SOLAR CHARGE CONTROLLER USING MAXIMUM POWER POINT TRACKING

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Abstract

This thesis, aim to design and simulation of a simple but effective charge controller with maximum power point tracker for photovoltaic system. It provides theoretical studies of photovoltaic systems and modelling techniques using equivalent electric circuits. As, the system employs the maximum power point tracker (MPPT), it is consists of various MPPT algorithms and control methods. P-Spice and MATLAB simulations verify the DC-DC converter design and hardware implementation. The results validate that MPPT can significantly increase the efficiency and the performance of PV.

Keywords: *solar charge controller, PWM(pulse width modulation), MPPT (maximum power point tracking), solar panel.*

1. Introduction

In India most of the people are living in rural area where national grid transmission line is not reached till now. The existing electric grids are not capable of supplying the electricity need to those poor people. So renewable energy sources (**photo voltaic panels** and wind-generators) are the best option.

Solar power have the advantage of being less maintenance and pollution free but their main drawbacks is high fabrication cost, low energy conversion efficiency. Since solar panels still have relatively low conversion efficiency, the overall system cost can be reduced using a efficient **solar charge controller** which can extract the maximum possible power from the panel .

In solar power system, **charge controlle**r is the heart of the system which was designed to protect the rechargeable battery.

1.1 What is a Charge Controller ?

A solar charge controller is fundamentally a voltage or current controller to charge the battery and keep electric cells from overcharging. It directs the voltage and current hailing from the solar panels setting off to the electric cell. Generally, 12V boards/panels put out in the ballpark of 16 to 20V, so if there is no regulation the electric cells will damaged from overcharging. Generally, electric storage devices require around 14 to 14.5V to get completely charged. The solar charge controllers are available in all features, costs and sizes. The range of charge controllers are from 4.5A and up to 60 to 80A.

1.2 Types of Solar Charge Controllers

The two types of charge controllers most commonly used in today's solar power systems

1. Pulse width modulation (PWM) and
2. Maximum power point tracking (MPPT).

Both adjust charging rates depending on the battery's maximum capacity as well as monitor the battery temperature to prevent overheating .

1.3 Pulse Width Modulation (PWM) ChargeController- Pulse width modulation (PWM) charge controller is the most effective means to achieve constant voltage battery charging by adjusting the duty ratio of the switches (MOSFET). In PWM charge controller, the current from the solar panel tapers according to the battery's condition and recharging needs. When a battery voltage reaches the regulation set point, the PWM algorithm slowly reduces the charging current to avoid heating and gassing of the battery; yet charging continues to return the maximum amount of energy to the battery in the shortest time. The voltage of the array will be pulled down to near that of the battery.

PWM system has the following advantages:

- Higher charging efficiency
- Longer battery life
- Reduced battery over heating
- Minimizes stress on the battery
- Ability to de-sulfate a battery

A PWM controller is not a DC to DC transformer. The PWM controller is a switch which connects the solar panel to the battery. When the switch is closed, the panel and the battery will be at nearly the same voltage.

Assuming a discharged battery, the initial charge voltage will be around 13V, and assuming a voltage loss of 0.5V over the cabling plus controller. The voltage will slowly increase with increasing state of charge of the battery. When absorption voltage is reached, the PWM controller will start to disconnect and reconnect the panel to prevent overcharge (hence the name; pulse width modulated charge controller)

1.4. Maximum Power Point Tracking

Nowadays, the most advanced solar charge controller available is the Maximum Power Point Tracking (MPPT). It is more sophisticated and more expensive. It has several advantages over the PWM charge controller. It is 30 to 40% more efficient at low temperature. The MPPT is based around a synchronous buck converter circuit. It steps the higher solar panel voltage down to the charging voltage of the battery.

It will adjust its input voltage to harvest the maximum power from the solar panel and then transform this power to supply the varying voltage requirement of the battery plus load.It is generally accepted that MPPT will outperform PWM in a cold temperature climate, while both controllers will show approximately the same performance in a subtropical to tropical climate.

The MPPT charge controller is a DC to DC transformer that can transform power from a higher voltage to power at a lower voltage. The amount of power does not change, therefore, if the output voltage is lower than the input voltage, the output current will be higher than the inputcurrent, so that the product P=VI remains constant. Hence, in order to get the maximum out of a solar panel, a charge controller should be able to choose the optimum current-voltage point on the current-voltage curve: the Maximum Power Point. An MPPT does exactly that.The input voltage of a PWM controller is, in principle, equal to the voltage of the battery connected to its output. The solar panel, therefore, is not used at its Maximum Power Point, in most cases.

Maximum Power Point Tracking is electronic tracking - usually digital. The charge controller looks at the output of the panels and compares it to the battery voltage. It then figures out what is the best power that the panel can put out to charge the battery. It takes this and converts it to best voltage to get maximum AMPS into the battery). Most modern MPPT's are around 93-97% efficient in the conversion. You typically get a 20 to 45% power gain in winter and 10-15% in summer. Actual gain can vary widely depending weather, temperature, battery state of charge, and other factors.
MPPT's are most effective under these conditions:

- Winter, and/or cloudy or hazy days - when the extra power is needed the most.

- Cold weather - solar panels work better at cold temperatures, but without an MPPT you are losing most of that. Cold weather is most likely in winter - the time when sun hours are low and you need the power to recharge batteries the most.

- Low battery charge - the lower the state of charge in your battery, the more current an MPPT puts into them - another time when the extra power is needed the most. You can have both of these conditions at the same time.

- Long wire runs - If you are charging a 12-volt battery, and your panels are 100 feet away, the voltage drop and power loss can be considerable unless you use very large wire. That can be very expensive. But if you have four 12 volt panels wired in series for 48 volts, the power loss is much less, and the controller will convert that high voltage to 12 volts at the battery. That also means that if you have a high voltage panel setup feeding the controller, you can use much smaller wire.

The initial investment may be excessive for the target population; these costs are expected to go down if the design is mass produced. Solar power source is ‘free’ making this system viable long-term solution for electrification. The implementation of a project such as this will make the use of hazardous items such as kerosene lamps and car batteries redundant.

Purpose of investment in solar power project is to enter in development of green energy technology, which is the only ultimate source of energy for future generations.

2. Review of Literature

Energy is the key influencing factor for development in all sectors, i.e., Industrial, Commercial, Agriculture, Domestic etc. as per capita energy consumption is one of the indicators of national development status. per capita energy consumption is about 600 units in our country, where as is it is 1400 units in China, 6898 units in Germany, 13,000units in U.S.A World average is about 2430 units.

India is the sixth largest country in the world in terms of generation and consumption levels. The total installed capacity of Power projects India is 1,47,402.81 MW, of this thermal mode of power generation including coal, gas and oil contributes 64.7%, Hydro contributes 24.65%, Nuclear 2.95% and Renewable energy 7.7%. The demand-supply gap, which is denoted as 'energy shortage' is 8.8% of the total energy requirement in 2009 and the peak shortage, which is a measure of shortage during peak power consumption hours is approximately 14 percent of installed capacity. The Government of India has initiated several reform measures to create a favourable environment for addition of new generating capacity in the country. The Electricity Act 2004 has put in place a highly liberal framework for generation. There is no requirement of licensing for generation and technology economic clearance from CEA for thermal generation projects.

The fast diminishing world reserves of fossil fuels, increasing demand for energy, particularly in developing countries, and the damage to the environment caused by; the consumption of large quantities of fossil fuels in the preceding century have encouraged intensified search for renewable and environment friendly sources of energy.

The use of renewable energy resources involves the tapping of natural flows of energy in the environment. If the resource is used in a sustainable fashion, the energy is removed at a rate comparable to that at which energy is being replenished. Renewable energy is thus inexhaustible as opposed to conventional sources of energy, which has a limited lifespan.

The use of conventional sources of energy such as fossil fuels has many adverse side effects. Their combustion products produce pollution, acid rain and global warming which are currently major global concerns. Conversion to clean energy sources can improve the quality of life throughout the planet earth, not only for humans, but for its flora and fauna as well. Consequently, the use of renewable energy can contribute to environmental protection not only for the present generation but for future generations as well.

Because of the foregoing, there is a need to develop method of renewable energy conversion systems and then to substitute it where application of fossil fuels are most vulnerable. With renewable energy technologies, a secure and diverse supply of energy can be secured and resources can be restored. Additionally, renewable energy is widely distributed and is available and indigenous to almost every region of the world. Currently, the World energy Council predicts that the contribution from renewable will rise to 30% and that biomass will continue to be the dominate source of renewable energy.

DISADVANTAGES AND LIMITAITONS OF CONVENTNIONAL ENERGY SOURCES

- Resources are limited.
- Environmental problems, emission of greenhouse gases.
- Dependency on imports.
- Dependency n global oil prices, which effect country economy.
- Transmission & distribution losses

ADVANTAGES OF NON-CONVENTIONAL ENERGY :

Conservation of limited conventional energy resources which can be made available for futurist generation.
Reducing imports and avoided cost can be invested for other development activities.
Reduction of G.H.G and other emissions for protecting environment.
Use of in-exhaustible energy sources like Solar, Wind, Biomass, Tidal etc.

3. Methodology

Solar charge controller performs 4 major functions:

- Charges the battery.
- Gives an indication when battery is fully charged monitors the battery voltage and when it is minimum,
- cuts off the supply to the load switch to remove the load connection.
- In case of overload, the load switch is in off condition ensuring the load is cut off from the battery supply.

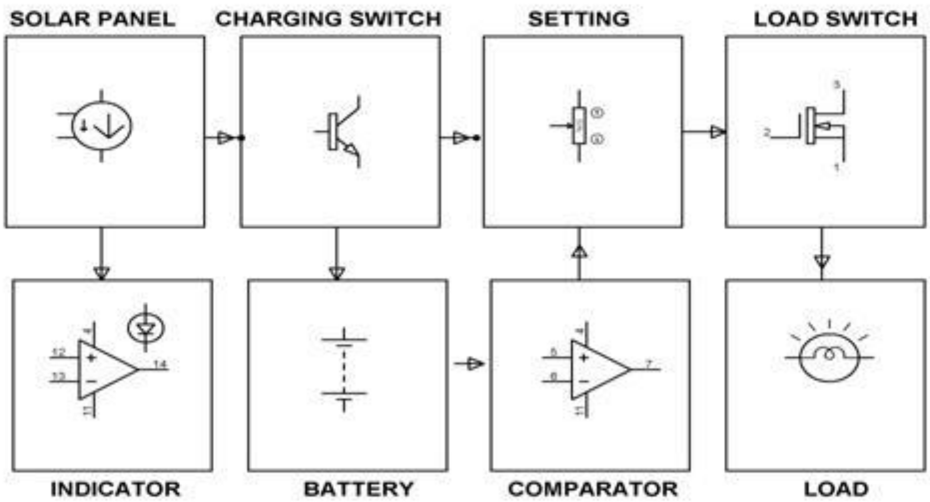

Figure 3.1 General Symbols And Their Meanings

A solar panel is a collection of solar cells. The solar panel converts the solar energy into electrical energy. The solar panel uses Ohmic material for interconnections as well as the external terminals.

So the electrons created in the n-type material passes through the electrode to the wire connected to the battery. Through the battery, the electrons reach the p-type material. Here the electrons combine with the holes.

When the solar panel is connected to the battery, it behaves like other battery, and both the systems are in series just like two batteries connected serially. The solar panel has totally consisted of four process steps overload, under charge, low battery and deep discharge condition.

The out from the solar panel is connected to the switch and from there the output is fed to the battery. And setting from there it goes to the load switch and finally at the output load. This system consists of 4 different parts-over voltage indication and detection, over charge detection, over charge indication, low battery indication and detection. Incase of the over charge, the power from the solar panel is bypassed through a diode to the

MOSFET switch. Incase of low charge, the supply to MOSFET switch is cut off to make it in off condition and thus switch off the power supply to the load.

3.2. BLOCK DIAGRAM OF SOLAR CHARGE CONTROLLER

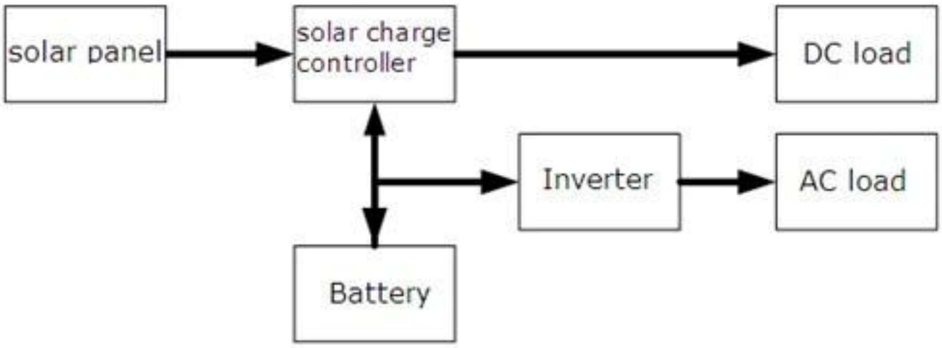

Figure 3.2 Block Diagram of Solar Charge Controller

Solar charge controller is a key component in any photo voltaic system that uses batteries to store energy. The main function of solar charge controller it to reduce the overall system maintenance and prolongs the battery life by regulating the charging voltage and current coming from the solar panels. It also protects the battery from both overcharging and deep discharging.

Today, most of the solar charge controllers utilize the Pulse Width Modulation (PWM) technique to adjust the charging voltage and current according to the charging status of the batteries. For instance, if the battery gets closer to fully-charged condition, the amount of solar power delivered to the batteries is lowered by lowering the duty cycle of the PWM signal. This approach has lesser stress on batteries during charging and thus extends their battery life

4. Working Principle

The principle behind a solar charge controller is simple. There is a circuit to measure the battery voltage, which operates a switch to divert power away from the battery when it is fully charged. Because solar cells are not damaged by being short or open-circuits, either of these methods can be used to stop power reaching the battery.

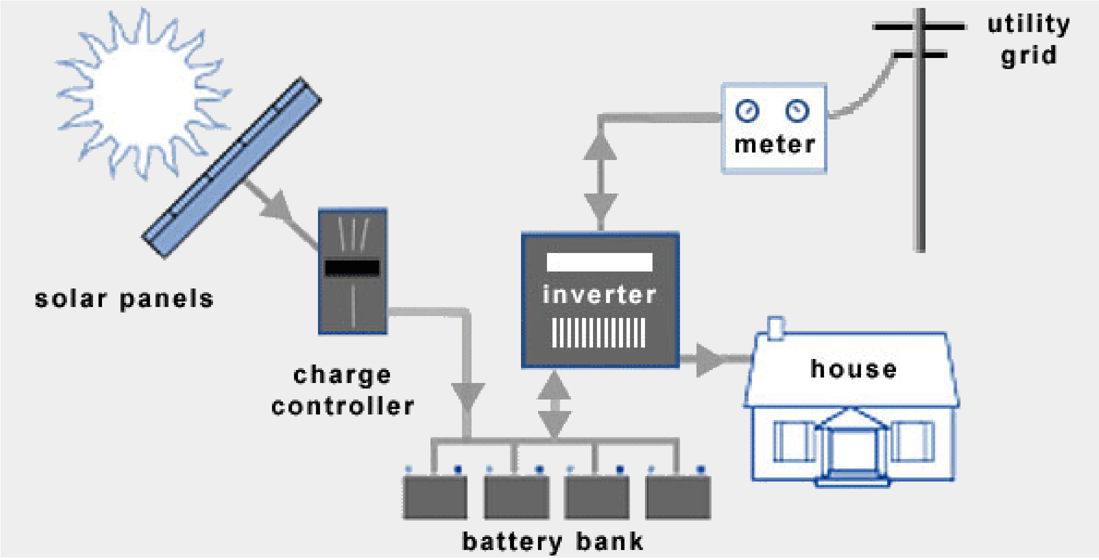

Figure 4.1Working Diagram

A controller which short-circuits the panel is known as a shunt regulator, and that which opens the circuit as a series regulator. Optionally there may also be a switch which automatically disconnects the power from the appliances or loads when the battery voltage falls dangerously low. This is known as a low-voltage disconnect function.

4.1 How A Maximum Power Point Tracker Works:

The Power Point Tracker is a high-frequency DC to DC converter. They take the DC input from the solar panels, change it to high-frequency AC, and convert it back down to a different DC voltage and current to exactly match the panels to the batteries. MPPT's operate at very high audio frequencies, usually in the 20-80 kHz range. The advantage of high-frequency circuits is that they can be designed with very high-efficiency transformers and small components.

Here is where the optimization or maximum power point tracking comes in. Assume your battery is low, at 12 volts. An MPPT takes that 17.6 volts at 7.4 amps and converts it down so that what the battery gets is now 10.8 amps at 12 volts. Now you still have almost 130 watts, and everyone is happy.

Ideally, for 100% power conversion you would get around 11.3 amps at 11.5 volts, but you have to feed the battery a higher voltage to force the amps in. And this is a simplified explanation - in actual fact, the output of the MPPT charge controller might vary continually to adjust for getting the maximum amps into the battery.

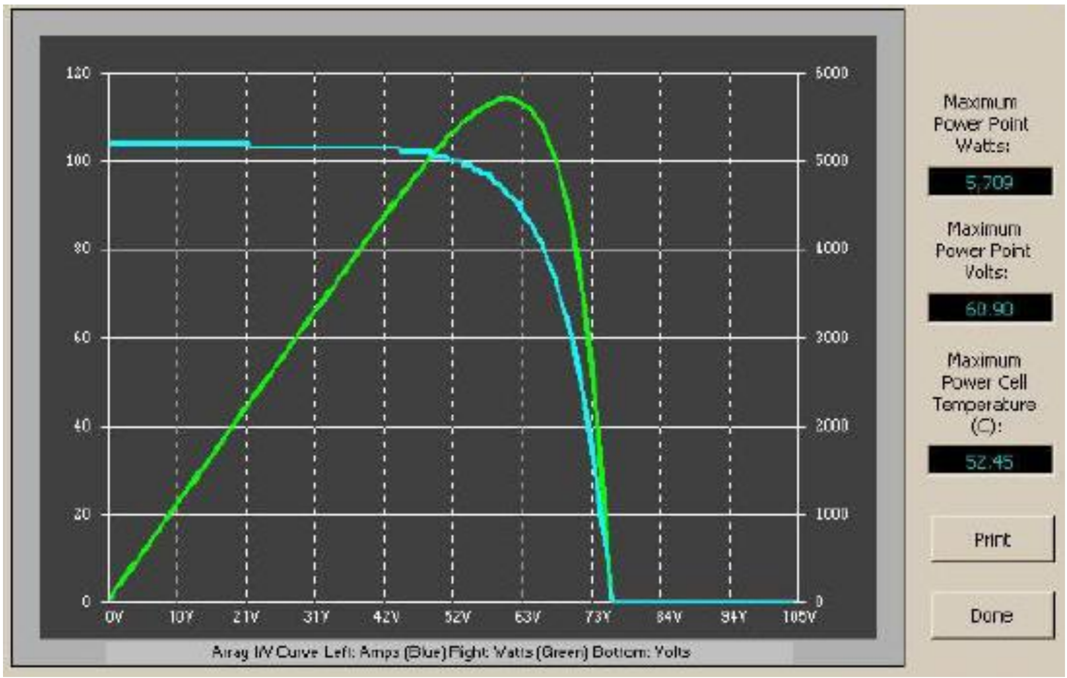

Figure 4.1 Working of MPPT

In the figure 4.1 look at the green line, you will see that it has a sharp peak at the upper right - that represents the maximum power point. What an MPPT controller does is "look" for that exact point, then does the voltage/current conversion to change it to exactly what the battery needs. In real life, that peak moves around continuously with changes in light conditions and weather.

An MPPT tracks the maximum power point, which is going to be different from the STC (Standard Test Conditions) rating under almost all situations. Under very cold conditions a 120-watt panel is actually capable of putting over 130+ watts because the power output goes up as panel temperature goes down - but if you don't have some way of tracking that power point, you are going to lose it. On the other hand under very hot conditions, the power drops - you lose power as the temperature goes up. That is why you get less gain in summer.

4. Circuit Diagram

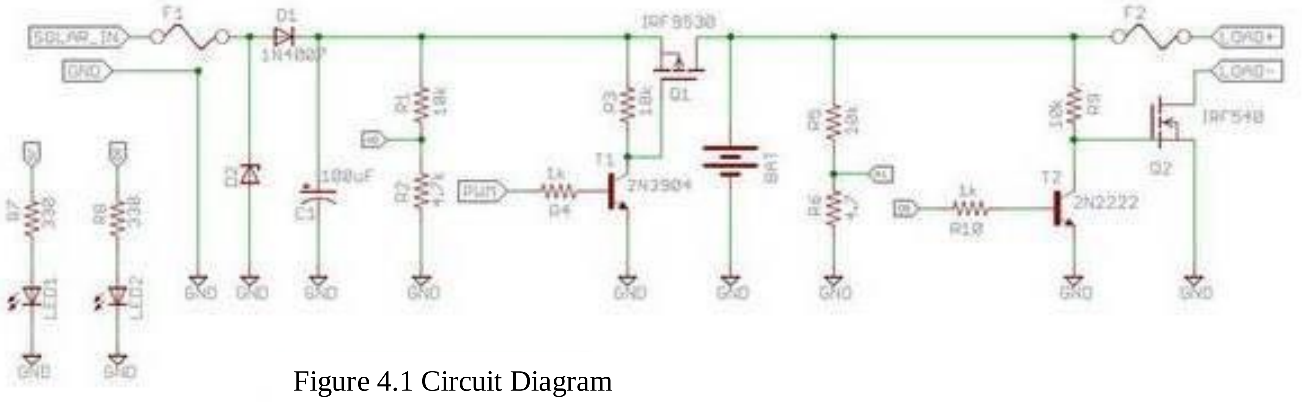

Figure 4.1 Circuit Diagram

The most essential charge controller basically controls the device voltage and opens the circuit, halting the charging, when the battery voltage ascents to a certain level. More charge controllers utilized a mechanical relay to open or shut the circuit, halting or beginning power heading off to the electric storage devices.

Generally solar power systems utilize 12V of batteries. Solar panels can convey much more voltage than is obliged to charge the battery. The charge voltage could be kept at a best level while the time needed to completely charge the electric storage devices is lessened. This permits the solar systems to work optimally constantly. By running higher voltage in the wires from the solar panels to the charge controller, power dissipation in the wires is diminished fundamentally.

The solar charge controllers can also control the reverse power flow. The charge controllers can distinguish when no power is originating from the solar panels and open the circuit separating the solar panels from the battery devices and halting the reverse current flow.

5. Design Overview

A detailed block diagram of the system is shown in which consists of following major components:

a) Solar panel
b) Battery
c) Charge Controller
d) Maximum Power Point Tracker
e) DC-DC converter

A brief description of each of the system components is given below,

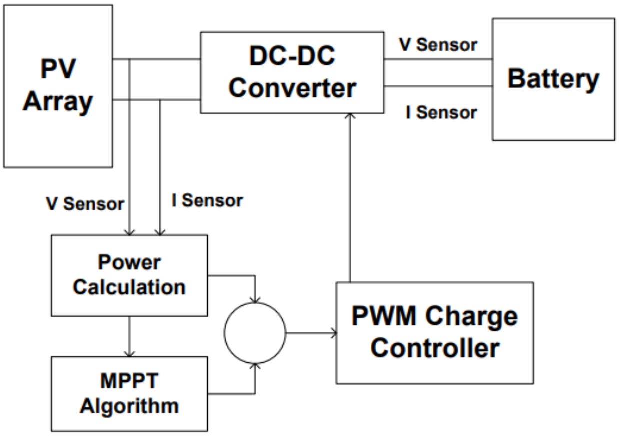

Figure: 5.1 System Description

a) **Solar Panel**:

A solar panel is a packaged connected assembly of photovoltaic cells. The solar panel can be used as a component of a larger photovoltaic system to generate and supply electricity in commercial and residential applications.

Solar panels use light energy photon from the sun to generate electricity through the photovoltaic effect. The majority of modules use wafer based cells or thin film cells based on non-magnetic conductive transition metals, telluride or silicon. Electrical connections are made in series to achieve a desired output voltage and or in parallel to provide a desired current capability. The conducting wires that take the current off the panels may contain silver, copper or other nonmagnetic conductive transition metals. The cells must be connected electrically to one another and to the rest of the system. Each panel is rated by its DC output power under standard test conditions, and typically ranges from 100 to 320 watts.

Depending on construction, photovoltaic panels can produce electricity from a range of light frequencies, but usually cannot cover the entire solar range (specifically, ultraviolet and low or diffused light). Hence, much of the incident sun light energy is wasted by solar panels, and they can give far higher efficiencies if illuminated with monochromatic light.

The advantages of solar panels are,

- They are the most readily available solar technology.
- They can last a lifetime.
- They are required little maintenance.
- They operate best on bright days with little or no obstruction to incident sunlight.

b) Battery :

In stand-alone photovoltaic system, the electrical energy produced by the PV array cannot always be used when it is produced because the demand for energy does not always coincide with its production. Electrical storage batteries are commonly used in PV system. The primary functions of a storage battery in a PV system are:

1) Energy Storage Capacity and Autonomy: to store electrical energy when it is produced by the PV array and to supply energy to electrical loads as needed or on demand.

2) Voltage and Current Stabilization: to supply power to electrical loads at stable voltages and currents, by suppressing or smoothing out transients that may occur in PV system.

3) Supply Surge Currents: to supply surge or high peak operating currents to electrical loads or appliances.

c) Charge Controller

A charge controller or charge regulator limits the rate at which electric current is added to or drawn from electric batteries. It prevents overcharging and may prevent against overvoltage, which can reduce battery performance or lifespan, and may pose a safety risk. It may also prevent completely draining ("deep discharging") a battery, or perform controlled discharges, depending on the battery technology, to protect battery life.

In simple words, Solar Charge controller is a device, which controls the battery charging from solar cell and also controls the battery drain by load. The simple Solar Charge controller checks the battery whether it requires charging and if yes it checks the availability of solar power and starts charging the battery. Whenever controller found that the battery has reached the full charging voltage levels, it then stops the charging from solar cell. On the other hand, when it found no solar power available then it assumes that it is night time and switch on the load. It 5 keeps on the load until the battery reached to its minimum voltage levels to prevent the battery dip-discharge. Simultaneously Charge controller also gives the indications like battery dip discharge, load on, charging on etc.

d) Maximum Power Point Tracker The maximum power point tracker (MPPT)

It is now prevalent in grid-tied PV power system and is becoming more popular in stand-alone systems. MPPT is a power electronic device interconnecting a PV power source and a load, maximizes the power output from a PV module or array with varying operating conditions, and therefore maximizes the system efficiency. MPPT is made up with a switch-mode DC-DC converter and a controller. For grid-tied systems, a switch-mode inverter sometimes fills the role of MPPT. Otherwise, it is combined with a DCDC converter that performs the MPPT function.

This thesis, therefore, chooses a method Perturb and Observe algorithm for digital control for MPPT. The design and simulations of MPPT will be done on the premise that is going to be built with a microcontroller.

e) DC-DC Converter DC-DC converters are power electronic circuits that convert a dc voltage to a different dc voltage level, often providing a regulated output.

The key ingredient of MPPT hardware is a switch-mode DC-DC converter. It is widely used in DC power supplies and DC motor drives for the purpose of converting unregulated DC input into a controlled DC output at a desired voltage level. MPPT uses the same converter for a different purpose, regulating the input voltage at the PV MPP and providing load matching for the maximum power transfer.

There are a number of different topologies for DC-DC converters. In this thesis we are using CUK dc-dc converter as it is obtained by using the duality principle on the circuit of a buckboost converter. MPPT is one of many applications of power electronics, and it is a relatively new area. This thesis investigates it in detail and provides better explanations. In order to understand and design MPPT, it is necessary to have a good understanding of the behaviors of PV. The thesis facilitates it using MATLAB models of PV cell and module. The other things such as DC-DC converter, microcontroller based charge controller are also explained elaborately.

6. Applications

- **Solar street light system** is system that uses PV module to convert sunlight into DC electricity. The system consumes only DC electricity and incorporates **solar charge controller** to store DC in the battery bank to supply during sunlight is not visible or nighttimes.

- **Solar home system** is system that takes energy generated from PV module to supply for home appliances or other household applications. The system incorporates **solar charge controller** to store DC in the battery bank and suits for using in any areas where utility grid is not available.

- **Hybrid system** is system that consists of multiple energy sources to provide full time, backup power or other purposes. It usually combines solar array with other forms of generation such as diesel generator and renewable energy forms (wind turbine generator and hydro generator, etc.) and incorporates solar charge controller to store DC in the battery bank.

- **Solar water pump system** is system that uses solar power to pump water from natural and surface reservoirs for home, village, water treatment, agriculture, irrigation, livestock and other applications.

7. Result & Conclusion

In this paper, a solar power charge controller has been discussed effectively i.e. how rechargeable battery is used to store energy with the help of solar charge controller with limiting the charging so as to remain batter safe.

The use of solar energy is essential for providing solutions to the environmental problems and also energy demand. The vast development to improve the efficiency by the MPPT algorithms encouraged the domestic generation of power using solar panels. The available MPPT techniques based on the number of control variables involved, types of control strategies, circuitry, and applications are possibly useful for selecting an MPPT technique for a particular application for grid tied or standalone mode of operations. This review has included many recent hybrid MPPT techniques along with their benefits for mismatched conditions such as partial shading, no uniformity of PV panel temperatures, and dust effects.

It is observed that Perturbation and Observation and Incremental Conductance methods are simple and used by many researches, but they have the slow tracking and low utilization efficiency. To overcome the drawbacks, fuzzy and neural network techniques are used in the present days by which the efficiency is increased. To boost up the voltage various DC-DC converters are used along with battery storage systems in order to store the excessive energy from solar PV panel.

The DC link voltage oscillations in the grid connected PV system can be obtained by using buck converters, SEPIC converters, and Zeta converters with reducing current ripple injected in the PV array and load. The harmonic content is reduced from the output of DC-DC converters using the filter circuits. The passive filters as LC, LCL, and LLCC are used for harmonic distortion as well as to improve the power quality. Filter capacitors are used to reduce high frequency current ripple.

This DC is again fed to the inverter for converting the DC to AC with various PWM techniques. These PWM inverter techniques yield the better AC outputs which are used to connect the grid interconnections and standalone AC loads.

Multilevel inverters with sinusoidal PWM and SVM are used to reduce the harmonics in the load voltage even in low switching frequency. Grid tied inverters with battery backup are preferred in hybrid systems for backup even if the grid goes down for both grid tied and off grid systems.

8. Future Scope

1. Smart Power Trackers :All recent models of digital MPPT controllers available are microprocessor controlled. They know when to adjust the output that it is being sent to the battery, and they actually shut down for a few microseconds and "look" at the solar panel and battery and make any needed adjustments.

2. We can also use it for Automatic Irrigation System as shown in figure

3. Hybrid of MPPT with mechanical tracking will give more efficiency, project can be extended in this direction.

4. Battery output is directly utilized to feed power in the dc grid which can be used for charging electronic devices like laptop, mobile directly.

5. By adding wifi module we can record our data in the system and optimize the data for better use.

6. Solar panel installed on urban and sub-urban areas with modified technology will lead in saving of our bill.

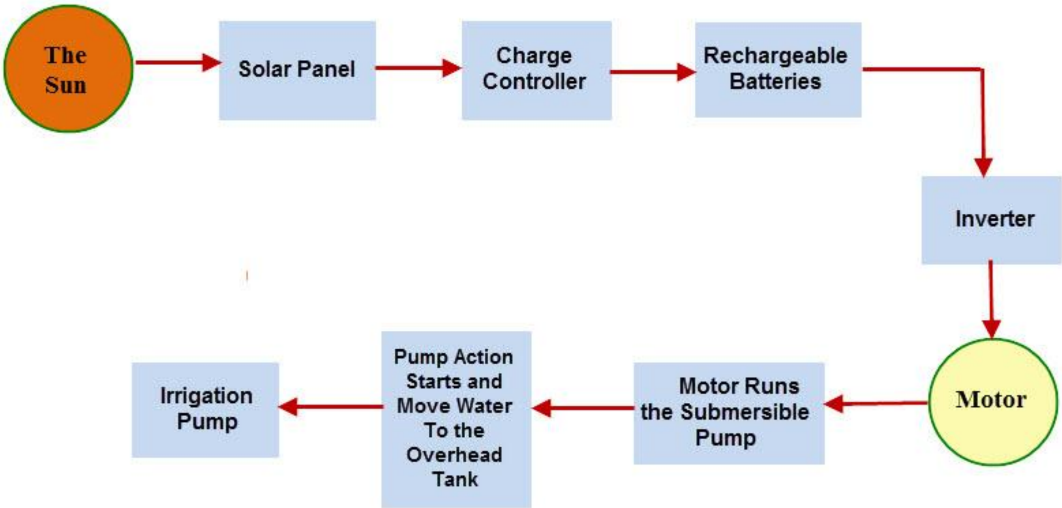

Figure 8.1Solar Charge Controller Used For Irrigation Purpose

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