----- RENEWABLE ENERGY TECHNOLOGIES -----

CHARGE REGULATORS IN GES

Preparation of Training Documents for Installation, Repair and Storage Systems of Solar Energy Systems Supported by Artificial Intelligence and Increasing Energy Efficiency

2023 -2-TR01-KA210-VET-00017445

This individual learning material was written within the scope of the Erasmus+ Project titled 'Preparation of Training Documents for the Installation, Maintenance and Storage Systems of Artificial Intelligence Supported Solar Energy Systems and Increasing Energy Efficiency'.
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It is intended to guide vocational education trainers. It is free for users, cannot be sold. It cannot be duplicated. It will be published as an e-book on the Project Website (https://ai-solarpower.com/)

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EXPLANATIONS

AREA	**Energetics**
BRANCH/PROFESSION	
THE NAME OF THE MODULE	**CHARGE REGULATORS IN GES**
DESCRIPTION OF THE MODULE	The module provides general information about Charge regulators in solar power generation systems and explains the installation, maintenance and repair of these systems.
DURATION	40/32
PRECONDITION	This module does not have any prerequisites.
COMPETENCY	Introduces the basic concepts and facts related to the subject.
PURPOSE OF THE MODULE	**General Purpose** This module on Charge regulators in solar power generation systems aims to provide participants with knowledge and skills in innovative energy solutions. **Objectives** CHARGE REGULATORS IN GES What are inverters? Types of inverters Toward an Inverter-Based Grid Grid Services and Inverters Solar charge controllers Main Types of Solar Charge Controllers

	How to Choose the Right Size of Charge Controller Grid-tied solar inverters Grid-tied solar inverters in the power grid

EDUCATIONAL ENVIRONMENTS AND EQUIPMENT	**Environment:** Renewable energy technologies area, renewable energy systems workshop **Equipment:** Basic electrical knowledge, basic electronic knowledge
MEASUREMENT AND EVALUATION	At the end of the module, the teacher will evaluate the knowledge and skills acquired in the module applications by using an assessment tool (multiple choice test, true/false test, gap filling, matching etc.).

Dear Students,

With the grid-connected energy storage market maturing and commercial projects starting up, companies in different sectors are increasingly interested in the potential of energy storage for their business. But insight into technical, market and financial aspects is essential to realizing that potential.

This module will help you to increase your overall understanding of the technical, market and financial aspects as well as the risks associated with combined solar and energy storage projects.

Moreover, the module is intended for students wishing to acquire a comprehensive overview of grid-connected energy storage and energy storage systems, and to have the latest technology, market conditions and issues clearly explained.

In addition, focusing on charge regulators, the technical information required for the uninterrupted use of solar energy will be presented.

LEARNING ACTIVITY –8

PURPOSE

To understand the operation and selection of charge regulators in grid-connected solar energy systems. This module will provide participants with innovative energy solutions aims to gain knowledge and skills in the subject.

RESEARCH

- Charge regulators in grid energy systems
- PWM and MPPT controllers
- Inverter-based grid
- Solar charge controllers

8. CHARGE REGULATORS IN GES

8.1 Introduction

The current energy market is going through a situation in which demand is increasing and, therefore, the power grid is more likely to experience voltage fluctuations. This fluctuation causes, in time, oscillations in energy sales prices, which has a direct impact on the end consumer.
One of the keys to reduce the possible risks underlying the current infrastructure of the electricity grid lies in the activity of electricity generators. These must guarantee grid stability, which means that, at certain times, more energy must be added to avoid causing an energy deficit. While it is true that renewable energies, due to their dependence on natural resources, are not capable of generating energy in a stable manner, there is a solution: integrating a storage system that stabilizes energy production.

Since solar panels produce different amounts of electricity depending on factors such as weather conditions, the charge controller ensures that excess power doesn't damage the batteries. Without a charge controller, a solar-powered system wouldn't be able to function optimally, and the batteries would quickly degrade. Besides, a charge controller can prevent overcharging, which will prolong the life of your battery and prevent damage to your system.

Solar photovoltaic (PV) generator is one of the most widely used renewable energy for produce electricity in industrial applications, that is essentially due to their; high reliability, relatively low cost, non-polluting, and modest maintenance requirements. So, solar PV systems are an ideal renewable energy source.

Figure 1: A Solar photovoltaic (PV) generator

PV panels can be used either offline or online. In offline applications, PV panels supply local loads which can be residential or commercial. In online applications, these modules not only supply local loads, but also are connected to the utility grid. In the last case, the system would be called "grid-connected PV system".

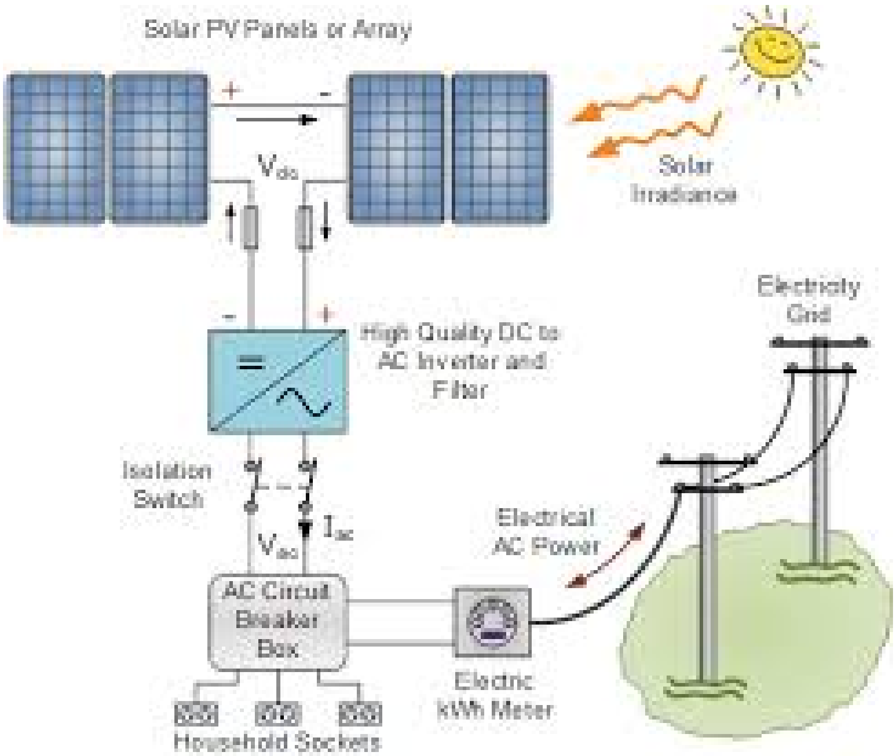

Figure 2: A grid-connected PV system

Power inverters used to ensure the combination of grid with solar sources in which the generated DC power from PV modules converted to AC power provide to electric equipment.

Inverter is therefore very important for grid connected photovoltaic systems. In grid connected solar inverter scheme, closed loops controls are traditionally implemented by fixed gain PID (proportional integral derivative) controllers. Conventional PID control laws provide good results in case of linear systems with constant parameters. Moreover, these control laws are limited in robustness and effectiveness. However, in the control systems, the robustness is of particular importance.

Recently, intelligent control acts are better than conventional controls. Artificial intelligent techniques classed on three big branches: fuzzy logic, neural network and evolutionally algorithms where the more popular used are genetic algorithms and particle swarm optimization. These proceeds have exhibited particular superiorities and used widely in electrical control systems like electrical machines control and the integrations of grid-power sources.

Artificial neural networks (ANNs) present an ideal solution for solving many problems in many applications of electrical systems as control, identification and classification. Many successes in the applications of this technique have been presented in the literature.

There is still a long way to go in this area, but the growing energy demand makes it increasingly necessary to balance the relationship between the power grid, power generation and its corresponding supply and subsequent consumption to meet the needs of power systems and consumers. Storage is the key to making this regulation stable, robust and long-lasting.

8.2 What are inverters?

An inverter is one of the most important pieces of equipment in a solar energy system. It's a device that converts direct current (DC) electricity, which is what a solar panel generates, to alternating current (AC) electricity, which the electrical grid uses. In DC, electricity is maintained at constant voltage in one direction. In AC, electricity flows in both directions in the circuit as the voltage changes from positive to negative. Inverters are just one example of a class of devices called power electronics that regulate the flow of electrical power.

Figure 3: A solar inverter

Fundamentally, an inverter accomplishes the DC-to-AC conversion by switching the direction of a DC input back and forth very rapidly. As a result, a DC input becomes an AC output. In addition, filters and other electronics can be used to produce a voltage that varies as a clean, repeating sine wave that can be injected into the power grid. The sine wave is a shape or pattern the voltage makes over time, and it's the pattern of power that the grid can use without damaging electrical equipment, which is built to operate at certain frequencies and voltages.

The first inverters were created in the 19th century and were mechanical. A spinning motor, for example, would be used to continually change whether the DC source was connected forward or backward. Today we make electrical switches out of transistors, solid-state devices with no moving parts. Transistors are made of semiconductor materials like silicon or gallium arsenide. They control the flow of electricity in response to outside electrical signals.

If you have a household solar system, your inverter probably performs several functions. In addition to converting your solar energy into AC power, it can monitor the system and provide a portal for communication with computer networks. Solar-plus–battery storage systems rely on advanced inverters to operate without any support from the grid in case of outages, if they are designed to do so.

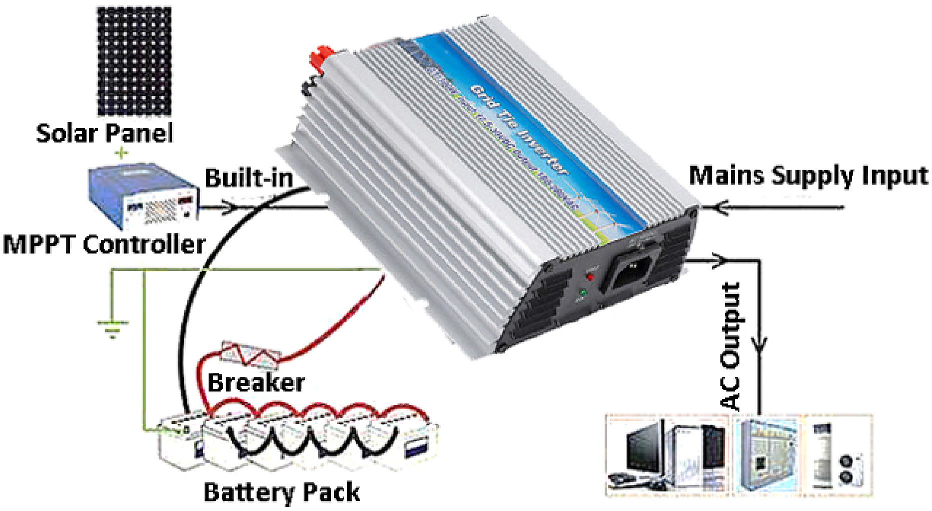

Figure 4: A solar inverter

8.2.1 Types of inverters

There are several types of inverters that might be installed as part of a solar system.

In a large-scale utility plant or mid-scale community solar project, every solar panel might be attached to a single central inverter.

String inverters connect a set of panels—a string—to one inverter. That inverter converts the power produced by the entire string to AC. Although cost-effective, this setup results in reduced power production on the string if any individual panel experiences issues, such as shading. Microinverters are smaller inverters placed on every panel. With a microinverter, shading or damage to one panel will not affect the power that can be drawn from the others, but microinverters can be more expensive.

Both types of inverters might be assisted by a system that controls how the solar system interacts with attached battery storage. Solar can charge the battery directly over DC or after a conversion to AC.

Manufacturer's datasheets for their inverters usually include the following data:

Rated output power: This value is provided in watts or kilowatts. For some inverters, they may provide an output rating for different output voltages. For instance, if the inverter can be configured for either 240 VAC or 208 VAC output, the rated power output may be different for each of those configurations.

Output voltage(s): This value indicates the utility voltages the inverter can connect to. For smaller inverters for residential use, the output voltage is usually 240 VAC. Inverters that target commercial applications are available for 208, 240, 277, 400, 480 or 600 VAC and may also produce three phase power.

Peak efficiency: The peak efficiency represents the highest efficiency that the inverter can achieve. Most grid-tie inverters on the market as of July 2009 have peak efficiencies of over 94%, some as high as 96%. The energy lost during inversion is for the most part converted into heat. Consequently, for an inverter to output its rated power it must have a power input that exceeds its output. For example, a 5000 W inverter operating at full power at 95% efficiency requires an input of 5,263 W (rated power divided by efficiency). Inverters that are capable of producing power at different AC voltages may have different efficiencies associated with each voltage.

Maximum input current: This is the maximum amount of direct current that the inverter can use. If a system, solar cells for example, produces a current in excess of the maximum input current, that current is not used by the inverter.

Maximum output current: The maximum output current is the maximum continuous alternating current that the inverter can supply. This value is typically used to determine the minimum current rating of the over-current protection devices (e.g., breakers and fuses) and disconnects required for the output circuit. Inverters that can produce power at different AC voltages have different maximum outputs for each voltage.

Peak power tracking voltage: This represents the DC voltage range in which the inverter's maximum point power tracker operates. The system designer must configure the strings optimally so that during the majority of the year, the voltage of the strings are within this range. This can be a difficult task since voltage fluctuates with temperature changes.

Start voltage: This value is not listed on all inverter datasheets. The value indicates the minimum DC voltage required for the inverter to turn on and operate. This is especially important for solar applications, because the system designer must be sure that there is a sufficient number of solar modules wired in series in each string to produce this voltage. If this value is not provided by the manufacturer, system designers typically use the lower band of the peak power tracking voltage range as the inverter's minimum voltage.

IPxx rating: The Ingress Protection rating or IP Code classifies and rates the level of protection provided against the ingress of solid foreign objects (first digit) or water (second digit), a higher digit means greater protection. In the US the NEMA enclosure type is used similarly to the international rating. Most inverters are rated for outdoors installation with IP45 (no dust protection) or IP65 (dust tight), or in the US, NEMA 3R (no windblown dust protection) or NEMA 4X (windblown dust, direct water splash and additional corrosion protection).

Certifications/Compliance: Certifications required by electric utilities and local electric codes for grid tie approval such as UL 1741 and emerging standard UL 1741SA[

8.3 Toward an Inverter-Based Grid

Historically, electrical power has been predominantly generated by burning a fuel and creating steam, which then spins a turbine generator, which creates electricity. The motion of these generators produces AC power as the device rotates, which also sets the frequency, or the number of times the sine wave repeats. Power frequency is an important indicator for monitoring the health of the electrical grid. For instance, if there is too much load—too many devices consuming energy—then energy is removed from the grid faster than it can be supplied. As a result, the turbines will slow down and the AC frequency will decrease. Because the turbines are massive spinning objects, they resist changes in the frequency just as all objects resist changes in their motion, a property known as inertia.

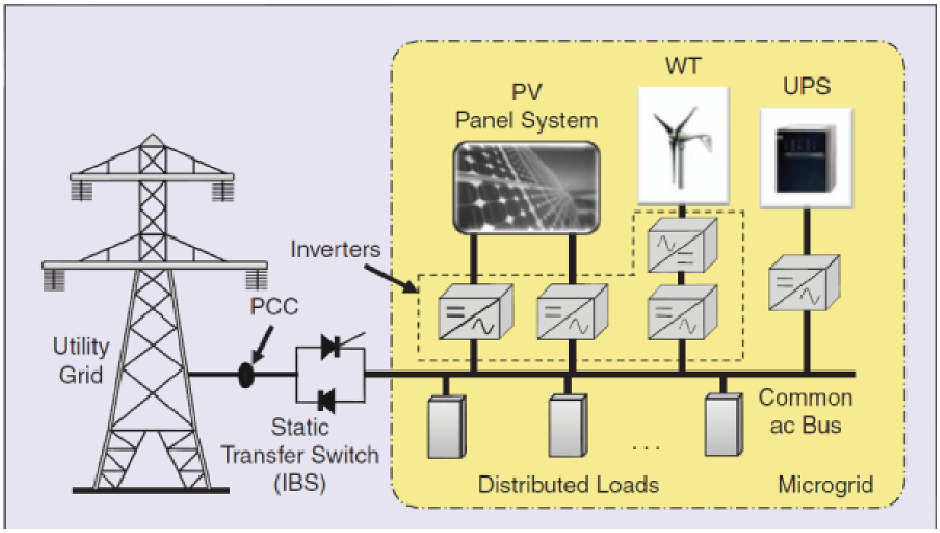

Figure 5: Inverter-Based Grid

As more solar systems are added to the grid, more inverters are being connected to the grid than ever before. Inverter-based generation can produce energy at any frequency and does not have the same inertial properties as steam-based generation, because there is no turbine involved. As a result, transitioning to an electrical grid with more inverters requires building smarter inverters that can respond to changes in frequency and other disruptions that occur during grid operations, and help stabilize the grid against those disruptions.

8.3.1. Grid Services and Inverters

Grid operators manage electricity supply and demand on the electric system by providing a range of grid services. Grid services are activities grid operators perform to maintain system-wide balance and manage electricity transmission better.

When the grid stops behaving as expected, like when there are deviations in voltage or frequency, smart inverters can respond in various ways. In general, the standard for small inverters, such as those attached to a household solar system, is to remain on during or "ride through" small disruptions in voltage or frequency, and if the disruption lasts for a long time or is larger than normal, they will disconnect themselves from the grid and shut down. Frequency response is especially important because a drop in frequency is associated with generation being knocked offline unexpectedly. In response to a change in frequency, inverters are configured to change their power output to restore the standard frequency. Inverter-based resources might also respond to signals from an operator to change their power output as other supply and demand on the electrical system fluctuates, a grid service known as automatic generation control. In order to provide grid services, inverters need to have sources of power that they can control. This could be either generation, such as a solar panel that is currently producing electricity, or storage, like a battery system that can be used to provide power that was previously stored.

Another grid service that some advanced inverters can supply is grid-forming. Grid-forming inverters can start up a grid if it goes down—a process known as black start. Traditional "grid-following" inverters require an outside signal from the electrical grid to determine when the switching will occur in order to produce a sine wave that can be injected into the power grid. In these systems, the power from the grid provides a signal that the inverter tries to match. More advanced grid-forming inverters can generate the signal themselves. For instance, a network of small solar panels might designate one of its inverters to operate in grid-forming mode while the rest follow its lead, like dance partners, forming a stable grid without any turbine-based generation.

Reactive power is one of the most important grid services inverters can provide. On the grid, voltage— the force that pushes electric charge—is always switching back and forth, and so is the current—the movement of the electric charge. Electrical power is maximized when voltage and current are synchronized. However, there may be times when the voltage and current have delays between their two alternating patterns like when a motor is running. If they are out of sync, some of the power flowing through the circuit cannot be absorbed by connected devices, resulting in a loss of efficiency. More total power will be needed to create the same amount of "real" power—the power the loads can absorb. To counteract this, utilities supply reactive power, which brings the voltage and current back in sync and makes the electricity easier to consume. This reactive power is not used itself, but rather makes other power useful. Modern inverters can both provide and absorb reactive power to help grids balance this important resource. In addition, because reactive power is difficult to transport long distances, distributed energy resources like rooftop solar are especially useful sources of reactive power.

8.4 Solar charge controllers

A highly critical component of any solar system, whether it's used for powering a communications tower, road sign or even a caravan, is the solar charge controller.

A solar charge controller is an electronic device used in off-grid and hybrid off-grid applications to regulate current and voltage input from PV arrays to batteries and electrical loads (lights, fans, monitors, surveillance cameras, telecom and process control equipment, etc.). The controller safely charges and maintains batteries at a high state of charge without overcharging. A good solar charge controller can extend battery life, whereas a poor quality charge controller can cause battery failure and which causes the entire off-grid system to shut down. Solar charge controllers are also commonly called solar charge regulators.

Solar charge controllers are therefore an invaluable piece of equipment that help maximize solar output in photovoltaic systems, ensuring effective usage of these forms of renewable energy.

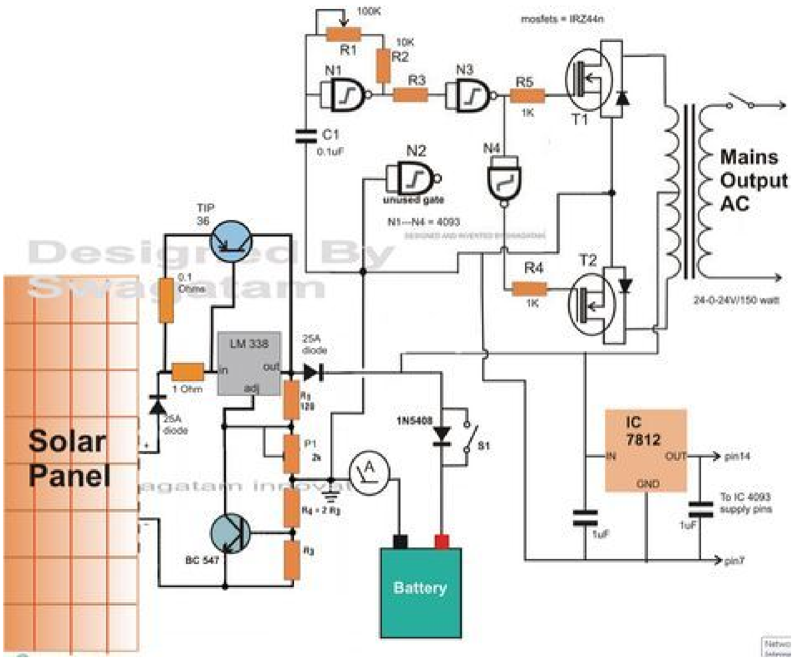

Figure 6: Solar charge controller

Solar charge controllers are used in off-grid systems to maintain batteries at their highest state of charge without overcharging them to avoid gassing and battery damage. This helps to prolong battery life. Charge controllers also deliver proper current and voltage that meets the rated capacity of electrical loads. Without a charge controller connected to the PV array, the array would deliver too much power which would destroy the batteries and loads.

The solar charge controller works by measuring the voltage of the batteries and the solar panels and adjusting the flow of electricity accordingly. When the batteries are fully charged, the controller will reduce the amount of electricity flowing into the batteries to prevent overcharging. On the other hand, if the batteries have a low charge, the controller will increase the flow of electricity to recharge them. Some controllers can also track the weather and adjust the charging parameters based on the amount of sunlight available, ensuring optimal charging efficiency.

Do we always need a charge controller? Not always, but usually. Generally, there is no need for a charge controller with the small maintenance, or trickle charge panels, such as the 1 to 5-watt panels. A rough rule is that if the panel puts out about 2 watts or less for each 50 battery amp-hours, then you don't need one.

For example, a standard flooded golf car battery is around 210 amp-hours. So to keep up a series pair of them (12 volts) just for maintenance or storage, you would want a panel that is around 4.2 watts. The popular 5-watt panels are close enough, and will not need a controller. If you are maintaining AGM deep cycle batteries, such as the Concorde Sun Xtender then you can use a smaller 2 to 2-watt panel.

8.5 Main Types of Solar Charge Controllers

Solar charge controllers typically deploy either pulse width modulation (PWM) or maximum power point tracking (MPPT) technology to regulate and deliver the right amount of current and voltage from PV arrays to run electrical loads and safely charge batteries during the day. Then during the evening when there is no sunshine, the controller allows the battery bank to run the electrical loads. Solar controllers have electronic protections to protect against nighttime reverse current, short circuiting, high voltage, high temperatures, and battery reverse polarity. Additionally some controllers have low voltage disconnect capabilities and are equipped with LED warning lights to alert about installation errors and faults within the system.

PWM is the original method and has been around for many years while MPPT is the newer more efficient method. MPPT has been specifically designed to reduce the efficiency loss in charging batteries from solar panels.

PWM controllers: PWM controllers regulate the voltage from the solar panels to the battery at a fixed rate. They're well-suited for smaller, simpler solar systems and come with a number of useful features, including low cost and low maintenance. However, their functionality is limited to fixed solar panel configurations, and they tend to be less efficient than their MPPT counterparts.
In other words, a PWM controller clamps the solar panel output voltage to match that of the battery until it’s fully charged, then clamping it further to float charge the battery. The output from the controller is maxed at the solar panel’s output current
The controller uses very simple algorithms to determine the correct voltage required for charging the batteries.

PWM solar charge controllers employ rapid output switching to regulate the average output voltage effectively. By adjusting the pulse width (duty cycle), the output voltage or current can be finely tuned, ensuring reliable and efficient control.

During battery charging, the PWM controllers adapt the waveform to meet the specific needs of the battery, enabling optimized charging based on its current state.

Upon reaching full charge, the PWM controllers switch to a trickling state(float charging), providing a consistent, small current flow to maintain the battery at its fully charged state.

However, the voltage and current output of solar panels will constantly vary due to external factors such as light intensity. As a result, when using a PWM solar charge controller, some waste is inevitable.

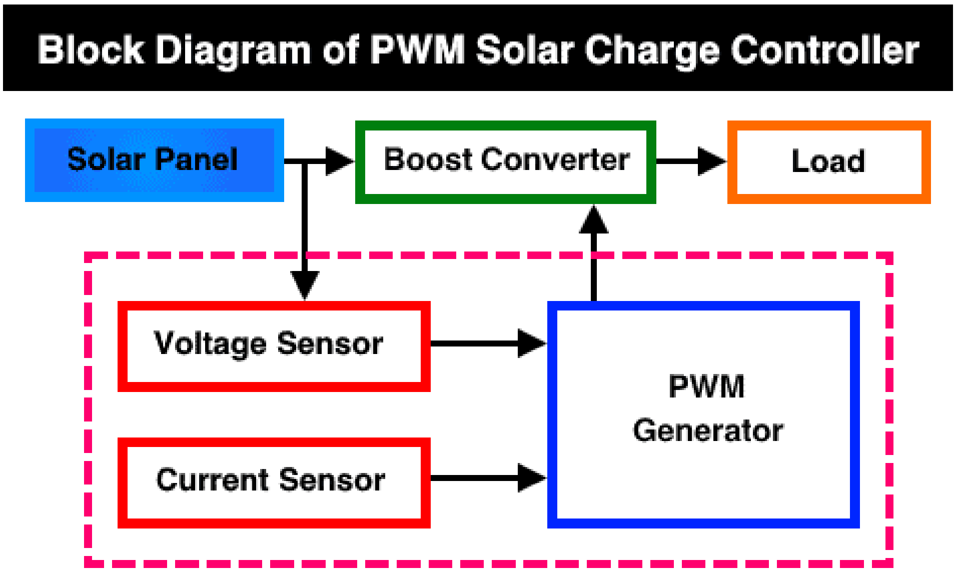

Figure 7: PWM Solar Control

MPPT controllers**:** MPPT controllers are efficient and versatile, better suited for larger and more complex solar systems. They can track the maximum power point of the solar panel, providing up to 30% more power than a PWM controller, and can work with any type of solar panel configuration. However, their increased performance comes at a higher price point compared to PWM controllers. Despite the price, solar charge products with MPPT controllers are more popular on the market.

In a solar photovoltaic system, each photovoltaic module has a working point determined by its connected load. As the irradiance falling on the module changes, the working point also varies throughout the day when the load remains constant.

MPPT solar controllers can detect the voltage and current of the solar panels in real-time and continuously calculate the current power output (P=U*I).
By comparing the current power with previous values, the MPPT solar charge controller can determine whether the current working point is above or below the maximum power point. It then adjusts the output voltage accordingly, bringing the working point closer to the maximum power point, thereby extracting and delivering the maximum available power from the photovoltaic array to the load.

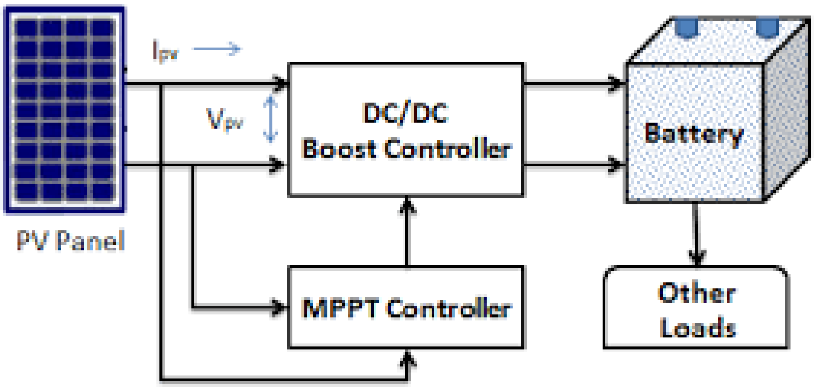

Figure 8: Block diagram of a MPPT controller

Using this maximum power point ensures that the panel is producing at its peak and the full wattage produced by the solar panel is being converted to charge for the batteries.
MPPT controllers have a greater input voltage range, allowing greater voltages in the cables from the panels to the solar charge controller. This again increases the efficiency of the system by reducing voltage loss in the cabling.
All power generated by the solar panels is converted into charge for the batteries.

The first solar charge controller schematic below illustrates how a solar charge controller is connected to power a direct current (DC) load, and the second one pertains to an alternating current (AC) load.

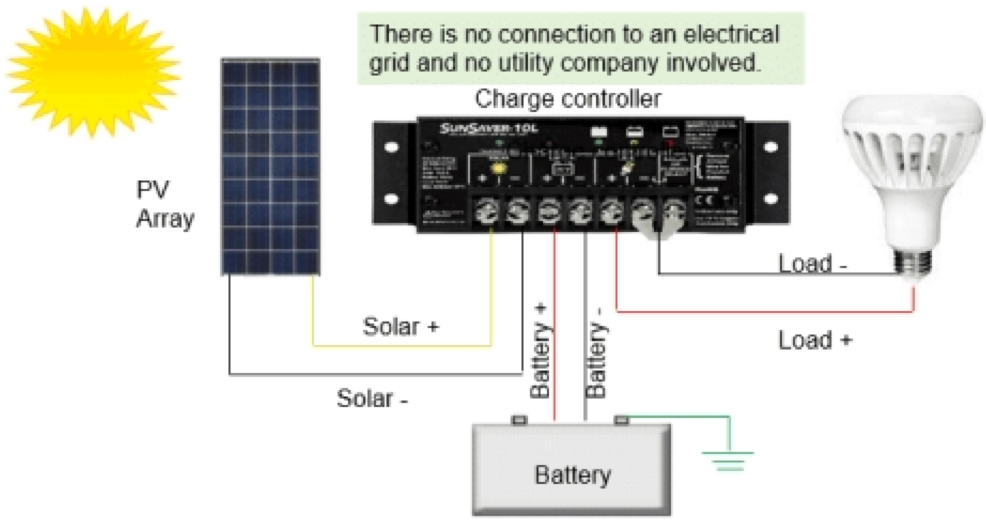

Figure 9: Off-grid Diagram with DC Load

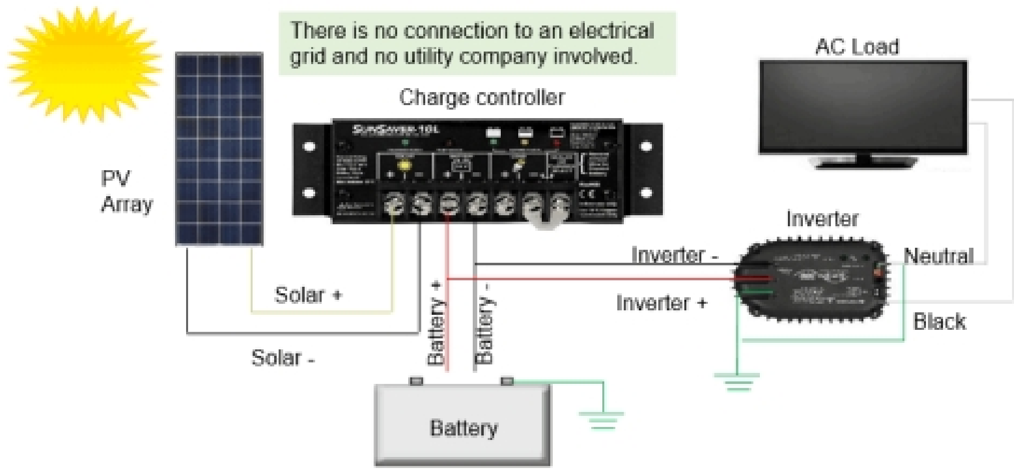

Figure 10: Off-grid Diagram with AC Load

It's important to note that the inverter is connected and powered from the battery, not the controller's load terminals like we did in the DC load example. That's because the inverter can have a high energy surge upon startup, and this high current surge might be higher than the rated capacity of the charge controller, whereas the batteries will be able to meet the high energy surge requirement.

Based on the different working principles of these two controllers, it is easy to identify the key difference between them:

Compared to PWM controllers, MPPT controllers have a significantly higher input voltage rating than the battery banks they charge. This is because MPPT controllers possess the unique ability to step down the voltage to match the battery bank's voltage and then boost the current to compensate for any power loss.

The different working principles of PWM controllers and MPPT controllers lead to specific areas of application for each type. In the following situations, a PWM solar controller would be a better choice:

- Small solar energy systems, such as installing lead-acid batteries in a camper, where the solar panel voltage closely matches the battery voltage.
- When charging efficiency is not a primary concern, such as maintaining the charge of marine batteries.
- Cost-saving installations, as PWM controllers are generally more budget-friendly.

On the other hand, MPPT solar controllers are better suited for the following scenarios:

- Regions with variable weather or harsh environments, as they can adapt to changing solar panel output and optimize energy capture throughout the day.

PWM SOLAR CHARGE CONTROLLERS	**MPPT SOLAR CHARGE CONTROLLERS**
PROS	
• Durable, mostly available with passive heat sink style cooling • A tried and tested solar controller which has been used for years • Relatively inexpensive, depending on the voltage and current required • Available in a range of voltage ranges like 12, 24 and 48V with the current range of 5- 60A • Simple to install, operate and maintain • Comes standard with Low Voltage Disconnects	• Can increase charging efficiency by up to 30% • Can be used on solar systems with a higher input voltage than the battery bank • Available up to 80A • Generally has a longer warranty than a PWM controller • Greater flexibility allows for solar system expansion

	• Input voltage is not restricted by the battery or system voltage • Most come standard with reporting and alarm functions
CONS	
• To use a PWM controller on the solar system, the solar input nominal voltage must match the battery bank nominal voltage • PWM is not available over 60A • System growth is often limited • Cannot be used on high voltage grid connect solar systems • Greater efficiency loss when batteries are at a low voltage	• More expensive than a PWM controller • Generally larger in physical size • Manufacturer guides are essential to correctly sizing an appropriate solar system • Not all come MPPT controllers come standard with Low Voltage Disconnect Units • Greater complexity with more expertise required by the installer to install and commission the controller

- Solar photovoltaic arrays with a higher voltage than the battery bank, ensuring safe charging and discharging.
- When aiming to maximize energy efficiency and output for cost-effectiveness, such as in commercial and industrial projects or residential solar setups with battery storage. MPPT controllers have a higher conversion rate for solar panels compared to PWM controllers and can absorb at least 30% more electricity.

In situations where there are two or more solar panel arrays, and the photovoltaic output power exceeds the capacity of a single charge controller, using two or more charge controllers with one battery bank can provide a practical solution. This approach is especially effective with MPPT charge controllers since different arrays may have diverse maximum power points, allowing for optimal power output.

However, it is essential to connect the charge controllers in parallel to ensure uniform voltage and current distribution across all batteries. This balancing of voltage and resistance within the battery bank helps avoid overcharging and potential battery damage.

To maintain system compatibility and safety, ensure that the combined capacity of the charge controllers does not surpass the maximum charging capacity of the battery bank. For a smoother integration, it is advisable to use the same type of solar charge controllers when employing multiple units.

What happens with an oversized solar charge controller?

Using an oversized solar charge controller can have both advantages and disadvantages. On the positive side, an oversized controller allows more current flow, which may be beneficial if you plan to expand your solar array in the future. It can also lead to reduced voltage drop and improved system efficiency.

However, the downsides include higher costs and potential inefficiency at lower solar panel capacities. Additionally, an oversized controller might not operate at its optimal efficiency level, resulting in wasted energy. Therefore, it is essential to carefully consider your system's requirements and balance the pros and cons before choosing a solar charge controller.

8.6 Why 12 Volt Panels are 17 Volts?

The obvious question then comes up - "why aren't panels just made to put out 12 volts". The reason is that if you do that, the panels will provide power only when cool, under perfect conditions, and full sun. This is not something you can count on in most places. The panels need to provide some extra voltage so that when the sun is low in the sky, or you have heavy haze, cloud cover, or high temperatures, you still get some output from the panel. A fully charged "12-volt" battery is around 12.7 volts at rest (around 13.6 to 14.4 under charge), so the panel has to put out at least that much under worst-case conditions.

Contrary to intuition, solar panels work best at cooler temperatures. Roughly, a panel rated at 100 watts at room temperature will be an 83 watt panel at 110 degrees.

The charge controller regulates this 16 to 20 volts output of the panel down to what the battery needs at the time. This voltage will vary from about 10.5 to

14.6, depending on the state of charge of the battery, the type of battery, in what mode the controller is in, and temperature. (see complete info on battery voltages in our battery section).

Using High Voltage (grid tie) Panels With Batteries

Nearly all PV panels rated over 140 watts are NOT standard 12-volt panels, and cannot (or at least should not) be used with standard charge controllers. Voltages on grid tie panels vary quite a bit, usually from 21 to 60 volts or so. Some are standard 24-volt panels, but most are not.

What happens when you use a standard controller

Standard (that is, all but the MPPT types), will often work with high voltage panels if the maximum input voltage of the charge controller is not exceeded. However, you will lose a lot of power - from 20 to 60% of what your panel is rated at. Charge controls take the output of the panels and feed current to the battery until the battery is fully charged, usually around 13.6 to 14.4 volts. A panel can only put out so many amps, so while the voltage is reduced from say, 33 volts to 13.6 volts, the amps from the panel cannot go higher than the rated amps - so with a 175 watt panel rated at 23 volts/7.6 amps, you will only get 7.6 amps @ 12 volts or so into the battery. Ohms Law tells us that watts are volts x amps, so your 175-watt panel will only put about 90 watts into the battery.

Using an MPPT controller with high voltage panels

The only way to get full power out of high voltage grid tie solar panels is to use an MPPT controller. See the link above for detailed information on MPPT charge controls. Since most MPPT controls can take up to 150 volts DC (some can go higher, up to 600 VDC) on the solar panel input side, you can often series two or more of the high voltage panels to reduce wire loss or to use smaller wire. For example, with the 175-watt panel mentioned above, 2 of them in series would give you 46 volts at 7.6 amps into the MPPT controller, but the controller would convert that down to about 29 amps at 12 volts.

8.7 How to Choose the Right Size of Charge Controller

Solar charge controllers are available in different sizes suitable for solar arrays with varying voltages and currents. Choosing the incorrect size can lead to both power loss and inefficiency. Thus, it's crucial to choose the right size for your solar array, as this will help ensure optimal performance.

When choosing a solar controller, there are four key points to consider:

- Compatible battery type(s) and battery voltage.
- Maximum input power of the solar panels.
- Maximum input voltage of the solar panels.

- Maximum charging current of the battery.

Firstly, you need to check the voltage rating of the charge controller. Typically, PWM controllers are designed to operate with either 12 or 24 volts, whereas MPPT controllers can handle systems with 12, 24, 36, and 48 volts.
And most charge controllers have an amperage rating. PWM controllers with smaller capacities may be rated at 10, 20, or 30 amps. While MPPT controllers for larger solar arrays, are often rated at higher amperage - typically 80 to 100 amps.
Then, to calculate the potential amperage output of a solar array, we need to take a simple calculation according to this formula: Amps = Watts / Volts.
Suppose we have a solar array which provides 800 watts of power while operating at 12 volts. In this case, we could readily calculate the amps output by such an array through the formula: Amps = 800 watts / 12 volts = 66.67 amps.
Thus, this solar array can produce up to 66.67 amps. Accordingly, it's recommended to use a charge controller rated at 70 amps to avoid overloading and possible malfunction.

8.8 Other Things You Need to Know About Solar Charge Controllers

Apart from the above-mentioned information, there are a few other important things you need to know about solar charge controllers if you're planning to use one.

Displays and Metering

The display provides real-time information about the charging process, the battery voltage, and other crucial parameters. And these information are important in effectively monitoring and managing your solar system. Metering, on the other hand, measures the amount of energy coming into the solar system from the solar panels. This information enables you to calculate important metrics, such as the system's efficiency and energy consumption.

Control Set Points vs. Temperature

The temperature plays a critical role in battery charging. The charging process is more effective in warm temperatures, where batteries can efficiently conduct energy. On the other hand, low temperatures hinder the battery's ability to distribute energy, resulting in slower charging speeds.

Therefore, most charge controllers have control set points for room temperatures. And to regulate the voltage for various temperatures, most charge controllers feature temperature compensation. What’s more, some charge controllers even support custom control set points based on temperatures.

Equalization

Equalization does somewhat what the name implies - it attempts to equalize - or make all cells in the battery or battery bank of exactly equal charge. Essentially it is a period of overcharge, usually in the 15 to 15.5 volt range. If you have some cells in the string lower than others, it will bring them all up to full capacity. In flooded batteries, it also serves the important function of stirring up the liquid in the batteries by causing gas bubbles. Of course, in an RV or boat, this does not usually do much for you unless you have been parked for months, as normal movement will accomplish the same thing. Also, in systems with small panels or oversized battery systems you may not get enough current to really do much bubbling. In many off-grid systems, batteries can also be equalized with a generator charger.

PWM

Quite a few charge controls have a "PWM" mode. PWM stands for Pulse Width Modulation. PWM is often used as one method of float charging. Instead of a steady output from the controller, it sends out a series of short charging pulses to the battery - a very rapid "on-off" switch. The controller constantly checks the state of the battery to determine how fast to send pulses, and how long (wide) the pulses will be. In a fully charged battery with no load, it may just "tick" every few seconds and send a short pulse to the battery. In a discharged battery, the pulses would be very long and almost continuous, or the controller may go into "full on" mode. The controller checks the state of charge on the battery between pulses and adjusts itself each time.

The downside to PWM is that it can also create interference in radios and TV's due to the sharp pulses that it generates. If you are having noise problems from your controller, see this page.

Load, or "Low Voltage Disconnect" output

Some controllers also have a "LOAD", or LVD output, which can be used for smaller loads, such as small appliances and lights. The advantage is that the load terminals have a low voltage disconnect, so it will turn off whatever is connected to the load terminals and keep from running the battery down too far. The LOAD output is often used for small non-critical loads, such as lights. A few, such as the Schneider Electric C12, can also be used as a lighting controller, to turn lights on at dark, but the Morningstar SLC lighting controller is usually a better choice for that. Do not use the LOAD output to run any but very small inverters. Inverters can have very high surge currents and may blow the controller.

Most systems do not need the LVD function - it can drive only smaller loads. Depending on the rating of the controller, this may be from 6 to 60 amps. You cannot run any but the smallest inverter from the LOAD output. On some controllers, such as the Morningstar SS series, the load output can be used to drive a heavy duty relay for load control, gen start etc. The LOAD or LVD output is most often used in RV & remote systems, such as camera, monitor, and cell phone sites where the load is small and the site is unattended.

"Sense" terminals

Some charge controllers have a pair of "sense" terminals. Sense terminals carry very low current, around 1/10th of a milliamp at most, so there is no voltage drop. What it does is "look" at the battery voltage and compares it to what the controller is putting out. If there is a voltage drop between the charge controller and the battery, it will raise the controller output slightly to compensate.

These are only used when you have a long wire run between the controller and the battery. These wires carry no current, and can be pretty small - #20 to #16 AWG. We prefer to use #16 because it is not easily cut or squished accidentally. They attach to the SENSE terminals on the controller, and onto the same terminals as the two charging wires at the battery end.

"Battery System Monitor”

Battery system monitors, are not controllers. Instead, they monitor your battery system and give you a pretty good idea of your battery condition, and what you are using and generating. They keep track of the total amp-hours into and out of the batteries, and the battery state of charge, and other information. They can be very useful for medium to large systems for tracking exactly what your system is doing with various charging sources. They are somewhat overkill for small systems, but are kind of a fun toy if you want to see what every amp is doing.

8.9 Grid-tied solar inverters

As the demand for renewable energy continues to grow, more and more homeowners are turning to solar power to reduce their reliance on traditional fossil fuels. Solar energy is clean, sustainable, and affordable, and can help homeowners save money on their energy bills while reducing their carbon footprint. One of the key components of any solar energy system is the grid-tied solar inverter. In this blog, we will explore the benefits of grid-tied solar inverters for homeowners.

A grid-tied solar inverter is a device that converts the direct current (DC) produced by solar panels into alternating current (AC) that can be used to power homes and businesses. The inverter is connected to the power grid, which allows homeowners to sell excess energy back to the grid when their solar panels produce more electricity than they need. This process, known as net metering, allows homeowners to earn credits on their energy bills and reduce their overall energy costs.

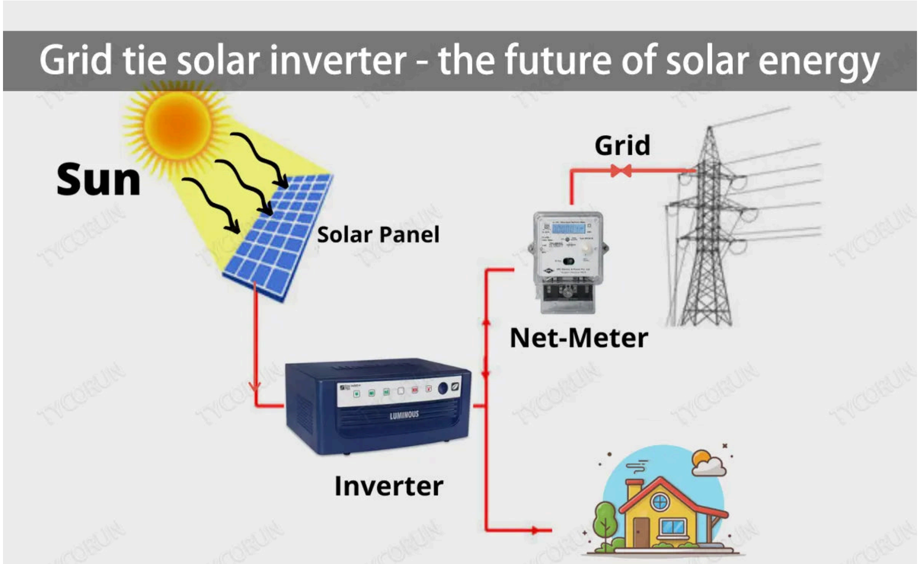

Figure 11: Solar Inverter

Benefits of Grid-Tied Solar Inverters

- *Lower Energy Bills*: One of the primary benefits of a grid-tied solar inverter is that it can help homeowners save money on their energy bills. By generating their own electricity and selling excess energy back to the grid, homeowners can offset the cost of their energy consumption and reduce their overall energy costs.
- *Increased Energy Independence*: With a grid-tied solar inverter, homeowners can generate their own electricity and become less reliant on traditional fossil fuels. This can provide a sense of energy independence and help homeowners reduce their carbon footprint.
- *Minimal Maintenance*: Grid-tied solar inverters require very little maintenance, as they do not have any moving parts. This can save homeowners time and money in the long run.
- *Environmental Benefits*: By generating electricity from a renewable source like solar power, homeowners can significantly reduce their carbon footprint and help mitigate the impacts of climate change. This can help protect the environment for future generations.
- *Increased Property Value*: Homes with solar energy systems, including grid-tied solar inverters, tend to sell for more money than homes without them. This can provide a significant return on investment for homeowners who choose to install solar energy systems.

In conclusion, grid-tied solar inverters offer a variety of benefits for homeowners. From lower energy bills to increased energy independence and environmental benefits, grid-tied solar inverters can help homeowners save money, reduce their carbon footprint, and increase the value of their property. As the demand for renewable energy continues to grow, grid-tied solar inverters are becoming an increasingly popular choice for homeowners who want to make the switch to solar power.

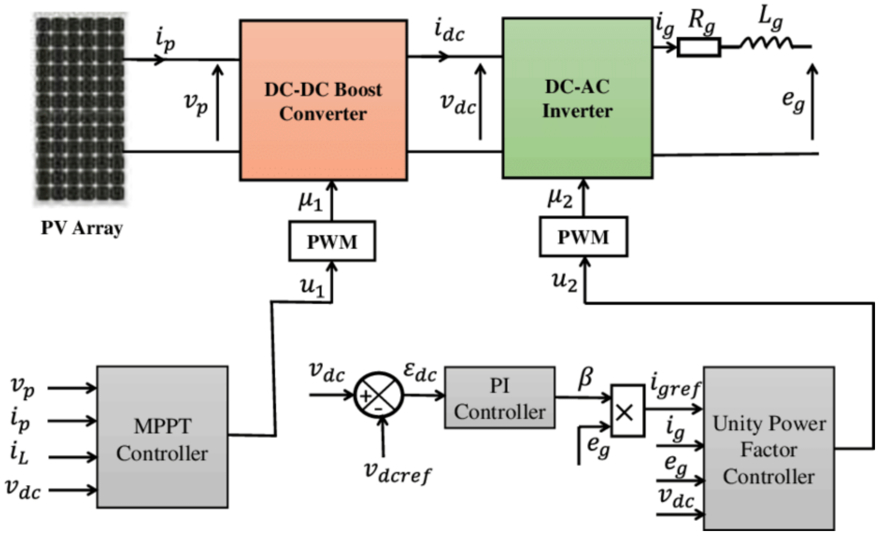

Figure 12: Control scheme of the grid-connected PV system.

8.10 Grid-tied solar inverters in the power grid

Grid-tied solar inverters are also important for ensuring the stability and reliability of the power grid. Unlike off-grid solar systems, which are not connected to the power grid and rely on energy storage to supply power during times when solar energy is not available, grid-tied solar systems are connected to the power grid and can draw energy from it when needed. This means that during times of low solar energy generation, homes and businesses can still access the power they need from the grid.

Moreover, grid-tied solar inverters play a critical role in balancing the supply and demand of electricity on the power grid. When solar energy production is high, excess energy can be sent back to the grid, which can then be used to meet the energy demands of other customers. Conversely, when solar energy production is low, homes and businesses can draw energy from the grid to meet their own energy needs. This helps to ensure that there is a consistent supply of electricity on the grid and reduces the need for expensive and polluting fossil fuel power plants to meet energy demands.

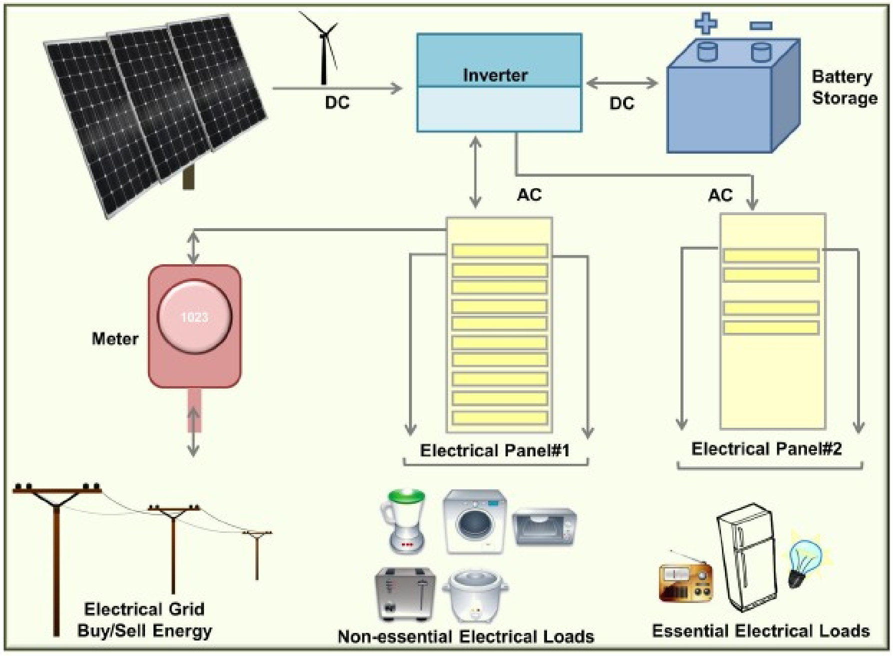

Figure 13: Grid tied solar inverter

Another advantage of grid-tied solar inverters is their ability to improve the efficiency of solar energy systems. Solar panels generate DC electricity, which is not compatible with most household appliances and devices, which run on AC electricity. Without a grid-tied solar inverter, homes and businesses would need to use batteries to store DC electricity and convert it to AC when needed. However, this process is inefficient and can result in energy losses. By using a grid-tied solar inverter, homes and businesses can convert DC electricity to AC in real-time, reducing energy losses and improving the overall efficiency of the solar energy system.

As more and more homes and businesses turn to solar energy, the role of grid-tied solar inverters in the transition to renewable energy becomes increasingly important. By enabling solar energy to be efficiently integrated into existing power grids, grid-tied solar inverters can help to reduce greenhouse gas emissions and promote the transition to a cleaner, more sustainable energy future.

Grid-tied solar inverters are a crucial component of the shift towards renewable energy. By converting DC to AC and enabling excess energy to be sent back to the power grid, grid-tied solar inverters make solar energy more accessible, stable, and reliable. Additionally, they improve the efficiency of solar energy systems and help to balance the supply and demand of electricity on the power grid, reducing the need for polluting fossil fuel power plants. As renewable energy sources like solar power continue to grow in popularity, it is essential that we have the infrastructure in place to support their integration into existing power grids. Grid-tied solar inverters play a critical role in this infrastructure and are an important tool in the transition to a cleaner, more sustainable energy future.

However, it is important to note that grid-tied solar inverters are not without their limitations. One of the biggest challenges associated with grid-tied solar inverters is their reliance on the power grid. During power outages or grid failures, homes and businesses with grid-tied solar systems may be unable to access the electricity they need, even if they have solar panels and a functioning grid-tied solar inverter. This limitation underscores the importance of backup power solutions, such as battery storage or diesel generators, to ensure that homes and businesses can still access electricity during emergencies.

In addition, the use of grid-tied solar inverters raises important regulatory and policy questions. Many utility companies have been resistant to the growth of solar energy and net metering, which they argue can undermine their revenue streams and the stability of the power grid. Some utilities have proposed fees or other restrictions on the use of grid-tied solar systems, which could limit their ability to contribute to the renewable energy supply. These debates underscore the need for thoughtful and proactive policies that can support the growth of renewable energy while ensuring that the power grid remains stable and reliable.

8.11 Conclusion

Overall, the importance of grid-tied solar inverters in the transition to renewable energy cannot be overstated. By enabling homes and businesses to generate their own electricity and send excess energy back to the power grid, grid-tied solar inverters make solar energy more accessible and help to balance the supply and demand of electricity on the grid. They also improve the efficiency of solar energy systems and reduce the need for polluting fossil fuel power plants. As we continue to grapple with the challenges of climate change, it is essential that we invest in the infrastructure needed to support the growth of renewable energy sources like solar power. Grid-tied solar inverters are a critical component of this infrastructure and are helping to pave the way towards a cleaner, more sustainable energy future.

MEASUREMENT AND EVALUATION 8

Read the questions carefully and choose the correct answer.

1. The following is not one of the categories of inverters.

A) PMW
B) TRF
C) PWM
D) MPPT

2. Which of the following is not one of the basic features of an inverter?

A) Rated output power
B) Peak efficiency
C) Start voltage
D) Computing power

3. Which are the main benefits of Grid-Tied Solar Inverters?

A) Lower Energy Bills
B) Lower Energy Independence
C) No Maintenance
D) Neglectable Environmental Benefits

4. Which of the following sentences is not true for Grid-tied solar inverters in the power grid?

A) They are important for ensuring the stability and reliability of the power grid
B) They play a critical role in balancing the supply and demand of electricity on the power grid

C) One of their biggest challenges is their reliance on the power grid
D) During power outages or grid failures, homes and businesses with grid-tied solar systems can always access the electricity they need

5. Which point is not important when choosing a solar controller?

A) Compatible battery type(s) and battery voltage
B) Maximum input power of the solar panels
C) Weight of the battery
D) Maximum charging current of the battery

MODULE EVALUATION

Write the appropriate words in the empty spaces in the sentences below.

1. ………………………, provides real-time information about the charging process.

2. ……………………, manage electricity supply and demand on the electric system by providing a range of grid services.

3. …………………….., generate DC electricity, which is not compatible with most household appliances and devices, which run on AC electricity.

4. …………………….., is often used as one method of float charging.

5. ………………………, attempts to equalize - or make all cells in the battery or battery bank of exactly equal charge.

6. …………………………, have a significantly higher input voltage rating than the battery banks they charge.

7. …………………………….., regulate the voltage from the solar panels to the battery at a fixed rate.

Write the letters 'T' if true and 'F' if false opposite the information given below.

1.( ) It is essential to connect the charge controllers in parallel to ensure uniform voltage and current distribution across all batteries.

2.( ) The output voltage value indicates the utility voltages the inverter can connect to.

3.( ) Homes with solar energy systems, including grid-tied solar inverters, tend to sell for less money than homes without them.

4.( ) Inverter-based generation can produce energy at a fixed frequency.

5.( ) Peak power tracking voltage represents the AC voltage range in which the inverter's maximum point power tracker operates.

1. How to Choose the Right Size of Charge Controller?

2. Which are the main types of Solar Charge Controllers?

EVALUATION

Please compare your answers with the answer key. If you have incorrect answers, you need to revise the Learning Activity. If you answer all the questions correctly, please contact your teacher and move on to the next learning activity.

ANSWER KEYS

Measurement and Evaluation-1:

1	B
2	D
3	A
4	D
5	C

Module EVALUATION:

Gap Filling:

1	THE DISPLAY
2	GRID OPERATORS
3	SOLAR PANELS
4	PWM
5	EQUALIZATION
6	MPPT CONTROLLERS
7	PWM CONTROLLERS

True(T) - False(F)

1	T
2	T
3	F
4	F
5	F

1. **What can be done to increase energy efficiency in artificial intelligence applications in solar tracking systems?**
   Solar charge controllers are available in different sizes suitable for solar arrays with varying voltages and currents. Choosing the incorrect size can lead to both power loss and inefficiency. Thus, it's crucial to choose the right size for your solar array, as this will help ensure optimal performance.
   When choosing a solar controller, there are four key points to consider:
   - Compatible battery type(s) and battery voltage.
   - Maximum input power of the solar panels.
   - Maximum input voltage of the solar panels.
   - Maximum charging current of the battery.

2. **What are the advantages of artificial intelligence in solar tracking systems?**
   Solar charge controllers typically deploy either pulse width modulation (PWM) or maximum power point tracking (MPPT) technology to regulate and deliver the right amount of current and voltage from PV arrays to run electrical loads and safely charge batteries during the day. Then during the evening when there is no sunshine, the controller allows the battery bank to run the electrical loads.
   FAQ
   Is a Solar Charge Controller Always Necessary?
   For off-grid solar installations with batteries, a solar charge controller is always necessary. The only exception is when using very small 1 or 5-watt trickle chargers. Conversely, grid-tied residential systems do not require a charge controller as the utility grid governs the electricity flow and manages the spare power.
   Do 100-Watt Solar Panels Require Charge Controller?
   If a 100-Watt solar panel is used to power a battery, a solar charge controller is necessary. Some small solar systems include only a single 100-watt panel and a battery. These systems need solar charge controllers to regulate the current entering the battery.
   Are Charge Controllers Needed for 7-Watt Solar Panels?
   You don't need a charge controller for a 7-watt solar panel. These panels are specifically designed for low-voltage trickle charging, which means you don't have to worry about regulating the electrical flow.

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These references provide information on the applications of different methods and algorithms to improve the effectiveness of solar regulators.