TECHNO-ECONOMIC ANALYSIS OF A 2.5MW GRID-CONNECTED SOLAR PHOTOVOLTAIC SYSTEM AT NAVRONGO IN THE UPPER EAST REGION OF GHANA

By

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(BSc. ELECTRICAL ENGINEERING (Hons)

A Thesis submitted to the School of Graduate Studies, Kwame Nkrumah University of Science and Technology, Ghana, in partial fulfilment of the requirements for the

Degree of

MASTER OF SCIENCE IN RENEWABLE ENERGY TECHNOLOGY

DEPARTMENT OF MECHANICAL ENGINEERING

FACULTY OF MECHANICAL AND AGRICULTURAL ENGINEERING

COLLEGE OF ENGINEERING

JUNE, 2019

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 degree of the university, except where due acknowledgement has been made in the text.

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ABSTRACT

This study presents the performance assessment of a 2.5MW utility scale grid-connected, ground mounted solar photovoltaic power plant installed at Navrongo, Ghana (10^0 53’N, 01^0 06’W).The study uses the actual performance data (hourly energy output and environmental data from June 2013 to May 2016) from the Navrongo plant which has 8640 modules inclined at fixed angle of 12.5^0, five inverters and a power transformer which helps to connect the plant to the national grid. A total energy of 10643.3MWh was generated within the period under review with a yearly average of 3547.8MWh. Furthermore, the average daily reference yield, final yield, performance ratio, capacity factor and system efficiency of the PV installation over the reporting period were found as 5.92 h/day, 4.17 h/day, 70.4%, 17.2 and 11.53% respectively. These performance indicators are compared with those of countries like Italy, Crete, Morocco South Africa and Jordan. A simple payback period for the plant was found to be 7.2 years with carbon dioxide saving of 3852 metric tons. The findings from this study indicates that grid connected solar photovoltaic system for electricity generation is feasible in Ghana and could contribute significantly to Ghana’s electricity generation deficit without degrading the environment.

DEDICATION

This work is dedicated to my immediate family especially my lovely wife Mrs. Joyce Okine Yamoah.

ACKNOWLEDGEMENT

I am very grateful to God Almighty for how far He has brought me. It has been by his mercy and grace.

I also want to appreciate very much my supervisors; Professor Muyiwa Adaramola and Dr. Lena Mensah. Their supervision and guidance have made this work possible. I appreciate them very much.

I am also grateful to the following people for their contribution in making this work a success; Majeed Koranteng of Wa Polytechnic, Mr. Stephen Abasse of the Navrongo Solar plant and Mr. Emmanuel Narteh of GRIDCo, Techiman.

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

A	Amps
AC	Alternating Current
CDM	Clean Development Mechanism
CF	Capacity factor
CFU	Carbon finance unit
CO_2	Carbon dioxide
CSP	Concentrated solar power
CUF	Capacity utilization factor
DC	Direct Current
ECG	Electricity Company of Ghana
eGRID	Emission and generation resource integrate database
EPA	Environmental Protection Agency
FiT	Feed in tariff
GHG	Greenhouse gas
GW	Gigawatt
H	Hour
Hz	Hertz
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IFC	International Finance Co-operation
IHD	Individual harmonic voltage distribution
kg	Kilogram
km	Kilometre
kVA	Kilovolt Amps
kW	kilowatt
kWh	Kilowatt hour
kWh/m^2	Kilowatt hour per meter square
kWp	kilo – Watt peak
LCO	Light Crude Oil
m	Metre
mm	Millimetre

MVA	Megavolt Amps
MW	Megawatt
MWh	Megawatt hour
MWp	Mega-Watt peak
NG	Natural Gas
NPV	Net present value
ONAN	Oil natural air natural
P_R	Performance ratio
PURC	Public Utility Regulatory Commission
PV	Photovoltaics
PV	Photovoltaic
PVPS	Photovoltaic Power Systems Programme
RMI	Rocky mountain institute
TWh	Terawatt hour
USTDA	US Trade and development Agency
V	Volts
VRA	Volta River Authority
Y_R	Reference Yield

CHAPTER 1: INTRODUCTION

1.1 Background

Energy is seen as a major driving force behind rapidly developing economies. The link between growth in economy and increased energy usage can be seen in countries around the world with both developing and advanced economies. (Energy Commission, 2006). Among other forms of energy, access to electricity has been found to have tremendous effect on health, education, agriculture, industrialization and businesses. In the rural areas, electricity helps to reduce rural-urban migration in search of non-existing jobs and other modern facilities. Other benefits include agro-businesses, agro-processing and crop irrigation (Kemausuor et al, 2012). In fact, increase in electricity production and use translates into better quality of life and creation of wealth. There is, therefore, the need for increase in production of electricity if a nation wants to see massive development because it is an indisputable ingredient for economic development.

The per capita electricity output is a useful parameter for comparing the levels of development of various regions in the world as shown in Table 1.1 (IEA, 2010). It shows the total electricity output of the region per the population of the region. It can be observed that North America and the European countries (EU – 27) have higher per capita electricity output. This is as a result of industrialization and the fact that most of the population depend more on the use of electrical gadgets for their everyday lives. A lot of electricity is needed for the industries to function. Middle East, China, India and some South-East Asian countries also have an appreciable amount of per capita output because they are also coming up as industrial giants. However, Africa has the least per capita electricity output, indicating that Africa is the least industrialised region, having communities which are yet to be connected to the grid, whilst those connected are not using the power much because of poverty.

Table 1-1 Per capita electricity output

REGION	PER CAPITA ELECTRICITY OUTPUT(kWh/cap)
North America	10,201
EU-27	5,730
Middle East	3,094
China	2,164
Latin America	1874
Africa	520
India	528
The World	2515

Source: IEA, 2010

According to International Energy Agency (IEA), the world's total electricity production in 2013 was 23,322TWh. This quantity of electricity was generated by different fuel sources of generation. They are coal – 41.3%, Natural Gas - 21.7%, Hydro – 16.3%, Nuclear – 10.6%, Oil – 4.4% and others (Renewable) – 5.7% (IEA, 2015). This is represented in Figure 1.1

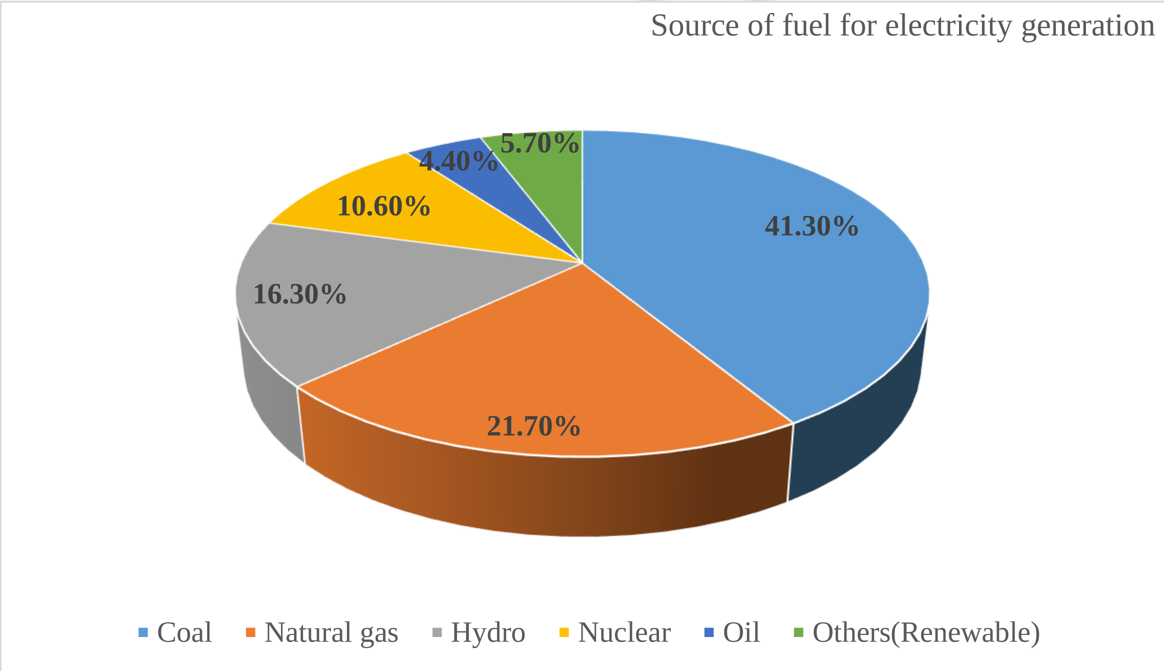


Figure 1-1 World Electricity Generation in 2013 by various fuel sources

The development and use of electricity resources come with certain challenges. Some of the challenges are variety of negative environmental impacts such as global warming, acid rain, air toxics, land use and water impacts. (Rosen et al, 1995). Fossil fuel types like oil, coal, nuclear and natural gas have in recent times attracted growing concerns about their levels of pollution in causing unprecedented changes to the global ecological environment and climate. Due to the devastation on the environment that comes with the use of fossil fuel for electricity generation, World Leaders have been meeting to come out with conventions and agreements to reduce this environmental degradation.

The United Nations Development Programmes (UNDP) World Energy Assessment in 2000 revealed numerous difficulties humanity may have to contend with when changing from fossil fuel source to renewable energy source. (World Energy Assessment, 2000). Some of the challenges are as follows: (World Energy Assessment, 2000)

1. How to change the means of providing energy for development to meet sustainable development goals.
2. How to combine higher energy efficiencies, renewable technologies and advanced energy technologies to realise sustainable future.
3. Setting priority for finding ways to accelerate new methods of providing energy to achieve the sustainable development goals.

1.2 Justification

The basic aim of Ghana government's development plan is to attain macro-economic stability and economic growth and in move on to a middle income status by 2020. (Ministry of Energy, 2010). In the light of this, total energy supply in Ghana must increase greatly to meet our developmental targets. Ghana faces an uphill challenge in providing the required energy to maintain the expanding economy coupled with the growing population in a reliable and sustainable manner, having in mind the environmental and economic impact of energy production and use (Energy Commission, 2006).

Inexhaustible renewable energy sources are seen as an option to augment the inadequacy of fossil-fuel based fuel power generation since renewable energy resources abound in Ghana. For example, the average sunshine duration in Ghana ranges from 5.3hours per day to 7.7hours per day (Singh, et al, 2015). The average monthly solar irradiation ranges from 4.4kWh/m^2 to 5.6kWh/m2. In fact, in the savannah zone (Northern, Upper East, Upper West, part of Brong Ahafo and part of Volta Regions) average solar irradiation ranges from 4.0kWh/m^2 to 6.5kWh/m^2. A strategic target to achieve 10% renewable energy penetration from the current level of 0.6% of Ghana's final energy mix has been set (Energy Commission, 2016). This should be achieved by the year 2030.

In line with this National Policy, Volta River Authority adopted a renewable energy policy to develop and operate renewable energy plants. The development and operation of these plants were to be done in an efficient, cost effective and environmentally sustainable manner. Volta River Authority has, therefore, targeted to develop about 160 MW of installed renewable energy capacity over a period of five years (2010 – 2015) of which 14MW would come from solar sources (Volta River Authority, 2017). This target does not include large and small scale hydro generation. Volta River Authority, established in 1961 as a result of the Volta River Development Act (Act 46) is a state – owned electricity utility responsible mainly for power generation in Ghana.

Volta River Authority has therefore built a 2.5MW solar photovoltaic power plant in Navrongo in the Upper East Region of Ghana. The 2.5MW facility is the largest utility-scale grid connected PV plant in West Africa, a similar facility in Cape Verde which has a capacity of 7.5MW(ECREEE, 2010).

In view of the fact that it is the first utility-scale grid-connected solar photovoltaic system in Ghana, it is important that performance analysis of the system is undertaken to know how the plant is performing. This would help to know the energy yield per day, month and year. The effect of temperature and seasonal variation on the energy yield from the power plant would have to be determined. By this analysis, system and component efficiency, losses and optimum performance indices would have to be determined. This analysis can quickly identify any design flaws and failures so as to prevent economic losses due to operation performance.

This study is particularly important to stakeholders (Eg. Government, Academia, Investors, Industries, Utilities Regulatory bodies, Financial Institutions etc.) to help make informed decision with respect to solar photovoltaic power plant. It would also help operators of such plants to opt for optimum performance of the power plant, correct any design flaws, if any, and also reduce cost in terms of operations and maintenance. Regulatory bodies can also assess the approved feed-in-tariff to know its impact on economic viability of solar PV system in this country) as well as help in framing of policy.

Although there are many studies that have examined the performance of solar photovoltaic power plants globally, limited information is openly available on the outdoor performance of this type of power plant in Ghana. A similar study was presented by Quansah et al (Quansah et al, 2017 and Quansah et al, 2016). It must however, be noted that the study presented by Quansah et al was for a small-scale nature and was in a different climatic zone. Whereas the study of Quansah et al was for a humid tropical climate, this study is for a savannah zone where solar radiation and ambient temperature are generally higher. These environmental conditions and mode of installation could lead to different system performance.

1.3 Global Development and Installation of Solar Photovoltaic Systems

The increase in world population and industrialization is accompanied with more demand for electricity. For this growing demand to be met, more coal, oil, natural gas power plants are being constructed. This increases the level of harmful emissions being released to the surroundings. (Bollinger, 2007). According to International Energy Agency (IEA), the world's total electricity production in 2013 was 23,322TWh. Out of that 73.6% came from fossil fuel sources (IEA, 2015).

Renewable energy sources are however, sources of energy that are natural, continuous, inexhaustible, largely available and environmentally friendly. They are continuously available and do not run out as they are being continuously replenished by nature at the same rate or faster than they are being used or consumed. An example of these energy sources are solar, wind, rain, tides, biomass and geothermal. These sources are enormous in supply and can never get depleted as they get constantly renewed or replenished by nature (AET, 2014). It is on the basis of the aforementioned qualities of renewable that world leaders have resorted to using solar energy to produce electricity.

Solar energy comes from the sun. In fact, the quantity of energy released is 8000 to 10000 times the energy need on earth. This energy is renewable since it is believed that sunlight will be abundant for the next 5 billion years. The energy from the sum can be harnessed through the use of photovoltaic cells, solar thermal technology and concentrated solar power (CSP) technology.

Many developed economies have injected quite a number of solar driven electricity into their national grids to provide a substitute to the traditional power to reduce their high import bills as a result of fuel for power generation and also protect their environment.

According to International renewable energy statistics, as at the end of 2014, the total global installed capacity of solar powered electricity generation is 178GW. This is about one percent of the total world's electricity utilization (IRENA, 2015). The main disadvantage of using solar energy to generate electricity is the initial cost of the installation. This has improved dramatically by the use of improved technology for the manufacturing of the solar panels. This accounts for the increasing use of solar powered electricity generation in recent time. For example in 2015 solar power capacity grew by 26% largely due to price decline of up to 80% since 2010 for solar photovoltaic modules (IRENA, 2016). Out of the total global capacity of 227GW as at the end of 2015, Europe accounts for 43%, Asia (Mostly China and Japan) 40% and 13% North America (IRENA STATS. 2016).

1.4 Objectives

The main goal of this thesis is to carry out technical and economic performance analysis of the 2.5MW Navrongo solar Power Plant. The specific objectives are:

1. Examine its technical performance by determining the monthly and annual relevant performance indices for the power plant, using the PVSYST software.
2. Undertake economic performance analysis using relevant economic indicators and relevant simulation software (RETSCREEN)
3. Compare the performance of the system with similar studies.
4. Validates simulated values with measured data.

1.5 Outline of Thesis

The following is a brief summary of the overall layout of the thesis;

(a) Chapter 1 Introduction.

(b) Chapter 2 reviews relevant literature/publication on grid-connected Solar Photovoltaic systems and its performance.

(c) Chapter 3 presents theoretical consideration on solar PV system as well as technical and economical performances indicators.
(d) Chapter 4 gives detail of Methodology and Implementation.
(e) Chapter 5 presents Results and Discussion.
(f) Chapter 6 discusses the Conclusion and Recommendations.

CHAPTER 2: LITERATURE REVIEW

This chapter presents review of relevant similar works and publications on Performance of Grid-connected photovoltaic systems.

2.1 Performance of Grid-Connected Photovoltaic System.

For sustainable development of the photovoltaic industry, exact and more consistent assessments of photovoltaic systems are crucial. Performance assessment is very crucial for manufacturers, researchers, system integrators and end customers. This is because they help the manufacturer to review the standard of quality of the existing product, the researcher to know future needs, system integrators and customers also are guided in their future decision making on any product. (B. Marion et al, 2005).

The performance parameters evaluation permits the identification of operational problems, encourage the comparison of system that might differ as far as design, technology or geographical area and accept models for performance estimation during the design stage. (B. Marion et al, 2005).

2.2 Performance of 170 Grid Connected Photovoltaic Plant in Northern Germany

A study of performance of 170 grid connected Photovoltaic plants in Northern Germany was conducted and published in1997 (U. John et al 1997) This study was carried out with the German 1000 roof PV programme where PV plants of (1-5kWp) total peak power of 5MWp were installed on the roof of buildings. A total of 172 PVs were monitored. Ac electricity meters were connected to register the total PV energy. Additionally the PV system are equipped with solar integrators to obtain in-plane radiation and other site conditions. An annual Final yield between 430-875h with a mean of 66% performance ratio was also noted.

2.3 A Review on Grid-Connected Photovoltaic System in Brazil

In Brazil performance study of ten sites showed an average final yield of 1230h and performance of 0.6 – 0.8. It also showed that the nation has the potential to join the world PV market because it has one of the best irradiation resources in the world (1,500 to 2,000 kWh/m² per year global horizontal irradiation) vast land area. (8.5millionkm²) and high electricity tariffs (0.264USD/kWh). (Nobre, et al, 2015)

2.4 Performance Analysis of a Photovoltaic System in Kurdistan of Iraq

Another performance study was conducted in Iraq-Kurdistan. This study designed a 200kW ground mounted PV System based on the average radiation rate and used Photo-Voltage Geographical Information System (PVGIS) simulation software. The PV panels were inclined at 32 degrees to give optimum electricity production. This study was done in neighbouring areas like Iran, Turkey, Kuwait and Saudi Arabia. It was shown that Kurdistan in Iraq was more suitable with annual final yield of 1699hours and capacity factor of 19.39%. This study concluded that the cost required to build a 200k W PV system is less than the cost that is needed to feed natural gas or gasoline based plant for a year. (Ari et al, 2015).

2.5 Performance Analysis of a 190kwp Grid Interactive Solar Photovoltaic Power Plant in India

Similar performance study has been carried out in India using a 190kW solar photovoltaic power plant installed. The daily final yield, reference yield and performance ratio were found to vary from 1.45 to 2.84 hours, 2.29 to 3.53 and 55-83% respectively. The annual performance ratio, capacity factor and system efficiency were found to be 74%, 9.2%and 8.3% respectively. The annual average measured energy yield was found to be 812.kWh comparable to the predicted energy yield of 823kWh using PVSYST software simulation. The variation in the measured and predicted energy yield was 1.4% with estimated system losses of 31.7%. The energy generation was maximum in March, September and October with the minimum in January. (Sharma et al, 2013).

2.6 Comparative Analysis of Measured and Simulated Performance of the Morocco First MV Grid Connected Photovoltaic Power Plant in Morocco

In Morocco, performance studies were carried out to compare measure and simulated performance values of a grid connected PV system with a capacity of 806.52kwp located at Assa, Southern Morocco. The study was to compare the measured values with the result from a PVSYST software. At the end of study period, measured final yield of 1650.6kWp/kW, performance ratio of 70.14% and system efficiency of 9.97% was compared with the simulated values of 1716.02kWp/kW final yield, 77.9% performance ratio and 10.36% system efficiency. The comparison of the final yield of this system with other locations worldwide shows that the site is good for power generation (Boughamrane et al, 2016)

2.7 Performance Analysis of Different Grid Connected Solar Photovoltaic System Technology Located in Humid Tropical Climate

Another study carried out in Ghana by Quansah et al, 2017 on performance analysis of different grid connected solar photovoltaic (PV) system technologies with combined capacity of 20kW located in humid tropical climate showed a performance ratio between 48.84% and 71.26%. In this study, the objective was to assess the performance of different solar cell technologies namely: poly-crystalline silicon (pc-si), monocrystalline silicon (mc-si), copper Indium diselenide (CIS) thin film, amorphous silicon (a-si) and heterojunction incorporation thin (HIT) film. The study concluded that poly-crystalline silicon performed better followed by amorphous silicon (a-si) and then heterojunction incorporation thin (HIT) film. The least performed cell technology is the copper Indium selenide (CIS).

2.8 Performance evaluation of 10MW Solar Photovoltaic Power Plant in India

Performance evaluation of 10MW grid connected solar photovoltaic power plant in India was carried out. It was done by manually extracting the parameters of power generation through SCADA system. The results were compared with the results from PVSYST software and Solar GIS. An annual performance ratio of 86.12% and final yield of 715.4 – 1850.55 were obtained. The monitored annual energy output was 15,605.9MWh whilst that of the PVSYST and Solar GIS were 16048MWh and 16403MWh respectively. This shows that the actual performance closely matches with the simulated performance of PVSYST and Solar GIS over the entire year. (Kumar et al, 2015).

2.9 Analysis of Measured and Simulated Performance Data of a 3.2kWp Grid Connected Solar Photovoltaic System in South Africa.

Okello et al in South Africa analysed and compared the measured and simulated performance values of a 3.2kWp grid connected photovoltaic system at the Nelson Mandela Metropolitan University. The plant consist of 14 poly-crystaline silicon modules connected in two strings at a fixed angle of 34 degrees. The input climate data to the software were measured values obtained from the site and Meteonorm derived climate data. The study resulted in a measured final yield of 1788kWh/kW/year, with predicted final yield of 1787kWh/kW/year for simulation using site measured climate data and 1792kWh/kW/year for simulation using Meteonorm derived data. Similarly a measured performance ratio of 84.3% was obtained whilst 84.4% and 87.5% were obtained from the simulations. The study concluded that although the simulation results were similar, better comparison between measured and predicted results were obtained with simulations using measured weather data at the site. (Okello et al, 2015)

2.10 Research Gap

From the studies that have been reviewed so far there is an observation of an emerging trend in the performance parameters. They are as follows: performance ratio ranges from 50 to 70% and final yield from 800kWh/kW to 1650kWh/kW per annum. It was also observed that these grid-connected system studies were all on small scale. It is therefore, important that a large scale grid-connected system is studied to compare the performance parameters with the small scale ones.

CHAPTER 3: THEORETICAL CONSIDERATIONS FOR GRID CONNECTED PV SYSTEM

This Chapter presents the theoretical considerations for Grid-connected Solar Photovoltaic System. Topics to be discussed include Electricity Power Plants in Ghana, Solar photovoltaic power plants, Solar Resource and Photovoltaic System development in Ghana and Solar Photovoltaic System design and types.

3.1 Electricity Power Plants in Ghana

Hydroelectricity has been Ghana's parent energy source. However fossil fuel powered-electricity plants have been added to the electricity generation plants to meet the growing energy demands in Ghana. The current electricity generation mix is now about 42.3% hydro, 57.1% thermal and 0.6% renewable (Solar) (Energy Commission, 2016).The electricity generation mix in Ghana is presented in Table 3.1.

Table 3.1 Present generation mix in Ghana. The fossil fuel used are Natural Gas (NG), Light Crude Oil (LCO) and Diesel. (Source: Energy Commission, 2016)

Table 3-1 Generation mix in Ghana

Name	Installed Capacity(MW)	Fuel type
Akosombo	1020	Hydro
Kpong	160	Hydro
Bui	400	Hydro
Aboadzie (Tapco)	330	NG/LCO
Aboadzie (Tico)	330	NG/LCO
Tema (TT1PP)	110	NG/LCO
Tema (TT2PP)	45	NG/Diesel
Tema (TT2P-X)	49.5	NG
Osonor (CENIT)	110	NG/LCO
KTPP	220	Thermal
Tema Mine Reserve Plant	80	NG/Diesel
Sunon Asogli 1	200	NG
Sunon Asogli 2	180	NG

Karpower	250	Thermal
Ameri Power	230	Thermal
Navrongo Solar	2.5	Sunlight
BXC Solar	20	Sunlight
Total	**3737**	

Source: Energy Commission, 2016

3.2 Solar PV Power Plants

In view of the negative environmental impacts that conventional electricity generation brings, it is better to turn to renewable energy technology. This is because it is an infinite source of energy and will not run out, unlike other source like fossil fuel. It also has a much lower environmental impact than conventional energy technologies.

Solar electricity is produced by converting radiation from the sun into electricity, either by using photovoltaic (PV) effect, or concentrated solar power (CSP). Concentrated solar system uses lenses or mirrors and tracking devices to focus a large quantity of sunlight into a small beam. Photovoltaic systems, however, changes sunlight directly to electric currents by the use of photovoltaic effect.

The photons in sunlight can free an electron from its bond and cause it to conduct electricity. (Home Power Magazine, 2012). Once a solar photovoltaic system is in place for electricity generation, the energy source is free and will never be influenced by economic discords in the energy market. Many developed and developing countries are now shifting to solar energy due to its minimal environmental pollution in the course of electricity generation. As at the end of 2015 the countries in table 3.2 had the highest Installed Photovoltaic Solar Photovoltaic energy capacity.

Table 3-2 Top ten countries with highest PV installed capacity

Country	**Installed Capacity (MW)**
China	43,530
Germany	39,700
Japan	34,410
USA	25,620
Italy	18,920
UK	8,780
France	6,580
Spain	5,400
Australia	5,070
India	5,050

(Source: IEA – PVPS Report, 2016 cited in Mcfadden, 2017)

Solar PV can be used in various applications such as in consumer products (e.g., calculators and solar-powered lamps), small-and large-scale electricity for residential homes (both in rural and urban areas), commercial and industrial buildings as well as for remote highway signs. Furthermore, solar PV provides electricity to all satellites in space.

3.3 Solar Resource and Photovoltaic Systems Development in Ghana

3.3.1 Solar Energy Resource in Ghana

Ghana lies close to the equator and therefore has solar energy in abundance but is yet to be tapped. Table 3.3 shows the solar resource at the various locations.

Table 3-3 Solar resource of Ghana

LOCATION	SOLAR RESOURCE	REMARKS
Around Kumasi	4.4 – 5.6kWh/day with sunshine hours of 5.3hours	The area lies in semi – cloudy forest region
Upper East, Upper West, Northern, Northern part of Brong Ahafo and Volta regions	4 – 6.5kWh/day with sunshine ours of 7hours	The area has one major rainy season between July and September follow by harmattan between November and February.
Ashanti, part of Brong Ahafo, Eastern, Western, part of Central andVolta regions	3.1 – 5.6kWh/day	The area is a forest area
Greater Accra, coastal part of Volta and Central regions	4.0 -6.5kWh/day	This the coastal areas

Source: Singh, et al, 2015

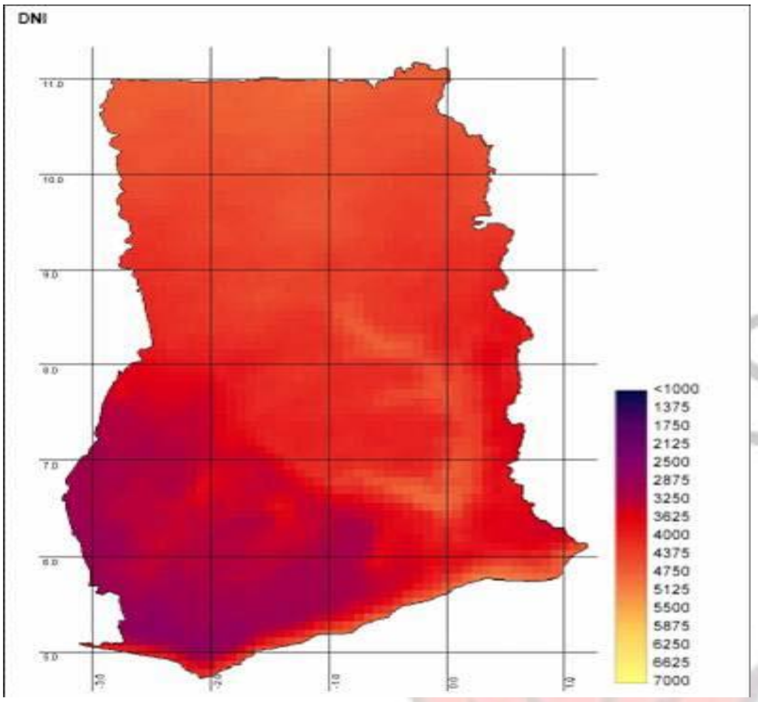


Figure 3.1 Solar Radiation map, Ghana. Source Dadzie, 2008

3.3.2 Photovoltaic Systems Development in Ghana.

Despite the fact that Ghana abounds in sun powered energy resources, not much of this potential is utilized. In the early part of 1999, after Ghana went through its electricity crisis in 1997, a lot of companies entered the PV market to take advantage of the crisis to push for a switch to the use of renewable energy. However, in less than a year most of them had folded up apparently due to lack of regulatory frame work and incentives to support that sector of the economy (Mawuli, 2000).

Around 2010, the total capacity of Grid – connected solar photovoltaic system was 160kWp. This was made up of 50kWp at Ministry of Energy, 101.75kWp in individual homes sponsored by Energy Commission of Ghana, 4kWp at Kwame Nkrumah University of Science and Technology college of Engineering and 4.25kWp at Ghana Energy Commission premises.

In 2011, a Renewable Energy Law (Act 832) was enacted to provide some incentives and regulatory framework to encourage private sector investment. The provision of this law includes: Feed-in Tariff (FiT), Renewable Energy Purchase Obligation, Net Metering (Distributed generation), off-grid electrification of isolated communities, Research and Development, Renewable Energy Fund and establishment of a Renewable Energy Authority (Singh, et al, 2015). This regulatory framework has given way for more investment in the PV Industry in Ghana. Table 3.4 below shows some of the PV projects undertaken in Ghana by the VRA.

Table 3-4 Solar PV projects by Volta River Authority

PRESENT (MW)	FUTURE (MW)	SITE
2.5	10	NAVRONGO
-	12	KALEO/LAWRA
-	100	BONGO

Source: Singh et al, 2015

In April 2016, Ghana’s first solar manufacturing plant with an annual production capacity of 30MW was opened in Kpone in the Greater Accra Region of Ghana. In the same month, a Chinese company Beijing Xiaocheng commissioned 20MW solar PV plant at Onyandze in Greater Accra (PV magazine, 2016). The Solar PV plants has 40,480 pieces of polycrystalline silicon panels, 20 step-up transformers, 20 inverter rooms attached to the transformer, 33kV overhead transmission line of 9km to ECG sub-station near Winneba.

3.4 Design and Type of Solar PV system

3.4.1 Design Type and Component

A solar cell is a device made up of two layers of a semi- conductor material that can convert solar energy into direct current electricity through the photovoltaic effect. One layer of the device is positively doped and the other negatively doped. (Bagre, 2012) Whenever light enters the cell, some photons of the light are absorbed by the semiconductor atoms causing electrons to flee from the negative layer of the cell to flow through an external circuit back into the positive layer. The flow of electrons in this manner constitutes an electric current. The current that is internally generated in a solar cell is proportional to the amount of solar power striking a surface. (Bagre, 2012.)

3.4.1.1Type of Solar cells

There are three main types of solar cells, namely, monocrystalline, polycrystalline and amorphous cells.

- **Monocrystalline cells**

This type of cells are made using cells cut from a single crystal of silicon. They have a greater degree of purity of the material and ensure the best performance in terms of efficiency (approximately 18% conversion of incident sunlight). It is slightly more expensive as a result of the complex manufacturing processes it goes through to obtain the level of purity of the material, (Singh, 2010).

- **Polycrystalline Silicon cells**

This is made by cutting micro-fine wafers from ingots of molten and recrystallized silicon. They have a lower level of purity and therefore less expensive to manufacture. As a result its efficiency is slightly compromised (approximately 14% conversion of incident sunlight). (Sing, 2010)

- **Amorphous Silicon**

This is the deposition of a thin layer of silicon crystal on surfaces of other materials such as glass. It has the lowest efficiency (approximately 8% of incident sunlight.)

The solar cell is the basic building block of the photovoltaic system. The voltage generated by one cell is inadequate (typically 0.6V). Several of the solar cells are connected in series and parallel to form a module. When the cells are connected in series their voltages add up and when they connect in parallel, their current add up. The cells are sealed in an environmentally protective laminate to form a module. A photovoltaic panel is made up of one or more modules assembled pre-wired field installable unit. Array is a complete power generating unit consisting of a couple of photovoltaic panels.

3.4.1.2 Components of solar PV system

The following are major component of solar photovoltaic system

- 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 AC load.
- Batteries that stores energy for night time usage and period when there is no or low irradiance.
- Charge Controller : controls the amount of charge on the battery

3.4.2 Types of Photovoltaic System

Photovoltaic system comes in three forms:

- grid-connected,
- stand-alone
- hybrid system.

3.4.2.1 Grid Connected System

With this system, solar photovoltaic (PV) modules generate electricity from sunshine as it incident on it. The power generated from module is a DC. An electronic device known as an inverter, is used to change the power generated to alternating current at the frequency of the grid. It also meets other conditions that makes it possible to connect the generated power from the PV system to the national grid. In this system the PV modules are either mounted on rooftop of residential buildings or on an acquired area of land to generate power. The power generated is connected into the mains electrical supply of a building or directly into the public electricity grid (DGS, 2008). The electrical power need of the structure where the PV system is mounted is supplied by the PV system and any extra energy is fed to the grid. (DGS, 2008; Kumi and Brew-Hammond, 2013).

The capacity of rooftop PV system may be small as compared to ground mounted PV system. They range from 5-20kW while those on commercial buildings can reach 100kW or more.

Many developed and developing countries have developed plans to increase their electricity production using Rooftop PV system. Example of some of the projects include Gunma project in Japan commissioned in 2012, which contains 550 houses with rooftop grid-connected PV system. The total capacity is estimated to be 2.2MW in a 1km area which corresponds to 85% penetration level of PV electricity. At the end of 2015, Germany had installed PV capacity of 40GW of which 74% were made up of rooftop solar PV system. 70% of these rooftop system had capacity less than 10kW and were mounted on one or two family houses. United State of America added about 2GW of distributed solar photovoltaic such as rooftop solar to its installed capacity. China added 970MW of rooftop PV system to its capacity in the first three months of 2016. This system eliminates losses that would have occurred in the transmission lines since the generation is done at the consumers premises.

With the central grid-connected system, the PV modules are mounted on an acquired area of land to generate power and fed into the national grid. This system has higher capacity ratings in the range of kilowatts and megawatt. The main components are as follows:

- Solar PV Modules: these convert sunlight directly to electricity.
- Inverter: converts the direct current generated by the solar PV modules to alternating current.
- Transformer which steps up the power generated for transmission
- Transmission line to link the plant to the grid
- Mounting System

Figure 3.2 shows a simplified grid-connected solar photovoltaic system

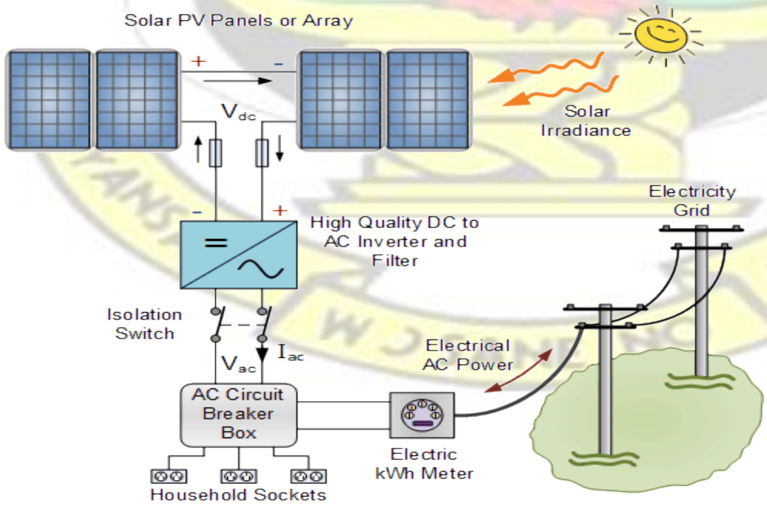


Figure 3.1 Simplified Grid Connected PV system (Source AET, 2014)

According to International renewable energy statistics, as at the end of 2014, the total global installed capacity of solar powered electricity generation was 178GW most of which were grid-connected. This was about one percent of the total world electricity consumption (IRENA, 2015). The PV system revolution in 2014 was led by China, Germany, Japan, USA, Italy and many more. Countries like India, Chile, South Africa, Bulgaria Ukraine and Slovakia all grew significantly in their PV system installation.

3.4.2.2 Stand-alone PV System

Stand-alone PV systems refers to a PV system which has no connection with the public utility network. It produces electrical energy from the sunshine, uses it or stores it in batteries to be used at night and periods of low sunshine. They supply DC and/or AC loads in isolated areas.

A typical Standalone system has the same components as the grid connected system with the addition of the following:

- Batteries that stores energy for night time usage and period when there is no or low irradiance.
- Charge Controller : controls the amount of charge on the battery

Since this system has no connection to the grid, it is important that the energy storage capacity is chosen correctly to avoid a situation where the load would be more than storage and therefore cannot be supplied (Lugue and Hegedus, 2003).

The inverter also plays vital role if AC loads are to be supplied because as a voltage source, it determines the voltage wave shape, amplitude, and frequency. It must also be able to supply current surges, for example starting currents in motors, and an amount of reactive power that would be demanded by the loads (Whitaker et al, 2008).

They are usually used in watches, scientific calculators, Telecommunications, traffic signs, solar home systems and water pumping systems. (DGS, 2008; Kumi and Brew-Hammond, 2013).

In some developed countries for instance Germany and Japan subsidies are provided for electricity storage technology for PV systems. Germany already has ten thousand rooftop solar PV system coupled to battery storage systems (IRENA, 2015). In a number of countries a lot of businesses are entering into the market of leasing solar PV systems coupled with battery storage technology. In Australia 16MW of off-grid system was installed in 2014 whilst China can boast of 40GW in the same year. In most European countries, off-grid application is mainly used for remote areas where accessibility to fuel source is difficult for example mountain sites. Most European countries in 2014 installed about a MW per country with Sweden with 1.1MW. In Japan about 1MW was installed bringing their installed capacity to 125MW (IRENA, 2015). In France, the Island of La Reunion operated more than 150MW of PV to supply a total population of 840,000. In Bangladesh, there is an ongoing installation of 6million PV system to provide basic electricity to 30 million people. This is expected by the end of 2017. India is expecting 2GW of off-grid PV installation by the end of 2017.

3.4.2.3 Hybrid System

A grid connected PV system is a less sophisticated and least expensive type of PV system. The absence of storage battery eliminates its maintenance issues and thereby makes the system more efficient. It must, however, be noted that since the grid connected system is not a separate power source like the stand-alone system, anytime there is interruption of power in the grid, the system also goes off. This weakness in the grid connected system was overcome by introducing a storage battery to form a hybrid system. (AET, 2014). Figure 3.3 below shows a grid connected PV system with battery storage

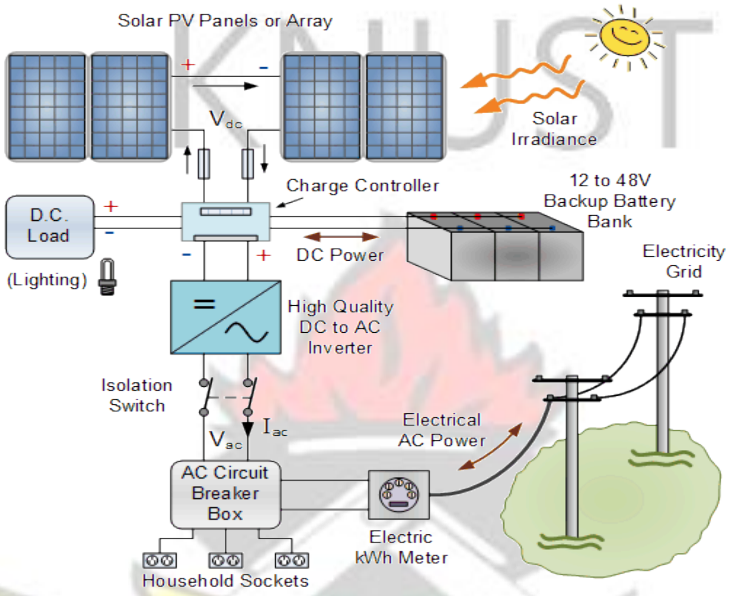


Figure 3.2 Grid connected PV system with battery storage (Source: AET, 2014)

The hybrid system has the same configuration as grid connected PV system with battery storage and charge controller added. The charge controller controls how the battery should be charged to be ready for use when needed (AET, 2014).

One of the disadvantages of the hybrid solar PV system with the battery is the cost. However, with the increase in the price of retail electricity, the cost of solar PV system with battery decreases. This phenomenon poses a threat to the economies of utility companies especially areas where there is sunshine throughout the year. According to Rocky Mountain Institute (RMI) it was revealed among other things that utility companies will have their revenues eroded if customers resort to this hybrid system.

Analysis show that in Westchester County, New York the national grid's supply to non -residential customers will shrink from 100% today to 25% by around 2030 to less than 5% by 2050. On the other hand, solar PV contribution may rise significantly to make up the difference. The report projects how utilities in the US North East would lose their energy sales by 2030 (RMI, 2015).

Residential

- 58 million MWh annually
- 9.6 million customers
- $ 15.4 billion

Commercial

- 83 million MWh annually
- 1.9 million customer
- 19.4 billion

This means that with the increase in the retail price of electricity many customers will find it economical to shift to the hybrid solar PV system.

3.5 Economic Analysis

The importance of economic analysis of the project cannot be over emphasized. They point out the financial viability or otherwise of the project. A simple payback period and levelized cost of energy (LCOE) economic indicators were used to assess the economic performance of installation. In addition to the above financial indicators, answers to the following questions were also addressed: (i) can this installation recover its investment cost within 10 years of FiT? (ii) Is this FiT appropriate or not for installation? (iii) Using appropriate assumptions, what is the LCOE of this installation over its expected economic project life of 25 years?

3.5.1 Payback Period

This is the period it would take for a project to break- even or generate enough money to cover the start-up cost. . The simple payback period can be determined by the following

$$SP = \frac{C\,I}{I\alpha} = \frac{C\,i}{E\alpha - FiT} \quad \ldots\ldots\ldots\ldots\ldots(2.1)$$

Where C_I is the initial or investment cost

$I\alpha$ is the average annual revenue

The average annual revenue is given by the average annual electricity produced by the installation ($E\alpha$) and FiT.

According to International Finance Corporation (IFC), a payback period of 8 – 18 years is allowable for a utility scale grid connected solar PV system. (IFC, 2015). The life span of a solar project is normally 25years. A payback period of 15years is chosen for this project.

3.5.2 Levelized Cost of Energy (LCOE)

This is a measure of the marginal cost of electricity over a period of time. This indicates the average electricity price needed for a net present value of zero when a discounted cash flow analysis is performed. Therefore, considering the investment cost, operation and maintenance cost and any other cost, LCOE represents the minimum cost of energy that a power plant can sell electricity to recover all these costs over its economic life. It is given as

$$LCOE = \frac{C\,RFxCi + Co\alpha m}{E\alpha} \text{ cost/kwh} \ \ldots\ldots\ldots\ (2.2)$$

Where $Co\alpha m$ is the annual operation and maintenance cost

Ci is the annualized investment cost and

CRF is the capital recovery factor which is given by:

CRF $(i, n) = \frac{i(1+i)^n}{(1+i)^n - 1}$ ………….. (3.3)

Where i is the interest rate (in fraction) and n is the payback period (in years)

3.6 Feed in Tariff Scheme

A feed in Tariff scheme has been established by the Renewable Energy Act (Act 832) to guarantee the sale of electricity generated from renewable energy sources. It consist of the obligation by utilities to purchase power from the renewable energy sources at the rate set by the Public Utility Regulatory Commission of Ghana (PURC). This is a constitutionally mandated body established in October 1997 by Act of Parliament of Ghana. (Act 538) to regulate the provision of electricity and water. (PURC Source)

3.7 Greenhouse Gas Savings

One of the merits of using solar PV energy system is that during electricity generation, it produces no greenhouse gas (GHG). The average grid emission factor (GEF) for solar energy conversion systems in Ghana between 2013 and 2015 was 0.00037 metric tonnes/kWh (NES, 2016). This factor indicates the amount of carbon dioxide that can be avoided by using solar PV to generate in Ghana. Using this emission factor, the carbon dioxide saved by this Navrongo solar PV power plant was estimated. The annual avoided carbon dioxide by the power plant is estimated as:

$(CO_2)_a = 0.00037 * E_a$ (metric tons)……………….. (3.4)

where E_a is kWh.

- **Daily Generated Energy**: This is defined as the total energy generated by the plant.

- **Daily Delivered energy:** After power has been generated part of it is used at the plant to power control equipment, air conditioners and other equipment in the control room. The rest of the energy generated is delivered to the grid. This is the daily Delivered energy.

Monthly and yearly energy generated and delivered are calculated from the daily energy data.

3.8 Technical Performance Parameters

Technical Performance evaluation allows the operational challenges that may exist to be detected, facilitate the comparison of systems that are different in terms of design, technology or geographical location and validate models for system performance estimation during the design phase. (B Marian et al, 2005). On the basis of the importance of technical evaluation, certain parameters have been set by International Energy Agency (IEA) photovoltaic power system program to be used. According to International Energy Agency (IEA) Photovoltaic Power Systems Program, IEC standards 61724, performance of a grid connected PV system can be examined by a set of performance parameters in respect to energy production, solar resource and the overall effect of system losses.

The performance parameters include:

1. Final PV System Yield
2. Reference Yield
3. Performance Ratio
4. Capacity Factor
5. Capacity Utilization Faction
6. System efficiency(syst)

7. Total energy generated by the system

The performance of any grid-connected PV systems can be evaluated and compared irrespective of the location, orientation angle, tilt angle and installed capacity.

3.8.1 Total Energy Generated by the PV System.

The total daily power generated ($E_{AC,d}$) and Monthly power generated ($E_{AC,m}$) by the Pv system given as follows

$$E\,(_{AC,d}) = \sum_{t=1}^{24} \mathrm{E(AC,t)} \quad E(_{AC,m}) = \sum_{d=1}^{N} \mathrm{E(AC,d)} \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.1)$$

Where E ($_{AC,d}$) is the total generated energy per day

E ($_{AC,m}$) is the total generated per month

E (AC,t) is the hourly generated energy

3.8.2 Final Yield:

It is defined as the total AC energy generated by the PV system for a defined period (daily, monthly, annually) divided by the rated output power of the installed PV system. This is given by

$$Y_f = \frac{\mathrm{Eac}}{\mathrm{P\ pvrated}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.2)$$

Where Y_f = Final yield

Eac= Total Ac energy generated

PV rated is rated output power of the PV system.

3.8.3 Reference Yield (Y_R)

It is defined as the ratio of the daily total irradiance reaching the surface of the PV array in kWh/m^2 to the PV array's reference irradiance.

$$YR = \frac{\text{Daily total in plane irradiance}}{\text{reference irradiance}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(3.7)}$$

Where the reference irradiance is $1000W/m^2$ for Standard Test Condition

3.8.4 Performance Ratio (PR)

It is defined as the ratio of the Final yield (Y_f) to the reference (Yr)

$$\text{Performance ratio} = \frac{Yf}{YR} \ldots\ldots\ldots\ldots\ldots\ldots \text{(3.8)}$$

Where Yf =Final Yield

Yr = Reference Yield

3.8.5 Capacity Utilization Factor.

The capacity factor also known as Capacity utilization factor (CUF) of the photovoltaic system is the ratio of actual energy generated by the system to the equivalent energy output from a similar system that works 24 hours a day. (Sharma et al, 2013)

$$CF = \frac{\text{Eac}}{\text{Ppv rated 8760}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.9)}$$

Where E_{ac} is the energy generated

P_{pv} is the power rating capacity of the plant.

3.8.6 System Efficiency

This can be described as the system's ability to convert the Sun's energy they are exposed to into useable electricity.

$$\text{System eff.} = \frac{\text{Eac,d}}{\text{Ht}} \times \text{Aa} \quad \ldots\ldots\ldots\ldots\ldots \; (3.10)$$

Where Ht is the total horizontal irradiance on the array plane

Aa is the total area of the pv array

$E_{ac,d}$ is daily Ac output.

The significance of these performance parameters is to help detect operational challenges if any, compare system that are different in design, technology and sizes. This would help in evaluating different project proposal and technology. (B. Marion et al, 2005)

CHAPTER 4: METHODOLOGY AND IMPLEMENTATION

This chapter presents Methodology and Implementation. Topics to discuss includes design of the Navrongo Solar Power Plant, Schematic diagram of the plant, data collection and monitoring system.

4.1 Design of Solar PV Power Plant.

The Navrongo Solar Power Plant is the first of its kind to be integrated into the national grid. It is built on a twelve acre land. The 2.5MVA Solar PV Plant consists of 8640 modules from SUNTECH with Model number STP 295-24/Vd.

There are 18 modules in each string. With a voltage at open circuit voltage of 45.1V, 18 Modules in a string gives 811.1V which falls within the operating voltage of the inverters. Sixteen strings are combined in a combiner box (Joint box). This means that sixteen strings form an array. Table 4.1 shows the specification for the PV modules.

Table 4.1 PV module specification

Parameter	Value
Make	Suntech
Model number	STP 295-24/vd
Rated Maximum Power(Pmax)	295W
Output Tolerance	O/+ 5%
Current at Pmax(IMP)	8.27A
Voltage at Pmax(Vmp)	35.7V
Short Circuit Current (Isc)	8.57A
Open Circuit Voltage (Voc)	45.1V
Nominal Operating Cell Temperature	45^{o}C ±2^{o}C
Weight	27kg
Dimension	1956mm*50m
Maximum System Voltage for IEC/600v for UL maximum series	1000V
Fuse Rating	20A
Cell Technology	Multi-Si
All technical data at Standard test condition	AM= 1.5
E=1000w/M2	TC=25^{o}C

There are Five Power conditions Unit (Inverters) at this plant with output power rating of 500kW. Six PV arrays are connected to each Inverter. In the table 3.2 are the specifications for the Inverter.

Table 4.2 Inverter specification

Parameter	Value
Make	Guanya power
Model number	GSG-500KTT
Maximum input voltage	900Vdc
Maximum Input Current (DC)	1200 A
Operating Temperature Range	20-55^{o}C
Operating Humidity Range	0-95
MPPT Range	440-850
Protection Levels	IP 44
Nominal Output Power(AC)	500 kW
Maximum Output Power(AC)	550 kW
Nominal Operating Voltage	415V
Nominal Frequency Range	50Hz
AC Voltage Range	330-460
Maximum Efficiency	97.7%

The PV Modules are inclined at an angle of 12.5^{o} facing south and are being held in position by metal support structures. The number of modules connected in series to make a string are 18. There are sixteen strings connected in parallel to form an array. This means that an array in this power plant is made up of 288 modules with capacity of 295W each. These are connected together through an array joint box or combiner box. Six pair of DC lines from the array joint boxes are connected to a 500kW three phase inverter manufactured by Guanya power. The three phase inverter also known as Power Condition Unit converts the DC power fed into it from the PV modules to alternating current. There are a total of 30 array boxes and 5 Power condition units at the plant. The power condition unit has an inbuilt facility for maximum power point tracking. A spacing of 3m is kept between two consecutive rows of PV modules to avoid shading. A pyro meter is used to measure the global solar radiation at the plant.

The output of the five power condition units or inverters are connected to the 2.5 MVA step-up power transformer. This transformer steps up the voltage from 415V to 34.5kV. The power plant is connected to the grid through a 10km transmission line to Navrongo Substation. The solar power plant is operated by five technical personnel who report to the Director of Generation Department of the Volta River Authority. The specification of the power transformer is shown in the table 4.3

Table 4.3 Power Transformer Specifications

Parameter	Value
Type	S11 – 2500/34.5
Number of phase	3
Rated Frequency	50Hz
Condition for Use	Outdoor
Rated Power	2500kVA
Rated Voltage	34500/4/5 V
Type of cooling	ONAN
Connection Symbol	Dynll
NO- Load loss	234 kW
Load Loss	222 kW
No load Current	0.139 A
Short Circuit impedance	6.79%
Untanking Weight	4520kg
Transportation Weight	5705kg
Weight of Oil	1960 kg
Total Weight	8065 kg
No. of Transformer Oil	DB-25

4.2 SCHEMATIC DIAGRAM OF THE 2.5MW SOLAR POWER PLANT

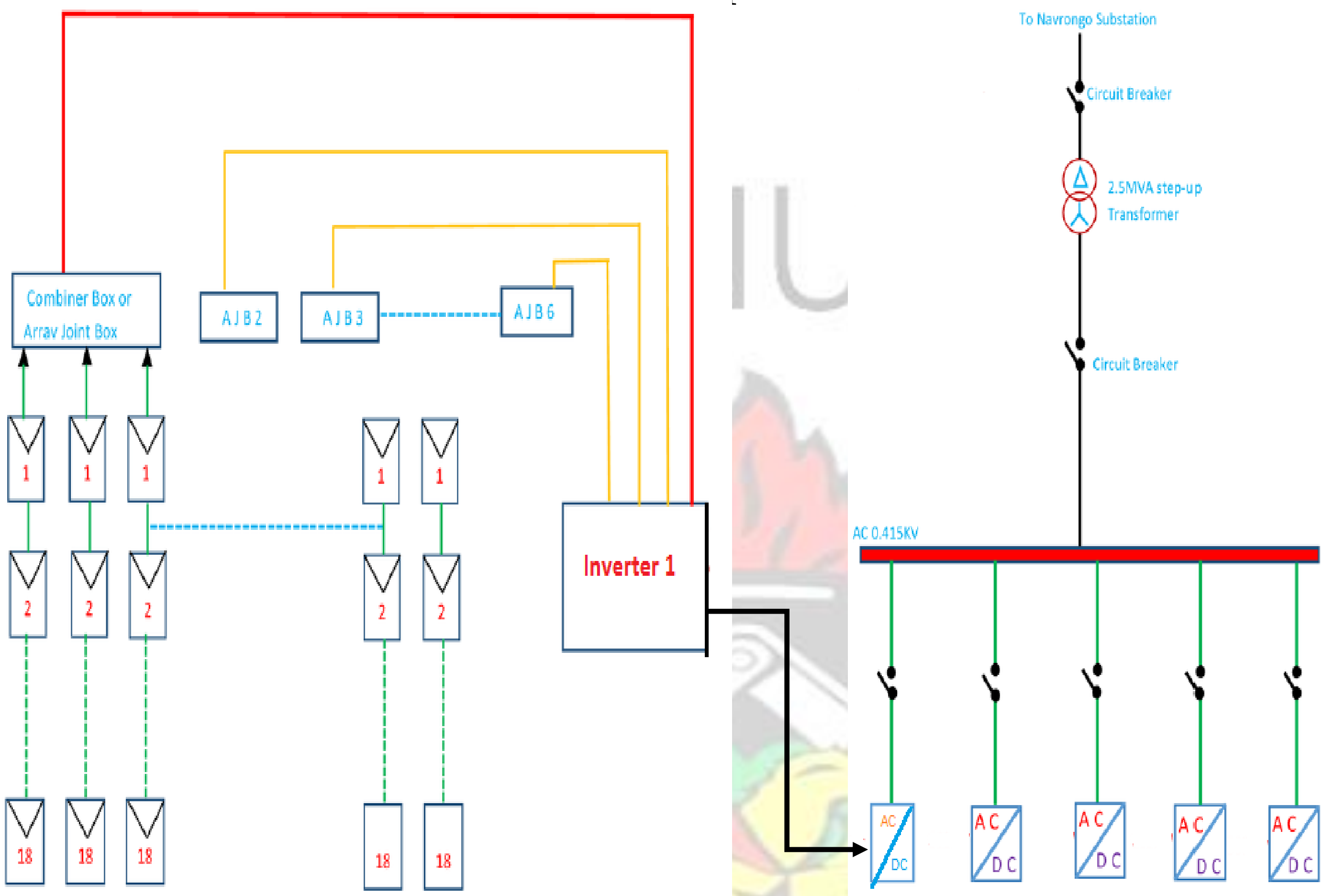


Figure 4.1 Schematic diagram of the Navrongo Plant

Total No. of modules for the plant – 8640

Total No. of power conditioning unit – 5

Total No. of Array Joint Boxes – 30

18N0. of modules in series

16N0 of string in parallel

6N0 of Array feeding 1 Inverter

Total No. of modules connected to 1 inverter=1728

Total No. of Array Joint Box (A J B) =6 for each Inverter

4.3 SCHEMATIC DIAGRAM OF THE COMBINER BOX OR ARRAY JOINT BOX

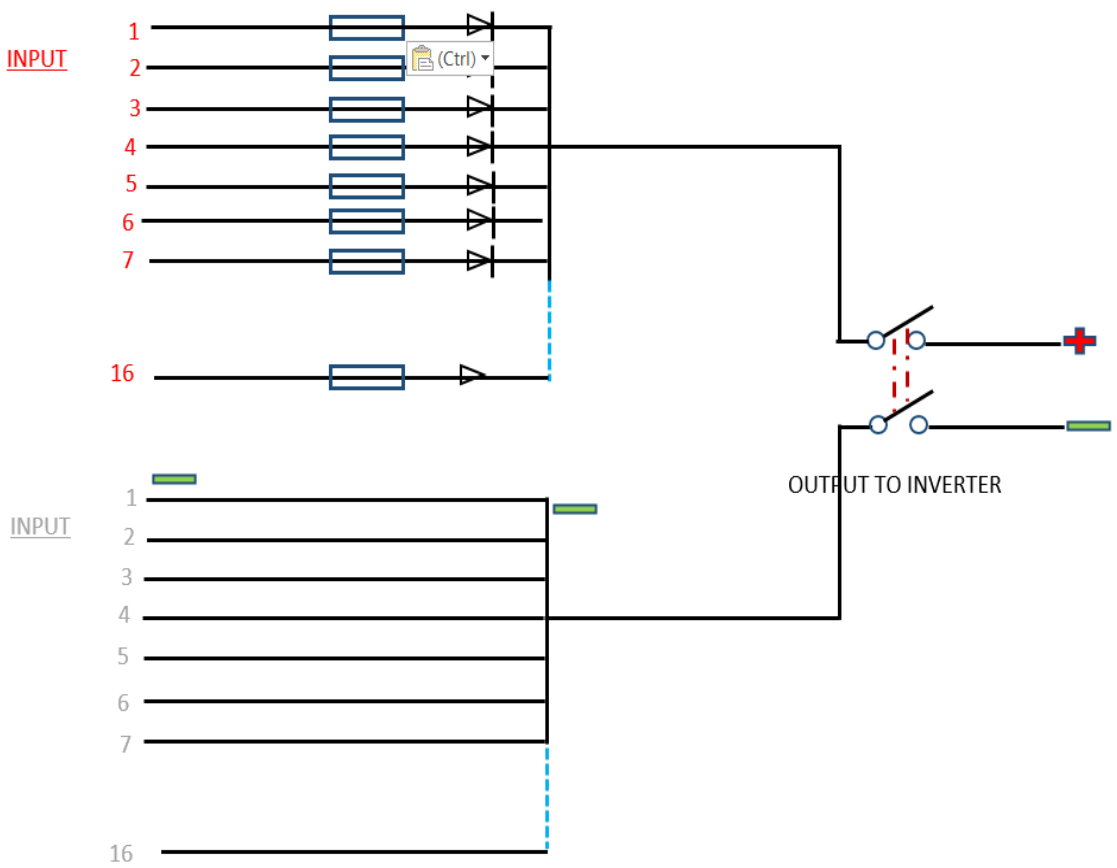


Figure 4.2 Schematic diagram of combiner box or array joint box

Figure 4.3 Solar modules from the Navrongo Solar PV plant (Source: Authors own image)

Figure 4.4 Solar modules from the Navrongo solar PV plant. (Source: VRA, 2017)

4.4 Data Collection and System Monitoring

There is a data logger that monitors and records the output of the DC array from the photovoltaic modules, the AC output from the Inverters and other conditions of these equipment. This data is recorded in 20minutes interval. It is then transmitted to a communication receiver in the control room which is linked to the console for monitoring. There is also a pyrometer which measures the global solar radiation falling at the plane of the modules and also the temperature of the environment.

However, the pyrometer has been out of use since July 2015.

4.5 Methodology

4.5.1 Economic Indicators

The economic analysis was undertaken using the actual energy production data from the power plant. The indicators that point out the financial viability of the plant are Simple Payback Period, Levelized Cost of Energy (LCOE) and Greenhouse Gas savings. Using the present feed-in-tariff, the Simple payback period and Levelized cost of electricity for the power plant is calculated.

These indicators can again be compared with predicted values from the retscreen software to see how they differ. This software is a simple easy –to- use, Excel based software. It is a decision support tool designed to help decision makers and energy professionals to evaluate the financial viability of renewable energy, energy efficiency and cogeneration projects. (Retscreen, nd)

RETScreen Financial Analysis - Power project

Financial parameters

General		
Fuel cost escalation rate	%	
Inflation rate	%	
Discount rate	%	10.0%
Project life	yr	25
Finance		
Incentives and grants	$	
Debt ratio	%	
Income tax analysis	☐	

Annual income

Electricity export income		
Electricity exported to grid	MWh	3,833
Electricity export rate	$/MWh	161.00
Electricity export income	$	617,155
Electricity export escalation rate	%	
GHG reduction income	☐	
Net GHG reduction	tCO2/yr	752
Net GHG reduction - 25 yrs	tCO2	18,812
Customer premium income (rebate)	☐	
Other income (cost)	☐	
Clean Energy (CE) production income	☐	

Project costs and savings/income summary

Initial costs			
Power system	100.0%	$	8,000,000
Balance of system & misc.	0.0%	$	0
Total initial costs	**100.0%**	**$**	**8,000,000**
Annual costs and debt payments			
O&M		$	60,865
Fuel cost - proposed case		$	0
Total annual costs		**$**	**60,865**
Periodic costs (credits)			
Annual savings and income			
Fuel cost - base case		$	0
Electricity export income		$	617,155
Total annual savings and income		**$**	**617,155**

Financial viability

Pre-tax IRR - equity	%	4.8%
Pre-tax IRR - assets	%	4.8%
After-tax IRR - equity	%	4.8%
After-tax IRR - assets	%	4.8%
Simple payback	yr	14.4
Equity payback	yr	14.4
Net Present Value (NPV)	$	-2,950,532
Annual life cycle savings	$/yr	-325,054
Benefit-Cost (B-C) ratio		0.63
Energy production cost	$/MWh	245.80
GHG reduction cost	$/tCO2	432

Yearly cash flows

Year #	Pre-tax $	After-tax $	Cumulative $
0	-8,000,000	-8,000,000	-8,000,000
1	556,290	556,290	-7,443,710
2	556,290	556,290	-6,887,420
3	556,290	556,290	-6,331,129
4	556,290	556,290	-5,774,839
5	556,290	556,290	-5,218,549
6	556,290	556,290	-4,662,259
7	556,290	556,290	-4,105,969
8	556,290	556,290	-3,549,678
9	556,290	556,290	-2,993,388
10	556,290	556,290	-2,437,098
11	556,290	556,290	-1,880,808
12	556,290	556,290	-1,324,518
13	556,290	556,290	-768,227
14	556,290	556,290	-211,937
15	556,290	556,290	344,353
16	556,290	556,290	900,643
17	556,290	556,290	1,456,934
18	556,290	556,290	2,013,224
19	556,290	556,290	2,569,514
20	556,290	556,290	3,125,804
21	556,290	556,290	3,682,094
22	556,290	556,290	4,238,385
23	556,290	556,290	4,794,675
24	556,290	556,290	5,350,965
25	556,290	556,290	5,907,255

Cumulative cash flows graph

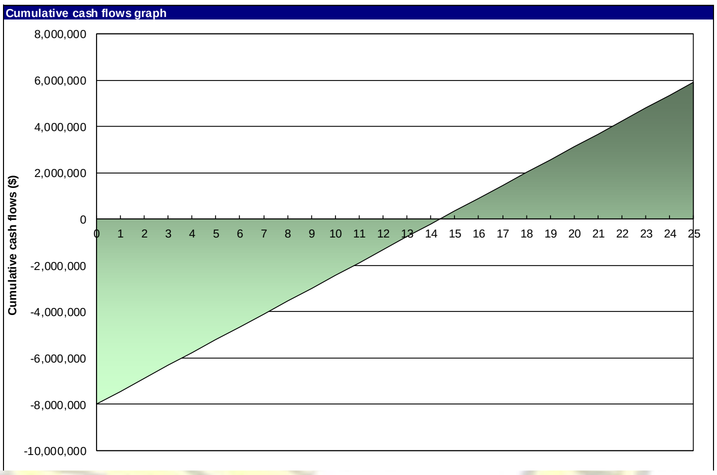


Figure 4.5 Screenshot from Retscreen Simulation

4.5.2 Technical performance analysis

A simulation software, PVSYT was used to obtain the predicted technical performance parameters. This is an energy modelling tool designed to be used in the solar industry to simulate the performance of solar photovoltaic systems. It is used to study, size and carryout performance analysis of standalone and grid connected PV systems. It mainly requires global solar radiation data, ambient temperature, electrical and mechanical specification as input data.

The technical performance value that were obtained from the simulation software were compared with the calculated values that were obtained from the actual operational data from the plant. The daily measured operational records used from the plant were from June 2013 to May 2016. This was analysed from June 2013 to May 2014, June 2014 to May 2015 and June 2015 to May 2016. From the analysis the relevant Technical indices were calculated. These values were compared with other similar projects across the globe.

PVSYST V5.74		22/01/17	Page 2/3

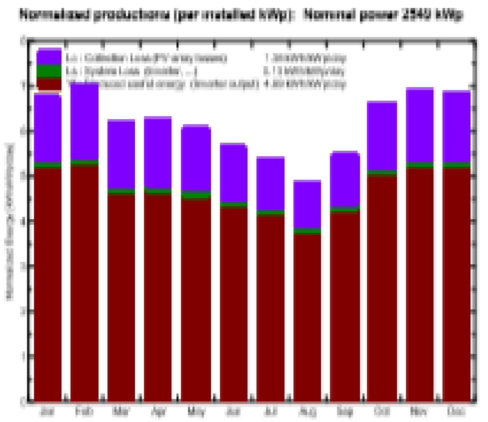
Grid-Connected System: Main results

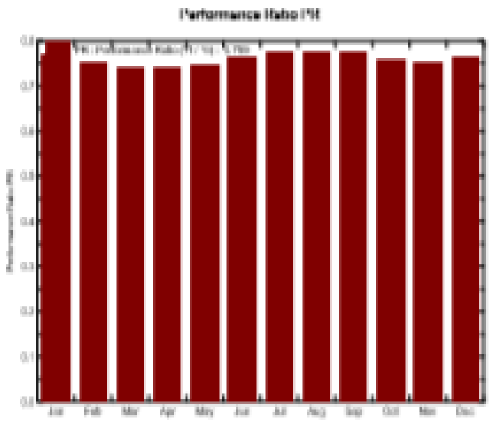
Project : **Grid-Connected Project at Navrongo**

Simulation variant : **Navrongo Plant**

Main system parameters	System type	**Grid-Connected**		
PV Field Orientation	tilt	13°	azimuth	0°
PV modules	Model	STP 295-24/Vd	Pnom	295 Wp
PV Array	Nb. of modules	8640	Pnom total	**2549 kWp**
Inverter	Model	Ingecon Sun 500 TL U X208 Indoor	Pnom	500 kW ac
Inverter pack	Nb. of units	5.0	Pnom total	**2500 kW ac**
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**4362 MWh/year**	Specific prod.	1711 kWh/kWp/year
	Performance Ratio PR	75.9 %		





Navrongo Plant
Balances and main results

	GlobHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	EffArrR %	EffSysR %
January	187.4	25.81	210.1	205.1	423.2	411.8	12.02	11.69
February	182.8	28.72	195.6	191.8	397.4	377.1	11.75	11.44
March	199.4	32.08	193.7	189.2	379.9	365.8	11.58	11.26
April	193.3	32.67	188.3	182.5	366.0	356.3	11.59	11.29
May	201.4	31.92	169.7	162.2	369.5	359.7	11.68	11.37
June	183.5	29.11	170.0	163.8	340.3	331.5	11.94	11.63
July	178.3	27.40	165.9	160.7	330.0	320.1	12.08	11.77
August	156.2	26.50	150.6	145.2	305.9	297.6	12.12	11.79
September	165.4	26.81	164.8	159.4	333.8	324.8	12.08	11.76
October	196.0	29.43	206.2	200.6	408.7	387.6	11.82	11.50
November	186.6	28.34	207.4	202.6	409.7	398.6	11.79	11.48
December	185.8	25.74	212.3	207.4	423.4	411.7	11.88	11.57
Year	2207.2	28.79	2255.5	2183.7	4481.8	4361.7	11.85	11.53

Legends:	GlobHor	Horizontal global irradiation	EArray	Effective energy at the output of the array
	T Amb	Ambient Temperature	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	EffArrR	Effic. Eout array / rough area
	GlobEff	Effective Global, corr. for IAM and shadings	EffSysR	Effic. Eout system / rough area

Figure 4.6 Screenshot from PV SYST Simulation

PVSYST V5.74		22/01/17	Page 1/3

Grid-Connected System: Simulation parameters

Project :	**Grid-Connected Project at Navrongo**			
Geographical Site	**Navrongo**		**Country**	**Ghana**
Situation	Latitude	10.9°N	Longitude	1.1°W
Time defined as	Legal Time	Time zone UT+0	Altitude	198 m
	Albedo	0.20		
Meteo data :	Navrongo, Meteonorm SYN File			

Simulation variant :	**Navrongo Plant**	
	Simulation date	22/01/17 10h25

Simulation parameters

Collector Plane Orientation	Tilt	13°	Azimuth	0°
Horizon	Free Horizon			
Near Shadings	No Shadings			

PV Array Characteristics

PV module	Si-poly Model	**STP 295-24/Vd**		
	Manufacturer	Suntech		
Number of PV modules	In series	16 modules	In parallel	540 strings
Total number of PV modules	Nb. modules	8640	Unit Nom. Power	295 Wp
Array global power	Nominal (STC)	**2549 kWp**	At operating cond.	2303 kWp (50°C)
Array operating characteristics (50°C)	U mpp	533 V	I mpp	4325 A
Total area	Module area	**16765 m²**		
Inverter	Model	**Ingecon Sun 500 TL U X208 Indoor**		
	Manufacturer	Ingeteam		
Characteristics	Operating Voltage	350-820 V	Unit Nom. Power	500 kW AC
Inverter pack	Number of Inverter	5 units	Total Power	2500 kW AC

PV Array loss factors

Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
=> Nominal Oper. Coll. Temp. (G=800 W/m², Tamb=20°C, Wind=1 m/s.)			NOCT	56 °C
Wiring Ohmic Loss	Global array res.	2.1 mOhm	Loss Fraction	1.5 % at STC
Module Quality Loss			Loss Fraction	0.1 %
Module Mismatch Losses			Loss Fraction	2.0 % at MPP
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Parameter	0.05

User's needs :	Unlimited load (grid)

Figure 4.7 Screenshot from PV SYST Simulation

CHAPTER 5: RESULTS AND DISCUSSIONS

In this chapter, actual generation and relevant meteorological data at the site of the Navrongo solar power plant as well as simulations are presented and analysed.

5.1 Results of technical performance

5.1.1 Total energy generated

From the measured generated data shown in Appendix A, the total generated energy for Year One (June 2013- May 2014) is 3835.62 MWh, Year Two (June 2014 –May 2015) is 3770.02MWh and Year Three (June 2015 – May 2016) is 3037.5MWh.

The result is presented in fig 5.1 and table 5.1. It should be noted that part of the energy generated by the plant is used to power some air conditioners in the control room and other equipment. The energy delivered to the grid is, therefore, less than the energy generated.

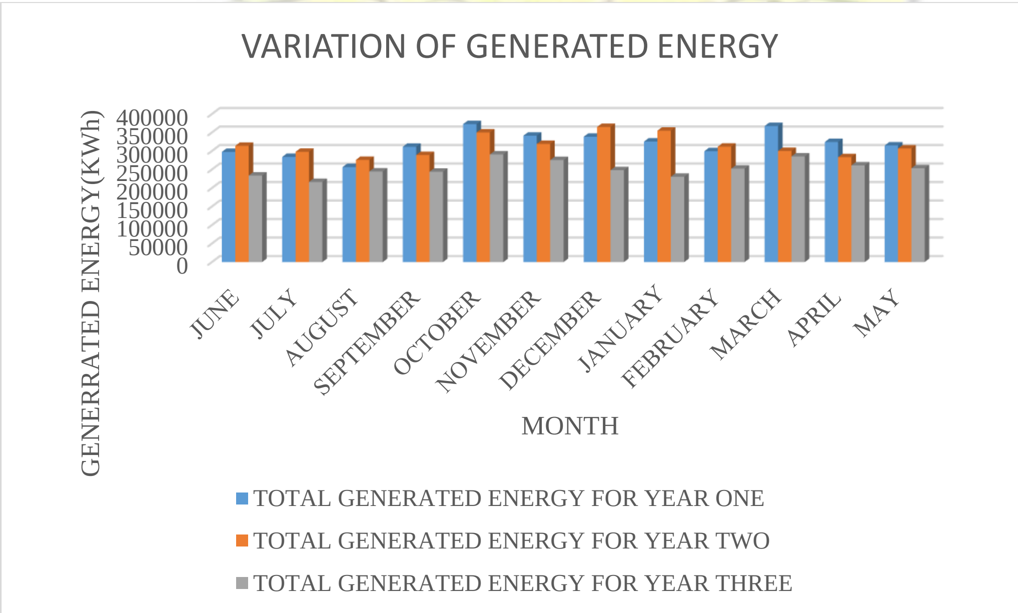


Figure 5.5 Monthly energy generated by the plant

Table 5.1 Generated energy for the three year period

MONTH	TOTAL GENERATED ENERGY FOR YEAR ONE	TOTAL GENERATED ENERGY FOR YEAR TWO	TOTAL GENERATED ENERGY FOR YEAR THREE
JUNE	297646.28	314161.25	233813.93
JULY	284176.67	297876.75	216558.44
AUGUST	256763.66	276206.22	244772.27
SEPTEMBER	311539.72	289431.8	244278.13
OCTOBER	372676.68	350236.52	290943.3
NOVEMBER	341517.02	319327.82	275730.13
DECEMBER	338570.62	364977.19	248251.3
JANUARY	325705.77	355208.7	230613.56
FEBRUARY	299625.28	311827.93	252371.6
MARCH	367739.31	300364.96	285379.94
APRIL	324528.61	283614.34	261213.28
MAY	315134.78	306945.2	253536.34

The following observations were made from figure 5.1 and table 5.1

- The monthly energy generated decreased from 372.7MWh in October 2013 to 216.6MWh in July 2015 with an average 295.6MWh.
- The generated energy depends on the global radiation and other site conditions. Any variation, therefore, in these parameters result in the variation of energy generated.
- Months of high generation is an indication of high global radiation and other favourable weather conditions and low generation indicates low radiation, cloudy weather and other unfavourable condition.
- The generated energy in Year Two and Year Three is on the decline. The decline between Year One and Year Two was 1.7% and Year One and Year Three is

20.8%. Since the pyrometer that is supposed to measure the site condition was out of service within that period, it was difficult to attribute this to the global radiation and site condition. *This may, however be attributed to photovoltaic module degradation.*

5.1.2 Reference yield (Yr)

The reference yield given in hours, is an indication of peak sun-hour at the reference irradiance. This is an indication of the theoretical energy available to the solar modules. The result is presented in Figure 5.2 and Table 5.2.

Table 5.2 Reference yield for Year One and Year Two

MONTH	REFERENCE YIELD(YEAR ONE)	REFERENCE YIELD(YEAR TWO)
JUNE	151.96	188.5
JULY	141.1	174.9
AUGUST	161.8	160.9
SEPTEMBER	151.4	161.2
OCTOBER	204.9	205.1
NOVEMBER	180.8	166
DECEMBER	182.5	186.9
JANUARY	184	187.1
FEBRUARY	184.38	175.9
MARCH	201.1	192
APRIL	192.7	179
MAY	196.2	206.5

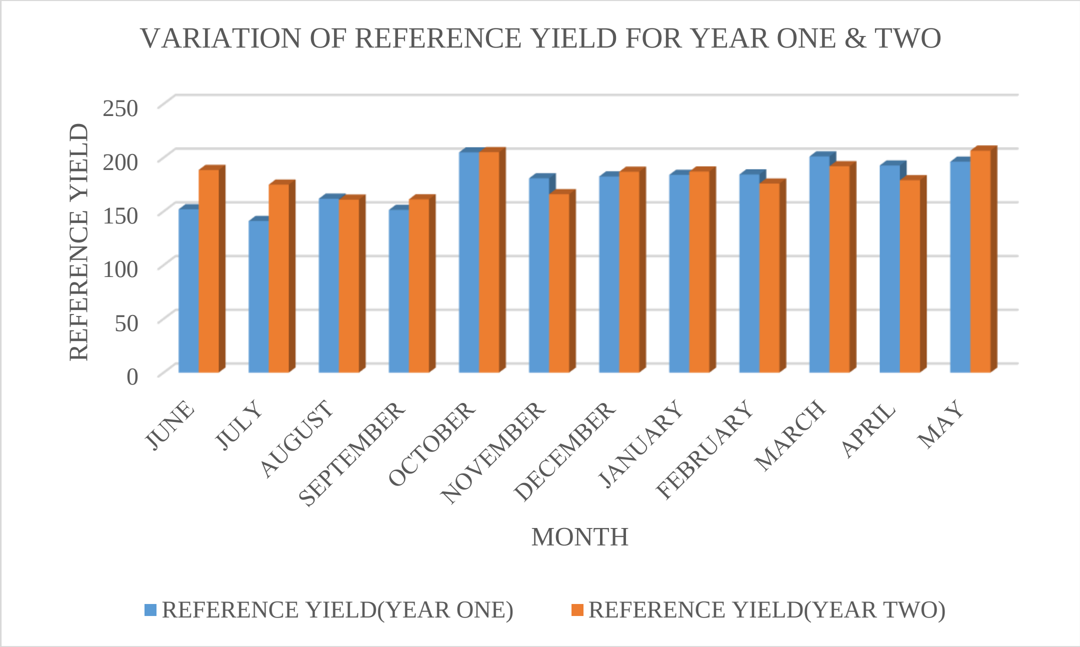


Figure 5.6 Monthly variation of reference yield for Year One and Year Two

The following observations can be made from Table 5.2 and Fig 5.2:

- The peak sun hours increased from 4.555h/day in July 2013 to 6.6h/day in October 2013 resulting in an annual average peak sun hours of 5.19h/day and a total of 2158.4h
- Although year two had higher peak sun hours than year one, generated energy declined slightly in year two as can be seen in Table 5.3. This may be attributed to factors like system outages or reduced maintenance.
- Since the solar plant is grid connected, anytime the power from the system is off, the inverters also switch off. This is a safety measure to prevent islanding which can cause accident in the utility's network. The inverters must necessarily see voltage from the system to be able to switch on.

The data for *reference yield for Year Three could not be obtained, because the instrument for the measurement of global radiation at the plant got damaged in the Third year.*

5.1.3 Final yield (Yf)

This section presents the final yield for the period from June 2013 to May 2015(Year one & two). The data is presented in figure 5.3 and table 5.3

Table 5.3 Final yield for Year One and Year Two

MONTH	FINAL YIELD (YEAR ONE)(h/day)	FINAL YIELD (YEAR TWO)(h/day)
JUNE	119.06	123.2
JULY	113.7	119.2
AUGUST	102.7	110.5
SEPTEMBER	124.6	115.8
OCTOBER	149.1	140.09
NOVEMBER	136.6	127.7
DECEMBER	135.4	146
JANUARY	130.3	142.1
FEBRUARY	119.85	124.7
MARCH	147.1	120.1
APRIL	129.8	113.4
MAY	126.1	122.8

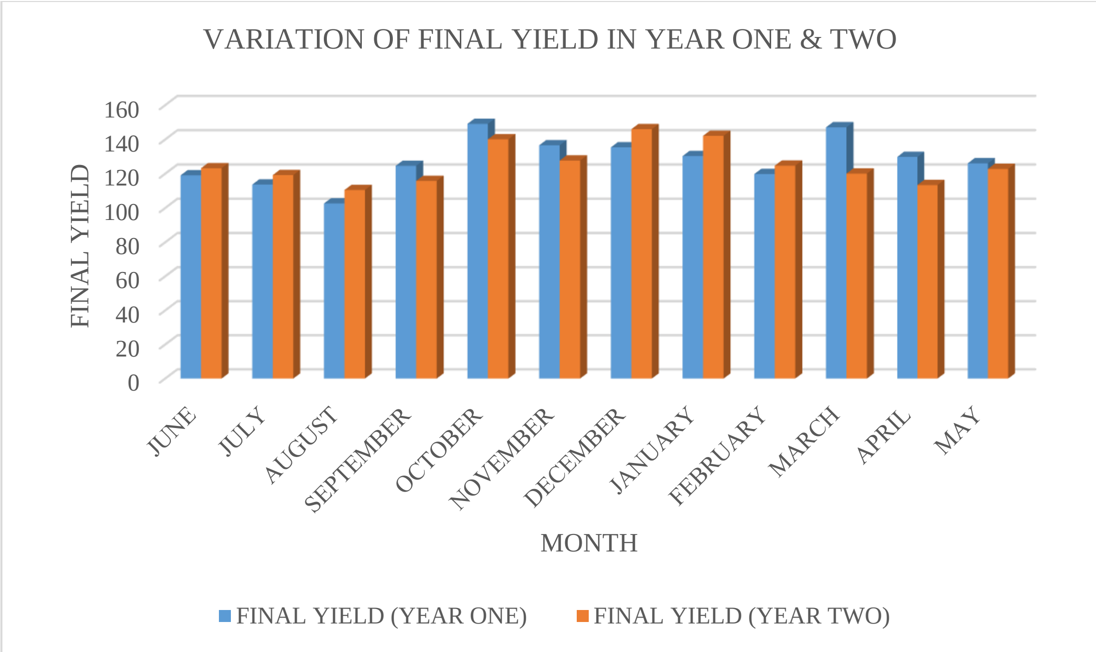


Figure 5.7 Variation of final yield for Year One and Year Two

The following observations were made from Figure 5.3 and Table 5,3

- The final yield increased from 3.3h/day(102.7h for the month) in August 2013 to 4.8h/day(149.1h for the month)in October 2013 with an average of with an average of 4.17h/day.
- The plant operated effectively for 1520 hours per year.
- Final yield for July, August and September were relatively low. This could be attributed to heavy cloudy conditions and high moisture weather content that occurs at that time of the year.
- The reference yield is the measure of theoretical energy available to the solar modules while the final yield indicates how many hours a day the solar pv system must operate at its rated power to produce the same amount of energy as measured.

5.1.4 Performance ratio

The monthly performance ratios for year one and two are shown in Fig 5.4 and Table 5.5.

Table 5.5 Performance Ratio for Year One and Year Two

MONTH	PERFORMANCE RATIO YEAR ONE (%)	PERFORMANCE RATIO FOR YEAR TWO(%)
JUNE	78.35	65.4
JULY	80.5	68.1
AUGUST	63.5	68.7
SEPTEMBER	82.3	71.8
OCTOBER	72.8	68.3
NOVEMBER	75.6	77
DECEMBER	74.2	78.1
JANUARY	70.8	75.7
FEBRUARY	65	70.9
MARCH	73.1	62.6
APRIL	67.4	63.4
MAY	64.2	59.5

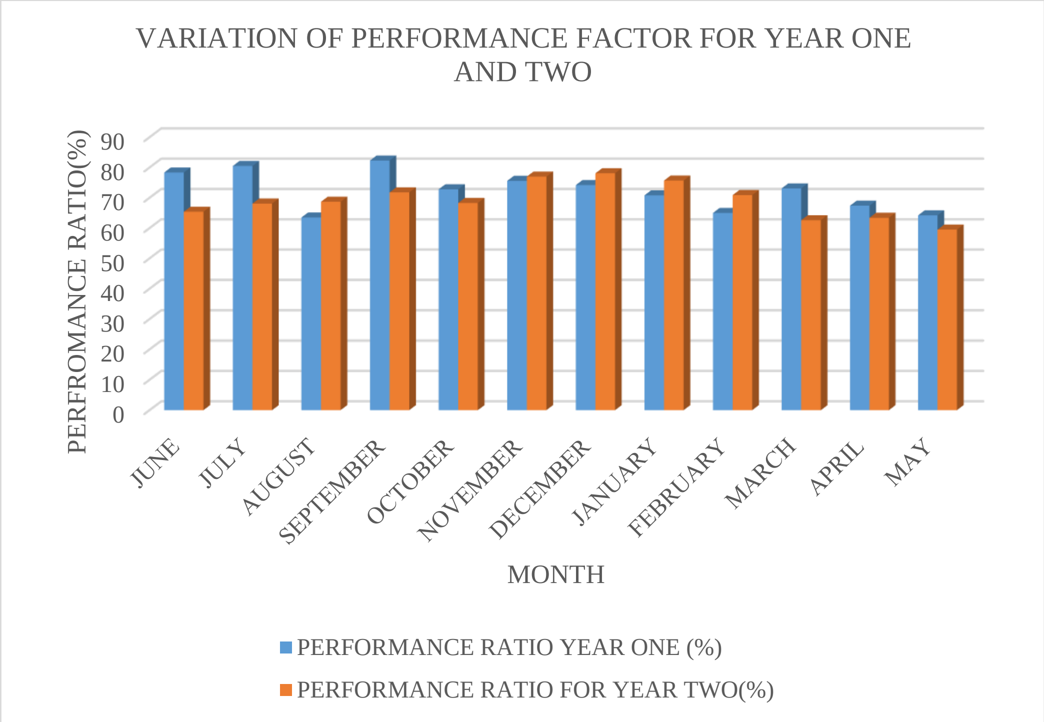


Figure 5.4 Monthly variation of performance ratio for year one and two

The Performance Ratio increased from 59.5% in May 2015 to 82.3% in September 2013 with an average of 70.6% over the period as shown in figure 5.4 and table 5.4.

It was observed that performance ratio was high between June and September but was reduced between February and May. Although the period between February and May was characterised by high reference yield as evidenced in figure 5.3 and table 5.3, the relative low performance ratio could be attributed to high ambient temperature resulting in high module temperature and reduction in module performance. The site ambient temperature was, however, relatively low between June and September and could contribute to the modules relatively high performance. This can be shown in figure 5.5.

5.1.5 Monthly ambient temperature at Navrongo

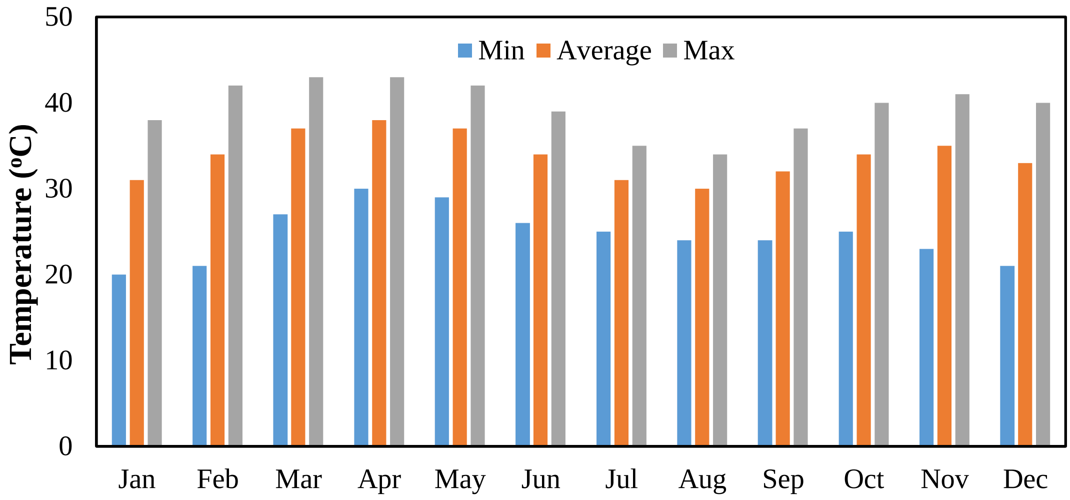


Figure 5. 5 Monthly ambient temperature at Navrongo

5.1.6 Capacity factor for a photovoltaic system

Table 5.5 Capacity factor for year one and two

MONTH	CAPACITY FACTOR FOR YEAR ONE	CAPACITY FACTOR FOR YEAR TWO(%)
JUNE	16.54	17.1
JULY	15.3	16
AUGUST	13.8	14.8
SEPTEMBER	16.7	16.1
OCTOBER	20	18.83
NOVEMBER	18.4	17.7
DECEMBER	18.2	19.6
JANUARY	17.5	19.1
FEBRUARY	17.83	16.8
MARCH	19.8	16.1
APRIL	18	15.2
MAY	16.9	16.5

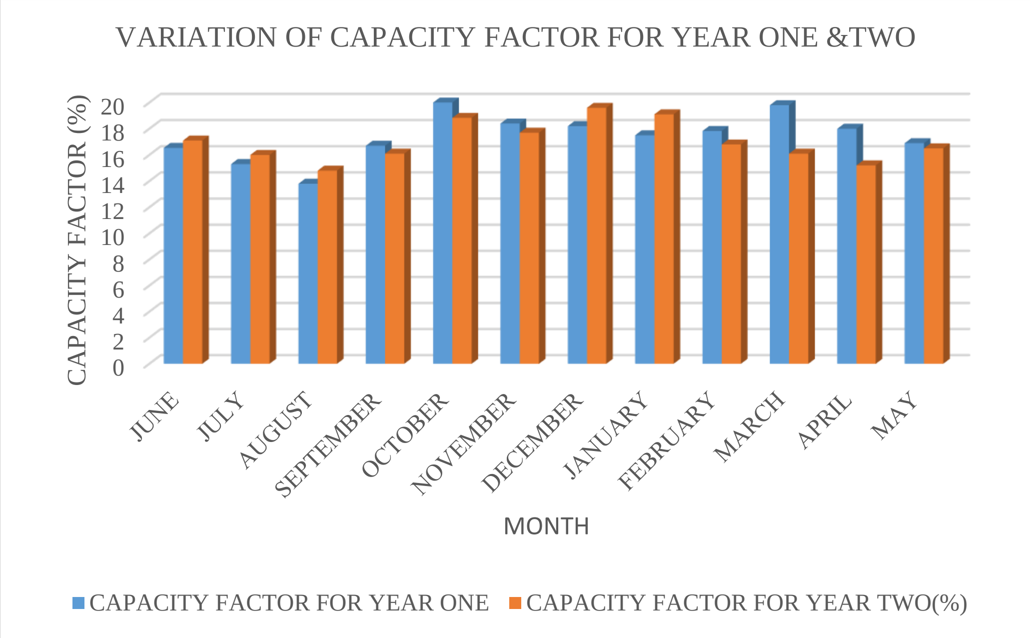


Figure 5.6 Variation of Capacity factor

The monthly capacity factor which is based on the assumption that the installation is expected to generate electricity 24 hours per day is presented in Fig 5.6 and table 5.5. From the figure and the table, it is seen that the capacity factor increases from 13.8% in August to 20% in October with a monthly average of 17.2% over the three year period. This is because the capacity factor varies with the actual energy generated. As the actual energy generated increases the capacity factor also increases and vice-versa.

5.1.6 Result of PVSYST simulation.

To determine the technical performance indicators, the PVSYST simulation software was used. The global radiation input to the software was generated using Meteonorm 7.0 software. The result of the simulation is shown in Table 5.6.

Table 5.6 Results from a PVSYST simulation

Description	Unit	Simulated Value
Annual energy produced,	MWh	4362
Final Yield (Annual),	h/year	1711
Performance Ratio,	%	75.9
Collection losses (Daily),	h/day	1.360
System losses(Daily),	h/day	0.130
Produced Useful Energy (Daily),	h/day	4.690
Reference Yield (Daily),	h/day	5.296
Collection loss, %	%	22
System loss,	%	2.1
Produced useful Energy,	%	75.0
System Efficiency,	%	11.53

5.1.7 Comparison of Simulated and Measured Generated Energy.

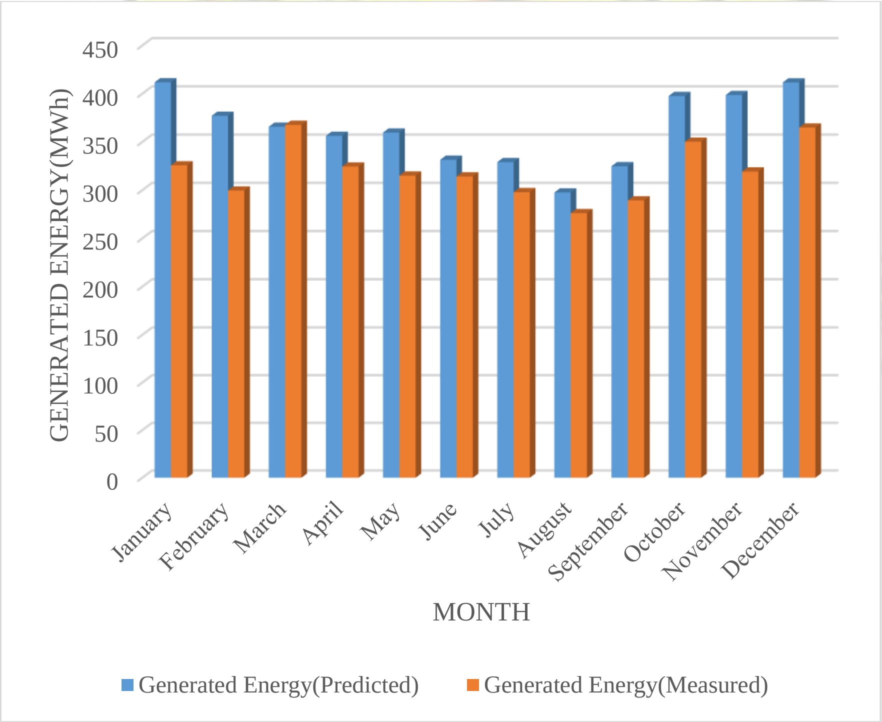


Figure 5.7 Comparison of Simulated and Measured Generated Energy

5.1.8 Comparison of Technical Performance Indicators.

Table 5.7 Technical Performance indicators

Indicator	Measured	Simulated	Percentage reduction	Remarks(allowable value 8.7%)
Generated energy(MWh)	3835.66	4362	13.7	Violated
Reference Yield (h/year)	2132.84	2254.3	5.6	Within
Final Yield(H)	1534.3	1711	11.5	Violated
Performance Ratio (%)	72	75.9	5.4	Within
Capacity factor (%)	17.5	19.9	6.4	Within

The simulated annual energy generated is 4362MWh. This can be compared to the measured generated energy in year one which had a value of 3835.6MWh. This is a percentage reduction of 13.7%. The highest generated energy was realized in January with the minimum in August. With the measured value the highest generated energy was realized in October and the minimum in August. Table 5.7 shows the performance indicators for both measured and simulated values with some percentage reduction.

The differences in the indicators is as a result of the software tool used to generate the global radiation used to do the simulation. Theverand, et al, (2010) agree that 8.7% variation is allowed. The simulated and measured energy generated is compared and shown in Figure 5.7. In addition to the acceptable percentage of reduction in the software tool, there is also practical situations like system outages, equipment failure, shut down for maintenance, etc. In the year under review there were total of eleven days of total shutdown where there were no generation at all as can be seen in Appendix A. These situations accounts for the differences in the simulated and the measured output.

5.2 Results of economic analysis

5.2.1 Monthly energy sales

The tariff for electricity generated from this plant is GH¢ 64.41 according to PURC of Ghana, and this price is guaranteed for ten years. (PURC, 2012) After the ten-year period, PURC would review the tariff to meet the present economic conditions for another ten years. From this rate for the sale of electricity, the energy sales from the energy delivered to the grid from the plant can be calculated. The sale of energy is presented in Table 5.8 and illustrated in Figure 5.8.

Table 5.8 Energy sales in Ghana cedis

MONTH	YEAR ONE	YEAR TWO	YEAR THREE
JUNE	187063.97	198377.8	142137.2
JULY	179958.1	188543.9	135452.5
AUGUST	165355.8	177876.8	154289.5
SEPTEMBER	200631.6	186394.1	152589.4
OCTOBER	238099.7	225552.32	182612.6
NOVEMBER	216944.3	205647.1	172856
DECEMBER	214027	235045.3	155641.9
JANUARY	209754.5	225039.36	145672.8
FEBRUARY	184196.88	197608.8	159332
MARCH	233915	189954.2	179985.1
APRIL	205989.8	178980.48	163022.2
MAY	198648.2	187693.8	159988.9

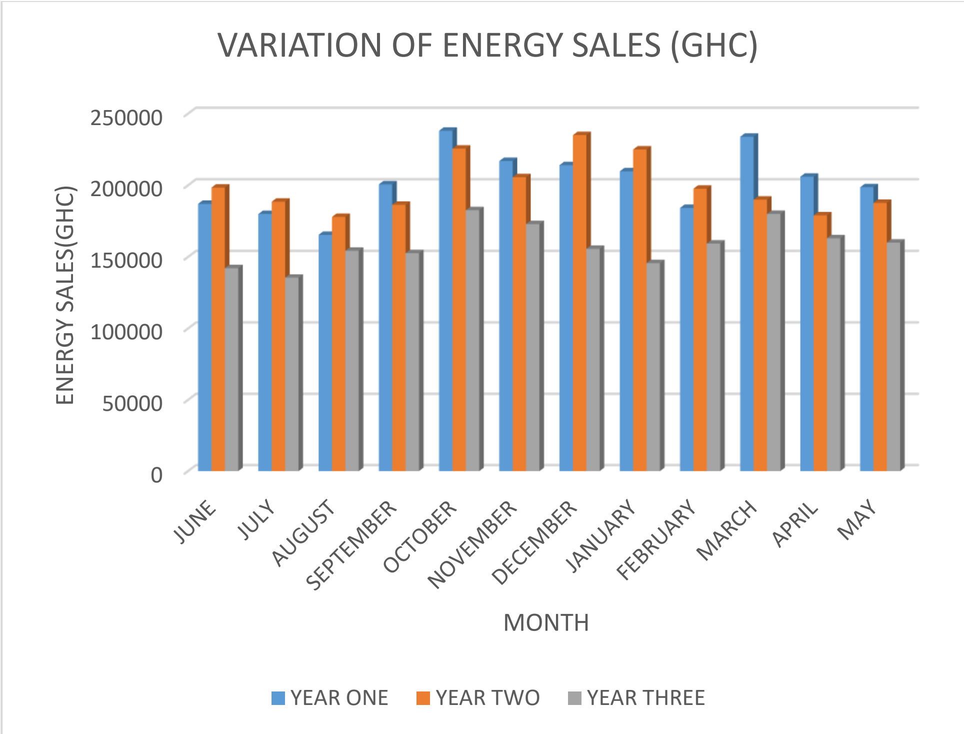


Figure 5.8 Energy Sales in Ghana cedis

I. It can be realized that in year one highest sale of GH¢238,099.7 was made in October and the lowest sale GH¢ 165,355.8 was made in August.

II. In Year Two, the highest sale was in December and amounted to GH¢235,045.3 and lowest in August and amounted GH¢177,876.8.

III. Year Three had highest sale of GH¢ 182, 612.6 in October and lowest sale of GH¢135,452.5 in July.

5.2.2 Payback Period

The Payback Period was calculated based on the following data:

- Initial cost of the Plant - $ 8,082,025.00
- Annual average electricity delivered to the grid – 3470.11MWh (over the monitored period)
- Feed-in-Tariff – GH₵0.644/KWh

- Exchange rate to the dollar - US$1.00 = GH¢1.99 (at the time of commissioning of the installation).

Based on the data shown a simple payback period of the installation is about 7.2 years. Therefore, based on this simple payback approach, it can be concluded that the installation can recover its investment cost within ten years of the approved feed-in tariff period.

However, if similar installation is granted the same feed-in tariff of GHc0.644/kWh using the current exchange rate of US$1.00 = GH¢4.25 (as of June, 2017) , the simple payback period of such project would be about 15.4 years. Hence, it can be concluded that success of these types of projects in Ghana can be influenced by prevailing economic conditions.

It should be noted here that, simple payback does not take into consideration the time value of money and annual O&M cost, which is accounted for through real interest (discount) rate. With current interest rate and inflation rate of 22.5% and 13%, respectively in Ghana and using Fisher expression the discount rate is estimated as 8.4%. Therefore, the discounted payback period for a situation where the exchange rate is US$1.00 = GH¢1.99, is 11.5 years. For an economic viable, utility-scale grid-connected solar PV system, a payback period between 8 and 18 years is recommended (International Finance Corporation, 2015). Hence, the Navrongo solar PV power plant can be said to be economically viable and that approved feed-in tariff may be considered as generous.

5.2.3 Levelized Cost of Energy (LCOE)

The levelized cost of energy per unit kWh (LCOE) was estimated based on the following assumptions: (i) the economic lifetime (n) of a solar PV installation is normally taken as 25 years, (ii) the real interest rate is taken as 8.4% (as estimated previously), (iii) the operating and maintenance (O&M) cost of a solar PV installation typically ranges between 1% and 5% of the investment cost (Essah, 2011). For this analysis, the O&M cost is assumed to be 3%, which is the average value of this range, of the annual cost of installation (system price/lifetime) and (iv) the installation annual energy output assumed be the same as the average output over the study period.

$$\text{LCOE} = \frac{\text{C RFxCi} + \text{Co}\alpha\text{m}}{\text{E}\alpha} \text{ cost/kwh} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.2)$$

Where Coαm is the annual operation and maintenance cost

Ci is the annualized investment cost and

CRF is the capital recovery factor which is given by:

Eα is annual average energy delivered to the grid

$$\text{CRF } (i, n) = \frac{i(1+i)^n}{(1+i)^n - 1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.3)$$

Where *i* is the interest rate (in fraction) and *n* is the payback period (in years)

Based on these assumptions, using equations 3.2 & 3.3 the LCOE of the system is estimated as US$0.229/kWh (or GH¢0.455/kWh, with US$1.00 = GH¢1.99 when the installation was commissioned).

The final retail tariff for residential and non-residential consumers in Ghana comprises of energy charge, street light charge, national electrification charge and service charge (Electricity tariff reckoner, 2017). In addition, residential consumers with monthly electricity consumption of up to 300 kWh per month and all non-residential consumers benefit from subsidies and relief support (Electricity tariff reckoner, 2017). It can be observed from this that the estimated LCOE is significantly lower than final retail tariff being paid by all non-residential consumers irrespective of their electricity level per month. For example, based on the current final retail tariff, non-residential consumer would pay GH¢350.55 per month when 300 kWh of electricity is consumed. However, using the estimated LCOE, this consumer would pay GH¢136.50 per month for this amount of electricity. Furthermore, using the current exchange rate of US$ 1= GH¢4.25, this consumer would pay GH¢291.98 per month of 300 kWh of electricity consumed. This indicates that for this class of consumers, investment in solar PV energy system could be considered as economically viable for non-residential electricity users in Ghana.

For the residential electricity consumers, it is noted that this solar PV installation LCOE is lower for consumer with electricity usage of at least 60 kWh per month and the cost benefit of this installation increases as electricity usage increases. For instance, based on the current final retail tariff, residential consumer would pay GH¢189.47 per month of 300 kWh of electricity consumed. However, using the estimated LCOE, this consumer would pay GH¢136.50 per month, which is about 28% lower the retail tariff, for 300 kWh of electricity.

5.2.4 Greenhouse Gas saving

Table 5.9 Greenhouse Gas savings

Year	Energy Gen.	Energy Del.
Year 1	1419.18	1390.4
Year 2	1394.96	1367.73
Year 3	1123.9	1093.7

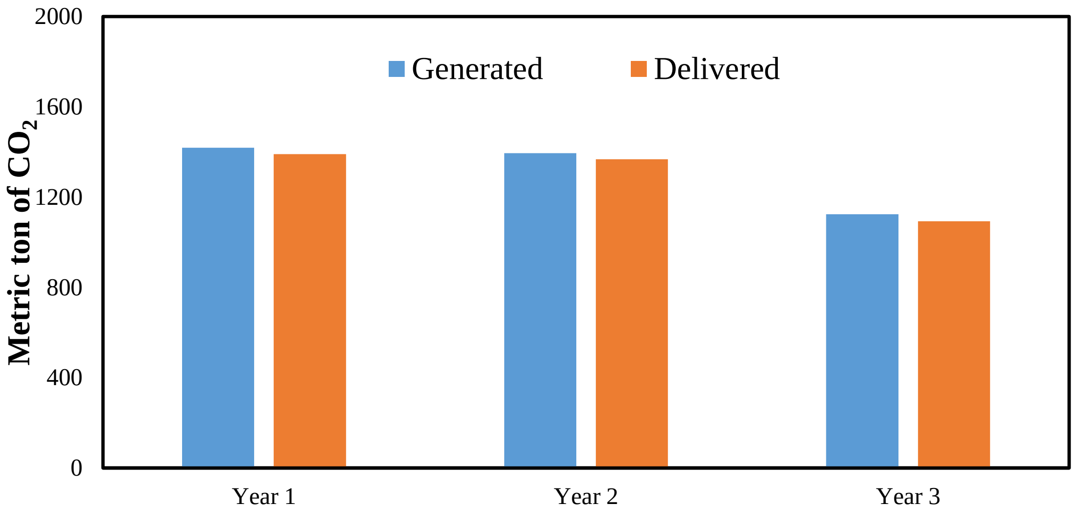


Figure 5.9 Yearly avoided carbon dioxide by the solar PV installation

Figure 5.9 and Table 5.9 shows the amount of carbon dioxide that will not be released into Ghana's environment as a result of this installation.

I. Based on electricity generated by this installation, a total of 3898 metric tonnes of carbon dioxide is avoided over the three year monitoring period, with an average 1313 metric tonnes per year.

II. However, based on the actual electricity fed into the utility grid, 1284 metric tonnes per year of carbon dioxide have been saved.

III. For a hypothetical car with CO_2 emission of 150g/km and covering 10,000 km/year, this car would produce 1.5 metric tonnes of carbon dioxide per year.

IV. Therefore, this amount of carbon dioxide saved by this solar PV installation is equivalent to removing over 850 gasoline- or diesel powered cars from Ghanaian road annually.

5.3 Power Quality Measurement

According to the Energy Commission of Ghana as stated in the Ghana Grid code for Renewable connected Variable Renewable Energy Power plant, individual harmonic voltage distortion (IHD) limits for odd harmonics shall not exceed 2% and that for even harmonics 1%. Total harmonic voltage distortion shall not exceed 3% at the point of connection. (Energy Commission, 2015).

Measurement done at the point of connection indicated 1.4% harmonics, which is within the allowable limit.

5.4 Comparison of photovoltaic system performance.

Table 5.10 Performance studies of some installed PV system in the world

Source	Country	Performance ratio (%)	Final yield(h/day)
Ned Xoubi, 2015	Jordan	82.6	1939
Kymakis et al, 2009	Crete	67.3	1.96-5.07h/day
Sharma et al, 2013	India	74	1.45-2.84h/day
Boughamrane et al, 2016	Morocco	70.14	1650.66
C. Camaro et al, 2011 cited in (Hussin et al, 2013)	Italy, Rome	87	3.37/day
Hussin et al, 2013	Malaysia, Shah Alam	85	3.46/day
Kagilik, et al, 2013	Libya	76.9	1783
Okello et al, 2013	Port Elizabeth, South Africa	84	-
Quansah, et al, 2016	Kumasi, Ghana	48.8 – 71.3	-
De Lima et al, 2016	Northeastern, Brazil	82.9	1685.5
Ari et al, 2015	Kurdistan, Iraq	-	1699
Present study	Navrongo, Ghana	70.5	1520

I. These values can be compared with the performance ratio of the Navrongo Solar Plant where performance ratio 70.6% was obtained. This value is higher than performance ratio of Crete (67.3 %). It is also comparable with those of countries like Morocco (70.14 %) and India (74 %) and lower than that of Italy (87 %), Malaysia (85 %), South Africa (84 %) and Jordan (82.6 %).

II. On final Yield, the Navrongo plant has annual final yield of 1520 hours. This is higher than that of India (2.84 h/day), Crete (5.07 h/day) and Malaysia (3.46 h/day) but lower than that of Jordan (1939 h/day), Morocco (1650 h/day), Brazil (1686 h/day) and Libya (1783 h/day).

CHAPTER 6: CONCLUSION AND RECOMMENDATION

6.1 Conclusion

The performance of the 2.5MW solar photovoltaic power plant at Navrongo, Ghana has been analysed using operational data from the plant from June 2013 to May 2016. Due to a malfunction of the monitoring equipment at the site, the reference field, final yield, performance ratio and capacity factor were evaluated for the period from June 2013 to May 2015, whilst the final energy output was evaluated for the entire period.

The performance of the Navrongo Solar plant at the end of the studies can be summarized as follows:

- Within the reporting period, the installation generated 10643.3 MWh electricity, and delivered 10410.3 MWh of electricity to the national grid. The difference of 233 MWh between generated and delivered represents the amount of electricity that was consumed at the installation site.
- Based on generated electricity, the annual daily reference yield and final yield of the installation were found to be 5.92 h/day (or 2159 hours per year) and 4.17 h/day (or 1520 hours per year), respectively.
- The annual performance ratio and capacity factor of the installation are respectively, 70.6% and 16.2%. The relatively low value of the performance ratio of this installation could be as a result of high ambient temperature in the northern part of Ghana. That notwithstanding, the estimated performance is within the range expected for solar PV installation in tropical region.
- Using prevailing exchange rate at the time of commission of US$1.00 = GH¢1.99 the installation would deliver 3470.11MWh of electricity annually, have a payback period of 7.2 years is realized and hence the installation can recovers its

investment cost within the ten years of the guaranteed approved feed-in tariff period.

- Using the same feed-in tariff of GHc0.644/kWh, at the current exchange rate of, US$1.00 = GH¢4.25 (as of June, 2017), a simple payback period of about 15.4 years is realized, which, as per IFC recommendation is still economically viable.
- Using current grid emission factor in Ghana and quantity of electricity fed into the national grid, over 3852 metric tonnes of carbon dioxide have been avoided by this solar PV power plant since its installation.

The finding from this studies indicates that grid connected solar photovoltaic system for electricity generation is feasible in Ghana and could contribute significantly to Ghana's electricity generation deficit without degrading the environment.

6.2 Recommendations

The following recommendations are made for future work or research.

1. The weather station located at the plant which is faulty should be repaired and put to use immediately. This would enable easy monitoring of the solar resource and the temperature of the plant.

2. Further operational data should be obtained from the plant to carry out further analysis. This is needed to draw conclusion with regards to the seeming decline of the generated energy. It is recommended that after five years of operation of the plant, a trend analysis can be conducted on the generated energy to see how it comes out.

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APPENDIX A

DATE	MONTH	DAILY GENERATED ENERGY (kWH)	DAILY DELIVERED ENERGY (kWH)	TEMP (°C)	GLOBAL RADIATION (wh/m²)
6/1/2013	JUNE	12089.55	11880	27.517	505.42
6/2/2013		10742.38	10410	24.76	490.58
6/3/2013		13048.74	12330	24.76	494.67
6/4/2013		11790	11280	32.336	556.55
6/5/2013		7031.9	6870	27.7	294.22
6/6/2013		11081.26	10860	28.966	496
6/7/2013		11468.45	11280	36	560.36
6/8/2013		9380.09	9120	34.3	512.33
6/9/2013		9267.85	9120	32.736	490.91
6/10/2013		6969.05	6750	22	254.08
6/11/2013		12396.61	12180	29.317	546.42
6/12/2013		11482.49	11250	36.25	568
6/13/2013		11583.93	11460	36.915	608.18
6/14/2013		11268.56	11010	35.609	522.64
6/15/2013					
6/16/2013					
6/17/2013		11695.34	11490	37.889	564.09
6/18/2013		11618.2	11430	32.65	507.182
6/19/2013		10639.86	10440	30.59	524.9
6/20/2013		3568.87	3420	35.9	638.182
6/21/2013		9818.54	9720	27.645	200.09
6/22/2013		2409.46	2280	31.133	281.33
6/23/2013					
6/24/2013		8408.23	8220	32.1	407.18
6/25/2013		10854.2	10590	33.96	534.33
6/26/2013		9070.08	8940	33.14	400
6/27/2013		3007.38	2880	28.473	96.455
6/28/2013		10521.14	10320	33.309	514
6/29/2013		10562.97	10320	34.564	613
6/30/2013		9293.48	9180	31.08	482

DATE	MONTH	DAILY GENERATED ENERGY (kWH)	DAILY DELIVERED ENERGY (kWH)	TEMP (°C)	GLOBAL RADIATION (wh/m²)
7/1/2013	JULY	9487.22	9210	30	412
7/2/2013		9586.5	9540	29.94	412
7/3/2013		12925.99	12750	35.4	562
7/4/2013		7919.31	7800	28.3	380
7/5/2013					
7/6/2013		8807.01	8640	29.46	427
7/7/2013		10412.93	10260	30.42	440.75
7/8/2013		9236.82	9090	27.97	368.58
7/9/2013		8283.03	8190	28.88	345.67
7/10/2013		11805.17	11685	28.87	559.83
7/11/2013					
7/12/2013		11194.58	11040	28.04	508
7/13/2013		10801.2	10680	31.16	564.45
7/14/2013		3632.8	3540	25.518	134.09
7/15/2013		10440.72	10320	27.97	409.92
7/16/2013		9753.24	9660	29.45	441.75
7/17/2013		11487.6	11340	30.92	483
7/18/2013		11518.63	11280	29.97	480.25
7/19/2013		7558.04	7470	27.81	305.92
7/20/2013		3757.71	3660	31.5	325
7/21/2013		10050.58	9840	29.08	360.92
7/22/2013		11118.77	10920	29.7	486.58
7/23/2013		11889.62	11730	31.3	618
7/24/2013		2316.37	2220	22.82	78.3
7/25/2013		6982.8	6810	26.42	297.25
7/26/2013		11859.67	11730	28.41	572.73
7/27/2013		8126.8	7980	27.82	321.2
7/28/2013		12068.24	11970	30.68	520.5
7/29/2013		6869.48	6660	26.95	281.5
7/30/2013		4707.47	4560	26.89	195.9
7/31/2013		10619.34	10470	28.66	467.2

DATE	MONTH	DAILY GENERATED ENERGY (kWH)	DAILY DELIVERED ENERGY (kWH)	TEMP (°C)	GLOBAL RADIATION (wh/m²)
8/1/2015	AUGUST	7702.39	7500	28.04	362.67
8/2/2015		9621.85	9450	28.31	403.4
8/3/2015		10676	10500	29.28	357.9
8/4/2015		11651.06	11580	30.01	488
8/5/2015		11253.44	11130	29.1	508.6
8/6/2015		8796.26	8670	27.56	358.6
8/7/2015		3624.16	3540	23.64	130.3
8/8/2015		7292.81	7080	26	336.3
8/9/2015		9607.81	9211	27.37	329.7
8/10/2015		10108.32	9990	28.07	441.8
8/11/2015		8002.68	7890	31.92	761.3
8/12/2015		3615.52	3510	25.52	111.2
8/13/2015		9049.56	8940	27.26	357.5
8/14/2015		10530.57	10620	28.77	434
8/15/2015		3396.44	3270	24.67	118.9
8/16/2015		5894.09	5370	26.5	342.9
8/17/2015		10402.9	10350	28.46	433.2
8/18/2015		1138.89	1140	28.04	505.3
8/20/2013		11050.23	10950	28.26	450.92
8/21/2013		8205.85	8010	25.18	331.4
8/22/2013		10068.65	9960	27.82	417
8/23/2013		6120.73	6060	29.49	499.9
8/24/2013		11624.39	11520	29.46	482.8
8/25/2013		2865.98	2760	23.64	110.2
8/26/2013		10531.65	10410	28.87	542.2
8/27/2013		7934.43	7800	27.4	2909.9
8/28/2013		12522.6	12420	29.64	499.4
8/29/2013		5559.53	5400	26.06	182.4
8/30/2013		5183.14	5040	25.6	223.3
8/31/2013		9786.43	9690	27.21	416.92

DATE	MONTH	DAILY GENERATED ENERGY (kWH)	DAILY DELIVERED ENERGY (kWH)	TEMP (°C)	GLOBAL RADIATION (wh/m²)
9/1/2013	SEPTEMBER	8787.57	8640	28.01	366.73
9/2/2013		10880.25	10740	28.74	463.5
9/3/2013		9839.85	9750	29.68	308.58
9/4/2013		9349.06	9180	29.06	352.55
9/5/2013		4428.2	4320	23.73	177.33
9/6/2013		8151.35	7980	25.38	277.25
9/7/2013		11364.56	11340	26.98	480.33
9/8/2013		13504.18	13380	29.83	607.83
9/9/2013		8868.78	8760	26.04	353.17
9/10/2013		12660.47	12600	26.99	505.42
9/11/2013		9631.35	9510	26.96	451.82
9/12/2013		7787.92	7680	26.23	355.92
9/13/2013		8617.58	8490	2744	344
9/14 2013		3736.4	3600		
9/15/2013		9577.86	9510	28.79	493.73
9/16/2013		10045.18	9930	30.5	532.83
9/17/2013		12681.28	12480	31.18	519
9/18/2013		13477.18	13440	31.38	570.75
9/19/2013		13110.8	13050	33.05	577.83
9/20/2013		13140.75	13110	30.97	570.17
9/21/2013		11688.61	11460	27.53	465.68
9/22/2013		11544.26	11460	31.88	565.58
9/23/2013		8199.66	8070	26.92	316.42
9/24/2013		9552.23	9360	26.73	429.33
9/25/2013		9754.32	9690	27.47	278.67
9/26/2013		11743.11	11730	29.93	534.17
9/27/2013		11204.3	11190	28.08	428.67
9/28/2013		11659.74	11610	28.81	534.5
9/29/2013		13649.61	13620	29.32	582
9/30/2013		12903.31	12750	31.59	536.33
		311539.72	308430		

DATE	MONTH	DAILY GENERATED ENERGY (kWH)	ACCUMULATED DELIVERED ENERGY (kWH)	TEMP (°C)	GLOBAL RADIATION (wh/m²)
10/1/2013	OCTOBER	13542.77	1603650	29.8	564.3
10/2/2013		13651.77	1617300	31.0	586.8
10/3/2013		10948.5	1628190	28.7	423.3
10/4/2013		12144.05	1640310	28.5	501.1
10/5/2013		12496.97	1652790	29.8	561.9
10/6/2013		13301.01	1666020	31.2	578.4
10/7/2013		13014.47	1678980	29.5	589.0
10/8/2013		3966.28	1682820	24.1	159.8
10/9/2013		12724.69	1695450	28.0	513.2
10/10/2013		6423.47	1701660	25.8	267.1
10/11/2013		12921.38	1714470	30.1	549.3
10/12/2013		11105.81	1725450	30.9	493.6
10/13/2013		10669.52	1736040	32.2	622.9
10/14/2013		13067.89	1749000	31.0	842.6
10/15/2013		10901.56	1759800	29.6	569.4
10/16/2013		12752.48	1772580	30.4	667.5
10/17/2013		12490.49	1784910	32.2	579.3
10/18/2013		12552.55	1797330	32.0	564.6
10/19/2013		10849.22	1808070	31.7	583.1
10/20/2013		12902.23	1820850	31.8	582.3
10/21/2013		13237.08	1833990	31.6	591.2
10/22/2013		12562.27	1846590	31.3	592.3
10/23/2013		13145.07	1859400	31.3	592.3
10/24/2013		13726.79	1873050	32.2	604.4
10/25/2013		13216.56	1886160	31.6	589.3
10/26/2013		11806.25	1897890	31.5	550.2
10/27/2013		12792.15	1910550	32.4	585.3
10/28/2013		11983.79	1922400	31.6	528.1
10/29/2013		13371.71	1935690	33.0	596.5
10/30/2013		12547.15	1948140	32.3	502.8
10/31/2013		11860.75	1959870	31.6	542.7

DATE	MONTH	DAILY GENERATED ENERGY (kWH)	ACCUMULATED DELIVERED ENERGY (kWH)	TEMP (°C)	GLOBAL RADIATION (wh/m²)
11/1/2013	NOVEMBER	11119.85	1970790	31.90	427.25
11/2/2013		13041.18	1983720	32.34	570.75
11/3/2013		11647.86	1995210	30.77	498.42
11/4/2013		13324.48	2008530	31.92	589.58
11/5/2013		13016.63	2021460	31.68	561.58
11/6/2013		12120.58	2033460	32.10	556.92
11/7/2013		11953.84	2045220	32.40	529.42
11/8/2013		11002.21	2056020	32.56	472.83
11/9/2013		12088.47	2067930	32.63	499.17
11/10/2013		12354.78	2080110	33.22	535.00
11/11/2013		12303.52	2092230	33.47	535.92
11/12/2013		12183.72	2104260	32.46	523.67
11/13/2013		12146.21	2116260	32.53	550.00
11/14/2013		12381.49	2128470	32.47	541.75
11/15/2013		11457.65	2139720	32.31	499.42
11/16/2013		11371.04	2150880	32.85	490.67
11/17/2013		1220.39	2152050	32.13	459.18
11/18/2013		12069.32	2163930	33.20	515.17
11/19/2013		11228.85	2174970	32.77	484.17
11/20/2013		11167.87	2185980	32.66	505.75
11/21/2013		12588.98	2198460	33.41	552.58
11/22/2013		10974.42	2209200	33.09	482.58
11/23/2013		12070.4	2221140	33. 35	483. 13
11/24/2013		10327.4	2231310	32.06	427.92
11/25/2013		11865.07	2243010	32.73	537.33
11/26/2013		10423.73	2253270	31.42	457.25
11/27/2013		11895.02	2264940	31.87	512.67
11/28/2013		11469.53	2276220	33.86	485.67
11/29/2013		12734.41	2288790	35.03	542.08
11/30/2013		7968.12	2296740	38.10	294.33

DATE	MONTH	DAILY GENERATED ENERGY (kWH)	ACCUMULATED DELIVERED ENERGY (kWH)	TEMP (°C)	GLOBAL RADIATION (wh/m²)
12/1/2013	DECEMBER	11455.49	2308080	31.76	546.58
12/2/2013		12184.2	2320080	32.05	505.42
12/3/2013		11965.72	2331840	32.93	514.5
12/4/2013		9945.9	2341590	32.83	392.17
12/5/2013		12658.6	2354250	32.11	541.83
12/6/2013		12038.29	2366040	29.88	562
12/7/2013		12613.53	2378490	27.93	526.42
12/8/2013		12717.13	2391090	28.63	531.75
12/9/2013		11947.99	2402880	29.45	503.08
12/10/2013		11797.61	2414490	29.67	498.42
12/11/2013		10704.87	2424990	30.7	451.67
12/12/2013		11422.3	2436210	31.53	489.17
12/13/2013		11304.66	2447370	31.67	474.42
12/14/2013		9234.66	2456340	29.93	429.25
12/15/2013		893.1	2457210	27.64	378.08
12/16/2013		8942.72	2465910	26.55	376.75
12/17/2013		10593.71	2476290	27.22	457.92
12/18/2013		11394.51	2487480	27.36	497.17
12/19/2013		11526.75	2498880	27.36	489.83
12/20/2013		12167.52	2510970	28.28	542.58
12/21/2013		9339.34	2520090	28.43	433.92
12/22/2013		11075.86	2530920	29.08	461.58
12/23/2013		10786.08	2541510	29.43	484.33
12/24/2013		10903.72	2552220	29.72	472.75
12/25/2013		10736.98	2562690	30.68	470.42
12/26/2013		11598.76	2574030	32.68	548.17
12/27/2013		11481.12	2585190	31.69	537.25
12/28/2013		11543.19	2596530	31.03	549.08
12/29/2013		11577.45	2607690	32.08	543.67
12/30/2013		11063.19	2618400	31.56	504
12/31/2013		10955.67	2629050	28.45	494

DATE	MONTH	DAILY GENERATED ENERGY (kWH)	DAILY DELIVERED ENERGY (kWH)	TEMP (°C)	GLOBAL RADIATION (kwh/m²)
1/1/2014	JANUARY	10969.02	10530	31.3417	6.1
1/2/2014		11311.14	10950	31.475	6
1/3/2014		8690.45	8430	31.3083	5.7
1/4/2014		12553.63	12150	31.225	566.833333
1/5/2014		11771.98	11310	30.4833	539.75
1/6/2014					
1/7/2014		10561.6	10170	29.48	492
1/8/2014		10676	10110	30.29	477.25
1/9/2014		10387.3	9930	30.39	493.08
1/10/2014		7294.97	6930	30.81	444
1/11/2014		10970.1	10410	30.59	514.12
1/12/2014		11713.16	11130	28.97	525.25
1/13/2014		10740.22	10110	29.76	517.5
1/14/2014		11505.67	10890	30.15	555.08
1/15/2014		12178.32	11460	30.81	586.67
1/16/2014		11627.63	10860		
1/17/2014		9581.1	8820	30.97	457
1/18/2014		4952.18	4800	26.8	317.64
1/19/2014		9140.49	8970	29.13	369.5
1/20/2014		11171.11	11010	32.15	509.42
1/21/2014		11600.92	11490	32.84	526.17
1/22/2014		12758.96	12720	32.11	559.58
1/23/2014		11745.27	11580	31.86	505.33
1/24/2014		12670.19	12570	33.1	581.25
1/25/2014		870.71	810	33.1	543.75
1/26/2014		9070.08	8880	32.38	401.42
1/27/2014		8686.13	8520	32.82	565.17
1/28/2014		13434.85	13350	32.37	598.67
1/29/2014		12662.92	12540	32.27	583.42
1/30/2014		12069.61	11880	32.93	535.25
1/31/2014		11635.19	11490	30.08	530.17

DATE	MONTH	DAILY GENERATED ENERGY (kWH)	DAILY DELIVERED ENERGY (kWH)	TEMP (°C)	GLOBAL RADIATION (wh/m²)
2/1/2014	FEBRUARY	13627.22	13620	27.74	615.67
2/2/2014		13627.22	13620	27.74	615.67
2/3/2014		12930.02	12810	28.92	598.17
2/4/2014		12033.97	11850	32.04	523.33
2/5/2014		6165.8	6060	32.6	506.83
2/6/2014		11980.84	11790	33.96	652.2
2/7/2014		9413.28	9240	33.94	582.33
2/8/2014		12128.14	11970	32.71	557.42
2/9/2014		11577.45	11400	33.34	534.33
2/10/2014		11350.81	11280	33.21	534.82
2/11/2014		11697.25	11640	33.15	606.67
2/12/2014					
2/13/2014		12826.42	12720	33.35	617
2/14/2014		13219.8	13140	32.03	642.92
2/15/2014		1685.55	1650	31.39	639.5
2/16/2014		11784.94	11610	31.48	561.08
2/17/2014		10596.95	10380	32.49	508.33
2/18/2014		9207.95	9000	33.45	501.67
2/19/2014		11061.03	10830	33.52	536.08
2/20/2014		11577.45	11400	32.72	533
2/21/2014		10186.29	10080	32.05	586.5
2/22/2014		11871.55	11730	33.81	588.08
2/23/2014		8798.37	8670	35.69	615.67
2/24/2014		7821.11	7710	35.72	605.08
2/25/2014		11207.54	10950	34.75	554.58
2/26/2014		11123.09	10920	35.53	542.33
2/27/2014		9127.82	8910	33.98	481.67
2/28/2014		11235.33	11040	32.25	524.33

DATE	MONTH	DAILY GENERATED ENERGY (kWH)	DAILY DELIVERED ENERGY (kWH)	TEMP (°C)	GLOBAL RADIATION (wh/m²)
3/1/2014	MARCH	11722.88	11580	29.98	534.92
3/2/2014		13310.73	13200	31.28	632
3/3/2014		13631.54	13560	32.94	668.08
3/4/2014		13426.21	13320	34.75	671.25
3/5/2014		12945.14	12900	34.18	642.17
3/6/2014		12592.22	12480	34.9	661.42
3/7/2014		12539.88	12360	34.26	610.17
3/8/2014		13546.01	13440	34.5	690.67
3/9/2014		12914.11	12810	35.38	664
3/10/2014		11996.75	11850	34.01	708.58
3/11/2014		9358.78	9120	33.69	617.08
3/12/2014		10750.23	10530	35	492.5
3/13/2014		9602.7	9390	34.98	497.5
3/14/2014		9396.58	9120	35.37	488.75
3/15/2014		12320.8	12150	35.33	619.5
3/16/2014		12598.7	12450	36.95	619.33
3/17/2014		10412.14	10140	34.57	474.25
3/18/2014		12869.33	12720	35.36	625.5
3/19/2014		9890.32	9690	34.07	445.33
3/20/2014		12816.99	12660	36.23	600.75
3/21/2014		12693.95	12540	35.23	553.92
3/22/2014		13236	13110	33.88	664.25
3/23/2014		13099.21	13020	34.12	649.92
3/24/2014		12775.16	12660	34.61	554.17
3/25/2014		13217.14	13050	35.6	595.17
3/26/2014		12458.96	12330	37.05	608.08
3/27/2014		9413.57	9180	35.25	393.92
3/28/2014		12499.42	12300	35.21	594.33
3/29/2014					
3/30/2014					
3/31/2014		4328.92	4200	25.21	184

DATE	MONTH	DAILY GENERATED ENERGY (kWH)	DAILY DELIVERED ENERGY (kWH)	TEMP (°C)	GLOBAL RADIATION (wh/m²)
4/1/2014	APRIL	13945.87	13860	32.18	703.08
4/2/2014		13694.68	13620	35.84	692.63
4/3/2014		13257.31	13140	34.96	651.33
4/4/2014		11391.56	11160	35.02	508.92
4/5/2014		11818.13	11700	35.76	596.17
4/6/2014		9590.82	9390	33.47	456
4/7/2014		11964.64	11820	35.23	633.58
4/8/2014		4963.27	4800	27.67	220.42
4/9/2014		13216.85	13110	32.62	663.25
4/10/2014		9605.94	9450	32.57	547.92
4/11/2014		12979.41	12810	33.85	619.93
4/12/2014		12041.82	11910	35.13	594.92
4/13/2014		8661.87	8460	33.71	357.58
4/14/2014		10639.86	10350	32.13	478.25
4/15/2014		13212.53	13080	34.44	657.55
4/16/2014		12816.99	12660	35.8	652.42
4/17/2014		13242.48	13110	37.42	729
4/18/2014		11992.43	11910	35.45	649.17
4/19/2014		12625.7	12510	33.49	639.92
4/20/2014		8941.93	8790	34.76	592
4/21/2014		10755.34	10500	33.03	492.42
4/22/2014		12591.14	12420	35.43	586.33
4/23/2014		10397.02	10170	31.92	442.92
4/24/2014		12140.02	11910	33.96	580.58
4/25/2014		12798.63	12630	35.97	674.08
4/26/2014		9532	9360	33.52	448.67
4/27/2014		10202.49	10050	30.71	448.33
4/28/2014		12780.56	12600	34.29	631.42
4/29/2014		2727.32	2580	25.44	113
4/30/2014					

DATE	MONTH	DAILY GENERATED ENERGY (kWH)	DAILY DELIVERED ENERGY (kWH)	TEMP (°C)	GLOBAL RADIATION (wh/m²)
5/1/2014	MAY	11265.28	11130	31.16	597.67
5/2/2014		11898.26	11640	34.12	588.67
5/3/2014		4393.14	4230	29.73	269.25
5/4/2014		10338.2	10170	32.08	461.08
5/5/2014		10715.67	10500	33.37	535.17
5/6/2014		6548.67	6300	27.46	289.33
5/7/2014		10188.45	9450	31.2	567.75
5/8/2014		10546.77	10410	31.24	617.18
5/9/2014		10808.76	10650	31.01	430.75
5/10/2014		10109.4	9930	30.28	465.33
5/11/2014		12245.78	12060	31.28	622.58
5/12/2014		11586.09	11400	33.03	550.75
5/13/2014		12311.08	12090	33.27	629.33
5/14/2014		10288.02	10080	30.3	492.5
5/15/2014		8584.69	8370	29.7	469.92
5/16/2014		12222.31	12000	32.42	606.67
5/17/2014		13150.47	12990	34.09	688.75
5/18/2014		10891.05	10740	33.99	608.33
5/19/2014		12282.22	12120	31.3	642.17
5/20/2014		12623.25	12450	34.85	608.75
5/21/2014		11965.72	11760	36.63	663.67
5/23/2014		9684.2	9420	35.14	622.17
5/24/2014		1124.35	1050	35.33	646.5
5/25/2014		7602.03	7350	30.81	351.5
5/26/2014		10669.81	10470	34.16	553.17
5/27/2014		8342.93	8130	35.47	489.58
5/28/2014		9975.85	9750	33.75	550.33
5/29/2014		7380.79	7170	33.22	580.42
5/30/2014		10841.95	10620	32.93	524.67
5/31/2014		12312.16	12060	35.48	626.75