Chapter 2

Versatile Applications of Solar Cells

Vivian Chimezie Akubude¹, Ugochukwu Kingsley Ebisike², Kevin Nnanye Nwaigwe³,
Jelili Aremu Oyedokun⁴, Ayooluwa Peter Adeagbo⁵

¹Department of Agricultural and Bioresource Engineering, Federal University of Technology,
Owerri, Imo State, Nigeria

²Department of Electrical and Electronics Engineering, Federal University of Technology,
Owerri, Imo State, Nigeria

³ Department of Mechanical Engineering, University of Botswana, Botswana

⁴ Engineering and Scientific Services Department, National Centre for Agricultural
Mechanization, Ilorin, Kwara State, Nigeria.

⁵Department of Electrical and Electronics Engineering, Adeleke University, Ede, Osun State,
Nigeria

akubudevivianc@gmail.com

Abstract

Solar cells have changed the way electricity is generated; it helps the world to reduce carbon emission, and consequently makes our electric grid system more resilient and reliable. Hence, this chapter presents the concept of solar cells and the basic principle of operation. The chapter also discusses materials in construction of solar cells including conventional semiconductors such as silicon and emerging/organic materials such as perovskite and quantum dots. Various applications of solar cells which include space research, telecommunications, grid connections, stand-alone connections and off-grid applications are also highlighted. Given the versatile application of solar cells, it is the future of electricity generation.

Keywords

Solar Cells, Photovoltaic Cells, Energy, Applications, Silicon

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1. Introduction

Solar cells are devices that convert light energy into electrical energy [1]. Solar cells have found applications in several devices including calculators and satellites. Its earliest use was majorly in space but presently they are in more common applications. During the last century, the world has seen phenomenal changes in the power industry due to science and technology. There are different methods of generating electrical power used in powering up our electrical appliances. This chapter explores the use of solar cells for generating power using energy derived from the sun and its versatile applications.

Solar cells or photovoltaic cells as it is sometimes called converts solar energy into electricity via the use of solar panels [2]. It traps energy from the sun converting it into electricity. It is made of bluish black colouration and usually octagonal in shape. Solar cells can be thought of like cells in a battery. They are bundled into larger units to form solar panels. A beam of sunlight actually contains smaller particles known as photons, when a solar cell comes between the paths of this beam of sunlight, the photons are intercepted by the solar cell which converts them into free-flowing electrons, and these

free-flowing electrons are what constitute electric current. Each cell produces a few volts of electricity (about 0.5 volts for silicon cell), to get a specific voltage level that will be suitable for use; a reasonable number of solar cells must be bundled together into modules, panels and array. They possess certain qualities that make them stand out among other energy sources, some of these qualities include durability, portability, low maintenance requirement and they are also used to generate power in remote conditions, i.e., they can be deployed for powering electrical devices from the closest electrical outlet [3].

Solar technique of power generation is incredibly amazing, clean, very easy and cheap to implement, this has prompted lots of research and exploration into how to turn it into a stand-alone power generation scheme for both small and large machines and buildings. With solar, the need to spend time, money and effort to drill oil, mine coal or do some other form of strenuous activities that involved tilling the earth to get resources most of which needs to be used under controlled conditions in order to get power are eliminated. The sun itself is a natural mega power station, capable of supplying the world with enormous amount of energy for as may be required or demanded and the biggest advantage of it is that it never goes off. The sun produces a carbon-free source of energy.

There are also disadvantages of solar energy, but they are very few and currently being researched to be improved upon in usage. Energy variation is a prominent challenge of solar energy. The energy level trapped from sunlight is at its lowest point at morning and evening respectively while it is at its peak at midday when the sun is directly overhead. Another common challenge is production and processing equipment. Production of solar panels and other devices used to harness the sun's radiation and transform it to electrical energy in suitable voltages for transmission and consumption tends to involve high level technical expertise and research together with funds. These are required to produce good solar panels that can effectively transform solar energy to electrical energy. Solar energy via solar cell is converted directly into direct current (DC), and since most electrical devices or equipment run on alternating current, an inverter is needed to convert this direct current (DC) supply by the solar panels into AC in a suitable voltage that will be viable for transmission and consumption by home appliances.

Finally, engineers will need to design new devices which are easily powered directly from the output of solar panels. Bad weather conditions and dark hours also contribute to the challenges encountered in solar technology. One of the effects of revolution of the earth is that it causes changes in the sun's visibility from the earth and this in turn gives rise to changes in weather conditions which in turn brings about seasons. In tropical Africa, there are basically two seasons: the wet (rainy) season and the dry season while four seasons exist in Europe, America and some parts of Asia, they are namely: autumn,

spring, summer and winter. The summer season in the western world is similar to the dry season in tropical Africa and this season is known for minimal or no rainfall and maximum sunlight. The solar energy gotten during this period is maximum and this makes it the peak season for using solar technique for power generation. Other seasons are characterized by rainfall and poor visibility (though not all the time). The solar energy harnessed during this time is minimal. An effect of rotation of the earth is that it brings about day and night. Solar activity during the day is high while solar activity at night is not even present. This means that at night, devices being powered directly via solar panels will not function because their source of energy, the sun, is not present. This is a major drawback because it shows that solar technology cannot work at certain periods. However, with the discovery of secondary cells (cells that can be recharged), this drawback is completely eliminated, because the energy from the sun could be stored in these batteries and used during the dark periods or periods with weather conditions that causes low visibilities. Similarly, cost of construction of storage facilities is also a concern. It costs a lot to construct large batteries which are used to store the converted electrical energy from the sun by the solar panels. It also takes a lot of batteries to store electrical energy that can be used to power an entire factory [4]

Figure 1 basic principle of operation of solar cell [4]

2. Working principle of solar cell

Solar cells operate on the principle of photovoltaic effect which literally means voltage produced from light. Figure 1 [5] describes the fundamental principle of operation of solar cell. It comprises of a sandwich of n-type semiconductor and p-type semiconductor. Photons from sunlight hit the upper surface of the cell, the photons which are depicted by the yellow arrows and star, carry their energy downwards through the cell. Also, they donate their energy to electrons in the p-type layer. This energy is utilized by the electrons to overcome the hindrance at the layer by moving over it up to the n-type layer and finally it gets out into the circuit. The excess flowing electrons through the circuit then lights up the bulb.

3. Applications of solar cells

3.1 Space research

Solar cells are utilized in powering space vehicles, satellites and telescopes, because they tend to supply the world with certain information about the earth and they are also used to relay telecommunication signals, going off abruptly due to diminishing fuel sources could be catastrophic for people who rely on them for certain information. Also, it cost much travelling to space to refuel these machines and vehicles. The only way of mitigating and consequently eliminating the need for refuelling by travelling back to space is by harnessing the power of the sun and converting it into electrical energy that will be needed to power these vehicles. Using solar cells to power space vehicles is very economical and reliable as the cost incurred is only the cost of manufacturing and attaching solar.

Figure 2 International space station [6]

The Figure 2 [6] shows the international space station which is still under construction. It is an example of a solar powered station. It is proposed to be the most powerful solar array in space containing 250,000 solar cells and the entire array will be able to power a small neighbourhood. Also, Figure 3 [7] shows the picture of a satellite in space. Attached to its sides are solar panels to power it up by converting the energy of the sun into electrical energy.

Figure 3 Picture of a satellite in space [7]

3.2 Telecommunications

In our world today, we desire to have an efficient communication system that enables us to reach any part of the world we want to. In order to achieve this, we have to deploy telecoms infrastructure in certain remote and isolated areas which ranges from hills and mountain tops to deserts and forest regions. The effect of this will tell on both cost of installation, operation and maintenance on the particular firm. It is a known fact that the aim of every business is to make profits and to achieve this in this context, the operator must establish self-sustainable mobile networks with higher efficiency and profitability and remains competitive in a lower Average-Revenue-Per-User (ARPU) environment. The best way to make this a reality is by deploying solar panels and batteries in such remote locations where these Base Transceiver Station sites will be constructed so as to be the major source of power supply to the site. Recall that the cost of construction and deployment of solar panels to power these telecom equipment is nothing compared to

outages and cost of transportation to access these sites regularly, also the sun only goes down at night and the energy converted during the day is already stored in batteries to compensate for the unavailability of the sun at night, the change-over process will be made automatic via a contactor so as to prevent outage and manual handling. Furthermore, Signals required by communication systems need amplification after certain intervals so as not to degrade. Various relay towers are stationed to boost high grounds which are mostly favoured as the sites for repeater stations. In remote applications, these stations are far from the electric grid and may not be served by electricity from the grid, in such scenario, there will be breach in communication, because it will be tasking and costly to set up power stations at remote locations to power up repeaters. To reduce the difficulty, solar devices and systems are being installed as a viable alternative [8]

3.3 Grid connected applications

When using solar panels in a community's grid system, the modules are connected to an inverter such that the output voltage from the panel which is in direct current (DC) will be converted to alternating current (AC) voltage which is used by our domestic and industrial appliances [9]. Leftovers from this system can then be sold to the electric grid of a community from which it could be used to power up other homes under the control of the grid as shown in Figure 4 [10]. However, there is a limitation to the use of solar cells in grid systems. The constraint is due to the fact that solar cells only operate when there is sunlight. In night hours and periods of bad weather where visibility is poor, they do not work and as such a backup system, usually a battery is required to make sure that the electricity supply is not interrupted. Systems of this nature are most commonly used in houses or commercial buildings to offset electricity cost. A well-designed solar cell electricity generating system with a proper storage facility can be a very intelligent method of displacing electricity usage from the grid during peak hours [8].

Figure 4 Grid connected residential solar pv energy [6,10]

3.4 Stand-alone devices

With the recent advancement in solar technology, certain systems are now being digitized in such a way that they can make use of the direct current (DC) voltage generated by the solar panels at the particular magnitude, and they do not rely on or require the electric grid system. These devices are sometimes referred to as stand-alone devices. In the night or in the event of bad weather conditions where sunlight visibility is poor, a battery storage system is used. There are lots of devices that directly use solar energy for its operations and they use batteries to ensure continuity of power during the night and bad weather condition. Some of them are listed and briefly explained below:

Solar water heaters: they are basically water heaters made up of collectors and storage tanks as shown in Figure 5 [11]. These systems use the Sun to heat water in collectors generally mounted on a roof. The heated water is then stored in a tank similar to a conventional gas or electric water tank [11].

Figure 5 Solar heater [11]

Solar street light: in our world today most street lights found on the streets are being powered by solar technology as opposed to the conventional way of powering them up via the grid system. They operate of the same principle of solar cells, just that this time, their output which is DC is directly used to power up a DC light. The solar street lights comprise of solar cells, which absorb the solar energy during daytime. The photovoltaic cells convert solar energy into electrical energy, which is stored in the battery. The lamp has already been programmed by a microprocessor to come on after certain hours, and go off once it senses sunlight, and it consumes the electricity already stored in the battery. During the day- time the battery gets recharged and the process keeps on repeating every day. Figure 6 [12] shows the picture of a solar street light.

Figure 6 Solar street light [12]

Portable lightning and charging systems:

Nowadays, torch lights and certain LED lamps and other home appliances that makes use of rechargeable batteries like fans, radios, refrigerators, mobile phones and power banks are now designed in such a way that their batteries are being charged directly from the sun via solar cells as shown in Figure 7a-e [13]. This technique makes these devices portable and free from charging by electricity supplied through the national grid, thus saving energy cost for the user and making the device more mobile [8]

Solar powered pumping machine:

Solar powered pumping is another exciting device that makes use of renewable energy by way of harnessing the energy from the sun to drive a motor which drills water from an open well, stream or underneath the ground. The system basically uses solar cells in a solar photovoltaic system to convert the energy from sun into electrical energy which is used for the smooth running of the motor pump. This system makes it easier to use the pump anytime there is sunlight and it eliminates the need to power the pumps via electricity supplied through the national grid. This system finds great applications in countries with low power supply and in countries where clean water supply is poor and not centralized. It also finds applications in agriculture as it can be used for irrigation purposes. It basically consists of a solar PV system with a surface mounted centrifugal pump which is compatible with the solar panel (a direct current motor) and the series of pipes to channel the water pressure [14].

a. solar powered reading lamp

b. solar powered keyboard

c. solar powered window charger

d. solar powered sound system

e. solar powered flashlight

Figure 7a – e Portable lightning and charging systems [13]

3.5 Solar photovoltaic winnower cum dryer

This is a suitable device for separating threshed agricultural produce and also for drying fruits and vegetables with forced circulation of air. The system as shown in Figure 8 [14] is made up of PV module, compatible winnower, pre-air heating tunnel and specially designed solar drying cabinet. Research shows that the system is more efficient when compared with open sun drying. This is also seen when different fruits and vegetables gets dried in less than half the time it will take to dry under direct sun. The overall quality of the dried material is improved by improving the fan speed with more irradiance. The system can be enhanced by providing certain properties for illumination coupled with the addition of a battery and charge regulator, therefore making it a suitable device for processing different agricultural produce and utilizing the generated PV electricity for one or another purpose throughout the year [14].

Figure 8 Solar PV winnower cum dryer cum [14]

3.6 Solar photovoltaic duster

Crop safety and security against pest and diseases is an essential aspect of agriculture. Solar PV duster is a new device used for spraying insecticide and pesticide powder on crops. It basically consists of a small unit solar PV panel carrier, battery compatible dusting unit. The panel can concurrently charge the battery and provides shade for the user (as shown in Figure 9) [12]. The system can run an ultra-low volume (ULV) sprayer and be used to light up a light emitting diode (LED). The device can be used for lighting the house throughout the year and for operating the duster/sprayer as and when required [12].

Fig. 9 solar PV sprayer [14]

3.7 Solar powered cars

With the world delving into use of renewable energy systems to produce electricity in order to reduce carbon emissions, the need to manufacture cars that will run on renewable energy is very crucial. Solar powered cars are vehicles that use electrical energy resulting from converted sunlight energy to drive the car [15]. This electrical energy serves as fuel in driving the car. They have the capacity to store solar energy and utilize at night or in the absence of direct sunlight. Its use is advantageous in terms of environmental and noise pollution reduces fuel costs, sustainable and eco-friendly and doesn't incur additional costs except battery replacement.

However, when designing photovoltaic vehicles, there are two drawbacks, namely: aesthetics of the car, which must accommodate the solar panels in terms of weight and beauty and also the cost of mining these solar cells. Research shows that the present marketable operated solar panels that are in use have just 15 to 20% efficiency; this implies more solar panels will be required to power a solar car. But achieving this will create two problems – weight and cost.

3.8 Solar aviation

In order to meet the demands of achieving a friendly ecosystem characterized by low carbon emission into the atmosphere, the aviation industry which runs mainly on fossil fuels (crude oil) must be made to run entirely on renewable energy sources and one of the best and efficient way of achieving this is by the use of solar cells on all aircrafts, the outcome of this will be known as solar powered aircraft. The principle of operation of a solar powered aircraft is very much like that of the conventional aeroplane only that it doesn't make use of fossil fuels and it emits no CO₂ as such. In a solar powered aeroplane for example, certain parts of the wings are lined up with solar cells which are usually

bundled to form solar panels. During a flight, the operation of a solar powered plane automatically switches between battery and solar power. The solar cells are used to convert solar energy from the sun into electrical energy; this electrical energy is then used to power electrical propellers which in turn drive the flight of the plane. When the sun is active, solar energy which is converted into electrical energy runs the aircraft's propellers and charges the batteries or fuel cells used by the plane to its peak. In order to achieve faster charging of the batteries to its peak, the pilot needs to reduce his flight cruising speed. During the dark periods (at night or in clouds), the batteries or fuel cells control the operation of the flight propellers.

However, solar planes are not the future of flight; this is due to certain reasons some of which includes:

- Inability to carry enough passengers and cargoes because the solar system and the storage battery have already taken most space contributing to weight of the plane.
- Low energy density; the weight of lithium-polymer batteries is a bit much and when loaded on to the plane, it adds more weight to the plane and this greatly increases the energy needed for take-off. Except research is done to produce light weight solar panels and batteries, it may be unlikely to have solar planes as part of the flying vehicles on earth. [16,17]

3.9 Off-grid power

Solar cells also find wide application as an off-grid energy source. For instance, several traffic, emergency and construction road signs and also electronic bill boards use solar cells for power during the day time. Such equipment are also loaded with batteries to power them up at night, decreasing the need for gasoline-powered generators for remote and mobile uses. Also some scientific research centres are situated far away from the town especially those used for weather and mining purposes, these facilities needs power to facilitate their activities. Since they are situated far from the heart of the town, the cost of extending transmission/distribution line to such location is capital-intensive coupled with high power loss due to the distance involved. As a result, solar PV system is used to power these facilities. Moreover, solar panels can be used to provide electricity for rural areas that are far away from the town and not connected to the grid. Solar cells bundled together to form solar panels could be used to build a charging station for electric vehicles. Finally, in areas where natural disasters occurs, solar panels are used to provide temporary power supply to such areas so as to speed up evacuation of people and valuables from the area, and carrying out restructuring and maintenance of the location [18].

3.10 Medical applications

Solar cells also find applications in medicine; they can actually be placed on the skin to continuously recharge implanted electronic medical devices. Most implanted devices are electronic in nature and their power is supplied via batteries and these batteries in turn greatly influence the sizes of these devices. To enable these devices last long for their purposes, more batteries are added and some are actually redundant so that when one stops, the other takes over, but this in-turn creates a larger device. But the challenge is that when the power in such medical device batteries runs out, it will necessitate either recharging or replacement. In most cases this means that patients have to undergo implant replacement procedures, which is not only expensive and tedious but also holds the risk of medical complications. Current research conducted in Switzerland shows that about 12 microwatts could be generated by 3.6 centimetres square of solar panel which is sufficient enough to power up or extend the battery life of a pacemaker or any other active human implant device [19].

3.11 Solar powered inverters and uninterruptible power supply (UPS)

An inverter is basically a device that converts direct current usually supplied by a battery into alternating current while Uninterruptible Power Supply (UPS) is a device that serves as battery backup when the electrical power fails or drops to low voltage level. In mission critical data centres, UPS systems are used for just a few minutes until electrical generators take over. UPS systems can be set up to alert file servers to shut down in an orderly manner when an outage has occurred, and the batteries are running out. The inverter and the UPS can be combined together to form online uninterruptible power supply (UPS). In online uninterruptible power supply (UPS) system, the inverter perpetually provides clean power from the battery while it charges it, and the computer and other sensitive equipment is never receiving power directly from the AC outlet. Nevertheless, online UPS units contain noiseless cooling fans which may need location planning for home user or small office. The inverter discussed here is charged directly from an AC source usually gotten from the central electric grid. However, with solar inverters, there is virtually no need for AC charging except at night periods when the sun is not present. The sun will continuously charge the battery and provide DC power for the inverter to use while the UPS makes sure the devices attached to it never go short of power in the exact voltage required by them [20].

3.12 Hybrid applications

Solar PV technology that comprises of solar cells can be used with other power generating systems using both renewable and non-renewable energy sources. This is

referred to as hybrid. This is done in order to have a higher power delivery to the load system and also at a lower cost than when only PV technology is used if properly controlled. Examples include PV-wind hybrid, PV-wind-diesel hybrid, PV-diesel generator etc.

Conclusions

The use of solar cells is still developing, more and more applications keep coming and with time, a good percentage of the world's energy will be generated using solar cells. Solar cells are a good substitute to global air pollution emanating from energy generation using fossil fuels and they can be made portable with little cost and efforts when compared to what is involved in drilling oil and mining coal. This chapter gradually explained solar cell and its applications. It is important to support solar technology so as to reduce global warming and all other hazards associated with the use of fossil fuel and also it is cheaper when deployed to use in some respects.

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