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# Development Of A Software Package For The Design Of Solar Powered Street Lighting System: Case Of Oduduwa Road, University Of Ibadan, Ibadan, Nigeria

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## ABSTRACT

The world as a whole is currently running out of energy to meet its needs. The over usage of conventional energy to alleviate this hunger has resulted in widespread pollution. As a result, renewable energy sources must be used to lessen this impact. The objective of this project was to create a computer software package that could be used to simulate photovoltaic (PV) street lighting installations using Oduduwa Road at the University of Ibadan as a case study. The design work was done using photometric laws and PV lighting design criteria, as well as the standard solar photovoltaic equations. Solar energy data needed were obtained from the Nigeria Meteorological Agency, Ibadan Station, for a location of 7°30N Latitude and 3°54 E Longitude (Oduduwa Road, University of Ibadan) while an annual average solar radiation of 2.50 kWh/m day were used in the design equations. The street lighting system generated a total daily load of 18.7 kWh. The obtained overall battery storage capacity, number of batteries required, solar panel capacity, number of panels, number of poles and number of lamps were 360wh, 30, 180Watts, 42, and 53 respectively. The total cost obtained is ₦10,340,000, with a 1.4-year payback period. A computer software package for simulating photovoltaic (PV) street lighting installations was developed and tested, with the results comparing favourably well to the manual design, hence, the developed package is recommended. It was also observed that the time taken in the manual design was far more when compared with that of the software package.

**Keywords:** Renewable Energy, Photovoltaic, Design, Photometric, Stand-Alone

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## 1. INTRODUCTION

Until now, people all over the world have depended on fossil fuels for their energy needs. Fossil fuels are limited, expensive and polluting the environment. The rapid upturn in the development and adoption of solar power is no news to anyone and this is due to the growing concerns for the depletion of the world's natural resources and our future energy supply. Energy gotten from the sun is a renewable type of energy, that is, it is naturally gotten and can never be used up. Such resources are free of cost and also available in abundance, that is, it is never used up. The sunlight that hits the Earth in an hour has more energy than the people of the world use in a year. For our region, solar energy is the amplest, direct and clean form of renewable energy especially in Nigeria. Total solar energy absorbed by the Earth is about 3,850,000 extra joules (EJ) in one year, which is approximately twice as much as all the non-renewable

resources on the earth found and used by the human being, including coal, oil and natural gas. Solar photo voltaic system is a system that can be used t generate electricity using radiation from the sun. To have a better understanding of the PV system, there is the need to expatiate on the phrase itself. The prefix 'Photo' means produced by sunlight and the suffix 'voltaic' refers to electricity produced by chemical reaction (American Society of Mechanical Engineers, 2012). To summarize, PV system refers to chemical reaction produced by sunlight to generate electricity.(Mughal et al., 2018)ABSTRACT

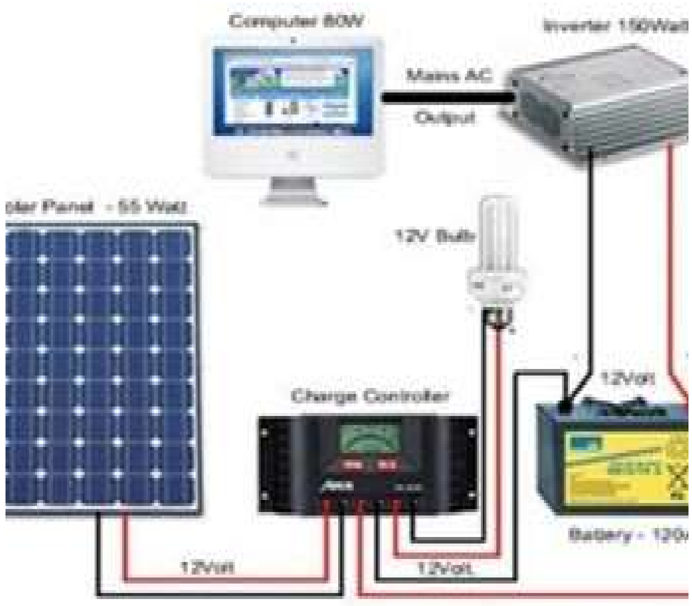


Figure 1: A Simple PV system

### 1.1 History

Solar energy has been used in various ways since the 7th century BC. Early uses of the sun's energy focused on heat and passive solar design. In 1839, the human race encountered a major milestone in the evolution of solar energy: the defining of the photovoltaic effect. At the age of 19, a young French scientist by the name of Edmund Bacquerel discovered the photovoltaic effect whilst doing research in his father's lab with an electrolytic cell made up of two metal electrodes placed in an electrolyte.(Passago et al., 2020)

By 1980 solar panel power plants were built with ARCO solar, producing more than 1 megawatt of photovoltaic modules a year. The company helped set up the first megawatt-scale power station in Hesperia, California. That year construction on a U.S. Department of Energy project named Solar One was finished. Solar One produced 10 megawatts of current, guiding the sun's energy into a common focal point to produce heat. The heat ran a steam turbine generator. It did so using 1818 mirrors, each mirror being 40m2 (430 ft2) with a total area of 72,650 m2. By 1985 sales of photovoltaic cells had reached $250,000,000. The University of South Wales had increased the efficiency for silicone solar cells to 20%. This was under 1-sun conditions. A year later ARCO released the first commercially available thin-film solar power module.

In 1994 The National Renewable Energy Lab in America developed a solar cell. The cell was made from gallium indium phosphide and gallium arsenide. It breaks the 30% efficient mark, meaning that it converts 30% of the sun's light that strikes it into usable power. A skyscraper in New York City (right) used these new higher efficiency thin cells on a selection of its floors. They helped to meet the buildings energy needs a few years later. We now reach the year 2000, Construction of solar panels at the largest plant reached a production capacity of 100 megawatts of power a year. Solar power had become big business for producers and sellers the world over. People worldwide, especially those in leadership roles were becoming increasingly aware of the need t o lower our dependence on fossil fuels. More eco-friendly means of powering our lives needed to be found. Scientific endeavour in the renewable energy industry was increasing greatly. Solar power was the flagship technology.

Fuelled by the advance in semiconductor technology, solar cells are one of the most promising candidates for alternate energy sources. Photovoltaic (PV) system is a green power source that converts sunlight to electricity. It has many applications as in space satellites and orbital stations, solar vehicles, power supply for loads in remote areas, and street lighting systems.(Szabo, 2018)

## 2. LITERATURE REVIEW

Street lighting has been around since humans began living together. As early as 500 BC, the ancient Romans used oil lamps filled with vegetable oil in front of their houses. In 1802, William Murdock used a gas light fuelled with coal gas. Not long after that the city of London, England decided that instead of just having the lamps in front of homes, the use of the gas lights lit an entire street in 1807. The United States began to use these gas lights as well but not until 1816. The city of Baltimore, Maryland was the first city to use gas lights. From gas lights, improvements were made, and the gas lights were switched to electric lights which are more energy efficiency. Yablochkov Candle, invented by Pavel Yablochkov in 1875, was the first electric street light to use arc lamps in 1878. Three years later in Paris, France, the city began replacing the gas lamps with electric lamps. The United States followed suit and by 1890, 130,000 arc lamps were installed on many city streets. Once the electric street lights came along, improvements were made little by little. Today, there is many lights to choose from. There are many traditional street lights that are efficient, but some very old street lights still in use are not energy efficient.

Solar photovoltaic street lights can be very energy efficient if the systems are set up correctly. Solar lights are the most advanced electrical sources of light in the world, there is no other light source that provides so many benefits while also minimizing heat and CO2 output. To maintain the highest level of international manufacturing and testing standards so that our products are durable and safe for the environment. Whatever aspect of lighting that it prioritizes, solar lights are superior in many categories. Energy efficiency, life, colour rendition, lumen depreciation, waste/heat output, glare etc. Solar lights are truly the next generation of electric lights that is set to displace several existing forms of electric lighting.

There were numerous reviews in the past covering solar design and particularly daylighting simulation tools, mainly concerning simulation accuracy. Fuelled by the advance in semiconductor technology, solar cells are one of the most promising candidates for alternate energy sources.(Allery et al., 2018). Photovoltaic (PV) system is a green power source that convert sunlight to electricity. It has many applications as in space satellites and orbital stations, solar vehicles, power supply for loads in remote areas, and street lighting systems. (Jakica, 2018).

a. Solar Cell

Crystalline Solar cell technology: Crystalline solar cells are the most efficient solar cells in the market. The PV cells based on silicon are generally long lasting and more efficient than any other cells. However, higher temperature for operation results in reduction of efficiency.

b. Parts of a PV module

1. • Front Surface: This is essentially a glass cover. It should be able to reflect light at a low level for the wavelength in question. It should be able to transmit a lot of information. Iron glass is commonly used for a variety of reasons, including its low cost, stability, and strength, as well as its excellent transparency and impermeability to gases and water.
2. • Encapsulant: It establishes tight connections between the cells in the module. It must be stable over a wide temperature range, have minimal thermal resistance, and be very transparent. The rear and front surfaces of formed cells are covered with a thin layer of EVA (ethylene vinyl acetate).
3. • Back Surface: It's a back sheet for a PV module, and it's composed of glass or a thin polymer.

c. Types of Solar Cell

Monocrystalline solar cell Technology: Monocrystalline solar cells are the highest efficient solar cells, produced from silicon wafers after 1a lengthy fabrication process. Their effectiveness ranges from 15 to 18 percent. They come in a variety of shapes, including round, square, and semi- round. Their thickness ranges from 0.2 to 0.3mm. Square or semi-round cells are more expensive than round cells because more material is wasted in the manufacturing process, yet round cells are still employed infrequently since they do not properly utilize module space. They come in a variety of colors, including black, dark blue (with an anti- reflection coating), and grey (without anti-reflection coating).

i. Polycrystalline solar cell technology: Polycrystalline solar cell technology has a lower cost per unit area than monocrystalline solar cells, yet the polycrystalline and monocrystalline module structures are comparable. The module's efficiency is improved by using huge square cells. Their effectiveness ranges between 13 and 16 percent. They come in square shapes with a thickness of 0.24-0.3mm. Blue (with anti-reflection coating), grey, gold, brown, green (without anti-reflection coating), and silver are some of the colours offered

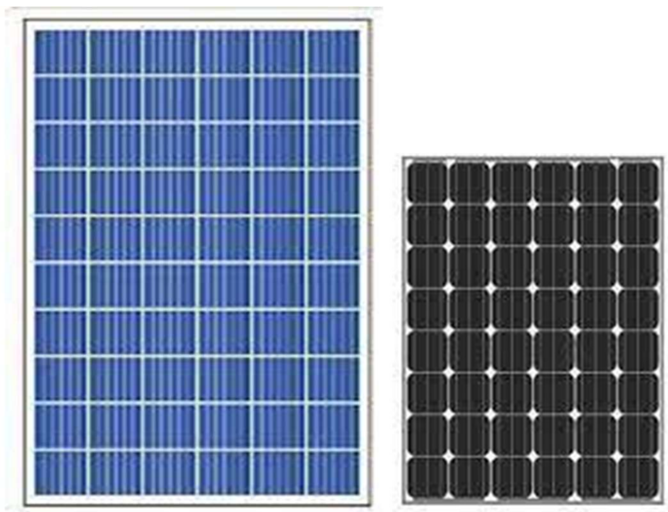

Figure 2: Solar Cell

d. Charge Controller

A charge controller, also known as a charge regulator, is a voltage and/or current regulator that prevents batteries from becoming overcharged. It regulates the voltage and current going to the battery from the solar panels. Because most "12 volt" panels produce around 16 to 20 volts, the batteries will be harmed by overcharging if there is no regulation. To reach full charge, most batteries require between 14 and 14.5 volts.

1. Simple 1 or 2 stage controls: This rely on relays or shunt transistors to control the voltage in one or two steps. These essentially just short or disconnect the solar panel when a certain voltage is reached. For all practical purposes these are dinosaurs, but you still see a few on old systems - and some of the super cheap ones for sale on the internet. Their only real claim to fame is their reliability; they have so few components, there is not much to break.
2. 3-stage and/or PWM: These are pretty much the industry standard now, but you will occasionally still see some of the older shunt/relay types around, such as in the very cheap systems offered by discounters and mass marketers.
3. Maximum power point tracking (MPPT): These are the ultimate in controllers, with prices to match but with efficiencies in the 94% to 98% range, they can save considerable money on larger systems since they provide 10 to 30% more power to the battery

### e. Battery

Batteries accumulate excess energy created by your PV system and store it to be used at night or when there is no other energy input. Batteries can discharge rapidly and yield more current that the charging source can produce by itself, so pumps or motors can be run intermittently. The battery's capacity for holding energy is rated in amp- hours: 1 amp delivered for 1 hour = 1-amp hour. Battery capacity is listed in amp hours at a given voltage, e.g. 220 amp-hours at 6 volts. Manufacturer's typically rate storage batteries at a 20-hour rate: 220 amp-hour battery will deliver 11 amps for 20 hrs. This rating is designed only as a means to compare different batteries to the same standard and is not to be taken as a performance guarantee. Batteries are electrochemical devices sensitive to climate, charge/discharge cycle history, temperature, and age. The performance of the battery depends on climate, location and usage patterns. For every 1.0 amp-hour you remove from your battery, you will need to pump about 1.25 amp-hours back in to return the battery to the same charge state of charge. This figure also varies with temperature, battery type and age. Different chemicals can be combined to make batteries. Some combinations are low cost but low power also, others can store huge power at huge prices. Lead-acid batteries offer the best balance of capacity per dollar and it's a common battery used in stand-alone power systems.
Lead – Acid Batteries

The lead-acid battery cell consists of positive and negative lead plates of different composition suspended in a sulfuric acid solution called electrolyte. When cells discharge, sulphur molecules from the electrolyte bond with the lead plates and releases electrons. When the cell recharges, excess electrons go back to the electrolyte. A battery develops voltage from this chemical reaction. Electricity is the flow of electrons. In a typical lead-acid battery, the voltage is approximately 2 volts per cell regardless of cell size. Electricity flows from the battery as soon as there is a circuit between the positive and negative terminals. This happens when any load (appliance) that needs electricity is connected to the battery. Good care and caution should be used at all times when handling a battery. Improper battery use can result in explosion.

### f. Battery Cycles

Batteries are rated according to their "cycles". Batteries can have shallow cycles between 10% and 15% of the battery's total capacity, or deep cycles up to 50% to 80%. Shallow- cycle batteries, as those for starting a car, are designed to deliver several hundred amperes for a few seconds, then the alternator takes over and the battery is quickly recharged. Deep-cycle batteries or the other hand, deliver a few amperes for hundreds of hours between charges. These two types of batteries are designed for different applications and should not be interchanged. Deep-cycle batteries are capable of many repeated deep cycles and are best suited for PV power systems. RV or Marine "Deep-Cycle" - 12 volt batteries usually 80 and 160-amp hour capacity. A compromise between shallow and true deep cycle batteries. Life expectancy is about 2 to 3 years. Lead-Calcium Batteries Occasionally these shallow-cycle batteries recycled from the telephone company are used in remote power systems. At 400 pounds per 2 volt cell and cycle limited to 15% - 20%, these batteries are not recommended.Sealed Batteries - These are liquid-tight batteries that can operate in any position without leaking acid. Because of the seal construction, you cannot check cell conditions with a hydrometer. Vents prevent pressure build-up in case of gassing.

Recommended only for situations where hydrogen gassing during charging cannot be tolerated, or the battery is going to be moved a great deal, or to be fit in tight spaces. Require lower voltage charge controls. Most AGM batteries (absorbed glass mat) have a life expectancy of 2-5 years, and 5-10 years for higher quality Gel cell batteries. Most sealed batteries are AGM. True Deep-Cycle Batteries - True deep-cycle batteries are specifically designed for energy storage and deep-cycle service. They tend to have larger and thicker plates as shown in the image above. Ideal for renewable energy systems, deep-cycle batteries withstand having a majority of their capacity used before being recharged and survive hundreds and even thousands of 80% cycles. It is recommended to use 50% as the normal maximum discharge and leave 30% for emergencies. Do not use the bottom 20%, the less deeply you cycle your battery, they longer it will last. Available in many sizes and types.


Figure 3: Battery

g. Light Source

The choice of source is important decision in any lighting system design, particularly for PV lighting application where the energy efficiency of the light affects the size and cost of the power source. Factors to be considered in lamp selection include efficiency, colour, and lifetime and lumen depreciation.

Luminous Efficiency: A representation of lamp or luminaire efficiency, generally expressed in luminous emitted per watt consumed (Lm/W). Typical lamp efficiencies range from a low 15Lm/W for some incandescent lamps up to 180Lm/W for low-pressure sodium lamps Lamp Lumen depreciation (LLD): sometimes referred to as lumen maintenance, LLD refers to a lamp's lumen output reduction over as lifetime, generally expressed as a percentage of initial rated output as a function of lamp burn hours. For some types of lamps, depreciation of lamp lumen output makes it practical to replace many lamps before they actually burn out. Colour: this is determined by the spectral content or wavelength.

Life time: This refers to the life span or range of the lamp. Light sources can be categorized into three groups. Incandescent, fluorescent and high intensity discharge (HID) sources HID lamps include four major categories - high pressure sodium, metal halide, mercury vapour and low pressure sodium. LED is usually used as lighting source of modern solar street light, as the LED will provide much higher Lumens with lower energy consumption. The energy consumption of LED fixture is at least 50% lower than HPS fixture which is widely used as lighting source in Traditional street lights.

LEDs lack of warm up timealso allows for use of motion detectors for additional efficiency gains. Table 2.2 lists general characteristics of common lamp types. Quality of Light. The most significant measure of a lighting installation is the amount of illumination it provides. The required illumination levels are related to the tasks to be performed under the illumination. Thus, critical tasks involving long hours working with small parts such as electronics assembly require high illumination levels, while parking lots and storage yards require less illumination due to the nature of the anticipated activity. For signal lighting applications, the luminance (brightness) of the source is the quantitative measure of system performance. In the PV lighting design for the purpose of street lighting, the specification required of the lamps are:

1. High luminous efficacy
2. Long life span
3. High lumen maintenance
4. Low lamp size (wattage)

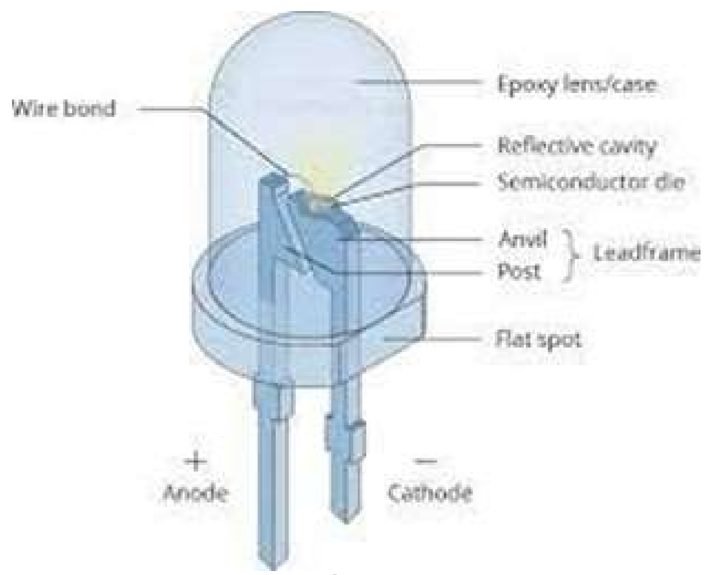


Figure 4: LED lamp

## 3. METHODOLOGY

The monthly mean and daily data of Global Solar Radiationand sunshine hours were collected from the Nigeria Meteorological Agency department, Ibadan Station for design analysis. The Topographic lay out of University of Ibadan coupled with the existing design on Oduduwa road, University of Ibadan were collected from Works and MaintenanceDepartment, University of Ibadan for design analysis. Oduduwa road, University of Ibadan, Nigeria located on Latitude 7º 30' N and Longitude 3º 54' E, with Elevation (Altitude) 233m, hence it enjoys two climatic seasons in a year the rainy season from April to October and the dry season from November to March. Before, the street lamps on Oduduwa Road, University of Ibadan are being powered through now IBEDC (IbadanElectricity Distribution Company) and the central generator is being used as a backup. Each lamp has wattage of 200W and they run for 12 hours every day out of which 8 hours of electricity is supplied by IBEDC and the remaining 4 hours of electricity is supplied by the backup generator.

Currently,the street lamps on Oduduwa Road, University of Ibadan arebeing powered through centralized PV Solar system becauseof the shaded arca on both sides of the road. Each lamp has wattage of 30W of Low Sodium Pressure Vapour Bulb(LSPVB) and they run for 12 hours every day. Oduduwa Road, University of Ibadan now experiencing total night blackout due to poor maintenance of the facility.

### 3.1 System design and sizing analysis

System sizing is the process of evaluating the adequatevoltage and current ratings for each component of the photovoltaic system to meet the electric demand at the facility and the same time calculating the total price of the entire system. The design of PV lighting systems involves a number of steps andpossible iterations to select and size the individual components required for a functional system.

The followingsteps outline the process for designing the PV lighting systemof Oduduwa Road, University of Ibadan.

1. Determining the quantity and quality of lighting needed
2. Determining the magnitude and duration of the lightingelectrical load on average daily and seasonal basis.
3. Estimating battery storage size based on the desiredautonomy period and maximum and average daily efficiency.
4. Estimating PV array size based on the time of the yearwith the highest daily lighting load and minimum solar radiation
5. Determining the till angle of the system that will give maximum insolation based on the coordinates of the site (i.e. Latitude and Longitude of the site).

The new design on Oduduwa Road, University of Ibadan Street lamps would be design based on Stand - alone solar street lighting system (Regulated standalone system with battery and DC load). Each lamp has wattage of 30W of LED lamp couple with Deep cycle Battery, Mono crystalline Solar panel and Charge controller.

### 3.2 Factors affecting system sizing

1 The average power demand in Watt-hour per day this can be obtained by itemizing all appliances and their hours of use each day which is referred to as the load profile.

2 Geographical location that dictates the tilt angle, panel orientation and the average sun hours per day.

3 Home design, which plays a major role in maximizing the amount of the generated power by considering the following points: keeping the southern area free from any barrier that prevents the sun ray from reaching the panel, windows should be designed to face the south to keep the house as warm as possible and insulation can be used to minimize the amount of heat losses.

4 The use of low - voltage DC powered electric appliances, nowadays available in the market, is also an important factor in minimizing the photovoltaic system cost.

5 Frequency of switching which determines how often major rotationary loads are switched on and off such as refrigerators and water pumps. Such loads draw high currents every time they start and these loads must be accounted for.

### 3.3 Load sizing

The first step to take when designing a PV lighting system is to quantify the magnitude and duration of the electrical load. It is the electrical load that determines the size cost of a PV system, therefore the energy efficiency of the load is a critical concern. For this reason, steps are often taken to improve the efficiency of lighting design as part of any PV lighting application. As discussed earlier, this may involve several factors including selection of more efficient light sources and improved luminaire design, better aiming and distribution of the light in order to estimate the lighting electrical load of Oduduwa Road, University of Ibadan. (Odunfa & Akinpelu, n.d.).

### 3.4 Photometric laws

Two basic photometric laws are used in almost all lighting design practice - the inverse square Law and the Cosine Lawof Incidence, these two photometric laws were also used in the PV lighting design of Oduduwa Road, University of Ibadan to determine the required Illumination.

i. Inverse Square law: states that illumination is directlyproportional to the square of the distance between the source and the surface.
ii. Cosine Law of incidence: illumination is directlyproportional to the angle of incidence. Combining the two laws, the equation below isobtained.

$$E = \frac{I\ x\ cos\theta}{D^2}$$

Where
E = Illumination
I= Luminous intensity
Length of road = 0.790km = 790m
Width of road = 30m (i.e 15m by 15m)
θ = Angle of incidence
D = distance (i.e pole height = 10m)
Luminous efficacy of LED bulb = 150Lumenwatt

### Calculations

$$\text{Load (watt)for each bulb} = \frac{Luminous\ intensity}{luminous\ efficacy\ of\ bulb}$$

$$= \frac{4050}{150}$$

Finding the Total Load

$Total\ Load\ in$ wh/day
$= Watt\ of\ each\ LED\ x\ No\ of\ Lamps\ x\ hrs\ of\ operation$
= 30 $x$ 52 $x$ 12
= 18720$wh/day$

The required wattage by Solar Panels System

= 18720 $x$ 1.3 (1.3 is the factor used for energy lost in the system)
= 24336 Wh/day

Finding the Size and No. of Solar Panels

$W_{Peak}$ Capacity of Solar Panel

$$= \frac{24336Wh}{3.2}$$
= 6142.5$W_{Peak}$

Required No of Solar Panels

$$= \frac{7605}{180W}$$
= 42.3

No of Solar Panels = 42.3

Solar Panel Modules approximately 43

This way, the 43 solar panels each of 180W will capable to power up our load requirements.

$$pole\ spacing = \frac{Length\ of\ road}{No\ of\ lamps}$$
$$= \frac{790}{52}$$
= 15.2m
= 16m

For proper design, we are going to use 30W of a Light Emitting Diode (LED) for a pole
Thus,

$$\text{Number of poles} = \frac{Length\ of\ road}{Pole\ spacing}$$
$$= \frac{790}{15.2}$$
= 51.9
= 52 poles

The total number of 30W LED bulb that would be required in this design is 52 bulbs. Thus, the maximum load estimated for the street lighting of Oduduwa road, University of Ibadan per day is 18.7kwh.

### 3.5 Battery sizing

The number of batteries that would be used depends on the power rating of the appliances which will be operated during the critical period. It is difficult to define the first value of consecutive cloudy days. Fairly good estimate could be made based on familiarity with the location. However, the table below gives a safe estimate based on the geographical location (degrees of latitude North or South) of the installation, hence the geographical location of Oduduwa road, University of Ibadan (a latitude of 7.44(7° 26' N) and a longitude of 3.90 (3°54' E ) is used in the design.

Battery Type - Deep Cycle Battery
Power = 30W
Nominal System Voltage (V) = 120v
DC Battery voltage = 12v

Recall that
P = IV

$$\mathrm{I} = \frac{P}{V}$$

$$\mathrm{I} = \frac{30}{12}$$

I = 2.5Amps

Battery watt hour of the system = Power (P) x Working hours (hrs)

= 30 x 12 = 360Wh

$$\text{Amp sun hour} = \frac{Battery\ watt\ hour\ of\ the\ system}{Battery\ voltage}$$

$$= \frac{360}{12}$$

= 30Ah

$$\text{For 50\% Depth of Discharge (DOD)} = \frac{Amp\ Sun\ hour}{DOD}$$

$$= \frac{30}{0.5}$$

= 600Ah

Average sur hour per day = 5hours

$$Derating\ Factor = \frac{1}{1.2}$$

= 0.8

$$Total\ amp - rating\ of\ the\ system$$

$$= \frac{days\ of\ autonomy\ x\ consumption\ of\ energy}{amp\ rating\ of\ the\ chosen\ battery}$$

$$= \frac{3\ x\ 18720}{12}$$

= 4680 $Amp - hour$

$Total\ Number\ of\ batteries$

$$= \frac{Total\ amp - hour\ rating\ of\ the\ system}{amp - rating\ of\ the\ chosen\ battery}$$

$$= \frac{4950}{200}$$

= 23.4 $batteries$

### 3.6 PV array sizing

The size of modules is expressed by the power it can deliver in bright sunlight (peak sun). This peak power is then expressed in peak hour (Wp). It is better than working in m$^2$ because there is no need to consider the efficiency of the solar cells.

If the efficiency is increased a smaller module is needed to obtain the same peak hour as with module having lower efficiency. However, we assume that only power delivered is important. The number of modules needed is obtained, expressed in peak watts (Wp), by dividing the energy use profile (in Wh/day) by the solar radiation.

### Calculations

Average sun hour per day = 5hours

$$Derating\ Factor = \frac{1}{1.2}$$
= 0.8

Module type = Mono crystalline

Module efficiency = 50%

$Wattage\ of\ the\ solar\ module$

$$= \frac{Total\ watt\ hour}{Average\ sun\ hour\ per\ day\ x\ Derating\ factor}$$

$$= \frac{360}{5\ x\ 0.8}$$

= 90W

$Solar\ module\ watt\ required$

$$= \frac{Wattage\ of\ Solar\ module}{Module\ Efficiency}$$

$$= \frac{90}{0.5}$$
= 180$W$

$maximum\ voltage\ of\ the\ chosen\ module$ = 18$V$

$Maximum\ Current\ of\ chosen\ module$ = 15 $Amps$

$Nominal\ voltage\ of\ the\ chosen\ module$ = 12$V$

Recall that,

$$I = \frac{Wattage\ of\ Solar\ Module}{Maximum\ Voltage}$$

$$= \frac{180}{18}$$

= 10 $Amps$

$$I = \frac{Wattage\ of\ the\ solar\ module}{Nominal\ Voltage}$$

$$= \frac{180}{12}$$

= 15$Amps$

### 3.7 Charge Controller Sizing

Controller is also very important for solar street light. A controller will usually decide to switch on /off charging and lighting. Some modem controllers are programmable so that user can decide the appropriate chance of charging, lighting and dimming. Charge controller are used to prevent over-charging and over-discharging of the battery. This would help in making the battery last longer.

There are three general types of charge controller, mainly:
1. Simple ON/OFF Controller
2. Pulse Width Modulated (PWM) Controller
3. Maximum Power Point Tracking (MPPT) Controller

Most charge controllers operate at three stages to complete the charging cycle of the batteries. These stages vary according to different times and buttery voltages.

PWM can be employed to control the charging at the stages:
1. BULK stage
2. ABSORPTION stage
3. FLOAT stage

Calculations
Maximum voltage of the chosen module = 18V

Maximum Current of the chosen module = 15Amps

Nominal voltage of the chosen module = 12V

Recall that,

$$I = \frac{Wattage\ of\ Solar\ Module}{Maximum\ Voltage}$$

$$= \frac{180}{18}$$

= 10 $Amps$

$$I = \frac{Wattage\ of\ the\ solar\ module}{Nominal\ Voltage}$$

$$= \frac{180}{12}$$

= 15$Amps$

Charge controller available is 20Amps

The charge controller should be 25% greater than the solar panel short circuit current.

Size of solar charge controller in Amp
= Short circuit current of PV x 1.25
$W_{peak}$ of panel / voltage of battery x 1.25
=6142.5 / 12 x 1.25
=639.8 amps

## 4 COST ANALYSIS

### 4.1 Cost of photovoltaic power lighting system against other power sources

In the design of a PV system, one should not just look at the initial cost of installation alone but also at the running cost for the whole intended lifetime of the power system. Other points to be considered are listed below.

1. Photovoltaic running cost are more or less zero at least until the battery needs to be changed
2. Grid extension can also have a high initial cost depending on how far a line has to be extended
3. A diesel generator can be of low initial cost but the running cost can be high, especially since fuel and regular maintenance will be required just like all engine, it can need special replacement parts that can be very expensive to supply on short notice.

### 4.2 Cost estimation for powering the lighting system via PV stand - alone power System

The table below shows the cost of PV lighting components needed for the project installation on Oduduwa Road, University of Ibadan.

Table 1: Cost Analysis

| S/N | COMPONENTS | QUANTITY | RATE (₦) | SUB–TOTAL (₦) |
|---|---|---|---|---|
| 1 | Solar Panels | 42 | 30,000 | 1,980,000 |
| 2 | Battery | 30 | 173,000 | 5,190,000 |
| 3 | Lamp | 52 | 20,000 | 1,040,000 |
| 4 | Charge Controller | 21 | 30,000 | 630,000 |
| 5 | Miscellaneous | - | - | 1,500,000 |
| | | | | ₦10,340,000 |

Before, the street lamps on Oduduwa Road, University of Ibadan were being powered through PHCN (Power Holding Company of Nigeria) now IBEDC (Ibadan Electricity Distribution Company) and the central generator is now being used as a backup, each lamp as a wattage of 200W and they run for 12 hours every day out of which 8 hours of electricity is supplied by IBEDC and the remaining 4hours of electricity is supplied by the backup generator. Because of the shaded region on both sides of the road, the street lamps on Oduduwa Road, University of Ibadan, are currently powered by a centralized PV Solar system. Each light is a Low Sodium Pressure Vapour Bulb (LSPVB) with a wattage of 30W that runs for 12 hours every day. Estimating the total fond of these street lamps powered via electric grid (i.e IBEDC)

we have 200W x 66Units of pole x 8Hours of IBEDCduration = 106kWh

- Load per day = 106kWh
- IBEDC rate = ₦66.04 per kWh
- Energy charge per day = 106kwh x 66.04per kWh =7,000.24/day
- Energy charge per year = ₦7,000.24 x 365days =2,555,087.6/year
- Fixed charge = N120/ month x 12 = ₦1, 440/year

Meter maintenance charge = Scrapped by FederalGovernment of Nigeria (FGN)

- VAT = N106/month x 12 = ₦1, 272/year
- Total Energy charge / year = ₦2,555,087.6+₦1, 440 +₦1, 272
  = 2,557,799.6/year

1. For the central generator, when it is powering the10.8KW (200W x 66 poles) street lighting for 4hours, the consumption rate is about 50Litres

- Cost of a litre of diesel = ₦254
- Total cost of running the generator for 4hours/day = ₦254 x50 = 12,700/day
- Total running cost of generator/year = ₦12,700 x 365 = ₦4,635,500/year

2. Total energy cost per year for the combined IBEDC andCentral generated
   = ₦2,557,799.6 + ₦4,635,500 = ₦7,193,299.6/year

- Total energy charge for the next 20 years (assuming there isno change in IBEDC rates, VAT and diesel price) = ₦7,193,299.6 x 20 = ₦143,865,992

### 4.3 The Software

The aim of this project is to design and simulate software package for a Solar photovoltaic installation in stand- alone system which would be able to calculate the Load, array, battery, charge controller, inverter (if need be) and any tilt angle. Flutter and Microsoft Excel were used to designed and simulate various PV components. I choose to use Flutter andMicrosoft Excel because it is more organized and its platform are independent i.e. it can run on any Operating system irrespective of the type be its windows, Linux or Macintosh.

Flutter is used for coding and simulation. Although the program has been restricted based on the market survey carried out, it can still be used for any kind ofsystem given the specifics of the site like Battery types, Battery specification, Module type, Module specification, Factor of safety, Site location and so on shows the homepage and tool of the software. When you click on the software Icon of the PV System, there are a couple entries which are called the inputs, once they are inputted, the software automatically does the calculations and gives the Output needed for the design of the PV system.

The software has been created in such a way that it isavailable on all devices including Android, Microsoft, Iphone, Macbook, Linux e.t.c. also, the inputs which can be modified, added or deleted to erase existing option that was originally made available in the software. Here, one can include the type of module, battery type, bulb type, inverter (if need be) that would be used in the design and the programautomatically adds the new item to the database without exiting the program.


Figure 5: Flutter App

Table 2: Module sizing

| S/N | DATA REQUIRED | VALUE |
|---|---|---|
| 1 | Total Load consumption | |
| 2 | Average sun hours per day | 5hours |
| 3 | Design month | August |
| 4 | Solar radiation of the design month | 2.50whm$^2$/day |
| 5 | Optimum angle of inclination (tilt angle) | 14$^o$ (facing south) |
| 6 | Derating factor | 0.8 |
| 7 | Peak watt of the chosen module (Wp) | 180W |
| 8 | Maximum voltage of the chosen module | 18V |
| 9 | Maximum current of the chosen module | 15A |
| 10 | Total number of modules needed | 52 |
| 11 | Module type | Mono Crystalline |

Table 3: Battery Sizing

| S/N | DATA REQUIRED | VALUE |
|---|---|---|
| 1 | Total Load consumption | |
| 2 | Days of autonomy | 3 days |
| 3 | Design month | August |
| 4 | Solar radiation of the design month | 2.50whm$^2$/day |
| 5 | Battery efficiency | 80% |
| 6 | Derating factor | 0.8 |
| 7 | Amp- rating of the chosen battery | 200Ah |
| 8 | Nominal system voltage | 12V DC |
| 9 | Battery Voltage | 12V |
| 10 | Total number of battery needed | 30 |
| 11 | Battery type | Deep Cycle |
| 12 | Charge controller amp rating | 20A |
| 13 | Total number of 30W LED bulb | 52 |


Figure 6: Interface of the Software package

Table 4: Sizing summary of an Existing Design

| S/N | DATA REQUIRED | VALUE |
|---|---|---|
| 1 | Total Load consumption at night time | |
| 2 | Days of autonomy | 3 days |
| 3 | Battery efficiency | 80% |
| 4 | Derating factor | 0.8 |
| 5 | Amp- rating of the chosen battery | 200Ah |
| 6 | Nominal system voltage | 12V DC |
| 7 | Battery Voltage | 12V |
| 8 | Total number of battery needed | 30 |
| 9 | Battery type | Lead Battery |
| 10 | Charge controller amp rating | 52 |
| 11 | Total number of 30W LED bulb | 45 |
| 12 | Total number of poles | 45 |
| 13 | Pole Spacing | 18m |
| 14 | Module type | Mono crystalline |
| 15 | Pole height | 10m |
| 16 | Lamp type | LPVB (80W) |
| 17 | Tilt angle | $15^{o}$ |

Table 4: Sizing summary of an Existing Design

| S/N | DATA REQUIRED | VALUE |
|---|---|---|
| 1 | Total Load consumption at night time | |
| 2 | Days of autonomy | 3 days |
| 3 | Battery efficiency | 80% |
| 4 | Derating factor | 0.8 |
| 5 | Amp- rating of the chosen battery | 200Ah |
| 6 | Nominal system voltage | 12V AC |
| 7 | Battery Voltage | 12V |
| 8 | Total number of battery needed | 30 |
| 9 | Battery type | Deep Cycle |
| 10 | Charge controller amp rating | 19amps |
| 11 | Total number of 30W LED bulb | 52 |
| 12 | Total number of poles | 52 |
| 13 | Pole Spacing | 16m |
| 14 | Module type | Mono crystalline |
| 15 | Pole height | 10m |
| 16 | Tilt angle | $13^{o}$ |


Figure 7a: Interface of the Software package


Figure 7b: Interface of the Software package

## 5. CONCLUSION

From the cost analysis, it can be seen that the most cost efficient option of the two power sources PVlighting and IBEDC/Diesel generator is thePhotovoltaic (PV) stand-alone system. Apartfrom the fact that using diesel generator to runstreet lighting system is not cost efficient. It also poses a threat to the environment due to the emission of greenhouse gases ($CO_2$ and CO)from the combination of the fuel. Therefore, the use of Stand-alone Photovoltaic System to power Oduduwa road street lighting is most viable of all the three power options because

1. It is readily available
2. It is environmental friendly
3. It is relatively cost efficient
4. It guarantees a constant supply of electric power
5. The FLUTTER simulation shows results ofa PV module. The PV module parameters acquired through simulation are identical tothe PV specs found on the data sheet. The safety factor utilized in this study has a value between 1.2 and 1.3. The PV systemmust provide 15W/18V for 12 hours (18.7 kWh). Solar radiation incident on one square meter at the chosen location is estimated to be 2.50 kWh/m2. To meet thedaily load demand of Oduduwa road, an array configuration of 52 solar PV panels is required.
6. When choosing a controller, we must ensure that the output voltage is

identical to the nominal battery voltage. In addition, the maximum PV voltage should be lower than the controller's maximum voltage rating. The chosen controller has a maximum output current of 20 amps and a controller voltage of 15 volts. The total number of controllers required for the planned PV system, which is coupled to an18V battery bank, is 52.

7. The total cost of this project was found outto be ₦10,340,000 with a payback of 1.4 years which ascertains the viability of this project. Therefore, the viability andsubsistence of the solar photovoltaic systems and the reduction in design time are established.

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