KWAME NKRUMAH UNIVERSITY OF SCIENCE AND

TECHNOLOGY KUMASI GHANA

SCHOOL OF GRADUATE STUDIES

TECHNO-ECONOMIC ANALYSIS OF STAND ALONE SOLAR PV SYSTEMS FOR REMOTE BASE STATIONS IN GHANA.

(A CASE STUDY AT ABOFREM VODAFONE CELL SITE)

By

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A Thesis submitted to the Department of Mechanical Engineering,

Kwame Nkrumah University of Science and Technology in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

College of Engineering

JUNE, 2015

DECLARATION

I hereby declare that this submission is my own work towards the MSc and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University except where due acknowledgment has been made in the text.

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ABSTRACT

Information and Communications Technologies (ICT) have become an important part of today's global economy. ICT infrastructural development is developing at a very fast pace in Ghana. Growth is above the 1.1% average for Sub-Saharan Africa. The growth in the sector has meant a massive investment in telecommunication infrastructure such as base stations from telecom companies such as Vodafone, Millicom, Glo, Espresso, MTN etc. Hundreds of base stations have been installed all over the country. Currently base stations depend mainly on the national grid, with diesel generators as backups, for its power requirement. In some remote or hilly areas where there are no grid supplied electricity, base stations are usually powered with diesel fuelled generators since lengthy grid extensions may not be cost effective. In addition to high fuel delivery and consumption costs, maintenance of the generators can also be expensive in terms of parts and labour time working on the unit. There are also concerns about environmental pollution using diesel generators. Photovoltaic technology has the ability to convert solar energy into electricity consuming no fossil fuels, using no moving parts, creating no pollution and noise, and lasting for years with little maintenance. The environmental, noise, reliability and power availability benefits of the PV system make it an attractive option. Ghana, being a few degrees north of the equator, is endowed with enormous solar energy resource spread across the entire country. Daily solar radiation level ranges from 4 kWh/m^2 to 6 kWh/m^2. The annual sunshine duration ranges between 1800 to 3000 hours offering very high potential for grid connected and off grid applications. In this thesis work, the use of solar PV technology as a cost effective source of power for cellular base stations in remote or hilly areas, far off the national grid, is reviewed. RETScreen software is used to determine the technical and financial viability of the PV system.

The study shows that even though the initial investment in solar PV is higher than conventional diesel engines, overtime it becomes more cost efficient. The NPV is positive which indicates a potentially feasible project. The Benefit-Cost (B-C) ratio is greater than 1 indicating a profitable project and an equity payback of 4.9 years.

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LIST OF ABBREVIATIONS

AC	Alternative current
AH	Ampere hour
BTS	Base Transceiver Station
CFL	Compact Fluorescent Lamp
DC	Direct current
DG	Diesel generator
DOD	Depth of Discharge
GHG	Green house gasses
GHC	Ghana Cedis
G	Generator
KVA	Kilo volt ampere
KWh	Kilo watt hour
LCC	Life Cycle Cost
MFN	Most Favored Nation
PV	Photovoltaic
PDB	Power Distribution Board
RE	Renewable Energy
STC	Standard Test Condition
SMPS	Switched Mode Power Supply
USD	United States Dollars
VA	Volt ampere
Wh	Watt hour
Wp	Watt Peak

ACKNOWLEDGMENT

First of all, I would like to thank the almighty God for giving me the strength and knowledge to carry out this project. I would also want to thank my supervisor and examiner David Ato Quansah for his able guidance and support to perform the thesis work. I also want to thank all my teachers and fellow students for their support during the course work. I have learnt many useful working skills when we were working together. Apart from this I am also grateful to all those who directly or indirectly contributed to the completion of my thesis work. Finally, I can't forget my family members and friends for their encouragement and support.

CHAPTER 1

INTRODUCTION

1.1 Background

Information and Communications Technologies (ICT) have become an important part of today's global economy. ICT infrastructural development in Ghana is progressing comparatively faster to other low income countries and above the 1.1% average for Sub-Saharan Africa (GIPC, 2014). The growth in the sector has meant a massive investment in telecommunication infrastructure from telecom companies such as Vodafone, Millicom, Glo, Esspresso, MTN etc. Hundreds of Base Stations have been installed all over the country.

The power consumption of wireless access networks has become a major economic and environmental issue. Providing dedicated power supply for base stations is one of the major issues for mobile communication system. In particular, base stations cause more than 50% of the operator's power consumption (Deruyck, et al. 2010), which makes the design of base station a key element for determining both the environmental impact of wireless networking and the operational expenditure.

Currently base stations depend mainly on the national grid, with diesel generators as backups, for its power requirement. In some remote and hilly areas where there are no grid supplied electricity, base stations are usually powered with diesel fuelled generators since lengthy grid extensions may not be cost effective. In addition to high fuel delivery and consumption costs, maintenance of the generators can also be expensive in terms of parts and labour time working on the unit. There also concerns about environmental pollution using diesel generators.

Photovoltaic technology has the ability to convert solar energy into electricity consuming no fossil fuels, using no moving parts, creating no pollution and noise, and lasting for years with little maintenance. The environmental, noise, reliability and power availability benefits of the PV system make it an attractive option.

Ghana, being a few degrees north of the equator, is endowed with enormous solar energy resource spread across the entire country. Daily solar radiation level ranges from 4 kWh/m^2 to 6 kWh/m^2. The annual sunshine duration ranges between 1800 to 3000 hours offering very high potential for grid connected and off grid applications (Ministry of Energy, Ghana 2014).

Before the actual deployment of the PV system to the base station, it is very important to get an estimate the number of photovoltaic (PV) cells, size of inverters and batteries required and also the cost of production of energy per unit. Software's such as RETScreen enables to simulation of cost efficient deployable solar powered base stations.

1.2 Objectives

The main objective of this thesis is to assess the financial and technical viability of stand-alone photovoltaic systems for base stations located in areas where it is not cost efficient to run power transmission lines or have alternative generation such as diesel generator. This thesis would focus on Vodafone's Abofrem cell site.

The specific objectives are outlined below:

- To size the PV system and related balance of system.
- To do a Technical and Financial performance assessment as well as greenhouse gas emission analysis of the project.

1.3 Methodology

This thesis shall be accomplished by using the methodology below:

- Review existing literature for background information.
- Study various PV System technology and configuration.
- Obtain climate information data.
- Site visit to collect load data in the BTS station to build a load profile and estimate the energy and load.
- Collect data on prices of PV system and accessories from reputable websites.
- Technical and Financial performance analysis and greenhouse gas emission analysis of the project using RETScreen.

CHAPTER 2

LITERATURE REVIEW

2.1 Solar Energy

Solar energy refers to the use of solar radiation. The Earth receives 1400 W/m² of incoming solar radiation at the upper atmosphere. Approximately 30 % is reflected back to space while the rest is absorbed by clouds, oceans and land masses. At the earth level the Energy received is assumed to range from 0 to 1000 W/m² depending on the location and period of the day and year. The mean value for the earth is 200 W/m². Africa is known to have the highest potential of solar energy potential of about 5 kWh/day/m². Three main collection means are used for solar energy and are the photovoltaic panel, solar concentrating systems and solar thermal collectors.

2.1.1 Main use of Solar Energy

Solar technologies are broadly characterized as either passive or active depending on the way they capture, convert and distribute the energy. Active solar techniques use photovoltaic panels or solar concentrating systems to convert sunlight into useful electricity for various purposes. Passive solar techniques include selecting materials with favourable thermal properties, designing spaces that naturally circulate air, and referencing the position of a building to the Sun. Active solar technologies increase the supply of energy and are considered supply side technologies, while passive solar technologies reduce the need for alternate resources and are generally considered demand side technologies. Solar energy is used in Africa for remote area electrification, water pumping, cooking, lighting in villages especially.

2.1.2 Role of solar energy in current and future energy systems

Fossil fuels have served the energy needs of the world for over a century but proven reserves of fossil fuels indicates 46 years for oil, 58 years for natural gas and almost 150 years for coal of consumption at current rates (IEA, 2010). There is therefore the need for a more sustainable clean source of energy.

About 885 million terawatt hours (TWh) of solar energy reach the earth's surface in a year, that is 6200 times the commercial primary energy consumed by humankind in 2008 and 4200 times the energy that mankind would consume in 2035 (IEA, 2011). It takes the sun one hour and 25 minutes to send us the amount of energy the world would consume in a year. Solar energy unlike gas, oil or coal energy is non-polluting. It is sustainable and helps for the protection of our environment. It does not release carbon dioxide, nitrogen oxide, sulphur dioxide or mercury into the atmosphere like many conventional forms of energy. Hence solar energy does not contribute to global warming, acid rain etc. Solar energy systems have lower operations and maintenance cost. They operate silently, do not release offensive smells and do not require you to add any fuel.

These have made solar energy emerge as one of the most rapidly growing renewable energy source in the world. The growth of the global PV market has been impressive since 2003, with an average annual growth rate of 40% in 2009 and about 135% in 2010. The cumulative installed global PV capacity grew from 0.1 GW in 1992 to 40 GW at the end of 2010, with 42% being installed in 2010 alone (IEA, 2011). In 2011 renewable accounted for almost half of the estimated 208 GW of electric capacity added globally with solar PV accounting for almost 30% of the new renewable capacity (REN21, 2011). The International Energy Agency predicts that we will produce 662 GW of solar energy by 2035.

One reason for the rapid deployment of solar technologies is that prices of solar energy technologies continue to fall. For example, since 1998, installed PV system prices have fallen by 6-7% per year on average. From 2011 to 2012, installed prices fell by \$0.88/W (14%) for systems less than 10 kW and by \$0.3/W (6%) for systems greater than 100 kW (NREL, 2014). Technological advancement and investments will drive the price of solar technologies further.

The initial cost or investment is the main disadvantage when installing a solar energy system, largely because of the high cost of the collecting systems. Solar panels require quite a large area for installation to achieve the level of required energy. The efficiency of the system also depends on the location of the sun, although this problem can be overcome with the installation of a higher number of components. The production of solar energy is influenced by the presence of clouds or pollution in the air. Again, no solar energy will be produced during night-time although a battery backup system will solve this problem.

The quest for a cleaner, very abundant and inexhaustible energy resource for mankind means solar energy will be an important source of energy for the future.

2.2 Photovoltaic Technology

2.2.1 Nomenclature

- **Cells** - Semiconductor device that converts sunlight into direct current(DC) electricity
- **Modules** - PV modules consist of PV cell circuits sealed in an environmentally protective building block of PV systems
- **Panels** - PV panels include one or more PV modules assembled as a pre-wired, field
- **Arrays** - PV array is the complete power of any number of PV module

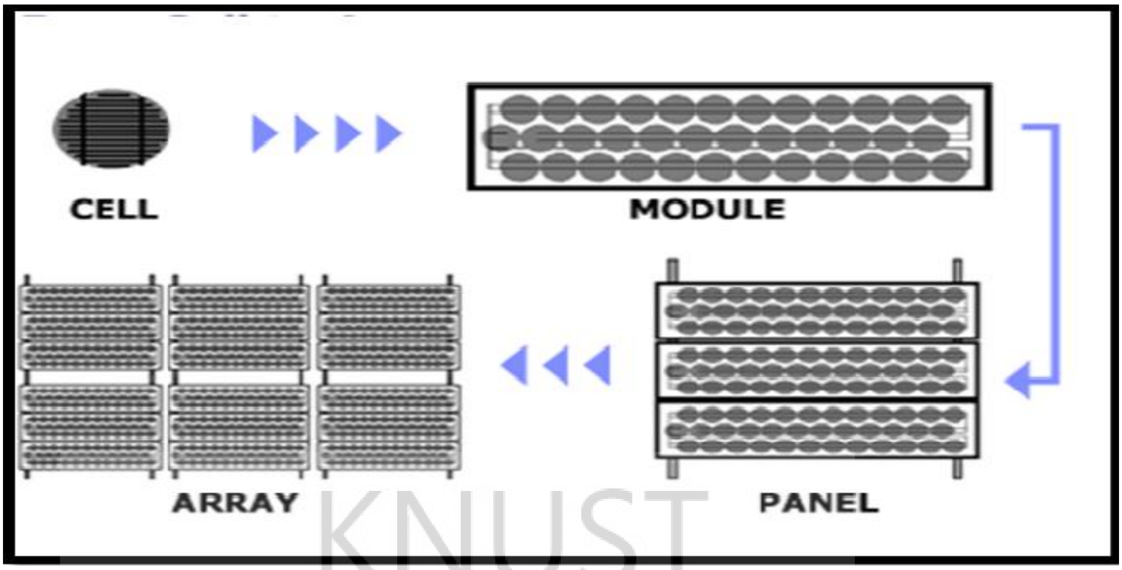

Figure 2.1: From PV cell, Module, Panel to Array.
(Source: Florida Solar Energy Center, 2014)

2.2.2 Photovoltaic Cell

A solar cell is a semiconductor that can convert solar energy into Direct Current (DC) electricity through the photovoltaic phenomenon. Energy from solar cell is dependent on the amount of solar irradiation accessible by the cell. A solar cell is made up of at least two layers of semiconductor materials. One layer has a positive doping, the other is negatively doped. When light enters the cell, some of the photons of the light are absorbed by the semiconductor atoms, freeing electrons from the negative layer of the cell to flow through an external circuit and back into the positive layer. This flow of electrons constitutes an electric current. The photocurrent which is internally generated in a solar cell is proportional to the irradiance.

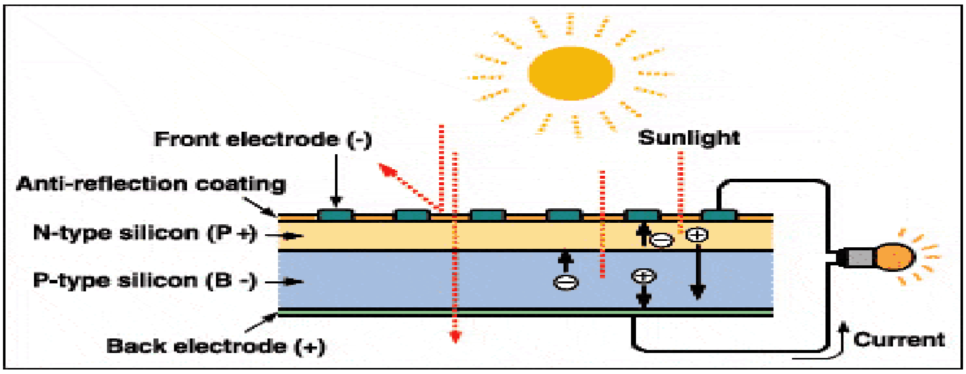

Figure 2.2 Photovoltaic cell (Source: ENGINEERING.com, 2014)

The main types are amorphous, polycrystalline and mono-crystalline silicon cells. Mono-crystalline silicon cells have a greater degree of purity of the material and ensure the best performance in terms of efficiency. Polycrystalline silicon cells have a lower purity and involve less efficiency than the mono-crystalline type. Amorphous Silicon cell is the deposition of a thin layer of silicon crystal (1-2 microns) on the surfaces of other materials, such as glass or plastic ones. It has the lowest efficiency.

2.3 Environmental Impact of the PV Technologies

Photovoltaic (PV) technology has many environmental advantages for generating electricity over fossil fuel technologies. They do not produce any noise, toxic-gas emissions, or green house gases. However there are some negative environmental impacts of solar systems, especially during PV manufacturing. Materials used in some solar systems can create health and safety hazards. Among the most dangerous substances related with PV systems from a life cycle approach are stated below

- **Silica (SiO_2).** The mining of metallurgical grade silica can produce silica dust that has been associated with silicosis, a severe lung disease.
- **Cadmium (Cd).** Extremely toxic. Potential to cause kidney, liver, bone, and blood damage from ingestion and lung cancer from inhalation.
- **Silane (SiH_4).** It is extremely explosive. Dangerous for workers and communities.
- **Chlorosilane ($HSiCl_3$).** Very toxic and highly flammable
- **Silicon Tetrachloride ($SiCl_4$) (waste).** Extremely toxic substance. Causes skin burns and is a respiratory, skin and eye irritant.
- **Hydrogen selenide (H_2Se).** Highly toxic and dangerous at concentrations as low as 1 part per million in the air.

- **Sulfur hexafluoride (SF6).** Extremely potent green house gas. Accidental or fugitive emissions will greatly undermine green house gas reductions gained by using solar power.
- **Selenium dioxide (SeO2).** Potential formation at high temperatures. It is a tissue poison like arsenic.
- **Sodium hydroxide (NaOH), hydrochloric acid (HCL), sulfuric acid(H2SO4), nitric acid (HNO3), hydrogen fluoride (HF), phosphine (PH3) or arsine (AsH3), Isopropyl alcohol (C3H8O).** These components require special handling and disposal procedures because of possible chemical burns and risks from inhalation of fumes.
- **Kerf** (waste silicon dust from sawing c-Si wafers). May generate silicon particulate matter that will pose inhalation problems for production workers and those who clean and maintain equipment.
- **Lead (Pb).** Highly toxic to the central nervous system, endocrine system, cardiovascular system and kidneys.
- **Brominated flame retardants (BFRs), Polybrominated biphenyls (PBBs) and Polybrominated dephenylethers (PBDEs). Hexavalentchromium (Cr(VI)).** They are considered carcinogenic

2.4 Solar PV Configuration Systems

Photovoltaic power systems are generally classified according to their functional and operational requirements, their component configurations, and how the equipment is connected to other power sources and electrical loads.

The two principal classifications are stand-alone systems and grid-connected or utility-interactive systems. Photovoltaic systems can be designed to provide DC and or AC power service, can operate interconnected with or independent of the utility grid and can be connected with other energy sources and energy storage systems.

2.4.1 Direct Coupled

In the direct-coupled system, the output of a PV module or array is directly connected to a DC load. A maximum power point tracker (MPPT) is used between the array and load to help better utilize the available array maximum power output. In this system there is no electrical energy storage (batteries) hence the load only operates during sunlight hours. Direct-coupled systems are suitable for applications such as water pumping and refrigerators.

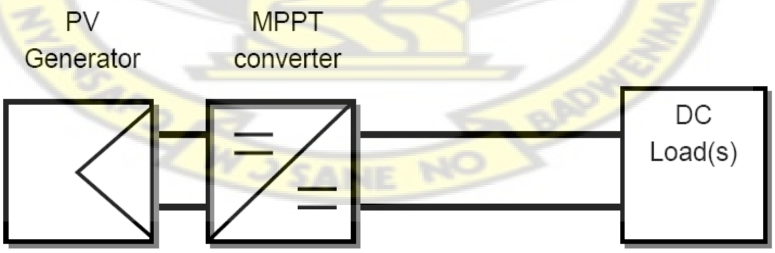

Figure 2.3 Direct coupled system (Source: Florida Solar Energy Center, 2014)

2.4.2 Standalone System

In the standalone system a Charge Controller connected to a PV array regulates charging of a battery bank and feeds DC loads and an inverter. The battery bank stores DC energy to be used in the night and periods of low solar radiation. The Inverter converts direct current energy to alternating current (AC) energy to feed AC loads.

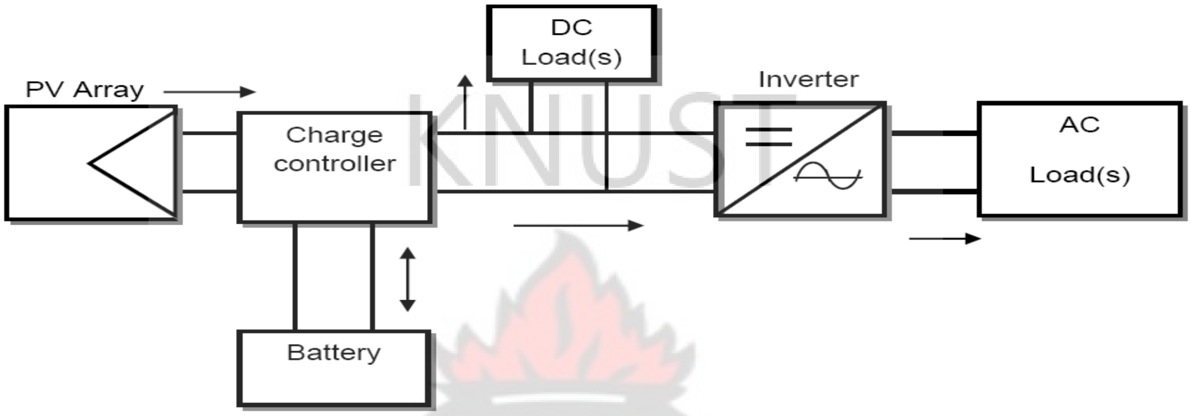

Figure 2.4 Standalone System (Source: SYNERGY ENVIRO ENGINEERS, 2014)

2.4.3 Grid Connected PV System

In a grid-connected system, the PV modules is connected to the electric grid through an inverter. The grid absorbs the electricity when there is excess and provides electricity when the PV modules production is insufficient.

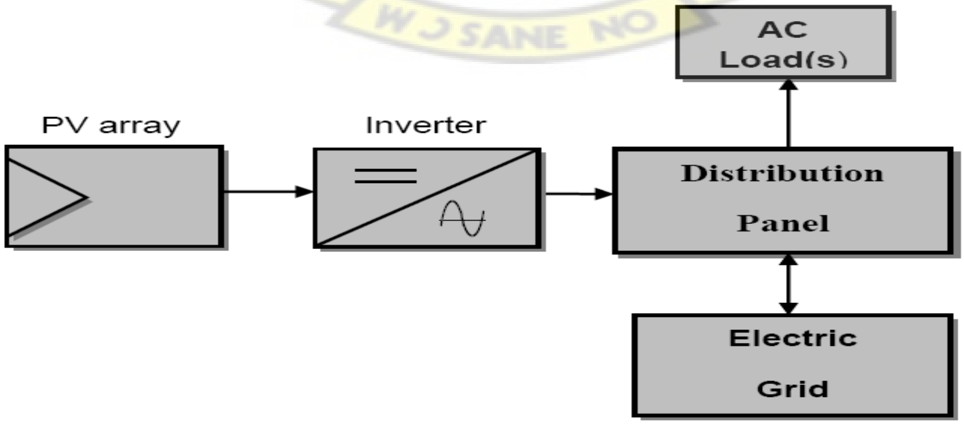

Figure 2.5 Grid connected system (Source: Florida Solar Energy Centre, 2014)

2.4.4 Hybrid System

In a hybrid system, PV is combined with other forms of generation. The other form of generation may be a type able to modulate power output as a function of demand. The other form of generation maybe a diesel generator or wind.

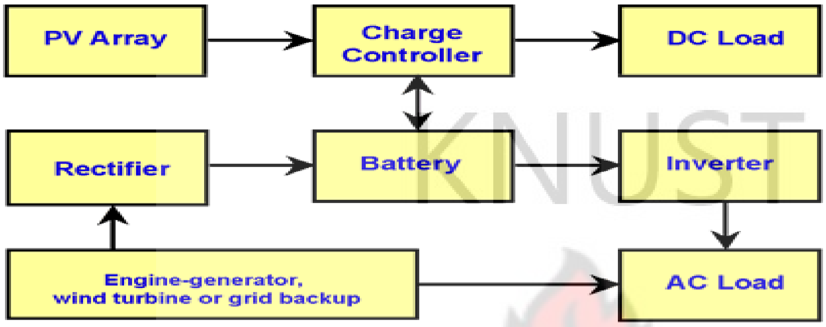

Figure 2.6 Hybrid system (Source: Florida Solar Energy Center, 2014)

2.5 Stand-Alone PV System Components

2.5.1 Solar Panels

Solar photovoltaic panel consist of silicon crystals used to convert the sun's rays into electricity. They produce DC power which is used to charge batteries or feed the load either directly or through an inverter. The panels are available in different sizes, voltages and amperages. They can be wired in series, in parallel or both depending on how the system is designed.

2.5.2 Charge Controllers

Charge controllers prevent Battery Overcharge by limiting the energy supplied to the battery by the PV array when the battery becomes fully charged. They also prevent battery over discharge by disconnecting the battery from electrical loads when the battery reaches low state of charge.

Charge controllers can also provide load control functions by automatically connecting and disconnecting an electrical load at a specified time. Different technologies are available for selection including Pulse Width Modulation (PWM) and Maximum Power Point Tracking (MPPT) charge controllers.

2.5.3 Inverters

An inverter is a device that converts DC power from the battery bank to AC power for various loads. There are two types of inverters, synchronous and static or stand-alone (PolarPower.org, 2014). Synchronous inverters are capable of being tied into the electrical grid. Static inverters are designed for independent and utility free power systems. Static inverters are most often used for stand-alone PV applications. In selecting an inverter the DC voltage input must match the battery voltage of the system. AC power output must also be adequate to satisfy all of the AC powered equipment that might be on at one time (PolarPower.org, 2014).

2.5.4 Battery Bank

The battery storage in a PV system stores electrical energy when it is produced by the PV array and supplies energy to electrical loads as needed or on demand. It also supplies power to electrical loads at stable voltages and currents, by suppressing or smoothing out transients that may occur in PV systems**.** The battery storage also supplies surge or high peak operating currents to electrical loads or appliances.

Lead-acid batteries are most commonly use due to their wide availability in many sizes, low cost and well understood performance characteristics. In a few critical, low temperature applications nickel-cadmium cells are used, but their high initial cost limits their use in most PV systems. (Source: Wikipedia, 2014).

2.6 Mounting Solar Panels

How solar panels are mounted have an effect on power output of the solar panels. Below are some considerations when mounting solar panels to obtain maximum power.

2.6.1 Orientation

The preferred orientation should be facing the equator, in which case the azimuth angle is 0° in the Northern Hemisphere and 180° in the Southern Hemisphere.

2.6.2 Inclination

Another consideration to obtain maximum power output is the proper angle of inclination. As a rule of thumb, the solar panels angle of inclination should be set equal to the latitude of the area. Two common mount types are fixed and Tracking.

2.6.3 Fixed Panel Mount

Fixed solar panel mounts are the simplest and least expensive way to mount solar panels. The panels are normally attached to a building’s roof or the panels may be ground mounted on a series of frames or supports. Ground mounted panels are more susceptible to shading issues and impact damage. Fixed panel mounts will not allow you to adjust for seasonal changes in the sun’s track.

2.6.4 Tracking Panel Mount

In tracking solar panel mounts, solar panels are made to follow the path of the sun during the day. This maximises the direct solar light that the panels can receive.

Two styles of trackers exist, a one-axis and a two-axis. In a one axis tracker, the sun is tracked from east to west at a fixed angle of inclination. The two-axis tracker will track the suns east to west movement as well as the seasonal declination movement of the sun.

Even though tracking type is most efficient, they are more expensive, require maintenance and are subject to malfunction.

2.7 Cellular Base Station

The primary function of the telecommunication base station is to transmit and receive radio signals from a mobile unit over an air interface. It facilitates wireless communication between user equipment and a network.

User equipment are devices like mobile phones (handsets) and computers with wireless Internet connectivity. The network can be that of any of the wireless communication technologies like Global System for Mobile Communication (GSM), wireless local loop, Wi-Fi, or other wide area network (WAN) technology.

They are generally made up of several antennas mounted on a metallic tower and a house of electronics at the base of the tower often called a shelter. The elements within a shelter include analogue and digital signal processors, power amplifier, transceiver, microwave and support equipment such as rectifier, air conditioning elements (for indoor shelters) and lighting. The station may be powered from the national grid and diesel generators. The area covered by base station signals is called cell.

(Source: Wikipedia, 2014)

Figure 2.7 Typical outdor base station in Ghana

2.7.1 Power requirements of Cellular Base Stations

Base stations represent the main contributor to the energy consumption of a mobile cellular network, with a share greater than 50%. (Deruyck, et al. 2010). Several factors can affect the base station power consumption. These include the traffic load (which varies as a function of time), varying nature in demand of the services, statistical population of an area and whether the site is indoor (BTS housed in a shelter) or outdoor. In light of these variables, it is unrealistic to create one load profile for all cell tower power system configurations.

In indoor base stations, air conditioning units play a major role in determining the power required at the base station. Typically there will be two air conditioning units: a primary and a secondary unit. For outdoor applications, there is no requirement for air conditioning; hence total power is significantly reduced.

2.8. Introduction to RETScreen 4 Software

RETScreen 4 is an Excel-based clean energy project analysis software tool that helps quickly determine the technical and financial viability of potential renewable energy, energy efficiency and cogeneration projects.

The RETScreen Photovoltaic Project Model can be used to evaluate the energy production and financial performance of photovoltaic projects. There are three basic applications that can be evaluated with the PV model: On-grid applications, which cover both central-grid and isolated-grid systems; Off-grid applications, which include both stand-alone systems and hybrid systems and Water pumping applications.

RETScreeen software has five step standard project analyses.

2.8.1 Energy Model

In the energy worksheet, the user specifies parameters describing the location of the energy project, the type of system used in the base case, the technology for the proposed case, the loads and the renewable energy resource. In turn, the RETScreen Software calculates the annual energy production or energy savings. A flowchart of the algorithms used to calculate the energy production of PV systems in RETScreen is shown in figure 2.8.

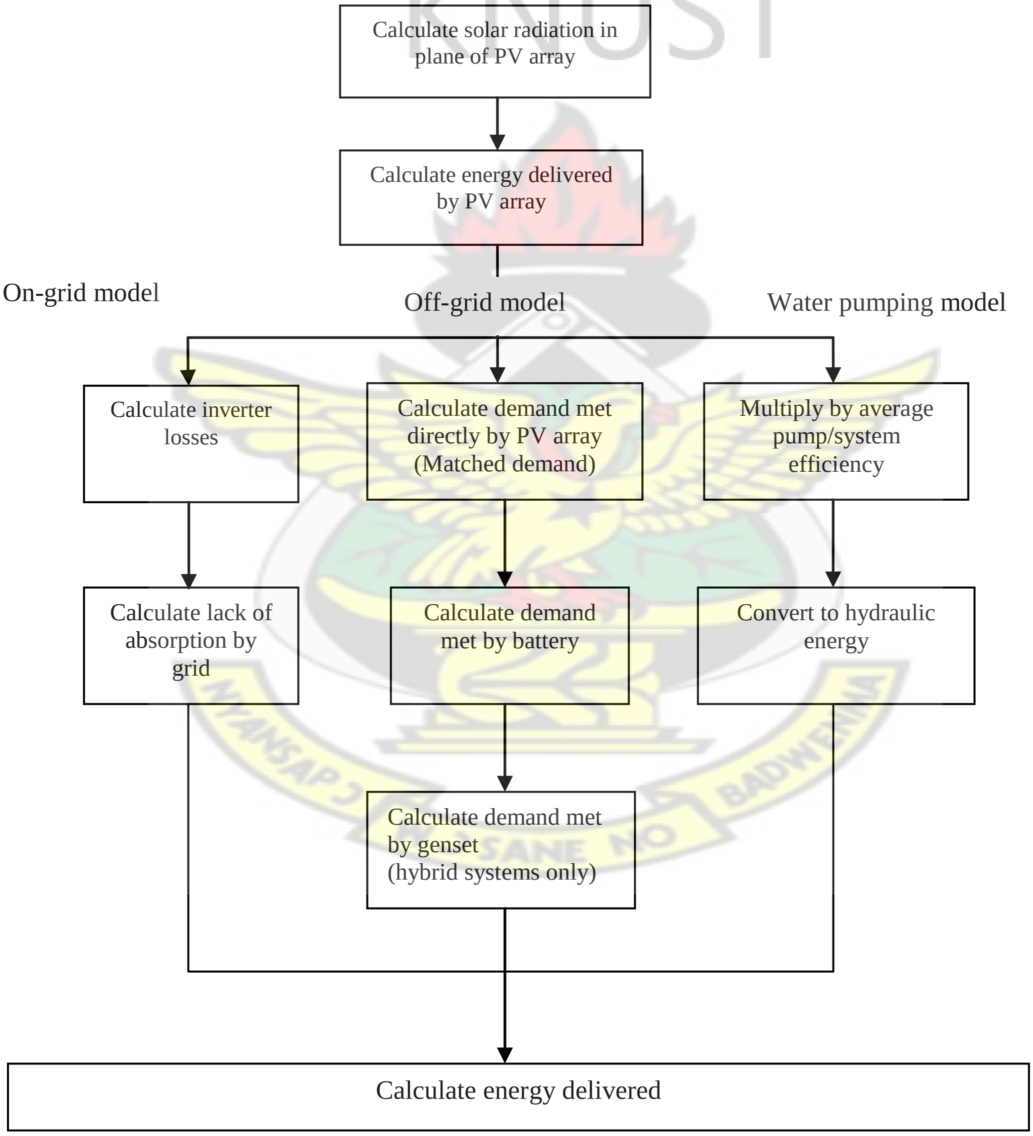

Figure 2.8 flowchart of energy production of PV systems (Source: RETScreen)

2.8.2 Cost Analysis

In this worksheet, the user enters the initial, annual and periodic costs for the proposed case system as well as credits for any base case costs that are avoided in the proposed case

2.8.3 Greenhouse Gas (GHG) Analysis

This optional worksheet helps determine the annual reduction in the emission of greenhouse gases stemming from using the proposed technology in place of the base case technology.

2.8.4 Financial Analysis Model

In this worksheet the user input various financial parameters, such as discount rates, inflation rate, project life and fuel escalation rate. From this RETScreen calculates a variety of financial indicators (e.g. net present value and simple payback) to evaluate the viability of the project. The model assumes that the initial investment year is year 0; the costs and credits are given in year 0 terms, thus the inflation rate (or the escalation rate) is applied from year 1 onwards and the timing of cash flows occurs at the end of the year. Below shows how RETScreen calculates some key financial indicators

i. *The internal rate of return (IRR)* is the discount rate that causes the Net PresentValue (NPV) of the project to be zero. It is calculated by solving the following formula for *IRR*: $0 = \sum_{n=0}^{N} \mathrm{C_n} / (1 + \mathrm{IRR})^{\mathrm{n}}$ where *N* is the project life in years and *Cn* is the cash flow for year *n.*

ii. *Simple payback (SP):* The simple payback *SP* is the number of years it takes for the cash flow (excluding debt payments) to equal the total investment.

SP = $\frac{C-IG}{(C_{ener}+C_{capa}+C_{RE}+C_{GHG})-(C_{O\&M}+C_{fuel})}$

Where C is the total initial cost of the project, IG is the value of incentives and grants, C_{ener} is the annual energy savings or income, C_{capa} is the annual capacity savings or income, C_{RE} is the annual renewable energy (RE) production credit income, C_{GHG} is the GHG reduction income.

iii. *Net present value (NPV):* The net present value *NPV* of a project is the value of all future cash flows, discounted at the discount rate, in today's currency. It is calculated by discounting all cash flows as given in the following formula:

NPV = $\sum_{n=0}^{N} \frac{\dot{C}_n}{(1+R)^n}$

where r is the discount rate, $\dot{C}_n$ the after-tax cash.

iv. *Benefit-Cost (B-C) ratio:* The benefit-cost ratio, *B-C*, is an expression of the relative profitability of the project. It is calculated as a ratio of the present value of annual revenues (income and/or savings) less annual costs to the project equity:

B-C = $\frac{NPV+(1-f_d)C}{(1-f_d)C}$

where C is the total initial cost of the project and f_d is known as debt ratio.

2.8.5. Sensitivity & Risk Analysis

This worksheet assists the user in determining how uncertainty in the estimates of various key parameters may affect the financial viability of the project.

CHAPTER 3

PV SYSTEM DESIGN

3.1 Analysis of Electrical Loads

Figure 3.1 shows the power layout for all loads at the base station. A diesel generator working 24 hours all day throughout the year supply all the power needed. Battery banks take over the power supply when the generator goes off. Table 3.1 below shows the assessment of power at the site. The microwave and the base transceiver station (BTS) both consume DC power. The DC load varies during the day reaching its peak at mid-morning around 11:00 am. Due to the variable nature of the DC load, the study will use the highest of the daily peak loads recorded during the period under study. The highest daily peak DC current recorded for the study is 11 A (528 W) for the BTS and 4 A (192 W) for the microwave. The site also uses AC current for the external security. Two CFL lamps rated at 20 W and 25 W each are used as security lighting.

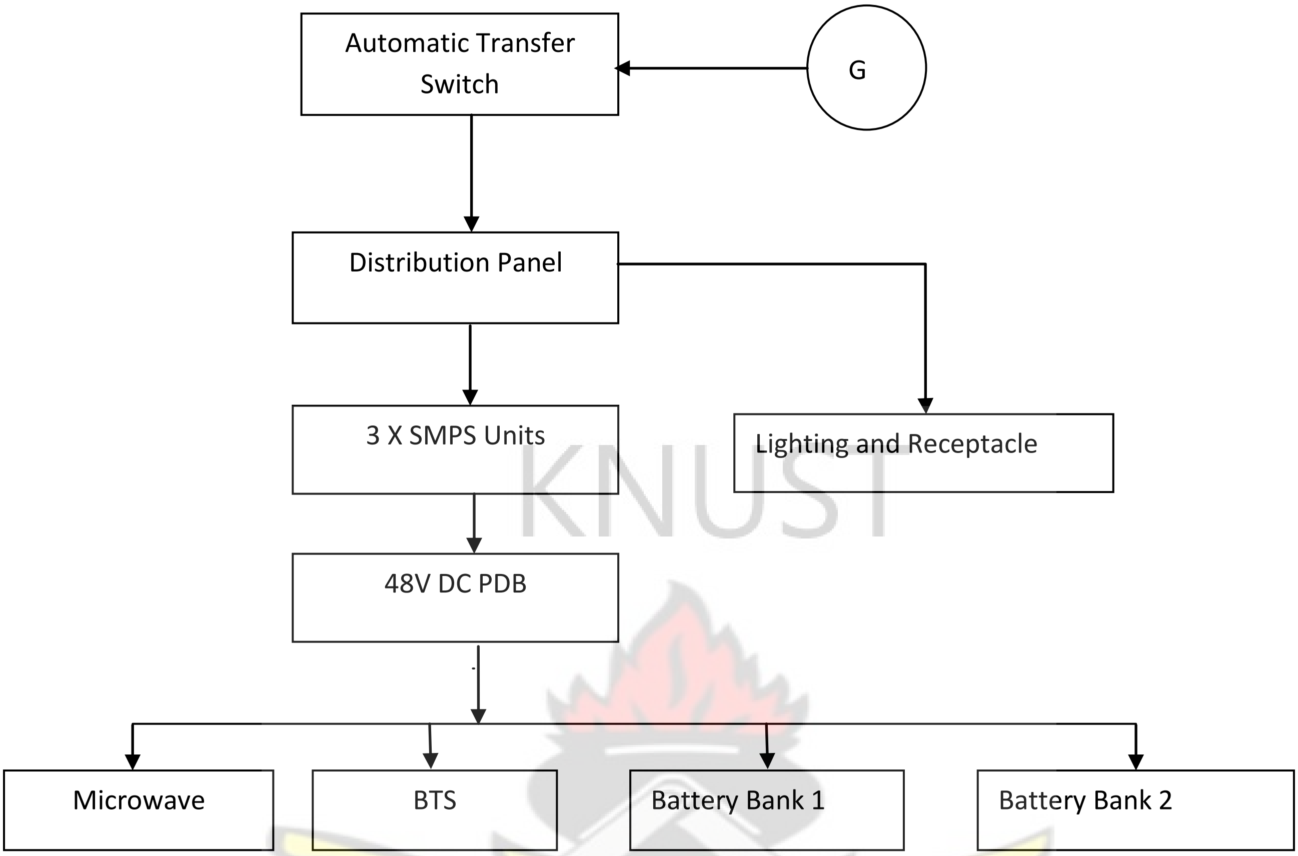

Figure 3.1 Power layout for loads at base station

Table 3.1 Cell Site Load Assessment

Load	Voltage	Power	Time
	V	W	Hours /Day
CFL Lamp 1	230V AC	20W	12
CFL Lamp 2	230V AC	25W	12
BTS	48V DC	528W	24
Microwave	48V DC	192W	24

3.2 Stand Alone PV System Design Architecture

Figure 3.2 is the block diagram which shows the design architecture, where the solar panels will be connected to a Charger/Controller. The charge controller senses battery voltage and regulates charging of a battery bank. The battery bank stores DC energy to be used in the night and periods of low solar radiation. An Inverter converts direct current energy to alternating current (AC) energy to feed AC loads. From table 3.1, the total AC load is (20+25) = 45 W. DC loads are served from the charge controller. Telecommunication equipment requires 48 V DC. From table 3.1, the total DC load is 528 W +192 W = 720 W.

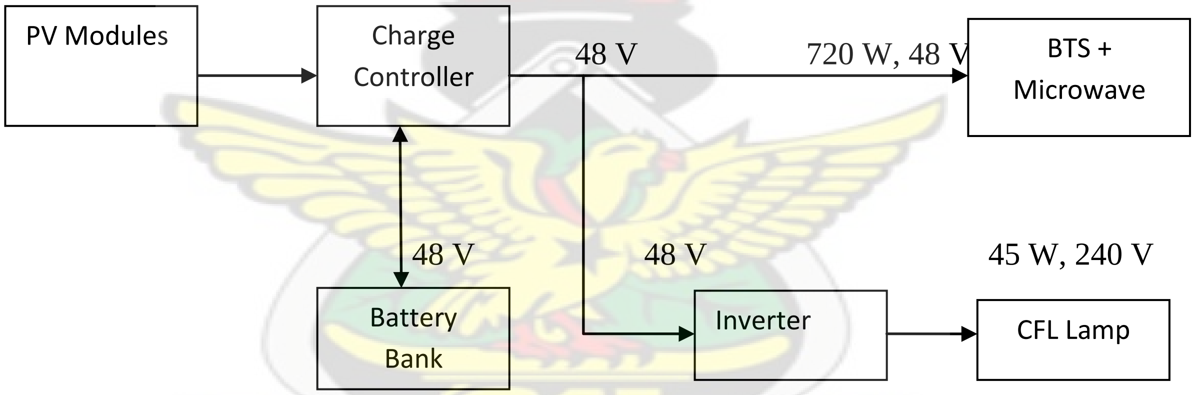

Figure 3.2 Stand alone PV design architecture

3.3 Sizing of Components

3.3.1 Inverter Sizing

The inverter converts direct current energy to alternating current (AC) energy to feed AC loads CFL lamp 1 and 2. The inverter rating must meet two conditions:

Nominal power ≥ Power estimated x 1.1

Surge power ≥ Power estimated x 2

From table 3.1, the total AC power estimate = (20+25) = 45 W**.**

$$\boldsymbol{Nominal\ power\ \geq 45 \times 1.1 = 49.5\ W}.$$

$$\boldsymbol{Surge\ Power\ \geq 45 \times 2 = 90\ W}.$$

The inverter should therefore have a power rating of at least 49.5 W and a surge power of at least 90 W. The selected inverter should also be able to supply the required 240 V for the security lamps.

3.3.2 Proposed Case Daily Energy Demand Estimation

The total daily energy demand is needed to estimate the battery bank capacity and the PV peak power capacity. The daily energy demand (E) of each load is given by the formula E (Wh) =Power (W) of the load x hours (h) of use per day. For the AC loads, the power used for computing the energy demand is the rectified power. The rectified power for the AC load is the power taking into account the inverter efficiency. It is defined by;

$$\boldsymbol{Rectified\ Power\ = \frac{Power}{Inverter\ \ Efficiency}}.$$

The inverter selected for the study has an efficiency of 95%. The energy demand table is given in table 3.2.

Table 3.2 Base station energy demand table

Load	Power	Time	Rectified Power	Daily Energy
	W	Hours /Day	W	Wh
CFL Lamp 1	20	12	21.05	252.63
CFL Lamp 2	25	12	26.32	315.79
BTS	528	24	528	12672
Microwave	192	24	192	4608
Total Daily Energy Demand				**17,848.42**

The estimated daily energy demand is therefore 17,848.42 Wh. In this study 15% of the energy has been taken as margin of safety. Total daily energy demand to be considered $= 17{,}848.42 \times 1.15 = 20{,}525.68\ Wh$.

3.3.3 Battery Bank Capacity (C_{BB})

To size the battery bank the following data are needed

- Daily energy consumption demand E_d (Wh)= 20,525.68 Wh
- Battery Efficiency B_{eff}
- Battery Nominal Voltage V_{BB}
- Depth of Discharge (DOD).
- Number of days of autonomy (T_{aut}).

The size of the battery bank C_{BB} (Ah) = $\frac{E_d \times T_{aut}}{V_{BB} \times B_{eff} \times DOD}$

Most telecom equipment requires 48 V for operation. Therefore the study will use 48 V battery bank (V_{BB}) voltage. The study will also use an assumed 3 days of autonomy (T_{aut}). The days of autonomy is the number of days that the system, starting from a state of full charge, would be able to meet the load using the batteries only. Assuming a battery of DOD 75% and efficiency of 90%. The energy demand to be considered is 20,525.68 Wh

$$C_{BB}\ (Ah) = \frac{20{,}525.68\ \text{Wh} \times 3}{48 \times 0.75 \times 0.9}$$

C_{BB} (Ah) = 1900 Ah

The batteries will be connected in a series parallel combination to achieve the nominal storage voltage of 48 V and the total capacity of 1900 Ah.

3.3.4. Photovoltaic Array Peak Power (W_p) Sizing

To size the PV array the following data is required:

- Daily energy demand E_d (Wh/d) = 20,525.68 Wh
- Monthly average solar radiation H_i (kWh/m^2/d)
- PV Derating Factor E_{gen} (Typically 80%)
- Battery Efficiency B_{eff} (%)= Typically 90%

$$\boldsymbol{W_p = \frac{E_d}{H_i \times B_{eff} \times E_{gen}}}$$

Assuming each PV module has a peak power of 300 W at STC, and a maximum voltage and current of 36.5 V and 8.22 A respectively. Table 3.4 below gives detailed characteristics of an ideal characteristics PV module needed for the study. The PV array will be sized to satisfy the average daily load demand of the period with the lowest solar radiation (H_i) of 3.78 kWh/m^2/d (Table4.1). In this way, sufficient solar energy is available at all times of the year. The energy demand (E_d) to be considered is = 20,525.68 Wh. A PV derating factor of 80% is used. The battery efficiency is 90%.

$$\mathbf{W_p = \frac{20{,}525.68\ Wh}{3.78 \times 0.9 \times 0.8} = 7541.77\ W}$$

Total Number of modules needed to supply 7541.77 W $= \frac{7541.77\ W}{300\ W} = \mathbf{25.14 \approx 26}$

Actual peak power to be installed = 26 ×300 = 7800 W

The PV models will be arranged in 2 parallel strings, each having 13 series models.

Table 3.3 Characteristics of PV module for the study

Electrical Characteristics	
Watts (STC)	300 W
Watts (PTC),	No
Maximum Voltage (Vmp)	36.5 V
Maximum Current (Imp)	8.22 A
Open Circuit Voltage (Voc)	45 V
Short Circuit Current (Isc)	8.74 A
Power Tolerance	0 to +5%
Module Efficiency	15.63%

(source : Sun Electronics, 2014)

3.3.5 Charge Controller Sizing

The charge controller Nominal current must be greater than the Max Current of the PV generator and maximum load current. The nominal voltage must also be equal to the system voltage.

The PV generator current = Current for one string x number of string.

Current for one string = 8.22 A (Table 3.4), Number of strings = 2

- ***PV generator current = 2 × 8.22 = 16.44 A***
- Max Load current = DC load current + AC loads current

The total DC current load is 15 A (table 3.1).

The total AC load current $\boldsymbol{I}_{\boldsymbol{ac}} = \frac{\boldsymbol{P_r}}{(\boldsymbol{Vac \times pf})} = \frac{\mathbf{45}}{\mathbf{240 \times 0.8}}$ 0.25 A

Maximum current = (15+0.25) =15.25 A. The PV generator current is greater than the maximum load current, hence the controller must have at least a nominal current of 16.44 A.

CHAPTER 4

ANALYSIS WITH RETSCREEN

4.1 Energy Analysis with RETScreen Software

The objective is to simulate the PV system designed for the cell site. The modules, charge controller, battery bank and an inverter have been calculated. The daily energy consumption rates have been estimated and the power to be generated has also been estimated. Table 4.1 shows a summary of the input parameters into RETScreen for the energy simulation.

Table 4.11: Summary of input parameters into RETScreen energy model

Parameter	Value	Remarks
Fuel rate	US$ 1 per Litre	Present cost of a litre of diesel
Generator Capacity	11 kW	Capacity of diesel generator currently at the base station
Generator Heat rate	10,285.7 kJ/kWh	Heat rate for the generator. See appendix 5
Annual O&M cost	US$ 1,800	Cost of minor servicing
Electricity - daily - Base Case	DC-17.28 kWh, AC- 0.54 kWh	Total energy demanded at site
Electricity - daily - Proposed Case	DC-17.28 kWh, AC- 0.569 kWh	Total energy required from PV system
Days of autonomy	3 days	Authors' assumption
Batter Voltage	48 V	Most Telecom equipment are rated 48 V DC
Battery Efficiency	90 per cent	Typical Battery efficiency for solar system batteries
Battery Maximum depth of discharge (DOD)	75 per cent	Typical DOD for solar system batteries
Charge controller efficiency	95 per cent	Typical controller efficiency
Battery Storage Capacity	1900 Ah	Calculated based on an assumed autonomy of 3 days for PV system
Solar resource data	See Table 4.1	Obtained from RETScreen Climate database
Tracking Mode	Fixed	Slope of 6.5^{o} due south
Module Specifications	See Table 3.3	Characteristics of PV module used for the study
Inverter Efficiency	95 per cent	Typical inverter efficiency

4.1.1 Solar Resource Data

The Abofrem cell site is an outdoor base station located about 5 km from Bibiani in the western region of Ghana. The site is located on a hill off the national electricity grid. Solar radiation data for Abofrem is however not available in the RETScreen database. The nearest location for weather data is in Bibiani about 5 km away. Bibiani weather data would therefore be used for this study. Bibiani has latitude of 6.5^0 N, a longitude of -2.3^0 E and an elevation of 207 m above sea level. Table 4.2 shows estimated solar radiation received on average during one day on a slope surface at the site. The slope is equal to the absolute value of the latitude of the site which is 6.5^o N: This is the slope which in general maximizes the annual solar radiation in the plane of the solar PV.

Table.4.2 solar radiation data for Bibiani

Month	Daily Solar Radiation $kWh/m^2/day$
Jan	5.54
Feb	5.64
Mar	5.47
Apr	5.28
May	4.98
Jun	4.33
Jul	3.99
Aug	3.78
Sep	3.94
Oct	4.65
Nov	5.17
Dec	5.24
Annual Average	4.83

Source:RETScreen

4.1.2 Existing Energy System

An existing 11 kW diesel generator is meeting the energy needs of the site and it is to be replaced with PV. Every month the base station is supplied with 2000 litres of diesel. An amount of US$ 50 is typically charged to conduct minor services on such a diesel generator in Ghana. Table 4.2 shows the minor maintenance interval and the cost involved for the existing diesel generator.

A typical diesel engine can go 30,000 hours or more between major overhauls (Cummins Power Generation, 2014). In the study, it is assumed the diesel generator will be replaced after 35000 hours or 5 years instead of the major overhaul. An important generator parameter needed for the RETScreen analysis is the heat rate. The 11 kV generator has a heat rate of 10,285.7 kJ/kWh. The study uses the current cost of a litre of diesel of US$ 1.

The existing system daily AC energy demand = 45 W × 12 h = 540 Wh

The existing system daily DC energy demand = 720W × 24h = 17,280 Wh

Table 4.3 Maintenance Interval for Minor servicing of DG

Maintenance	Interval (Hours)	Maintenance cost/Service (US$)	No. of times /year	Total Cost per Year (US$)
Minor Service	250	50	36	1,800

4.1.3 Battery Storage

The battery bank has been sized with an assumed days of autonomy of 3 days. This is the number of days that the system, starting from a state of full charge, would be able to meet the load using the batteries only. The design came up with battery capacity of 1900 Ah. Solar PV system batteries typically have a depth of discharge of 75% and efficiency of 90%.

4.1.4 Photovoltaic Array Models

The peak power capacity based on the design is 7800 W_p. A module with capacity 300 W and efficiency of 15.6% is selected for the study. Total Number of the modules needed to produce the 7800 W_p is 26. The PV models will be arranged in 2 parallel strings, each having 13 series models.

4.1.5 Controller

The nominal current of the charge controller selected should be greater than or equal to the total load current of 16.44 A and should also have an output system voltage of 48 V.

4.1.6 Inverter

An off-grid inverter which can produce more than 50 W of pure sine wave power at 240 VAC for AC loads is selected for the study.

4.1.7 Proposed PV Mount

The panels will be ground mounted on a series of frames mounted at the available space within the site area. The solar panels will be fixed mount to make the design simple and less expensive. Since ground mounted panels are more susceptible to shading, steps would be taken to clear trees around which might cause it. The panels would be mounted at a slope equal to the absolute value of the latitude of the site which is 6.5^{o} N: This is the slope which in general maximizes the annual solar radiation in the plane of the solar collector. The panels would also be orientated true south to face the equator as Ghana is in the Northern Hemisphere. Therefore the azimuth angle is 0.

4.2 Energy Simulation Result and Analysis

The PV system designed is simulated in the RETSCreen energy model as shown in appendix 1. The result is presented in table 4.4

Table 4.4 Energy analysis results table

Parameter	Value	Remarks
Electricity rate - base case	US$ 0.56 per kWh	Average electricity rate for the base case power system
Total electricity cost	US$ 3,644	Total annual electricity cost for the base case system
Electricity - annual Base Case	6.504 MWh	Annual Load demand from the base case system
Electricity - annual -PV System	6.515 MWh	Annual Load demand from the PV system
Battery Capacity	1500 Ah	Suggested nominal capacity of the battery bank for the PV system.
Solar collector area	49.9 m^2	Area that will be covered by the PV array
Capacity factor	18.6 per cent	Ratio of the average power produced by the PV system over a year to its rated power capacity
Electricity delivered to load	6.53 MWh	Annual electricity that will be delivered to the load by the PV system

The designed PV system will be able to deliver a total annual energy of 6.53 MWh to the load. This represents 100.2% of the annual load requirements of the base station. This means the designed system can meet the entire annual energy requirement.

In order to achieve autonomy of 3 days, RETScreen proposes a battery bank capacity of at least 1500 AH. Hence the calculated value of 1900 AH can support the base station.

The model calculates the capacity factor, which represents the ratio of the average power produced by the PV system over a year to its rated power capacity. The capacity factor of the system is 18.6%. This compares favourably with typical values for photovoltaic system which range from 5% to 20%.

4.3 Cost Analysis

In order to choose a solar PV system over diesel generators for the cell site, a clear concept on the implementation cost is needed. Table 4.5 is a summary of input parameters for the cost analysis in RETScreen.

Table 24.5 Summary of input parameters into RETScreen cost model

Parameter	Value	Remarks
Photovoltaic	US$ 2.05 per watt peak	Average cost of PV on the Ghanaian market. See Appendix 6
Diesel Engine	US$ 10,728.26	Cost of 11 kW diesel engine on the local market.
PV Mount	US$ 1000	Set of ground mounting system needed for a solar collector area of 45 m^2
Inverter	US$ 0.51 per watt	Average cost of PV on the Ghanaian market. See Appendix 8
Battery Bank	US$ 1.80 per Ah	Average cost of deep cycle solar battery on the Ghanaian market. See Appendix 7
Charge controller	US$ 7.14 per Amp	Average cost of charge controller on the Ghanaian market. See appendix 9
Feasibility study as per cent of Capital Cost	1 per cent	Authors' assumption
Contingency funds as per cent of Capital Cost	30 per cent	Authors' assumption
Installation cost as per cent of Capital Cost	10 per cent	See Appendix 10
O&M as per cent of Capital Cost	10 per cent	Authors' assumptions

Appendices 6 – 10 are tables showing prices of some system components collated in Ghana as at the end of July 2014. The exchange rate used is 1 US dollar = 3.4 Ghana cedis as at 31 July 2014 (http://www.oanda.com/currency/converter/).

The diesel generator presently at site is assumed to be replaced after 35000 hours or 5 years of service. The batteries are expected to last for 15 years and will be replaced in the 16^{th} year.

4.4 Financial Analysis

The most important financial parameters needed for the study are the discount rate, inflation and fuel escalation rate. The fuel escalation rate is the projected annual average rate of increase in base case fuel costs over the life of the project. Ghana imports most of it fuel requirements from the international markets. Fuel prices therefore depend largely on the prices on the international markets. In North America, long-term fuel cost escalation rates range anywhere from 0 to 5% with 2 to 3% being the most common values (RETScreen, 2014). In this study a fuel escalation rate of 3% will be used.

Inflation for the next 25 years in North America is currently forecasted to range between 2 and 3% (RETScreen, 2014). An inflation rate of 3% will be used for the study.

The discount rates can be taken as the prevailing commercial interest rate. The present Ecobank dollar interest rate of 11% will be used for the study.

The expected lifetime of the equipment also affect the results of the investment analysis. The expected solar panel lifetime of 25 years is used for the Net Present Value (NPV) calculations. The expected lifetime for the battery bank is fifteen years. The charge controller and inverter are assumed to also last 25 years.

Table 4.63 Summary of input parameters into RETScreen Financial model

Parameter	**Value**	**Remarks**
Discount rate	11 per cent	Based on ECOBANK Ghana dollar interest rate
Inflation rate	3 per cent	US$ -denominated
Fuel escalation rate	3 per cent	US$ -denominated
Project life	25 years	Typical for solar PV projects

4.5 Financial Results and Analysis

The result of the financial simulation is presented in Table 4.7.

Table 4.7 Financial analysis results table

Parameter	Value
Equity payback	4.9 years
Net Present Value (NPV)	US$ 16, 367
Benefit-Cost (B-C) ratio	1.86

The equity payback represents the length of time that it takes for the proposed project to recoup its own initial investment (equity) out of the project cash flows generated. The equity payback considers project cash flows from its inception as well as the leverage (level of debt) of the project. The study gives an equity pay back of 4.9 years.

The model also calculates the NPV for the proposed PV system. The NPV is the value of all future cash flows discounted at the discount rate in today's currency. The NPV for the system is US$ 16,367. Positive NPV values are an indicator of a potentially feasible project. The net Benefit-Cost (B-C) ratio is the ratio of the net benefits to costs of the project. The Benefit-Cost (B-C) ratio for the project is 1.86. Ratios greater than 1 are indicative of profitable projects.

4.6 Environmental Benefit of the solar PV System

The emission of 49 tCO_2 is avoided by switching from diesel powered site to the PV system. This is equivalent to 11.4 barrels of crude oil not consumed.

4.7 Sensitivity Analysis

This section presents the results of the sensitivity analysis simulated by RETScreen software. The table below shows what happens to the equity payback when 2 key parameters, initial cost and base case fuel cost, are varied by the indicated percentages. The sensitivity analysis is performed at a sensitivity range of 30%.

The sensitivity range (%) defines the maximum percentage variation that will be applied to all the key parameters in the sensitivity analysis results tables. Parameters are varied using the following fraction of the sensitivity range: -1, -0.5, 0, 0.5 and 1.

The sensitivity analysis below shows what happens to the equity payback when the key indicators are varied.

Table 4.8 Sensitivity analysis table

Initial costs		**Fuel cost - base case**				
		2550.582	**3097.136**	**3643.689**	**4190.242**	**4736.795**
		-30%	**-15%**	**0%**	**15%**	**30%**
13,333	**-30%**	4.9	4.7	4.5	4.3	4.1
16,190	**-15%**	7.8	4.9	4.7	4.5	4.3
19,047	**0%**	9.1	6.1	**4.9**	4.7	4.5
21,905	**15%**	9.3	8.5	5.6	4.9	4.7
24,762	**30%**	9.5	9.1	7.2	5.4	4.9

The lowest equity payback period is 4.1 years and it is obtained when there is 30% increment in the base case fuel cost and a 30 % reduction in the initial cost of the PV system. The highest equity payback period is 9.5 years and it is obtained when there is 30% reduction in the base case fuel cost and a 30 % increment in the initial cost of the PV system.

PV module cost is an important component of the PV system initial cost. Since 1998, installed PV system prices have fallen by 6-7% per year on average. From 2011 to 2012, installed prices fell by $0.88/W (14%) for systems less than 10 kW and by $0.3/W (6%) for systems greater than 100 kW (NREL, 2014).

These figures are in line with analyst downward-trajectory projections for expected market pricing of PV systems. Therefore as PV prices fall equity payback is expected to fall.

The cost of diesel on the other hand is already prohibitive. All indications suggest that oil-derived fuels will continue to increase in cost as a result of rapidly increasing demand.

In terms of energy security, it is highly possible that there will be continuing periods of fuel shortages as supplies keep dwindling. Therefore as fuel prices rise equity payback reduces and hence solar becomes more attractive in the long run.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

There are many base stations in remote locations or not easily accessible places where maintenance can be expensive and time consuming. The Cost of fossil fuels is on the increase which means that as times pass the running costs will keep getting higher with DG generators. The cost of electricity from the DG also is increasing steadily. The high quantity of carbon emissions from diesel generators is affecting the environment negatively. This study has shown that it is cost efficient, in the long term, to supply the base stations in such remote areas off the national grid using stand alone PV systems. For the system under study, the NPV is positive which indicates a potentially feasible project. The Benefit-Cost (B-C) ratio is also greater than 1 indicating a profitable project. The high initial investment can be recouped in 4.9 years.

5.2 Recommendations

My recommendation is to urge telecom companies in Ghana to deploy stand alone PV systems especially for remote base stations far from the national grid.

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APPENDIX 1

Energy Model

RETScreen Energy Model - Power project

Power project

Base case power system

Grid type		Off-grid
Technology		Reciprocating engine
Fuel type		Diesel (#2 oil) - L
Fuel rate	$/L	1.000
Capacity	kW	11.00
Heat rate	kJ/kWh	10,286
Annual O&M cost	$	1,800
Electricity rate - base case	$/kWh	0.560
Total electricity cost	$	3,644

Load characteristics

⦿ Method 1
○ Method 2

	Unit	Base case	Proposed case
Electricity - daily - DC	kWh	17.280	17.280
Electricity - daily - AC	kWh	0.540	0.569
Intermittent resource-load correlation			Zero

☐ **Percent of month used**

		Base case	Proposed case	Energy saved
Electricity - annual - DC	MWh	6.307	6.307	0%
Electricity - annual - AC	MWh	0.197	0.208	-5%
Peak load - annual	kW		1.00	

Proposed case power system

Inverter

Capacity	kW	0.5	Peak load - annual - AC
Efficiency	%	95%	
Miscellaneous losses	%	0%	

Battery

Days of autonomy	d	3.0	
Voltage	V	48.0	
Efficiency	%	90%	
Maximum depth of discharge	%	75%	
Charge controller efficiency	%	95%	
Temperature control method		Ambient	
Average battery temperature derating	%	0.2%	
Capacity	Ah	1,900	1,500
Battery	kWh	91	

Technology Photovoltaic

Resource assessment

Solar tracking mode		Fixed
Slope	°	6.5
Azimuth	°	0.0

Photovoltaic

Type		mono-Si	
Power capacity	kW	7.80	780.0%
Manufacturer		Canadian Solar	
Model		mono-Si - CS6X-300M - MaxPower	26 unit(s)
Efficiency	%	15.6%	
Nominal operating cell temperature	°C	45	
Temperature coefficient	% / °C	0.40%	
Solar collector area	m²	49.9	
Control method		Maximum power point tracker	
Miscellaneous losses	%		

Summary

Capacity factor	%	18.6%	
Electricity delivered to load	MWh	6.53	100.2%

Peak load power system

Technology	Not required

APPENDIX 2

Cost Analysis

Initial costs (credits)	Unit	Quantity	Unit cost	Amount	Relative costs
Feasibility study					
Feasibility study	cost	1	$ 231	$ 231	
Subtotal:				$ 231	1.2%
Development					
Development	cost			$ -	
Subtotal:				$ -	0.0%
Engineering					
installation 10% of Capital cost	cost	1	$ 2,127	$ 2,127	
Subtotal:				$ 2,127	11.2%
Power system					
Photovoltaic	kW	7.80	$ 2,050	$ 15,990	
Road construction	km	0	$ -	$ -	
Transmission line	km	0	$ -	$ -	
Substation	project	0	$ -	$ -	
Energy efficiency measures	project	0	$ -	$ -	
Diesel Engine Cost	credit	1	$ 10,728	$ (10,728)	
BOS: Battery, Inverter, Controller, PV mount cost	cost	1	$ 5,047	$ 5,047	
Subtotal:				$ 10,309	54.1%
Balance of system & miscellaneous					
Spare parts	%			$ -	
Transportation	project			$ -	
Training & commissioning	p-d			$ -	
Contingency fund (30%)	cost	1	$ 6,381	$ 6,381	
Contingencies	%		$ 19,047	$ -	
Interest during construction			$ 19,047	$ -	
Subtotal:		Enter number of months		$ 6,381	33.5%
Total initial costs				$ 19,047	100.0%

Annual costs (credits)	Unit	Quantity	Unit cost	Amount
O&M				
Parts & labour	project	1		$ -
O&M as a per centage of capital cost (10%)	cost	1	$ 2,127	$ 2,127
Contingencies	%		$ 2,127	$ -
Subtotal:				$ 2,127

Annual savings	Unit	Quantity	Unit cost	Amount
Fuel cost - base case				
Diesel (#2 oil)	L	1,844	$ 1.976	$ 3,644
Subtotal:				$ 3,644

Periodic costs (credits)	Unit	Year	Unit cost	Amount
Battery	cost	15	$ 3,420	$ 3,420
Diesel Engine	credit	5	$ 10,728	$ (10,728)
End of project life	cost		$ -	$ -

APPENDIX 3

Emission Analysis Worksheet

Base case system GHG summary (Baseline)

Fuel type	Fuel mix %	Fuel consumption MWh	GHG emission factor tCO2/MWh	GHG emission tCO2
Diesel (#2 oil)	100.0%	19	0.266	4.9
Total	100.0%	19	0.266	4.9

Proposed case system GHG summary (Power project)

Fuel type	Fuel mix %	Fuel consumption MWh	GHG emission factor tCO2/MWh	GHG emission tCO2
Solar	100.0%	7	0.000	0.0
Total	100.0%	7	0.000	0.0

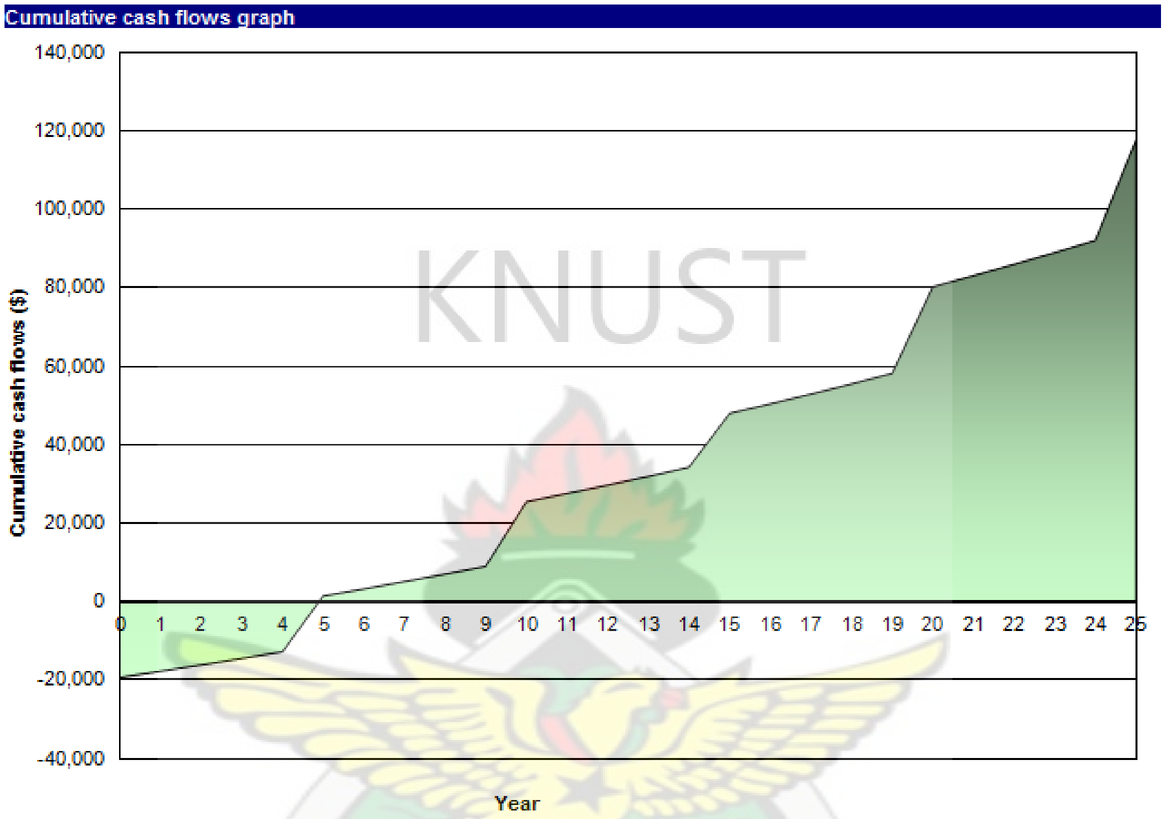
GHG emission reduction summary

	Base case GHG emission tCO2	Proposed case GHG emission tCO2	Gross annual GHG emission reduction tCO2	GHG credits transaction fee %	Net annual GHG emission reduction tCO2
Power project	4.9	0.0	4.9		4.9

Net annual GHG emission reduction	4.9	tCO2	is equivalent to	11.4	Barrels of crude oil not consumed

APPENDIX 4

Cumulative Cash Flow graph



APPENDIX 5

Diesel Generator Heat Rate Calculation

Heat rate is the amount of heat energy in the fuel that is manifest as shaft power or electric power as a result of the engine's energy conversion process.

Heat rate, kJ/kWh = [3,600 / Efficiency (%)] x 100

Diesel engines are among the most efficient simple-cycle power generation options available. Efficiency levels increase with engine size and range from about 35% for small high-speed diesels up to 55% (on an LHV basis) for the large bore, slow speed engines (33% - 52% on an HHV basis).

Assuming an efficiency of 35% for the generator, the ***Heat rate, kJ/kWh*** $= [\boldsymbol{3,600} \div \boldsymbol{Efficiency}\ (\%)] \times \mathbf{100} = \left(\frac{\mathbf{3600}}{\mathbf{35}}\right) \times \mathbf{100} = \mathbf{10285.7}\,\frac{\boldsymbol{kJ}}{\boldsymbol{kWh}}$.

Appendix 6

Price data for solar modules in Ghana

dealer	Module price	Type	(GH₵)	US$	US$/watt
1	120	Poly	749.3	220.38	1.84
	50	Poly	327	96.18	1.92
	30	Poly	218	64.12	2.14
2	130	Poly	650	191.18	1.47
	170	Mono	900	264.71	1.56
3	130		750	220.59	1.70
	245		1500	441.18	1.80
	50		350	102.94	2.06
4	100	Poly	600	176.47	1.76
5	120	Poly	600	176.47	1.47
6	250	Poly	2500	735.29	2.94
7	130	Poly	1139	335.00	2.58
	30	Mono	289	85.00	2.83
	50	Mono	445	130.88	2.62
	80	Mono	715	210.29	2.63
	100	Mono	894	262.94	2.63
	130	Mono	1160	341.18	2.62
	190	Mono	1696	498.82	2.63
	300	Mono	2672	785.88	2.62
	30	Poly	243	71.47	2.38
	50	Poly	358	105.29	2.11
	80	Poly	573	168.53	2.11
	140	Poly	1004	295.29	2.11
	280	Poly	2003	589.12	2.10
8	50	Poly	350	102.94	2.06
9	50	Poly	250	73.53	1.47
	200	Poly	900	264.71	1.32
10	170	Poly	900	264.71	1.56
	110	Poly	600	176.47	1.60
11	200			302.00	1.51
12	50	Poly	250	73.53	1.47
Average price					2.05

Appendix 7

Price data for deep cycle solar battery in Ghana

Dealer	Capacity (Ah)	Price (GH₵)	price (US$)	US$/Ah
1	100	750	220.59	2.21
2	100	585	172.06	1.72
3	100	600	176.47	1.76
	200	1400	411.76	2.06
4	100	600	176.47	1.76
	170	750	220.59	1.30
5	100	350	102.94	1.03
6	200	1050	308.82	1.54
7	170	800	235.29	1.38
8	170	1200	352.94	2.08
9	100	750	220.59	2.21
	165	900	264.71	1.60
	190	1200	352.94	1.86
11	170	1781	523.82	3.08
12	170	900	264.71	1.56
	100	450	132.35	1.32
	100	400	117.65	1.18
	200	1000	294.12	1.47
13	200		500.00	2.50
14	170	950	279.41	1.64
15	20	200	58.82	2.94
	100	650	191.18	1.91
16	100	750	220.59	2.21
17	200	1050	308.82	1.54
18	170	720	211.76	1.25
Average cost				1.80

Appendix 8

Price data for solar Inverters in Ghana

	Capacity (W)	Price (GH₵)	US$	US$/Watt
1	150	230	71.88	0.48
2	300	111.1	34.72	0.12
	600	1842	575.63	0.96
	3000	6630	2071.88	0.69
3	800	2950	921.88	1.15
	1200	3800	1187.50	0.99
	1600	4550	1421.88	0.89
	1500	2200	687.50	0.46
4	1480	1400	437.50	0.30
	1600	1750	546.88	0.34
	2000	1950	609.38	0.30
	4000	3750	1171.88	0.29
5	2000	3170	990.63	0.50
6	4000	4500	1406.25	0.35
	1600	3200	1000.00	0.63
	800	1000	312.50	0.39
	750	850	265.63	0.35
	500	780	243.75	0.49
7	2000	1750	546.88	0.27
8	6000	4500	1406.25	0.23
Average				0.51

Appendix 9

Price data for charge controllers in Ghana

dealer	Capacity (A)	Price (GH₵)	price US$	US$/A
1	20	300	88.24	4.41
2	10	194	57.06	5.71
	10	119.7	35.21	3.52
	60	763.8	224.65	3.74
3	20	400	117.65	5.88
4	40	760	223.53	5.59
	30	450	132.35	4.41
5	40	1152	338.82	8.47
6	30	1350	397.06	13.24
	40	1495	439.71	10.99
7	60	2800	823.53	13.73
	20	630	185.29	9.26
8	30	400	117.65	3.92
Average				7.14

Appendix 10

Installation cost of PV systems in Ghana

	Installed capacity (W)	Installation cost (GH₵)	Installation cost (US$)	installation cost(US$/W)
[1]1	1000	1020	458	0.458
2	400	1680	494	1.235
3	480	1600	470	0.979
4	240	1000	294	1.225
5	400		600	1.5
6	500	1275	375	0.75
7	1000	1180	347	0.35
Average				0.93