# DESIGN AND CONSTRUCTION OF A SOLAR POWERED STREETLIGHT SYSTEM

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## Abstract

Illumination is one of the factors for determining the development level of any community. Due to the erratic nature of power in the Nigeria, an alternative, reliable and efficient source of power must be looked into. The alternative source must also be able to save power. This informed the idea behind this project. The solution herein proposed is solar powered street light with automatic switching. The system will include the solar panels, charge controllers/switching unit, inverter, battery bank and the luminaires. This system will function by turning the luminaires on at night and turning off the luminaires at dawn automatically while charging takes place when the luminaires are off. The combination of these units will result in well-lit roads using a reliable and efficient power source. The system being tested has been confirmed to be very reliable and efficient as a solar panel can be used for an average of 25 years.

Keywords: Illumination, Inverter, Power, Solar, Switching.

## 1 INTRODUCTION

In distinguishing between a developed and an undeveloped community, a criterion normally considered is the brightness of the community at night. This factor affects the economy of Africa in numerous ways. Because of this fact Africa has been tagged the “Dark Continent”.

It can be observed from satellite images taken at night that Africa is still underdeveloped. A major problem is in power generation in Africa. Power generated in Africa is insufficient and cannot cater for the needs of outdoor lights. Over the years the use of fossil fuels to generate electricity has not produced enviable results. Besides, fossil fuels have caused a lot of havoc to the ecosystem with Africa not being able to tap into the advantages of using fossil fuels to generate electricity. Therefore the need for an alternative source of generating electricity arises. The alternative source must be cheap, reliable and efficient.

An alternative energy source is solar energy. This is a preferable choice as Africa is in the tropics with considerable amount of sunlight in a day that can be converted into electricity.

Solar energy utilisation is on the rise in our modern world as the fossil fuels have great adverse effect on our environment. Solar energy as a form of renewable energy has been in use since the times of Archimedes in 212 BC. At the time solar energy was being converted to heat energy for defence purposes. Other notable scientists have made countless improvements in the utilisation of solar energy since then. In 1839, Edmond Becquerel a French scientist discovered the photovoltaic effect. In 1966 the first orbiting astronomical observatory was launched by NASA which was powered by 1KW photovoltaic array. As at 1999 the cumulative installed photovoltaic capacity in the world had skyrocketed to 1000MW. Today, solar energy is being used to generate electricity worldwide [1].

## 2 PROPOSED SYSTEM

The proposed system will comprise of solar panel, charge controller/switching unit, battery bank, and luminaires.


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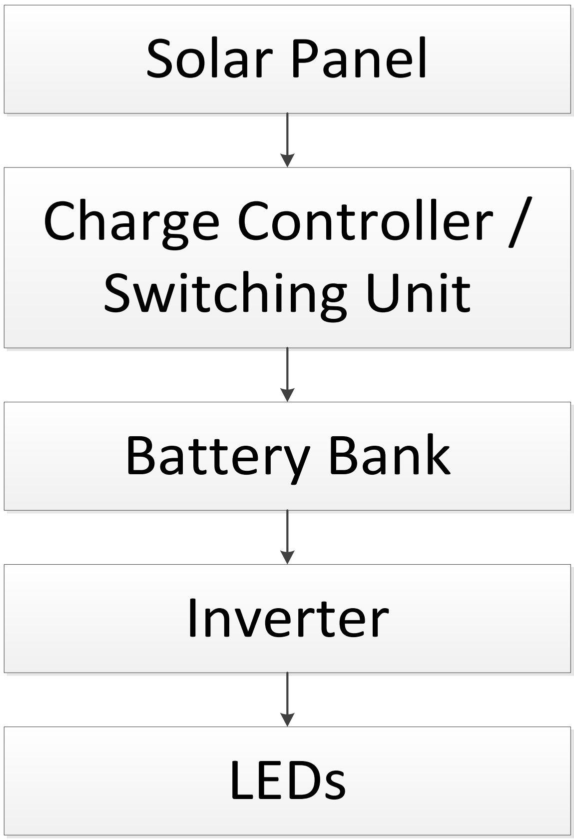


Fig. 1: The Proposed System.

### 2.1 Solar Panel Module:

A Solar panel module is a collection of several solar cells. A solar cell is a semiconductor device designed to turn solar irradiance into electricity. (Solar irradiance is electromagnetic energy from the sun. Electromagnetic energy from other sources such as lamps can also be used by solar cells to generate electricity if the energy of the photons is high enough to break up the electron pairs.). Photovoltaic energy conversion in solar cells consists of two important steps. The first is the absorption of light which generates an electron-hole pair. The electron and hole are then separated with electrons going to the negative terminal and holes to the positive terminal. Hence the generation of electrical power. Most of the available solar cells are made of silicon. The benefit of using silicon is its mature processing technology. The large abundance in the crust of the earth, and its non-toxicity makes it a wise and obvious choice. The silicon is used in PV cells for mono crystalline (single crystalline) and multi crystalline photovoltaic module production. In mono crystalline silicon, the crystal lattice of the entire sample is continuous with no grain boundaries. Multi crystalline are composed of a number of smaller crystals or multiple small silicon crystals. In general, mono crystalline silicon wafer is better in performance than the multi crystalline silicon wafers [2]. The voltage of the electric current from a single or multi-crystalline silicon solar cell is 0.5 volts. This results from the voltage across the N/P barrier layer of the solar cell. The current or amperage of the solar cell is dependent on the number of electrons that are knocked into the conduction band. This current is proportional to the amount of solar radiation incident on the solar cell. The current from the solar cell can be increased by increasing the area of the solar cell or by increasing the amount of solar radiation incident on the solar cell. Solar cells can be thought of as solar batteries. If solar cells are connected in series, then the current stays the same and the voltage increases. If solar cells are connected in parallel, the voltage stays the same, but the current increases.

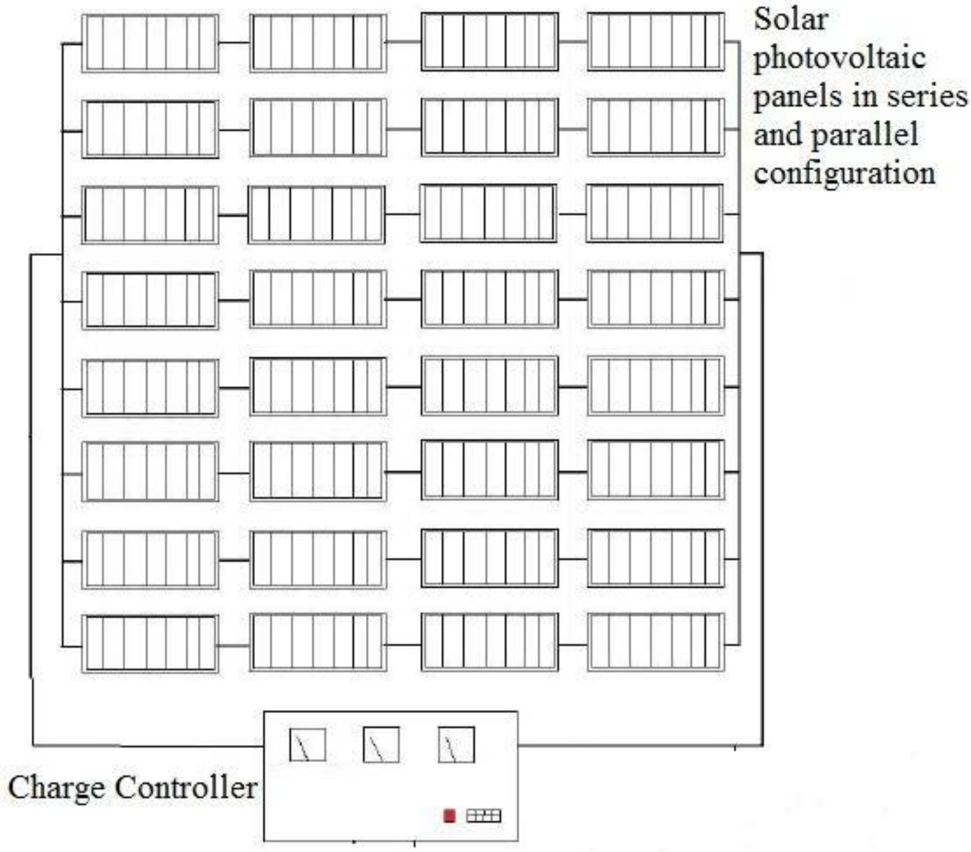


Fig. 2: Solar panel connection configurations.

Solar cells are combined to form a ‘module’ to obtain the voltage and current (and therefore power) desired. For example, to form a 12-volt module, 24 solar cells have to be connected in series. A group of solar cells put together is often called a photovoltaic module. Power is equal to current multiplied by voltage. The power rating of a photovoltaic module is typically quoted as the power output of the module when the incident solar radiation is 1000 watts/meter squared and the temperature is 25º C. This is a typical value of solar radiation around the middle of a clear summer day. A one-meter square module that is 15% efficient would therefore have an output of 150 Watts on a clear day near noon. A photovoltaic array produces direct current that is used to power the “load”. This can range from charging a battery in a calculator to powering a communications system to powering a building or city. When a PV array is connected to an electrical equipment that runs on alternating current, it must first be connected to an inverter that changes the direct current to alternating current [3].

## 2.2 Charge Controller/Switching Unit.

The primary function of a charge controller in a solar power system is to maintain the battery at highest possible state of charge, when the photovoltaic module charges the battery the charge controller protects the battery from overcharge. Ideally, charge controller directly controls the state of charge of the battery. Without charge control, the current from the module will flow into a battery proportional to the irradiance, whether the battery needs to be charging or not. If the battery is fully charged, unregulated charging will cause the battery voltage to reach exceedingly high levels, causing severe gassing, electrolyte loss, internal heating and accelerated grid corrosion. Actually charge controller maintains the health and extends the lifetime of the battery [4]. Solar Charge controller can be configured to stop the flow of current to the battery when the rated current level of the battery is reached. Charge controllers can also be referred to as Charge Regulators. A series charge controller or series regulator disables further current flow into batteries when they are full. A shunt charge controller or shunt regulator diverts excess electricity to an auxiliary or "shunt" load, such as an electric water heater, when batteries are full. Simple charge controllers stop charging a battery when they exceed a set high voltage level, and re-enable charging when battery voltage drops back below that level. Pulse width modulation (PWM) and maximum power point tracker (MPPT) technologies are more electronically sophisticated, adjusting charging rates depending on the battery's level, to allow charging closer to its maximum capacity. Charge controllers may also monitor battery temperature to prevent overheating. Some charge controller systems also display data, transmit data to remote displays, and data logging to track electric flow over time [4].

### *2.2.1 Pulse Width Modulation (PWM)*

Pulse Width Modulation (PWM) is a very effective means to ensure constant voltage battery charging by switching the solar system controller's power devices. When in PWM regulation, the current from the solar array flows according to the battery's recharging needs and condition. In the past simple on-off regulators were used to limit the rate at which batteries gas out when a solar panel produced excess energy. On-off regulators have been earlier known for battery failures and increasing load disconnections. PWM is the first significant advance in solar battery charging. PWM solar chargers use technology close to other modern battery chargers. When a battery voltage reaches the manufacturer's rated voltage, the PWM algorithm slowly decreases the charging current to avoid heating and gassing of the battery, but the charging continues to return the maximum amount of energy to the battery in the shortest time. The benefits are a higher charging efficiency, fast recharging, and a healthy battery always at full capacity.

### *2.2.2 Maximum Power Point Tracking (MPPT)*

The PV array has a highly non-linear current-voltage characteristic varying with the irradiance and temperature that substantially affects the array power output. The maximum power point tracking (MPPT) control of the PV system is therefore critical for the success of a PV system. MPPT algorithms, ranging from simple hill-climbing algorithms to fuzzy logic and neural network algorithms are used in the application of MPPT. The three main versions of the hill climbing algorithm, P&O, MP&O and EPP, are described below [5].

### *2.2.3 Switching Unit*

This unit is essential for the switching on and off of the luminaires. In the evening when the sun is setting, the switching unit switches the outdoor lights on. Also when the sun is rising at dawn the switching unit switches the lights off. The switching unit functions by switching the path of current. At dawn the switching unit switches current path from solar panel to luminaires to solar panel to battery. This change switches off the luminaires and charges the battery bank during the day. Likewise, at dusk the switching unit switches current path from solar panel to the battery to solar panel to luminaires. This change stops the charging of the battery and then powers the luminaires.

## 2.3 Battery Bank

A battery is a device that converts chemical energy into electrical energy and vice versa. It is used to store up charges for use later. Batteries store charges in form of DC voltage. The amount of charges to be stored determines the size of the battery. A battery convert's energy stored in the chemical bonds of a material into electrical energy via a set or oxidation/reduction (redox) reactions. Redox reactions are chemical reactions in which an electron is either required or produced. For primary batteries, this is a one-way process – the chemical energy is converted to electrical energy, but the process is not reversible and electrical energy cannot be converted to chemical energy. This means that a primary battery cannot be recharged. For a secondary battery, the conversion process between electrical and chemical energy is reversible, – chemical energy is converted to electrical energy, and electrical energy can be converted to chemical energy, allowing the battery to be recharged [6].

## 2.4 Inverter

Inverters change Direct Current (DC) to Alternating Current (AC). Stand-Alone inverters can be used to convert DC from a battery to AC to run electronic equipment, motors, appliances, etc. Synchronous Inverters can be used to convert the DC output of photovoltaic (PV) modules, a wind generator or a fuel cell to AC power [7].

## 2.5 Luminaires

Luminaires can be in different types as listed in the following sub-sections.

### 2.5.1 Incandescent Lamp

Incandescent lamp is a pathway to achieving artificial light. It comprises of a filament made from a very thin strip of tungsten doubly coiled for reducing filament cooling and increasing the chances of producing large light output. The filament is normally enclosed in a glass tube filled with gases like nitrogen or argon to reduce the evaporating rate of the filament [8].

### 2.5.2 Discharge Lamps

Discharge lamp is another way of producing artificial light. Discharge lamps operate on the basis of the arc discharge. There is a constant arc between two electrodes that causes the filling to give light. This principle can be used with different metals and filler materials. The range includes metal halide lamps, sodium lamps and mercury vapor lamps. Almost all discharge lamps need control gear to ignite them and limit their current.

### 2.5.3 Metal Halide Lamps

The introduction of metals and iodides improves the color and luminous intensity of metal halide lamps. With their very short discharge arc, they come very close to the idea of a point light source, which means their light is very easy to focus exactly where needed, and they offer a high utilization factor [9].

### 2.5.4 Gas Discharge Lamps

In this type, the aim is achieved by exciting a gas trapped in a glass casing. Unlike incandescent lamps, gas discharge lamps have no filament and do not produce light as a result of current passing through a solid. Rather, the atoms or molecules of the gas inside a glass or translucent ceramic tube, are ionized by an electric current through the gas or a radio frequency of the tube. This generates light which is usually either visible light or ultraviolet rays. The colour of the light depends on the mixture of gasses inside the tube as well as the pressure and type and amount of the electric current or radio frequency power [10]. An example is fluorescent lighting. Fluorescent lighting is achieved by passing current through a gas in a glass case. The gas is usually mercury vapour. When current passes through the mercury vapour, invisible ultraviolet rays are produced. The internal coating of the glass case helps transform the rays to visible light [8].

### 2.5.5 LED Lighting

LED lighting is another type of lighting. LED makes use of light emitting diode to produce light. LED is characteristic of low power consumption, high efficiency, long lifespan, superior light quality, high lumen maintenance, even light distribution and cost efficient [8]. Light-emitting diodes (LEDs) are a semiconductor technology with their application to general purpose lighting rapidly growing. LEDs have significant potential for energy savings. Light-emitting diodes (LEDs) are semiconductor devices that convert electricity to light. LED lighting is also known as “solid state lighting” because the light is emitted from a solid object.

## 3 METHODOLOGY

For the proposed system to operate properly and give the desired output, the solar panel should be mono-crystalline. This is because mono-crystalline panels are better than multi-crystalline panels. The mono-crystalline solar panel is a better choice as it can still convert light into charges even with very faint light. This feature will be of great benefit for regions with varying light intensities. The solar panels should be connected in parallel or in series depending on the amount of power that is required to be generated. Connecting in series results in voltage build-up while parallel connection results in current build-up. The solar panel array is then connected to the charge controller for regulation of voltage to charge the battery bank. The switching unit’s basic function is to compare the voltage at the charge controller output with a predetermined reference voltage. A comparator will perform this function perfectly or a micro-controller that can function as a comparator. The result of the comparison will inform the switching on and off of the luminaires. When the output voltage of the charge controller is greater than the reference voltage, the comparator switches to the on state and allows the flow of current while on the other hand, if the reference voltage is greater than the output voltage of the charge controller the comparator switches to the off state cutting off the flow of current. The battery bank is next in line. The battery gets charged up whenever the comparator is in its on state. The battery discharges when the comparator is in the off state. The inverter is just to convert the DC voltage of the battery to AC voltage to power the luminaires.

# 4 TESTS AND RESULTS

On assembling the proposed system, the following test results was observed,

Table 1 – Battery Charge Condition Table for 12V battery.

| BATTERY CONDITION | 12V |
|---|---|
| BATTERY NEAR FULL CHARGE WHILE CHARGING | 14.4 – 15.0 |
| BATTERY NEAR FULL DISCHARGE WHILE CHARGING | 12.3 – 13.2 |
| BATTERY FULLY CHARGED WITH LIGHT LOAD | 12.4 – 12.7 |
| BATTERY FULLY CHARGED WITH HEAVY LOAD | 11.5 – 12.5 |
| BATTERY NEAR FULL DISCHARGE WHILE DISCHARGING | 10.2 – 11.2 |

Table 2 – Table of Switching On and Off Test result.

| Test Day | Switch On Time | Switch Off Time |
|---|---|---|
| 1 | 6:55 PM | 6:52AM |
| 2 | 7:01 PM | 6:54 AM |
| 3 | 6:59 PM | 6:55 AM |
| 3 | 6:58 PM | 6:52 AM |
| 4 | 6:55 PM | 6:55 AM |
| 5 | 7:00 PM | 6:52 AM |
| 6 | 6:59 PM | 6:52 AM |
| 7 | 6:40 PM | 7:00 AM |
| 8 | 6:45PM | 6:58 AM |

From the tests carried out, I deduced that the sun irradiance at 7:00 PM will not give sufficient voltage output (> 10V). Test Days 7 and 8 had cloudy evenings as it rained those evenings. I also deduce that the sun irradiance around 7:00 AM will be enough to make the luminaires switch off.

The test also confirmed that switching on and off of the lights is possible.

# 5 CONCLUSION

From the test carried out it was determined that the system is highly reliable, easy to maintain and requires little human supervision.

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