CHAPTER THREE

PHOTOVOLTAIC SYSTEM

3.1 Introduction

Renewable energy is energy derived from natural resources that are replenished is that are not implemented. Are fundamentally different from fossil fuels from petroleum, coal, natural gas, or nuclear fuel used in nuclear reactors. Renewable energy does not usually produce residues of carbon dioxide (CO2) or harmful gases or increase global warming, such as when fossil fuels or harmful atomic residues from nuclear reactors are burned.[2]

Solar energy is the most readily available and free source of energy since prehistoric times, it is estimated that solar energy equivalent to over 15000 times the world annual commercial energy consumption reaches the earth every year.

Sudan receives solar energy on the region of 5 to 7 kWh/m for 300to 300 days in a year. This energy is sufficient to set up 20 MW/m solar power plants [2].

3.2 Solar Energy

The sun is probably the most important source of renewable energy available today. Traditionally, the sun has provided energy for practically all living creatures on earth, through the process of photosynthesis. The solar energy is a highly familiar alternative clean energy type [1]**.**

Photovoltaic power systems are generally classified according to their functional and operational requirements, their component configurations, and how the equipment is connected to other power sources and electrical loads.

The two principal classifications are grid-connected or utility-interactive systems and stand-alone systems [2].

Photovoltaic systems can be designed to provide DC and/or AC power service, can operate interconnected with or independent of the utility grid, and can be connected with other energy sources and energy storage systems [2].

The spectrum of the Sun's solar radiation is close to that of a black body with a temperature of about 5,800 K. The Sun emits Electromagnetic radiation across most of the electromagnetic spectrum. Although the Sun produces Gamma rays as a result of the nuclear fusion process, these super-high-energy photons are converted by internal absorption and thermalization to lower-energy photons before they reach the Sun's surface and are emitted out into space. As a result, the Sun does not emit gamma rays, from this process, although it does produce gamma rays from solar flares. The Sun does also emit X-rays, ultraviolet, visible light, infrared, and even radio waves. The only direct signature of the nuclear process is the emission of neutrinos. Solar energy has two main types of systems that are used globally nowadays: the Solar Photovoltaic (PV) systems and the Solar Thermal systems. Fig (3.1) shows the sun light spectrum [3].

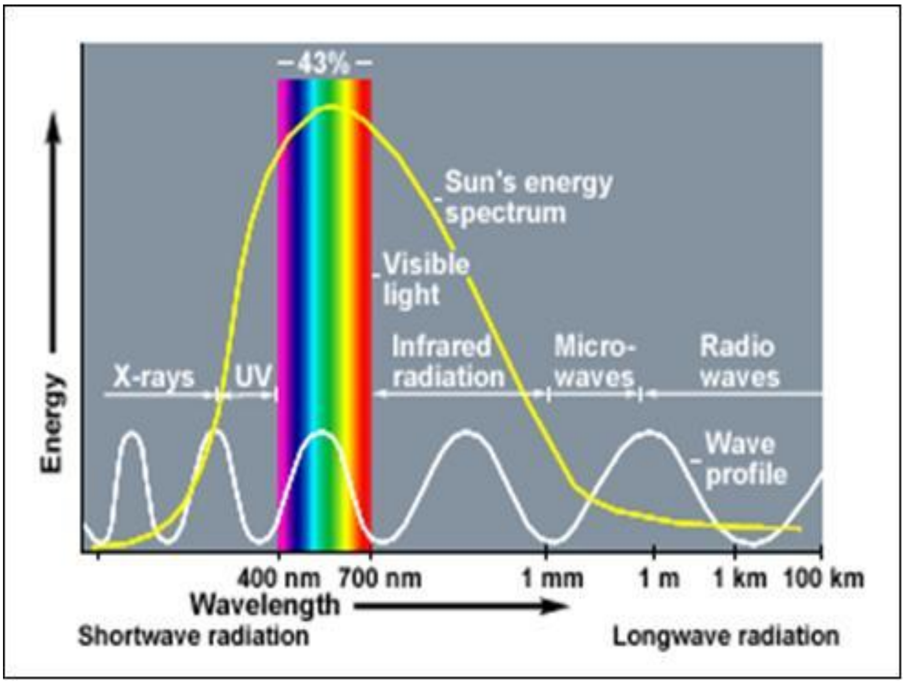

Fig (3.1) Sunlight spectrum

3.3 Advantages of Solar Energy

-Solar energy is the world's major renewable energy source and is available everywhere in different countries.

-Photovoltaic panels do not have any moving parts, operate silently and generate no emissions.

-The solar technology is highly modular and can be easily scaled to provide the required power for different loads [2].

3.4 Photovoltaic

Photovoltaic (PV) is the method of generating electrical power by converting solar radiation into direct current electricity using semiconductors and an effect called the photovoltaic effect. To generate electricity and make use of it using the Photovoltaic effect, you will need an electrical device that does the conversion process of light into electricity called the Photovoltaic Cell (also called the Solar Cell) [4].

3.4.1 Photovoltaic effect

The photoelectric effect was first noted by a French physicist, Edmund Becquerel, in 1839, who found that certain materials would produce small amounts of electric current when exposed to light. Albert Einstein won a Nobel Prize in 1921 due to his description of the nature of light and the photoelectric effect on which photovoltaic technology is based [4].

In simple terms, the photovoltaic effect describes the conversion of light into an electric current. To describe this mechanism more formally, it is best to think of light in terms of a stream of photons where each photon carries one quantum of energy [4].

3.4.2 Photovoltaic cell

Photovoltaic cell or solar cell is a device which converts the light energy into electrical energy. When light is allowed to fall on this cell, the cell generates a voltage across its terminals. This voltage increases with the increase in light intensity. The cell is so designed that a large area is exposed to light which enhances the voltage generation across the two terminals of the cell [1]..

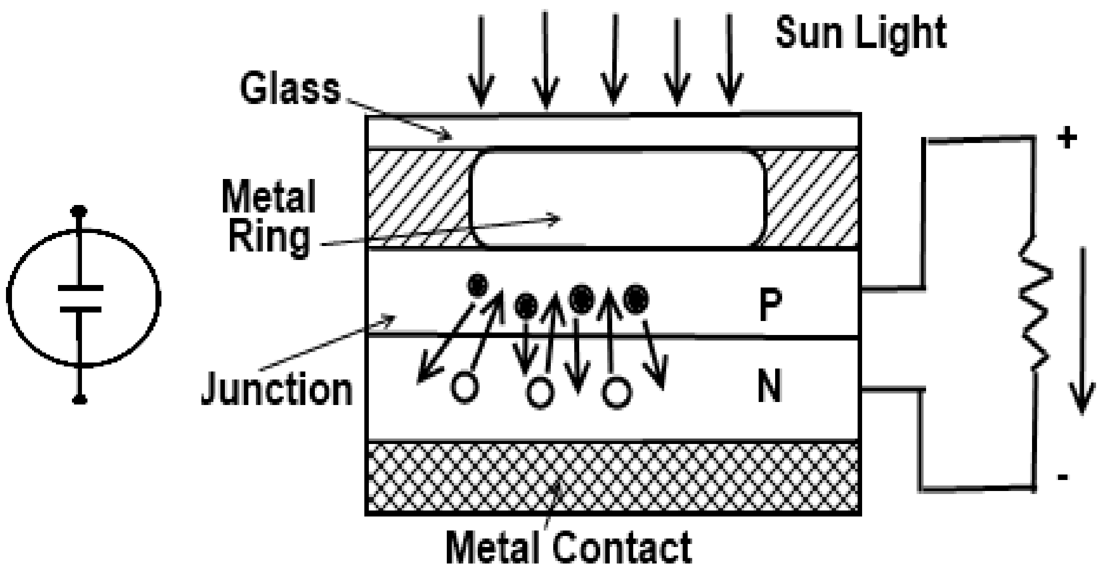

Fig (3.2) Solar cell

As shown in fig (3.2), the Solar cell is like an ordinary diode. It consist of silicon, germanium PN junction with a glass windows on the top surface layer of P-Type, the P-Type material is made very thin and wide so that the incident light photon may easily reach to PN junction. The P nickel plated ring around the P layer acts as the positive output terminals (anode), and the metal contact at the bottom acts as a Cathode. Silicon and germanium are the most widely used semiconductors materials for solar cells, although gallium arsenide, Indium arsenide and Cadmium arsenide are also being used nowadays [3].

In a solar cell, there will be both n-type and p-type silicon in contact with each other. Electrons will move across from the n-type to the p-type at their junction as they will be attracted to the nearby holes. Once this has happened at the junction, this area acts a barrier, stopping further electrons moving across and an electric field exists across the junction. Fig (3.3) shows the silicon P-N junction [3].

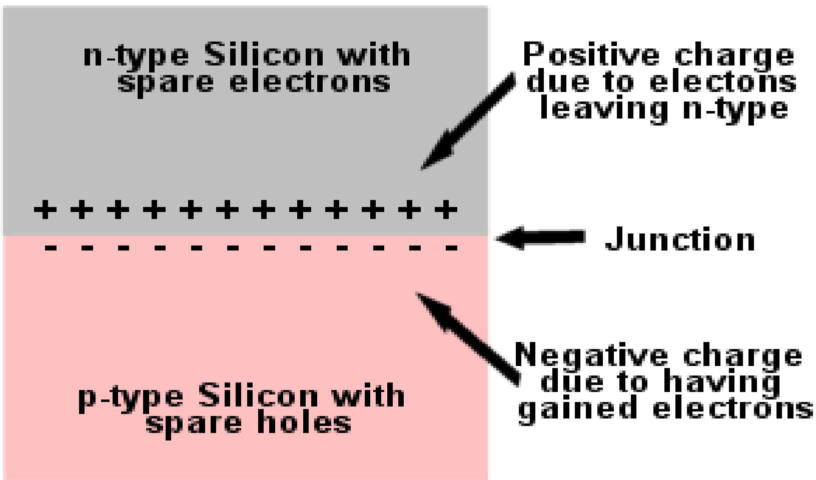

Fig (3.3) Silicon P-N junction

If light energy is absorbed by the cell, the energy will push electrons across the junction and, if an electrical circuit is made between the two silicon types, the electrons will flow through it, back to where they came from, and continue to do so [3].

3.5 Photovoltaic System

A PV system is the system that uses the photovoltaic effect to convert the solar radiation into electricity depending on the PV effect. PV system in its simplest form may contain an array of PV modules, one or more DC to AC power converter (inverter), electrical wiring, and either battery with a charge controller or no batteries to store energy [1].

Solar systems can be a small PV system is capable of providing enough AC electricity to power a single home, or even an isolated device in the form of AC or DC electric (rooftop systems), or it can be large grid-connected PV power system capable of providing an energy supply for multiple consumers, or even off-grid plants to supply villages or small towns [1].

3.6 Photovoltaic System Components

PV systems -with their different sizes, applications and usages- usually consist of the following components:

3.6.1 Photovoltaic modules

A PV module is a group of solar PV cells connected in series or parallel in one oriented plane to construct one panel. Each module is rated by its DC output, and typically range from 100 to 320 watts. The PV module is considered as the main component of the PV system, as it's converts the sun light into DC current. A typical PV module is shown in Fig (3.4) [1].

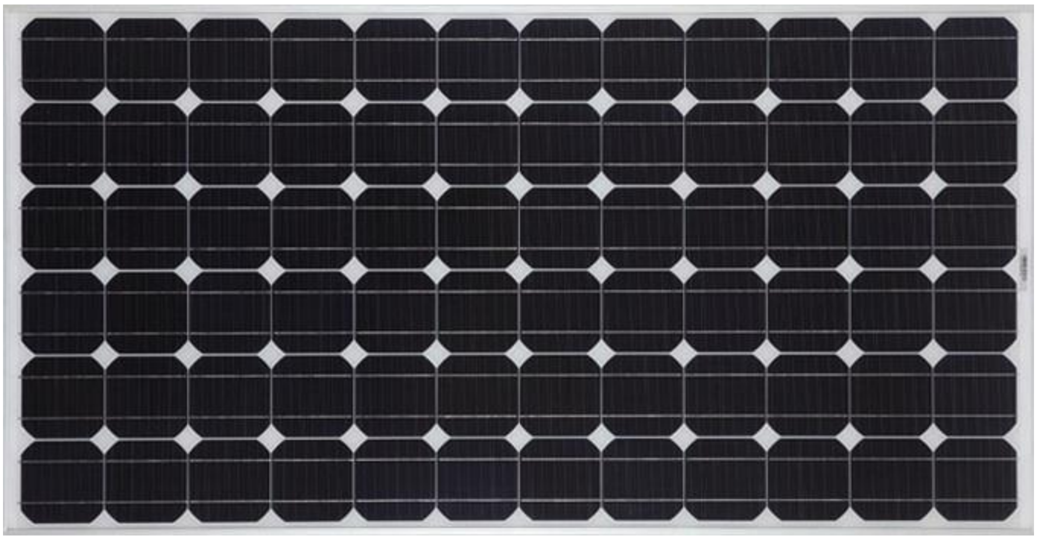

Fig (3.4) PV module

PV modules often have a sheet of glass on the front (sun up) side, allowing light to pass while protecting the semiconductor wafers from abrasion and impact due to wind-driven debris, rain and hail [1].

Solar cells are also usually connected in series in modules, creating an additive voltage. Connecting cells in parallel will yield a higher current however; very significant problems exist with parallel connections. For example, shadow effects can shut down the weaker (less illuminated) parallel string (a number of series connected cells) causing substantial power loss. Although modules can be interconnected to create an array with the desired peak DC voltage and loading current capacity as shown in fig (3.5) below [1].

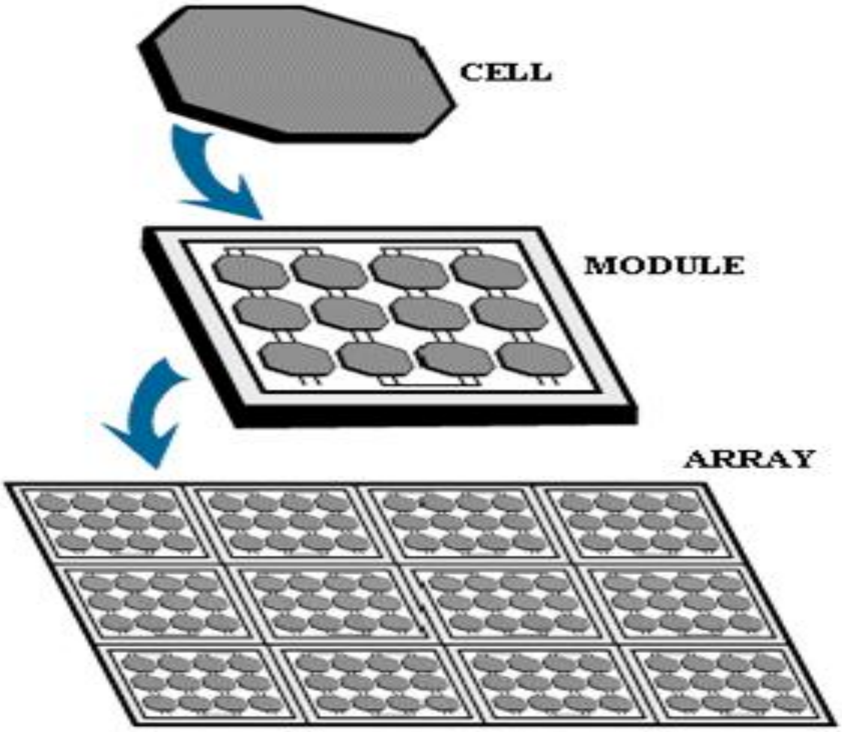

Fig (3.5) PV (cell – module – array)

There are four main types of photovoltaic solar panels for both commercial and residential use. They are:

-Mono-crystalline cells

Made of large silicon crystal .Single-crystal wafer cells tend to be expensive, and because they are cut from cylindrical ingots, do not completely cover a square solar cell module without a substantial waste of refined silicon. Hence most *c-Si* panels have uncovered gaps at the four corners of the cells. Fig (3.6) shows the Mono-crystalline PV cell [4]**.**

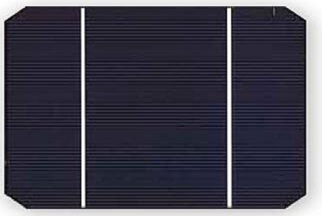

Fig (3.6) Mono-crystalline PV cell

-Polycrystalline cells

Also called multi-crystalline silicon, (poly-Si or mc-Si).Characterized by its shattered glass look because of the manufacturing process of using multiple silicon crystals.

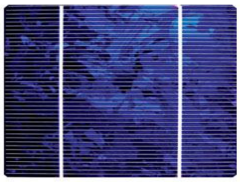

Fig (3.7) Polycrystalline PV cell

-Amorphous silicon cells

These panels can be thin and flexible which is why they are commonly referred to as "Thin Film" solar panels. Amorphous silicon solar panels are common for building integrated photovoltaic applications because of their many application options and aesthetics. They are cheaper and are not affected by shading. Drawbacks are low efficiency; loss of wattage per sq. ft. installed and heat retention. They can be manufactured using silicon, copper indium dieseline (CIS) or cadmium telluride (CDTE) [4].

Fig (3.8) Amorphous silicon (thin film) PV cell

-Mono-like multi-crystalline cells

Uses existing polycrystalline casting chambers with small "seeds" of mono material. The result is a bulk mono-like material with poly around the outsides. When sawn apart for processing, the inner sections are high-efficiency mono-like cells (but square instead of "clipped"), while the outer edges are sold off as conventional poly. The result is line that produces mono-like cells at poly-like prices [4].

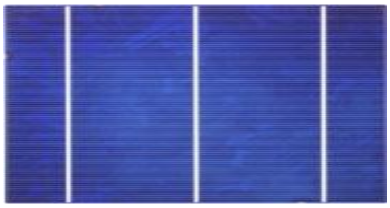

Fig (3.9) Mono-like multi-crystalline PV cell

3.6.2 Batteries

In stand-alone photovoltaic power systems, the electrical energy produced by the PV panels cannot always be used directly. As the demand from the load does not always equal the solar panel capacity. Battery banks are generally used to store electrical energy when it’s not being used.

Common battery technologies used in today's PV systems include, the valve regulated lead-acid battery– a modified version of the conventional lead–acid battery, nickel–cadmium and lithium-ion batteries. Compared to the other types, lead-acid batteries have a shorter lifetime and lower energy density.

Batteries that are able to handle the constant charging and discharging are known as deep-cycle batteries. Batteries need to have a good charging efficiency, low charging currents and low self-discharge. Under ideal conditions a new deep-cycle battery would be 90% efficient [1].

The important characteristics to look for are:

-Capacity
-Cycle life / price / performance
-Size and space requirements
-Efficiency
- Self-discharge rate
- Installation - vertical or horizontal
- Environmental - will batteries be placed in high temperatures, near water supplies or in wildlife parks etc [1].

3.6.3 Inverters

A power inverter, or inverter, is an electronic device or circuitry that changes direct current (DC) to alternating current (AC).The input voltage, output voltage and frequency, and overall power handing depend on the design of the specific device or circuitry, The inverter does not produce any power; the power is provided by the DC source .The DC input to the inverter can be from any of the following sources:

- Rectified DC output of the variable speed wind power system.

- DC output of the photovoltaic power modules.

- DC output of the battery used in the photovoltaic power System.

The figures (3.10) represent the three inverter circuit

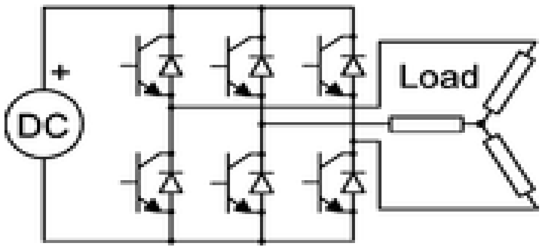

Fig (3.10) Three phase inverter circuit

Mainly Solar inverters may be classified into three broad types:

-Stand-alone inverters

It used in isolated systems where the inverter draws its DC energy from batteries charged by PV arrays. Many stand-alone inverters also incorporate integral battery chargers to recharge the battery from an AC source, when available.

-Grid-tie inverters

Which match phase with a utility-supplied sine wave. Grid-tie inverters are designed to shut down automatically upon loss of utility supply, for safety reasons. They do not provide backup power during utility outages [4].

-Battery backup inverters

Are special inverters which are designed to draw energy from a battery, manage the battery charge via an onboard charger, and export excess energy to the utility grid these inverters are capable of supplying AC energy to selected loads during a utility outage, and are required to have anti-islanding protection [4].

3.6.4 Charge controller

The charge controller is a necessary part of your power system that charge batteries, whether the power source is PV, wind, hydro, fuel, or utility grid. Its purpose is to keep your batteries properly fed and safe for the long term.

A charge controller is an electronic voltage regulator, used in off-grid systems and grid-tie systems with battery backup that controls the flow of power from the charging source to the battery. The charge controller automatically tapers, stops, or diverts the charge when batteries become fully charged [4].

-Series controllers

When the voltage level reaches to the charge cut-off level the power from the PV generator is blocked by the switch in S1 in Fig (3.11). After the voltage drops again below the charging cut-off voltage level S1 switches back on [4].the figure (3.11) represent series charge controller.

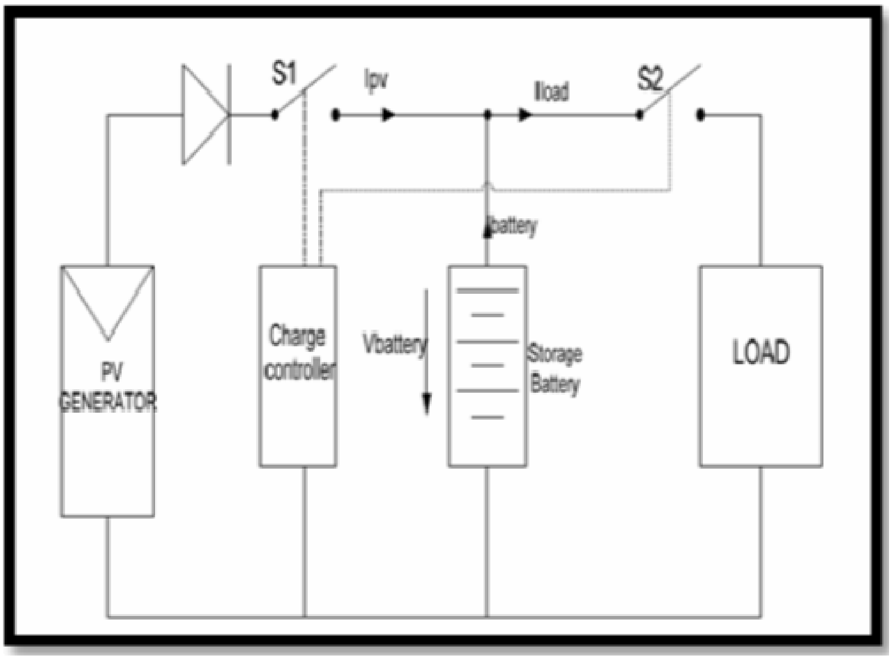

Fig (3.11) Series charge controller

-Shunt controllers

When the charge cut-off voltage is reached charge controller continuously reduces the power of the module. Since it reduces the power continuously the unwanted power is short-circuited via the array, this creates heat in the system. This method is usually used for battery when charging is safe and swift [4].the figure (3.12) represent shunt charge controller.

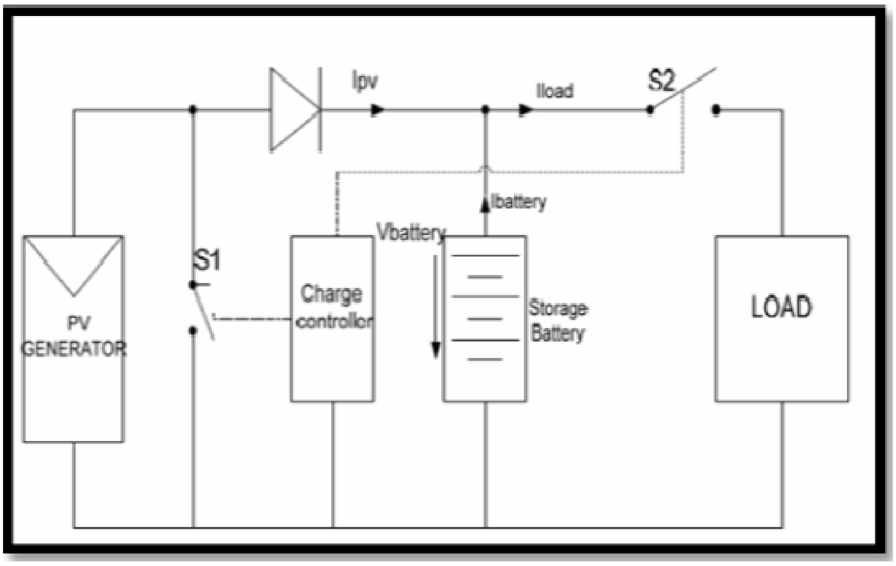

Fig (3.12) Shunt charge controller

Some charge controllers have additional features, such as a low voltage disconnect (LDV), which preventing completely draining ("deep discharging") a battery that may entirely ruin some batteries. Also they perform controlled discharges, depending on the battery technology, to protect battery life. The terms "charge controller" or "charge regulator" may refer to either a stand-alone device, or to control circuitry integrated within a battery pack, battery-powered device, or battery recharger [4].

3.7Grid-Connected Solar PV Systems

Grid-connected or utility-interactive PV systems are designed to operate in parallel with and interconnected with the electric utility grid. The primary component in grid-connected PV systems is the inverter, or power conditioning unit (PCU). The PCU converts the DC power produced by the PV array into AC power consistent with the voltage and power quality requirements of the utility grid, and automatically stops supplying power to the grid when the utility grid is not energized. Fig (3.13) represent grid-connected photovoltaic system [2].

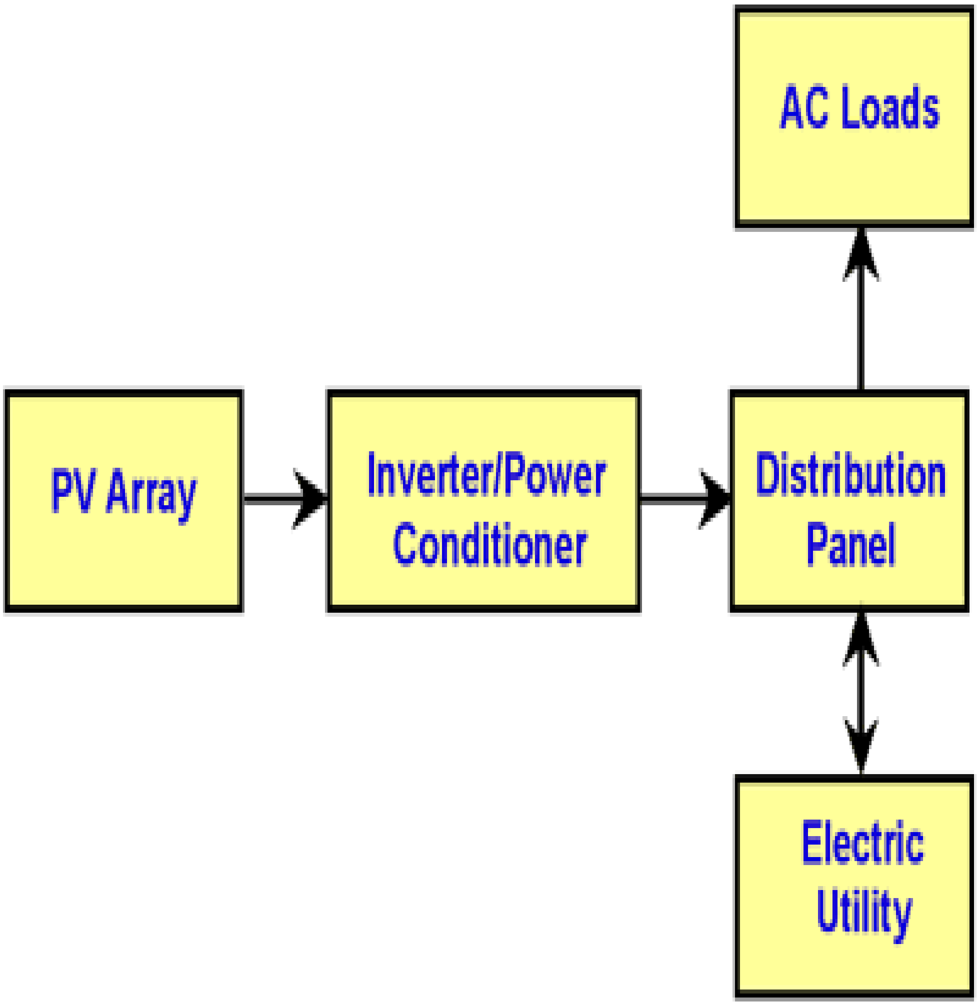

Fig (3.13) Diagram of grid-connected Photovoltaic system.