Design, Implementation and Testing of a Solid State Charge Controller for SPV Systems

A Project report submitted in partial fulfilment

of the requirements for the degree of B. Tech in Electrical Engineering

Bachelor of Technology

In

ELETRICAL ENGINEERING

By

1. **PRATIM SEN (EE2017/012)**
   University Roll: 11701617051
2. **ABHIRUP CHATTERJEE (EE2017/030)**
   University Roll: 11701617078
3. **USHNISH KANTI CHAKRABORTY (EE2017/032)**
   University Roll: 11701617020
4. **KRISHNA PRASAD SAMANTA (EE2016/058)**
   University Roll: 11701616054
5. **SREEPARNO MAJUMDER (EE2015/059)**
   University Roll: 11701615054

Under the supervision of

Asst professor – Dr. Ashoke Mondal

Department of Electrical Engineering

Department of Electrical Engineering

RCC INSTITUTE OF INFORMATION TECHNOLOGY

CANAL SOUTH ROAD, BELIAGHATA, KOLKATA – 700015, WEST BENGAL

Maulana Abul Kalam Azad University of Technology (MAKAUT)

2022

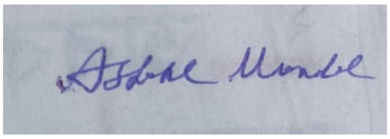
CERTIFICATE

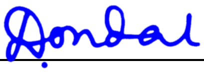
To whom it may concern

1. This is to certify that the project work entitled (**Design, Implementation and Testing of a Solid State Charge Controller for SPV Systems)** is the bona fide work carried out by

(PRATIM SEN (EE2017/012)
University Roll: 11701617051
ABHIRUP CHATTERJEE (EE2017/030)
University Roll: 11701617078
USHNISH KANTI CHAKRABORTY (EE2017/032)
University Roll: 11701617020
KRISHNA PRASAD SAMANTA (EE2016/058)
University Roll: 11701616054
SREEPARNO MAJUMDER (EE2015/059)
University Roll: 11701615054

students of B.Tech in the Dept. of Electrical Engineering, RCC Institute of Information Technology (RCCIIT), Canal South Road, Beliaghata, Kolkata-700015, affiliated to Maulana Abul Kalam Azad University of Technology (MAKAUT), West Bengal, India, during the academic year 2021-22, in partial fulfillment of the requirements for the degree of Bachelor of Technology in Electrical Engineering and this project has not submitted previously for the award of any other degree, diploma and fellowship.





Signature of the Guide

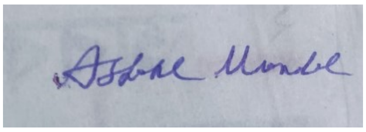
Name: Ashoke Mondal

Designation: Prof. & HOD , ECE , RCCIIT

Signature of the HOD, EE

Name: D. Mondal

Designation Professor



Signature of the External Examiner

Name: Ashoke Mondal

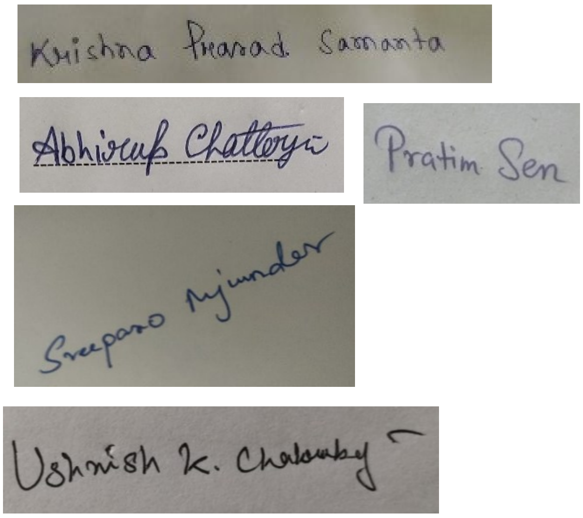
Designation: Prof. & HOD , ECE , RCCIIT

ACKNOWLEDGEMENT

It is my great fortune that I have got opportunity to carry out this project work under the supervision of **(Dr. Ashoke Mondal)** in the Department of Electrical Engineering, RCC Institute of Information Technology (RCCIIT), Canal South Road, Beliaghata, Kolkata-700015, affiliated to Maulana Abul Kalam Azad University of Technology (MAKAUT), West Bengal, India. I express my sincere thanks and deepest sense of gratitude to my guide for his constant support, unparalleled guidance and limitless encouragement.

I wish to convey my gratitude to Prof. (Dr.) Debasish Mondal, HOD, Department of Electrical Engineering, RCCIIT and to the authority of RCCIIT for providing all kinds of infrastructural facility towards the research work.

I would also like to convey my gratitude to all the faculty members and staffs of the Department of Electrical Engineering, RCCIIT for their whole hearted cooperation to make this work turn into real



Signature of the Students

Place:

Date: 15/06/2022

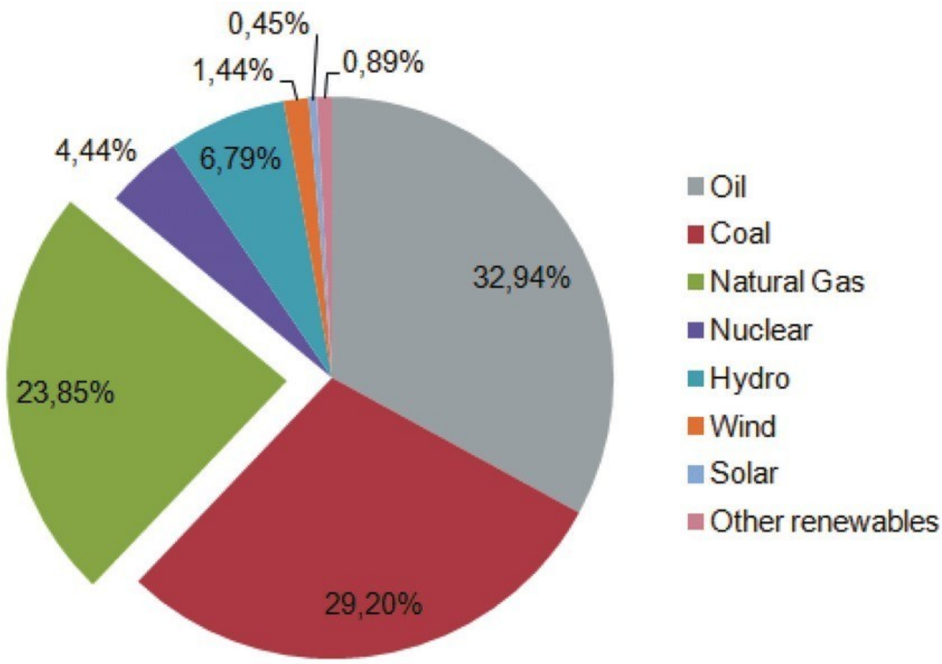
Table of Contents:

Introduction

Solar cell is a key device that converts the light energy into the electrical energy in photovoltaic energy conversion. In most cases, semiconductor is used for solar cell material. The energy conversion consists of absorption of light (photon) energy producing electron–hole pairs in a semiconductor and charge carrier separation. A p–n junction is used for charge carrier separation in most cases. It is important to learn the basic properties of semiconductor and the principle of conventional p–n junction solar cell to understand not only the conventional solar cell but also the new type of solar cell. The comprehension of the p–n junction solar cell will give you hints to improve solar cells regarding efficiency, manufacturing cost, consuming energy for the fabrication, etc. This chapter begins with the basic semiconductor physics, which is necessary to understand the operation of p–n junction solar cell, and then describes the basic principles of p–n junction solar cell. It ends with the concepts of solar cell using nanocrystalline materials. Because the solar cells based on nanocrystalline materials are complicated compared with the conventional p–n junction solar cell, the fundamental phenomena are reviewed.

Energy:

Energy is the ability of a physical system to perform work. We use energy in our daily livesfrom various sources for doing work. We use muscular energy for carrying out physical work, electrical energy for running multiple appliances, chemical energy for cooking food, etc. For this, we need to know the different energy sources to obtain energy in its usable form. This article will familiarize you with two important sources of energy: conventional energy and non-conventional energy.



Global Usage of Non-conventional Resources

Disadvantages of Conventional Energy Sources:

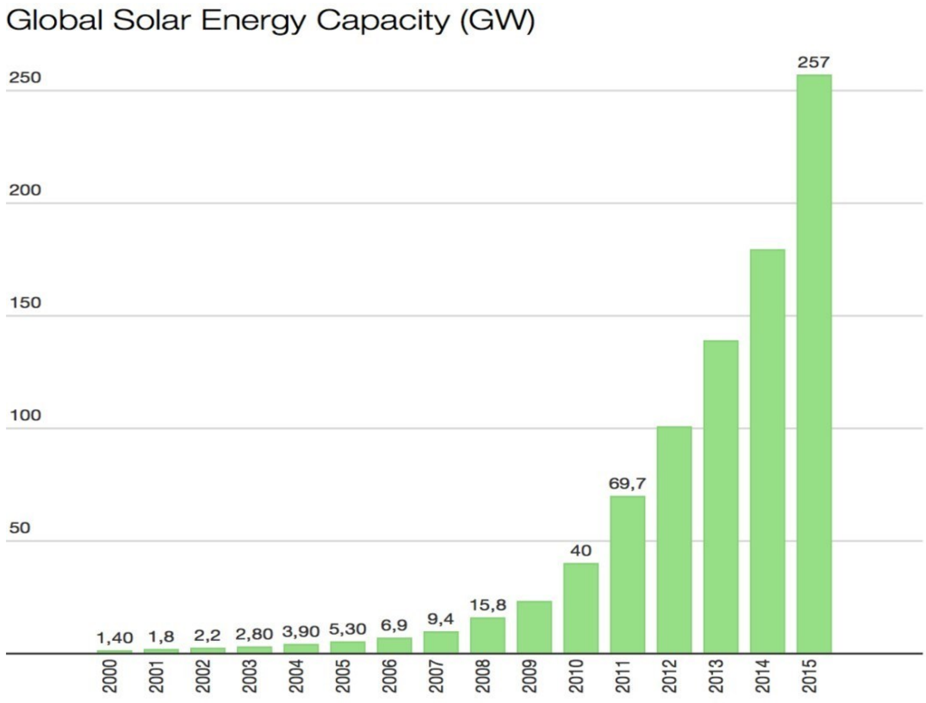
- Pollution: The major disadvantage of these conventional sources is that they cause high pollution. The burning of firewood and fossil fuels result in air pollution.
- Exhaustible: The major problem while using conventional sources especially fossil fuels is that they are exhaustible sources. It takes millions of years for them to be renewed and replenished.
- Risky: Accidents may occur while extracting conventional energy from mines.
- High cost: The extraction of conventional energy sources are very costly both economically and environmentally.

Why we Need Solar Energy?

Energy from Sun is **Free** and **most readily available**. Solar energy **creates pure, clean, and renewable power from the sun**, a perfect alternative to fossil fuels, such as natural gas and coal. It also reduces carbon footprint and greenhouse gases worldwide.

What is the future of solar?

Solar PV could **cover a quarter of global electricity needs by mid-century**, becoming the second largest generation source after wind. Global capacity must reach 18 times current levels, or more than 8 000 Giga Watts by 2050.



Growth of Solar Energy over the Years

Solar Cell

What Are Solar Cells?

Solar panels contain solar cells that can harness **solar energy** and produce power for households and businesses. To produce power, solar cells require daylight, but even when it's cloudy, you can still use the **solar panel** system.

Solar cells are made of semiconductor materials like silicon and require advanced technologies to be manufactured. Fortunately, there is continuous development in the solar cell industry as researchers push to discover ways to increase their efficiency through various methods.

In the UK, there is a strong focus on **clean energy**, especially solar cells, because they have many advantages. Stats show that the solar capacity of the UK had reached around 14 gigawatts (GW) at the beginning of 2021. If this trend continues, it can contribute to **lowering CO2emissions** in everyday life and minimising your electricity bill. More so, you can sell back the excess electricity from your solar panels to the national grid.

While present-day solar cells offer **plenty of advantages for homeowners** and businesses, there are also a few disadvantages of solar cells.
Below we enumerate the advantages and disadvantages of solar cells.

Advantages of Solar Cells

1. Renewable Energy

The most obvious advantage of solar cells is that they use solar energy, which is a renewable energy source.

Renewable energy is recovered from the sun, the wind, and waves - which in this case is the sun. Solar cells harness the energy from the sun and transform this into electricity which can be used in residential and commercial sectors.

The special thing about solar energy is that it will never be exhausted. This might seem trivial, but we can rely on solar energy as a sustainable source of electricity production forever. Also, it can be used to generate both electricity and heat, either through **solar PV** or **solar thermal** systems.

2. Economy-friendly Energy

The other benefit of using solar cells is that they provide a great opportunity to create savings on your electric bill since you do not pay for the energy that you generate. For example, you can reach an annual electricity bill savings of between £160 and £430 depending on the number of panels you use.

At the same time, you have the opportunity to monetise your photovoltaic system. Of course, you should have a grid-connected solar system to buy and sell electricity to the electricity network.

At the same time, you can obtain several **solar panel grants** and there will be more economic benefits to be gained in the future. Moreover, solar cells can outperform any other energy systems when it comes to maintenance costs. They don't have any moving components and you don't have to be worried about the repair.

3. Environmentally Friendly Energy

With solar cells occurs almost no pollution, and this is a great advantage. The discharge of waste and pollution is unavoidable in relation to the production of solar cells, the transport of these, and when you install them.

However, this is a minimal fraction, compared to that of traditional energy sources. Besides, with advances in recycling solar cells, concerns over end-of-life solar cells have significantly decreased. Also, solar cells don’t produce any noise pollutions so they’re perfect for urban areas, especially houses.

4. Innovative Energy

Photovoltaics is a popular topic in green energy and is considered to be a good solution to prevent climate change. It is also one of the most technologically advanced fields of industry among other types of renewables.

It has already made an innovative branch of study under continuous research and development. With unprecedented funds governments are putting in this field, it has generated countless jobs at different levels from PV installers to researchers and scientists. So another advantage of the solar cell industry is the job opportunities it can provide in case the investments continue.

5. Long Term Energy

PV systems often have a long life and good durability. At the same time, there is often a guarantee of at least 20 years on your PV panels, making it a reliable electricity source on your roof.

6. Selling Energy

If your home has solar cells, it is often easier to sell the property at a higher price. In the UK, there are some grants and incentives available if you want to invest in solar cells.

7. Infinite Energy

When you have the opportunity to extract energy from sun rays, this is a source of energy that will never be exhausted, therefore, this is an innovative market under continuous research and development.

Disadvantages of Solar Cells

Using solar cells might have some drawbacks. Here are some of the most important disadvantages of solar cells that you need to consider when going solar.

1. High Investment

One of the most important disadvantages of solar cells is the relatively high **installation cost of solar panels**. For example, the estimated cost of a 5kW solar PV system is around £7000 - £9000, depending on your roof type and other conditions.

Fortunately, there is a solution to this drawback. Most banks in the UK provide energy lending, which gives a low interest to you as a customer or green energy investor.

More importantly, you must bear in mind that the energy produced by solar cells is free and you don’t have any operational costs. In fact, PV panels don’t need any fuels so the initial cost can be offset after a while.

2. Interior Needs

Not all households can satisfy their requirements and get the optimum out of their solar cells yet. Solar cells are very sensitive in terms of their location, which means that if there is shade on your lot, it is difficult to exploit solar installation optimally.

The solution to this is that you can be connected to the grid and hence can buy energy from others. In fact, in many cases, it might be difficult to rely solely on the electricity of solar panels. So grid-connected PV panels are the best choice you have.

3. Seasonal Energy

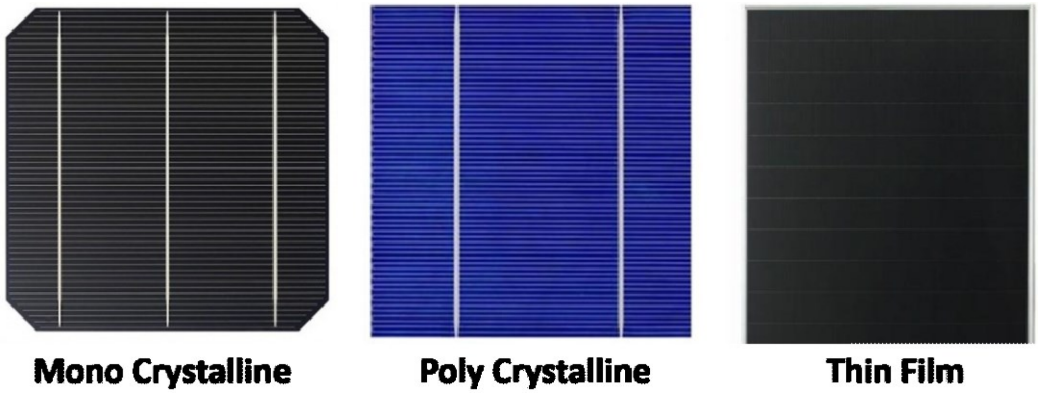
Compared to other types of renewable energy, the solar power plant is highly seasonal, since we can have periods of limited sun in the UK. The solution is to grid connect solar installations and purchase energy from the electricity network during periods with less energy to collect.

Investing in a **solar battery storage system** is also a good choice since it can store the energy generated during peak hours and make it readily available for cloudy and rainy days.

4. Solar Cells on Your Accommodation

It might be harder to install solar panels on older households, as they often have different designs that can provide shade. At the same time flat roofs where drifting snow may fall below the racks, become too heavy for a roof with solar cells. Therefore, it is important that you inquire about these things when you obtain offers.

Types of Solar Cell:



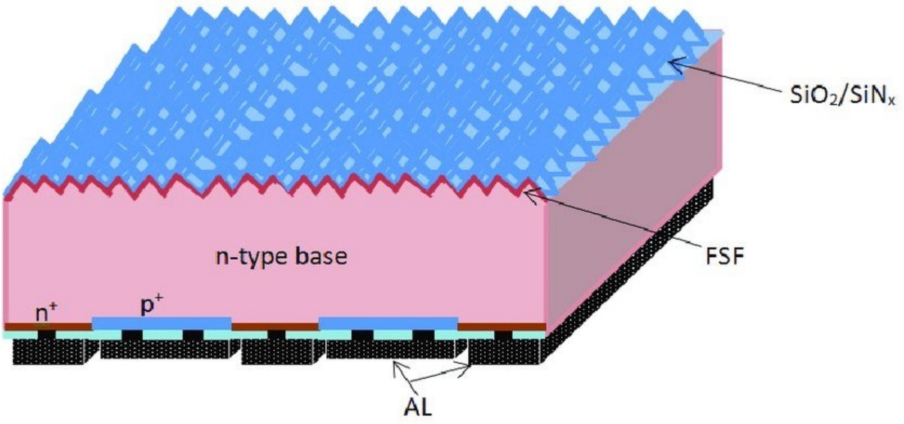
- **Mono Crystalline Solar Panels:** These are generally black coloured and are in a polygon shape. It is made up of single crystal silicon. Mono-Cryst lline Silicon has the highest efficiency among these three types i.e 15% – 24%. This Type of panels is the costliest. Mono Cıystalline solar panels have great heat resista t.

- **Poly Crystalline Solε r Panels:** These are generally blue coloured and are in rectangular shape. It is made up of polycrystalline silicon. Poly-Crystalline Solar panels have the efficiency between 13%-17%. This type of Solar panels is mostly used in India for residential and commercial rooftop installations. These type of solar panels are cheaper than the Mono Crystalline Solar panel.

- **Thin film Solar Panεls:** These are of rectangular shape with strai ht linings. These solar panels are very thin and are flexible. Due to their flexibility, they can be used in a variety of applications. these panels have efficiency 7%-15%. These solar panels are cheapest among all three types of solar panels.

What is Wafer?

A solar wafer is **a thin slice of a crystalline silicon (semiconductor)**, which works as a baseor substrate for microeconomic devices for fabricating integrated circuits in photovoltaics (PVs) to manufacture solar cells.



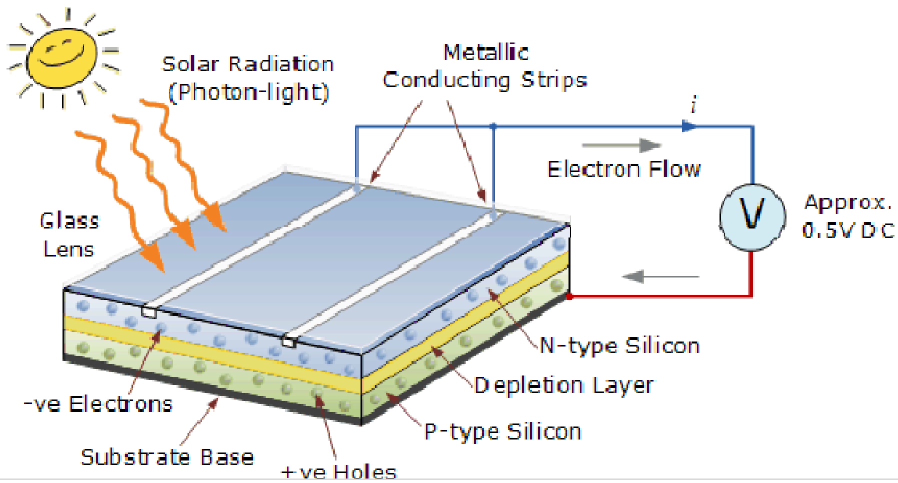
Structural diagram of a Sillicon Wafer

Photovoltaic Effect:

The **photovoltaic effect** is the generation of voltage and electric current in a material upon exposure to light. It is a physical and chemical phenomenon.

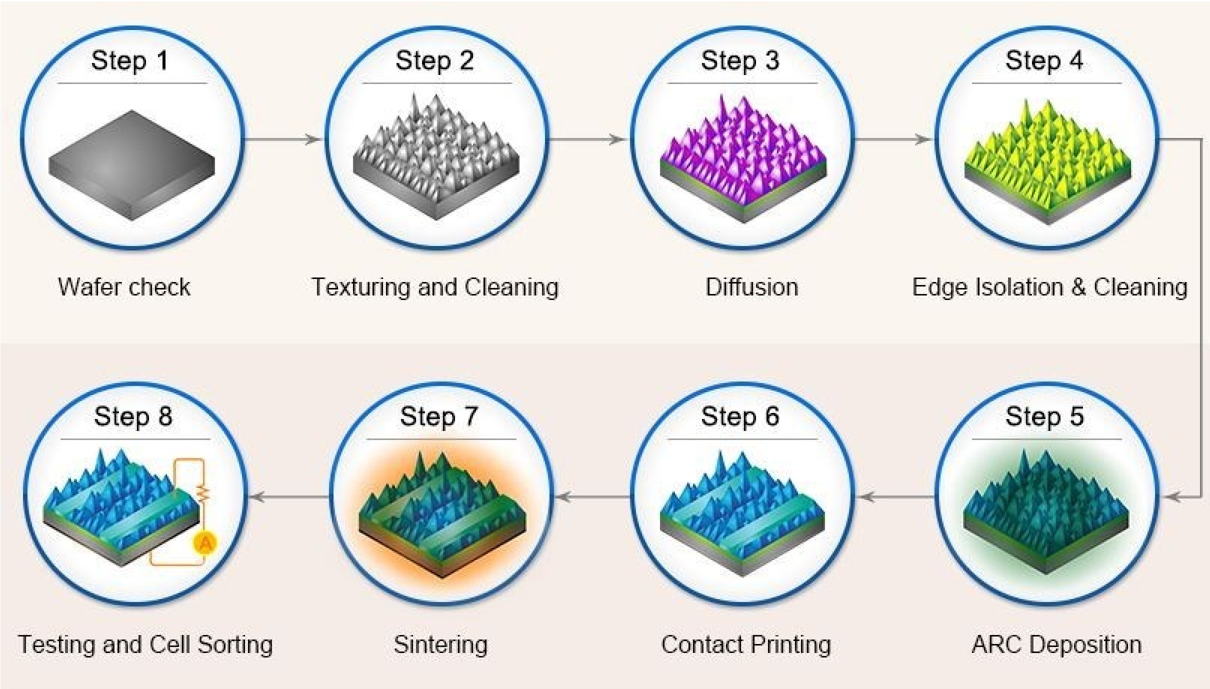
A photovoltaic cell is made of semiconductor materials that absorb the photons emitted by the sun andgenerate a flow of electrons. An electric field is created at the junction between the two layers.

When the electrons are excited by the photons, they are swept to the n-side by an electric field, whilethe holes drift to the p-side. The electrons and holes are directed to the electrical contacts



applied to both sides before flowing to the external circuit in the form of electrical energy. This produces directcurrent.

Processing of silicon wafers into solar cells:



Step 1: Pre-check and Pretreatment

The raw silicon wafer disks first undergo a pre-check during which they are inspected on their **geometric shape** and **thickness conformity** and on **damages** such as cracks, breakages, scratches, or other anomalities.

Following this pre-check, the wafers are split and **cleaned with industrial soaps** to remove any metal residues, liquids or other production remains from the surface that would otherwise impact the efficiency of that wafer.

Step 2: Texturing & Acid Cleaning

Following the initial pre-check, the front surface of the silicon wafers are **textured to reducereflection losses** of the incident light.

For monocrystalline silicon wafers, the most common technique is the **random pyramid texturing** which involves the coverage of the surface with aligned upward-pointing pyramid

structures. The proper alignment of the pyramids etched out is a result of the **regular, neat** atomic structure of **monocrystalline** silicon.

The regular, neat atomic structure of monocrystalline silicon also benefits the flow of electrons through the cell as with less boundaries electrons flow much better. Therefore, monocrystalline silicon has an electrochemical structural advantage offering more efficiency over the **grainy** atomic structures **of polycystalline silicon**.

The texturing of polycrystalline silicon wafers requires **photolithography** – a technique involving the engraving of a geometric shape on a substrate by using light – or **mechanical cutting of the surface** by laser or special saws.

After texturing, the wafers undergo **acidic rinsing** (or: **acid cleaning**). In this step, any post-texturing particle remains are removed from the surface.

Using **hydrogen fluoride (HF) vapour**, oxidized silicon layers on the substrate can be etched away from the wafer surface. The result is a wet surface that can be easily dried.

By using **hydrogen chloride (HCl)**, metallic residues on the surface can be absorbed by the chloride and thus removed from the wafer.

Step 3: Diffusion

Diffusion is basically the process of **adding a dopant** to the silicon wafer to make it more electrically conductive. There are basically 2 methods of diffusion: **solid-state diffusion** and **emitter diffusion**.

While the former method basically involves the already mentioned uniform doping of the wafers with the p-type and n-type materials, the emitter diffusion refers to the placing of a thin **dopant material-containing coating** on the wafer bypassing the wafers through a **diffusion coating furnace**.

Step 4: Etching & Edge Isolation

During diffusion, the n-type phosphorous diffuses not only into the desired wafer surface butalso **around the edges** of the wafer as well as on the backside, creating an **electrical path between the front and backside** and in this way also preventing electrical isolation betweenthe two sides.

The objective of the etching and edge isolation process is to **remove this electrical path** around the wafer edge by disk stacking the cells on top of each other and then exposing them to a plasma etching chamber using **tetrafluoromethane (CF_4)** to etch exposed edges.

Step 5: Anti-Reflective Coating (ARC) Deposition

In addition to the surface texturing, AR coating is often applied on the surface to further reduce reflection and increase the amount of light absorbed into the cell.

This anti reflective coating is very much needed as the reflection of a bare silicon solar cells is over 30%. For the thin AR Coating, **silicon nitride (Si3N4)** or **titanium oxide (TiO2)** is used. The color of the solar cell can be changed by varying the thickness of the anti reflection coating.

Step 6: Contact Printing and Drying

As the next step, **metal inlines** are printed on the wafer with the objective to create **ohmic contacts**. These metal inlines are printed on the rear side of the wafer, which is called **backside printing**.

This is achieved by printing the **metal pastes** with special screen printing devices that place this metal inlines onto the backside. After printing, the wafer undergoes a drying process.

Once dry, this process is followed by the printing of the **front side contacts**, then the wafer is another time dried.

Step 7: Sintering

After all, contacts have been printed on the rear and front sides, the screen-printed wafers are passed through a **sintering furnace** to solidify the dry metal pastes onto the wafers. Then, the wafers are **cooled** and can already be called solar cells.

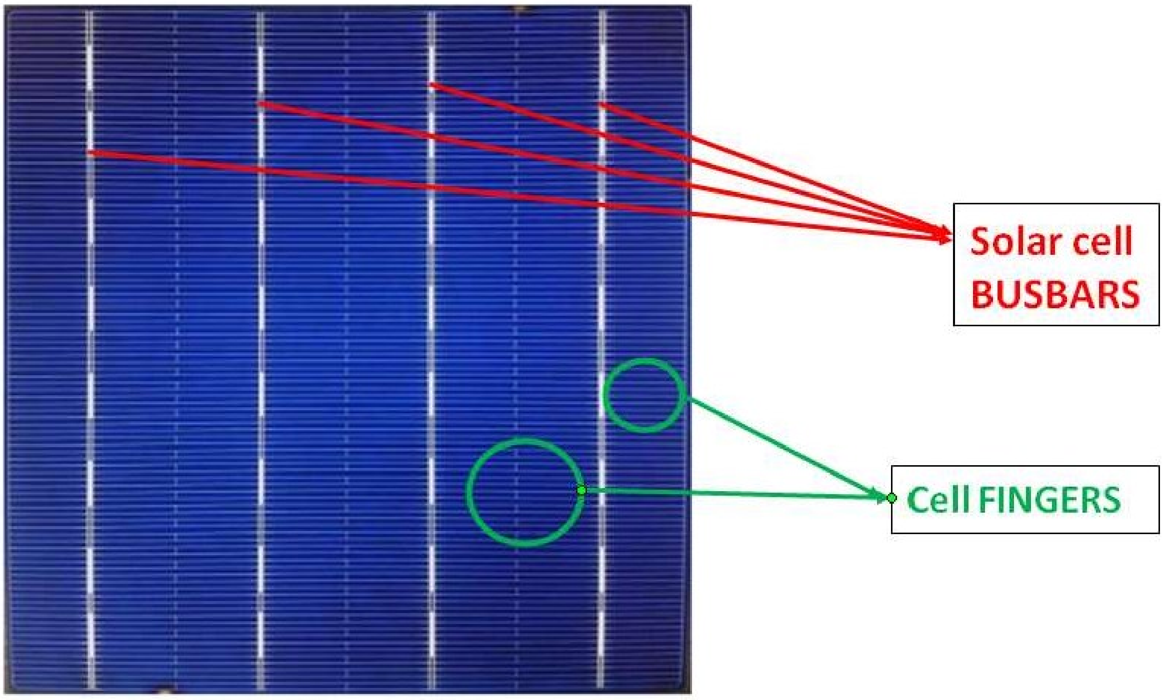
Step 8: Testing and Cell Sorting

In this final process, the now ready-to-assemble solar cells are tested under simulated sunlight conditions and then **classified and sorted** according to their efficiencies.

This is handled by a **solar cell testing device** that automatically tests and sorts the cells. The factory workers then only need to withdraw the cells from the respective efficiency repository to which the machine assorted the cells.

The solar cell then basically becomes a new raw material that is then used in the assembly of solar PV modules. Depending on the smoothness of the production process and the basic silicon wafer material quality, the final outcome in form of a solar cell is then further graded into different solar cell quality grades.

Structure of Solar Cell:



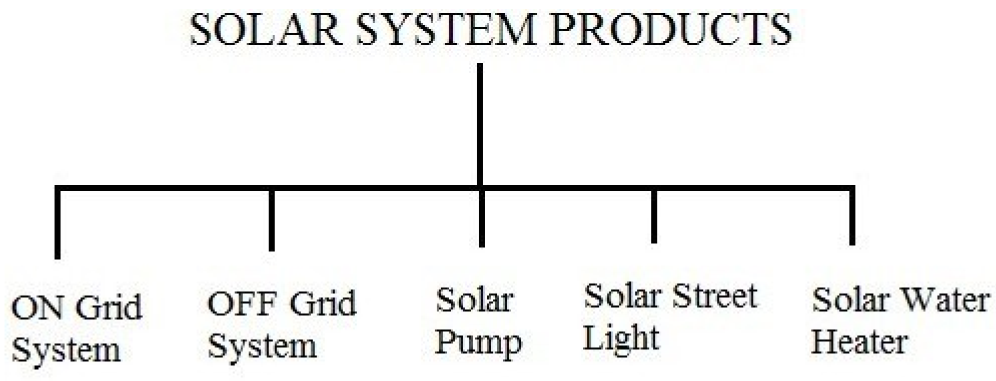
Busbars:

Thick metallic lines on the solar cell are called **Busbars** .The purpose of busbars in solar cells is to conduct the electric DC power generated by the cell when photons hit the cells. Commonly, solar cell busbars are made of copper plated with silver. The **silver plating** is necessary to improve current conductivity (front side) as well as to reduce oxidization (rear side). The most common solar cell design involves 2 or 3 full-line busbars printed onto the cell.

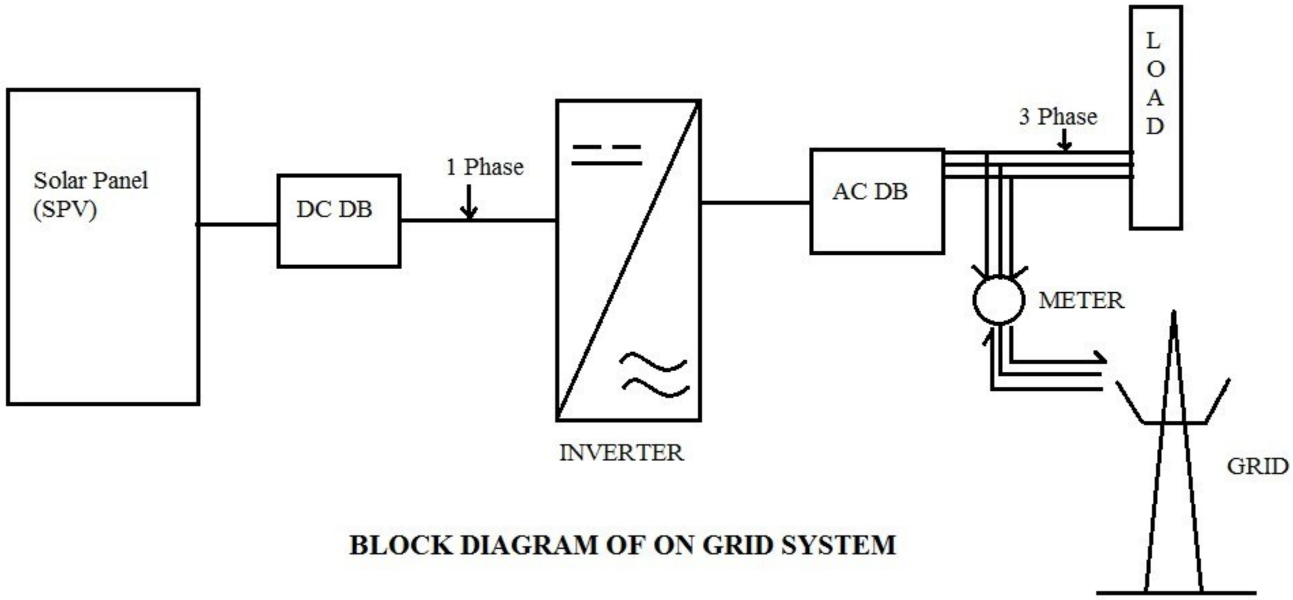
Fingers:

Perpendicular to the busbars are the metallic and super-thin **grid fingers** , which are connected by the busbar. The photo diodes are connected to the busbars via fingers. The fingers collect the generated current and deliver it to the busbars.

Products of Solar Energy



On Grid System:



BLOCK DIAGRAM OF ON GRID SYSTEM

An on-grid or grid-tied solar system is a system that works along with the grid. This means that any excess or deficiency of power can be fed to the grid through net metering. Many residential users are opting for an On-grid solar system as they get a chance to enjoy credit for the excess power their system produces and save on their electricity bills. One will always have power either from the solar system or from the grid. They do not have batteries.

These systems are best suitable when your power consumption is high and you wish to reduce your electricity bills. On-grid systems can be installed with or without net metering.

Working of on grid system:

- Sunlight hits the solar PV panels to produce electricity or solar energy.
- The electricity then runs from the solar panels to the inverter, which converts the power from a direct current (DC) to an alternating current (AC). The subsequent solar electricity can be used to power your electronic appliances.
- The solar power produced during the day runs through the switchboard to power the appliances you have in operation.
- Light bulbs, air conditioners, dishwashers, television, sound systems, and other AC-powered electronic devices can make use of solar-powered electricity.
- If the solar panels produce excess solar power or you have switched off your electrical appliances, the power will be transferred to the grid where it is measured by the meter box. Electricity retailers pay credits in exchange for the energy they return to the grid. At night, when your systems do not produce any energy, you can draw power from the grid and pay with the credits earned.

Benefits of On Grid System:

- ➢ Huge reduction in electricity bills

With net-meter in place, the consumer has to pay only for the surplus electricity he consumes, ensuring the bill generated every month is reduced drastically. Many of our customers have been able to reduce their monthly bills by 90%.

- ➢ Easy maintenance

The elimination of batteries in the on-grid system makes the maintenance quite easy. It also eliminates the cost of upkeep of the batteries

- ➢ Synchronize with other sources of power

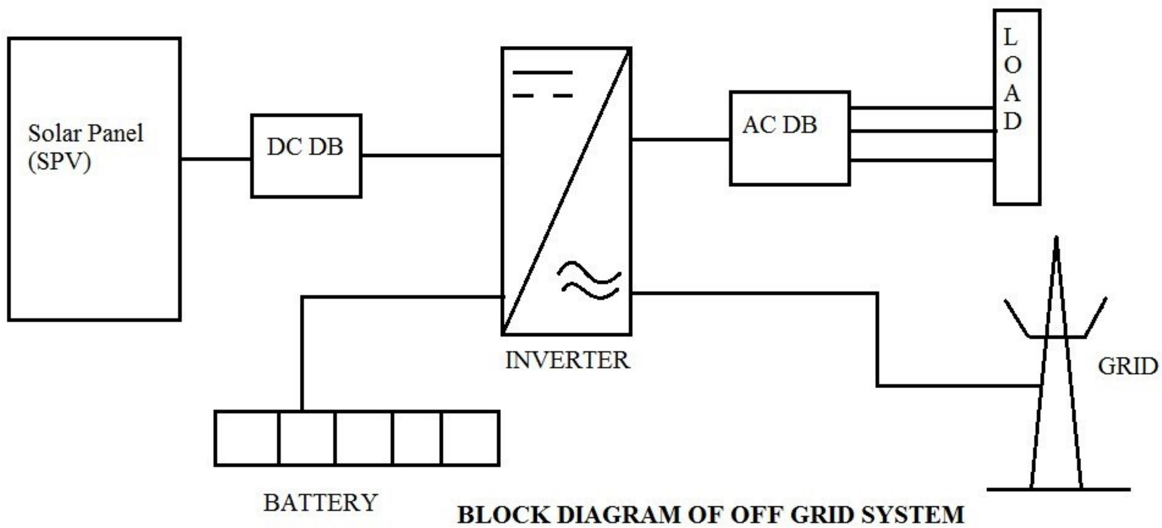
These systems can also synchronize with a diesel generator on site. This is important in case grid power is not available.

- Better ROI

Cost of a On-grid solar system is lower than other types of solar systems because there are no batteries. It also generates the highest amount of power compared to other types of solar systems. The minimal maintenance and reduction in monthly power bills ensure the customer gets an ROI of 25 – 30%. This means the customer earns Rs.25,000 for every 1,00,000 they invest in solar.

With these advantages, an on-grid system is best suited for a customer with stable grid power and minimal power cuts. Other than homes, even educational institutions, industrial units, commercial establishments install an on-grid system as the system can synchronize with diesel generators to provide uninterrupted power.

Off Grid System:



BLOCK DIAGRAM OF OFF GRID SYSTEM

An off-grid solar power system is not connected to the utility grid and uses an additional battery system. Usually, an off-grid system is designed to generate some excess electricity during the day which is transferred to the battery systems for storage. The energy stored in the batteries can then be used during the night or when it is cloudy. The users can opt for **off grid solar power systems** as per their energy goals. Based on the energy estimates, solar systems can be sized to generate enough energy to meet the user's energy requirements around the clock.

Benefits of Off Grid System:

- Avoid Power Outages

Power outages can occur without any warning. Losing electricity means living without lighting which can be an inconvenience short-term and incredibly stressful in the long-term. Often, a power outage will be over as soon as it begins, but sometimes the loss of electricity can extend longer. At times, it can happen for a day or even weeks depending on the cause of the outages and the length of time it takes to restore service.

Off-grid solar energy systems are reliable for outage situations as these systems store energy and always ready for potential disasters. A home with an off-grid solar power system can prolong having to experience blackouts amid any potential accidents.

- Reduced electricity costs

Fossil fuels are still the world's primary energy source. Among these are petroleum, coal, natural gas, and oil. As these finite resources deplete, their prices rise along with the cost to produce it which in turn increase consumers' electric bills.

Off-grid relies upon the sun to provide the power needed because it costs nothing in monthly electric bills. The inception and popularity of LED fixtures reduce the need for paying for maintenance because it only requires changing the battery.

- Easier Installation

The equipment for solar systems has been falling gradually for the past decade, but the cost for an off-grid solar setup continues to rise steadily. Many people decide to hire a professional because of the seemingly complicated process. However, these systems are not at all intricate.

A homeowner with a set of tools can install it on their own, which can help reduce the overall system cost substantially. Off-grid solar-powered systems invests anywhere compared to the traditional grid power where lines constrict to using existing poles and infrastructure or complete costly trenching to put the energy where it's necessary.

- Easy Alternative for Rural Areas

Electricity is one of the most significant problems of residents of rural and remote areas as these areas are prone to blackouts.

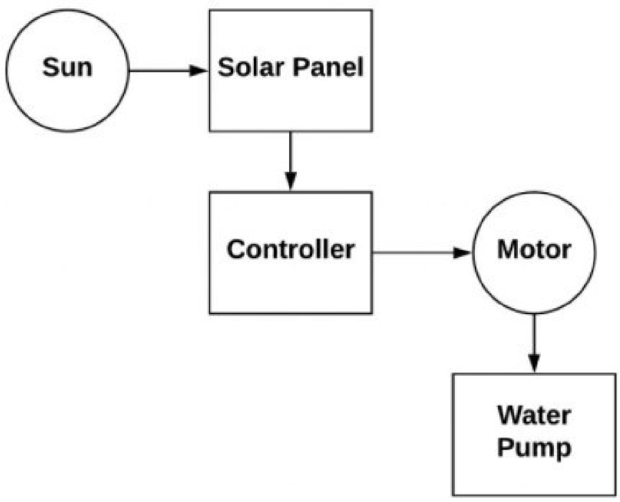
Since rural and remote areas have fewer infrastructures, connecting to the main electrical grid can be a challenge and incredibly costly but off-grid solar energy systems offset this significant role.

People who live in areas away from the main grid can save money through off-grid systems. These systems make it so users don't have to pay extra to connect to anything. It gives people the freedom to live anywhere while being able to produce and control power.

Drawbacks of Off-Grid Systems:

- Off-grid systems require you to purchase a back-up battery which can be bulky and expensive
- Solar battery systems require regular maintenance
- Off-grid options don't feature the feed-in-tariff as the system is not connected to the grid in any way

Solar Pump:



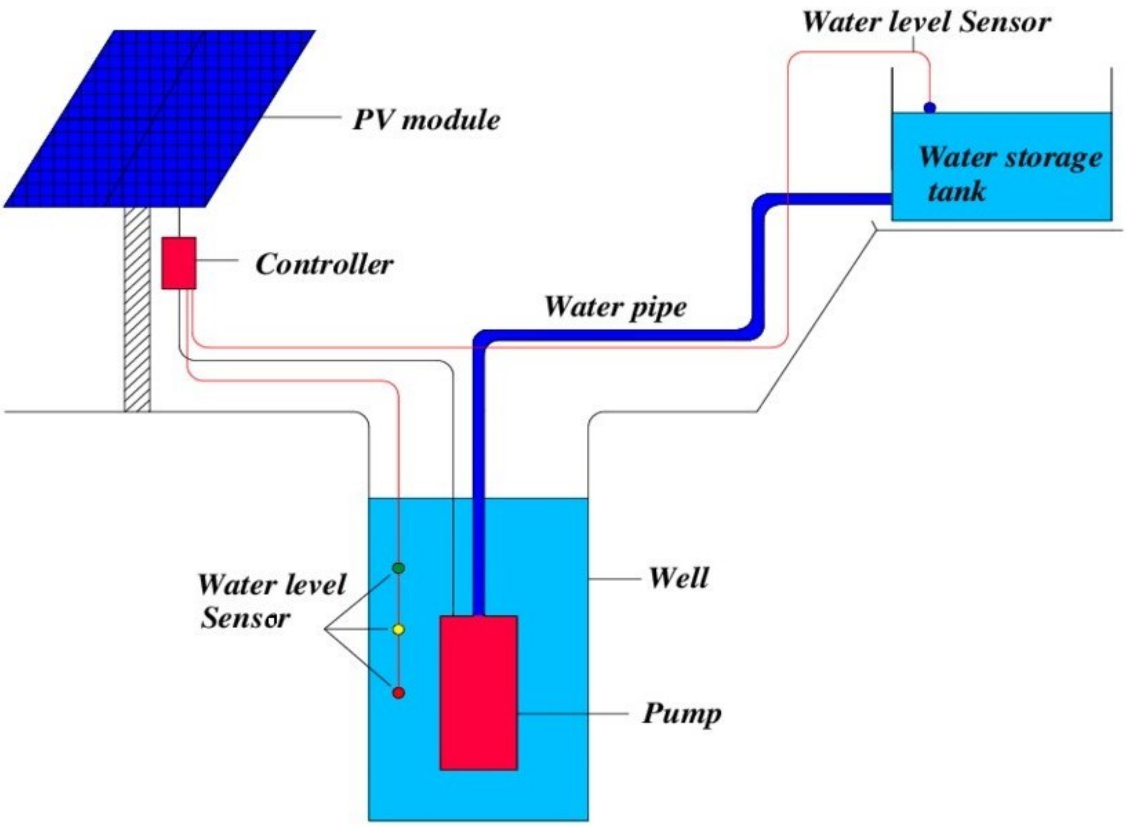
Solar pump definition is, as the name suggests the pump uses solar energy to function.

Solar-pumps are robust, installation is simple, minimum maintenance is necessary and very expensive when we compare with normal water pumps. The life span of these pumps is a maximum of 20 years.

But time to time the solar panels need to be cleaned for running. These kinds of pumps mainly used where there is an electricity problem otherwise consistent power supply is not accessible.

Working of Solar Pumps

When the solar energy drops sun rays on the PV panels then the solar panel converts the rays into electrical energy with the help of Si wafers fixed within the PV panels. Then the solar energy supplies to the electrical motor to operate the pumping system using cables. By the revolution of the shaft which is fixed to the pump, then the pump begins to pick up the soil water and supplies to the fields.



Solar Pump Applications:

The applications of solar pumps mainly used where pumping water is required.

- Water supply for animals
- Water supply for harvest irrigation
- Water supply for Cooking and Drinking water supply.

Advantages of a solar water pumping system:

- No fuel cost - as it uses available free sun light
- No electricity required
- Long operating life

- Highly reliable and durable
- Easy to operate and maintain
- Eco-friendly

Solar Pump Types

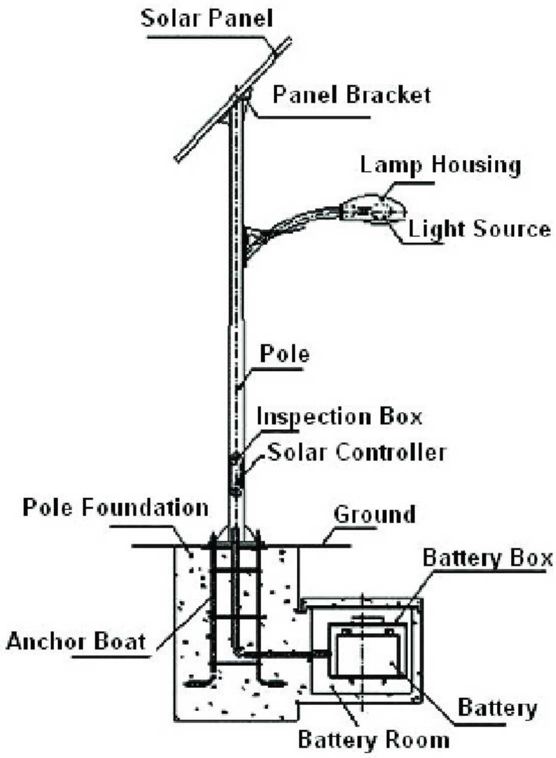
The solar-pumps are classified into four types namely submersible solar pumps, surface solar-pumps, DC pumps, and AC pumps. Most common type of pump used is submersible solar pump.

Submersible Solar Pumps

These pumps can lift the water up to 650 feet and fit within a big well. Whenever the water deepness in the well is above 20 feet from the surface then these pumps can work straightly and turn off batteries, solar panels, otherwise power source in some cases. Generally, water is pumped throughout the day as the sun is shining & the water is stored in a tank for utilize whenever required. It is suggested to store the water only in a good weather condition because if the weather is not good then the water will not pump. These types of pumpsmainly used in places wherever water is accessible at a larger depth & wherever open wells do not exist. The highest suggested depth for pumping is 50 meters

Solar Street Light:

Solar street lights have photovoltaic cells that are responsible for converting the sunlight's radiation into electricity. The device's semiconductor materials facilitate the process of conversion of solar energy into electricity. The electrical energy is stored in the solar batteries. If the illumination decreases to 10 lux, the circuit voltage of approximately 4.5V will be opened by the solar cell board. Then, the amount of voltage value moving from the battery to other parts of the street light system will be determined by the charge and discharge controller. Moreover, the charge and discharge controller is also known for protecting the battery.



Solar Street Light Components:

Solar panel

Solar panel is the most important part of each solar street light. The solar panel is responsible for converting solar energy into electric energy. A solar street light can either have mono-crystalline or poly-crystalline.

Lighting Fixture

Most solar street lights use LED technology. LED technology, makes it possible for the solar street lights to provide higher lumens, using lower power energy. As compared to the HPS fixtures, the rate of energy consumption of the LED fixture is 50% lower.

Rechargeable Batteries

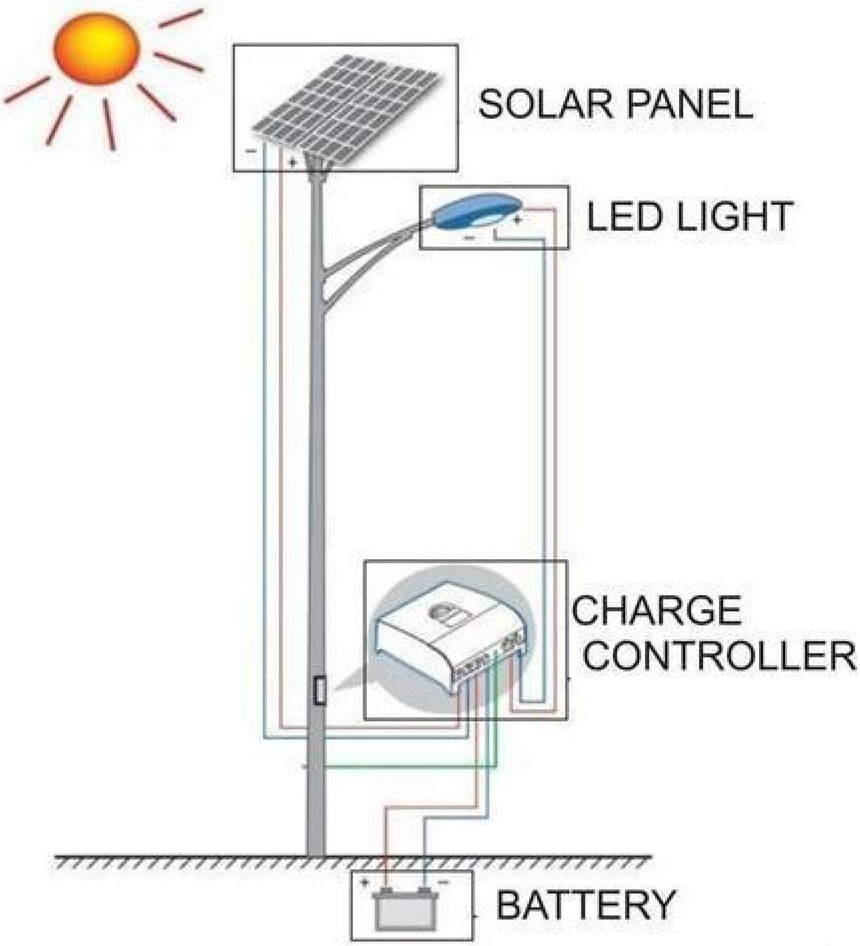
Just like the light fixture, the solar street light working principle cannot be effective without solar street rechargeable batteries. During the day, these batteries are meant for storing electric energy from the solar panel. Generally, solar street light is known for having two kinds of batteries: lead-acid batteries and gel cell deep cycle batteries.

Controller

This is also a significant part of solar street lights. In the solar street light working principle, the controller is responsible for determining when to switch on and off the lighting and the charging.

Pole

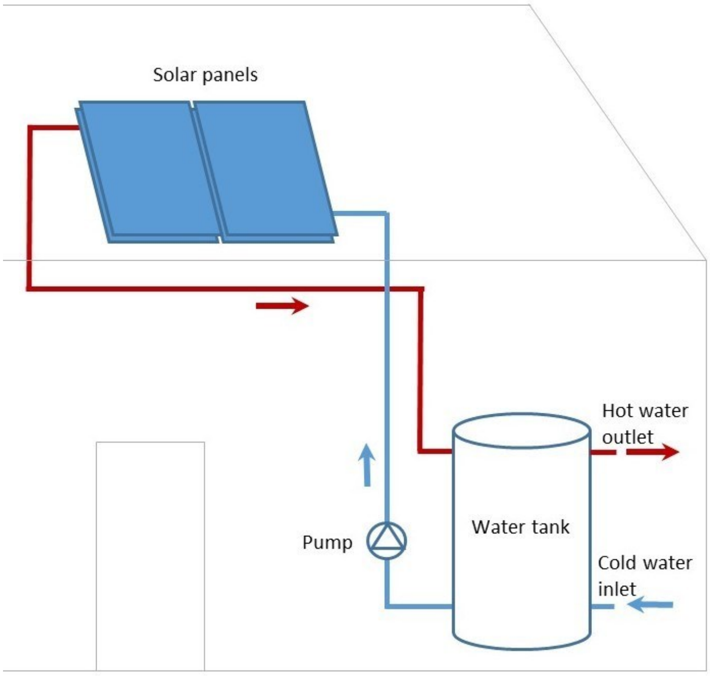
Strong poles are of great significance to the solar street light working principle since panels, fixtures and in some cases, batteries are mounted on them.



SOLAR WATER HEATER:

Solar water heating system is a device that uses solar energy to heat water for domestic, commercial, and industrial needs. Heating of water is the most common application of solar energy in the world. A typical solar water heating system can save up to 1500 units of electricity every year, for every 100 litres per day of solar water heating capacity.

Solar water heaters use natural sun light to heat water. This system works on the thermosiphon principle and is designed to provide hot water without consuming expensive electricity. This is the most effective way to generate hot water thereby saving costly power and is also environment friendly.



How do solar water heaters work?

The working of solar water heaters is very simple to understand. The solar water heaters use two common principles for its functioning. They are

- a black surface heats up when left in the sun, by absorption of solar radiation; The good absorption property of black surfaces is used to improve solar energy absorption in a solar heater
- The inside of car/ bus parked in sun for a long time becomes hot. This is because solar radiation can pass through the glass windows of the bus but cannot come out. It is

trapped inside and thus heats up the bus. Similarly water passing through insulatedpipes kept in the sun becomes hot

Advantages of solar water heater :

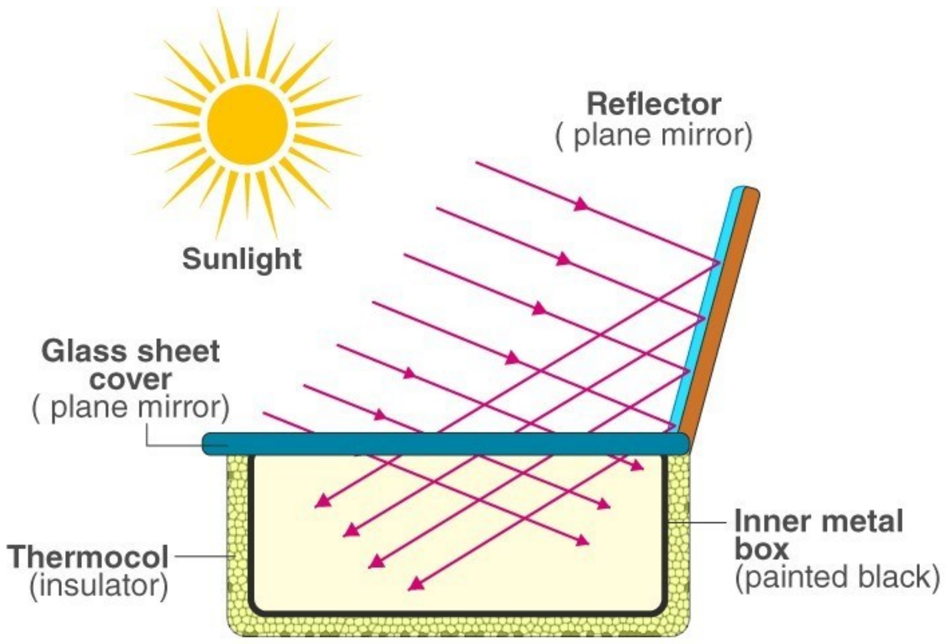
- Water heating bill savings
- Low maintenance
- Environmentally friendly

Disadvantages of solar water heater :

- High upfront installation costs
- Dependent on climate
- Only heats water

Solar Cooking:

A solar cooker, or solar oven, is a device which uses the energy of sunlight to heat food or drink to cook it or sterilize it. High-tech versions, for example electric ovens powered by solar cells, are possible, and have some advantages such as being able to work in diffuse light. However at present they are very unusual because they are expensive and have less efficiency. The vast majority of the solar cookers presently in use are relatively cheap, low-tech devices, great for use in developing countries

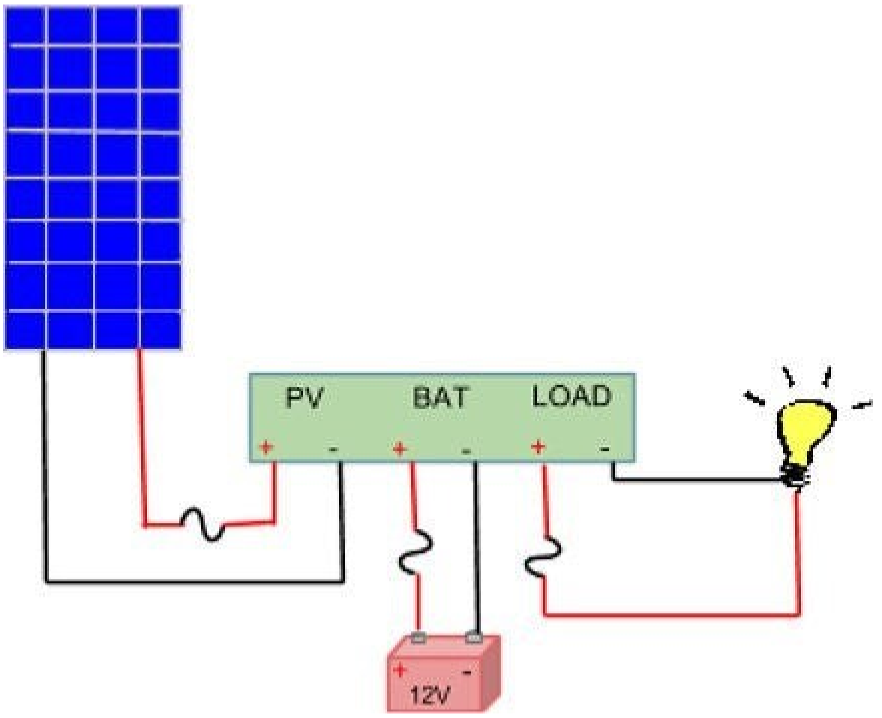


Solar Cooker

Solar Charge Controller

Solar Charge Controller is an electronic device that manages the power going into the battery bank from the solar array. It ensures that the deep cycle batteries are not overcharged during the day and that the power doesn't run back to the solar panels overnight and drain the batteries. Some charge controllers are available with additional capabilities, like lighting and load control, but managing the power is its primary job.

A solar charge controller is available in two different technologies, PWM and MPPT. An MPPT charge controller is more expensive and highly efficient than a PWM charge controller, and it is often worth it to pay the extra money.



- **PWM Solar Charge Controller:** A PWM solar charge controller stands for "Pulse Width Modulation". These operate by making a connection directly from the solar array to the battery bank. A 12V solar panel can charge a 12V battery. A 24V solar panel or a solar array is needed for a 24V battery bank, and 48V array is needed for 48V bank.

- **MPPT Solar Charge Controller:** An MPPT solar charge controller stands for "Maximum Power Point Tracking". It will measure the Vmp voltage of the panel and down-converts the PV voltage to the battery voltage. When the voltage is dropped to match the battery bank, the current is raised, with a 20V solar panel, you can charge a 12V battery bank.

If you try to charge a 12V battery with a 24V solar panel, you will be throwing over half of the panel's power away. If you try to charge a 24V battery bank with a 12V solar panel, you will be throwing away 100% of the panel's potential, and may actually drain the battery as well.

The Key Features of a Solar Charge Controller are:

- **Multistage charging of battery bank** - changes the amount of power set to the batteries based on its charge level, for healthier batteries.
- **Reverse current protection** - stops the solar panels from draining the batteries at night when there is no power coming from the solar panels.
- **Low voltage disconnect** - turns off the attached load when the battery is low and turns it back on when the battery is charged back up.
- **Lighting control** - turns attached light on and off based on dusk and dawn. Many controllers are configurable, allowing settings for a few hours or all night, or somewhere in between.
- **Display**- may show the voltage of battery bank, state of charge, amps coming in from solar panel.

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.

Charger Controller Types

Charge controls come in all shapes, sizes, features, and price ranges. They range from the small 4.5 amp (Sunguard) control, up to the 60 to 80 amp MPPT programmable controllers with computer interface. Often, if currents over 60 amps are required, two or more 40 to 80 amp units are wired in parallel. The most common controls used for all battery based systems are in the 4 to 60 amp range, but some of the new MPPT controls such as the Outback Power FlexMax go up to 80 amps.

Charge controls come in 3 general types (with some overlap):

Simple 1 or 2 stage controls which rely on relays or shunt transistors to control the voltage in one or two steps. These essentially just short or disconnect the solar panel when a certain voltage is reached. For all practical purposes these are dinosaurs, but you still see a few on old systems - and some of the super cheap ones for sale on the internet. Their only real claim to fame is their reliability - they have so few components, there is not much to break.

3-stage and/or PWM such Morningstar, Xantrex, Blue Sky, Steca, and many others. These are pretty much the industry standard now, but you will occasionally still see some of the older shunt/relay types around, such as in the very cheap systems offered by discounters and mass marketers.

Maximum power point tracking (MPPT), such as those made by Midnite Solar, Xantrex, Outback Power, Morningstar and others. These are the ultimate in controllers, with prices to match - but with efficiencies in the 94% to 98% range, they can save considerable money on larger systems since they provide 10 to 30% more power to the battery. For more information, see our article on MPPT.

Most controllers come with some kind of indicator, either a simple LED, a series of LED's, or digital meters. Many newer ones, such as the Outback Power, Midnite Classic, Morningstar MPPT, and others now have built in computer interfaces for monitoring and control. The simplest usually have only a couple of small LED lamps, which show that you have power and that you are getting some kind of charge. Most of those with meters will show both voltage and the current coming from the panels and the battery voltage. Some also show how much current is being pulled from the LOAD terminals.

All of the charge controllers that we stock are 3 stage PWM types, and the MPPT units. (in reality, "4-stage" is somewhat advertising hype - it used to be called equalize, but someone decided that 4 stage was better than 3). And now we even see one that is advertised as "5-stage"....

What is 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.

What is 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.

What is a 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.

What are the "Sense" terminals on my controller?

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.

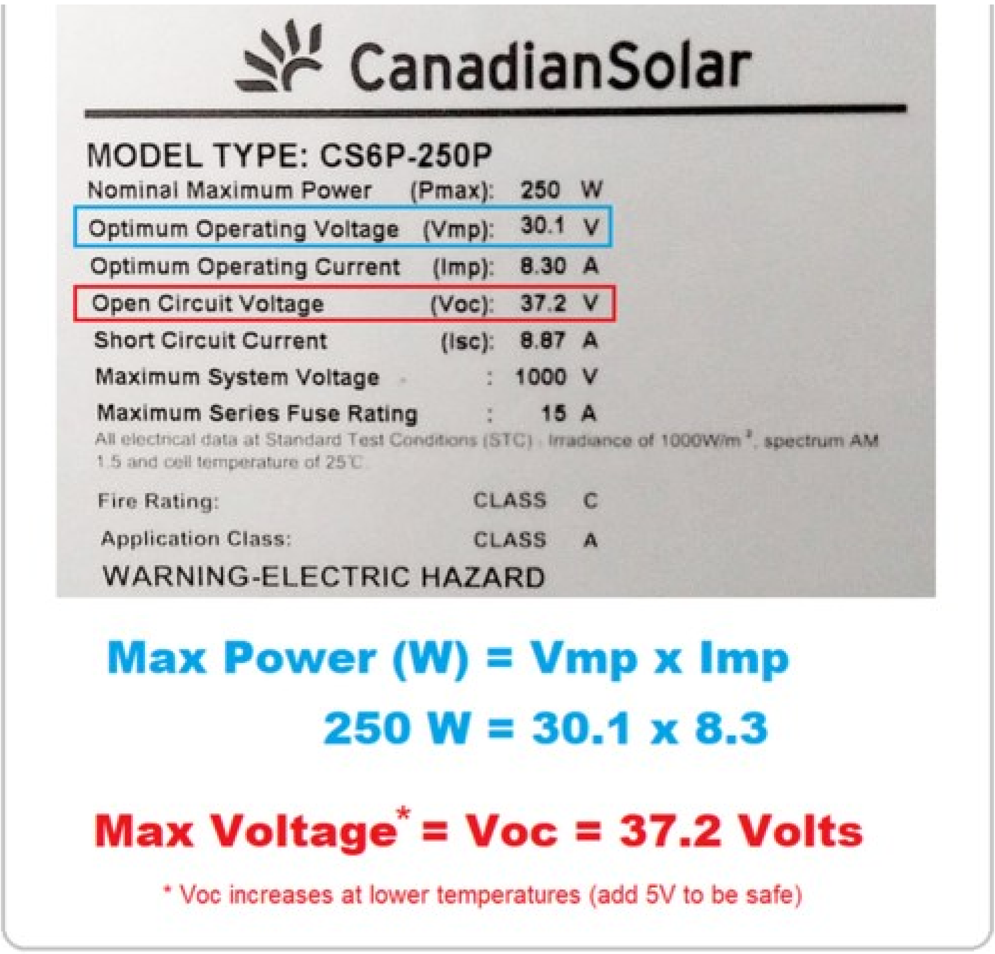
These are only used when you have a long wire run between the controller and the battery. These wires carry no current, and can be pretty small - #20 to #16 AWG. We prefer to use #16 because it is not easily cut or squished accidentally. They attach to the SENSE terminals on the controller, and onto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

What is a "Battery System Monitor"?

Battery system monitors, such as the Bogart Engineering TriMetric 2025A 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 :-). TriMetric's new PentaMetric model also has a computer interface and many other features.

Solar Panel Voltage Vs Battery Voltage

View fullsize



The label on the back of a solar panel should list the panel power, current and voltages (Voc).

For an MPPT charge controller to work correctly, the solar panel operating voltage must be at least 4V to 5V higher than the battery charging (absorption) voltage, not the nominal battery voltage. **On average, the real-world panel operating voltage is around 3V lower than the optimum panel voltage (Vmp).**

All solar panels have two voltage ratings which are determined under standard test conditions (STC) based on a cell temperature of 25°C. The first is the maximum power voltage (Vmp) which drops slightly under cloudy conditions or more so when the solar panel temperature increases. The second is the open-circuit voltage (Voc) which also **decreases at higher temperatures**. In order for the MPPT to function correctly, the panel operating voltage (Vmp) must always be several volts higher than the battery charge voltage under all conditions, including high temperatures - *see more detail about voltage drop and temperature below.*

12V Batteries

In the case of **12V batteries,** the panel voltage drop due to high temperature is not a big problem as most (12V) solar panels operate in the 18V to 22V range, which is much higher than the typical 12V battery charge (absorption) voltage of 14.4V. Also, common 60-cell (24V) solar panels are not a problem as they operate in the 30V to 40V range which is much higher.

24V Batteries

In the case of **24V batteries,** there is no issue when 2 or more solar panels are connected in series, but there is a problem when only 1 solar panel is connected. Most common (24V) 60-cell solar panels have a Vmp of 32V to 36V - While this is higher than the battery charging voltage of around 28V, the problem occurs on a hot day when the panel temperature increases and the panel voltage can drop by up to 6V. This large voltage drop can result in the solar voltage dropping below the battery charge voltage, thus preventing it from fully charging. A way to get around this when using only one panel is to use a larger, higher voltage 72-cell or 96-cell panel.

48V Batteries

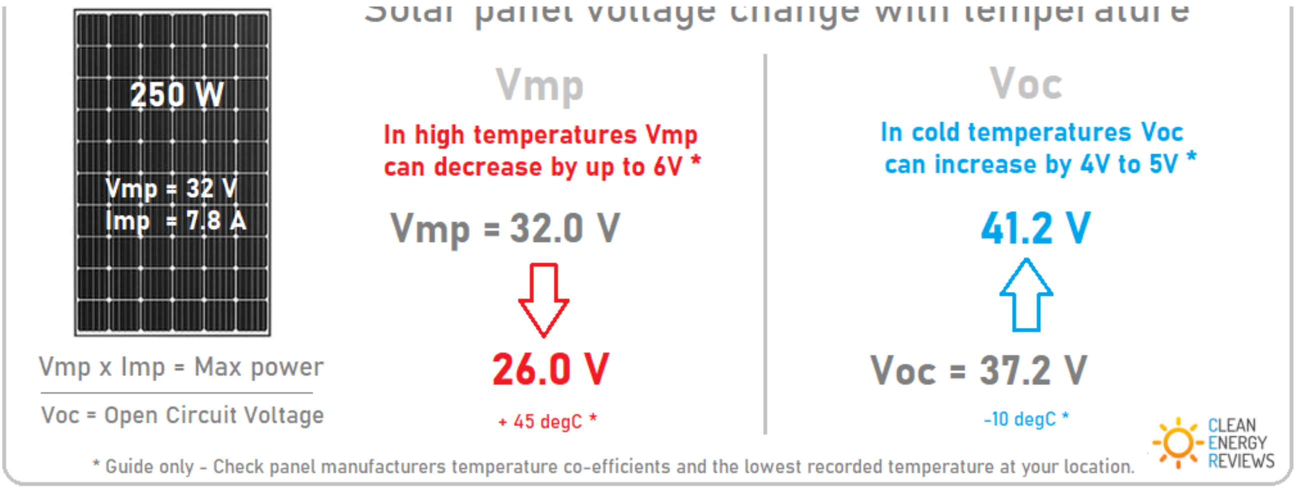
When charging **48V batteries,** the system will need at least 2 panels in series but will perform much better with 3 or more panels in series, depending on the maximum voltage of the charge controller. Since most 48V solar charge controllers have a max voltage (Voc) of 150V, this generally allows up to 3 panels to be connected in series. The higher voltage 250V charge controllers can have strings of 5 or more panels which is much more efficient on larger solar arrays as it reduces the number of strings in parallel and in turn lowers the current.

*Note: Panels connected in series can produce **dangerous levels of voltage** and must be installed by a qualified electrical professional and meet all local standards and regulations.*

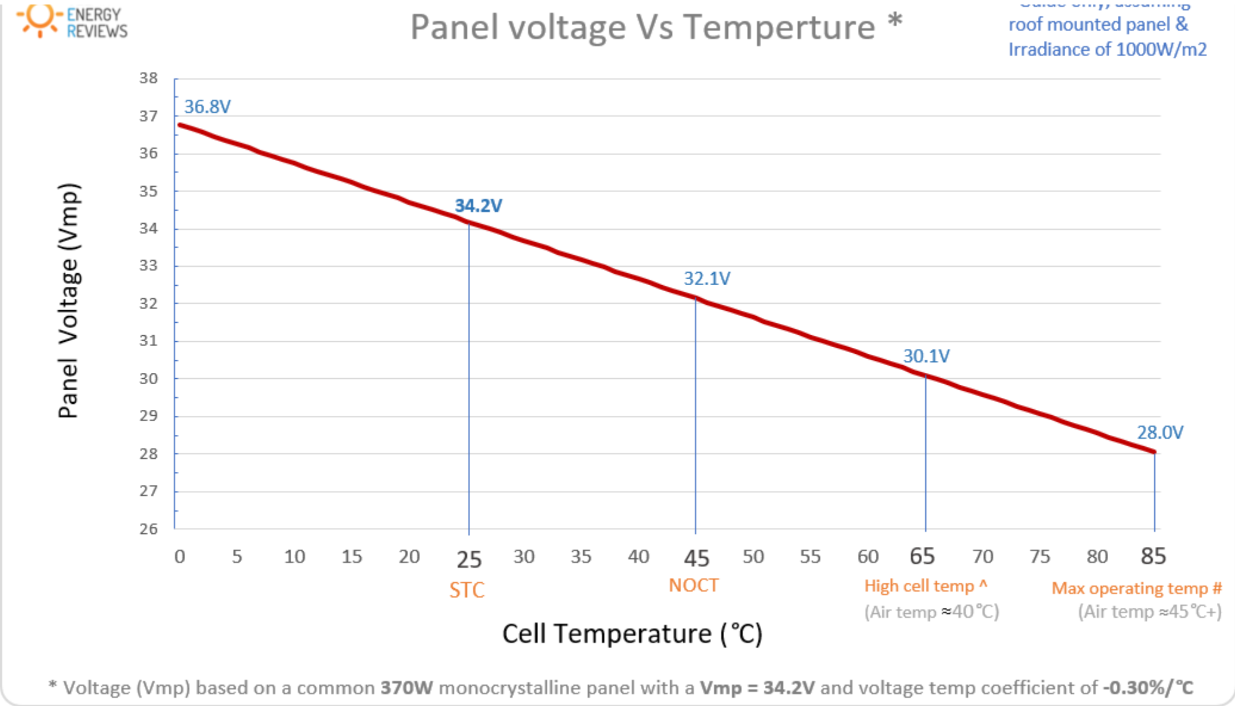
Solar Panel Voltage Vs Temperature

The power output of a solar panel can vary significantly depending on the temperature and weather conditions. A solar panel's power rating (W) is measured under *Standard Test Conditions* (STC) at a cell temperature of 25℃ and an irradiance level of 1000W/m2. However, during sunny weather, solar panels slowly heat up and the internal cell temperature will generally increase by at least 20℃ above the ambient air temperature; this results in increased internal resistance and a reduced voltage (Vmp). The amount of voltage drop is calculated using the voltage temperature co-efficient listed on the solar panel datasheet.

View fullsize



Both the Vmp and Voc of a solar panel will ***decrease*** during hot sunny weather as the cell temperature increases. During very hot days, with little wind to disperse heat, the panel temperature can rise as high as 80℃ when mounted on a dark coloured rooftop. On the other hand, in cold weather, the operating voltage of the solar panel can ***increase*** significantly, up to 4V or even higher in freezing temperatures. Voltage rise must be taken into account as it could result in the Voc of the solar array going above the maximum voltage limit of the solar charge controller and damaging the unit.



Solar panel voltage Vs Temperature graph - Based on a Trina Solar Honey M 370W solar panel

Panel Voltage Vs Cell Temperature graph notes:

- STC = Standard test conditions - 25°C (77°F)
- NOCT = Nominal operating cell temperature - 45°C (113°F)
- (^) High cell temp = Typical cell temperature during hot summer weather - 65°C (149°F)
- (#) Maximum operating temp = Maximum panel operating temperature during extremely high temperatures mounted on a dark rooftop - 85°C (185°F)

Voltage increase in cold weather

Example: A Victron 100V/50A solar charge controller has a maximum solar open-circuit voltage (Voc) of 100V, and a maximum charging current of 50 Amps. If you use 2 x 300W solar panels with 46 Voc in series, then you have a maximum of 92V. This seems ok, as it is below the 100V maximum. However, in extremely cold conditions the panel voltage will go much higher than the Voc. This is calculated using the voltage temperature co-efficient of the solar panel, which is typically 0.3% for every degree below STC - 25°C cell temperature. However, to simplify things, you can generally add 5V to the panel Voc (for temperatures down to ***-10°C **)***. In this case, you would end up with a Voc of 102V. This is now greater than the max 100V input voltage limit and could damage the MPPT or void your warranty.

Solution: There are two ways to get around this issue:

1. Select a different MPPT solar charge controller with a higher input voltage rating such as the Victron 150V/45A.
2. Connect the panels in parallel instead of series. The maximum voltage will now be 46V + 5V = 51 Voc. Note, this will only work if you are using a 12V or 24V battery system, but it's not suitable for a 48V system as the voltage is too low. Also note, in parallel the solar input current will double so the solar cable should be rated accordingly.

Sizing A Solar Charge Controller

Basic Guide

The charge controller Amp (A) rating should be 10 to 20% of the battery Amp/hour (Ah) rating. For example, a 100Ah 12V lead-acid battery will need a 10A to 20A solar charge controller. A 150W to 200W solar panel will be able to generate the 10A* charge current needed for a 100Ah battery to reach the adsorption charge voltage provided it is orientated correctly and not shaded. **Note: Always refer to the battery manufacturer's specifications.*

Advanced Guide

Before sizing a charge controller and purchasing panels or batteries you should understand the basics of sizing an off-grid solar power system. The general steps are as follows:

1. Estimate the **loads** - how much energy you use per day in Ah or Wh
2. **Battery** capacity - determine the battery size needed in Ah or Wh
3. **Solar** size - determine how many solar panel/s you need to charge the battery (W)
4. Choose the MPPT Solar Charge Controller/s to suit the system (A)

1. Estimate the loads

The first step is to determine what loads or appliances you will be running and for how long? This is calculated by - the power rating of the appliance (W) multiplied by the average runtime (hr). Alternatively, use the average current draw (A) multiplied by average runtime (hr).

- Energy required - **Watt hours** (Wh) = Power (W) x Time (hrs)
- Energy required - **Amp hours** (Ah) = Amps (A) x Time (hrs)

Once this is calculated for each appliance or device then the total energy requirement per day can be determined as shown in the **attached load table**.

Basic Off grid Load table

CLEAN ENERGY REVIEWS

Average Daily Consumption (kWh) — Winter

Qty #	Appliance	Power	Average		Comments
		W	Ave Run Time hr per day	Daily Energy kWh	
Adjust Quantity		Adjust if required	Please adjust this column		
Kitchen					
1	**Efficient Fridge**	125	24	1.25	As per Fridge Rating
1	Microwave	1200	0.2	0.24	
1	Toaster	900	0.1	0.09	
1	Elec Kettle	2400	0.1	0.24	
0	Elec Oven	2000	0.5	0.00	High consumption
4	LED Lights	10	5	0.20	
Laundry & bathroom & Hot water					
0.5	Washing machine	650	0.5	0.16	High Surge load
1	Water Pump (off-grid)	1100	1	1.10	High Surge load
4	LED Lights	6	1.5	0.04	
Lounge/Entertainment					
1	TV LED	100	4	0.40	
1	Computer Laptop	45	4	0.18	
1	Modem	8	24	0.19	
0	Reverse cycle A/C	1250	5	0.00	High consumption
6	LED Lights	10	4	0.24	
Bedrooms					
2	LED Lights	10	2	0.04	
0	LED Lights	10	2	0.00	
	TOTAL AC - Daily load			**4.37**	**kWh per day**
	Battery System Voltage =	24	V	182	Ah used per day

A basic load table used to help correctly size an off-grid solar and battery system - **Click image and download**

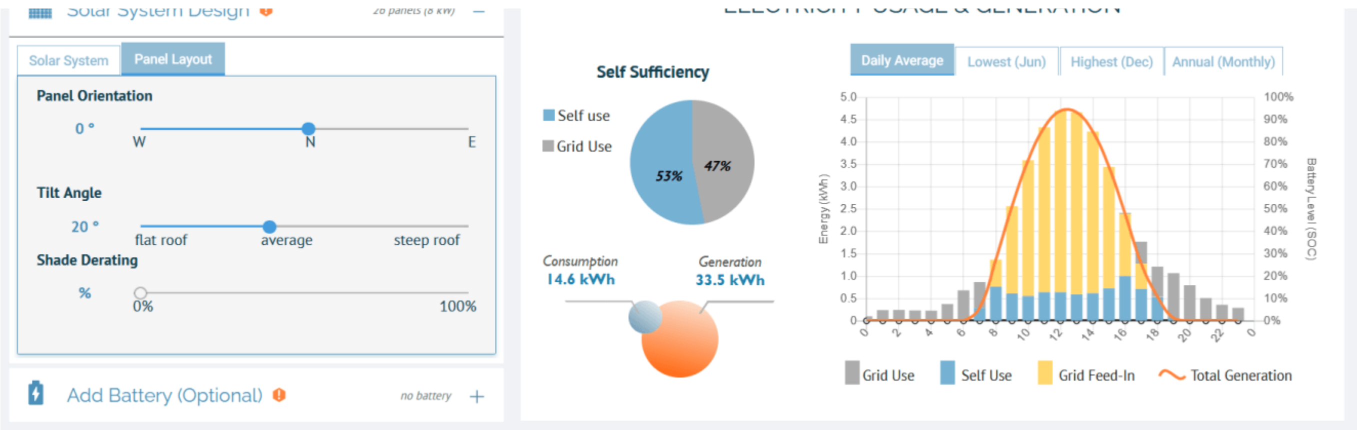
2. Sizing the Battery

The total Ah or Wh load is used to size the battery. Lead-acid batteries are sized in Ah while lithium batteries are sized in either Wh or Ah. The allowable daily depth of discharge (DOD) is very different for lead-acid and lithium, see more details about lead-acid Vs lithium batteries. In general, lead-acid batteries should not be discharged below 70% SoC (State of Charge) on a ***daily basis***, while Lithium (LFP) batteries can be discharged down to 20% SoC on a daily basis. *Note: Lead-acid (AGM or GEL) batteries can be deeply discharged but this will severely reduce the life of the battery if done regularly.*

For example: If you have a 30Ah daily load, you will need a minimum 100Ah lead-acid battery or a 40Ah lithium battery. However, taking into account poor weather, you will generally require at least 2 days of autonomy - so this equates to a 200Ah lead-acid battery or an 80Ah lithium. Depending on your application, location, and time of year, you may even require 3 or 4 days of autonomy.

3. Sizing the Solar

The solar size (W) should be large enough to fully charge the battery on a typical sunny day in your location. This is not simple as there are many variables to consider including panel orientation, time of year & shading issues. This is actually quite complex, but to simplify things we can roughly work out how many watts are required to produce **20% of the battery capacity in Amps**. Oversizing the solar array is also allowed by some manufacturers to help overcome some of the losses - see more details below. Note, you can use our free solar design calculator to help estimate the solar generation for different solar panel tilt angles and orientations.



The Clean Energy Reviews solar calculator can help estimate the solar generation for different panel orientations.

Solar sizing Example: *Based on the 20% rule, A 12V, 200Ah battery will need up to 40Amps of charge. If we are using a common 250W solar panel, then we can do a basic voltage and current conversion - 250W / 12V battery = 20.8A. So we would need at least 2 x 250W panels to get close to 40Amps charge. Remember there are several loss factors to take into account so slightly oversizing the solar is a common practice - See more about oversizing solar below.*

4. Solar Charge controller Sizing (A)

The MPPT solar charge controller size should be roughly matched to the solar size. A simple way to work this out is using the power formula:

Power (W) = Voltage x Current or (P = V*I)

If we know the total solar power in watts (W), and the battery voltage (V), then to work out the maximum current (I) in Amps we re-arrange this to work out the current - so we use the rearranged formula:

Current (A) = Power (W) / Voltage or (I = P/V)

For example: if we have 2 x 200W solar panels and a 12V battery, then the maximum current = 400W/12V = 33Amps. In this example, we could use either a 30A or 35A MPPT solar charge controller.

Oversizing Solar

Due to the various losses in a solar system, it is common practice to oversize the solar array to enable the system to generate more power during bad weather and under different conditions such as high temperatures where power derating can occur. The main loss factors include - poor weather (low irradiation), dust and dirt, shading, poor orientation, and cell temperature de-rating (refer to the power temperature co-efficient on the solar panel spec sheet for more details). Learn more about solar panel efficiency and cell temperature de-rating.

These various loss factors listed above can add up as high as 20%. For example, a 300W solar panel will generally produce 240W to 270W in summer due to the temperature power de-rating, and in winter or due to lower irradiance levels, depending on your location. For these reasons, oversizing the solar array beyond the manufacturers 'recommended or **nominal value**' will help to generate more power. Oversizing by 150% or more is possible on some professional MPPT solar charge controllers. However, not all solar charge controllers are designed to handle the excess power when the solar is operating at full capacity and this can damage some controllers. Therefore, it is important to always check the manufacturer allows oversizing - **Morningstar and Victron both allow oversizing beyond the *nominal values* listed on the datasheets but always double-check the manufacturer's specifications.**

MORNINGSTAR
PROFESSIONAL SERIES

Technical Specifications

Versions	TS-MPPT-30	TS-MPPT-45	TS-MPPT-60	TS-MPPT-60M
Electrical				
Maximum Battery Current	30 amps	45 amps	60 amps	60 amps
Nominal Maximum Operating Power* 12 Volt 24 Volt 48 Volt	 400 Watts 800 Watts 1600 Watts	 600 Watts 1200 Watts 2400 Watts	 800 Watts 1600 Watts 3200 Watts	 800 Watts 1600 Watts 3200 Watts
Nominal System Voltage	12, 24, or 48 volts DC			
Maximum PV Open Circuit Voltage**	150 volts DC			

Notes:

*Input power can exceed Nominal Maximum Operating Power, but controller will limit and provide its rated continuous maximum output current into batteries. This will not harm the controller (reminder: do not exceed Voc).

**Exceeding Maximum PV Open Circuit Voltage may damage the controller.

Example: Specification sheet from Morningstar highlighting this manufacturer allows oversizing of solar.

IMPORTANT - Oversizing solar is only allowed on some MPPT solar charge controllers such as those from Victron, Morningstar and EPever. Oversizing on other models could void your warranty and result in damage or serious injury to persons or property - always ensure the manufacturer allows oversizing and never exceed the maximum input voltage or current limits.

EPever AN Series - Oversizing solar * (EPever user manual)

According to "Peak Sun Hours diagram", if the power of PV array exceeds the rated charging power of controller, then the charging time as per the rated power will be prolonged, so that more energy can be obtained for charging the battery. However, in the practical application, the maximum power of PV array shall be not greater than 1.5 x the rated charging power of controller. If the maximum power of PV array exceeds the rated charging power of controller too much, it will not only cause the waste of PV modules, but also increase the open-circuit voltage of PV array due to the influence of environmental temperature, which may make the probability of damage to the controller rise. Therefore, it is very important to configure the system reasonably. For the recommended maximum power of PV array for this controller, please refer to the table below:

50% over-sizing solar allowed

Model	Rated Charge Current	Rated Charge Power	Max. PV Array Power	Max. PV open circuit voltage
Tracer1210AN	10A	130W/12V 260W/24V	195W/12V 390W/24V	92V① 100V②
Tracer2210AN	20A	260W/12V 520W/24V	390W/12V 780W/24V	
Tracer3210AN	30A	390W/12V 780W/24V	580W/12V 1170W/24V	
Tracer4210AN	40A	520W/12V 1040W/24V	780W/12V 1560W/24V	

① At 25°C environment temperature
② At minimum operating environment temperature

CLEAN ENERGY REVIEWS

More About Solar Sizing

As previously mentioned, all solar charge controllers are limited by the maximum input voltage (V - Volts) and maximum charge current (A – Amps). The maximum voltage determines how many panels can be attached (in series), and the current rating will determine the maximum charge current and in turn what size battery can be charged.

As described in the guide above, the solar array should be able to generate close to the charge current of the controller, which should be sized correctly to match the battery. Another example: a 200Ah 12V battery would require a 20A solar charge controller, and a 250W solar panel to generate close to 20A. (Using the formula P/V = I, then we have 250W / 12V = 20A).

SPV Charge Controller Hardware

3.1SOLAR CHARGE CONTROLLER UNIT

Solar Charge Controller Unit is a device that controls the charging process of the battery, monitors the status of the battery also generates alarms when required. Before microcontrollers, analog charge controllers were used. Nowadays microcontroller-based solar charge controllers are quite popular. The benefit of these CCUs is that we can use MPPT or PWM algorithms for controlling the charging process. These algorithms help to harness maximum power from the PV panel. Even nowadays displays could be interfaced to show the Battery Voltage, Current, and Load

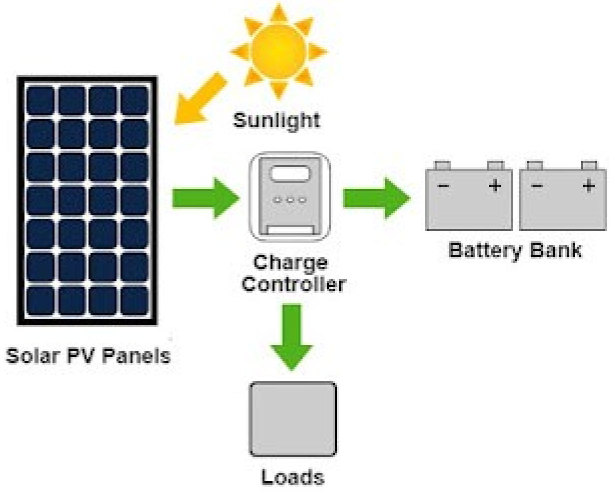
Specification of solar charge controller:-

Solar Charge Controller (6A)		
Sl. No.	Parameters	Specification
1.	Charging Current	Maximum 6 Amps
2.	Load Current	Maximum 6 Amps
3.	SPV Module Capacity	75Wp
4.	Battery Voltage	12V / 24V Automatic Switching
5.	Solar Panel Voltage	12V / 24V Automatic Switching
6.	Solar Panel Open Circuit Voltage	21V / 42V DC Maximum
7.	No Load Power	< 5 mA
8.	Charging Algorithm	PWM
9.	Dimension	178 x 100 x 51
10.	Protection Class	IP30
11.	Specific Temperature Range	-20°C to +50°C

3.2Why solar charging unit required??

At first we need to require how the solar output generated. Whenever photons are hits our solar panel electron start to flow under photo electric effect. But the problem is solar energy is very unpredictable that's why we need store this energy as well as use this energy as a output power. Here again one problem we face that battery always require constant voltage to charge. To do that solar charge controller comes into account. Solar charge controller protects our battery from overcharging as well as over discharging.

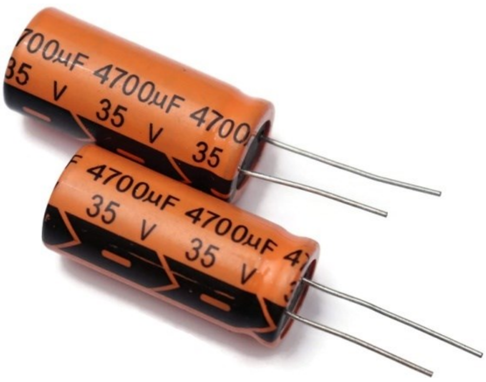
A typical **Solar DC system** , two terminal solar panel to access the solar output power, six terminal of solar charge controller (2 terminal draws the output power of solar panel, 2 terminal is to charge the battery as well as operate the load.) 2 terminal to access the controlled dc power.



3.3Item we require to make solar charging controller:

3.3.1Capacitor 470uf:-

capacitor, device for storing electrical energy, consisting of two conductors in close proximity and insulated from each other. A simple example of such a storage device is the parallel-plate capacitor. If positive charges with total charge +*Q* are deposited on one of the conductors and an equal amount of negative charge −*Q* is deposited on the second conductor, the capacitor is said to have a charge *Q*.

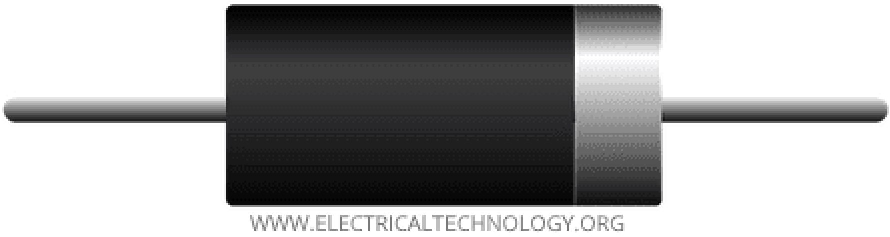


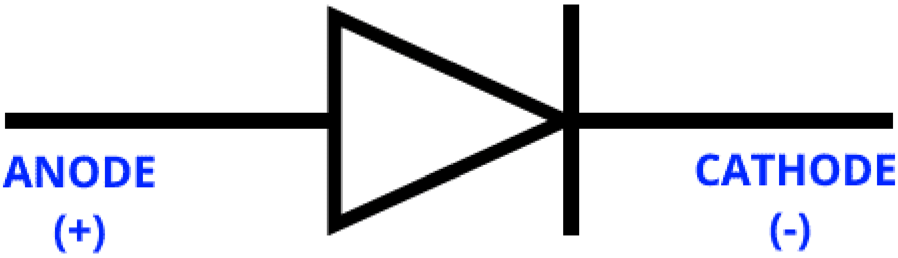
Capacitors have many important applications. They are used, for example, in digital circuits so that information stored in large computer memories is not lost during a momentary electric power failure; the electric energy stored in such capacitors maintains the information during the temporary loss of power. Capacitors play an even more important role as filters to divert spurious electric signals and thereby prevent damage to sensitive components and circuits caused by electric surges.

3.3.2IN4007:-

Diode, an electrical component that allows the flow of current in only one direction. In circuit diagrams, a diode is represented by a triangle with a line across one vertex.

The most common type of diode uses a *p*-*n* junction. In this type of diode, one material (*n*) in which electrons are charge carriers abuts a second material (*p*) in which holes (places depleted of electrons that act as positively charged particles) act as charge carriers. At their interface, a depletion region is formed across which electrons diffuse to fill holes in the *p*-side. This stops the further flow of electrons. When this junction is forward biased (that is, a positive voltage is applied to the *p*-side), electrons can easily move across the junction to fill the holes, and a current flows through the diode. When the junction is reverse biased (that is, a negative voltage is applied to the *p*-side), the depletion region widens and electrons cannot easily move across. The current remains very small until a certain voltage (the breakdown voltage) is reached and the current suddenly increases.



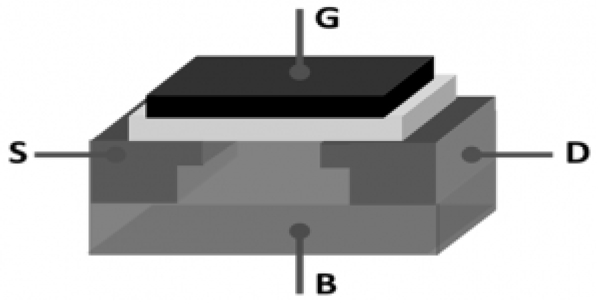


Light-emitting diodes (LEDs) are *p*-*n* junctions that emit light when a current flows through them. Several *p*-*n* junction diodes can be connected in series to make a rectifier (an electrical component that converts alternating current to direct current). Zener diodes have a well-defined breakdown voltage, so that current flows in the reverse direction at that voltage and a constant voltage can be maintained despite fluctuations in voltage or current. In varactor (or varicap) diodes, varying the bias voltage causes a variation in the diode's capacitance; these diodes have many applications for signal transmission and are used throughout the radio and television industries. (For more detail about these and other types of diodes, *see* semiconductor device.)

Early diodes were vacuum tubes, an evacuated glass or metal electron tube containing two electrodes—a negatively charged cathode and a positively charged anode. These were used as rectifiers and as detectors in electronic circuits such as radio and television receivers. When a positive voltage is applied to the anode (or plate), electrons emitted from the heated cathode flow to the plate and return to the cathode through an external power supply. If a negative voltage is applied to the plate, electrons cannot escape from the cathode, and no plate current flows. Thus, a diode permits electrons to flow from cathode to plate but not from plate to cathode. If an alternating voltage is applied to the plate, current flows only during the time when the plate is positive. The alternating voltage is said to be rectified, or converted to direct current.

3.3.4IRF740

- A MOSFET is a four-terminal device having source(S), gate (G), drain (D) and body (B) terminals. In general, The body of the MOSFET is in connection with the source terminal thus forming a three-terminal device such as a field-effect transistor. MOSFET is generally considered as a transistor and employed in both the analog and digital circuits. This is the basic **introduction to MOSFET**. And the general structure of this device is as below :



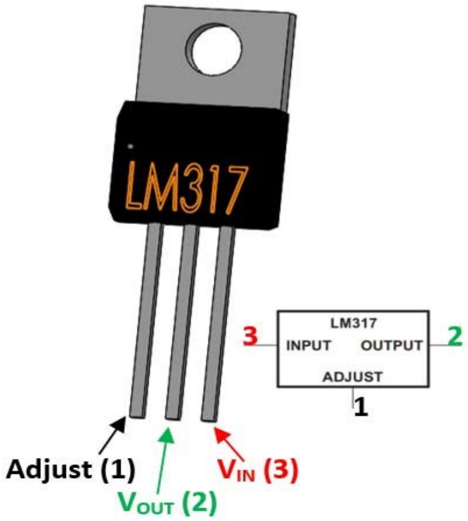
- MOSFET
- From the above **MOSFET structure**, the functionality of MOSFET depends on the electrical variations happening in the channel width along with the flow of carriers (either holes or electrons). The charge carriers enter into the channel through the source terminal and exit via the drain.
- The width of the channel is controlled by the voltage on an electrode which is called the gate and it is located in between the source and the drain. It is insulated from the channel near an extremely thin layer of metal oxide. The MOS capacity that exists in the device is the crucial section where the entire operation is across this.

- **3.3.5Pot**

A potentiometer is **a three-terminal resistor with a sliding or rotating contact that forms an adjustable voltage divider**. If only two terminals are used, one end and the wiper, it acts as a variable resistor or rheostat

- **3.3.6LM314T**

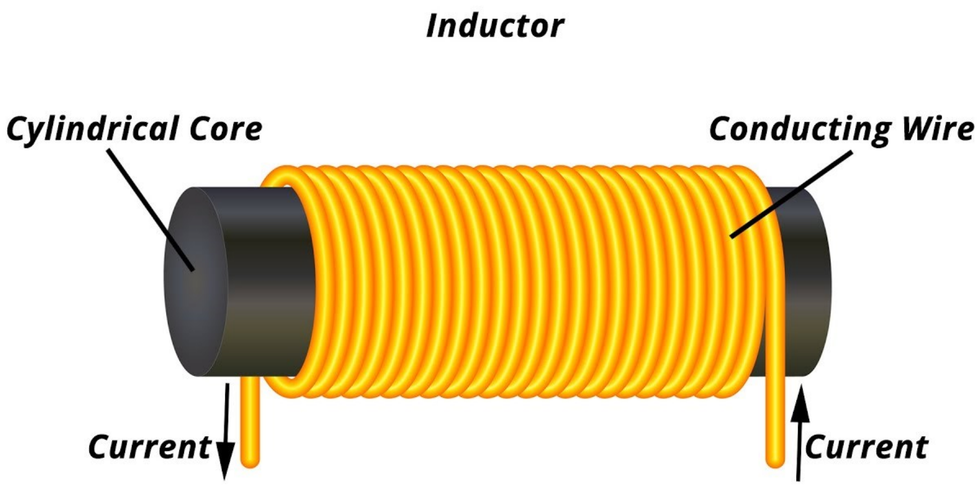
The LM317 is an adjustable 3−terminal positive voltage regulator capable of supplying in excess of 1.5 A over an output voltage range of 1.2 V to 37 V. This voltage regulator is exceptionally easy to use and requires only two external resistors to set the output voltage. Further, it employs internal current limiting, thermal shutdown and safe area compensation, making it essentially blow−out proof. The LM317 serves a wide variety of applications including local, on card regulation. This device can also be used to make a programmable output regulator, or by connecting a fixed resistor between the



adjustment and output.

3.3.7Inductor 1mH

An inductor is a passive component that is used in most power electronic circuits to store energy in the form of magnetic energy when electricity is applied to it. One of the key properties of an inductor is that it impedes or opposes any change in the amount of current flowing through it. Whenever the current across the inductor changes it either acquires charge or loses the charge in order to equalize the current passing through it. The inductor is also called a

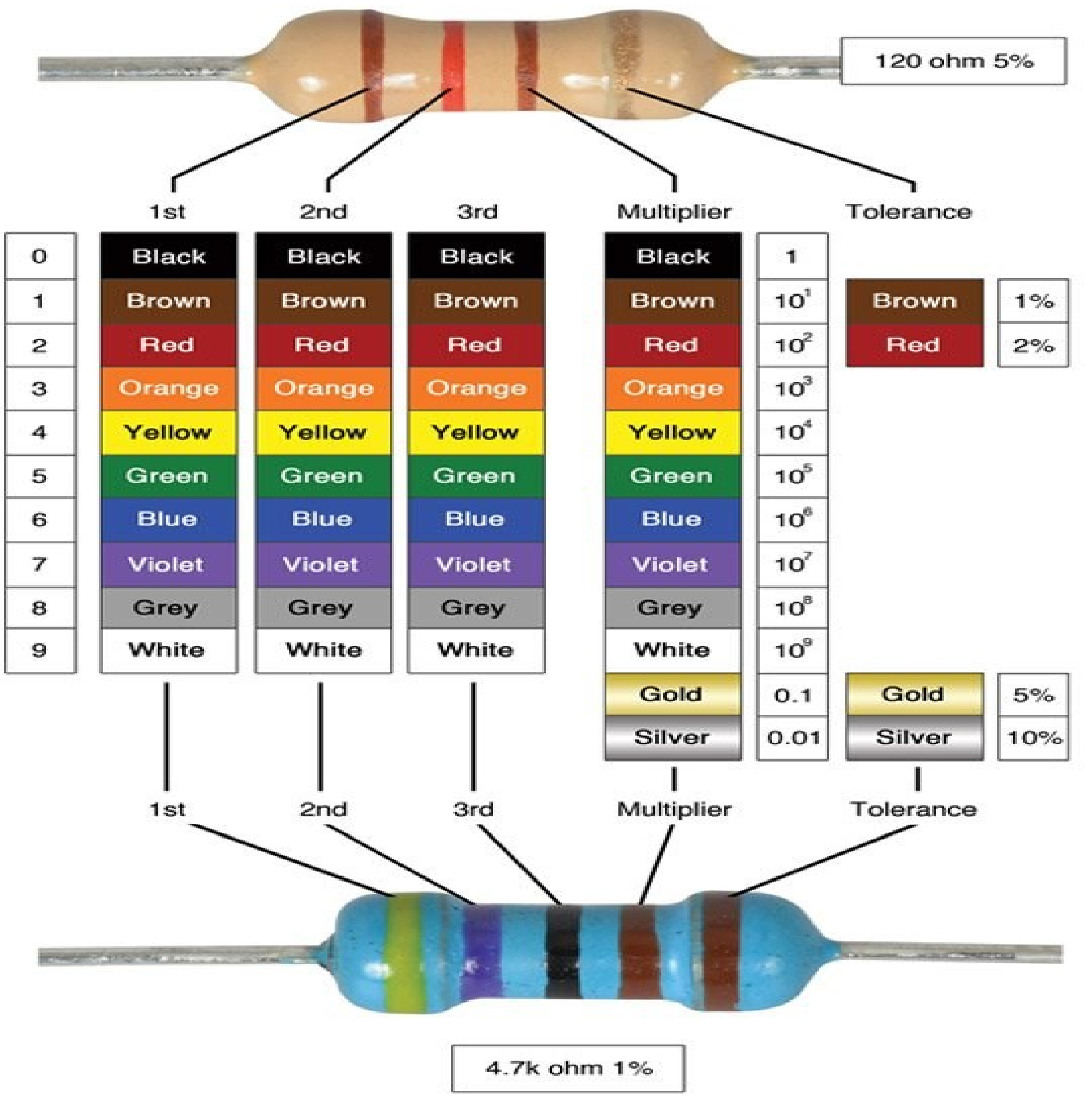


choke, reactor or just coil.

- **3.3.8Resistor (5K,4.3K,10K)**

A passive electrical component with two terminals that are used for either limiting or regulating the flow of electric current in electrical circuits.

The main purpose of resistor is to reduce the current flow and to lower the voltage in any particular portion of the circuit. It is made of copper wires which are coiled around a ceramic rod and the outer part of the resistor is coated with an insulating paint



PWM Charge Controller

One of the most adopted charge controllers for storing the energy from the solar panel to the battery backup is the Pulse Width Modulation (PWM) charge controller. Here the input solar energy has to pass through a switching circuit to store in the battery backup. This switching circuit is controlled by ICCPET 2020 Journal of Physics: Conference Series 1712 (2020) 012023 IOP Publishing doi:10.1088/1742-6596/1712/1/012023 3 Battery Reference Voltage an oscillator whose pulse width is varying with the amount of energy stored in the battery backup. The block diagram of the solar PWM charge controller is as shown in figure 1. Figure 1. Conceptual model of solar PWM charge controller. If the energy in the battery backup is less then the pulse width high state will be large enough and the pulse width of low state will be a single spike. The nature of pulses during the heavy charging mode is as shown in the figure 2. Figure 2. The output of PWM oscillator during low battery storage. The output of the PWM oscillator is then connected to a switching circuit to control the battery charging. Here most of the time of an entire pulse cycle the switch remains on and the solar energy will be getting stored in the battery backup. When the battery backup is getting filled the on stage of the pulse width will reduce and the off stage of the pulse width will increase. The nature of the pulse during the 50 % charged battery stage is as shown in the figure 3. Figure 3. The output of PWM oscillator during 50% battery storage.

Pulse Width Modulation (PWM) is the most effective means to achieve constant voltage battery charging by switching the solar system controller's power devices. When in PWM regulation, the current from the solar array tapers according to the battery's condition and recharging needs

Charging a battery with a solar system is a unique and difficult challenge. In the old days, simple on-off regulators were used to limit battery outgassing when a solar panel produced excess energy. However, as solar systems matured it became clear how much these simple devices interfered with the charging process.

The history for on-off regulators has been early battery failures, increasing load disconnects, and growing user dissatisfaction. PWM has recently surfaced as the first significant advance in solar battery charging.

PWM solar chargers use technology similar to other modern high quality battery chargers. When a battery voltage reaches the regulation setpoint, the PWM algorithm slowly reduces the charging current to avoid heating and gassing of the battery, yet the charging continues to return the maximum amount of energy to the battery in the shortest time. The result is a higher charging efficiency, rapid recharging, and a healthy battery at full capacity.

In addition, this new method of solar battery charging promises some very interesting and unique benefits from the PWM pulsing. These include:

1. Ability to recover lost battery capacity and desulfate a battery.
2. Dramatically increase the charge acceptance of the battery.
3. Maintain high average battery capacities (90% to 95%) compared to on-off regulated state-of-charge levels that are typically 55% to 60%.
4. Equalize drifting battery cells.
5. Reduce battery heating and gassing.
6. Automatically adjust for battery aging.
7. Self-regulate for voltage drops and temperature effects in solar systems
8.
9.

MPPT CHARGE CONTROLLER

Using a solar panel or an array of panels without a controller that can perform Maximum Power Point Tracking (MPPT) will often result in wasted power, which ultimately results in the need to install more panels for the same power requirement. For smaller/cheaper devices that have the battery connected directly to the panel, this will also result in premature battery failure or capacity loss, due to the lack of a proper end-of-charge procedure and higher voltage. In the short term, not using an MPPT controller will result in a higher installation cost and, in time, the costs will escalate due to eventual equipment failure. Even with a proper charge controller, the prospect of having to pay 30-50% more up front for additional solar panels makes the MPPT controller very attractive. This application note describes how to implement MPPT using the most popular switching power supply topologies. There are many published works on this topic, but only a tiny portion of them show how to actually implement the algorithms in hardware, as well as state common problems and pitfalls. Even when using the simplest MPPT algorithm with a well-designed synchronous switching power supply, it can be expected that at least 90% of the panel's available power will end up in the battery, so the benefits are obvious. The topology presented in this application note is an inverse SEPIC, but the techniques used here can be applied to buck, boost and SEPIC converters. The buck converter is a special case, since it has a linear voltage transfer function when operating in Continuous Conduction Mode (CCM). This simplifies things a lot, and the MPPT controller can be implemented by operating directly on the converter duty cycle. The other topologies have a nonlinear voltage transfer function, and operating directly on the duty cycle will yield unpredictable results, especially at high duty cycles. In this case, the algorithm modifies the solar panel operating voltage by using a proportional integral (PI) control loop, which steers the voltage to the desired value. SOLAR PANEL MPPT The main problem solved by the MPPT algorithms is to automatically find the panel operating voltage that allows maximum power output. In a larger system, connecting a single MPPT controller to multiple panels will yield good results, but, in the case of partial shading, the combined power output graph will have multiple peaks and valleys (local maxima). This will confuse most MPPT algorithms and make them track incorrectly. Some techniques to solve problems related to partial shading have been proposed, but they either need to use additional equipment (like extra

monitoring cells, extra switches and current sensors for sweeping panel current), or complicated models based on the panel characteristics (panel array dependent). These techniques only make sense in large solar panel installations, and are not within the scope of this application note. Ideally, each panel or small cluster of panels should have their own MPPT controller. This way the risk of partial shading is minimized, each panel is allowed to function at peak efficiency, and the design problems related to converters handling more than 20-30A are eliminated. A typical solar panel power graph (Figure 1) shows the open circuit voltage to the right of the maximum power point. The open circuit voltage (VOC) is obviously the maximum voltage that the panel outputs, but no power is drawn. The short-circuit current of the panel (ISC) is another important parameter, because it is the absolute maximum current you can get from the panel.

► Comparing the Two

If maximizing charging capacity were the only factor considered when specifying a solar controller, everyone would use a MPPT controller. But the two technologies are different, each with it's own advantages. The decision depends on site conditions, system components, size of array and load, and finally the cost for a particular solar power system.

► Temperature Conditions

An MPPT controller is better suited for colder conditions. As solar module operating temperature goes down, the Vmp1 increases. That's because the voltage of the solar panels operating at their peak power point at Standard Testing Conditions (STC is 25C°) is about 17V while the battery voltage is about 13.5V. The MPPT controller is able to capture the excess module voltage to charge the batteries. As a result, a MPPT controller in cool conditions can produce up to 20 – 25% more charging than a PWM controller.

In comparison, a PWM controller is unable to capture excess voltage because the pulse width modulation technology charges at the same voltage as the battery. However, when solar panels are deployed in warm or hot climates, their Vmp decreases, and the peak power point operates at a voltage that is closer to the voltage of a 12V battery. There is no excess voltage to be transferred to the battery making the MPPT controller unnecessary and negating the advantage of an MPPT over a PWM.

► Array to Load Ratio

In a scenario where the solar array is large relative to the power draw from the batteries by the load, the batteries will stay close to a full state of charge. A PWM controller is capable of efficiently maintaining the system without the added expense of an MPPT controller.

► Size of the System

Low power systems are better suited to a PWM controller because:

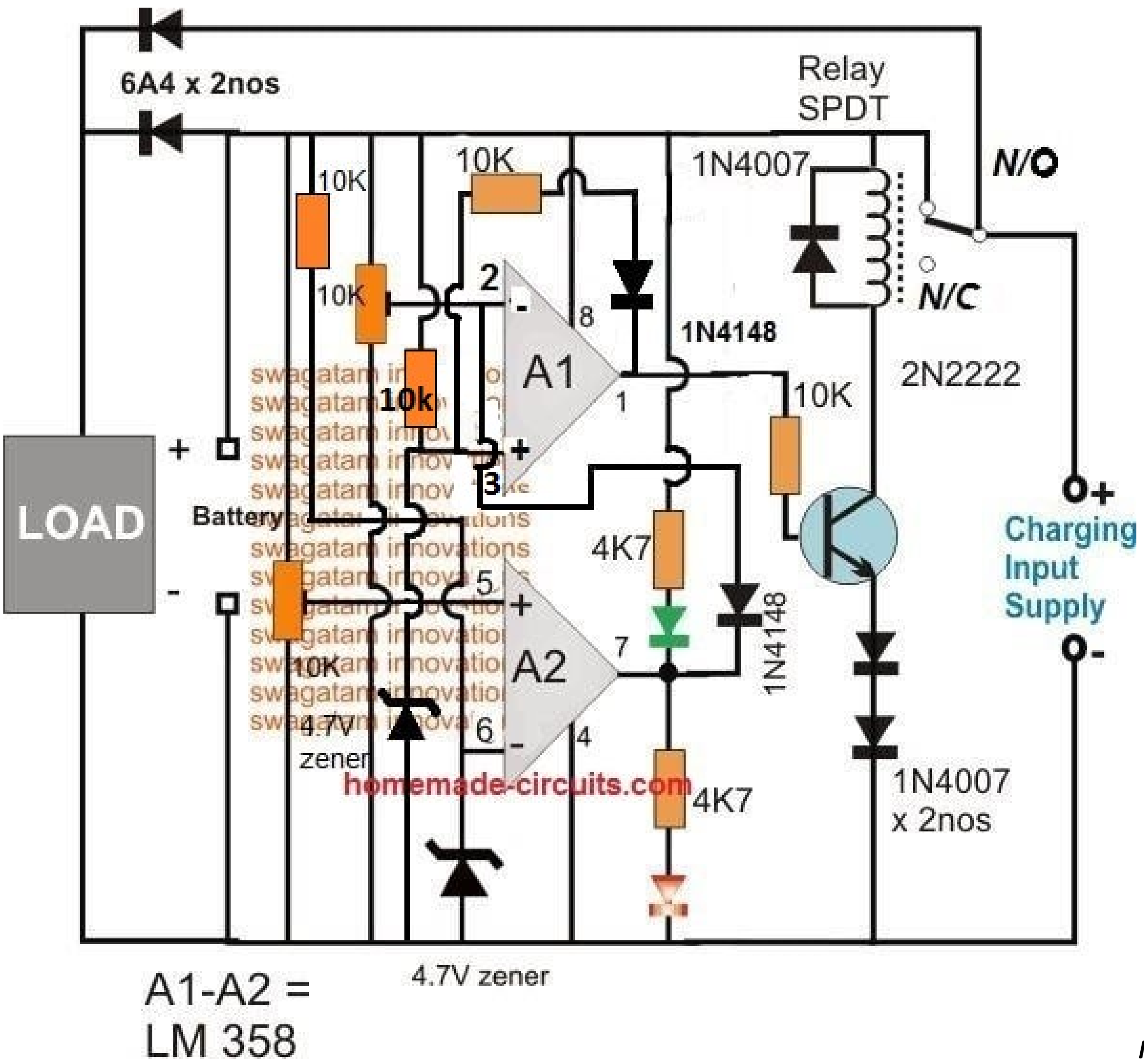
- A PWM controller operates at a relatively constant harvesting efficiency regardless of the size of the array
- A PWM controller is less expensive that a MPPT, so is a more economical choice for a small system

SPV Charge Controller Prototype Theory

Circuit Objectives and Requirements

1. As soon as I connect the external power automatically it will disconnect the battery and supply the system, in the meanwhile charging the battery.
2. Overcharging protection (which included in the above design).
3. Battery low and full charging indications (which included in the above design).
4. Also i don't know what is the formula to help how to determine the voltage required across my battery to charge it with(battery will be extracted of old laptops.total will be 22V with 6 apms at no load)
5. Furthermore, I don't know the formula to indicate how long my battery will last, and how to calculate the time if i want a battery to last me two hours.
6. Also, the cpu fan will supplied by the system too. It would be great too to add the option of a dimmer, my original plan was to vary between 26-30 v not need much more than that.

Circuit Diagram



Note: Please replace the 10K in series with the 1N4148, with a 1K

The Design

In all of my previous battery charger controller circuits I have used a single opamp for executing the full charge auto cut-off, and have employed a hysteresis resistor for enabling the low level charging switch ON for the connected battery.

However calculating this hysteresis resistor correctly for achieving the precise low level restoration becomes slightly difficult and requires some trial and error effort which can be time consuming.

In the above proposed opamp low high battery charger controller circuit two opamp comparator are incorporated instead of one which simplifies the set up procedures and relieves the user from the long procedures.

Referring to the figure we can see two opamps configured as comparators for sensing the battery voltage and for the required cut-off operations.

Assuming the battery is s 12V battery, the lower A2 opamp's 10K preset is set such that its output pin#7 becomes high logic when the battery voltage just crosses the 11V mark (lower discharge threshold), while the upper A1 opamp's preset is adjusted such that its output goes high when the battery voltage touches the higher cut off threshold, say at 14.3V.

Therefore at 11V, the A1 output gets positive but due to the presence of the 1N4148 diode this positive stays ineffective and blocked from moving further to the base of the transistor.

The battery continues to charge, until it reaches 14.3V when the upper opamp activates the relay, and stops the charging supply to the battery.

The situation is instantly latched due to the inclusion of the feedback resistors across pin#1 and pin#3 of A1. The relay becomes locked in this position with the supply completely cut off for the battery.

The battery now begins slowly discharging via the connected load until it reaches its lower discharge threshold level at 11V when the A2 output is forced to go negative or zero. Now the diode at its output becomes forward biased and quickly breaks the latch by grounding the latching feedback signal between the indicated pins of A1.

With this action the relay is instantly deactivated and restored to its initial N/C position and the charging current yet again begins flowing towards the battery.

This opamp low high battery charger circuit can be used as a DC UPS circuit also for ensuring a continuous supply for the load regardless of the mains presence or absence and for getting an uninterrupted supply through out its usage.

The input charging supply could be acquired from a regulated power supply such as an LM338 constant current variable constant voltage circuit externally.

How to Set the Presets

- Initially keep the 1k/1N4148 feedback disconnected from the A1 op amp.
- Move the A1 preset slider to ground level, and move the A2 preset slider to the positive level.

- Through a variable power supply, apply 14.2 V which is the full charge level for a 12 V battery across the "Battery" points.
- You will find the relay activating.
- Now slowly move the A1 preset towards the positive side until the relay just deactivates.
- This sets the full charge cut off.
- Now, connect the 1k/1N4148 back so that the A1 latches the relay in that position.
- Now slowly adjust the variable supply towards the lower discharge limit of the battery, you will find the relay continues to remain switched OFF due to the above mentioned feedback response.
- Adjust the power supply down to the lower battery discharge threshold level.
- After this, begin moving the A2 preset towards the ground side, until this turns A2 output to zero which breaks the A1 latch, and switches ON the relay back to the charging mode.
- That's all, the circuit is fully set now, seal the presets in this position.

Answers for other additional questions in the request are as given under:

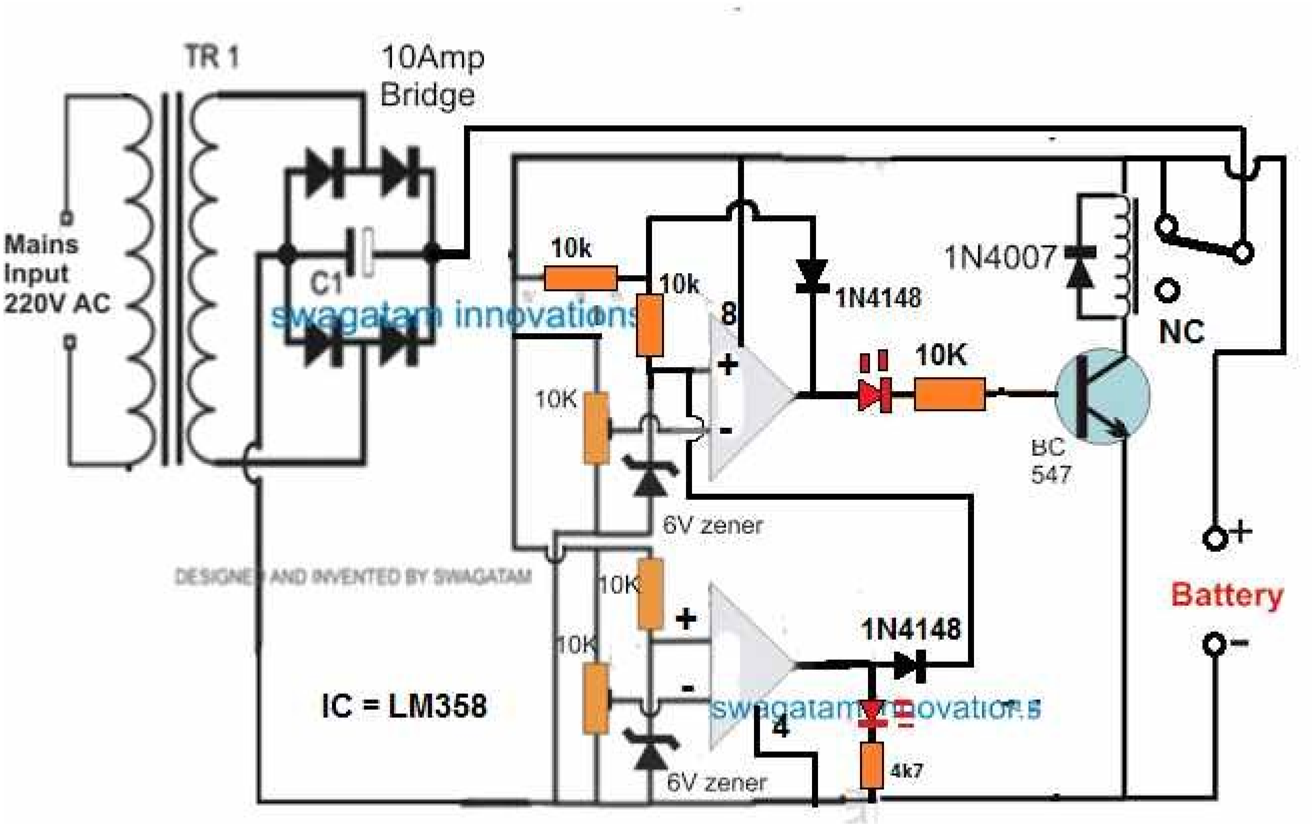
Formula for calculating full charge cut off limit is:

Battery voltage rating + 20%, for example 20% of 12V is 2.4, so 12 + 2.4 = 14.4V is the full charge cut off voltage for a 12V battery

To know the battery back up time the following formula can be used, which gives you the approximate battery back up time.

Backup = 0.7 (Ah / Load Current)

Another alternative design for making an automatic over/under charge cut-off battery charger circuit using two op amps, can be seen below:



How it Works

Assuming there's no battery connected, the relay contact is at N/C position. Therefore when power is switched ON, the op amp circuit is unable to get powered and stays inactive.

Now, suppose a discharged battery is connected across the indicated point, the op amp circuit gets powered through the battery. Since the battery is at a discharged level, it creates a low potential at (-) input of the upper op amp, which may be less than the (+) pin.

Due to this, the upper op amp output goes high. The transistor and the relay activate, and the relay contacts moves from N/C to N/O. This now connects the battery with the input power supply, and it begins charging.

Once the battery is fully charged, the potential at (-) pin of the upper op amp becomes higher than its (+) input, causing the output pin of the upper op amp to go low. This instantly switches OFF the transistor and the relay.

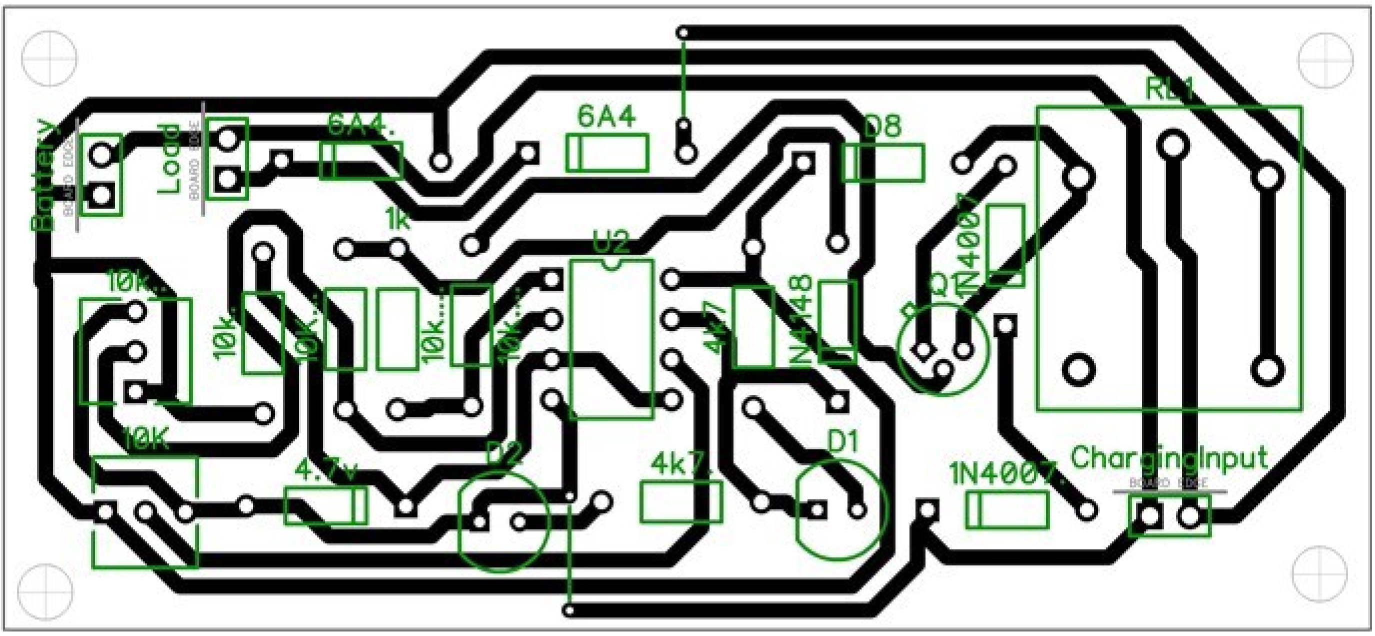
The battery is now disconnected from the charging supply.

The 1N4148 diode across the (+) and the output of the upper op amp latches so that even if the battery begins dropping it has no effect on the relay condition.

However, suppose the battery is not removed from the charger terminals, and a load is connected to it so that it begins discharging.

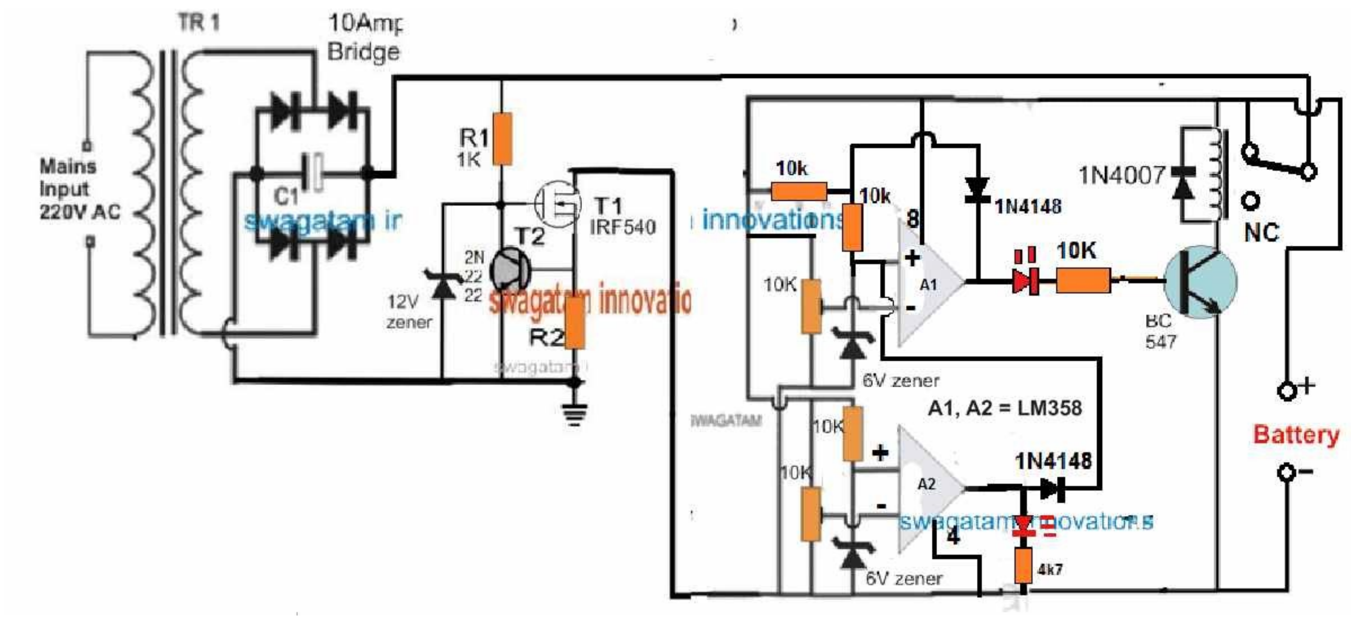
When the battery discharges below the desired lower level, the potential at pin (-) of the lower op amp goes lower than its (+) input pin. This instantly causes the output of the lower op amp to go high, which hits the pin3 of the upper op amp. This instantly breaks the latch, and switches ON the transistor and the relay to initiate the charging process yet again.

PCB Design



Adding a Current Control Stage

The above two designs can be upgraded with a current control by adding a MOSFET based current control module, as shown below:



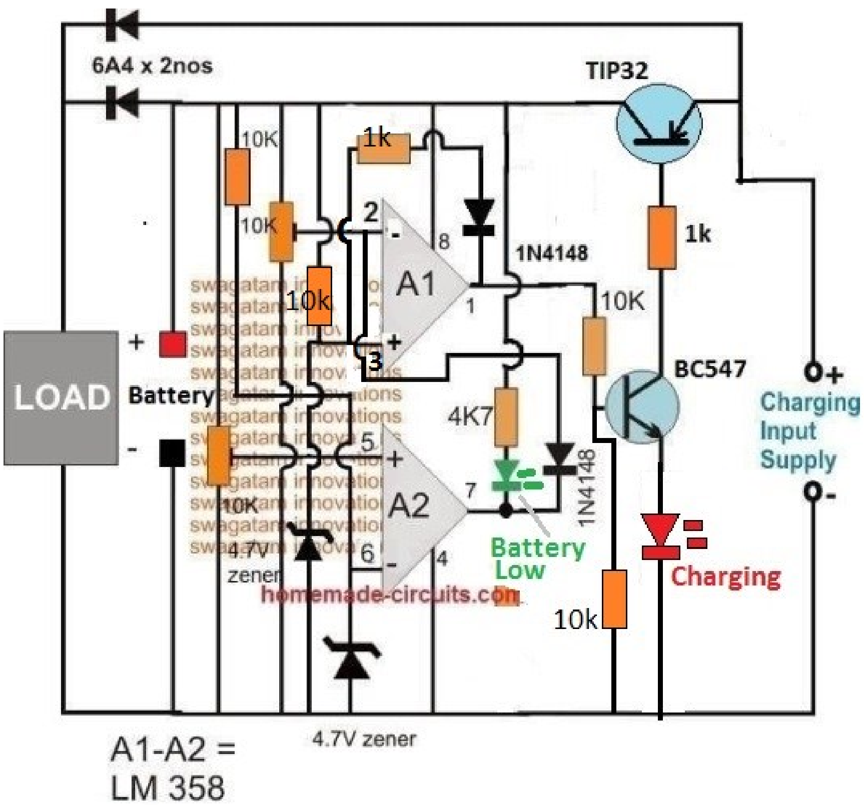
R2 = 0.6 / charging current

Adding a Reverse Polarity Protector

A reverse polarity protection can be included to the above designs by adding a diode in series with the positive terminal of the battery. Cathode will go the battery positive terminal, and anode to the op amp positive line.

Please make sure connect a 100 Ohm resistor across this diode, otherwise the circuit will not initiate the charging process.

Removing the Relay



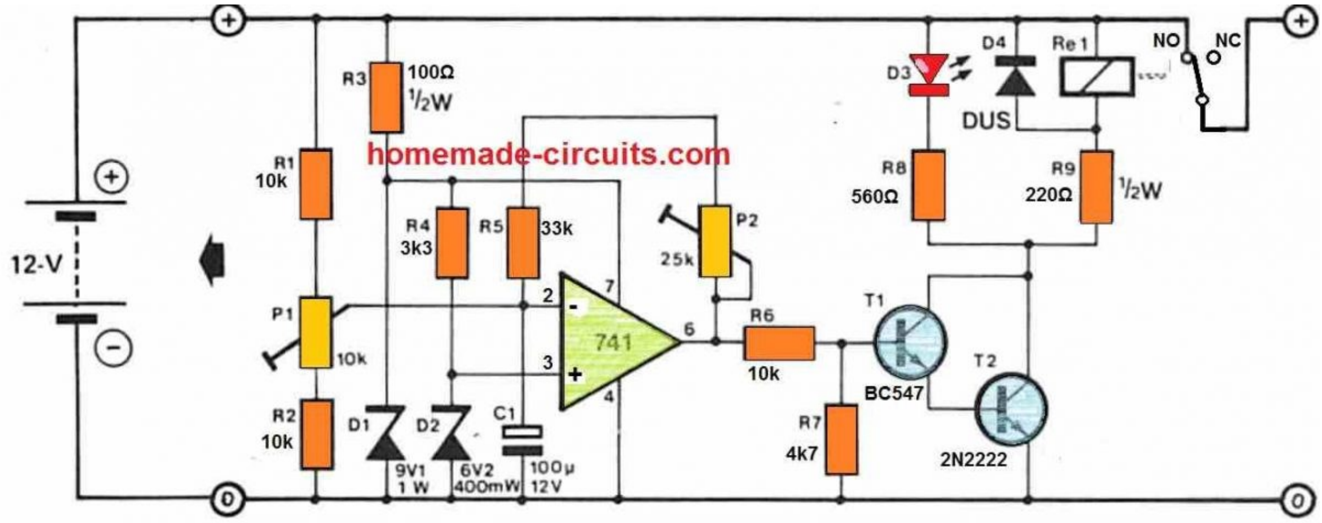
n the first opamp based battery charger design, it may be possible to eliminate the relay and operate the charging process through solid state transistors, as shown in the following diagram:

How the Circuit Works

- Let's assume A2 preset is adjusted at 10 V threshold, and A1 preset is adjusted at 14 V threshold.
- Suppose we connect a battery that is discharged at an intermediate stage of 11 V.
- At this voltage pin2 of A1 will be below its pin3 reference potential, as per the setting of the pin5 preset.
- This will cause the output pin1 of A1 to be high, turning ON the transistor BC547 and the TIP32.
- The battery will now start charging via TIP32, until is terminal voltage reaches 14 V.
- At 14 V, as per the setting of the upper preset, pin2 of A1 will go higher than its pin3, causing the output to turn low.
- This will instantly switch OFF the transistors, and stop the charging process.
- The above action will also latch the A1 op amp through the 1k/1N4148 so that even if the battery voltage drops to the SoC level of 13 V, the A1 will continue hold the pin1 output low.
- Next, as the battery begins discharging via an output load, its terminal voltage begins dropping, until it has dropped to 9.9 V.
- At this level, as per the setting of the lower preset, pin5 of A2 will drop below its pin6, causing its output pin7 to turn low.
- This low at pin7 of A2 will pull pin2 of A1 to almost 0 V, such that now pin3 of A1 becomes higher than its pin2.
- This will immediately break the A1 latch, and the output of A1 will once again turn high, enabling the transistor to switch ON and initiate the charging process.
- When the battery reaches 14 V, the process will repeat the cycle yet again

Single Op amp Automatic Battery Charger Circuit

Automatic battery chargers just aren't economical, but the protection they provide from overcharging and potential battery degradation is extremely appealing. The circuit illustrated here is meant to be a low-cost replacement to commercially available fully automated chargers. The concept is to pick a basic battery charger and install an add-on module that will automatically check the condition of the battery and turn off the charge current as soon as the battery gets fully charged.



How it Works

The circuit is simply made up of a comparator that checks the battery voltage in relation to a preset reference value. When the battery voltage surpasses a certain peak value, a relay is turned OFF, causing the charge current to be terminated. When the battery voltage declines below a certain specified lower limit, the relay activates, allowing the charge current to flow again. A 741 op-amp serves as the comparator. The op-amp's supply voltage is stabilized by R3 and D1, thus it is immune to fluctuations in battery voltage.

The reference voltage, that is supplied to the op amp's non-inverting input through R4 and D2, is generated through this stabilized supply. The reference voltage is compared with the battery charge voltage, via the resistive divider. As the battery charges, the voltage at the inverting input of the op-amp finally becomes higher than that on the non-inverting input, causing the output of the op-amp to go low, switching off T1 and T2. This causes the normally closed contact of the relay to open, cutting off the input charge current to the battery.

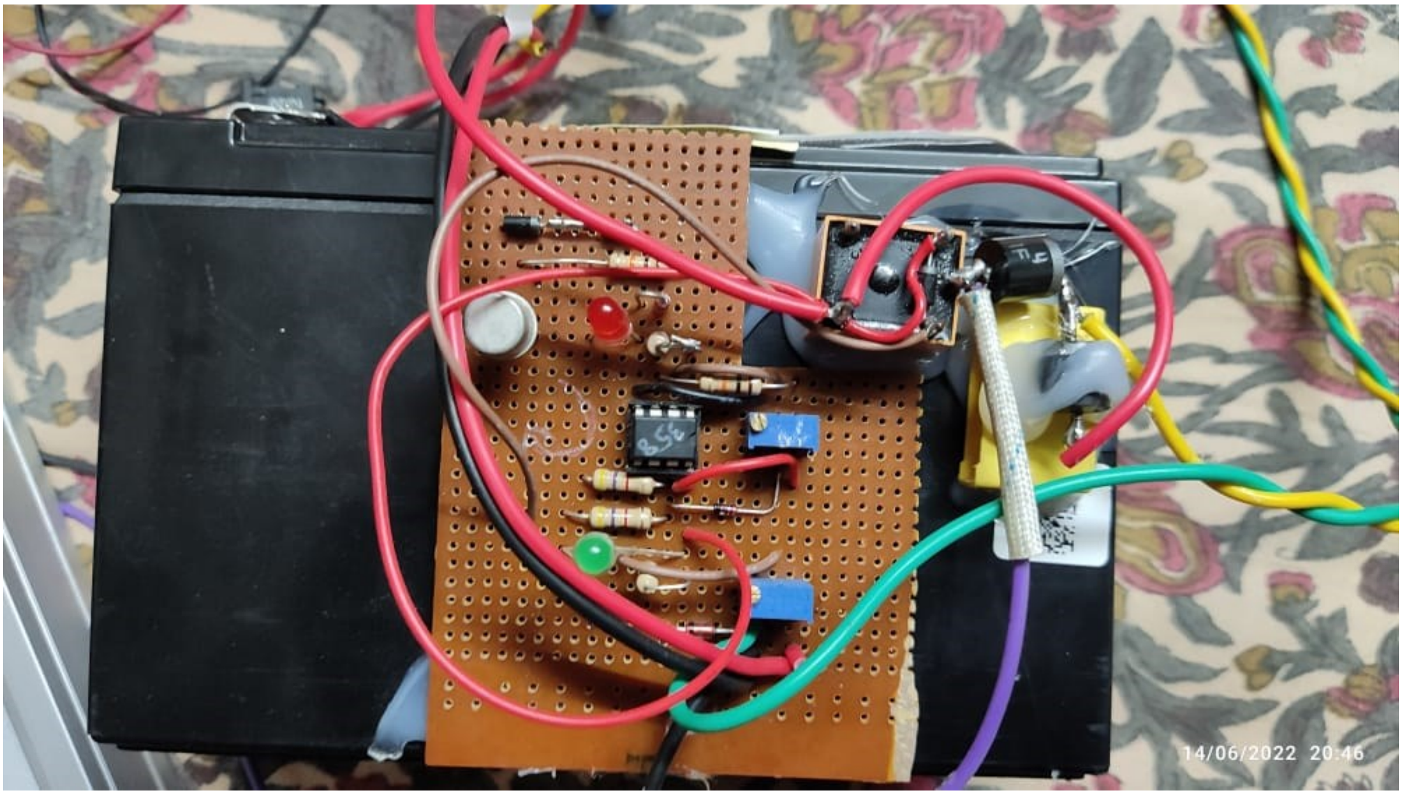
The battery full level will then illuminate LED D3 to show that it is completely charged. A part of the op-amp output voltage is sent back to the inverting input through P2 and R5 to discourage the battery from reverting to the charging mode at the smallest reduction in the battery voltage. The op-amp therefore works in the same way as a Schmitt trigger, with P2 determining the level of hysteresis, or the battery potential where the op-amp output can turn low again.

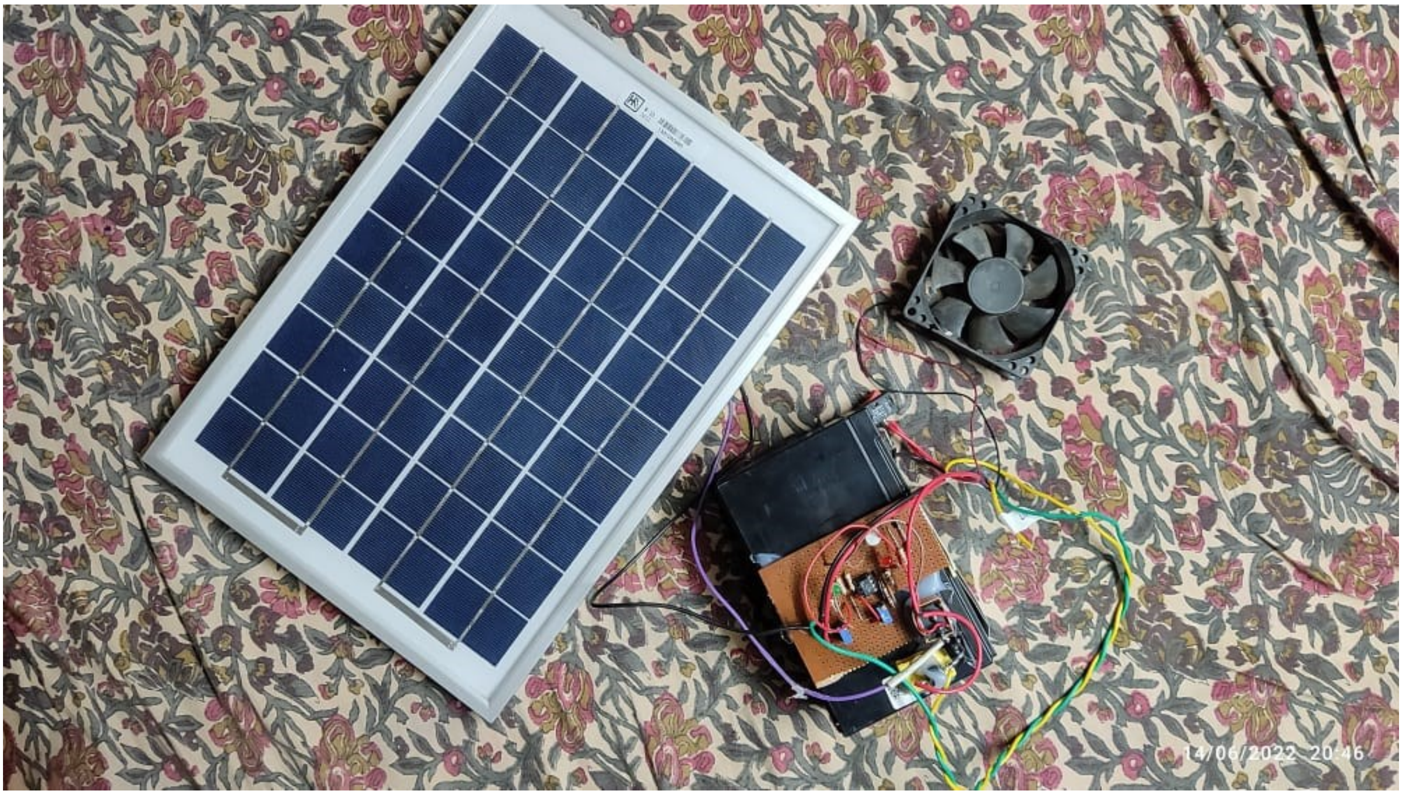
How to Setup

The easiest way to setup the circuit is to use an adjust stabilized voltage to simulate the battery voltage.

An input voltage of around 14.5 V is determined, and P1 is tuned so that the relay simply clicks off (opens). The voltage of the 'battery' is then lowered to 12.4 V, and P2 is tweaked until the relay reconnects and switches ON. Because P1 and P2 will have an effect on each other, the operation should be done numerous times.

Prototype Images





Conclusion and future scope

Conclusion

Here we developed a prototype which automatically charges the battery in respect to the voltage output and solar input. It will help in reducing human effort and error. Our circuit consists of LM358, 2N2222 transistor, MOR resistors, Diode, Zener diode, Solar cells, and battery. The prototype worked satisfactorily.

5.2 Result

The experimental model was made according to the circuit diagram and the results were as expected. The LED lights properly stated the status of the operation at each step. After the charge was completed, the circuit was stopped.

5.3 Future work

With help of this prototype, villages and even urban areas can be lightened up inexpensively. We are thinking about taking this as a mean of social improvement and business.

Reference

- [1] J. Adeeb, A. Farhan, and A. Al-Salaymeh, “Temperature Effect on Performance of Different Solar Cell Technologies,” J. Ecol. Eng., vol. 20, no. 5, pp. 249–254, 2019.
- [2] A. F. Sherwani, M. Asjad, and A. Haleem, “Performance evaluation of solar photovoltaic electricity-generating systems: an Indian perspective,” Int. J. Sustain. Eng., vol. 12, no. 1, pp. 70–75, 2019.
- [3] B. Parida, S. Iniyan, and R. Goic, “A review of solar photovoltaic technologies,” Renew. Sustain. Energy Rev., vol. 15, no. 3, pp. 1625–1636, 2011.
- [4] S. Mughal, Y. R. Sood, and R. K. Jarial, “A Review on Solar Photovoltaic Technology and Future Trends,” J. Phys., no. April, pp. 227–235, 2018.
- [5] A. Goetzberger, C. Hebling, and H.-W. Schock, “Photovoltaic materials, history, status and outlook,” Mater. Sci. Eng. R Reports, vol. 40, no. 1, pp. 1–46, 2003.
- [6] A. Luceño-s and A. Mar, “Materials for Photovoltaics : State of Art and Recent Developments,” Int. J. Mol. Sci., vol. 20, pp. 1–42, 2019.

THANK YOU