# DESIGN AND IMPLEMENTATION OF STAND-ALONE SOLAR-BASED STREET LIGHTING

BY

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(M.ENG/SEET/2008/1939)

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FEDERAL UNIVERSITY OF TECHNOLOGY

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THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL, FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGERIA IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF THE DEGREE OF MASTER OF ENGINEERING (M.ENG)

IN ELECTRICAL POWER AND MACHINES

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# DECLARATION

I hereby declare that this thesis titled: "Design and Implementation of Stand-alone Solar-based Street Lighting" is a collection of my original research work and it has not been presented for any other qualification anywhere. Information from other sources (published or unpublished) has been duly acknowledged.

3/05/2012

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# CERTIFICATION

The thesis titled: "Design and Implementation of Stand-alone Solar-based Street Lighting" by: Momodu Ganiyu Ademuyiwa (M.ENG/SEET/2008/1939) meets the regulations governing the award of the degree of Master of Engineering (M.Eng) of the Federal University of Technology, Minna and it is approved for its contribution to scientific knowledge and literary presentation.

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# ABSTRACT

This project work presents the design and implementation of Stand-alone Solar-based Street Lighting. The system comprises the Solar PV panel which converts solar energy to electricity for the charging of the battery via the charge controller. The inverter converts DC power from the battery to AC for powering the AC lamp for the lighting. A comparative analysis of economics of street lighting powered by electricity from public utility and solar-based energy in Nigeria was also presented. The results obtained shows that, the initial cost of installing solar-based energy for stand-alone street lighting is (₦ 6,281/hr), which is more expensive when using electricity from public utility which cost (₦ 2,002/hr); however, the case is reversed when considering the cost analysis over a period of 20 years. Hence, this emphasized the need to supplement and possibly replace the existing conventional street lighting powered by electricity from public utility with solar system.

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# ABBREVIATIONS, GLOSSARIES AND SYMBOLS

AC = Alternating Current

DC = Direct Current

PV = Photovoltaic

V = Voltage

$V_m$ = Maximum Voltage

$V_{oc}$ = Open circuit voltage

I = Current

$I_m$ = Maximum current

$I_{sc}$ = Short circuit current

P = Power

$P_m$ = Maximum Power

W = Watt

WH = Watthour

KW = Kilowatt

KWh = Kilowatthour

T = Temperature

AH = Ampere Hour

hr = Hour

₦ = Naira

$\alpha$ = Characteristics losses in electricity production and transportation equipment

$C_{equipment}$ = Equipment cost

$L_{equipment}$ = Life equipment duration

$C_{EWh}$ = Cost of public electricity utility per KWh

A = Anode

K = Cathode

G = Gate

S = Source

D = Drain

IRF = International Rectifier

MOSFET = Metal Oxide Semiconductor Field Effect Transistor

SCR = Semiconductor Controlled Rectifier

n = Transformer turns ratio

$M_a$ = Amplitude Modulation

$N_p$ = Transformer Primary winding turns

$N_s$ = Transformer Secondary winding turns

$V_p$ = Transformer Primary Voltage

$V_s$ = Transformer Secondary Voltage

$I_p$ = Transformer Primary current

$I_s$ = Transformer Secondary current

J = Operating Current Density

CFL = Compact Fluorescent

HID = High Intensity Discharge

LPS = Low Pressure Sodium

HPS = High Pressure Sodium

MV = Mercury Vapour

MH = Metal Halide

LED = Light Emitting Diode

# CHAPTER ONE

## 1.0 INTRODUCTION

### 1.1 BACKGROUND TO THE STUDY

Street lighting is a key element in the development of urban, sub-urban and rural districts across the nations. Therefore, effective and efficient installation would not only provide energy efficiency benefits, but also provide economic benefits, security benefits, etc. Energy efficient street lighting integrates efficient lamp technologies, efficient light distribution, pole placement, while using the least amount of energy and meeting various requirements for visibility and appropriate lighting levels.

The generation of electricity using solar technology to power street light without connecting to a public mains power supply is what is simply refers to stand-alone in this project. This becomes an alternative solution to provide efficient street lighting in Nigeria today, since the energy generated by the public utility is epileptic and is almost impossible to power the street lights. More so, that emphasis is now worldwide centred on utilization of renewable energy.

This system is designed for outdoor application, which could be used in un-electrified remote rural areas, residential, campus and villages' street lighting. The system is provided with a storage battery sufficient to operate the light for twelve hours daily. The system is provided with charge controller to prevent overcharge / deep discharge of the battery. It also has an automatic ON/OFF switch, made of photocell and relay switch to switch from dusk to dawn operation.

The Figure 1.0 described the stand-alone solar-based street light system, the system comprises of six basic units.

- The Solar panel receives energy directly from the sunlight through the process of photovoltaic effect and converts it to electricity.

- The Charge Controller receives voltage from solar panel and is responsible for charging and maintaining the discharge of the battery.
- The Storage Battery is used to store energy in readiness to power the lamp during the darkness.
- The inverter takes DC power from the battery and converts it into AC power which is then used to power the lamp.
- Relay switch and photocell are used in this project for daylight sensing, switch off the light during the day-time and switch on the light during the darkness.
- An energy efficient AC lamp is used for the lighting lamp for implementation of the system.

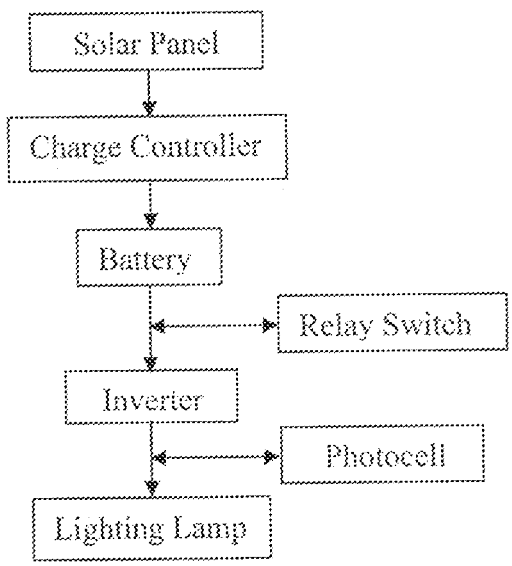



Figure 1.0: Stand-alone Solar-Based Street Lighting.

The PV modules have a service life span of 20 years (Mohammed, 2001), while the battery used requires lower maintenance; have long life and give better performance, these issues together with the driving force in need of affordable energy in developing countries and the environmental concern in developed countries makes this system unique.

One of the attractive features of this system is that, its output power is produced at the point of consumption and matches very well with the peak load demand for a given application and in fact, with the emerging of smart grid technology, the excess power from the system can be absorbs into the grid system, thereby improving the overall economy of the solar-based street lighting system.

## 1.2 MOTIVATION

In Nigeria today, several street lights have become mere decorative poles because they are hardly powered by public electricity. The electricity generated by the public utility is extremely low, making it almost impossible for street lights to be powered effectively.

Also, the high cost of fuel to run generators and their maintenance to power street light makes the solar-based street lighting more cost effective at the long run.

Likewise, the cost of installation of street lighting powered by electricity from public utility in remote areas is relatively high where there is no readily available power line or transmission line. Therefore, the alternative solution to the efficient street lighting is to switch over to stand-alone solar-based street lighting.

## 1.3 AIM AND OBJECTIVES

The aim of this project is to design and implement a Stand-alone Solar-based Street Lighting with the following objectives:

1. To encourage the utilization of renewable energy sources in Nigeria.
2. To show economic viability of solar based street lighting as against street lighting powered by electricity from public utility.

3. To encourage local production as against foreign importation of sub-standard solar based street lighting.
4. To achieve efficient energy saving in street lighting.

## 1.4 METHODOLOGY

To achieve the stated objectives of Stand-alone Solar-based Street Lighting, the following steps were adopted:

- Selection of required solar PV panel for charging the battery via the charge controller
- Carrying out circuit design based on requirements and identifying the components that will make up the units of the entire system.

Finally, carrying out the implementation of Stand-alone solar-based street lighting is achieved with an efficient standing pole attached with the circuit design in a box and Solar PV panel.

## 1.5 SCOPE AND LIMITATION OF WORK

The scope of this project is limited to the design and implementation of stand-alone solar-based street lighting using single panel of 60W for charging the battery via the charge controller. A lighting lamp of Compact Fluorescent was used for purpose of residential street lighting in order to replace an incandescent lamp (such as halogen) and high intensity discharge lamp (such as mercury or sodium lamp) for effective energy efficient. Carry out a comparative analysis on economics of street lighting powered by public electricity utility and solar-based in Nigeria.

## 1.6 ORGANIZATION OF THE REPORT

This project work is divided into five chapters. The first chapter introduces the technology of stand-alone solar-based street lighting and presents the aim of the project work. Chapter two presents literature review of the project matter, while chapter three presents the materials and methods analysis used for the implementation of the project. Chapter four shows the results obtained from the testing of the project and discussion of results and lastly chapter five presents conclusions and recommendations.

# CHAPTER TWO

# 2.0 LITERATURE REVIEW

## 2.1 INTRODUCTION

The history of street lighting started in the Arab empire from 9th to 10th centuries, especially in Cordoba and Spain (Dickinson *et al.,* 2000). Incandescent has been in use for street lighting for a long time now, it is cheap, reliable but operated in high voltage and consumed a lot of energy. The first street to use electricity to power street light was Mosley Street in Newcastle in February 1879 by Joseph Swan using incandescent lamp, then public square road in Cleveland, Oyio (US) in April, 1879. Likewise, South-Africa was the first city in Africa to power street lighting using electricity in September, 1882.

High Intensity Discharge (HID) lamps such as: Mercury Vapour (MV), Metal Halide (MH) and High Pressure Sodium (HPS) took the centre stage. The lamps provide greater amount of photopic illumination for low consumption of electricity energy.

The recent development in technology for street lighting lamps provides high level of scotopic lumen having low output power to replace high output power. The types of such lamps are Low Pressure Sodium (LPS), Compact Fluorescent (CFL) and Light Emitting Diode (LED).

Power supply in Nigeria is facing serious challenges and this is having adverse effect on street lighting which has turn them to mere decorative poles because they are hardly powered by electricity from public utility (Vanguard, 2008).

Therefore, the alternative solution for the street lighting requires the conversion of solar energy to power the street light, which this project advocate, considering the abundance of solar energy in Nigeria and its economic benefits.

Solar energy is energy from the sun. It is renewable, in-exhaustible and environmental pollution free. It has been in existence since $18^{th}$ century, when Edmund Becquerel in 1839 first observed and published this finding about the nature of materials that turned sunlight into energy. Charles Fritz in 1883 was the first man that turned the sun's rays into electricity. The solar cells used had a conversion rate of 1 – 2%. Henry Willsie in 1904 was the first man to successfully use power at night after generating the power during the day. It was not until 1954, when demonstration was carried out, that practical efficiencies could be achieved in converting radioactive radiation in the electrical energy using a silicon p-n junction photovoltaic cell and shortly thereafter, Calvin Fuller, Gerald Pearson, and Daryl Chaplin of bell laboratories accidentally discovered the use of silicon as a semiconductor, which led to the construction of a solar panel with an efficiency rate of 6% (Dickinson *et al.,* 2000).

Since 1954, work on Silicon and other semiconductor like Cadmium have been pursued with vigour. Other important materials and techniques have also been developed. The maximum theoretical efficiency of any single material is about 23% (Dickinson *et al.,* 2000). Means of increasing efficiency was by combining different semiconductor for better utilization.

Several works on solar energy have been carried out over the years throughout the world. Today, solar energy are being used to power street lightings, security lighting, parking lighting, garden lighting, and even domestic lights at home. Solar Street lighting saves money and it is pollution free. It is the best option for the future street lighting.

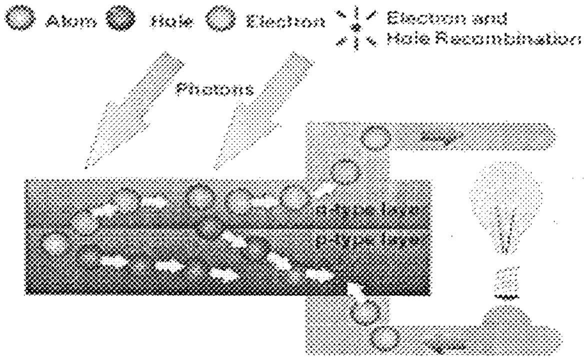
Electricity can be generated in so many ways such as hydro, Nuclear power, thermal, wind, solar energy, etc. Solar electricity generation comprises of the following components: Solar panel, Charge Controller, Storage Battery, Inverter and the Load.

## 2.2 SOLAR ELECTRICITY GENERATION

Radiation from the sunlight is capable of producing electricity. The sun is an extremely powerful energy source and solar radiation is the largest source of energy received by the earth. Solar radiation can be converted directly into electricity by Photovoltaic principle through solar cells. In such cells, a small electrical voltage is generated when light strike the junction between a metal and a semiconductor (such as Silicon) or a junction between two different semiconductors. The voltage generated from single photovoltaic cell is only a fraction of a volt. Electric power can be generated by connecting large numbers of individual cells together. If the intensity of solar radiation is low, huge and costly assemblies of such cells are required to produce more moderate amounts of power.

Summarily, electricity generation through the solar energy can be explicitly explained below as shown in Figure 2.1.

- Rays of sunlight hit the solar panel and are absorbed by semi-conducting materials such as silicon.
- Electrons are loose from their atoms, which allow them to flow through the material to produce electricity. This process whereby light (photo) is converted into electricity (voltage) is called the photovoltaic (PV) effect.
- The DC electricity is either used on DC load or stored in a storage battery.
- The storage battery used to power the inverter.
- The inverter turns DC electricity into AC (alternating current) electricity needed by home appliances.
- The AC power distributed to appliances or lights in the house (load)




Cross section through a solar cell

Figure 2.1: Solar Electricity Generation

### 2.2.1 SOLAR PANEL

This is a panel that receives energy directly from the sunlight and converts it into DC electricity. The solar panel also known as Photovoltaic (PV) panel. The panel is made up of silicon cells arranged in a series or parallel string that produces electric power when exposed to sunlight.

There are several types of solar panel and they are divided into categories:

(i) **Monocrystalline**: This panel is made from a single large crystal, it is the most efficient and expensive form of solar panel. It works better in low light conditions.

(ii) **Polycrystalline**: This panel is basically made of cast blocks of silicon which may contain many small crystals. It is probably the most common type right now. The panel is slightly less efficient and less expensive than single crystal.

(iii) **Amorphous**: The panel also known as "Thin film". It is made of silicon which is spread directly on large plates, usually like stainless steel. It is often much less efficient and cheaper to produce.

The output of a solar panel is usually stated in **WATTS**. Solar panel uses solar cells which are made up of semiconductor (silicon) and has much in common with solid state electronic devices, such as diodes, transistors, and integrated circuit. Solar cells are assembled into modules. In the course of this project, monocrystalline solar panel is used because it is the most efficient and commonly used for low voltage output.

### 2.2.2 PHOTOVOLTAIC EFFECT

This is the conversion of sunlight radiation into electricity through absorption of light by a semi-conducting material. The basic requirements for the photovoltaic effect are:

- Absorption of photons through the creation of electron-hole pairs in a semiconductor.
- Separation of the electron and hole, so that the electric field within the semiconductor is altered.
- Collection of the electrons and holes separately, so that current can be induced to flow in an external circuit from the semiconductor material.

The basic component of photovoltaic system is a solar cell which composed of semiconductor material. The most common semiconductor used nowadays is a pure single-crystal silicon wafer; it is doped p-type i.e. when small amount of impurity is added to the semiconductor material to induce holes in the silicon wafer. Another impurity is diffused on the top of the wafer, promoting unbonded electrons to become n-type in the silicon wafer (Encyclopedia, $10^{th}$ Edition).

Electrical voltage and current are generated when sun's radiation strike the junction between the two different semiconductor layer, n-type layer (electrons) and p-type layer (holes). The electrons from the n-type layer drift across the junction into the p-type layer. The holes also drift across the junction into the n-type layer and combine with electrons. The loss of holes from the p-type layer leaves some of its atom with a negative charge ion. Also, loss of electrons from the n-type layer leaves some of its atom with a positive charge ion, as shown in Figure 2.2.

An electric field is created across the junction of the n-type layer and p-type layer. This creation of electric field is like an electric cell connected between the layers. The electric cell created is known as in-built cell, with a value of 0.6V in a silicon semiconductor as shown in Figure 2.3. The solar panel used in this project is having an in-built cell connected in series / parallel to generate an open circuit voltage of 21.6V.

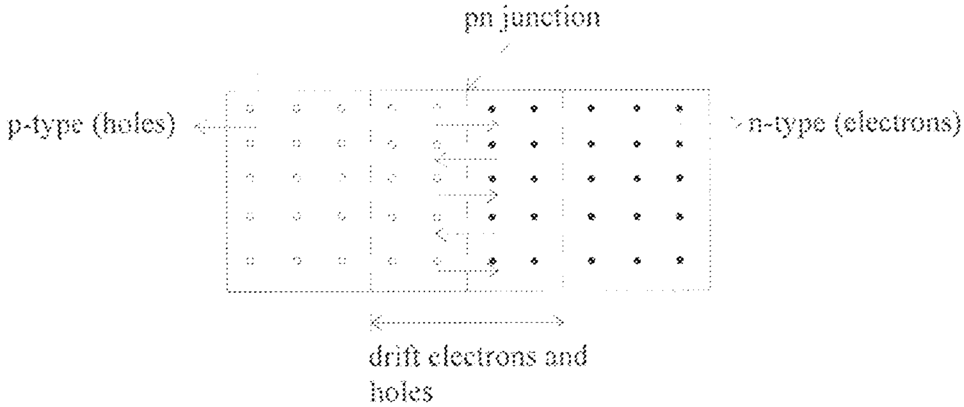



Figure 2.2: Electrons and Holes Drifting Across the Junction.

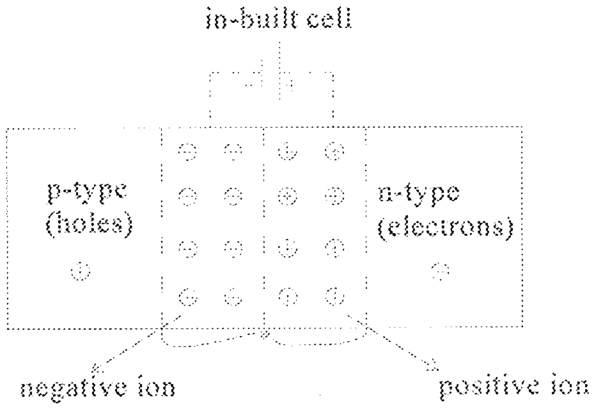



Figure 2.3: Potential Region is Formed.

The potential barrier of a junction permits the flow of electric current in only one direction. The junction acts as a rectifier or diode. The electrons can only flow from the p-region to the n-region, and electric current can only flow in the opposite direction. Therefore, electric current can flow only from n-side to the p-side of the junction. An equivalent circuit of a solar cell and V-I characteristics are shown in Figure 2.4 and Figure 2.5 below.

Under open-circuit condition (I=0), the terminal voltage increases with increasing light intensity (point A), and under short circuit condition (V=0), the magnitude of the current increases with increasing light intensity (point B). The photovoltaic cell delivers power to the external circuit when the current is negative and the voltage is positive (point C).

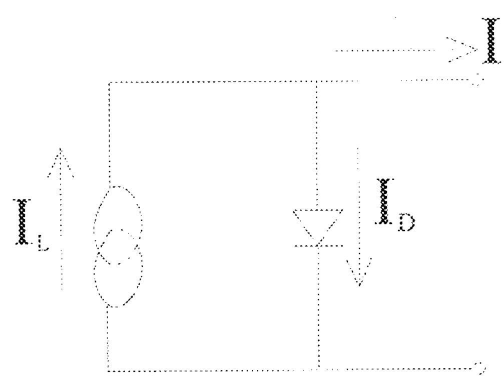



Figure 2.4: Equivalent Circuit of a Solar Cell

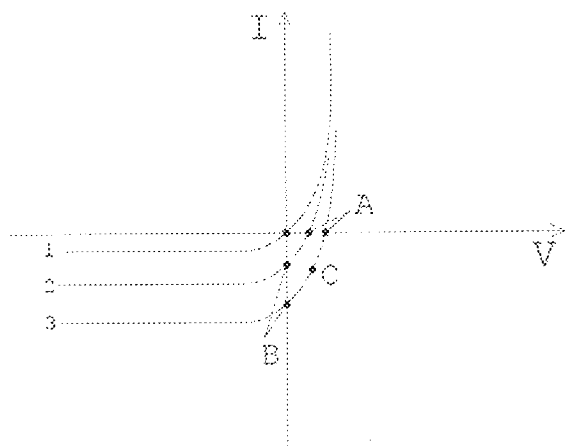



Figure 2.5: Solar Cell V-I Characteristics

## 2.3 CHARGE CONTROLLER

The charge controller is used to charge the battery and responsible for monitoring the state-of-charge of the battery. It ensures that the battery gets the charge current when is needed. That is, it acts like on and off switch which allows current to pass when the battery needs it and switch off when the battery is fully charged. In designing the charge-controller, one must consider the voltage of the design e.g. 12V, 24V, or 48V and the current capacity of the panel to use.

The charge controller has the following functions:

- To ensure that steady charge current gets to the battery from the solar panel, no matter how drained the battery may be, the charge controller ensures that the battery is readily charged.
- It protects the battery from being over-charged.
- It prevents battery drain. That is, current can only flow through the charge-controller to the battery and not reversible.

Similarly, once the battery has been drained to a certain predetermined level, controlled by measuring batteries voltage, the charge controller will not allow more current to be drained from the batteries until it will be recharged. This use of a charge controller is essential for battery long life.

## 2.4 STORAGE BATTERY

Another major component of a stand-alone solar-based street lighting is the battery. The battery retains or store energy that is trapped from the sun and makes the energy available to the load on demand.

For this project, a deep cycle batteries (**Gel type**) which are usually sealed lead-acid types was considered and used. Deep cycle battery has different sizes and designs, and we have three types of batteries, namely:

(i) **Flooded types**: These are lead-acid batteries that have caps to add electrolyte into the batteries container. All flooded batteries release gas when charged and should not be used indoors. If the flooded batteries are installed in an enclosure, then a venting system should be used to vent out the gas.

(ii) **Gel types**: These are sealed lead-acid batteries. The batteries have no vents and will not release gas during the charging process like flooded batteries do. Venting is not required in this battery and they can be used indoors. This battery maintains constant temperature and performs better.

(iii) **AGM types**: The battery is known as Absorbed Glass Mat. It consists of a woven glass mat which is used between the plates to hold the electrolyte. They are leak/spill proof, do not release gas when charging and have superior performance. They have all the advantages of all the sealed gel types and have higher quality, maintenance free, last longer, etc. They are more expensive and commonly used in airplanes, telecoms industry, hospitals, etc.

Lead-acid batteries are the most common types in solar energy system because they are readily available everywhere in the world. The deep cycle batteries used are designed to be discharged and re-charged many times. These batteries are rated in Ampere Hour (AH). When it is desire to make the electricity available again, the terminals of the battery are connected to the load and the substances on the battery plate retransform themselves to those originally present electricity as a product of their electrochemical reactions.

During the charging of the lead acid battery, the charger first applies a constant current charge, raising the cell voltage to a preset voltage and the battery is charged to 70% which is stage 1. During the topping charge in stage 2, the charged current is gradually reduced as the cell is being saturated to its capacity. The final stage is the float charge, which compensate for the self discharge. The illustration is shown in Figure 2.6 below.

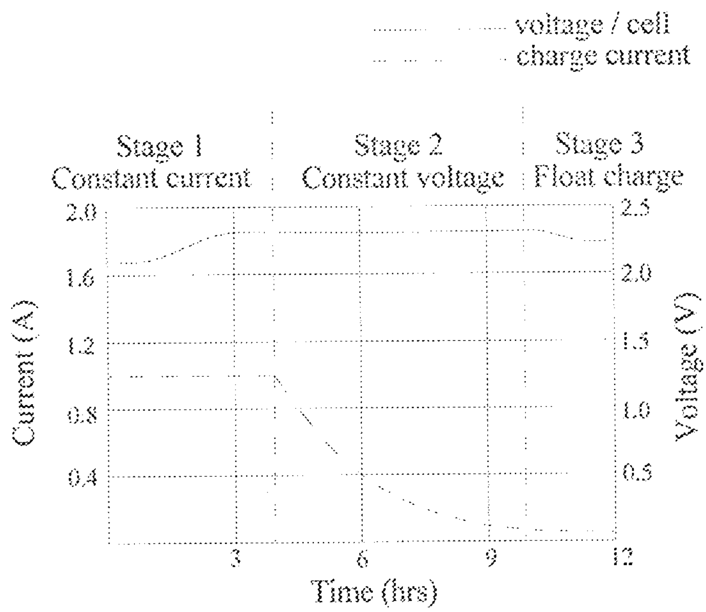



Figure 2.6: Charging Stages of Lead-Acid Battery

## 2.5 INVERTER

Many electric power applications require alternating current (ac) electricity. To obtain alternating current, a power conditioning system is required. A typical power conditioning system is an inverter which is responsible to convert DC current stored in the battery to AC current. It is characterized by power capacity.

Power capacity of an inverter is the amount of power the inverter can supply during normal operation, for typical period of time.

## 2.6 LOAD

The replacement of an incandescent street lamp and high energy wattage lamp of high intensity discharge lamp with a low energy lamp is highly encouraging nowadays. The low energy wattage lamp last longer and efficient. For example, a typical 250W HPS lamp can be replaced by a 70W MH, 100W LPS and 2x26W CFL lamp. Low energy wattage can save a lot of quantity of energy, huge amount of money and life. The inefficiency of incandescent and high wattage energy lamps causes environmental damage.

Lastily, conversion to effective energy efficient street lighting leads to an increase in the use of light, increase in comfort and well-being.

## CHAPTER THREE

## 3.0 MATERIALS AND METHOD

### 3.1 INTRODUCTION

This chapter presents the required materials, design procedure and the method adopted for the implementation of stand-alone solar-based street lighting.

### 3.2 SELECTION OF LAMP

The lamp chosen for this project is 2x26W CFL which is the required equivalent lamp for residential street lighting as indicated in table 3.1 below. It has light output lumen of 3600lm and a Rated Average Life Span (RALS) of 24000h (See Appendix 2).

**Table 3.1** : Equivalent lamp used for residential street lighting

| Lamp | Light Output Lumen | End of Life % output | Rated Average Life Span | No of Lamp for 20 years |
|---|---|---|---|---|
| 2x26WCFL | 3600 lm | 85% | 24000h | 4 |
| 80W MV | 3800 lm | 75% | 16000h | 6 |
| 125W MV | 6300 lm | 75% | 16000h | 6 |
| 70W LPS | 6500 lm | 89% | 20000h | 5 |
| 100W LPS | 9500 lm | 89% | 24000h | 4 |
| 70W MH | 5500 lm | 65% | 12000h | 10 |
| 100W MH | 8000 lm | 70% | 12000h | 10 |

### 3.3 SOLAR PV PANEL

The following are detail data on the solar PV panel selected for this project based on the lamp power requirement.

| | |
|---|---|
| Model | SLP060 – 12 |
| Maximum Power ($P_m$) | 60W |
| Maximum Voltage ($V_m$) | 17.2V |

| | |
|---|---|
| Maximum current ($I_m$) | 3.50A |
| Short Circuit current ($I_{sc}$) | 4.0A |
| Open Circuit voltage ($V_{oc}$) | 21.6V |
| Weight | 5.4kg |
| Dimension | 908 x 552 x 30 (mm) |
| Maximum system voltage | 1000V dc |
| Cell Technology | Mono-silicon |
| Operating Temperature | $-40^0C$ to $85^0C$ |

### 3.3.1 Determination of battery capacity and number of solar panel required for a given lighting lamp:

Consider a street light with 2x26W (CFL) bulb AC lighting load.

Inverter Output voltage = 240V

Operational Time = 12 hours (In Nigeria the street light is expected to be switched on from 6pm to 6am).

$$P = V \times I \qquad (3.1)$$

where, P = Output Power of the Lighting Load

V = Output Voltage of the Lighting Load

I = Output Load Current

∴ The Load Current, I

$$I = \frac{2 \times 26}{240} = 0.22A$$

Required Battery capacity (AH) $= 0.22A \times 12H = 2.64AH$

For effectiveness of the battery, it should not be drained more than 50% of its capacity.

Therefore battery capacity required $= 2.64AH \times 2 = 5.3AH$

However, a battery capacity of 12V 18AH was used in this project for longer duration and availability.

### 3.3.2 The number of solar panel used for the project:

From the rating of bulb (2x26W), 60W PV panel is chosen. Considering 8 hours the average sunshine in Nigeria and 12 hours operational time, therefore the number of 60W PV panel needed is given as follows:

$$No\,of\;Solar\;panel\;used = \frac{total\;dailyWH}{solar\;panel\;rating \times sunshine\;hours} = \frac{2\times 26\times 12}{60\times 8} = 1.3$$

This implies that, one number of 60W solar panel required to power 2x26W lamp.

### 3.3.3 Solar panel output power generated:

The solar PV panel delivers power to the charge controller circuit for charging of the battery during the day. Various output charging voltages and currents are measured and recorded. The results of the charging voltage and current from the panel via the charge controller are shown in chapter four, table 4.1.

## 3.4 CHARGE CONTROLLER OPERATION

As the light intensity increases on the solar panel, the maximum output voltage of 17.2V and current of 3.50A flows to the controller. The 12V battery is charged through the Semiconductor Controlled Rectifier (SCR), and the transistor T1 and T2 are used as switch to terminate the charging process when the battery becomes fully charged as indicated in Figure 3.1 below. The output voltage and current receives from the solar panel charges capacitor C through R1, LED and R2. The capacitor voltage rises in a very short time to make diode D2 to conduct, then the gate current trigger SCR into conduction. Hence, full charging current was passed through the cathode of SCR to the positive terminal of the battery whose negative terminal was connected directly to the variable resistor, R6.

During the charging of the battery before it becomes fully charged, the two transistors T1 and T2 remain in the non-conducting state. However, when the battery voltage rises and finally the battery becomes fully charged, the two transistors T1 and T2 are triggered into conduction. Therefore, T1 and T2 provide a discharge path for C. Hence, C discharges through R2, and T1-T2 switch, thereby cutting off the gate current of the SCR which stops conducting and terminate the battery charge. Thereafter, small trickle charge current keeps on flowing into the battery via the LED and transistor switch T1-T2. A glowing LED light indicates that the battery is under trickle charging (Theraja, 2005).

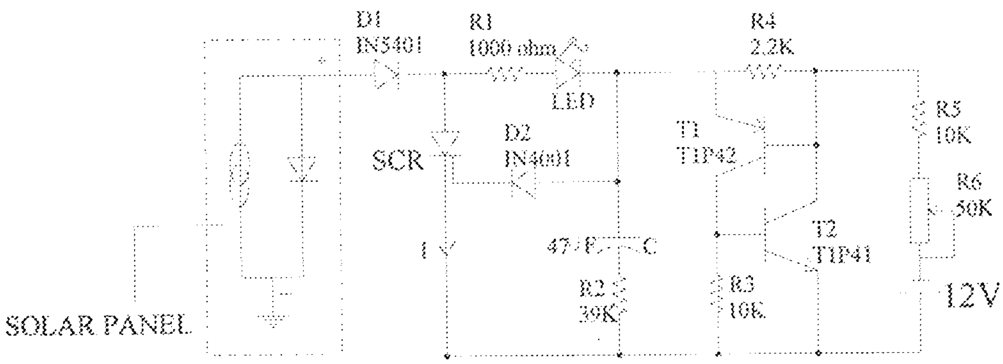



Figure 3.1: Charge Controller Circuit diagram

A Bipolar Junction Transistor was used as a regenerative switch, the circuit symbol and v-i characteristics of transistor are indicated in Figure 3.2 and Figure 3.3 below. The two transistors T1 and T2 together form an electronic switch that has two stable states, i.e. ON-state when T1 and T2 conduct and OFF-state when T1 and T2 do not conduct. The ON and OFF state of this switch was decided by the battery voltage and the setting of variable resistor, R6.

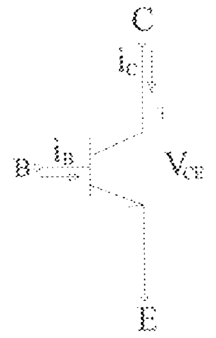



Figure 3.2: Circuit Symbol of a Transistor

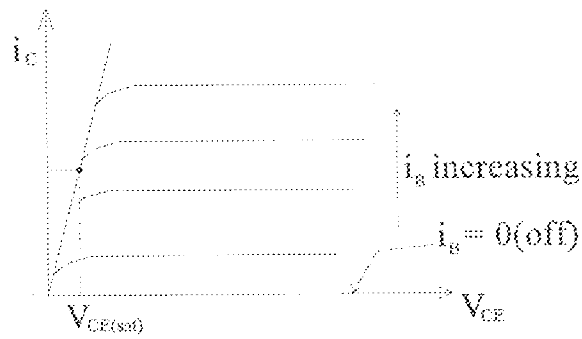



Figure 3.3: V-I Characteristics of a Transistor

A Semiconductor Controlled Rectifier (SCR) was employed for over-voltage protection. The SCR is also known as Thyristor. It consists of anode, cathode and the gate. The circuit symbol and the v-i characteristics of the thyristor are shown below in Figure 3.4 and Figure 3.5.

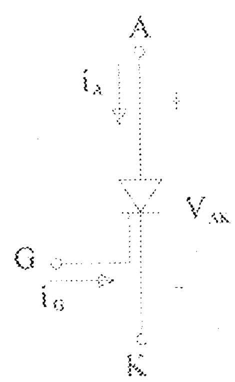



Figure 3.4: Circuit Symbol of a Thyristor

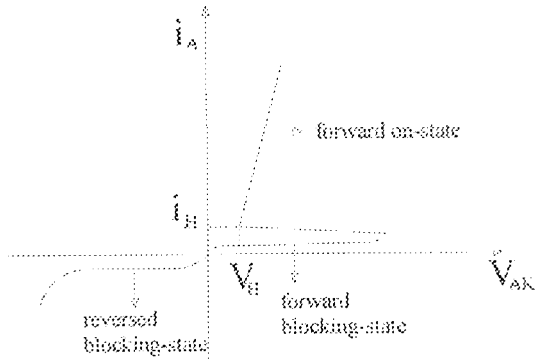



Figure 3.5: V-I Characteristics of a Thyristor

The uniqueness of this thyristor lies principally in its v-i characteristics. The main current flows from the anode (A) to the cathode (K). During the reversed biased, the thyristor blocks the forward voltage and not conduct. The thyristor can only be triggered into the on-state by applying a pulse of positive gate current for a short duration provided that the device is in its forward blocking state. The thyristor is switched off completely when anode current drops during the reversed biased.

### 3.4.1 Determination of Battery Charging Period:

Equation 3.2 is used to determine the battery charging time.

Battery Capacity = 12V, 18AH

Solar Panel Max. Power ($P_m$) = 60W

Solar Panel Max. Current ($I_m$) = 3.5A

Charging Period (t):

$$Q = I \times t \quad (3.2)$$

/here:

= Battery charging period expressed in Ampere Hour.

= Charging current

t = charging period

∴ Charging period, t

$$t = \frac{18}{3.5} = 5.14\,hours$$

It will take approximately 5 hours 15minutes to charge the battery during the normal sunshine intensity. But, however, if the sunshine intensity is very poor, the charging period will be higher than 5 hours 15minutes.

## 3.5 INVERTER DESIGN

The inverter inverts the battery dc voltage into an ac voltage. The inverter circuit used is composed of three stages, namely: the modulated astable signal generator, the power switching MOSFET driver and a voltage transformer. Figure 3.6 shows the block diagram of the inverter.

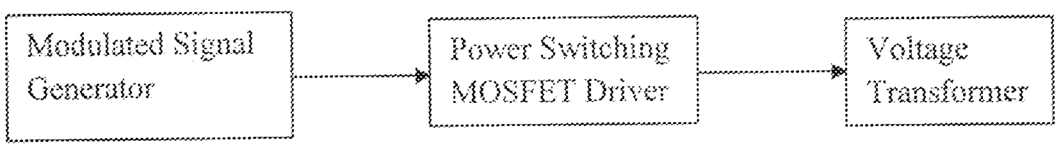



Figure 3.6: Inverter Block Diagram

### 3.5.1 MODULATED SIGNAL GENERATOR

The modulated signal generator is a square wave signal generator used as gating signals for switching the driver transistors ON and OFF alternately. The modulated signal generator is a square wave generator that makes use of 555 timer and a 4013 dual D flip flop. The 555 timer is used as astable multivibrator for this circuit design. Figure 3.7 and Figure 3.8 indicates the 555 timer pin-out diagram and the circuit configuration diagram. The output of the 555 timer goes HIGH when it receives a TRIGGER input and it stays there until the THRESHOLD input is driven, at the time the output goes

LOW and the discharge transistor is turned on. The trigger input is activated by an input level below 1/3 $V_{cc}$, and the THRESHOLD is activated by an input level above 2/3 $V_{cc}$. The 555 timer generates a regular wave output whose duty cycle is always greater than 50% because the timing capacitor is charged through the series pair $R_A + R_B$ but discharged through $R_B$ alone.

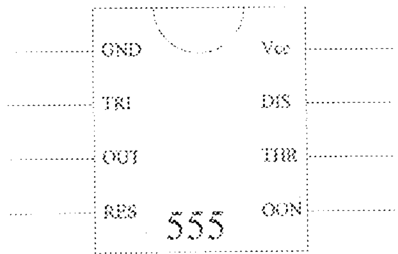



Figure 3.7: Circuit Symbol of 555 Timer

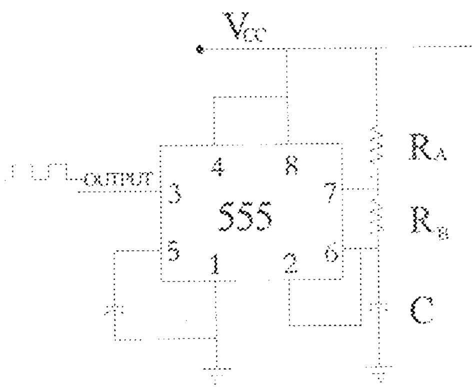



Figure 3.8: Circuit of 555 Timer

Calculation of frequency f, for this circuit design, given the following parameters,

C=4.7μF, $R_A = 1K\Omega$, $R_B = 2.7K$

The frequency of oscillation is 1/T, where T is total time required to complete a charge and discharge cycle.

$$T = 0.693C(R_A + 2R_B)\sec \quad (3.3)$$

$$f = \frac{1.44}{C(R_A + 2R_B)} H_Z \quad (3.4)$$

$$f = \frac{1.44}{4.7\times10^{-6}[1000 + 2(2700)]} H_z$$

$$f = 50H_z$$

Therefore, the frequency of oscillation is approximately equal 50Hz.

The output signal of 555 timer is connected directly to the pin 11 of the CD4013 dual D flip flop. The 4013 is a popular 14-pin CMOS dual D flip flop featuring wide supply voltage range (5 – 15V), high noise immunity and compatible with low power TTL. The connection diagram and truth table for the 4013 are shown below in Figure 3.9 and Table 3.2 respectively.

Each of the 4013's two flip flop has its own data-in (D), set (preset), reset (clear), and clock input and Q output. As the truth table indicates, the logic level at the D input is transferred to the Q output during the positive going transition of the clock pulse. If the clock is transitioning from a HIGH to a LOW, the output remains in their last state. If the reset input is brought HIGH, it doesn't matter what the clock and the D input are doing, Q is HIGH and Q is LOW. If the set line goes HIGH, Q goes HIGH and Q LOW, regardless of conditions on the clock and D input. Bringing both the set reset inputs HIGH at the same time is forbidden.

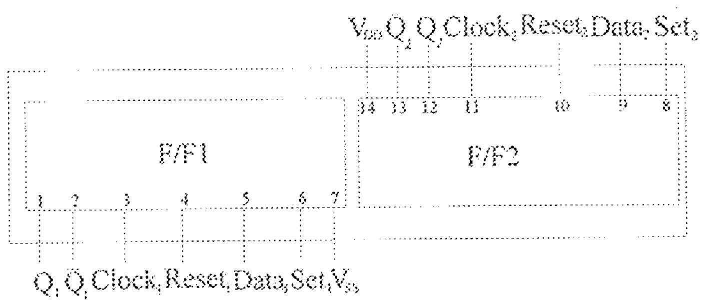



Figure 3.9: Connection Diagram of 4013 D Flip Flop

**Table 3.2**: Truth Table of 4013 D Flip Flop

| Cl | D | R | S | Q | $\bar{Q}$ |
|---|---|---|---|---|---|
| ↑ | 0 | 0 | 0 | 0 | 1 |
| ↑ | 1 | 0 | 0 | 1 | 0 |
| ↓ | x | 0 | 0 | Q | $\bar{Q}$ |
| X | x | 1 | 0 | 0 | 1 |
| X | x | 0 | 1 | 1 | 0 |
| X | x | 1 | 1 | 1 | 1 |

KEY:

X= No Change

x= Dont care case

1= On

0= Off

### 3.5.2 POWER SWITCHING MOSFET

The square wave signals are used as the gating signals for switching the driver transistors ON and OFF alternately. Since the signals are 180 degree out of phase, the push pull arrangement will only have one of the switches T1 and T2 in each half cycle of the output signal. Thus, they are ON or OFF in alternate half cycles as shown in Figure 3.10 below.

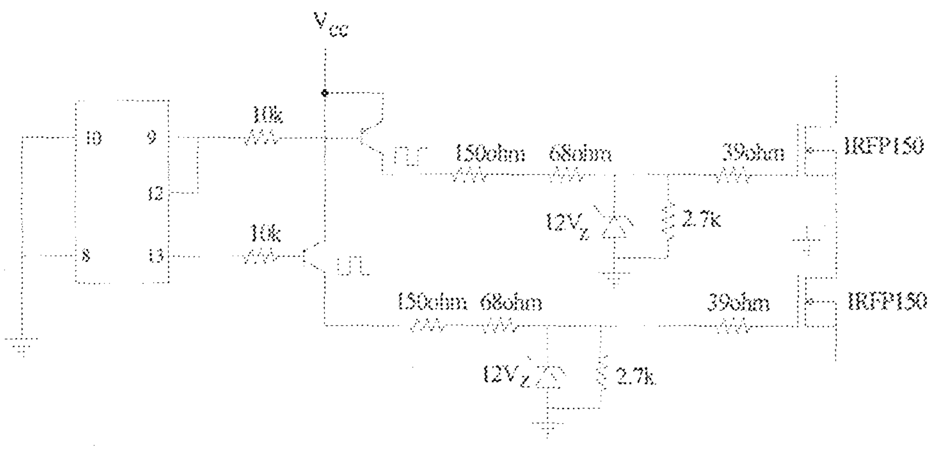



Figure 3.10: Circuit Diagram of Power Switching MOSFET Driver.

The MOSFET is a voltage-controlled device, that is, a voltage of specified limits must be applied between gate and source in order to produce a current flow in the drain.

Since the gate terminal of the MOSFET is electrically isolated from the source by a silicon oxide layer, only a small leakage current flows from the applied voltage source into the gate. Thus, the MOSFET has an extremely high gain and high impedance. The circuit symbol of a power MOSFET is shown below in Figure 3.11. Due to the high input impedance of MOSFET, its driver amplifier must be configured as a voltage buffer amplifier. The input impedance of a buffer amplifier is very high and the output impedance is very low. Hence, the input impedance matches with the output impedance of the buffer amplifier. This is necessary to avoid positive feedback, which may lead to oscillation. It must also be noted that, while the dc input impedance of the voltage is very high, its ac input impedance varies with frequency.

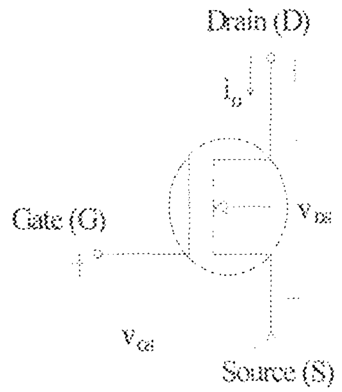



Figure 3.11: Circuit Symbol of a Power MOSFET

MOSFET can be used as a switch, since the conductor in the drain-to-source path controlled by the gate-to-source voltage, i.e. n-channel enhancement mode device. The current in the drain-to-source path can be switch or controlled by controlling the gate –to-source voltage as shown below in Figure 3.12

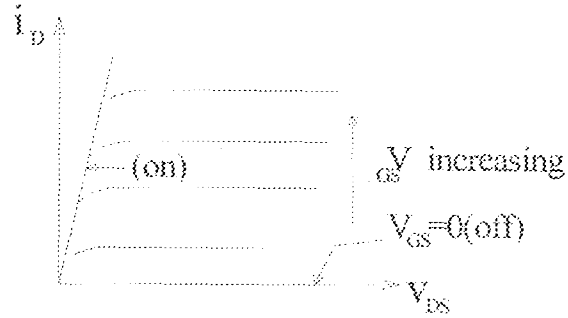



Figure 3.12: Typical V-I Characteristics of n-channel Mode MOSFET

The type of MOSFET used in the design of this project is IRFP 150. It is n-channel enhancement mode. IRFP150 is a power MOSFET with specification given below:

$V_{DS(max)}$ = 40V

$I_{D(max)}$ = 30A at $25^0$C

$P_{D(max)}$ = 250W

Advantages of using MOSFET as power switch.

- Small size
- Long life
- Ruggedness
- High frequency of response
- High power gain
- High immunity to radiation
- Low noise

### 3.5.3 VOLTAGE TRANSFORMATION

The type of inverter design used in this project was the push-pull configuration. This configuration requires two input signals to the switching transistors at 180 degree out of phase. To control the two halves of the output signal it utilizes a transformer with a centre –tapped primary winding as shown in Figure 3.13 below.

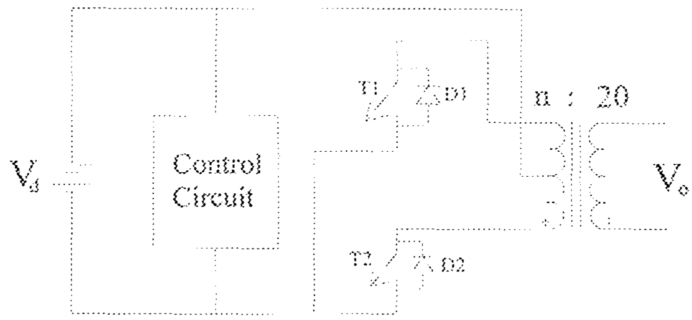



Figure 3.13: The Inverter Transformation Configuration

It is assumed that the output from the transformer flows continuously. With this assumption, in the first half cycle when $180^0$ out of phase signal flows, switch T1 closes and T2 opens, current flows in the upper half in the primary winding coil and induces current in the secondary coil. In the second half cycle T2 closes and T1 opens, current flows in the lower half of the primary winding coil and induce current in the secondary coil.

The reason for employing push-pull configuration is to minimize power losses. When a switching occurs at the primary of the transformer the voltage shifts from one half of the primary winding to the other half. The diodes D1 and D2 across the switch in the push-pull configuration serve to return inductive energy back to the supply bus.

Therefore, regardless of the value of output current from the transformer, the output voltage,

$$V_o = \frac{M_a V_{dc}}{n} \tag{3.5}$$

where, n = transformer turns ratio between the primary winding and the secondary winding.

$M_a$ = amplitude modulation factor which is equal to one for a square wave inverter

$M_a$ = 1 (Square wave inverter)

$V_{dc}$ = 12V battery voltage

The ratio of the transformer design is 1:20

Number of turns for primary winding, $N_p$ = 50 turns

Number of turns for secondary winding, $N_s$ = 1000 turns

$$\frac{N_p}{N_S} = \frac{1}{20} \tag{3.6}$$

Therefore,

$$V_o = \frac{1.0 \times 12}{1/20}$$

$$V_o = 240V$$

## 3.6 INVERTER TRANSFORMER DESIGN

Power = 300W

Primary voltage, $V_p$ = 12V

Secondary voltage, $V_s$ = 240V

J = 200cm/A [J – operating current density]; J≤ 200cm/A from the manufacturer data sheet for wire size material

K = 4 [for push pull configuration]

f = $50H_z$

Primary current, $I_p$

$$I_p = \frac{P}{V_p} \tag{3.7}$$

$$I_p = \frac{300}{12} = 25A$$

Secondary current, $I_s$

$$I_s = \frac{P}{V_s} \tag{3.8}$$

$$I_s = \frac{300}{240} = 1.25A$$

Wire size for primary winding = $I_p$ x J = 25 x 200 =5000cm

From the wire specification chart (see the table at Appendix 1), the wire gauge is AWG 13.

Wire size for secondary winding = $I_s$ x J = 1.25 x 200 = 250cm

From the wire specification chart (see the table), the wire gauge is AWG 26

**Selection of core size:**

$$A_e A_c = \frac{(0.68 P_o J)10^3}{f \times B_{max}} \tag{3.9}$$

where, $A_eA_c$ – core effective area in $cm^4$

$B_{max}$ – maximum flux density (given as 12000 at 240Vac)

f - frequency of the transformer

$P_o$ - Transformer power

J - Operating Current density

Therefore;

$$A_e A_c = \frac{(0.68 \times 300 \times 200)10^3}{50 \times 1200} = 68cm^4$$

From the manufacturer data sheet, a transformer core size of $70cm^4$ is selected with

$A_e = 10cm^2$, $A_c = 7cm^2$

Number of turns in primary winding, $N_p$

$$N_p = \frac{V_p \times 10^8}{K \times f \times B_{max} \times A_e} \quad (3.10)$$

$$N_p = \frac{12 \times 10^8}{4 \times 50 \times 12000 \times 10} = 50\,turns$$

Since the primary is center-tap, therefore the total number of turns in the primary is thus 100 turns with the center tap taken at the 50 winding.

Number of turns in secondary winding, $N_s$

$$N_s = \frac{V_s \times 10^8}{K \times f \times B_{max} \times A_e} \quad (3.11)$$

$$N_s = \frac{240 \times 10^8}{4 \times 50 \times 12000 \times 10} = 1000\,turns$$

The number of turns in the secondary winding is 1000 turns

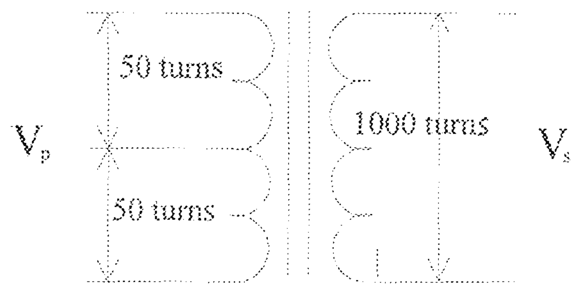



Figure 3.14: Schematic diagram of Transformer

### 3.7 ELECTROMECHANICAL RELAY SWITCH AND PHOTOCELL

The uniqueness of this relay switch lies in the utilization for daylight sensing, that is, prevent the light to be on during the day. The relay switch will only allow the lamp to be on during the darkness, in order to conserve a lot of energy and prevent wastage.

Relay switch is a device that has coil and contact pins. It has different specification, hence there are different types of relay. The relay employed in this design depends on the current and voltage power to energize it. The relay switch is energized by the 6V dc output voltage from the solar panel.

However, photocell is a light dependent device. It was responsible for switching the lamp on during the darkness and switch off during the daylight. The photocell device works in parallel with the relay switch. If the intensity of the sun is very poor and de-energize the relay switch during the daylight, the photocell will not allow the lamp to be on, in order to maintain the efficiency of the system.

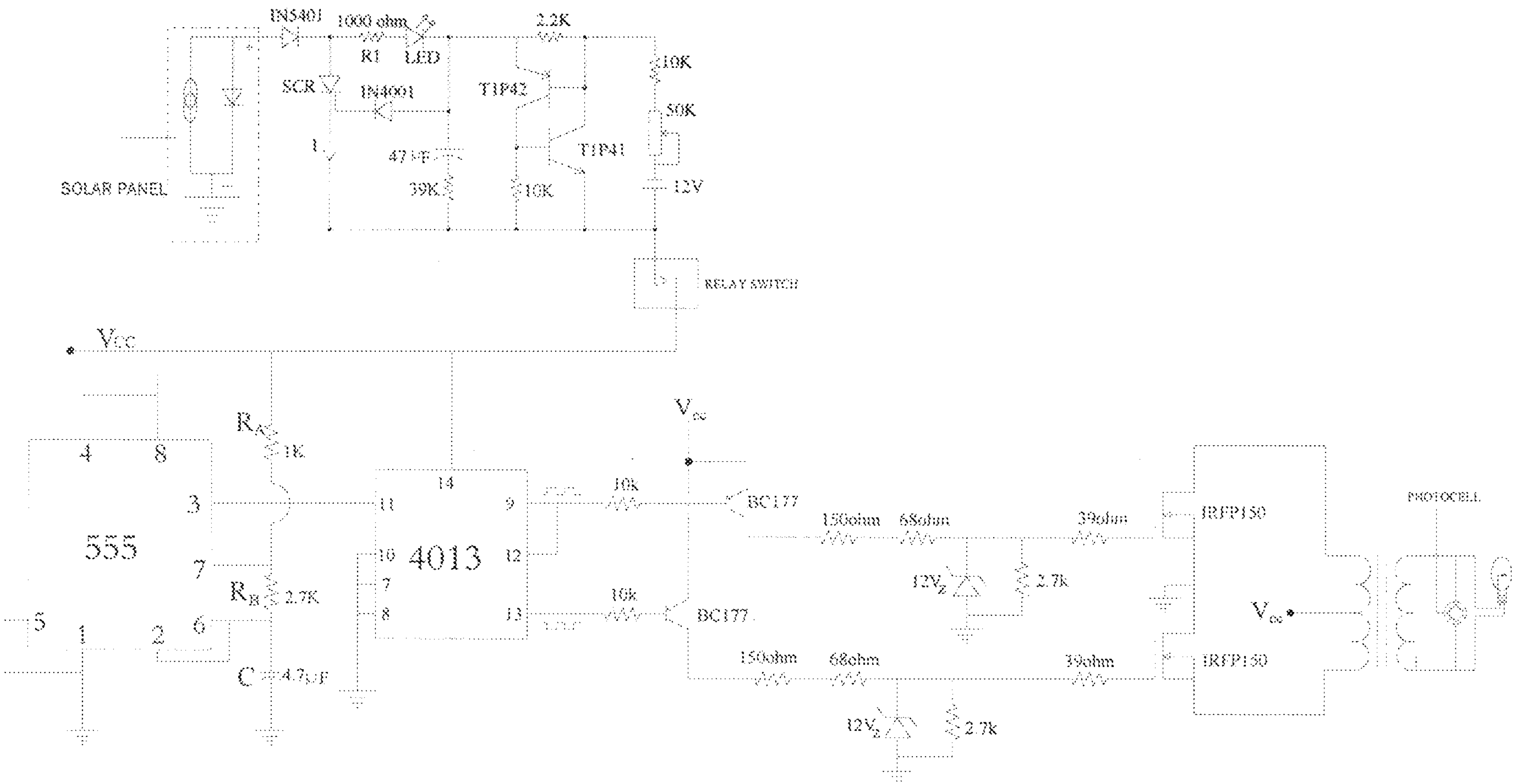



Figure 3.15: Overall circuit arrangement.

## 3.8 STANDING POLE CONSTRUCTION

The standing pole was constructed using a galvanized metal pole of 12ft by $2^1/_2$ inches round pipe thickness. The control box is made up of metal sheet of 1.5cm thickness with a dimension of 3ft by 2ft. An angle iron material was used for the solar panel based with a dimension of 3ft by 2ft. A round pipe of $1^1/_2$ inches thickness was used for the lamp.

The constructed standing pole is shown in Figure 3.16 below. The necessary available tools required to achieve the purpose were used. The standing pole is painted in silver colour for good reflector on the street.

**Note:** This project "Design and Implementation of Stand-alone Solar-based Street Lighting" has been mounted in front of Electrical and Electronics Engineering Department, Federal University of Technology, Minna. The pictorial diagram is shown below in plate II and plate III.

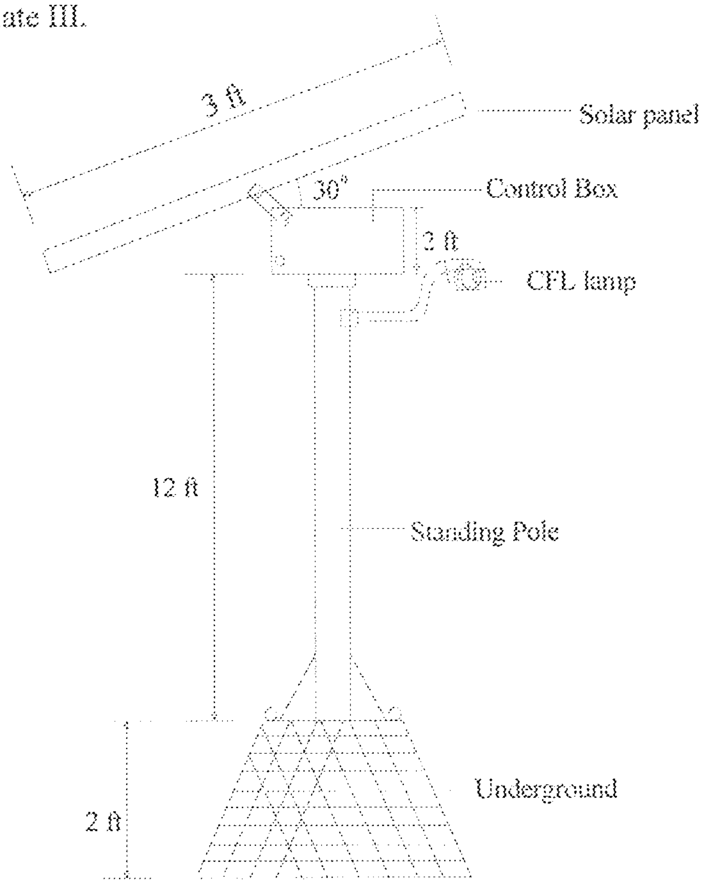


Figure 3.16: Stand-alone Solar-based Street Lighting

The Plate I below shows the pictorial diagram of solar panel, charge controller, inverter and lighting lampfor implememntation of stand-alone solar-based street lighting.

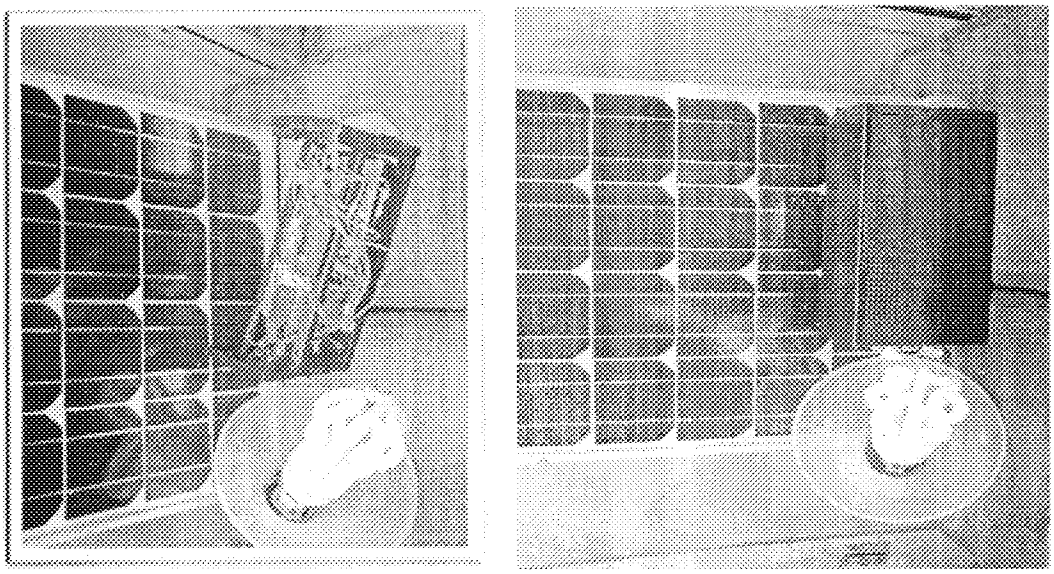


Plate I: Solar Panel, Control Circuit (Charge controller and Inverter) and lighting lamp for Stand-alone Solar-based Street Lighting

The Plate II below shows the pictorial diagram of mounted stand-alone solar-based street lighting after the implementation.

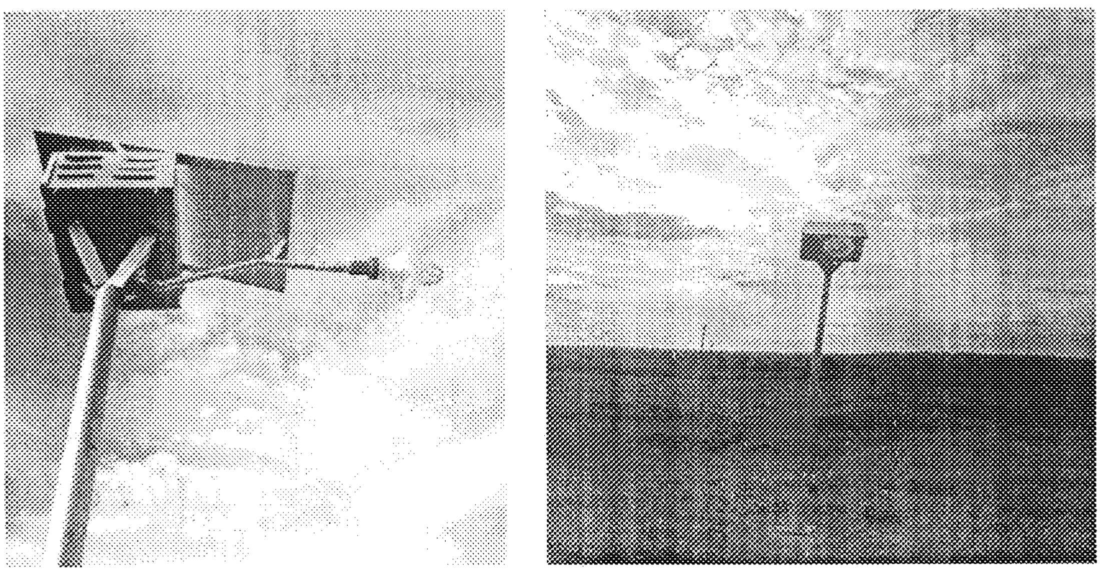
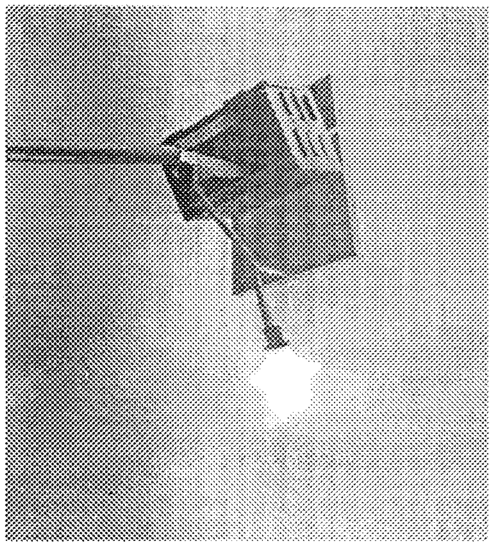


Plate II: Implementation of Stand-alone Solar-based Street Lighting System

The Plate III below shows the pictorial diagram of mounted stand-alone solar-based street lighting lamp switched on during darkness after the implementation.



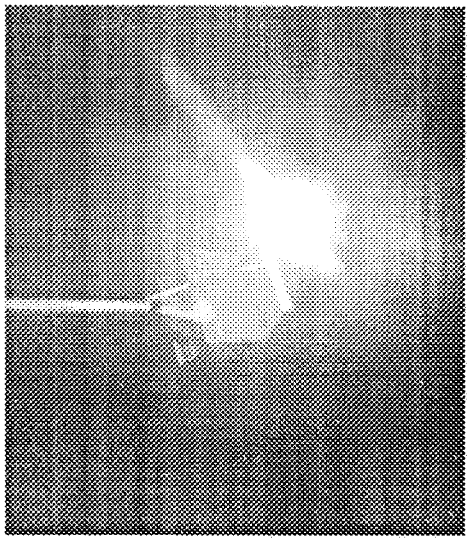


Plate III: Stand-alone Solar-based Street Lighting lamp Switched On During Darkness

## 3.9 ECONOMIC ANALYSIS

It describes the cost comparative analysis between street lighting powered by electricity from public utility and solar energy. The replacement of public street lighting with an effective and efficient solar street lighting depends to a large extent on which of these would be reduced economically.

- Types of discharge lamp e.g. (LPS, MH, MV, or CFL)
- Number of lamp installed/used.
- The lamp energy consumption
- The energy consumption cost.
- The prime lighting installation cost.

Equation (3.12) below can be used to analyze the energy efficient street lighting between the electricity supply by public utility and solar based energy (Oliver *et al.*, 2002)

Prime lighting installation cost per hour =

$$\frac{24}{operating\ duration\ per\ day} \times \sum \frac{C_{equipment}}{L_{equipment}} + \frac{P \times (1+\alpha) \times C_{kwh}}{1000} \qquad (3.12)$$

where, Operating duration per day = 12 hours

$C_{equipment}$ = equipment cost which include the cost of pole, cabling, lamp, luminaire, etc.

$L_{equipment}$ = life equipment duration

$C_{kwh}$ = Cost of public electricity utility per KWh

P = Active Power for lighting

α = Losses in electricity production and transportation equipment.

It is important to note that the term $C_{kwh}$ and α are variable data which depend on technology development, size of supply and market forces, losses in electricity production in Nigeria is approximately 30%.

The following assumption is made;

- Public street lighting energy bill, $C_{kwh}$ is subject to changing. Therefore, 5% increment is assumed for every two years period.
- Solar energy bill is considered to be constant. However, 5% increment can be added for maintenance cost for every year; these include: change of lamp, battery or inverter.

### 3.9.1 Determination of annual economic analysis of CFL lamp (2x26W) powered from public utility and Solar based for street lighting system.

Calculation of Energy Consumption for the lamp indicated above:

CFL Lamp Power = 2 x 26W = 52W = 0.052KW

Operating time per day = 12 hours

Energy Consumption (KWh)/day = 0.052 x 12 = 0.624KWh

Annual Energy Consumption = 0.624 x 365 = 227.76KWh

Calculation of Energy Consumption Cost for the lamp indicated above:

Note: Present rate of KWh by the PHCN single phase is **1KWh – ₦ 5.90**

2x26W CFL Lamp:

Annual Energy Consumption = 227.76KWh

Cost of Lamp = ₦ 1000

Annual Energy Consumption Cost = (5.90 x 227.76) + 1000 = ₦ 2,343.78

Prime installation and energy cost for one year using 2x26W CFL for residential street lighting:

**Case1.** When the energy source is electricity supply from public utility

2x26W CFL prime installation lighting cost per hour:

$C_{equipment}$ = ₦ 20,000

$L_{equipment}$ = 20 years

Power = 2x26W (0.052KW)

$\alpha$ = 30% (20,000) = ₦ 6000

$C_{kwh}$ = ₦ 5.90

$$\frac{24}{12}\times\sum\frac{20000}{20}+\frac{0.052\times(1+6000)\times C_{kwh}}{1000}=2\left[\frac{20000}{20}+\frac{0.052(1+6000)5.9}{1000}\right]=$$

₦ $2{,}002.00/hr$

The subsequent years up to $20^{th}$ years are calculated as above.

**Case2.** When the energy source is solar based

2x26W CFL prime installation lighting cost per hour:

$C_{equipment}$ = ₦ 20,000

$L_{equipment}$ = 20 years

Power = 2x26W (0.052KW)

$\alpha$ = 30% (20,000) = ₦ 6,000

$C_{kwh} = 1$

$$\frac{24}{12} \times \sum \frac{20000}{20} + \frac{0.052 \times (1 + 6000) \times C_{kwh}}{1000} = 2\left[\frac{20000}{20} + \frac{0.052(1+6000)1}{1000}\right] =$$

₦ $6,281.00/hr$

The subsequent years up to 20th years are calculated as above.

## 3.10 TESTING OF COMPONENTS

Each units of the circuit being constructed was tested on project board and finally soldered to the main Vero board.

Using the digital multimetre for measurement, the output voltage and current of solar PV panel was measured and recorded before connected to the charge controller. After connecting the solar panel to the charge controller, the charging output voltage and current was measured and recorded. This indicates the accumulation of charging power in the battery capacity. The results of the charging output voltage and current are indicated in chapter four, table 4.1.

Also, the output frequency of the signal generator designed using 555 timer and other components was tested and recorded. The output voltage of the power switching MOSFET of inverter was tested and recorded before the signal flows to the inverter transformer. Then, the output voltage after the inverter transformer stage was also tested and recorded.

## CHAPTER FOUR

## 4.0 RESULTS OF DATA AND DISCUSSION

### 4.1 INTRODUCTION

This chapter explains the results and discussion of results obtained from the test analysis carried out for the design and implementation of stand-alone solar-based street lighting.

### 4.2 SOLAR PV PANEL UNIT

Rated Power, P = 60W

Rated Voltage, V = 17.2V

Rated Current, I = 3.5A

Open circuit Voltage, $V_{oc}$ = 21.6

The Figure 4.1 below shows the graph of Solar PV Current / Voltage characteristics as obtained from the table in appendix 3.

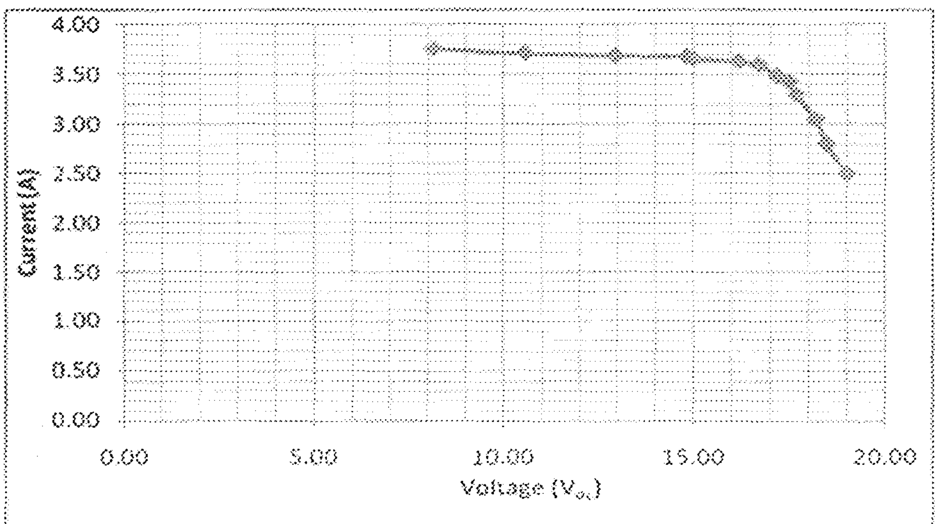



Figure 4.1: Solar PV Current / Voltage Characteristics.

The Figure 4.2 below shows the graph of Solar PV Power / Voltage characteristics as obtained from the table in appendix 3.

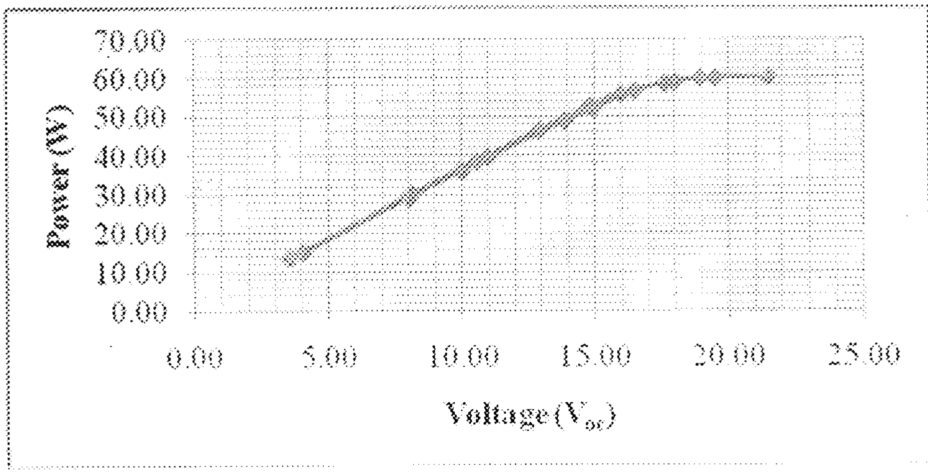



Figure 4.2: Solar PV Power / Voltage Characteristics.

## 4.3 CHARGE CONTROLLER AND INVERTER UNIT

The results obtained during testing were given below:

Charging output voltage = 13.7V

Inverter input voltage (DC) = between 11.5V and 13.0V

Inverter output voltage (AC) ≅ 240V

Output frequency = 50Hz

## 4.4 COMPARISON BETWEEN STREET LIGHTING POWER BY PUBLIC UTILITY AND SOLAR-BASED STREET LIGHTING.

The Table 4.1 below shows the economic analysis between the street light powered by electricity from public utility and solar-based system.

**Table 4.1:** Comparison Between Public Utility and Solar-based Street lighting

| Period | 1st yr Inst. | 2nd yr | 4th yr | 6th yr | 8th yr | 10th yr | 12th yr | 14th yr | 16th yr | 18th yr | 20th yr |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Public** cost (N/hr) | 2,002 | 4,005 | 6,007 | 8,010 | 10,013 | 12,016 | 14,020 | 16,023 | 18,027 | 20,030 | 22,034 |
| **Solar** cost (N/hr) | 6,281 | 6,595 | 6,925 | 7,271 | 7,634 | 8,016 | 8,417 | 8,838 | 9,280 | 9,744 | 10,231 |

The Figure 4.3 below shows the graph of variation in cost over a period for economic analysis between the street light powered by electricity from public utility and solar-based system.

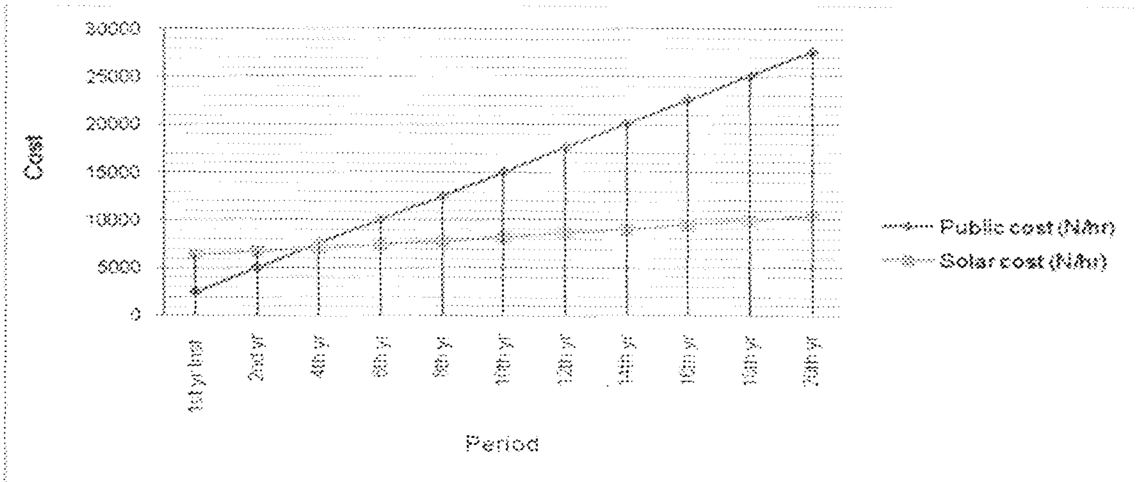



Figure 4.3: Variation in Cost over a Period between Street Lighting Powered by Electricity from Public utility and Solar-based.

## 4.5 DISCUSSION OF RESULTS

The results shown in appendix 3 were obtained from the measurement taken from the solar PV panel. Figure 4.1 shows the Solar PV Current / Voltage Characteristics as obtained from appendix 3. The graph shows that, as the open circuit voltage increases, the current reduces at room temperature between 25°C and 30°C. This agreed with the power equation 4.1.

$$P = V \times I, \qquad V = P/I \qquad (4.1)$$

Figure 4.2 shows the graph of Solar PV Power / Voltage Characteristics. The output power is slightly higher than the rated power of Solar PV panel between the periods of 12.00pm to 1.30pm; this indicated that the intensity of the sun is high during the periods. However, it is important to note that, the output voltage and power of the solar PV panel depends on weather condition rather than time of the day.

The open circuit voltage ($V_{oc}$) of the panel ranges between 0.0V to a maximum voltage of 21.6V. These voltages are fed to charge controller which gives an output charging voltage of 13.7V. With this charging voltage, it will take approximately 5hrs 15min to charge 12V 18AH lead acid battery used for the project during normal good weather condition. However, if weather condition is very poor, the charging period will be higher than 5hrs 15min. When the battery is fully charged, the charge controller prevents the overcharging. It was observed that, the output voltage of the inverter is approximately 240V at the minimum input voltage of 11.5V from the battery.

Table 4.2 shows the economic analysis between the streets light powered by electricity from public utility and solar-based. Figure 4.3 shows that the initial cost of installing Solar-based street lighting is (₦ 6,281.00 / hr), this is far higher than the initial cost of installing public electricity street lighting (₦ 2,002.00 / hr). However, in Figure 4.3, when the system analysis is considered for the period of 20 years, it was observed after six years that, the solar based street lighting is more economically viable and cheaper than the present street lighting powered by electricity from the public utility which gives earlier recovery of solar-based street lighting installation cost.

Solar-based street lighting have many advantages, it is clean, renewable and sustainable. The initial cost of solar-based street lighting which seems real is insignificant considering the payback opportunity in the new ideal of smart grid system whereby the excess power generated from the Solar PV panel when the battery is fully charged can be used to supply other residential electrical load during the day such as refrigerator, fan, or sell back to National grid.

# CHAPTER FIVE

## 5.0 CONCLUSIONS AND RECOMMENDATIONS

### 5.1 CONCLUSIONS

Stand-alone Solar-based Street Lighting for residential area has been designed, constructed and implemented. The need to supplement and eventually replace the existing conventional street lighting power by electricity from public utility in Nigeria today is being advocated since the economic analysis carried out between Solar-based street lighting and street light powered by electricity from public utility shows that the initial cost of solar-based street lighting is relatively high. However, it is insignificant with time and advancement in technology. Solar is readily available and more economically viable to power street lighting in Nigeria.

### 5.2 RECOMMENDATIONS

In carrying out the design, implementation and testing of this project, the following recommendations are suggested for further improvement.

- Since the maximum power from the solar PV panel cannot be achieved for the all day due to the variation in the intensity of the sun, a sun tracker can be incorporated to increase the efficiency of the system.
- The Department or University management can buy solar PV panel to reduce the cost of the project of this nature.
- A dc voltage booster can be incorporated to this project to boost the output voltage of solar PV panel during poor weather condition, particularly in raining season.

- I also recommend that meters such like pyranometer used in the measurement of sun intensity should be purchased by the department, so as to better study the characteristics of Solar PV panel and its application.
- The University should encourage the mass production of this project to be used within the University campus.

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## APPENDICES

**Appendix 1:** Wire Gauge specification table. *Chryssis, C. G. (1994)*

| Diameter over insulation (inches) | | Nominal circular ml. area | Resistance per 1000ft | Current capacity in milliamperes based on 1000cm/A | AWG |
|---|---|---|---|---|---|
| **Max.** | **Min.** | | | | |
| 0.13 | 0.133 | 16510 | 0.6281 | 16510 | 8 |
| 0.116 | 0.119 | 13090 | 0.7925 | 13090 | 9 |
| 0.104 | 0.106 | 10380 | 0.9985 | 10380 | 10 |
| 0.0928 | 0.0948 | 8230 | 1.261 | 8226 | 11 |
| 0.0829 | 0.0847 | 6530 | 1.588 | 6529 | 12 |
| 0.0741 | 0.0757 | 5180 | 2.001 | 5184 | 13 |
| 0.0667 | 0.0682 | 4110 | 2.524 | 4109 | 14 |
| 0.0595 | 0.0609 | 3260 | 3.181 | 3260 | 15 |
| 0.0532 | 0.0545 | 2580 | 4.02 | 2581 | 16 |
| 0.0476 | 0.0488 | 2050 | 5.054 | 2052 | 17 |
| 0.0425 | 0.0437 | 1620 | 6.386 | 1624 | 18 |
| 0.038 | 0.0391 | 1290 | 8.046 | 1289 | 19 |
| 0.034 | 0.0351 | 1020 | 10.13 | 1024 | 20 |
| 0.0302 | 0.0314 | 812 | 12.77 | 812.3 | 21 |
| 0.0271 | 0.0281 | 640 | 16.2 | 640.1 | 22 |
| 0.0244 | 0.0253 | 511 | 20.3 | 510.8 | 23 |
| 0.0218 | 0.0227 | 404 | 25.67 | 404 | 24 |
| 0.0195 | 0.0203 | 320 | 32.37 | 320.4 | 25 |
| 0.0174 | 0.0182 | 253 | 41.02 | 252.8 | 26 |
| 0.0157 | 0.0164 | 202 | 51.44 | 201.6 | 27 |
| 0.0141 | 0.0147 | 159 | 65.31 | 158.8 | 28 |
| 0.0127 | 0.0133 | 128 | 81.21 | 127.7 | 29 |
| 0.0113 | 0.0119 | 100 | 103.7 | 100 | 30 |
| 0.0101 | 0.0108 | 79.2 | 130.9 | 79.21 | 31 |
| 0.0091 | 0.0098 | 64 | 162 | 64 | 32 |
| 0.0081 | 0.0088 | 50.4 | 205.7 | 50.41 | 33 |
| 0.0072 | 0.0078 | 39.7 | 261.3 | 39.69 | 34 |
| 0.0064 | 0.007 | 31.4 | 330.7 | 31.36 | 35 |

**Appendix 2**: Selection of Lighting Lamp for Residential Street Lighting.
(*http://www.beka.co.za*)

# **BEKA**LANE
## HIGH PERFORMANCE RESIDENTIAL STREETLIGHT LUMINAIRE RANGE

## ORDERING DATA

| DESCRIPTION | LAMP | LAMP HOLDER | LUMEN | MASS (KG) |
|---|---|---|---|---|
| BEKALANE 2*26W CFL | 2*TC-D | G24d-3 | 3600 | 3.7 |
| BEKALANE 80W MV | HME 80W | E27 | 3800 | 3.7 |
| BEKALANE 125W MV | HME 125W | E27 | 6300 | 4.0 |
| BEKALANE 70W HPS | HSE 70W/I | E27 | 5600 | 3.7 |
| BEKALANE 70W HPS-T | HST 70W SUPER 4Y | E27 | 6500 | 3.7 |
| BEKALANE 100W HPS | HSE 100W SUPER 4Y | E40 | 9500 | 4.1 |
| BEKALANE 100W HPS-T | HST 100W SUPER 4Y | E40 | 10000 | 4.1 |
| BEKALANE 150W HPS | HSE 150W | E40 | 14000 | 5.3 |
| BEKALANE 150W HPS-T | HST 150W | E40 | 14500 | 5.3 |
| BEKALANE 70W MH | HIE 70W COATED WDL | E27 | 4900 | 3.7 |
| BEKALANE 70W MH-T | HIT 70W WDL | G12 | 6700 | 3.7 |
| BEKALANE 100W MH | HIE 100W COATED WDL | E27 | 8000 | 4.1 |
| BEKALANE 150W MH | HIE 150W COATED WDL | E27 | 12000 | 5.3 |
| BEKALANE 150W MH-T | HIT 150W WDL | G12 | 14500 | 5.3 |
| **MCB Version** | | | | |
| BEKALANE 80W MV/MCB | HME 80W | E27 | 3800 | 3.9 |
| BEKALANE 125W MV/MCB | HME 125W | E27 | 6300 | 4.2 |
| BEKALANE 70W HPS/MCB | HSE 70W/I | E27 | 5600 | 3.9 |
| BEKALANE 100W HPS/MCB | HSE 100W SUPER 4Y | E40 | 9500 | 4.3 |
| BEKALANE 70W MH/MCB | HIE 70W COATED WDL | E27 | 4900 | 3.9 |
| BEKALANE 100W MH/MCB | HIE 100W COATED WDL | E27 | 8000 | 4.1 |

* Standard finish: Grey

**Appendix 3:** Results of Solar Panel Output Voltage, $V_{oc}$, Charging Voltage $V_o$, Current (A) and Power (W).

| | | Voltage (V) | | | |
|---|---|---|---|---|---|
| S/N | Time | $V_{oc}$ | $V_o$ | Current (A) | Power (W) |
| 1 | 6.10 am | 3.55 | 2.05 | 3.78 | 13.42 |
| 2 | 6.30 am | 8.15 | 7.50 | 3.70 | 30.16 |
| 3 | 7.00 am | 10.57 | 8.70 | 3.65 | 38.58 |
| 4 | 8.00am | 12.94 | 10.89 | 3.60 | 46.58 |
| 5 | 9.30am | 14.81 | 13.70 | 3.55 | 52.58 |
| 6 | 10.45am | 16.00 | 14.60 | 3.50 | 56.00 |
| 7 | 11.00pm | 18.00 | 15.00 | 3.28 | 59.04 |
| 8 | 12.00pm | 19.50 | 16.40 | 3.08 | 60.06 |
| 9 | 1.00 pm | 21.50 | 17.20 | 2.80 | 60.20 |
| 10 | 1.30 pm | 18.99 | 16.30 | 3.16 | 60.01 |
| 11 | 2.00pm | 17.67 | 15.50 | 3.31 | 58.49 |
| 12 | 3.00pm | 16.50 | 14.90 | 3.44 | 56.76 |
| 13 | 3.30pm | 15.00 | 13.99 | 3.48 | 52.20 |
| 14 | 4.30pm | 13.90 | 12.50 | 3.52 | 48.93 |
| 15 | 5.00pm | 11.00 | 8.59 | 3.59 | 39.49 |
| 16 | 5.30pm | 10.00 | 7.99 | 3.61 | 36.10 |
| 17 | 6.00pm | 8.00 | 5.50 | 3.63 | 29.04 |
| 18 | 6.30pm | 4.05 | 3.5 | 3.69 | 14.94 |

**Appendix 4**: Bill of Engineering Measurement and Evaluation for Design and Implementation of Stand-alone Solar-based Street Lighting

| S/N | DESCRIPTION OF MATERIALS | UNIT | QUANTITY | RATE (N) | AMOUNT (N) |
|---|---|---|---|---|---|
| 1 | Solar PV Panel 12V 60W (Model: SLP060-12) | No | 1 | 80,000.00 | 80,000.00 |
| 2 | Solar Lead acid Battery, 12V 18AH | No | 1 | 20,000.00 | 20,000.00 |
| 3 | Design Charge Controller Circuit for 12V Battery | No | 1 | 10,000.00 | 10,000.00 |
| 4 | Design 300W Inverter Circuit (12V dc input to 240V ac Output) | No | 1 | 25,000.00 | 25,000.00 |
| 5 | 6V Relay Switch | No | 1 | 200.00 | 200.00 |
| 6 | 240V ac Photocell | No | 1 | 6,000.00 | 6,000.00 |
| 7 | Lighting Lamp | No | 1 | 1,000.00 | 1,000.00 |
| 8 | 4m Galvanized Pole complete with Solar panel base, lighting lamp pole and Control box. | No | 1 | 35,000.00 | 35,000.00 |
| 9 | Construction of Solar based Street Lighting Concrete Basement | No | 1 | 5,000.00 | 5,000.00 |
| 10 | 2x1.5mm2 PVC Copper cable | m | 10 | 150.00 | 1,500.00 |
| 11 | Transportation | Lot | Lot | 15,000.00 | 15,000.00 |
| | **TOTAL** | | | | **198,700.00** |