UNIVERSITY OF EDUCATION, WINNEBA

COLLEGE OF TECHNOLOGY EDUCATION, KUMASI

ECONOMIC AND TECHNICAL ANALYSIS OF 500KW GRID-CONNECTED SOLAR PHOTOVALTAIC POWER SYSTEM AT UNIVERSITY OF EDUCATION WINNEBA, KUMASI

ABUBAKAR AHMED

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A Dissertation in the Department of ELECTRICAL AND AUTOMOTIVE TECHNOLOGY EDUCATION, Faculty of TECHNICAL EDUCATION, submitted to the School of Graduate Studies, University of Education, Winneba in partial fulfillment of the requirements for the award of Masters of Technology (Electrical and Electronics Technology) degree.

AUGUST, 2015

DECLARATION

STUDENT'S DECLARATION

I, **Abubakar Ahmed**, declare that this Dissertation, with the exception of quotations and references contained in the Published works which have all been identified and duly acknowledged, is entirely my own original work, and it has not been submitted, either in part or whole, for another degree elsewhere.

SIGNATURE:…………………………………….

DATE:……………………………………………

SUPERVISOR'S DECLARATION

I hereby declare that the preparation and presentation of this work was supervised in accordance with the guidelines for supervision of Dissertation as laid down by the University of Education, Winneba.

NAME OF SUPERVISOR: **PROF. WILLIE K. OFOSU**

SIGNATURE:…………………………………….

DATE:……………………………………………

DEDICATION

This research work is dedicated to my late brother and nephew Iddrisu Ahmed and John Dimmy.

ACKNOWLEDGEMENT

I wish to express my profound gratitude to Almighty Allah for giving me life, knowledge and protection throughout the years. Also, it is my greatest desire to extend my appreciation to my supervisor, for his unlimited patience in advising, correction and valuable suggestions. My gratitude also goes to my Friends and colleges for their support during my study.

Finally, I sincerely give thanks to my wife and family for their encouragement.

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ABSTRACT

Grid-connected solar PV systems, though the fastest growing renewable energy technology in the world, have not been fully exploited in Africa, one of the reasons being the very high initial investment. Prices of solar PV systems have however been on a decline for the past few years due to technological innovations which have led to improvement in cell efficiencies and the economies of scale resulting from increase in production. The main purpose of this thesis is to perform, determine and evaluate a 500KW grid-connected solar photovoltaic power system for University of education Winneba Kumasi (UEW-K) using rooftops of buildings on campus. A solar resources assessment done to know the amount of solar radiation available at UEW-K showed that UEW-K receives about 4.30KWH/m^2/day. A roof assessment which considered parameters such as the surface orientation and pitch of roofs, roof area and the possibility of shading of the roof also revealed that there is about 21,848m^2 of roof space available for grid –connected solar PV installations. In technical analysis of 500kwp solar PV system, the three (3) commonest solar PV module technologies were selected and their performance simulated using PV system software. Amorphous silicon modules were found to perform better than monocrystalline and polycrystalline modules over the one (1) year simulation period. The financial analysis carried out using RET screen revealed that at a solar PV market price of US$4.45/WP and a tariff of US$0.11/kwh the project is not viable unless feed-in tariffs greater than US$0.43/kwh are paid. A study should therefore be carried out to examine the capacity of the utility grid in terms of how much electricity can be injected. This is because knowing the capacity of the utility grid will provide useful information about how much electricity from solar PV systems can be injected into the grid. It will be necessary to know

the impact of a 500KWp or higher capacity grid-connected solar PV system will have on the utility grid. It is therefore recommended that a study be carried out to address this issue.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

In recent times, issues bordering on sustainable energy development and climate change have been center stage in major world discussions. The international Energy Agency, in 2009, estimated that, if current government policies don't change, the world's primary energy demand is expected to increase by 1.5% annually from the year 2007 to the year 2030, an overall increase of about 40% (IEA, 2009). World electricity demand, on the other hand, is expected to increase by 2.5% annually during the same period (IEA, 2009). However, fossil fuels continue to dominate the world's fuel and this trend has led to a continued growth of carbon dioxide in the atmosphere, aggravating the adverse effects of global warming. It is reported that, the current thinking of stabilizing greenhouse gas emissions in the atmosphere at 450ppm, is expected to give rise to a global temperature increase of 2°C, and this can be achieved by cutting down on the volume of fossil fuels used (IEA, 2009).

Conventional energy sources like fossil fuels are fast depleting and these call for world leaders to put in place more sustainable energy policies to curb this trend. Renewable energy has been identified as one of the major solutions to this global energy problem. Renewable energy sources are generally carbon free or carbon neutral and hence provide one of the best ways to help mitigate the effects of climate change, the major setback with renewable energy technologies, however, it requires a very high initial capital. The cost of these renewable energy technologies have, however been on the decline over the past few years due to technology improvement and market maturity (REN21, 2010). Thy cost reduction comes as a big boost for most economics since it will encourages patronage of these technologies which will eventually lead to sustainable energy development as well as the mitigation of the effects of climate change.

Globally, renewable energy capacity grew at rates of 10-60% annually for many technologies over the five years period from the end of 2004 through 2009 (REN21, 2010). However, grid-connected solar photovoltaic systems remain the fastest growing energy technologies in the world, with 60% annual increases in cumulative installed capacity during the five-year period from the end of 2004 through 2009 (REN21,2010). Grid-Connected solar photovoltaic (PV) systems employ the direct conversion of sunlight into electricity which is fed directly into the electricity grid without storage in batteries. The solar PV modules used are a number of solar cells connected in series. Typical flat-plate modules achieve efficiencies between 10-15% (WEC, 2009).

1.2 Justification

Ghana has experienced a number of power crises over the last two decades; partly due to the heavy reliance on hydroelectric power which is more often than not dependent on the rainfall pattern of the country and partly also due to insufficiency in the generation capacity of the country. It has been estimated that, grid electricity demand would grow to about 18,000GWh by 2015 and even up to about 24,000GWh by the year 2020 about 6,900GWh in the year 2030 (energy commission, 2006). In order for Ghana to ensure secured uninterrupted electricity supply by the year 2020, the existing installed capacity of 170 NW as at 2006 must be doubled by 2020 (energy commission,2006).

1.3 Statement of the Study

The university depends on Electricity Company of Ghana (ECG) for its power supply, which has a lot of challenges with its power distribution systems and therefore has made it unreliable.

The problem to be investigated is to find alternative and dependable power sources for university of education Winneba, Kumasi. The problem was identified during the researchers four year stay in the university for his first degree, (2009-2013). The researcher found out that during power cut, administration and academic work of the university is distracted. The university also spends a lot of money to power the plant, and the plant could not supply the entire university.

1.4 Objectives of the Study

The main objective of the study is to perform a technical and economic analysis of a 500KW grid-connected solar photovoltaic power system for the university of education Winneba, Kumasi (UEW-K) using rooftops of buildings and car parks.

1.5 The Specific Objectives are;

1. to develop a standard project development framework for the planning of institutional large scale grid-connected solar PV systems. This would include:

i. The determination of the total area required for the project.

ii. Assessing the suitability of roots of buildings and car parks, in terms of roof strength and the possibility of shading for PV installations.

iii. Assessing the financial viability of the project.

2. to validate the framework in planning a 500KW grid-connected solar photovoltaic system for UEW-K.
3. to simulate the performance of the 500KW grid-connected solar photovoltaic system with suitable software packages and conducting technical as well as economic analysis based on the software simulation results.

1.6 Scope and the Organization of Thesis

This report covers the development of a standard project development framework to aid the planning technical and economic analysis of institutional large scale grid connected solar photovoltaic power systems. The framework development which included steps such as roof area assessment, roof surface orientation assessment, roof strength assessment and the assessment of the possibility of shading of the roofs was employed in planning, technical and economic analysis of a 500KW solar photovoltaic system for the UEW-K campus. The work however does not cover the detail design of the 500KW grid-connected solar PV power system.

The background to the project as well as the objectives are contained in chapter one. Chapter one also looks at the statement of the study as well as brief description of the scope and organisations of the project. Chapter two contains a review of the literature on solar PV system installation in Ghana, Africa and the world at large. It also contains a brief description of solar PV systems and their applications. The detailed assessment of the roof properties as well as PV system specifications contained in chapter 3. Chapter 3 ends with a detailed layout design of the PV system ready for installation.

The technical and economic analysis of the project are carried out using software packages and the results analyzed in chapter 4. Chapter 5 contains summary, conclusion and recommendations of the study.

CHAPTER TWO

REVIEW OF GRID-CONNECTED SOLAR PV SYSTEMS

2.1 Solar Energy and Applications

2.1.1 Basics of Solar Energy

Solar energy is the energy produced by the sun through a nuclear fusion reaction in which two hydrogen atoms combine to form a helium nucleus with the release of energy. Several of these reactions take place in the sun and the energy released is transmitted in the form of electromagnetic radiation (including visible light, infrared light and ultra-violet) (Quaschining, 2005).

Solar energy is unarguably the greatest source of energy for the earth and is regarded by many as the indirect source of energy for nearly every other form of energy on the earth with the exception of geothermal energy and unclear energy. It plays a very important role in the formation of fossil fuels and its effect on weather and climate greatly influences other energy sources such as wind, wave, hydro and biomass. It also serves as a direct energy source for solar theme as well as photovoltaic devices for both heating and electricity applications (Quasching, 2005).

2.1.2 Solar Radiation

The energy produced by the sun is transmitted to the planets and other celestial bodies through electromagnetic radiation. Most of these electromagnetic radiations emitted from the sun's surface are within the visible band of the radiation spectrum with a wavelength of about 500nm as shown in Figure 2.1. The amount of energy emitted by the sun's surface is approximately 63, 000, 000 w/m^2.

This energy is transmitted through space where it is intercepted by plants, other celestial bodies and particulate matter. The intensity of solar radiation that strikes the surfaces of these celestial bodies is determined by the inverse square law, which states that the intensity of radiation absorbed by a celestial body varies inversely with square of the distance from the source (Pidwimy et al., 2010).

$$\text{Intensity} = \frac{1}{d^2}$$

Where: 1 = intensify of radiation at one unit distance

d = Distance from source

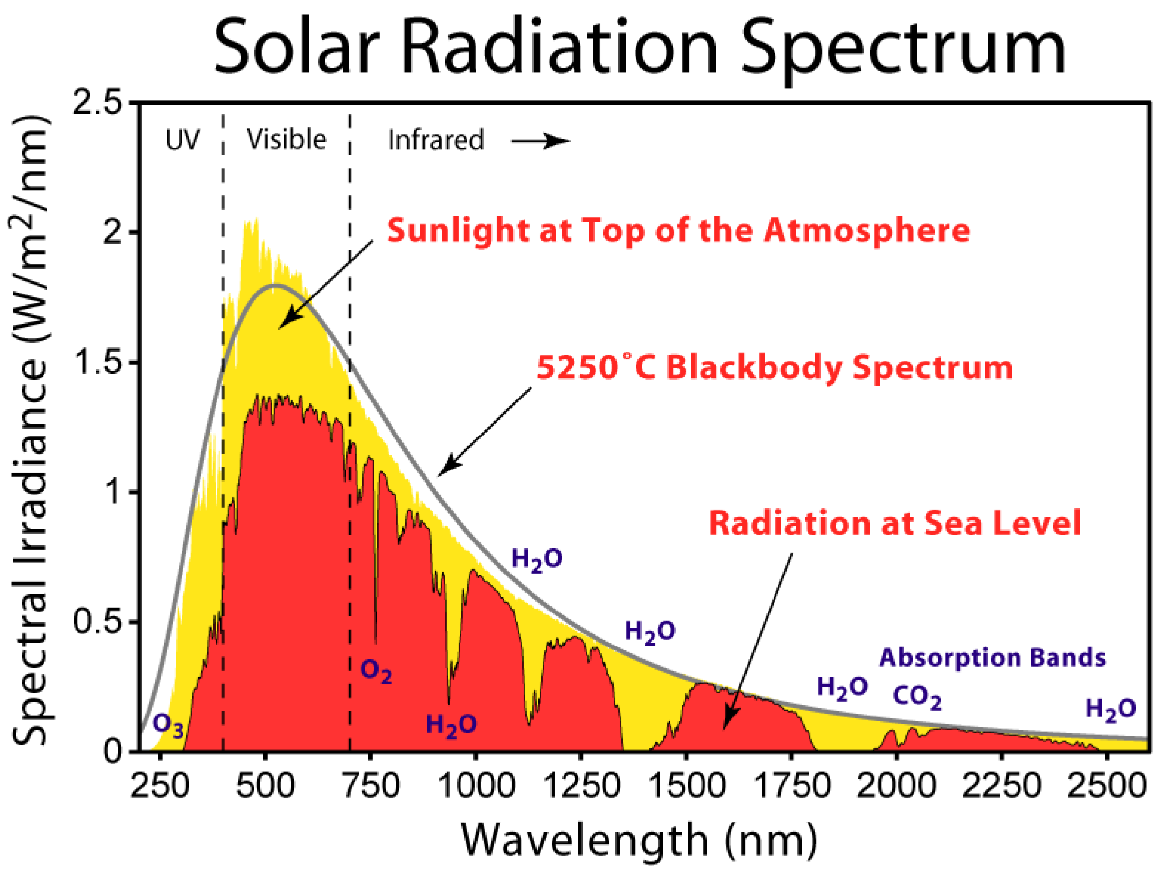


Figure 2.1: Solar radiation spectrum

Source: Quaschning (2005)

Given the amount of energy radiated by the sun and the Earth-sun distance varying from 1.47 x 10"m and 1.52 x 10"m, throughout the year, the amount of radiation often referred to as global insolation or total solar radiation and the energy this is measured in W/m^2.

2.1.2.1 Direct Solar Radiation

Direct solar radiation is the solar radiation directly from the sun without having been scattered by the atmosphere. This radiation comes from the direction of the sun and casts strong shadows of objects in its path. It is sometimes referred to as beam radiation on clear days, direct radiation accounts for a greater portion of the total solar radiation (Duffie et al., 1980).

2.1.2.2 Diffuse Solar Radiation

This is the solar radiation received from the sun after its direction has been changed by scattering by atmosphere. This radiation usually has no defined direction. On very cloudy days, the total solar radiation is almost entirely diffuse. Diffuse radiation is also referred to us sky or solar sky radiation (Duffie et al., 1980).

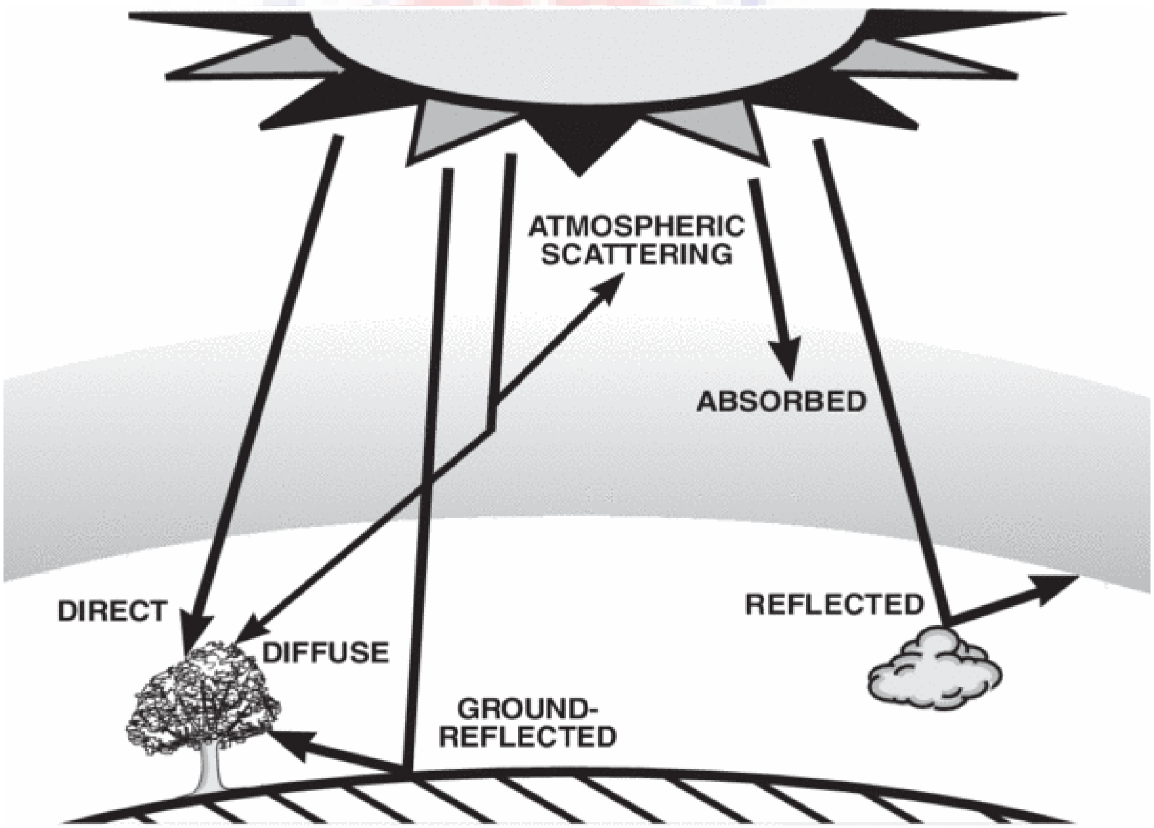


Figure 2.2: Illustration of Direct and Diffuse Radiation

Duffie et al., (1980)

2.1.2.3 Daily and Seasonal Variations of Solar Radiation

Solar radiation is largely affected by the angle of incidence; the angle at which the sun rays strike the earth surface (such that the intensity is higher when the sun is directly overhead at 90° from the horizon and reduces as the angle above the horizon reduces). This angle of incidence is affected by the location on the earth's surface (i.e. equator, northern hemisphere and southern hemisphere), the rotation of the earth on its axis and the orbital motion of the earth about the sun (Pidwirny et al., 2006).

The rotation of the earth on its axis cause day and night for all locations on the earth's surface. However, the length of the day varies for every location except the equator, which experiences equal lengths of day and night on every day of the year. Locations worth of the equator experience longer days during the summer solstice whereas locations south of the equator experience longer days in the winter solstice seasonal variation in day length is also affected by increasing latitude. These variation are caused by the movement at the earth in its elliptical orbit about the sun. These variations also explain why areas around the equator have higher solar irradiance values than those in the northern and southern hemispheres (Pidwirny et al., 2006).

2.1.2.4 Orientation and Inclination of Surface

The amount of solar radiation reaching a solar device depends on the angle of incidence at which the solar radiation hits the surface of the device. This angle is affected by the orientation as well as the inclination of the solar device.

The orientation defines the direction in which the panel faces, in terms of north, south, east or west. As a rule of thumb, solar collectors (in the northern hemisphere must be oriented southward and inclined at a certain angle to be able to absorb the maximum amount of solar radiation reaching its surface and those in the southern hemisphere must also be oriented northward. The azimuth angle specifies how many degrees the surface of the solar device diverges from the exact south-facing direction (Solar, Server, 2010).

The inclination on the other, defines the position of the solar device with respect to the horizontal. The angle of inclination describes the divergence of the solar device from the horizontal. The orientation and inclination, when properly set for a particular location, enables solar collectors to receive the maximum amount of solar radiation reaching the surface (Solar Server, 2010).

2.1.3 Solar Energy Applications

There are two major applications of solar energy:

- Solar thermal energy systems
- Solar photovoltaic systems

Solar photovoltaic systems are systems that convert sunlight directly to electricity. They are usually made of semiconductor materials such as silicon. Solar thermal systems on the other hand collect thermal energy in solar radiation and use it at high, medium or low temperature for various application using different technologies. These technologies can be classified into the following groups based on their working temperature:

- Low-temperature technologies (working temperature < 70°C) examples include; solar space heating, solar pound, solar water heating and solar crop drying.
- Medium – temperature technologies (70°C < working Temperature <200°C) examples include; solar distillation, solar cooling and solar cooking.
- High-temperature technologies (working temperature > 200°C) examples include; solar thermal power generation technologies such as parabolic trough, solar tower (central receiver system) and parabolic dish (Asif et al, 2007).

The main focus of this project, however, is in grid-connected solar photovoltaic power systems.

2.2 Solar Photovoltaic Systems

Photovoltaic systems are solar energy systems, which convert sunlight directly to electricity. The major component in PV systems is the solar panel which is formed by putting together several PV cells. Several modules form arrays and several arrays form a panel. Solar PV cells can be used for a wide range of power applications ranging from a few milliwatts in wrist watches and scientific calculators to several megawatts in central power stations. Solar cells are usually made of semiconductors materials such as silicon, gallium arsenide, cadmium telluride or copper indium dieseline.

2.2.1 Types of Solar Cells

Solar cells come in two major forms based on the nature of the material used in the production. The two main forms are crystalline solar cells and thin film solar cells.

Silicon is the most important materials in crystalline solar cells and also happens to be the second most abundant element on Earth. It is, however, not present in pure form, but in chemical compounds, with oxygen in the form of silicon dioxide (quarter or sand). This is taken through a series of chemical processes under varying conditions of temperature and pressure to form silicon waters, which are then turn into solar cells. Crystalline solar cells, so far, have the highest conversion efficiencies when it comes to photovoltaic cells.

The main types are monocrystalline and polycrystalline cells. Monocrystalline are the most efficient with efficiency ranging between 15.18% whiles polycrystalline cells have efficiency ranging from 13.16% (DGS, 2008).

Thin-film solar cells, on the other hand are manufactured by applying thin layers of semiconductor materials to a solid backing material. The composition of a typical thin-flim cell is shown in Figure 2.3. Although less efficient than crystalline silicon, thin-film solar cells offer greater promise for large-scale power generation because of ease of mass-production and lower materials cost. The commonest example of thin-film cells is the amorphous silicon cell with efficiency ranging between 5.7%.

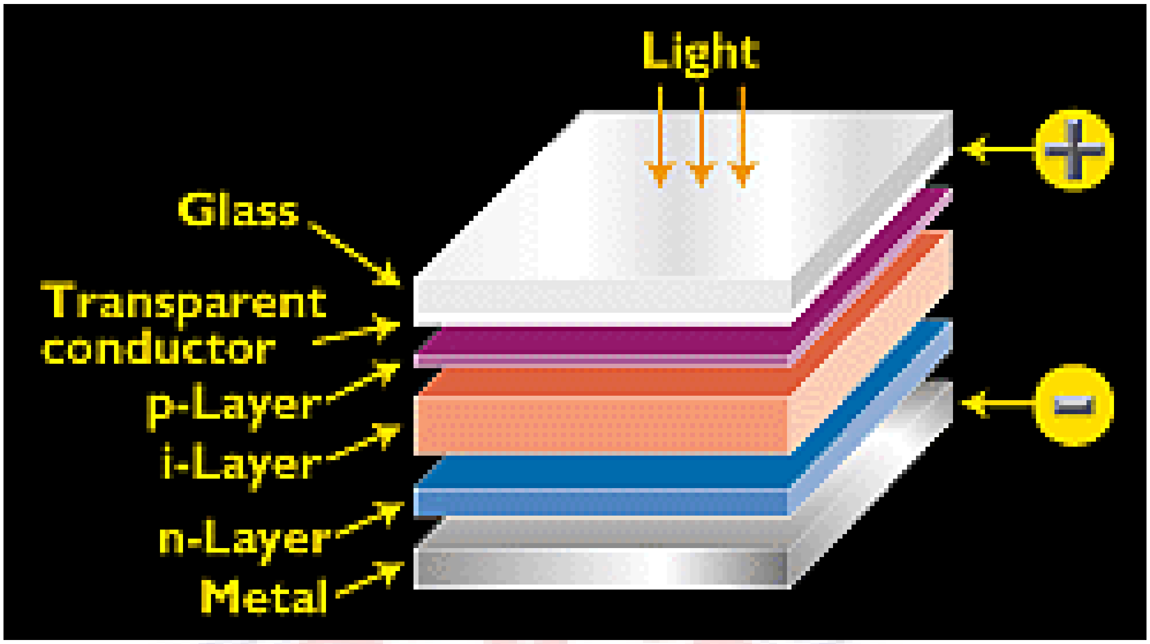


Figure 2.3: Typical thin-film amorphous silicon construction

2.2.2 Types of Photovoltaic System

Photovoltaic systems can be grouped under two main headings; namely grid-connected systems and off-grid systems.

2.2.2.1 Grid-Connected PV Systems

Grid-connected systems are system connected to an independent grid usually the public electricity grid and feeds electricity into the grid. These systems are usually employed in decentralized grid-connected PV applications and central grid-connected PV applications.

Decentralized grid-connected PV applications include rooftop solar PV generators (where the solar PV systems are mounted on rooftops of buildings) and building integrated system (where the PV systems are incorporated into the building).

In the case of residential or building mounted grid connected PV systems, the electricity demand of the building is met by the solar PV system and the excess is fed into the grid. Their capacities are usually in the lower kilowatts range (DGS. 2008). Central grid-connected PV applications have capacities ranging from the higher kilowatts to the megawatt range.

A typical grid-connected PV system comprises the following components:

- **Solar PV Modules**: These convert sunlight directly to electricity.
- **Inverter**: Converts the DC current generated by the solar PV modules to AC current for the utility grid.
- Main disconnect/isolator switch
- Utility grid

2.2.2.2 Off-Grid Systems

Off-grid PV systems are systems that are not connected to the public electricity grid. These systems require energy storage devices for the energy generated is not usually required at the same time as it is generated. They are mostly used in areas where it is not possible to install an electricity supply from the main electricity grid, or where electricity grid extension is not cost-effective or desirable. They are therefore preferable for developing countries where vast areas are still frequently not supplied by an electrical grid. Off-grid systems are usually employed in the following applications; consumer applications such as watches and scientific calculators, industrial applications such as telecommunications and traffic signs and remote habitations such as solar home systems and water pumping applications (DGS, 2008).

A typical off-grid system comprises the following main components:

- **Solar PV Modules**: These convert sunlight directing to electricity.
- **Charge Controllers**: Manage the charging and discharging of the batteries in order to maximize their lifetimes and minimize operational problems.
- **Battery or Battery Bank**: Stores the energy generated by the PV modules
- **Inverter**: Converts the DC current generated by the solar PV modules to AC current for AC consumer load.

2.3 Developments in the Solar Photovoltaic Industry

Solar PV is currently the fastest power generation technology in the world with about 15,000MW capacity installed in the year 2010 (EPIA et al., 2011). In all, the total installed capacity of solar PV systems is close to 40,000MW, with Europe alone contributing about 70% of this amount and North America, Japan, China and Australia following in that order. Grid-connected systems make up the majority of these figures and this is as a result of favorable incentives such as feed-in tariff schemes, tax rebates and investment subsidies available to the industry (EPIA et al., 2011: REN 21, 2011).

The solar PV industry has also seen tremendous improvement in efficiencies for the various technologies available on commercial scale. This improvement in technology and the continuous growth of the PV markers has led to drastic reduction in the cost of solar PV systems (EPIA et al., 2011).

2.3.1 Grid-Connected Solar PV in Developed Countries

The development of the global grid-connected PV systems market has largely been driven by the developed countries with Germany, Italy, Japan, USA and Spain among the top five countries with total installed capacities ranging from 24.7 GW in the case of Germany to 4.2GW in the case of Spain (EPIA et al, 2011).

In the year 2011 alone, about 27.7 GW of installed grid-connected solar PV systems were added. The developed countries alone contributed about 90% of the total capacity added as can be seen in Figure 2.4.

2.3.2 Grid-Connected Solar PV in Developing Countries

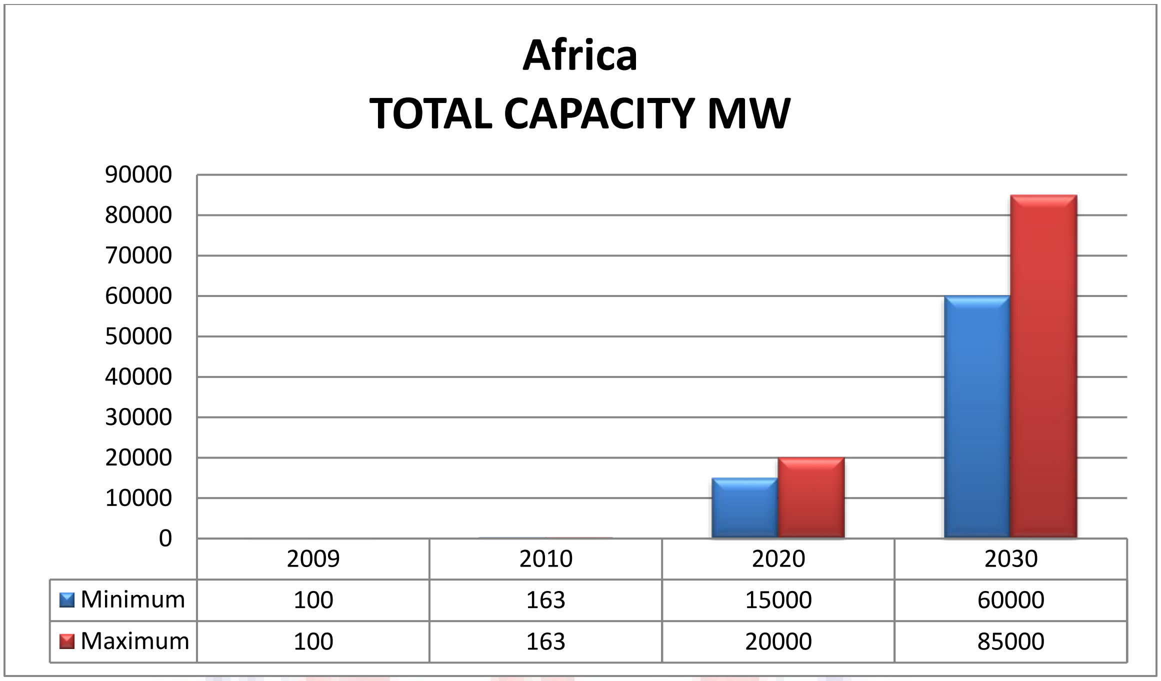
The developing world, most of which lie within the Sunbelt Region of the globe, offers a huge potential market for solar photovoltaic (PV) systems. The primary market for solar PV systems in developing countries has been off-grid applications such as solar home systems (SHS), mostly employed in rural electrification projects.

It is however important to note that a far larger market in developing countries is expected to emerge for grid-connected solar PV systems, which currently are not cost-competitive with other power generation sources such as hydro and thermal power.

In spite of the huge market potential for solar PV systems in developing countries, the successes of PV manufacturers and dealers to date have been few with most solar PV sales in the developing world made possible through donor-funded procurement programs, which provide the solar PV systems on a concessional basis to users with very little sales made directly to end-users. Currently, very few PV manufacturers or dealers provide financing to users or work with private lending institutions to do so and this has also contributed in the very small numbers in terms of solar PV deployment in developing countries.

Figure 2.4 reveals that, the rest of the world (most of which are developing countries) contributed only about 6% of the newly installed capacity of solar PV systems in the world in the year 2010.

(EPIA et al, 2011) currently, developing countries are contributing only about 6GW out of a total installed capacity of about 67GW in the world (EPIA et al, 2011). Africa as a continent contributed less than 1% of the world's total installed solar PV systems with an installed capacity of 163MW as at the end of 2010 (EPIA et al, 2011) as can be seen in Figure 2.5. This is as a result of the lack of instruments that help promote renewable energy technologies in general. Grid-connected solar PV systems are not that popular in Africa since most solar PV applications are employed in off-grid rural electrification prospects to rural communities (for lighting, educational and health applications) that are far from the national grid (EPIA et al, 2011). Presently, Cape Verde can boast of the largest grid-connected solar PV system capacity adding about 7.5MW of grid-connected solar PV systems by the end of the year 2011.



	2009	2010	2020	2030
Minimum	100	163	15000	60000
Maximum	100	163	20000	85000

Figure 2.4: Total installed capacity of grid-connected solar PV in Africa

The effect at promoting grid-connected solar PV systems in Ghana is spearheaded by the energy commission of Ghana.

CHAPTER THREE

GRID-CONNECTED SOLAR PV DESIGN

The planning of a grid-connected solar site assessment; which includes solar resources assessment for the area consideration, assessment of the possible grid connection points as well as requirements for grid connection and assessment of roof properties such as type, area, pitch/slope and the strength of the roof.

Shading analysis to determine the extent of shading on the building. Consideration was carried out, before finally selecting the most suitable roof design of the PV system.

Selection of solar PV system components modules and inverters was done using manufactures catalogue from based international solar system dealers. These provided some basic information about the area and weight of the panels as well as their electricity output systems. They also provided information about the input as well as output specifics and inverters, which was helpful in designing the layout of the system.

3.1 Site Assessment

The project site for this study is the University of Education Winneba Kumasi campus. U E W-K was chosen because, it is one of the colleges of technology in Ghana and as such can help enhance further study and research into grid connected solar PV system in the country.

The Ghana Grid Company limited specified in the Ghana grid code, the main requirements for the connection of an electricity generation source to the grid to be in the area of the voltage and frequency. Other requirement includes the power quality of the electricity delivered to the grid and the safety of grid maintenance personnel (GRIDCO, undated). Electricity distribution from the substations to the various building on the U E W-K campus is done by 3-phase alternating current (AC) of 41Sv/50Hz and as such the electricity to be fed into this same grid should be 3-phase alternating current (ac) of 41sv and frequency of 50hz with a+0-2Hz degree of freedom and normal deviation of electric time ranging from + 10 seconds to + 60 seconds as specified in the Ghana grid code (GRIDCO, undated). The power quality also takes into account the harmonies of the sinusoidal ac wave, the power factor, and also voltage flickers; therefore the inverters used in grid-connected PV systems must have the potential of controlling these parameters within the acceptable limits. It is important to note that, current inverter technologies come with mechanisms that are able to address power quality problems.

Like any source of electricity, solar PV systems are potentially dangerous to both people and property, and much attention has been given to finding ways to reduce these inherent safety risks. The main safety concern is about the safety of grid maintenance personnel during maintenance works on the grid. This is due to islanding, a situation where a portion of the utility grid that contains both load and generation source is isolated for the remainder of the utility grid but remains energized due to the presence of a generation source on that part of the grid (Collinson et al., 1999). The 500kw grid-connected to the U E W-K network through any of the transformer substations around the campus or at the main electricity intake point.

3.1.1 Solar Resources Assessment

There are two main sources of data for solar radiation at the surface of the earth ground measurement and calculations based on satellites data. Direct measurements of the solar radiation at ground level can be done with a number of different instruments including the pyrometer which is the most widely used solar radiation measuring device. The instrument measures all the radiation coming from the sun and from the sky or clouds at a specific location. Ground station measurements give the best results.

In the calculations based on satellites are used to measure the light (visible or infrared) coming from the earth, which is mainly the light reflected from the ground or from clouds. The calculation of the solar radiation at ground level must therefore be able to take atmosphere as well as that reflected by clouds.

The solar radiation data used for this study was from the solar and wind resources assessment (SWERA) report for Ghana. This data is from actual ground measurements of solar radiation measuring device. This data was however compared to some satellite data from NASA the American space agency and also PVGIS-helioclium developed by the joint research center of the European commission and is shown in figure 3.4. The comparison of solar radiation data reveals that, satellite solar radiation data (in the case of NASA) are much higher than actual data from ground measurements (SWERA).

The daily horizontal solar irradiance for Kumasi (UEW-K) used for this study was 4.30 kwh/m^3/day based on radiation data in the SWERA database.

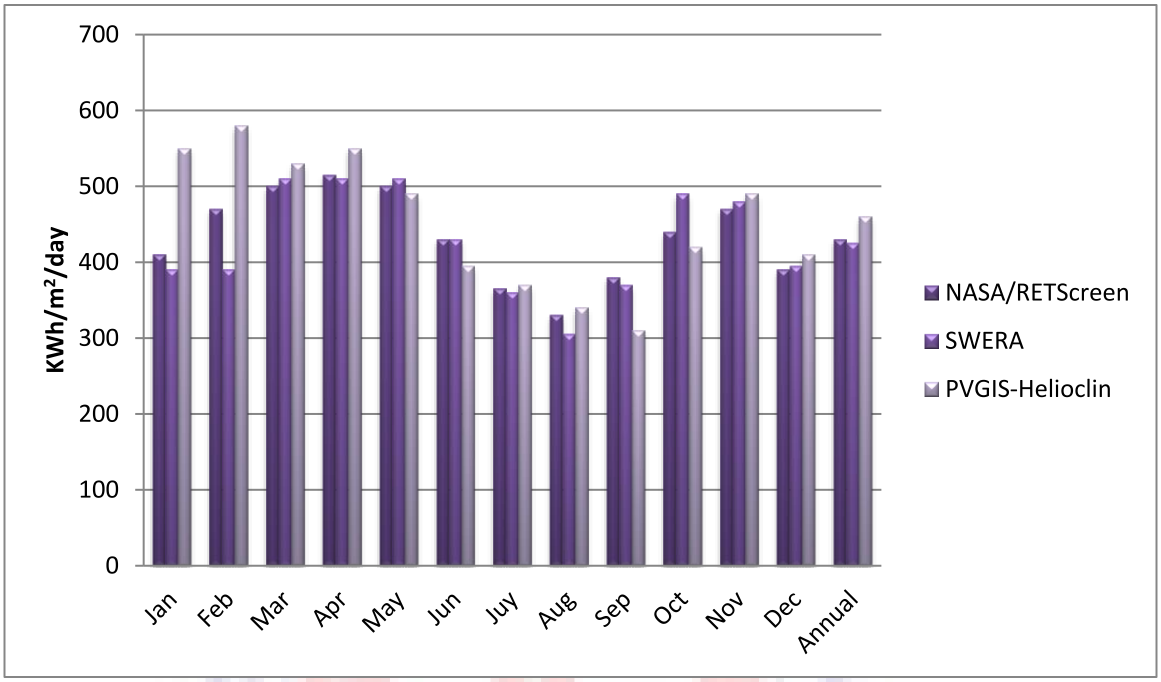


Figure 3.1: Comparison of solar radiation data from 3 different sources

The amount of solar radiation on the surface of a solar device depends on the orientation and inclination of the device. For every location, there is an optimum orientation and inclination which would enable a solar radiation device to receive maximum amount of solar radiation. It is always best to orients the solar device to face south at an optimum angle of inclination for locations in the northern hemisphere and vice versa. However, for roof mounted systems, the maximum amount of radiation is limited by the properties of the roof such as pitch/slope and orientation which cannot be changed. Gable and hipped roofs in U E W-K have slopes estimated to be about 15^0. Figure 3.5 shows the PV System simulation results for solar radiation at the different orientations (south, north, east and west) for a 15^0 angle of inclination and also for flat roofs. The figure shows that south facing roofs receive more solar radiation annually followed by east/west facing roofs, flat roofs and then north facing roofs.

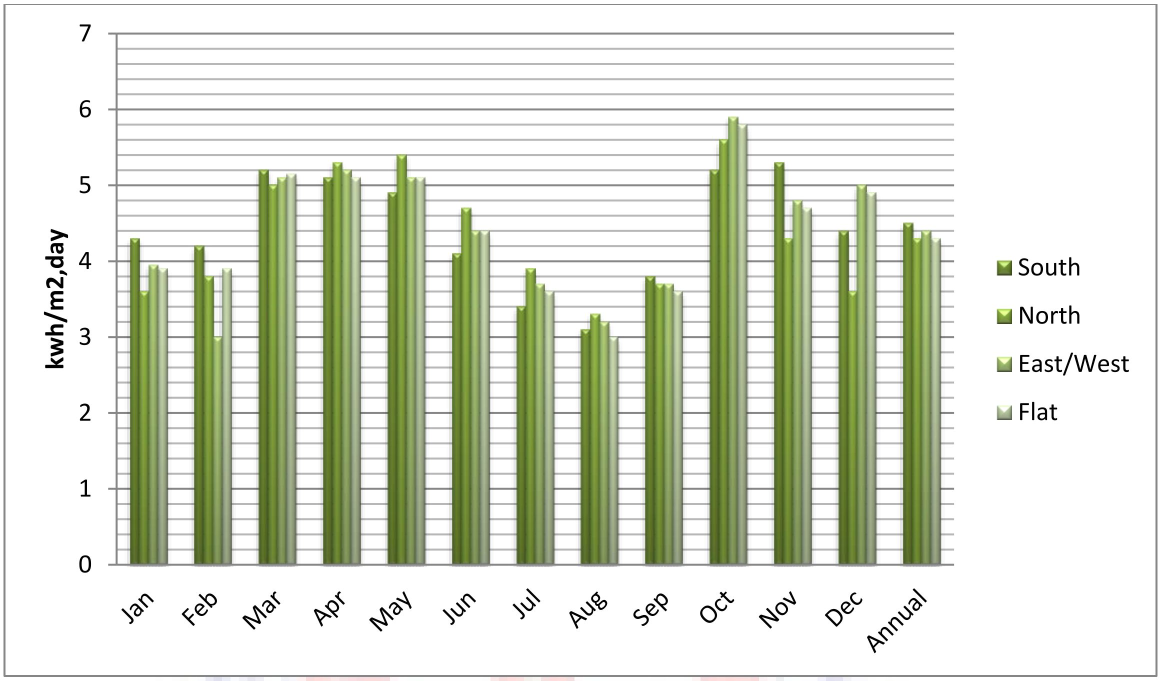


Figure 3.2: Solar radiation for different roof orientation including flat roofs.

3.2 Assessment of Roof Properties

The assessment of roof properties such as roof type, orientation and pitch, area, structural strength and the effects of shading on the roof is important because it helps one to know whether or not the roof will be suitable for the installation of grid-connected systems, in terms of carrying the weight of the solar PV system and also the amount of energy that can be generated from system installed on it. In all, fifty (50) buildings were assessed including academic/faculty buildings, non-academic administrative buildings, halls/hostels of residence on the campus. The study however did not take into consideration of uncompleted buildings as well as partly complete buildings.

3.2.1 Roof Type Assessment

There are seven (7) conventional types of roofs, namely; Flat, Gable, Hipped, Shed Mansard, Gambrel and Arch-shaped roofs as shown in figure 3.6 (Scharff et al., 2001). Roofs on the UEW-K campus was grouped under four (4) of the categories mentioned based on the shape of the roof. The three categories are Flat, Gable, Hipped and Arch-shaped roofs.

Gable roofs are the commonest type of roofs on the UEW-K campus, making up about 75% of the total number of roofs on the campus. A Gable roof has two upward sloping sides that meet in the middle at the ridge as shown in Figure 3.6. To be a true gable roof, both sides of the roof must slope at the same angle. Viewed from the end, the shape of a gable roof appears as a symmetrical triangle.

Flat roofs on the other hand make up 14% of the total roofs and are mostly found on the hall of residence and TL block. Flat roofs, as the name implies, are usually made flat but often given a slight slope of about 5° to enable rainwater to run-off the roof.

Hipped roofs accounted for only 5% of the building and are mostly found on the New Auditorium and Autonomy Hall on campus Hipped roof has many similarities to a gable roof but has four sloping surface instead of two. The intersection between the various surfaces is referred to as a hip (Scharff et al., 2001). Arch-Shaped roofs cover about 6% of buildings considered and are found on the New Hall complex.

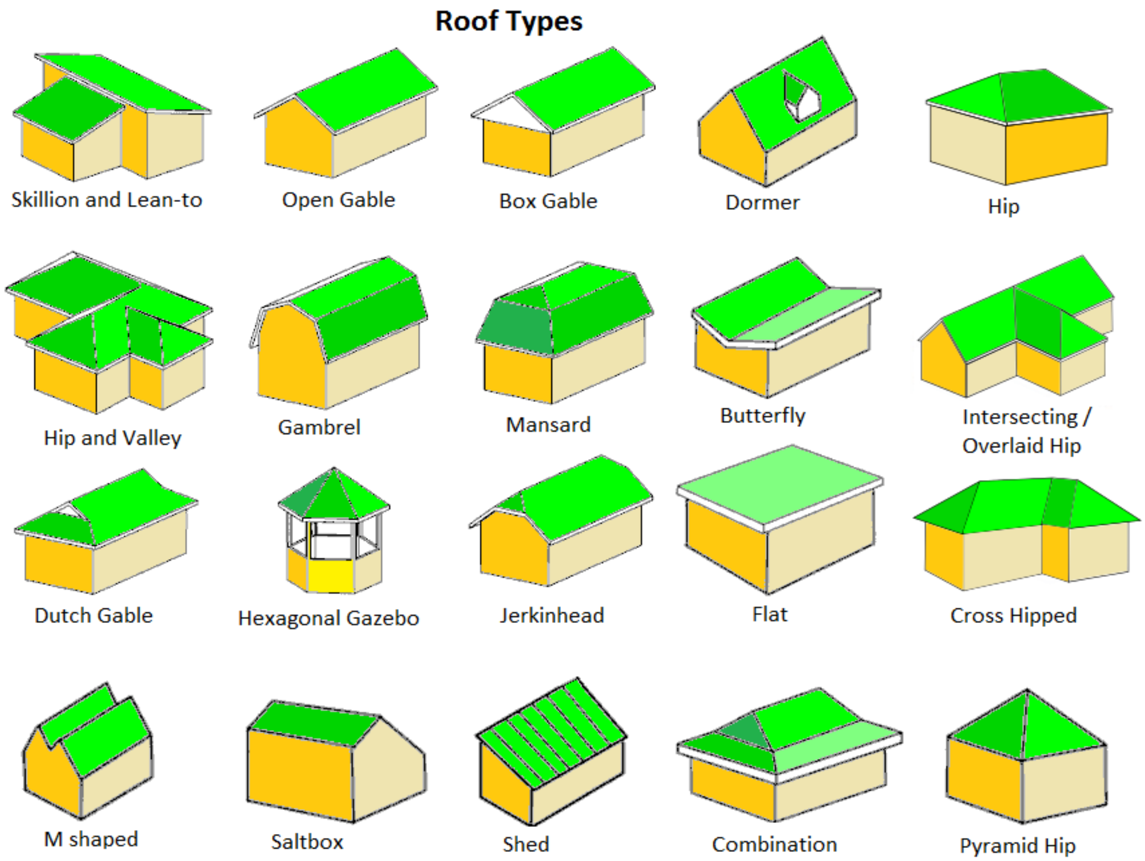


Figure 3.3: Types of roofs

Sources: Scharff et al., (2001)

3.2.2 Roof Area Assessment

The Europeans photovoltaic industry association (EPIA) estimates the total area required for the installation of solar PV system to range between $7m^2$/kwp and $15m^2$/kwp depending on the technology being used (EPIA et al 2011). Estimating the area of roofs for PV installations can be a very difficult task, particularly when the actual building drawings are not available and this is a very common phenomenon in Ghana. In the absence of building drawings as was experienced during this study, the roof area were estimated with the help of Google Earth, an internet based software package which shows the actual location of the building and also provide a tool to measure the ground area covered by the estimated ground area is therefore multiplied by the cosine of the roof slope to get the actual roof area. For the purpose of this work, a roof slope of 15 degrees (which is estimated to be the average slope of most of the roofs on the campus) was used. Multiplying the actual ground area covered by the buildings with the cosine of the roof slope increases the actual roof area by less than 4% as a result, it was ignored. The estimated roof area was assumed to be equal to the ground area covered by the building. In all, there is about 31.277m^2 roof areas available; 8.186m^2 facing north, 8.186m^2 facing south, 5.495m^2 facing east, 5.495m^2 facing west and 3.915m^2 flat and arch-shaped roofs.

3.2.3 Assessment of Orientation and Pitch/Slope of Roof

The orientation of a roof surface refers the direction in which the roof faces, i.e., north, south, east or west whereas the roof pitch/slope refers to the angle of inclination of the roof to the horizontal. Apart from the flat and arch-shaped roofs which are not oriented in any particular direction, the gable roofs have roof orientation in either the north-south or the east-west direction. Out of the total area of roofs considered, 26% have north-south orientation 15% in the east-west orientation and 12% have flat roofs. The gable and hipped roofs which have slopes pitches around 15°.

3.2.4 Roof Strength Assessment

The main function of roofs among other things is to protect buildings from adverse weather conditions such as storms; as such it is designed to withstand a certain amount of load caused by severe weather conditions. The strength of roofs is maintained dependent in the properties of the materials used in constructing the frame of roof as well as the roofing materials. Most of frames on the UEW-K campus are made from timber, in the case of smaller buildings, and steel, in larger buildings; all the building assessed have roof frames made of wood except the following Buildings, Autonomy, New Auditorium, New Hall, Faculty block, which have roof frames made of steel. The commonest roofing materials found on the roofs assessed are aluminum roofing sheets, concrete and asbestos roofing tiles, the latter (which is no longer in use because of its associated health risks) can only be found on the old auditorium.

For the purpose of this study, the method used to assess the strength of the existing roofs included an assessment of the roofing frame. The weight of the solar PV system is also considered in this assessment. The 2006 international building code specifies the maximum design load for ordinary flat and gable roofs as $960N/m^2$ (International Code Council, 2006). However, the average weight of solar PV systems together with accompanying mounting structures is about $150N/m^2$, which is clearly below the maximum design load for ordinary flat and gable roofs. Therefore the very old buildings with asbestos roofs, all the other building roofs were considered suitable for solar PV installations.

Possibility of shading of roofs shading analysis is one of the most essential steps in solar energy system design. In photovoltaic it is important to analyze shading caused by surrounding objects and vegetation since it can reduce the module output by as much as 50% depending on the type of solar cells: with thin film technologies having more tolerance for shading than crystalline silicon cell (Lenardic, 2011).

Shading analysis can be done in three main ways; using basic calculations involving some simple geometric equations, shading analyzer or sun path diagram on acetate and computer software packages. Shading analysis for this work was done through a visual inspection of the various buildings at different times of the day and the possibility of shading assessed based on the results of physical observations out of a total of about fifty (50) building considered, only two buildings showed signs of possible shading of their roofs either by neighbouring vegetation of other buildings and these include the Opoku Ware (II) old block and Atwima Hall.

3.2.5 Selection of Suitable Roofs

The selection of suitable roofs for grid-connected solar PV installations was done based on the following criteria, roof area, roof surface orientation and the possibility of shading from neighbouring buildings, vegetation or other obstacles.

In this work, large south-facing roofs devoid of shading of any sort from neighbouring buildings and other obstacles were preferred over others because they will not only house a larger number of installations but will also generate the maximum amount of electricity. An initial visibility study suggested that a total of about 31.277m^2 of roof area will be required to mount the 50KW grid-connected solar PV system. The roof assessment revealed that there is a total of about 8.186m^2 facing north, 8.186m^2 facing south, 5.495m^2 facing east 5.49m^2 facing west and 3.915m^2 flat and arch-shaped roofs available. In total, the amount of roof space available for solar PV installations is about 21.849m^2. out of these, south facing roofs are preferred because they receive the highest amount of solar radiation for the location followed by flat roofs, east/west facing roofs and north facing roofs in that order.

3.3 Selection of PV System Components

Grid connected solar PV system are usually made up of the following components; solar PV modules, inverters and other accessories including cables and metering devices. The selection on these components can be done with the help of catalogue from both local and international dealers.

3.3.1 Solar PV Module Selection

There are three main types of solar PV modules available on the market commercially. These include monocrystalline, polycrystalline and amorphous silicon modules.

Table 3.1 gives a comparison of the three module types in terms of efficiency, area/KWp and cost/Wp^2. The three main common modules available commercially were selected including monocrystalline, polycrystalline and amorphous silicon modules from schott solar were selected after which the results were compared.

Table 3.1: Comparison of PV module types

Module Type	**Efficiency (%)**	**Area/KWp (m^2)**	
Monocrystalline	13 – 19	7	2
Polycrystalline	11 – 15	8	246
Amorphous silicon	4 – 8	15	262

Source: EPIA et al., 2011 and Energiebau Sunergy Ghana Ltd.

Schott Solar modules (Schott Mono 190, Schott PROJECT Poly 185, Schott Asi 100) were selected because they have high efficiencies, can work better under high temperature conditions and were also recommended by Energiebau Sunergy Ghana Ltd, the leading installer of grid-connected solar PV systems in Ghana.

The mono-si module selected for this work is Schott Mono 190 with the following specifications:

Nominal power 190W voltage at Nominal Power (Vmpp) 36.4W

Efficiency (ŋ) 14.1% current at Nominal Power (Impp) 5.22 A

Area (A) 1.31m2 open circuit Voltage (V_{3c}) 45.111V

Cell type Mono-si No. of cells 72

The poly-si module selected for this work is Scholf PROJECT Poly 185 with the following specifications.

Nominal Power	185W	Voltage at Nominal Power (Vmpp)	23
Efficiency (ŋ)	13.9%	Current at Nominal Power (Impp)	7.8
Area (A)	1.34m2	Open current voltage (Voc)	29
Cell type	Poly-si	No. of cells	48

The A-si module selected for this work is Schott AS1 100 with the following specifications;

Nominal power	100W	voltage at Nominal power (Vmpp)	30.7V
Efficiency (ŋ)	6.9%	current at Nominal power (1mpp)	3.15A
Area (A)	1.45m2	open circuit voltage (V_{Bc})	40.9V
Cell type	a-si	No. of cells	24

3.3.2 Grid-Tie Inverter

Inverter selection for grid-connected solar PV systems is a very important step because of the role the inverter plays in the whole system; as the main connecter to the utility grid. It is important that the inverter output parameters fall within the grid operators' specifications. The following criteria were considered for the selection of inverters for this work.

- The output alternating current of the inverter must be a three phase AC current with a voltage of 415V at 50Hz to facilitate synchronization with the grid.
- The inverter capacity must be selected to match the capacity of the PV array usually the same as the PV array capacity. The input DC voltage of the inverter must be the same as the array output voltage.
- The inverter efficiency at full load should be above 95% to minimize losses.
- An in-built maximum power point tracker (MPPT) is important to maximize the power output of the PV array.
- An in-built utility fault protection feature should also be included to protect the system.

Based on the set of criteria listed above various capacities of sunny central and sunny Tripower inverts from SMA Technology were selected. These inverters are 3-phase and come with inbuilt maximum power point tracker (MPPT) and have maximum efficiency of about 95% and 98.2% for sunny central and sunny Tripower respectively.

Sunny central inverters come in capacities of 60KW, 90KW, 100KW and 125KW whiles the sunny Tripower inverters come in capacities of 8KW, 10KW, 12KW, 15KW and

17KW (SMA, 2010), since the array capacities would require a combination of inverters, a metlab algorithm was developed to do this combination.

3.3.3 Auxiliary Components

The components classified under this group include cables, metering devices: alternating current (AC) and direct current (DC) disconnect switches and the mounting structures for the PV system.

Cables are required for the connection of the various components together to form a system. The type of cables to be used depends on the type of current (either AC or DC) that flows through the system. DC cables will be required for the interconnections between the various modules and also the connection of the PV array to the DC input end of the inverter. The connection from the AC output end of the inverter to the utility grid requires the use of AC cables. The sizes of the cables depend on the length of cable required and also the amount of current which would flow through them.

Metering devices are important in the system because they help to measure the amount of energy injected into the grid. For the purpose of this project, a 3 – phase meter is required since the electricity generated is converted from DC to 3 – phase before injection into the grid. The specifics of each meter were selected based on the exact specification of the system such as the current flowing through the system.

AC and DC disconnect switches are required to enable isolation of the various components from the main system for maintenance.

Mounting structures help secure the PV arrays to the roofs of the buildings on which they are mounted. They are usually made of aluminum (the common material for the manufacture of mounting structures by most solar installers) since it is light weight, strong, and resistant to corrosion. The means of fastening these mounting structures to the roofs however, depends on the roof frame as well as the roof materials.

3.4 System Layout Design

The configuration of the various components in a grid-connect solar PV system can be done in four different ways, namely AC module, string, multi-string and centralized systems; based on the way the PV arrays are connected to the inverts. These configurations can be seen in the Figure 3.8 (Kjaer et al., 2005).

In the AC module configuration, one large PV cell is connected to an inverter case, the selected inverter should be able to amplify the very low voltage of the PV array for the grid whiles maintaining a high efficiency of conversion. This configuration is mostly suitable for smaller home systems and therefore would not be appropriate for larger systems since it increases the number of inverters required and in turn increase the total investment (Kjaer et al., 2005).

The string configuration involves the connection of single strings of PV modules inverters. A string is a grouping of modules wired in series to increase the voltage of the system. Most modern solar electric systems operate at 48 volts nominal and high-voltage grid tied system can use up to 600 volts meanwhile the modules available have voltages of 12 – and 24 volts. This therefore requires joining together modules to attain this higher voltage before connecting to an inverter and subsequently to the grid (Kjaer et al, 2005).

The multi-string inverter is a further development of the string inverter where several string are interfaced with their own DC – DC converters and subsequently connected to a common inverter. The advantage of this system is that, each string can be controlled individually without disrupting the operations of the whole array and also provides room for new strings to be added to the system. It is also less expensive compared to the string and the AC module configurations because the number of inverters used reduces (Kjaer et al., 2005).

Centralized system configuration involve dividing the PV modules into series connections (strings). With each generating a sufficiently high voltage to avoid further amplification. These strings are then connected in parallel, through string diodes, in order to obtain high power levels. This configuration, though cheaper than the others, comes with some very serious limitations including high-voltage DC cables between the PV modules and the inverter power losses due to a centralized MPPT, mismatch losses between PV modules, losses in the string diodes and a non-flexible design which is a disadvantage to mass production (Kjaer et al., 2005).

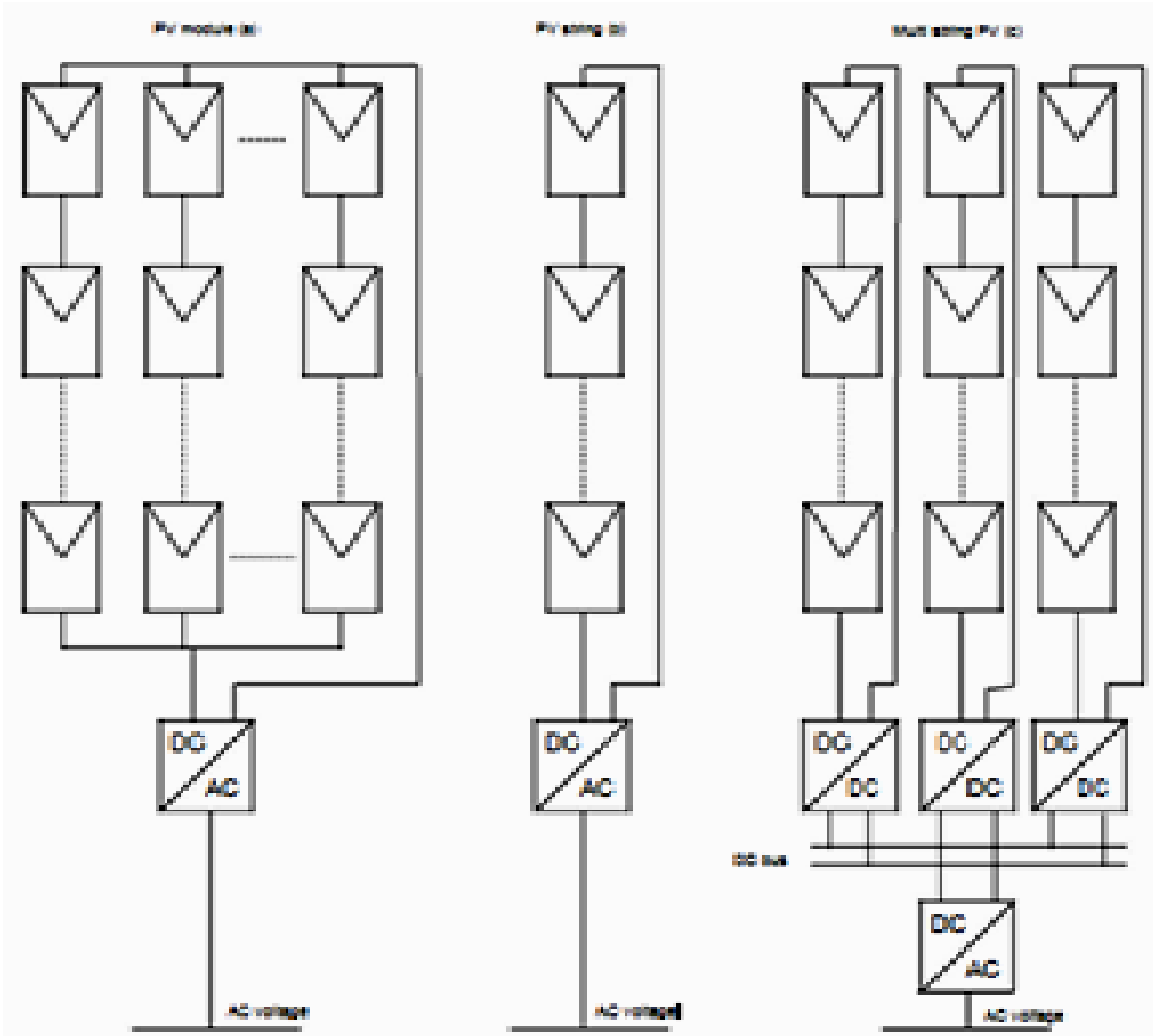


Figure 3.4: The electrical layout of the different system

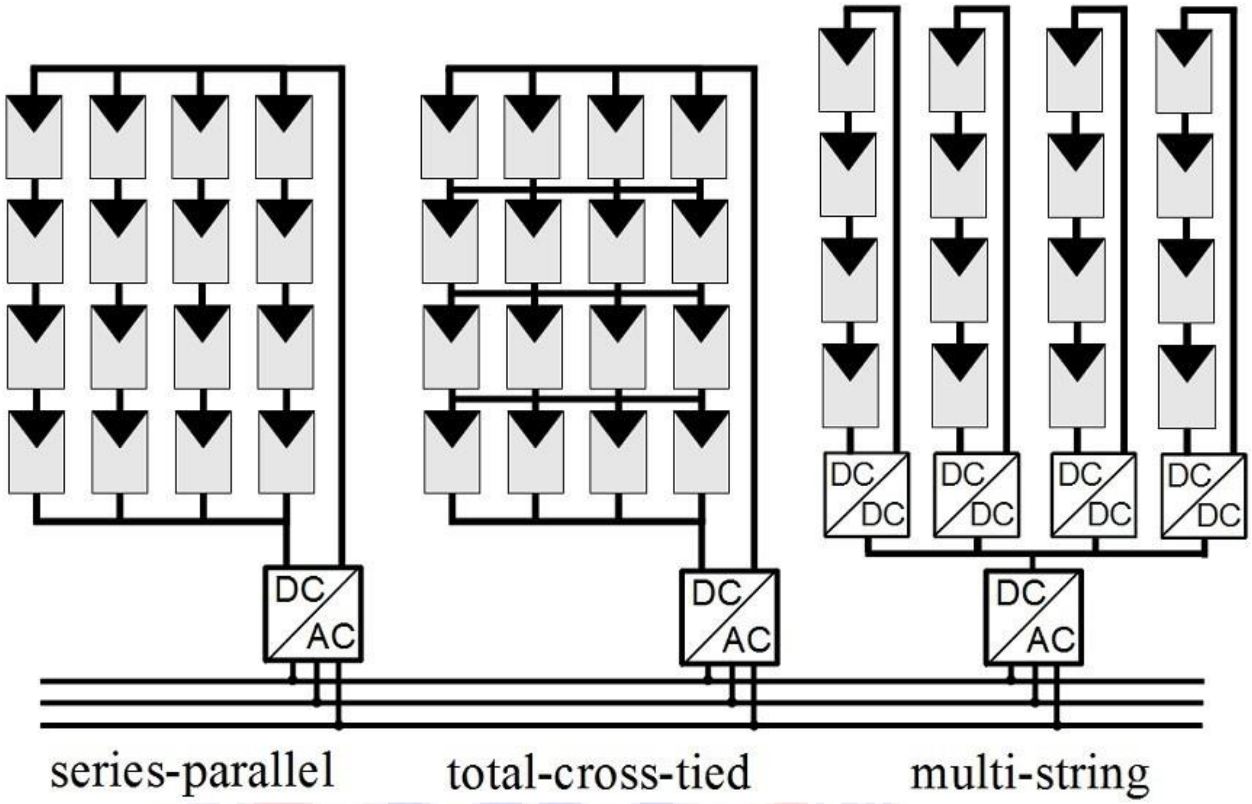


Figure 3.5: Types of PV array-inverter configurations

Source: Kjaer et al., (2005)

3.4.1 Design of 500KW Grid Connected Solar PV System

Design of the 500KW grid connected solar PV system was carried out for the three main solar PV technologies; monocrystalline, polycrystalline and amorphous silicon modules. These were installed on roofs inclined at an angle of about 15 degrees to the horizontal. The system is also made up of module numbers ranging between 2, 632 and 5000 depending on the chosen technology. It is expected that the system require a total area ranging between 3453m^2 and 7,247m^2 depending on the solar PV module technology chosen. Each module has area between 1, 31m^2 and 1, 45m^2 depending on the type of module used.

Sixty (60) 3 – phase inverters with capacities ranging from 5KW to 100KW (depending on the size of the PV array) was used to convert the DC electricity from the PV modules to AC to be fed into the electricity grid. Table 3.2 presents a summary of the design specifications.

Table 3.2: Summary of design specifications

Module type	Mono – si	Poly – si	A – si
Module capacity	190W	185W	100W
Total array capacity	500KW	500KW	500KW
Area required	3, 453m^2	3, 624m^2	7, 247m^2
No. of modules	2, 632	2, 702	5000
No of inverters	30	30	30

3.4.2 Layout of System

The layout selected for the system configuration; several strings of PV modules were connected to a single inverter. This help to minimize the total investment cost whiles maintain high system efficiency as well as increase flexibility in the Operation of the system. In this design, each building was classified as a subsystem with each subsystem comprising of several string connected to series of inverters and subsequently to the grid.

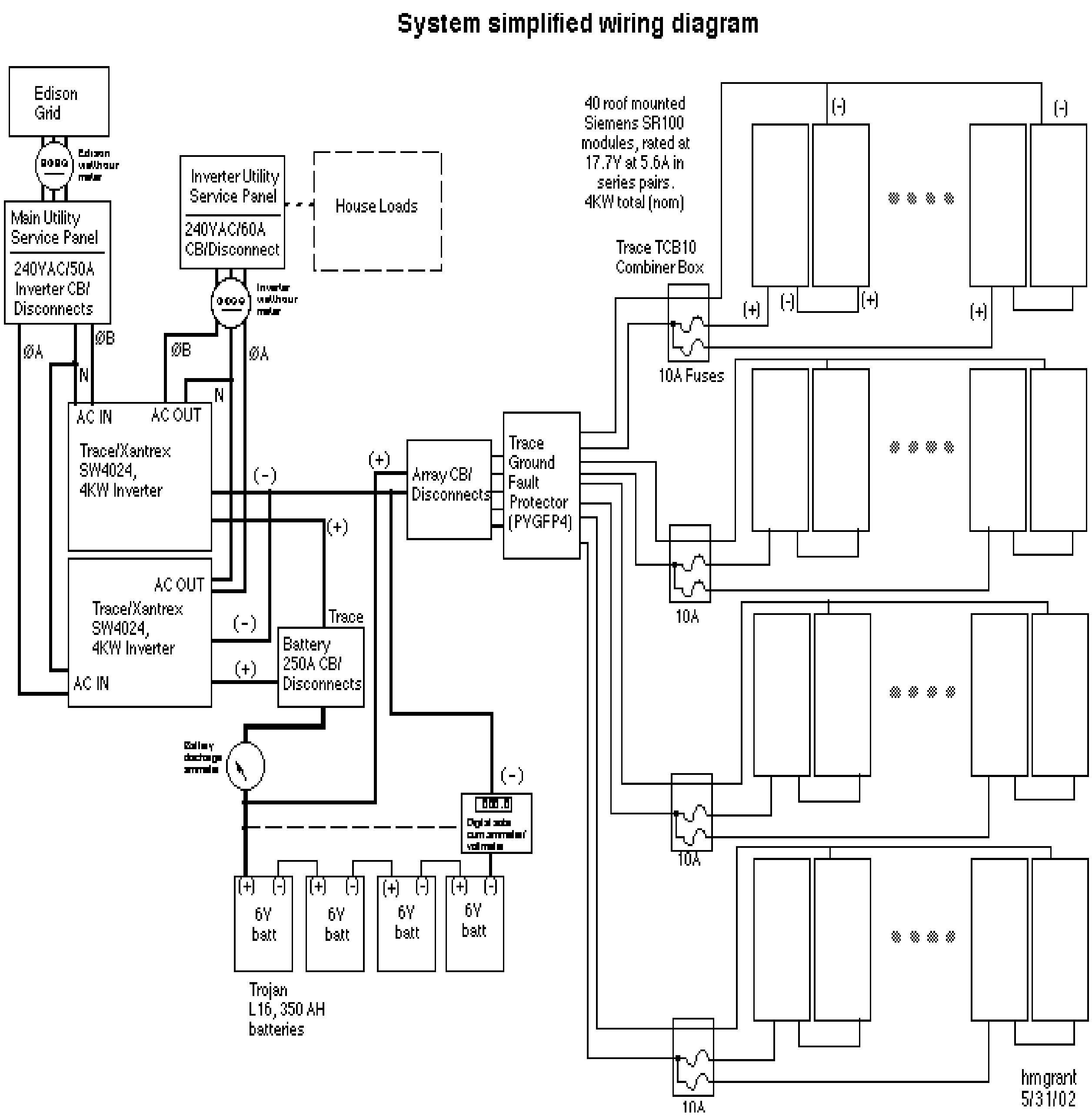


Figure 3.6: System simplified wiring diagram

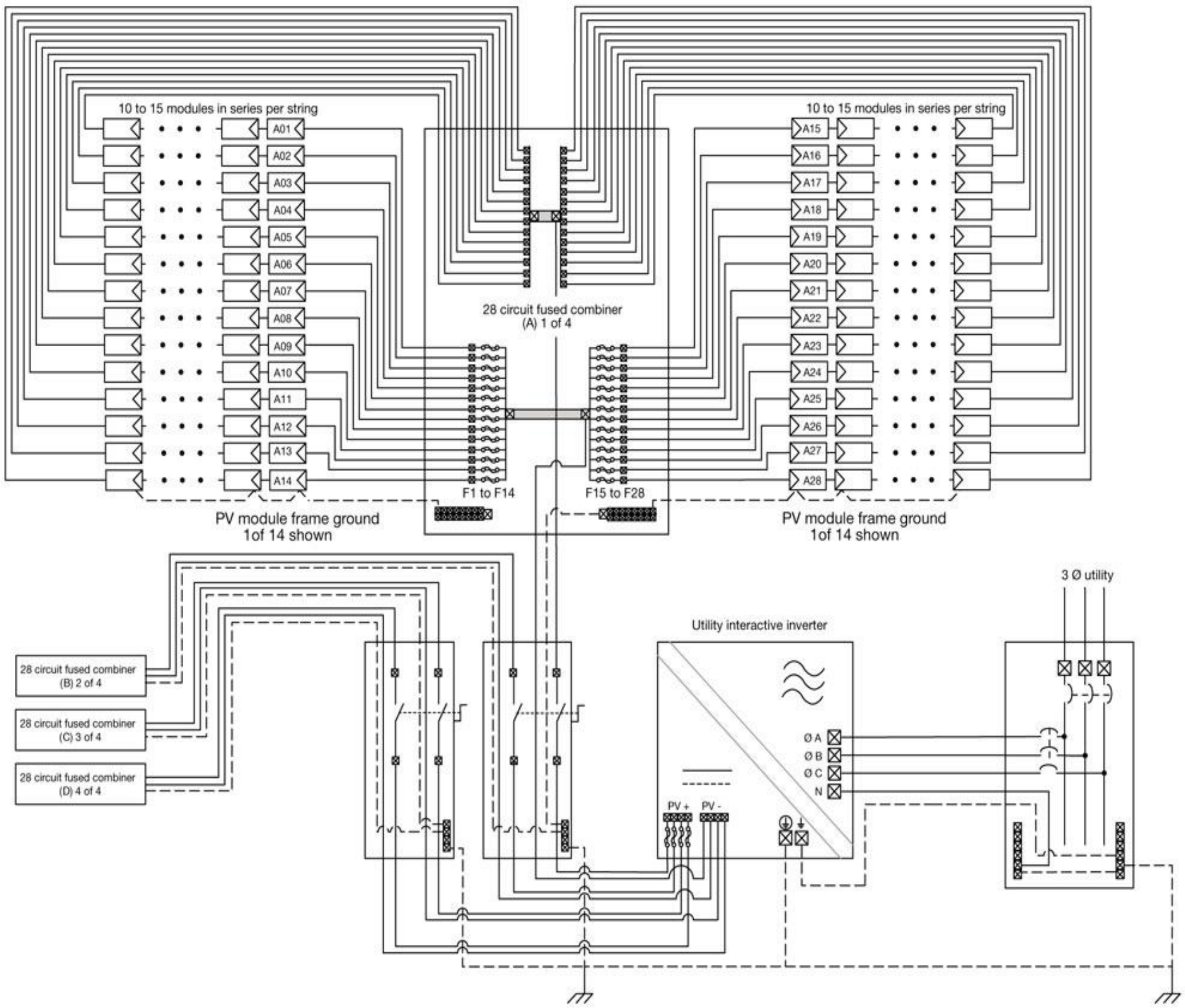


Figure 3.7: Three-line wiring diagram for a 250 kW commercial PV system with a single 3-phase inverter

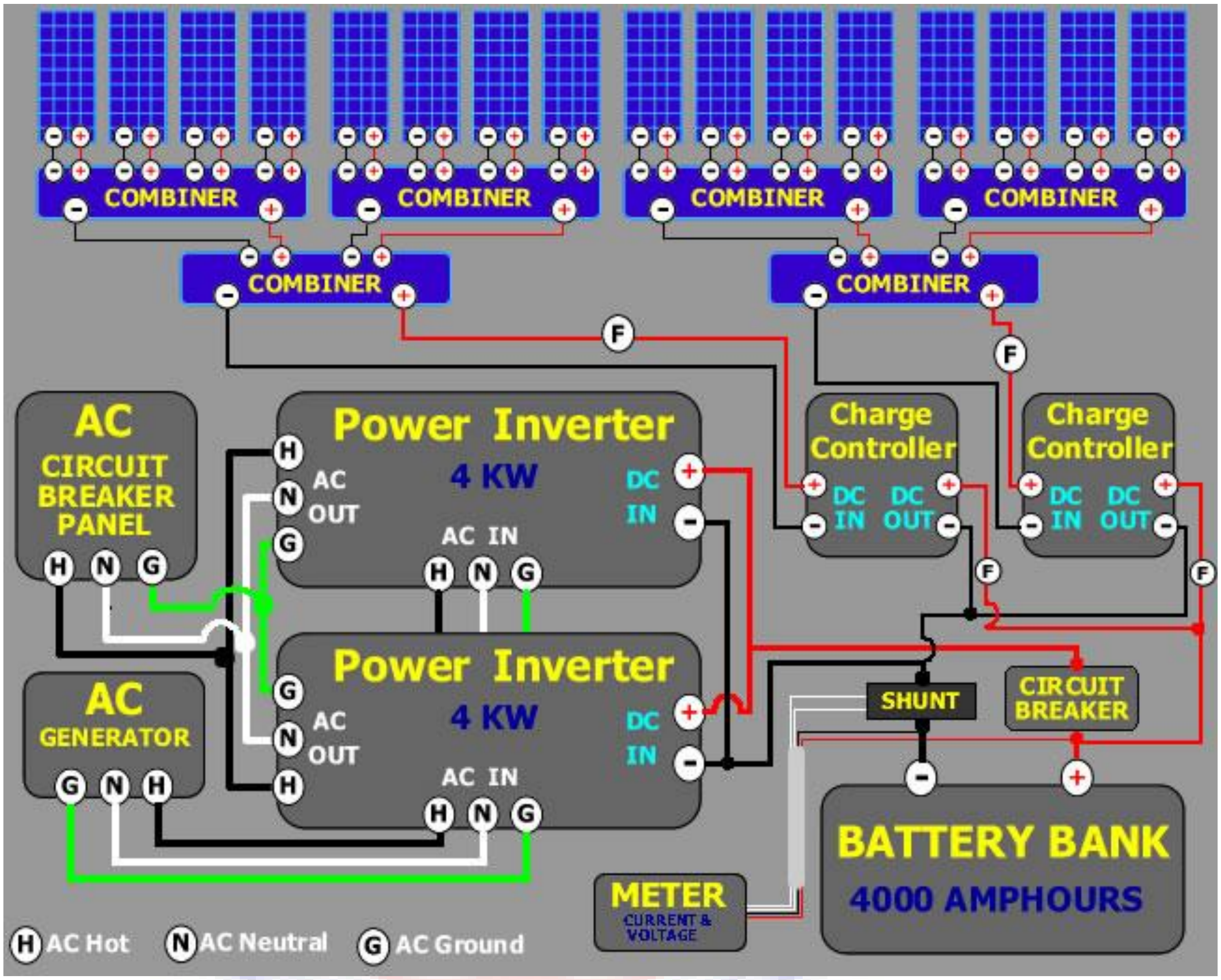


Figure 3.8: 8KW wiring diagram

CHAPTER FOUR

ANALYSIS AND DISCUSSION OF RESULTS

The preliminary studies of the 500KW Grid-connected solar PV system in Kumasi was carried out to analyse the technical performance of the system based on the results the PV system computer software simulation. PV system developed by the Group of Energy of the Institute for the Sciences of the Environment of the University of Geneva in Switzerland was used.

The economic analysis on the other hand was carried out to determine the cost and intended benefits of the project. This section also looks at the various financial options and their implications on the project. RET screen clean energy project analysis software was used for this simulation because it has strong financial modeling capabilities.

4.1 Technical Analysis

The International Energy Agency (IEA) photovoltaic power systems program describes, in its IEC standard 61724, parameters used to assess the performance of solar PV systems (Marion et al., 2005). These performance parameters are used to define the system performance with respect to the energy production, solar resource, and the overall effect of system losses.

These parameters include final PV system yield, reference yield, and performance ratio. The capacity factor of the system was also considered among the key parameters so that the system can be compared with other electricity generation sources in the country. These performance criteria were assessed for all three systems i.e. monocrystalline silicon, polycrystalline silicon and the amorphous silicon systems and the results compared. This assessment was done with the help of PV system software package which has an extensive database of meteorological data for different locations but can also take whether data specified by the user (SWERA data in this case), system components and their specifications from manufacturers and can simulate the performance of the PV system, taking into consideration the possible losses the system would suffer. More information on the software can be obtained from the developer's website.

4.1.1 Total Energy Yield

The total energy yield is the total amount of electricity that is injected into the utility grid by the 500KWp grid connected solar PV system.

The 500KWp amorphous silicon system is capable of injecting 1.299KWh of electricity into the utility grid annually as compared to 1,206KWh and 1, 197KWh by the monocrystalline silicon and polycrystalline silicon modules respectively. This is due to the fact that amorphous silicon suffers fewer losses as compared to monocrystalline and polycrystalline as explained in section 4.1.6 of this report. The results presented graphically in figure 4.1 show that, the months of March and October (both in the dry season of Ghana) record the highest electricity generation and the month of August recording the lowest amount of electricity generation for all three module types matching quite well the load curve presented earlier in Figure 3.1 monthly average electricity generation by the 500KW grid-connected solar PV system will be able to make up for about 10% of UEW-K's monthly electricity consumption.

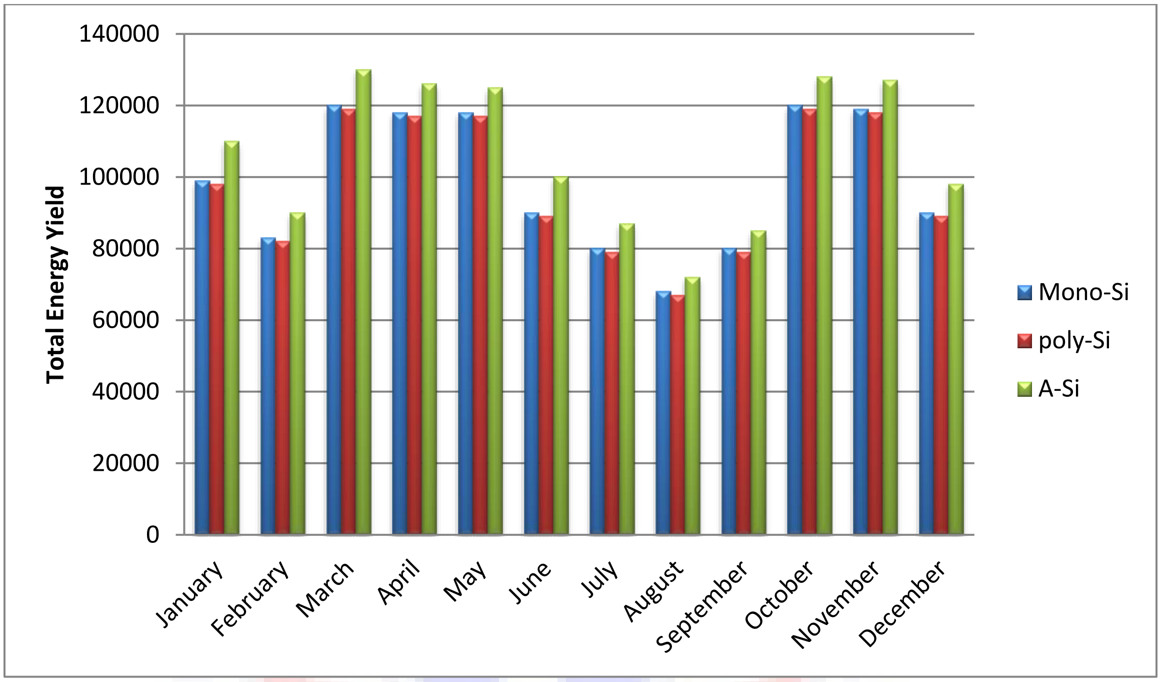


Figure 4.1: Total energy yield

4.1.2 Reference Yield

The reference yield, Yu is the ratio of the daily total irradiance reaching the surface of the PV array (in-plane irradiance) in KWh/m^2 to the PV array's reference irradiance (which is 1,000W/m2 for standard Testing Conditions) (Marion et al., 2005). It represents the number of daily peak sun-hours or an equivalent number of hours at the reference irradiance in a day, its units is hours. The reference yield also defines the amount of solar radiation available to a particular installation at a particular location and is a function of the location, orientation of the PV array, and weather variability.

$$Yr = \frac{Daily\ total\ in{-}plane\ irradiance}{Reference\ Irradicance}$$

All three module technologies receives the same amount of solar radiation as of which they all have the same reference yield of 4.29 hours with the month of November and march recording values as high as 8.18 hours and 5.12 hours respectively. The month of august recorded the lowest yield of 2.94 hours, figure 4.2 shows the profile of the reference yield and compares it to the final PV system yield for the three module technologies under consideration.

4.1.3 Final PV Array Yield

The final PV system yield also referred to as the yield factor or specific yield, if is the ratio of the net energy output (total energy yield) to the nameplate DC power of the installed PV array (Marion et al, 2005), it represents the number of hours that the PV array would need to operate at its rated power and orientation in a given situation to provide the same amount of net energy output. The parameter helps to compare the energy outputs of PV systems of different sizes.

$$Yf = \frac{Net\ Energy\ Output}{Array\ DC\ Power}$$

It can be observed from the results in figure 4.2 below that for the same rated capacity of system, amorphous silicon yields more in terms of energy output than monocrystalline silicon and polycrystalline silicon because amorphous silicon experiences less losses compared to mono crystalline and polycrystalline as discussed in section 4.1.6. The average

PV system yield is 3.56kwh/KWp/day for amorphous silicon 3.31KWh/KWp/day for mono crystalline silicon and 3.28kwh/KWp/day for polycrystalline silicon. The months of November and March recorded the highest values of PV system yield whereas August recorded the lowest for all three module technologies. A comparison between the reference yield and the final PV system yield gives an indication of the losses suffered by the system. The differences between the reference yield and the final PV system yield is equal to the losses suffered by the three module technologies.

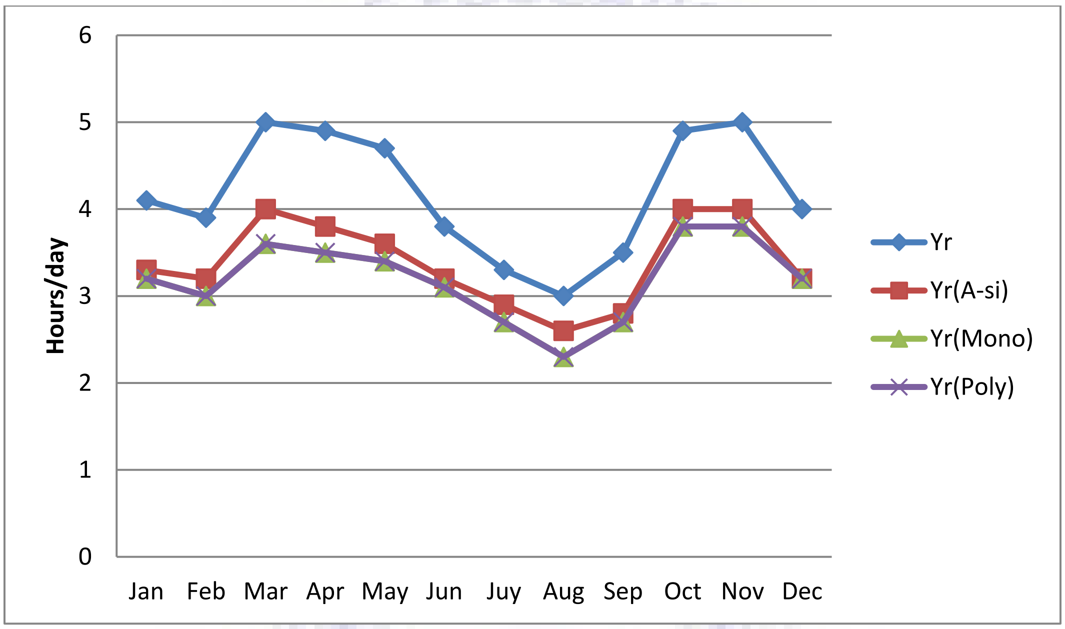


Figure 4.2: Comparison between reference yield and final yield

4.1.4 Performance Ratio

Performance ratio (PR) is defined as the ratio of the actual amount of PV energy delivered to the utility grid in a given period of time to the theoretical amount of energy7 generated by the PV modules under standard test conditions (STC) (Marion et al, 2005). It is also referred to as the ratio of the final PV system yield to the reference yield.

$$PR = \frac{Yf}{Yr}$$

The average performance ratio recorded for the module technologies being considered is 0.831, 0.772 and 0.766 for amorphous silicon, mono crystalline silicon and polycrystalline silicon respectively as presented graphically in figure 4.3.

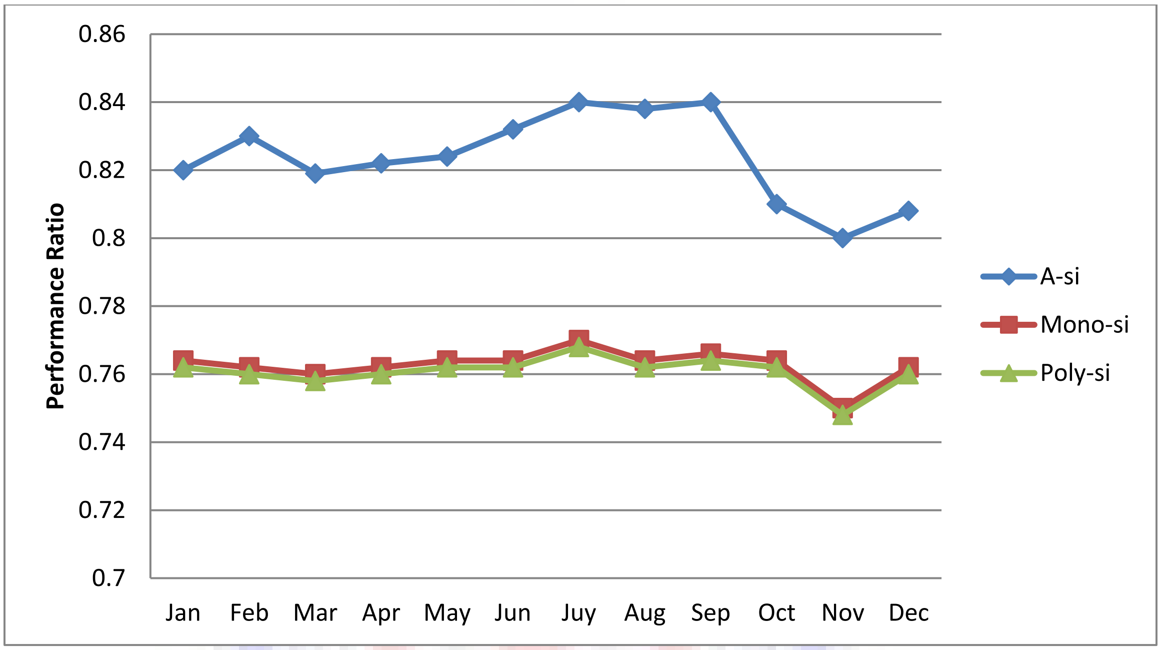


Figure 4.3: Average performance ratio for the system

4.1.5 Capacity Factor

The capacity factor of a power plant is the ratio of the actual output of a power plant over a period of time and its potential output it had operated at full nameplate capacity the entire time. Mathematically, capacity factor is the total amount of energy the plant would have produced at full capacity factors vary greatly depending on the type of fuel that is used and the design of the plant. It also provides a total for the comparison of the performance of different types of electricity generation plants.

$$Capacity\ Factor = \frac{Annual\ Energy\ Output}{Namelplate\ Capacity\ X\ No.of\ Days\ in\ a\ year\ X\ No.of\ Hours/Day}$$

The capacity factors are 14.8% for amorphous silicon, 13.8% for polycrystalline silicon. The graphic representation in figure 4.4 has a profile similar to that of the total energy yield presented in figure 4.1.

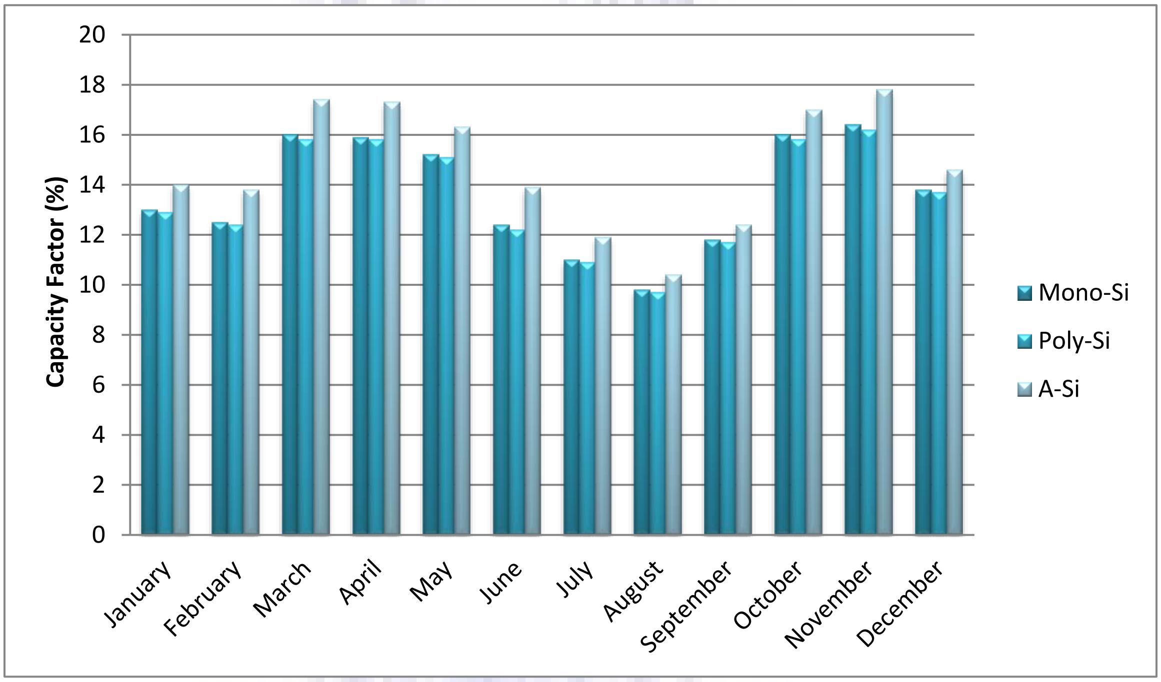


Figure 4.4: Capacity factor for the system

4.1.6 Losses

Losses suffered by grid-connected solar PV systems can be namely classified under two main headings, namely collection/array losses and system losses. Collection/array losses are associated with the collection and conversion of sunlight into DC electricity whereas system losses are associated with the conversion of DC electricity to A.C. electricity subsequent feeding into the grid (PV system, 2012).

The PV system simulation results showing the total losses suffered by each of the three module technologies presented in figure 4.5. The results show that, mono crystalline and polycrystalline modules operate with much higher losses than amorphous silicon modules specifically 11.779kwh/KWp/day and 12.067kwh/KWp/day for mono crystalline module and polycrystalline modules respectively as compared to 8.75kwh/KWp/day by amorphous silicon modules.

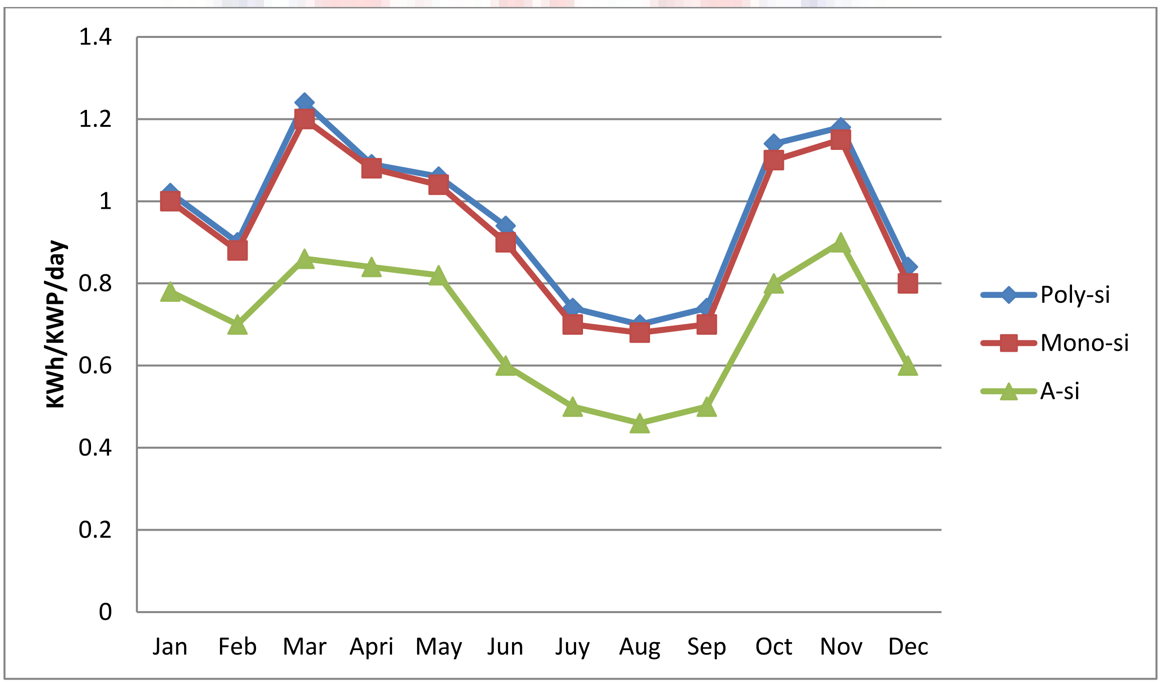


Figure 4.5: Total losses suffered by the three main PV module technologies

4.1.6.1 Collection/Array Losses

Collection/array losses are the losses associated with the collection of solar radiation and its conversion into electricity by solar panels. They include irradiance losses, incidence angle modifier (IAM) losses, thermal losses, module quality losses, module array mismatch losses and ohmic wiring loss. The incidence angle modifier (IAM) is an optical effect which corresponds to the weakening of the irradiation really reaching the PV cells surface, with respect to irradiation under normal incidence (PV syst.2012).

Thermal losses are the losses associated with the operation of the solar PV system under very high temperature conditions. The standard test conditions are specified for a cell temperature of 25^0c, but the modules usually work at higher temperatures hence the sources of this type of loss (PV syst.2012). The module quality losses are the losses due to the usage of the low quality material. It is typically around 0. 1% to 0.2% (PV syst.2012).

Losses due to "mismatch" are related to the fact that the real modules in the array do not rigorously present the same i/v characteristics as specified by manufacturers. Mismatch losses are the losses due to the varying tolerance level of the modules power capacities as specified by manufacturers (PV syst.2012). The wiring ohmic resistance induces losses (1^2R) between the power available from the modules and that at the characterized by just parameter R defined for the global array.

PV system simulation results reveal that, collection/array losses account for as high as 22.1% of the global horizontal irradiation available to the location of the PV systems. The comparison of the losses suffered by the three technologies presented in figure 4.6 show that amorphous silicon suffers much less collection/array losses than mono crystalline and polycrystalline modules. This is because the amorphous silicon modules have a lower temperature coefficient than monocrystalline and polycrystalline.

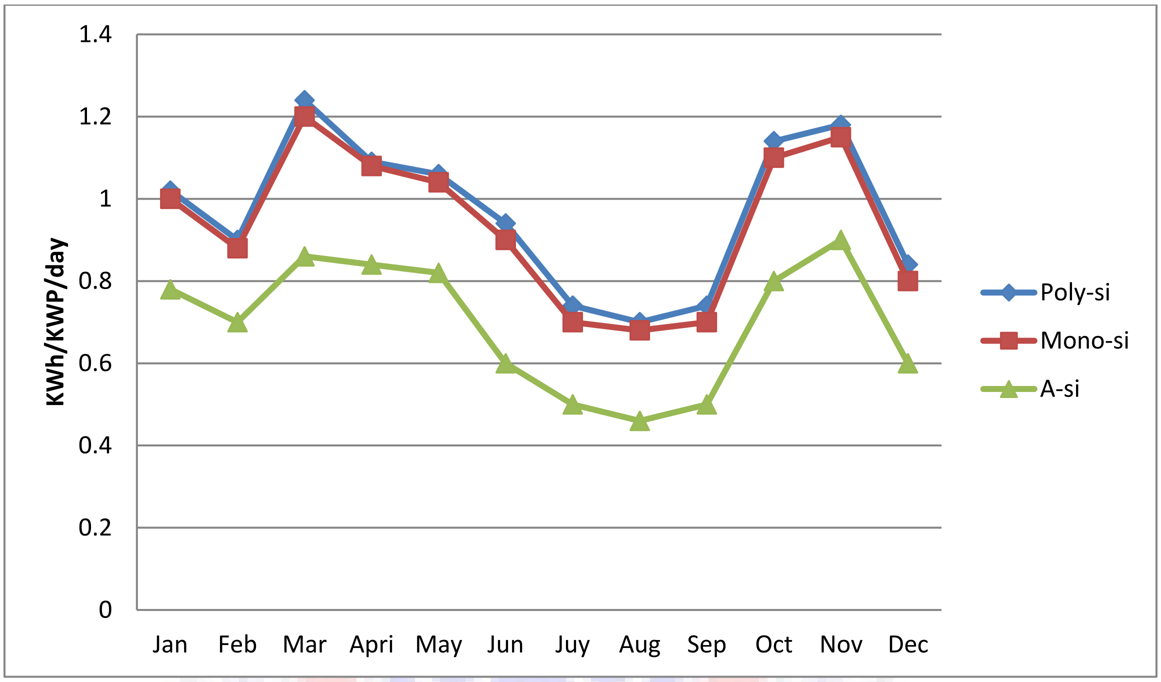


Figure 4.6: Collection losses for the system

4.1.6.2 System Losses

System losses on the other hand are associated with the conversion of the D.C produced by the solar modules to A.C by the inverters for feeding into the utility grid. They comprise of mainly of inverter losses. The system loss curves present in Figure 4.7 show that amorphous silicon cells suffer higher system losses/KWp for the same rated capacity than the other two technologies under consideration.

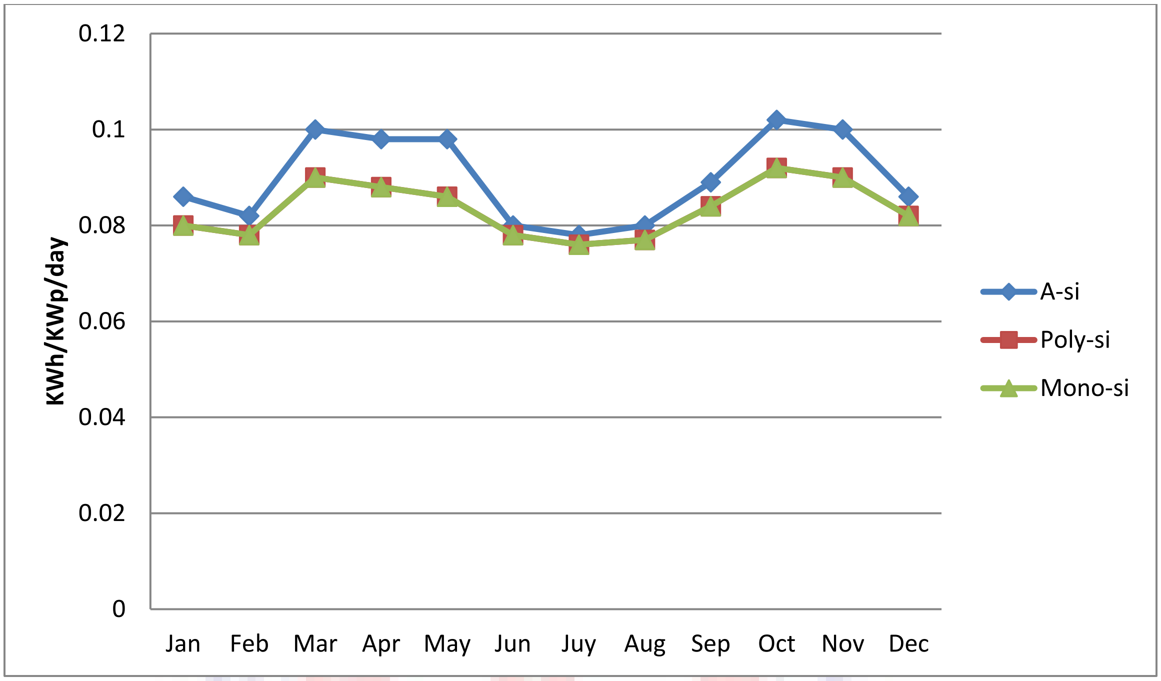


Figure 4.7: System Losses

The loss flow chart was generated through the PV system simulation and shows the details of the losses suffered by the three systems. A detailed comparison of the losses for the three systems show that the thermal loss for amorphous silicon is lower compared to monocrystalline silicon and polycrystalline silicon; an indication that amorphous silicon modules perform better than the other two under high temperature conditions.

4.2 Economic Analysis

The economic analysis in this work was carried out to assess the cost and intended benefits of the project. It was carried out with the help of RET screen software. The software has the capability of simulating some financial indicators such as net present value and simple payback period over the life of the project. RET screen also has the capability of simulating the technical performance as well as estimating the greenhouse gas saving potential of renewable energy projects over their entire operational life.

The analysis considers the total investment cost as well as the operation and maintenance cost of the system and matches it against the revenue generated from the sale of electricity to the utility grid. The main financial indicators used for this analysis are Net Present Value (NPV).

NPV is used in capital budgeting to analyze the profitability of an investment or a project. It is the difference between the present value of all revenues and the present value of all expenses, including savings, accrued during the life cycle of an investment. It is a standard method for long-term projects appraisal which takes into account the time value of money. It measures the excess or shortfall of cash flows, in present value terms, once financial charges are met. Net Present Value (NPV) is represented as

$$NPV = \sum_{t=0}^{N} \frac{Ct}{(1+r)}$$

Where Ct = Net cash flow (revenue + savings – expenses)

r = Discount rate

t = Period

N = Total number of periods

Net present value is an indicator of how much value is added to an investment under the specified conditions of discount rate, d, and the economic life time of the investment Ni positive NPV indicates the economic viability of an investment: the greater the value of the NPV, the more profitable the investment.

4.2.1 Total Investment, Operation and Maintenance Costs

The total investment cost comprises the following components: module, inverter, mounting structures, and installation. The cost of solar PV systems has reduced significantly over the years due to the massive improvement in the technology and also the economics of scale. For the purpose of this study, the cost of the solar PV system was taken from one of the leading solar PV installers in the country (Energiebau Sunergy Ghana) and the breakdown is presented in Table 4.1. The module cost alone accounts for about 53% of the total investment of US$ 4,450,00.

Table 4.1: Cost Breakdown for the Grid-Connected Solar PV System

Component	Cost ($/Wp)
Module	2.36
Inverter	0.51
Mounting structures	0.42
Accessories	0.24
Installation	0.92
Total	**4.45**

Grid-connected solar PV systems are globally considered as maintenance free system, mainly because of the very low level of maintenance carried out on the systems during their operational life compared to other electricity generation systems. The major maintenance works, however carried out on PV system are done on the inverters. For the purpose of this study, the operation and maintenance (O and N) costs for the systems is set at 5% of the capital cost as specified by the PURC draft feed-in-tariff policy and guidelines.

4.2.2 Financing Options and their Implications on Project Viability

The parliament of Ghana passed a Renewable Energy Act which has component for feed-in tariffs for electricity generated using renewable energy technologies (Ghana Parliament, 2011). This comes as a boost for investment in the renewable energy industry. The purpose of this section of the work is to look at the various financing options available to renewable energy investors and how they affect the viability of projects. This was done by first developing a business as used (BAU) scenario with the parameters below in the RET screen software package;

- ✓ Solar PV system cost = US$ 4.45/Wp
- ✓ Operating and Maintenance Cost = 5% of capital cost
- ✓ Project life = 25 years
- ✓ Discount Rate = 10%
- ✓ Inflation Rate = 0%
- ✓ Grant/Capital subsidy = 0%
- ✓ GHG Credit = US$ 0/tonne

Mother scenarios were developed, by varying the BAU parameters to analyse the impact feed-in tariffs (Fit), grants/subsidies, GHG income and reducing system. Cost would have on the viability of the project.

4.2.2.1 Feed-in Tariffs

This scenario presents the implications of various levels of feed-in tariffs, as a means of financing grid-connected solar PV projects, on the net present value of the project. The project is not viable yielding an NPV of about US$ 3, 000.000 at a feed-in tariff of US$ 0.11/KWh. The project however breaks even at a feed-in tariff of US$ 0.43/KWh, yielding positive NPV.

4.2.2.2 Grants and Capital Subsidies

Grants and capital subsidies unlike loans are not re payable and have served as incentives for the development of various renewable energy projects in Ghana. Ghana, currently, has a policy which allows importers of solar PV panels to do so without paying any duties on their imports. In addition to this, different levels of grants/capital subsidies when provided will encourage the development of grid-connected PV systems in the country by reducing the total investment cost of the system.

This scenario presents different levels of grants/subsidies and their effects on the net present value of the project. When a grant of 50% of the total investment cost is provided for the project, the project becomes viable at feed-in tariffs greater than US$ 0.23/KWh. On the other hand, when a grant is provided to cover 80% of the total investment cost, it takes a feed-in tariffs greater than US$ 0.11/KWh for the project to be viable.

4.2.2.3 Carbon Credit Financing

Grid-connected solar PV systems are globally regarded as carbon free during their operational life and as such are a very effective tool to help mitigate the effects of climate change. The 500KW grid-connected solar PV system designed in this project will save about 824 tonnes of Co_2 annually when compared to a thermal power plant generating the same amount of electricity but running on crude oil, which can be traded as specified by the Kyoto Protocol to bring additional revenue to the project. It is observed that GHG income doesn't affect the financial indicators much but then provides significant revenue to cater for the annual operation and maintenance cost of running the project.

4.2.2.4 Reducing PV System Cost

The cost of solar PV System has taken a downward turn over the past few years. The European Photovoltaic Industry Association (EPIA) believes this is as a result of technological innovation, production optimization, economies of scale, increasing the performance ratio of PV systems, extending the life of PV systems, development of standards and specifications as well as advancement in next generation technologies (EPIA, 2011).

A reduction in the cost of PV systems has a similar effect as grants/capital subsidies on the financial indicators; it improves the viability of the project by yielding more positive NPV. This suggests that grid-connected solar PV systems will be more viable in Ghana when there is reduction in the cost of the PV systems. This cost reduction like that of the world market will be due to an improvement in solar PV technology and maturity in market the Ghanaian solar PV market.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Africa, in spite of its huge potential for solar energy applications, has not seen much investment in the area mainly due to the very high investment cost associated with the technology. However, technological innovations leading to improvements in efficiency as well as the economics of scale stemming from mass production have and are still helping to bring down the cost of PV system.

It is expected that the framework developed in this study will make it easy for institutions to plan and analyse their own grid-connected solar PV system. The solar resource assessment carried out as part of the site assessment showed that, UEW-Kumasi receives about 4.30KWh/m^2 of global horizontal solar radiation per day. The institution also consumes an average of 6.199MWh of electricity annually which is taken from the national grid.

In all, about fifty (50) buildings were considered out of which 74% had gable roofs, 15% had flat roof, 6% had arch-shaped roofs and 5% were hipped roofs. About 48% of the roofs had north-south orientation, 27% had east-west orientation and 24% were flat roofs. The total roof area available is about 31, 277m^2; 8, 186m^2 facing north, 8, 186m^2 facing south, 5, 495m^2 facing east, 5.495m^2 facing west and 3, 915m^2 flat and arch-shaped roofs.

The selection of suitable roofs for grid-connected solar PV installations was done based on the following criteria; size of roof (roof area), roof orientation, roof strength and the possibility of shading from neighbouring buildings, vegetation or other obstacles.

Three solar PV module technologies were selected and their performance compared. These are monocrystalline silicon, polycrystalline silicon and amorphous silicon modules. The technical analysis showed that amorphous silicon modules, in spite of their low efficiencies, generate more electricity per rated output than monocrystalline silicon and polycrystalline silicon modules. This is because amorphous silicon modules have a lower temperature coefficient than monocrystalline and polycrystalline modules.

The 500KWp amorphous silicon system generated about 1, 299KWh of electricity annually with a performance ratio of 83.1% as compared to 1.206KWh and 772% by the 500KWp polycrystalline system. The 500KWp amorphous silicon system also operated with a capacity factor of 14.8% higher than the 500KWp monocrystalline and 500KWp polycrystalline systems which had capacity factors of 13.8% and 13.7% respectively. At prevailing solar PV system cost, and bulk generation charge, a capital intensive project of this kind is not feasible except at feed-in tariffs greater than US$ 0.43/KWh.

However, when grants/capital subsidies are provided to cater for about 50% of the total investment cost, the project becomes viable at a feed-in tariff of US$ 0.23KWh.

GHG income, on the other hand does not affect the viability of the project much since a 500KWp solar PV system saves only about 842 tons of Co_2 per annum.

5.2 Recommendations

The recommendations from this study are;

1. A study should therefore be carried out to examine the capacity of the utility grid in terms of how much electricity can be injected. This is because knowing the capacity of the utility grid will provide useful information about how much electricity from solar PV systems can be injected into the grid.
2. It will be necessary to know the impact a 500KWp or higher capacity grid-connected solar PV system will have on the utility grid. It is therefore recommended that a study be carried out to address this issue.

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