Solar Energy – Photovoltaic Solar power generation

A Photovoltaic Solar power generation facility – a demonstration plant, has been constructed at Lethabo Power Station.

1. Historic background.

The photoelectric effect was first noted by a French physicist, Edmund Bequerel, in 1839, who found that certain materials would produce small amounts of electric current when exposed to light. In 1905, Albert Einstein described the nature of light and the photoelectric effect on which today's photovoltaic technology is based. He later won a Nobel Prize in physics. The first photovoltaic module was built by Bell Laboratories in 1954

2. What is Photovoltaics (PV)?

Photovoltaics (PV) is a method of generating electrical power by converting solar radiation into direct current electricity using semiconductors that produces the photovoltaic effect. It is not the heat required form the sun but the amount of irradiation available.

A semiconductor is a material with electrical conductivity due to electron flow (as opposed to ionic conductivity), intermediate in magnitude between that of a conductor and an insulator. This means conductivity roughly in the range of 10^3 to 10^{-8} siemens per centimetre. Semiconductor materials are the foundation of modern electronics, including radio, computers, telephones, and many other devices. Such devices include transistors, solar cells, many kinds of diodes including the light-emitting diode, the silicon controlled rectifier, and digital and analog integrated circuits. Similarly, semiconductor solar photovoltaic panels directly convert light energy into electrical energy. In a metallic conductor, current is carried by the flow of electrons. In semiconductors, current is often schematized as being carried either by the flow of electrons or by the flow of positively charged "holes" in the electron structure of the material.

Common semiconducting materials are crystalline solids, but amorphous and liquid semiconductors are also known. Silicon is used to create most semiconductors commercially. Crystalline solids are a class of solids that have regular or nearly regular crystalline structures. This means that the atoms in these solids are arranged in an orderly manner.

Examples of crystalline solids are sugar, sugar candy, or rock candy. Sugar powder (which is solid but is not considered crystalline) consists of small invisible grains which can be heated up and converted to visible sugar crystal (common sugar) or to larger rock candy crystals. The crystalline nature of rock candy makes it transparent whereas power sugar from which it was made and has the same sugar molecules is opaque.

Dozens of other materials are used, including germanium, gallium arsenide, and silicon carbide. A pure semiconductor is often called an "intrinsic" semiconductor. The electronic properties and the conductivity of a semiconductor can be changed in a controlled manner by adding very small quantities of other elements, called "dopants", to the intrinsic material. In crystalline silicon typically this is achieved by adding impurities of boron or phosphorus to the melt and then allowing the melt to solidify into the crystal. This process is called "doping".

3. How do Photovoltaic (PV) cells generate electricity?

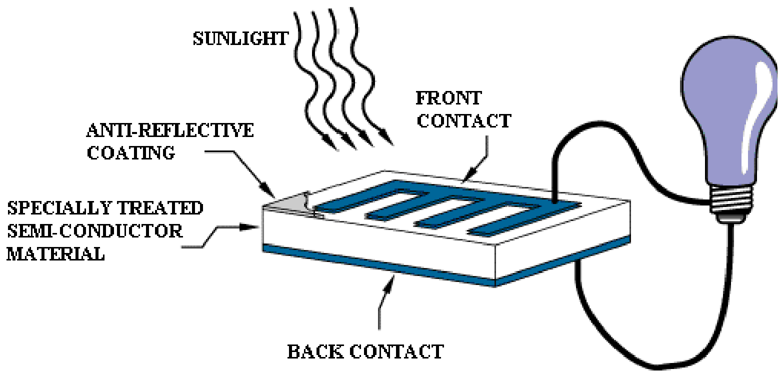
We cannot see electricity, therefore, we need to understand the science of how it is produced. In conventional power stations, Michael Faraday's principle of a magnet spinning inside a coil of wire is used. But, we also need to understand that in any which way we produce electricity, the role of atoms is important.

The atom

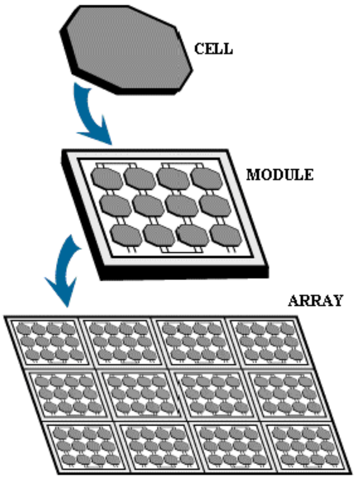
- All matter is made up of atoms. Atoms are made up of smaller particles, including electrons.
- Electrons spin around the centre or nucleus of an atom, just as planets orbit the sun.
- Electrons have a negative charge.
- The nucleus is made up of neutrons and protons. Protons have a positive charge and neutrons are neutral.
- Some kinds of atoms have electrons that are loosely attached. They can easily be made to move from one atom to another. When these electrons move among the atoms of matter, a current of electricity is created.

The photovoltaic effect refers to photons of light exciting electrons into a higher state of energy, allowing them to act as charge carriers for an electric current. The term photovoltaic denotes the unbiased operating mode of a photodiode; virtually all photovoltaic devices are some type of photodiode.

For solar cells, a thin semiconductor wafer is specially treated to form an electric field, positive on one side and negative on the other. Cells require protection from the environment and are usually packaged tightly behind a glass sheet. When light energy strikes the solar cell, electrons are knocked loose from the atoms in the semiconductor. If electrical conductors are attached to the positive and negative sides, forming an electrical circuit, the electrons can be captured in the form of an electric current -- that is, electricity. This electricity can then be used to power a load, such as a light, a tool etc.



A number of solar cells electrically connected to each other and mounted in a support structure or frame is called a photovoltaic module. Modules are designed to supply electricity at a certain voltage, such as a common 12 volt system. The current produced is directly dependent on how much light (irradiation) strikes the module.



Multiple modules can be wired together to form an array. In general, the larger the area of a module or array, the more electricity will be produced. Photovoltaic modules produce direct-current (DC) electricity. They can be connected in both series and parallel electrical circuits to produce the required voltage and current combination.

The first practical application of photovoltaics was to power orbiting satellites and other spacecraft, but today the majority of photovoltaic modules are used for grid connected power generation. In this case an inverter is required to convert the DC to AC. There is a smaller market for off-grid power for remote dwellings, boats, recreational vehicles, electric cars, roadside emergency telephones, remote sensing and cathodic protection of pipelines. Due to the growing demand for renewable energy sources, the manufacturing of solar cells and photovoltaic arrays has advanced considerably in recent years.

4. The Lethabo PV Plant

The construction of the Lethabo PV Plant started the first week of October of 2011. The plant went operational on 18 November 2011 and officially launched on 21 November 2011 by the Honourable Minister of Public Enterprises Mr Malusi Gigaba. It is a 575 kW plant constructed on a ± 0, 98 Hectares of land.

The Lethabo plant is of a single axis tracking structure. There are 1812 PV modules mounted on beams – tracker beams. Each module comprises 96 cells and produces up to 318 W each. The capacity of each PV module is ± 318 W at 64, 7 Volt and a current of 6.2 Amps. The modules are of the Monocrystalline design.

All the tracker beams, 268 in total, are mounted on 340 poles fixed into the ground with concrete. The tracker beams are arranged in 18 rows and depending on the length of a row of beams, some are fitted with 7 PV modules whereas others have as many as 16 PV modules / tracker. The panels (modules) are constructed 1,6M above ground level.

The plant structure faces north with the PV modules in an easterly direction. Each set of tracker beams is operated by hydraulic power cylinders supplied by 10 hydraulic oil supply pumps. There are 71 hydraulic power cylinders

The power produced, a direct current (DC), leaves each PV module of a tracker beam and is connected in series to junction boxes (String boxes). The output form the junction boxes are connected in parallel and fed to an inverter where the power is converted to AC power.

The inverter has an input rating of 400 to 700 Volts DC at a current of 1145 Amps. The AC output is 500 to 550 kW, at ± 300 volt and 955 amps. From the inverter, the power is stepped up to 11kV via a 630 kVA transformer and sent to the power stations services distribution boards from where power is fed to the main administration building.

The higher the temperature of one module, the lower the production output; the lower the temperature the higher production output. The inverter can produce power even if the irradiation is 60 W/m^2. With less than 200W/m^2, it is considered as bad irradiation.

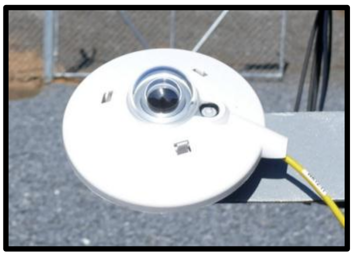
Efficiency in summer is less than winter, i.e. ±91% to 78%, production is higher.*
Overall efficiency is 20%. In summer, the plant is less efficient due to high temperatures.

Example: In summer with an energy input into the inverter of 1000 W the output would be 800W. In winter, with an energy input of 500W the output would be 350W.

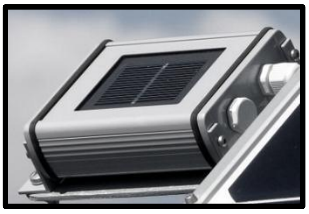
5. Basic control.

An on site meteorological station supplies data for the control of the plant. Wind speed is measured by anemometer (a second anemometer is placed on the roof of the control station.) Wind direction measured by a wind vane and a rainfall metre is also supplied. Ambient temperature is also measured.

Two horizontal calibrated solar cells measure the irradiation available for the modules at horizontal and tilt plane. Two additional cells are placed on a tracker module, metering is for reference purposes. A Pyrometer measures the irradiation onto the modules at all angles.



Pyrometer



Solar cells

All the information from these devices (calibrated solar cells and pyronometer) forms part of the control of the tracker system, i.e. allows the tracker modules to follow the sun from east to west so power could be produced. The control system sends a signal to the hydraulic oil pumps which allows the tracker beams to move, i.e. follow the sun in accordance the available irradiation from the sun.

After sunset, the tracker modules move to the horizontal position. In an event of high winds, 50kPh, the second anemometer gives a signal for modules to move to the horizontal position (defensive mode) to protect the plant.

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