already know:

Power *(in watts)* = **Voltage** *(in volts)* x **Current** *(in amperes)*

For example:

Suppose that a cell phone is charging connected to a 12.5 V battery. The amperage is 0.5 A.

How much power is consumed?
Using our formula, we multiply the voltage (12 V) by the amperage (0.5 A) and obtain as our result: 6 W.

We can say that the power our cell phone requires is 6 W.

CONSUMO DE PODER

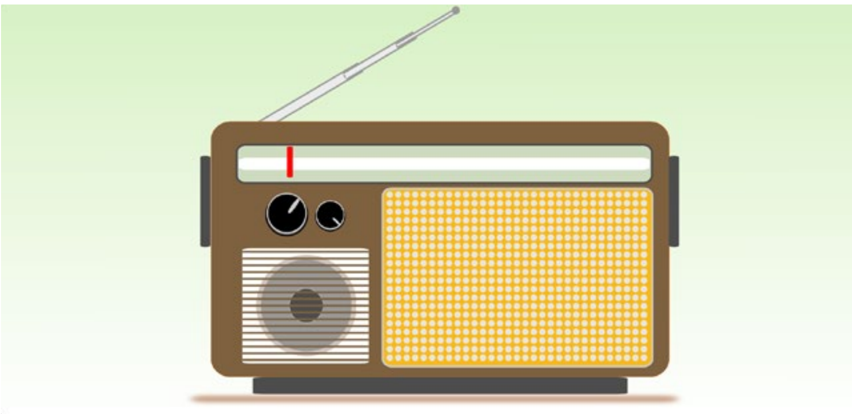
How much power or energy is actually consumed? As is logical to answer, the energy we consume depends on the time that elapses during the flow of current.

In other words, we know the power that a given device needs (6 W in the previous example), but we need to know what that device's power consumption is. That will depend on the time the device remains connected. Power consumption is calculated in watts per hour.

The unit of measurement for power consumption is the *watt hour (Wh)*. Sometimes, to handle large amounts more easily, we use the term *kilowatt hour (kWh)*, in other words, a thousand watts per hour.

Returning to our example, if the cell phone charges for three hours, its consumption would be the product of multiplying the power (6 W) by the three hours it was connected. Thus, in this case, we had a consumption of 18 Wh.

Now let's see another example:



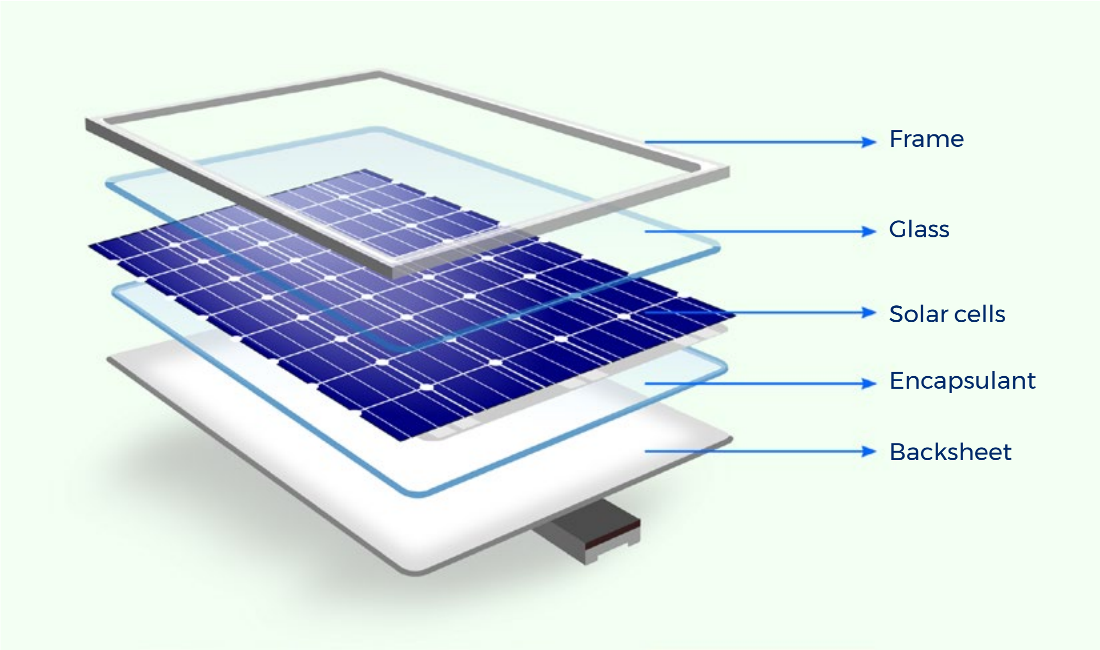
A radio is on for three hours. On the back of an appliance, we can almost always find a label that indicates its power (P). in this case, it says that the radio consumes 7 W of power.

Multiplying the power by the number of hours, we find that in three hours the radio consumes 21 Wh (7 W x 3 hours).

1.2. PHOTOVOLTAIC PANELS

Now that we have a clearer notion of electricity and electric current, we will see how photovoltaic panels produce electricity from sunlight.

Photovoltaic panels, in fact, are a group of solar cells whose functioning we will see later. The illustration below shows how these panels are constructed.



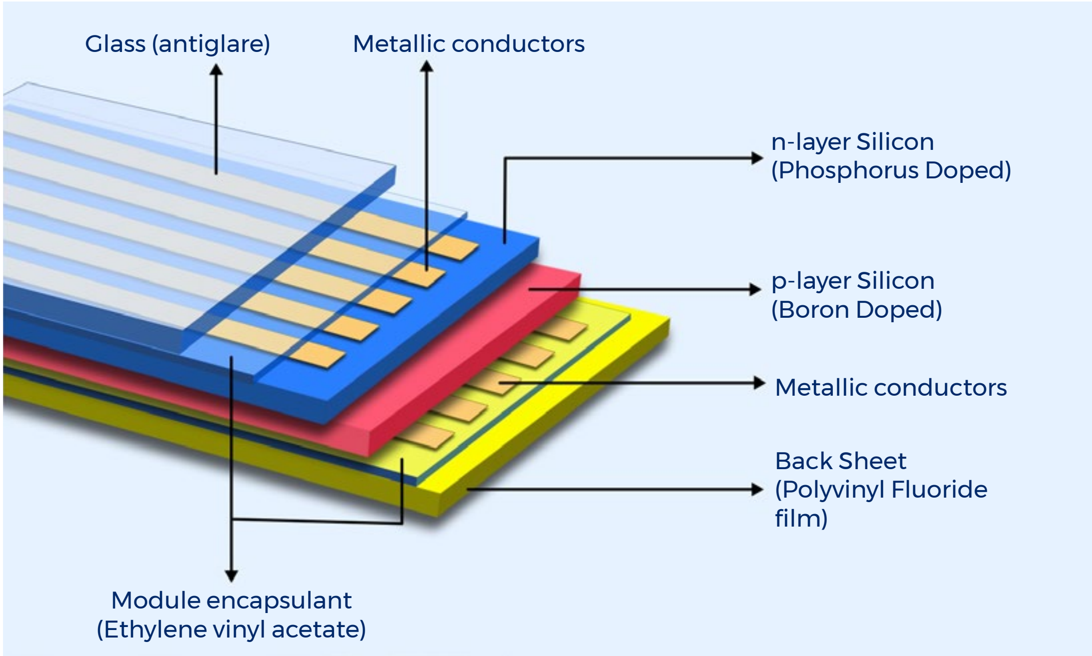
As the illustration shows, the solar cells in the panel are covered with a layer of glass, which protects them from rain and dust. But, as we have said, the sunlight captured is transformed into electricity in the solar cells. How is such a thing possible?

The solar cells are made of a chemical element that has the property of releasing electrons when it receives the photons or particles contained in sunlight. This element is silica, the basis of the material we know as silicon. Furthermore, the cells are formed by two layers or sections of silicon, each of which has been modified differently in its atomic structure by adding phosphorus ("doped" is the term used by scientists), in one case, and boride in the other.

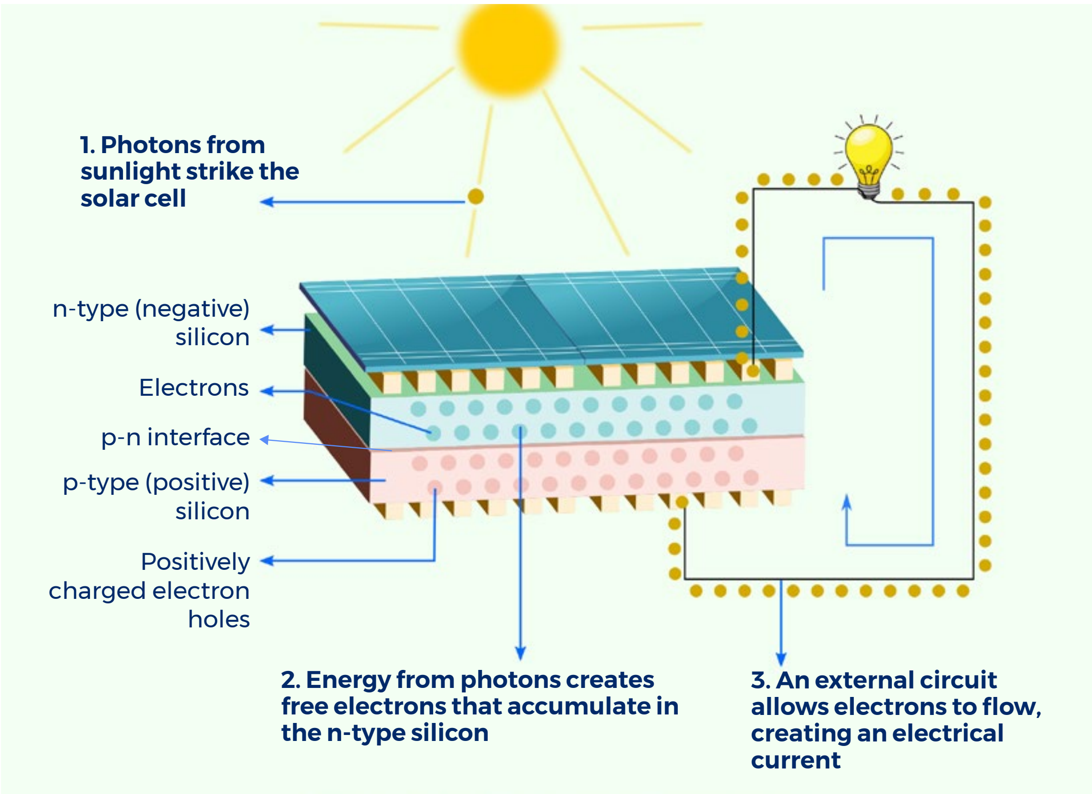
The layer on which the photons collide (layer n) has extra free electrons and below that layer is layer p, which has a positive charge and where there is an excess of holes, or empty spaces left by some electrons.

When the two layers are combined an electrical field is created that does not allow the electrons to move more than one way, thereby generating an electric current.

Let's see how solar cells are constructed:



In this other illustration we can see the functioning of photovoltaic panels:



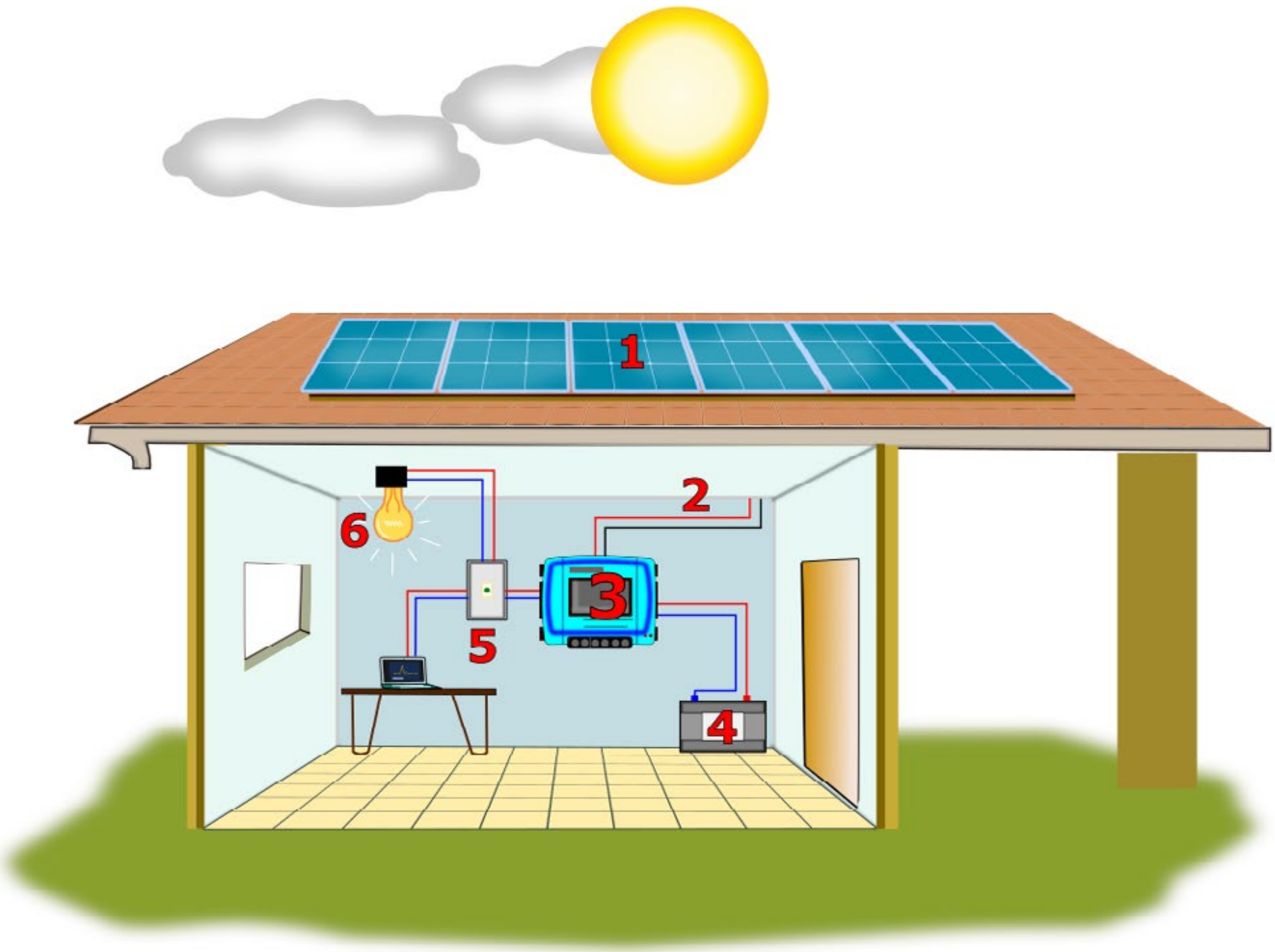
2.

GOOD PRACTICES WITH PHOTOVOLTAIC SYSTEMS

2.
GOOD PRACTICES WITH PHOTOVOLTAIC SYSTEMS

In this section we present some important ideas and concepts relating to the different components of a photovoltaic system. These ideas will be very useful to plan and dimension our system in terms of its capacity to generate enough power to meet our consumption needs. These points are also important to guide our decisions regarding the best equipment for us to use and its maintenance to achieve maximum efficiency.

Let's return to the illustration showing the main components of a photovoltaic system.



We will now offer some answers to the following questions for each component of the system.

1. Solar panels: How can we best use the light that comes from the sun? What precautions should we take to take care of our panels?

2. Wires: How do we choose the thickness of wires to have the least possible loss of energy?

3. Charge controller: What kind of controller is most suitable?

4. Batteries: What types of batteries are there? Which is most suitable?

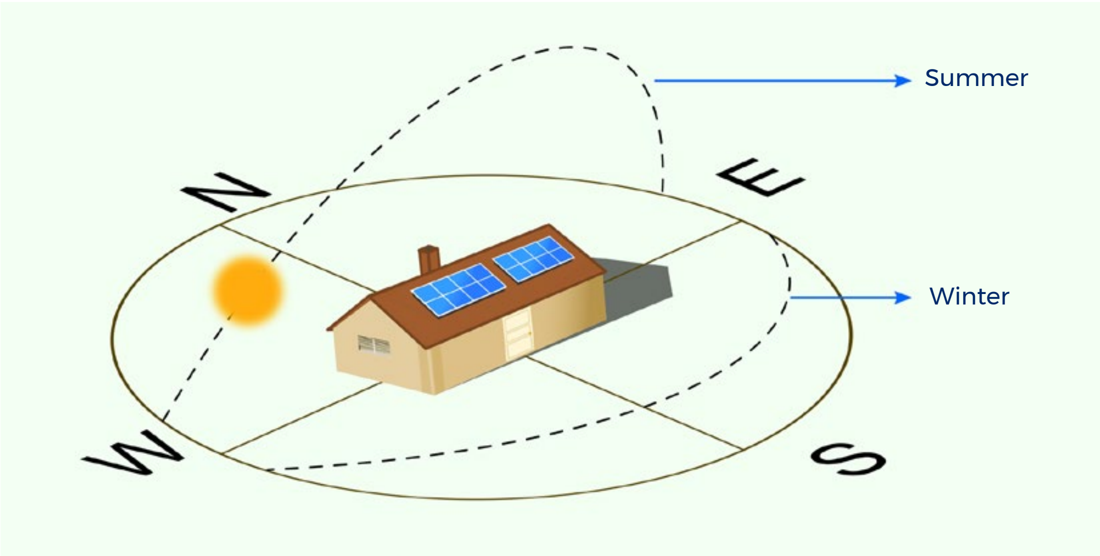
5. Electric charge: DC-DC and AC-DC converters, DC-AC inverters – which is most suitable?

The answers to these questions may help make our system as efficient as possible, and minimise loss of energy related to each of these components.

2.1 SOLAR PANELS

POSITIONING

The placement of our solar panels is the first factor to consider, since it will determine how much sunlight they receive. As we know, due to the inclination of the Earth and its rotation around the sun, its path across the horizon changes throughout the year.



Thus, the amount of light that reaches the panel varies not only throughout the day but also throughout the year. And the sun's trajectory is variable, depending on our location on the Earth.

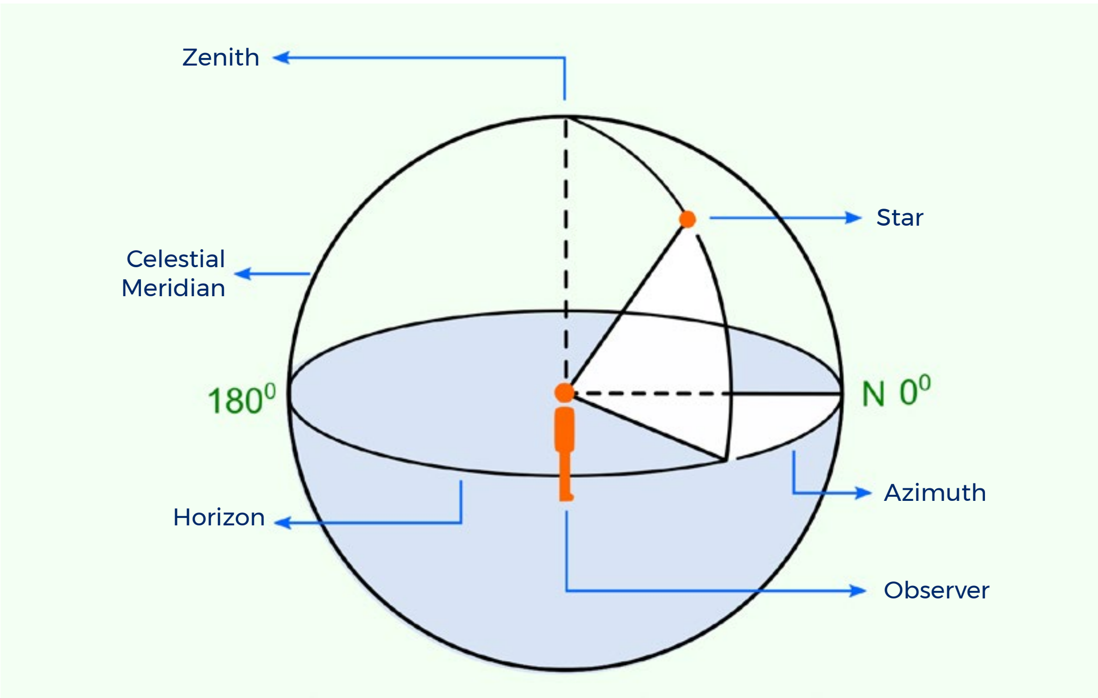
Two basic factors intervene in the positioning of our panels: orientation and inclination.

ORIENTATION

As regards orientation or direction, it depends on whether we are in the Northern or Southern hemisphere of the planet.

To maximise energy production, if we are in the Northern hemisphere, the panels should be installed facing South, in other words with the angle called azimuth at 180˚. On the contrary, if we are in the Southern hemisphere, the ideal orientation is to the North, with 0˚ of azimuth.

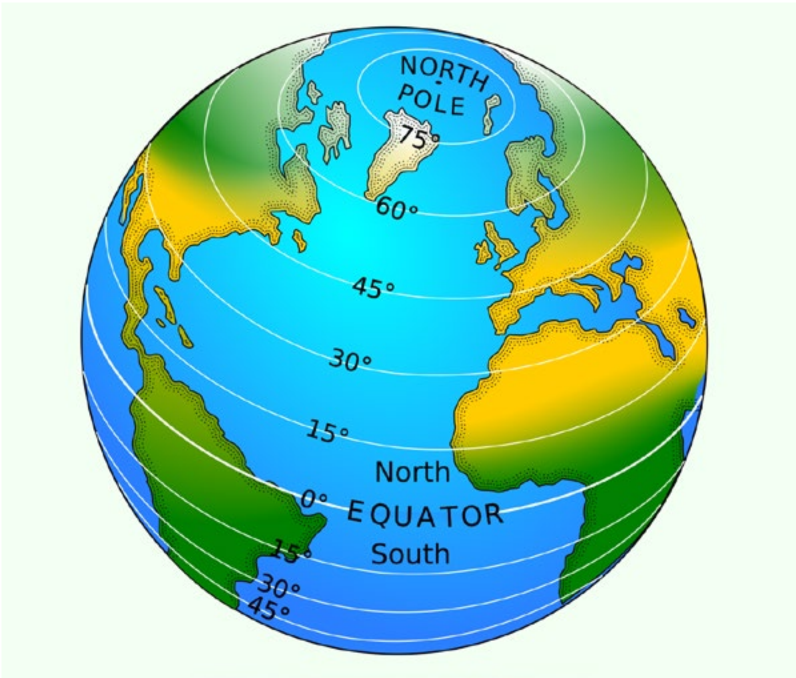
As we can see in the illustration below, the azimuth is the angle formed by the geographic North and a celestial body, measured clockwise around the observer's horizon.



North Hemisphere: Orientation to the Sur
South Hemisphere: Orientation to the North

INCLINATION

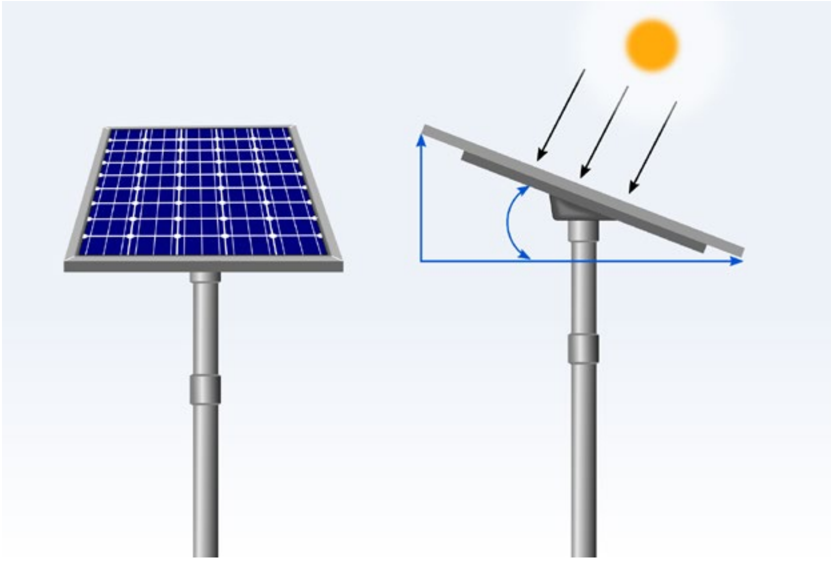
The ideal ***inclination*** of the panel is variable at each specific location and depends on the geographic latitude at which we are situated at a given point on Earth. Latitude is the angular distance between the equator and a given point on Earth, measured along the meridian on which that point lies. Depending on which hemisphere the point is located in, it may be North or South latitude.



The shape and inclination of the Earth cause sunlight to reach different points on the globe differently. Also, in its yearly movement around the sun, days are longer in summer and shorter in winter.

Bear in mind a basic rule to determine the inclination of panels:

The more perpendicular our solar panel is in relation to the sun, the more energy it will receive and the more power it will generate.



Depending on the latitude we are at, the angle of inclination we should use so that, when it is at the highest point on the horizon, the sun impacts the panels perpendicularly will vary.

There are multiple online resources with tables of inclination for different regions and cities. To calculate the ideal inclination for your panels, use the following formula:

a) For winter

In the winter months, when there is less sunlight, take your latitude, multiply it by 0.9 and then add 29 degrees.
For example: if your latitude is 40 degrees, the best angle to incline your panels in winter is: (40 x 0.9) + 29 = 65 degrees.

b) For summer

Take your latitude, multiply it by 0.9 and subtract 23.5 degrees.
For example: if your latitude is 40 degrees, your panels should be inclined at: (40 x 0.9) - 23.5 = 12.5 degrees.

c) For spring and autum

Take your latitude and subtract 2.5 degrees.
For example: if your latitude is 40 degrees, the best inclination for your panels in spring and autumn is: 40 - 2.5 = 37.5 degrees.

Since panels are often fixed and we cannot vary their inclination over the course of the year, it is advisable to consider that generation of electricity will vary with the seasons of the year. In such cases, it may be advisable to average the values for each season.

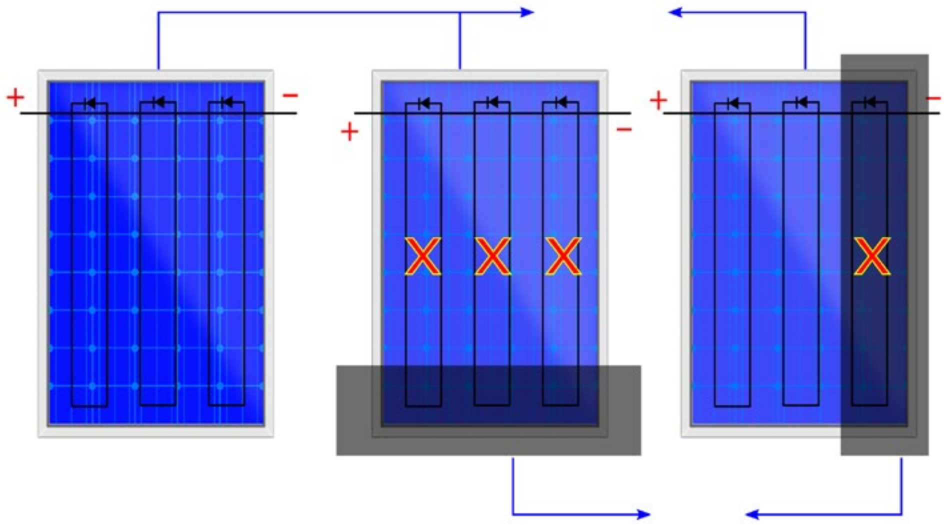
AVOID SHADE

Another important factor to consider is that, ideally, solar panels should not receive any shade. Bear in mind that shade on solar panels negatively affects the performance of the photovoltaic system. Remember that panels are formed by cells and when one or more cells are affected by shade, the flow of electrons alters its path and may take the wrong direction, resulting in a loss of energy and damage to system components.

In some cases it is impossible to completely avoid shade in areas on one or more panels. For that reason, panels have a device called a ***diode*** which acts to block the passage of contrary current, "skipping" the cells affected by shade and rerouting the electric current. Such diodes are activated when a solar cell cannot generate positive voltage due to shade.

In the illustration below we can see three situations for panels in relation to shade. The diodes are represented by small arrows at the top of the panel:

- On the left, we see a panel that is not affected by shade.
- In the middle, we see a panel on which shade falls horizontally on some cells but the entire panel's performance is affected.
- On the right, we see vertical shade that affects only one section of the panel.



Shade and solar panels

MOUNTING OF PANELS AND TEMPERATURE

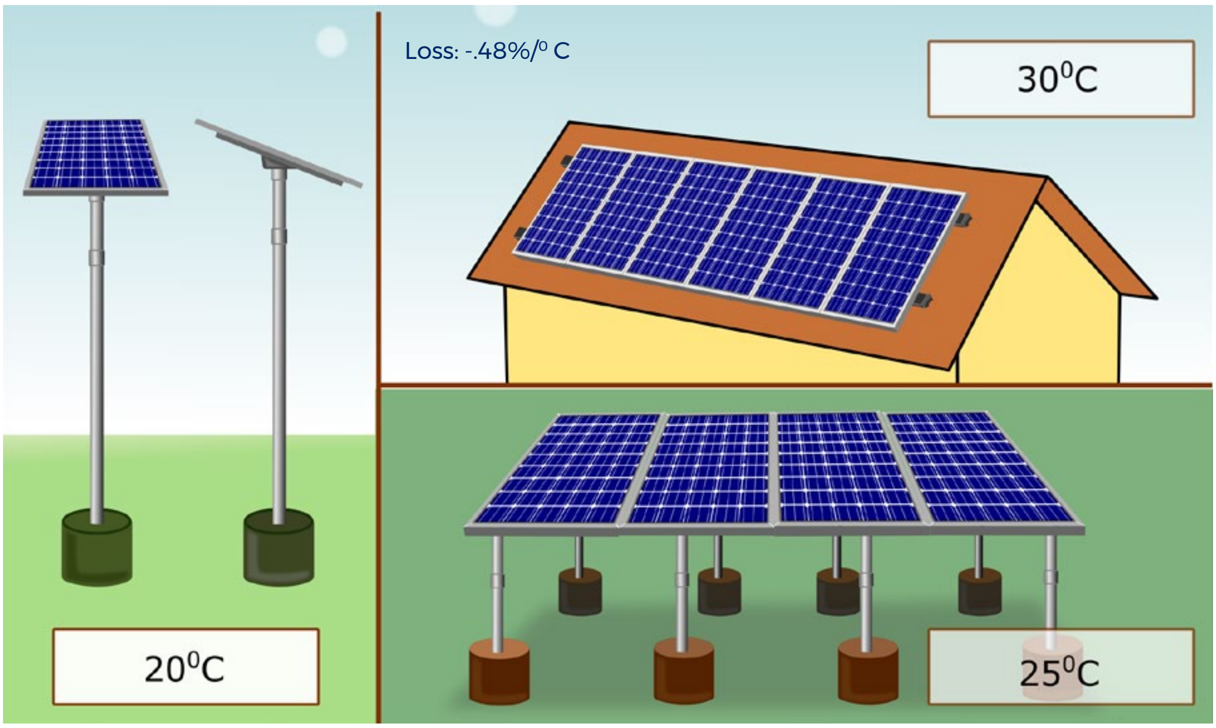
Another factor to consider is temperature, which depends on the type of mounting we use for our panels, since at higher temperatures resistance is greater. In other words, losses are greater when the temperature is higher and vice versa.

In the illustration below we see three types of mounting:

- In the first case, with panels on posts, the temperature generated is 20° C.

- On the top right we see panels placed directly on the roof and the temperature reaches 30° C.

- On the bottom right we have panels on bases at ground level. Here the temperature is 25°.



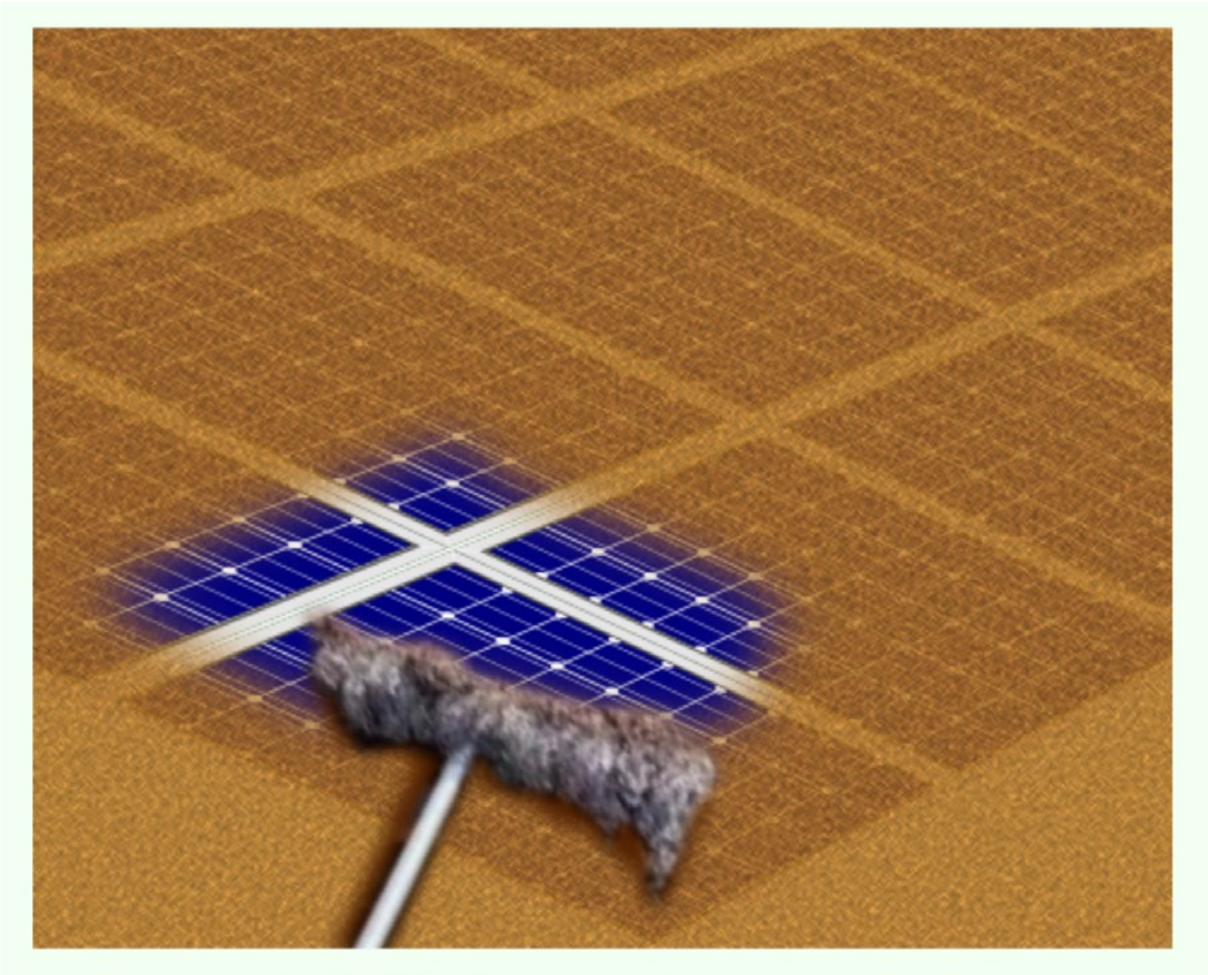
Mounting system temperature adder

Calculations show that the temperature can cause a loss of almost half a percentage point (0.48%) for each degree centigrade of temperature.

DUST ACCUMULATED ON THE PANEL

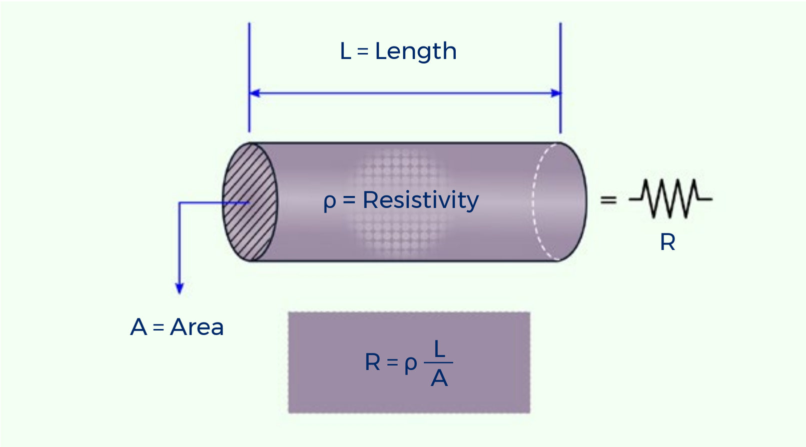
Another factor in possible energy loss is dust that accumulates on the surface of the panel. For this reason, depending on specific site conditions, it is advisable to clean the surface of panels with some frequency. Cleaning may be with water or possibly with a mild soap. If it proves necessary, a small amount of alcohol may be used.

It is estimated that panels that are cleaned weekly lose only 1% of energy due to dust that accumulates. In contrast, if the panels are not cleaned, the loss may reach 50%. Depending on the conditions of wind and dust to which panels are exposed at the site, with bimonthly maintenance losses may be between 3% and 7%.



2.2 WIRING

Another important factor to consider is the size of the wiring used, because there is a relationship between the inherent resistance of the material, the distance or length of wiring used, and the surface (thickness) of the wire. All these factors in turn are related to the amperage of the current to be transported.



The material with which wires are made presents a certain resistance (resistivity in the illustration). Normally, we use copper, which has low resistivity. However, the longer the wire, the greater the resistance it generates, and therefore the more energy is lost. This loss can be offset by increasing the area or surface area of the wiring.

The table below shows the appropriate wire to use, by surface area, for different amperages and lengths.

Max. current	1 metre	1-2 metres	2-3 metres	3-5 metres	5-7 metres	7-10 metres
1-20 A	4 mm²	4 mm²	4 mm²	4 mm²	6 mm²	6 mm²
20-30 A	4 mm²	4 mm²	6 mm²	6 mm²	10 mm²	16 mm²
30-40 A	4 mm²	4 mm²	6 mm²	10 mm²	16 mm²	16 mm²
40-60 A	6 mm²	6 mm²	10 mm²	16 mm²	16 mm²	21 mm²
60-100 A	10 mm²	16 mm²	16 mm²	21 mm²	21 mm²	35 mm²

Calculations show that in the wiring of our system, we will have a loss of around 4%.

2.3 LOAD CONTROLLERS

The load controller is an essential device for the operation of a photovoltaic installation. Its function is to regulate the flow of energy from the panels to the batteries to prevent an overload. It controls both the intensity and the voltage the batteries receive, so that they recharge under optimum conditions and are not damaged.

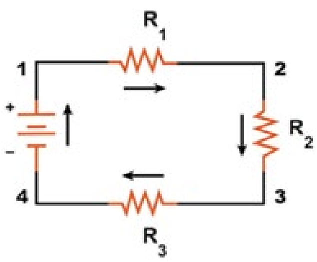
There are various types of controllers. It is important to know the two most common types and compare them. The table below shows a comparison of the main features of each type.

Types of load controllers

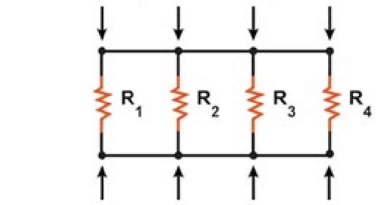
Pulse width modulation (PWM)	**Maximum power point tracking (MPPT)**
Measures the voltage and temperature of the battery bank.	Measures the voltage and temperature of the battery bank.
Cannot vary the voltage of the photovoltaic source (panels).	The voltage of the photovoltaic source (panels) can be controlled.
The type and array of modules should be designed based on the battery voltage.	Accepts various types of modules and configurations in series and in parallel. (See below.)
Less expensive.	May cost 1.5 to 2 times what the PWM costs.
Depends on the availability of solar panels with appropriate voltage.	There must be availability of the device.
A small system has more advantages with this type of controller.	If the system is larger, the benefits of this type of controller are greater.

CONFIGURATIONS IN SERIES AND IN PARALLEL

In a ***series circuit***, all components are connected end to end to form a single path for the flow of current. When elements of the circuit are connected in series, the voltages or resistances are added. For example, two 12-volt batteries connected in series provide 24 volts.



In a ***parallel circuit***, all the components are connected to one another with at least two electrically common nodes with the same voltage in each component. In circuits connected in parallel, the resistance or voltage remain the same.



2.4 BATTERIES

Batteries are the most expensive component of a photovoltaic system and are made of highly polluting materials. Therefore, it is necessary to take extreme care to ensure proper usage to extend their lifespan as much as possible.

Before discussing the different types of batteries, and some of their advantages and disadvantages, we need to see some basic points on the most critical aspects of batteries, which we should take into account both in choosing the equipment and for its protection. A wrong choice can cause a drastic reduction in the battery's lifespan. Batteries have a life cycle, in other words, a given number of charge and discharge cycles. Proper management of the battery prolongs that life cycle.

Some factors to consider for battery protection are:

- **Depth of discharge (DoD)**
  The batteries we use in photovoltaic systems have a limit in terms of their discharge capacity. In other words, they need to retain a certain amount of energy and not become completely discharged, which is what we call depth of discharge. A discharge greater than that tolerated may damage our equipment and shorten its life cycle. We need to be attentive, to respect each battery's specifications for depth of discharge. Normally, the manuals that come with these units present this information very clearly. In dimensioning our photovoltaic system, we need to bear in mind that we will not be able to use all the energy stored.

- **Proper charging**

Each battery presents a maximum current and a maximum voltage it can accept to charge, because the voltage affects battery temperature. As we will see, some batteries can withstand greater quantities of current and voltage and are less affected by temperature. Normally, load controllers recognise the type of battery that is connected, although we need to verify this since the controller may not recognise batteries with newer technology.

- **Proper discharging**

As with charging, each battery also has a maximum discharge current, and that limit must be respected so as not to damage it.

- **Temperature**

This factor is extremely important. High temperatures affect the life cycle and performance of batteries. Calculations show that a 10-degree increase in the temperature tolerated can reduce battery life by half. Therefore, the site where batteries are installed should be sufficiently cool and we need to avoid sites subject to high temperatures.

- **Maintenance**

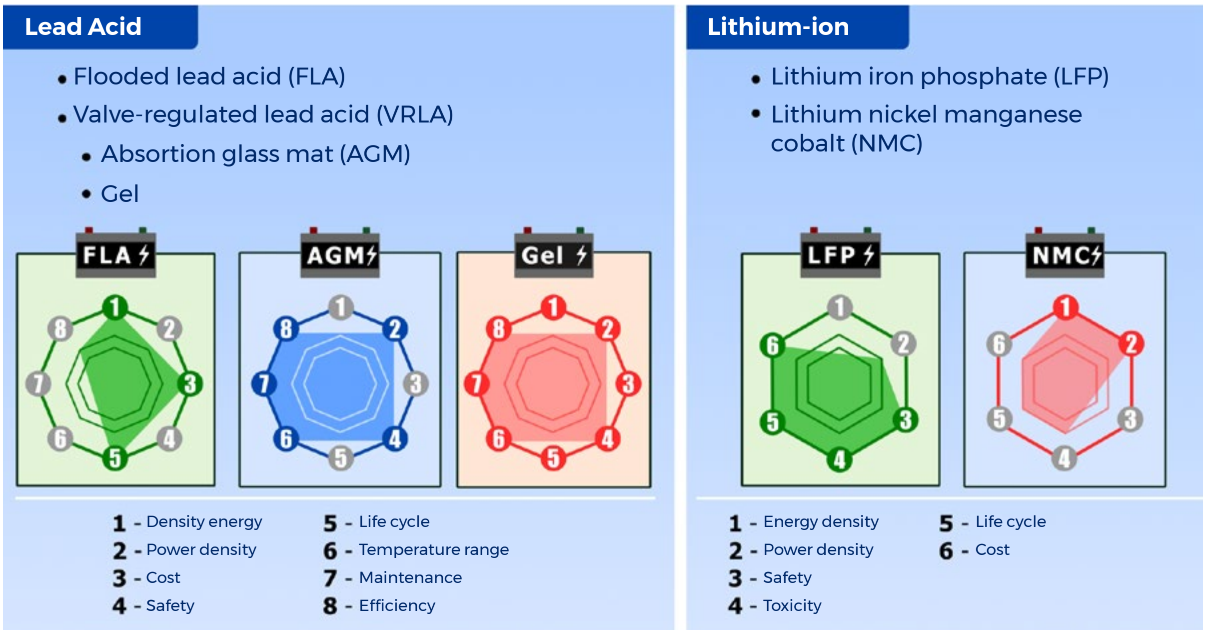
Each type of battery has different maintenance needs, which should be taken into account to choose the equipment best suited to our needs. Improper maintenance can damage a battery rapidly.

It is not recommendable to connect batteries in parallel.

TYPES OF BATTERIES

There are many types of batteries, but there are two main groups, called “lead-acid” and “lithium-ion” batteries. The first are still the most widely used. Lithium-ion batteries are newer and their use is starting to spread. These two groups are subdivided in different types, which gives rise to a variety of possibilities to choose the batteries most suited to our specific needs.

The diagram below compares some general features of these types and subtypes of batteries.



FLA batteries are the simplest, least expensive and longest lasting, and therefore are the most widely used. They also have the advantage of tolerating a good depth of discharge. This type of battery is still standard equipment for photovoltaic systems.

VRLA batteries, unlike FLA batteries, do not require maintenance, given that, since they are made from a solid material that does not evaporate, there is no need to replenish lost materials.

The group of VRLA batteries is in turn subdivided into AGM and gel. AGM batteries have the advantage of withstanding higher rates of charging and discharging than the rest. They are convenient when the user needs to handle greater quantities of energy without affecting their durability. Also, they are small in size. Gel batteries, because they contain no liquid, do not require specific positioning.

Batteries made with lithium (lithium-ion) have appeared recently and offer some advantages over the lead-acid type. There are many types of these new batteries, but in the graph we show two that appear to offer the greatest advantages for use in autonomous photovoltaic systems. One of them is the LFP, which has the feature of a longer life cycle than other types and low cost per kWh. It contains less environmentally toxic substances and has a lower risk of overheating. Another advantage of LFP batteries is that their components can be replaced; in other words, they can be repaired by replacing individual components, unlike lead-acid batteries.

On the other hand, NMC batteries can handle large quantities of energy in a short time. This type of batteries are being used in leading edge technologies like Tesla automobiles, for example.

2.5 OVER CURRENT PROTECTION DEVICES (OCPD)

For protection of batteries and the system in general, these devices break the circuit in case of an overload (short circuit). We have breakers and fuses, which perform similar functions. In the case of fuses, following a discharge they need to be replaced because they are rendered useless. Breakers have the ability to disconnect the circuit in case of a discharge, but do not need to be replaced and can just be reset. They are very simple devices that provide excellent protection for the equipment.

Breaker **Fuse**

2.6 LOAD TYPES AND CONVERTERS

The load produced in the photovoltaic system is direct current. Usually, devices like routers, antennas, cell phones or personal computers work with direct current. Practically all electronic devices need an alternating current (AC) to direct current (DC) converter to supply integrated circuits and other components that usually operate on direct current. In the case of the photovoltaic system, this conversion is unnecessary. For example, if our battery is 12 V and the router also works at 12 volts, it can be connected directly to the battery (taking care with polarity, a very important factor in DC circuits).

However, different equipment may work with different voltages in DC, therefore requiring a DC-DC converter, with which we can adjust the voltage to that required by the different devices. These DC-DC converters may be of two types:

- **Step down converter:** when the input voltage is higher than the output voltage.

- **Step up converter:** when the input voltage is lower than the output voltage.

Inverters have a different function: they convert direct current (DC) to alternating current (AC). These devices are costly but at times prove necessary when the equipment we need to connect only works with AC.

If the equipment works with DC, it will be more economical to opt for a DC-DC converter to provide different voltages than to invert DC to AC, and then reconvert it to DC.

3.

PRACTICAL APPLICATION TO DIMENSION A PHOTOVOLTAIC SYSTEM

3.

PRACTICAL APPLICATION TO DIMENSION A PHOTOVOLTAIC SYSTEM

STEP 1: EVALUATE THE DEMAND FOR ENERGY

a) Identify the devices to be powered:

- Three 3 W LED lights. Each one is used for four hours a day.
- A laptop computer that is used for eight hours a day with an average instantaneous power consumption of 15 watts.

Attention:
The use of a DC power source for the laptop computer represents a great improvement in efficiency, compared with a DC to AC inverter, which produces 230 V AC (80% efficiency), followed by a standard AC to DC power source (80% efficiency). We would have a 36% loss.

Total instantaneous load:
LEDs: 3 x 3 = 9 watts
Laptop: 15 watts
Total: 15 watts

b) Calculate the total demand for power consumption (Wh).

- LEDs: 9 V x 4 hrs. = 36 Wh
- Laptop: 15 V x 8 hrs.= 120 Wh

Total demand: 36 Wh +120 Wh =156 Wh per day

STEP 2: DECIDE THE NUMBER OF DAYS OF STORAGE OF THE BACKUP BATTERY THAT WILL BE NECESSARY DUE TO CLOUDY WEATHER

Due to the probability of cloudy days in most situations, allowing for a backup time of less than two or three days is a design flaw that will probably give rise to multiple problems and premature battery failure. Calculating a backup time of five days also means that the system will discharge the battery less than 10% on average at night. This low DoD level allows the battery to work for thousands of charge and discharge cycles before it wears out.

Therefore, if we calculate a five-day backup, storage needs are: 5 days x 156 Wh = 780 Wh.

Converting to amp hours, we have: 780 Wh / 12 V = 65 Ah

Attention:
If five consecutive days without solar energy happen only once a year, it is acceptable to allow the battery to discharge to 100% of its depth of discharge (DoD). However, if this is likely to occur more often, it is better to include a 30% margin to improve the battery's lifespan.

Thus, in our case we would have: 780 Wh x 1.3 = 1,014 Wh

STEP 3: DETERMINE THE NECESSARY SIZE (IN WATTS) OF THE SOLAR PANEL TO MEET THE ENERGY NEEDS CALCULATED PREVIOUSLY

Use https://globalsolaratlas.info to identify the lowest average daily sunlight based on a 1,000-watt panel. For example, in La Pampa, Argentina, June is the month with the lowest irradiation, receiving 3,319 watt hours a day on average.

Our example requires 156 Wh per day; therefore, the peak power required for the solar panel is = (156 Wh / 3319 Wh) x 1000 = 47 Watts.

Attention:
When the system starts up in the morning with a fully discharged battery, it should produce a power surplus (to power the equipment) while it is recharging to 100%, for which a safety margin of 40% should be added (and that assuming that there are no objects near or in front of the panel that may produce shade.)

Peak solar power required = 47 watts x 1.4 = at a minimum a 66-watt solar panel is needed.

STEP 4: BEAR IN MIND THE SIZE OF THE SOLAR PANEL TO DIMENSION BATTERY CAPACITY BASED ON STORAGE NEEDS IN AMP HOURS

Bear in mind that battery capacity and solar panel size are closely related. With a 100-watt solar panel, we can assume a maximum charging current of slightly more than 6 A at 12.5 volts, in other words, 6 x 12.5 = 75 watts. The reason the system does not reach 100 watts is that hot solar modules have an efficiency of approximately 80% and there are additional losses from the load regulator (the best option would be to use an FF-ESP32 charger, which has approximately 95% efficiency). Therefore, the total loss (not including losses in wiring) is at least 25%.

Although 30 amp hours (5 x 6 A) would be the minimum battery capacity for a 100-watt solar panel, it is better to use a factor of 10 for the maximum charging current, if possible. This is because a slower charge and discharge increases the battery's useful lifespan. Also, the lower the discharge current, the greater the effective capacity will be (the battery's rated capacity is usually that indicated by the manufacturer for a current that discharges the fully charged battery in 20 hours), but as mentioned previously, the battery's useful lifespan depends largely on the depth of discharge and the number of discharge/charge cycles, as well as the rate of charge and discharge. Also, if the limit of initial charging current is exceeded, the battery will suffer premature damage. With time, the battery will inevitably lose capacity due to wear, but if the battery is set to the maximum charge current when it is new, the system will have problems quickly.

For most AGM lead-acid batteries, the charge current should not normally exceed 30% of the battery's rated capacity in amp hours, although that will depend on the type of battery (check the data sheet to know the AC factor). Thus, the limit of initial charge current for a 7.2 Ah battery is 7.2 Ah x 0.3 = 2.16 A. In other words, the maximum panel size for this size battery would be 2.16 x 12.5 = around 25 watts. However, if the battery is larger – at least five times the maximum charge current – a standard AGM battery of a good quality brand will last at least five years. For example, a standard Kung Long or Panasonic AGM battery has a useful lifespan of 1,300 cycles at a 30% depth of discharge before the battery's capacity drops to 60% of its new capacity.

Using our previous example of 66 watts maximum panel power, but increased to 75 watts as the most likely available panel size, the maximum expected charge current is 4.75 amperes (25% loss due to temperature and DC/DC conversion loss in the charger circuit). This would indicate a battery capacity of 4.75 A x 5 maximum charge current = 23 Ah.

However, we need capacity for five days without sunlight, so 5 x 23 Ah = 100 Ah.

Attention:
Check that the rate of charge/discharge will not reduce the battery's useful lifespan.

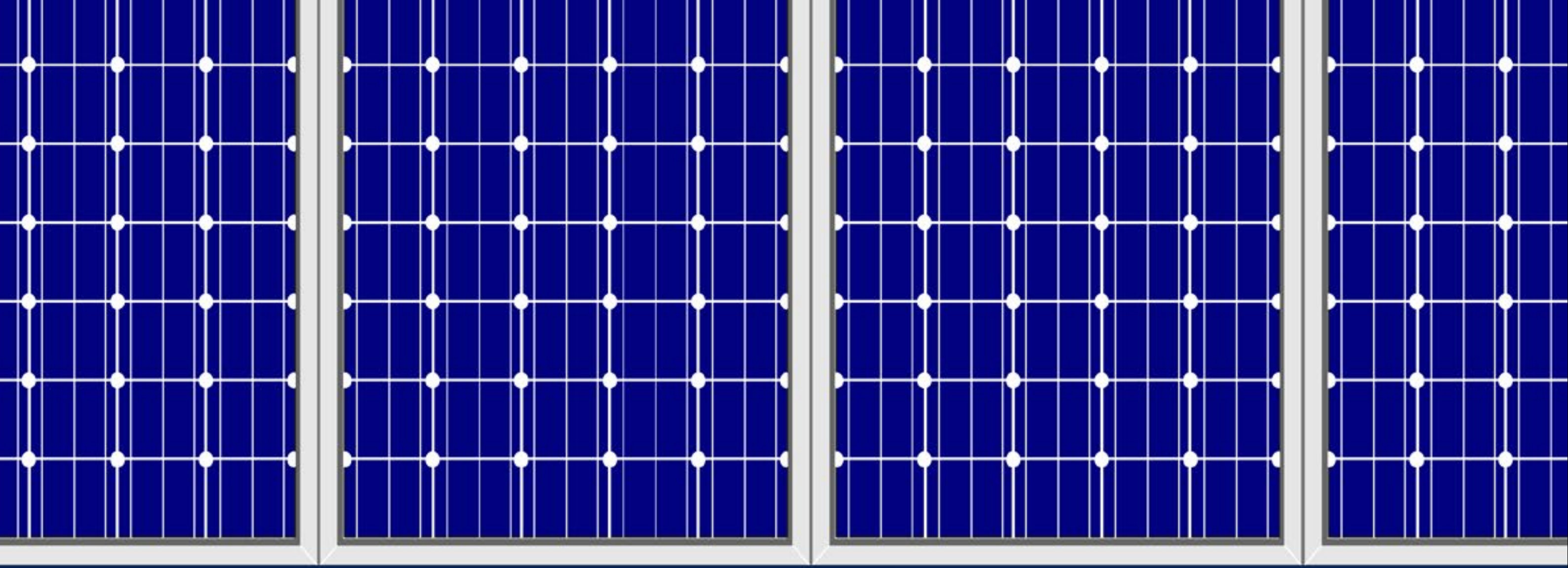
The maximum charge of 4.75 amps – 4.75 A/100 Ah – gives a ratio of maximum charge current of 0.0475 AC, which is excellent.

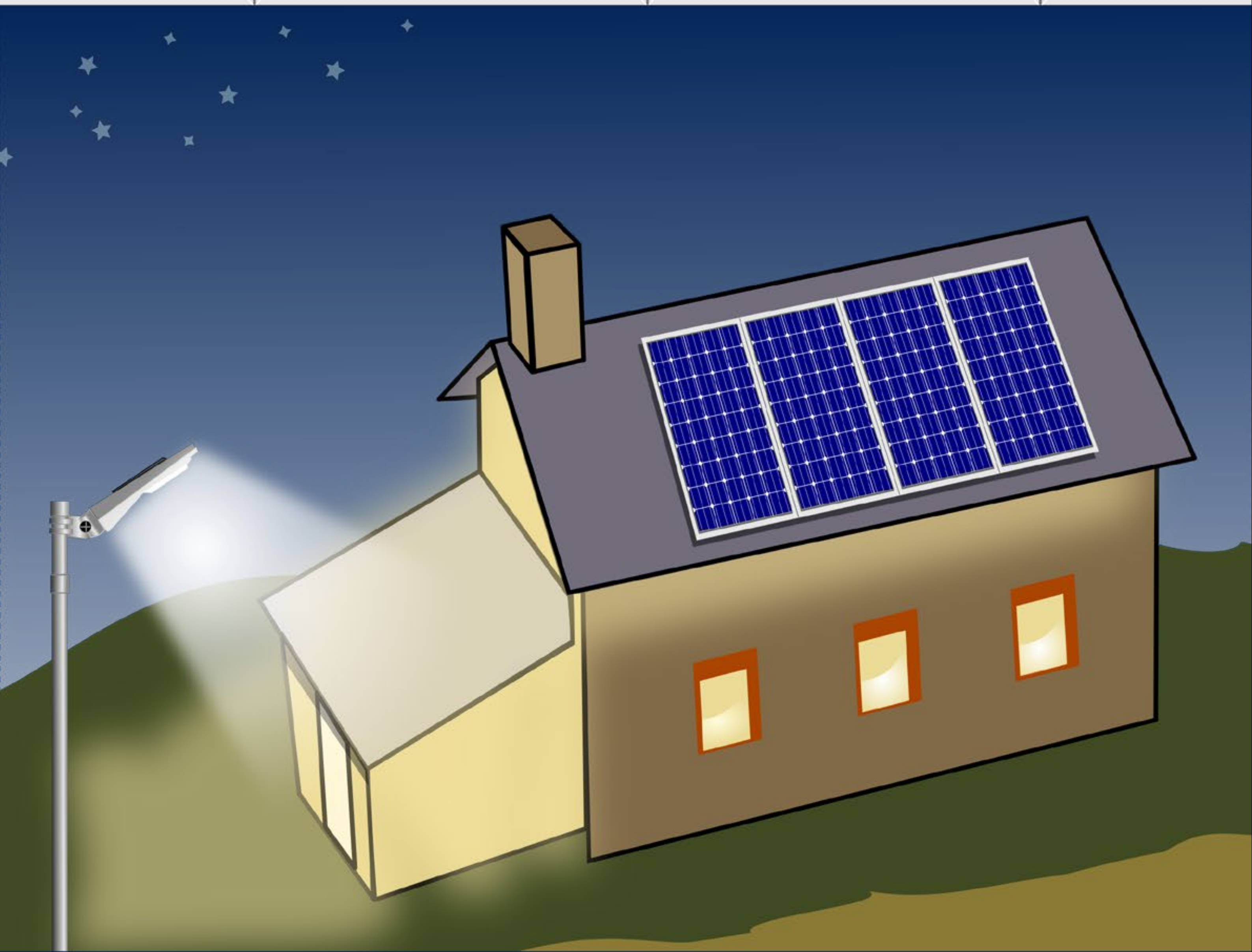
Instantaneous current = 24 Watt / 12 V = 2 amps.

AC discharge = 2 A / 100 Ah = 0.02 or 2% discharge per hour; therefore, even for eight hours of use in conditions of no sunlight, the battery would discharge only 16%, which is an acceptable margin.

STEP 5: CALCULATE THE NECESSARY SIZE/CAPACITY OF THE SOLAR LOAD REGULATOR

Load regulators are usually rated in volts and amperes. Assuming a 12 V system, the example would require a minimum load regulator capacity of 75 Watts/12 V = 6 amps.





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