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PRODUCT CONFIGURATION OF PHOTOVOLTAIC SYSTEM IN DEVELOPING COUNTRIES

- Case Ghana

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ABBREVIATIONS

MoE	Ministry of Energy
MoE& P	Ministry of Energy& Petroleum
UNCTAD	United nation Conference on Trade and Development
HEP	Hydro Electric Power
KWh	Kilowatt hour
NRC	National resources Canada
EMA	Energy Market Authority
BCA	Building and Construction Authority
IEA	International Energy Agency
FSEC	Florida Solar Energy Centre
CRO	Construction Review Online
GoG	Government of Ghana
ECG	Electricity Company of Ghana
EC-Ghana	Energy Commission of Ghana
NPA	National Petroleum Authority
CIA	Central Intelligence Agency
VRA	Volta River Authority
NREL	National Renewable Energy Laboratory
AIEDAM	Artificial Intelligence for Engineering Design, Analysis and Manufacturing
REEEP	Renewable Energy and Energy Efficiency Partnership
ECREEE	ECOWAS Centre for Renewable Energy and Energy Efficiency
EPIA	European Photovoltaic Industry Agency
PVPS	Photovoltaic Power Systems
EPVTP	European Photovoltaic Technology Platform
EMTC	Exide Management and Technology Company
CEC	Clean Energy Council
EASHW	European Agency for Safety and Health at Work
MSU	Michigan State University

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UNIVERSITY OF VAASA

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ABSTRACT

This study aims at introducing product configuration of photovoltaic systems in developing countries with focus on Ghana. The current problem of electricity production and delivery in Ghana forms the background of the objective of the study. Solving this, particular attention is focused on solar photovoltaic technologies. The objective was to look at how various configurations of photovoltaic systems would help either households or businesses in developing countries to improve their day-to-day life and activities. Focusing on photovoltaic system configurations offers households and businesses the options of standalone, backup or hybrid systems although, the study limits its options to backup systems as a result of the rationing of electricity in Ghana.

The theoretical part provided comprehensive background for the study with an insight into the current energy situation and the renewable energy policies in Ghana. Furthermore, an in-depth understanding of the different components (i.e. panels, charge controllers, inverters, battery and load) of a photovoltaic system is achieved with a look at their basic technical parameters.

The empirical research is conducted via a focus group study and a survey. The focus group study was conducted in Finland among African students while the survey was done in Ghana through questionnaire sent to 102 respondents via an online survey portal: Google Form. From the result, the most common areas of use for solar photovoltaic are for lighting, household and office appliances for which varied configuration can be established. The research established the electrification problem in Ghana and one key recommendation in solving this is the use of renewable energy such as solar photovoltaic systems.

KEY WORDS: Photovoltaic (PV), product configuration, developing countries, Ghana

1. INTRODUCTION

1.1 Background

"*Climate change, the possibility of fossil fuel scarcity, and the need to improve the security of energy supply have heightened the need for strong promoting renewable energies*" - (Algieri, Aquino & Succurro, 2011)

The demand for energy especially in developing economies is growing but the supply cannot meet up. Fossil fuel energy production and use pose great environmental challenges therefore there is a need to build a cleaner and resourceful energy future (IEA, 2012). According to the International Energy Outlook 2013 (IEO 2013) produced by the US Energy Information Administration, the energy consumption will increase by 56% by 2040 and much of this demand will take place outside the Organization for Economic Cooperation and Development (non-OECD) due to the increase in long-term and strong economic demand (EIA 2013).

Developing nations particularly those from sub-Saharan Africa, are struggling with stable energy supplies hence, facing electricity shortage. Currently, most of the continents electricity comes from hydroelectric power (HEP). Ghana is no exception to this problem as the bulk of energy generation and supply comes from the Akosombo HEP. Unpredictability in climatic conditions is a major problem in African continent today. This makes it impossible to predict when and the amount of rainfall at a particular time and place. The problem of energy crisis in Ghana has resulted in rationing of electricity by location. According to Algieri et al. (2011), this has led to low productivity, development and slow economic growth (Algieri et al. 2011; Ndzibah 2013).

Day-to-day activities in the rural areas often rely on biomass, candle or kerosene while the urban switches between the national grid and generator (for those who can afford it). For the purpose of this study, the focus is going to be on households in the urban areas of Ghana. It is important to note that some businesses are run from households in the urban therefore electricity consumption and uses are different from household to household. These household are either personally owned or rented. Therefore, the type of product configuration of photovoltaic system in the urban area will vary based on the purpose for which it is intended for (Ndzibah 2013; Ahiataku-Togobo 2012).

Algieri et al. (2011) explained that green technology and industries are considered new development in energy sustainability. Even though this is true, some part of the world still lack the necessary energy required for the daily activities. This problem has led to what energy experts call “energy poverty”. Energy poverty can be defined as the lack of adequate modern energy for the basic needs of cooking, warmth and lighting, and essential energy services for schools, health centers and income generation (Practical Action 2009; Algieri et al. 2011).

Ghana’s Ministry of Energy under their *Policy Framework and Guide for Development of Independent Power Producer* has asserted that the demand of energy for the last 10 years has increased by 5% therefore; there is a need to increase the availability of energy in developing economies such as Ghana (MoE-Ghana 2007; Ndzibah 2013).

Developing countries are nations with lower living standard, low Human Development Index (HDI), underdeveloped industries with low GDP per capital in comparison with other nations (O'sullivan & Sheffrin, 2003; World Bank, 2012; UNCTAD, 2007). These countries tend to have energy deficiency which has led to low level economic development. According to Ndzibah (2013), it’s worth nothing that all economies are dynamic “for better or worse” and developing economies are also dynamic due to globalization. Khara (2010) nevertheless added that this phenomenon is changing rapidly as developing countries are growing faster than developed countries due to younger “demographic transition”.

Finally, although the energy problems facing developing nations is general, this research hope to reduced, if not completely eradicate the situation by tapping into the abundance sources of renewable energy such as the sun (Karekezi & Kithyoma, 2003).

1.2 Research objectives and question

"The total solar energy that reaches the Earth's surface could meet existing global energy needs 10,000 times over."- EPIA & Greenpeace (2011)

Today's energy crisis has brought about lots of research in sustainability and renewable energy. Although, most of the research already conducted focuses on business and management practices and activities for such energy technologies in the African region which is limited to North and South, therefore, there is a need to look at the other parts of Africa (Ndzibah, 2013). According to Karekezi (2002a), the energy sector in Africa is divided into three distinct regions – North Africa (which depends on oil and gas), South Africa (which depends on coal) and finally Sub-Saharan Africa (which rely on biomass).

Sub-Saharan African use of wood (as a source of energy) has a serious environmental and health impact. An example is the air pollution from unvented charcoal cooking stoves which can contribute to respiratory problems in sub-Sahara Africa and erosion which is caused by deforestation. The consumption of wood and charcoal as a source of energy has led to very low consumption of modern energy (e.g. hydrocarbon such as petrol and diesel).In sub-Saharan (excluding South Africa), the consumption of hydrocarbon is at 292kgoe (kilograms of oil equivalent) from 317kgoe between 1980 and 2002 (World Bank, 2003). This means that sub-Saharan African generate only 24 per cent electricity (8 per cent in rural areas), the lowest in the world (Eberhard et al. 2008; Ram 2006).

According to Karekezi and Ranja (1997), Africa is blessed with significant renewable energy resources such as HEP (1.1 Gigawatt), geothermal (9000 Megawatt) and abundant solar, wind and biomass. Therefore there is a need to utilize and harnessed these sources of renewable energies. Although, it will be a monumental task to discuss all renewable energy sources Africa has to offer and for the purpose of these studies, solar as source energy will be the focus.

The main research objective of this study is to develop advantage in product configuration of photovoltaic systems for developing nations. The configuration will be based on usage segments in Ghana for urban sectors of the economy. A brief look at the rural sector will be considered. Thus, the main research question will be: *How product configuration of photovoltaic (PV) system can help reduce and improve energy crisis in developing countries and for that fact Ghana?* This objective will help explain photovoltaic system – *components* and *applications*. Additionally, a closer look into how this can help improve the problem of electrification in developing nation thereby improving standard of living and developments. It is important to also note that to achieve this, policy makers, investors and other stakeholders in the energy sector needs to throw their support behind the adoption of photovoltaic systems as one of the means of solving the energy crisis facing Ghana.

Hence, the main objectives of this research are:

- To give background and explain the electrification development in Ghana
- To find out the current policies in Ghana.
- To add value to current configuration standards
- To analyse and propose a set of product configurations of photovoltaic systems in solving the energy crisis in Ghana.

1.3 Limitation and definition

The research topic in question is broad and as such; there is a need to focus on a specific area. Africa has various sources of renewable energy to offer. The main renewable energies are: Solar, Wind, Hydro, Tidal, Wave, Land fill, Sewage and other bio gas, incineration of waste (municipal, industrial, hospital etc.), Geothermal, and Bio-fuel. Renewable energy sources such as solar and wind are known as intermittent renewable sources whereas some others like hydro and biomass are classified as non-intermittent sources (Zahedi, 1996).

To be able to understand the topic in question, there is a need to define some of the key terminology which will be used. Also a brief look at the various products that makes up the photovoltaic system needs to be discussed. According to Sustainable Resources (2014), "photovoltaic" is made of two words – "photo" which means light ("*photon*") and "voltaic" which means voltage ("*volt*" – unit of electric potential). Hence, photovoltaic (PV) uses photovoltaic cells (semiconductors) and other components to generate electricity by converting solar radiation into direct electricity (Shah et al., 1999; Pearce 2002; Ndzibah 2013, Sustainable Resources 2014).

Photovoltaic system is an arrangement of components designed to supply usable electric power for various purposes, using the Sun as the power source. Although there are other types of photovoltaic systems such as grid and off-grid connected systems, fort his study, the focus is on *standalone*, *backup* and *hybrid systems* (EMA & BCA 2009; Ndzibah 2013; NRC 2001).

Photovoltaic modules: these are made up of solar cells. A solar cell is formed from silicon - semi-conductor. Silicon is the second most abundant element on earth found in quartz and sand. These solar cells are the unit which converts sunlight to electricity. A collection of cells make up photovoltaic modules which when put together forms photovoltaic arrays. Although there are different types of photovoltaic cells, for the purpose of this study, the focus will be on - monocrystalline silicon photovoltaic and polycrystalline silicon photovoltaic (Ndzibah 2013; Sustainable Resources 2014).

Photovoltaic charge controller: This help prevents photovoltaic modules from overcharging the battery and vice versa. The excessive voltage could damage the batteries. To prevent this, a charge controller is used to maintain the proper charging voltage on the batteries (Ndzibah 2013; Sustainable Resources 2014).

Photovoltaic Inverters: Converts direct current (DC) from photovoltaic panels or modules into utility frequency alternating current (AC) which can be fed to appliances. Therefore, any unit that can convert a 12-volt battery or a direct solar current to 220/230 volt electricity is an inverter (Ndzibah 2013).

Battery: The battery serves as a storage device for the voltage generated by the solar cells. The stored voltage are later used during power disruption or to power some appliances while the electricity from the grid is used for equipment or appliances the required more energy to operate (Ndzibah 2013; Sustainable Resources 2014).

Product configuration is a way of modifying a product or components to meet the needs of a particular customer. The product or components may consist of mechanical parts, services, and or software (Mehrotra et al 2013; AIEDAM 2003; Haug et al 2012).

Photovoltaic standalone system is a system used by people who have no access to the national electric grid. This means that electrification is solely generated from photovoltaic system.

Photovoltaic backup system is recommended for those who have access to the national grid but are ready to use the photovoltaic system instead of a diesel or petrol powered generator in case of a power outage.

Hybrid photovoltaic system is a unit recommended for specific households or businesses with enormous energy requirement. For such requirements, key appliances are connected to the grid while the photovoltaic unit powers other equipment or machineries (Ndzibah 2013; NRC 2001; FSEC).

According to Merriam Webster (2014) online dictionary, the term “configuration” simple means “the way the parts of something are arranged”. FSEC (2002) explains that photovoltaic systems comprise of photovoltaic modules, photovoltaic arrays, inverter, charge controller and battery.

Developing countries are nations with lower living standard, low Human Development Index (HDI), underdeveloped industries with low GDP per capital in comparison with other nations (O'sullivan & Sheffrin 2003; World Bank 2012; UNCTAD 2007).

Ghana is a country located in West Coast of Africa surrounded in the North by Burkina Faso, to the East by Togo and to the West by Cote d'Ivoire with the Gulf of Guinea to the South. Ghana was formally known as Gold Coast until 1957 when it got independence from the United Kingdom in 1957. The capital of Ghana is Accra (Ghana Web 2014; GoG 2013).

1.4 Structure of the study

This research is meant to look at the energy situation in the case country Ghana, particularly the electrification problems and how this can be reduce and improve. Additionally, an investigation into how the role and types of renewable energy can help achieve afore mention goal. The focus will be on photovoltaic systems due to the abundance of sunlight. Various findings regarding photovoltaic systems will be reviewed in comparison with how these systems are implemented in Ghana. The findings will help improve the development of alternatives and reliable energy in developing countries. This research will commence with a review of the energy situation in Sub-Saharan Africa with particular importance to the energy problem facing Ghana. The end with the research objectives, questions, limitation and definition are reviewed.

Chapter 1 examines the energy situation in developing countries. A look at sub-Sahara various energy sources being used. The research objectives and questions were elaborated. Finally, definitions and the limitations of the studies were examined.

Chapter 2 will look at the historical, political and technical frame work of the energy sector, particularly the electrification of the case country – Ghana. This will also include examining the various types of the energy systems as well as the capacity and future energy potentials. Finally, a brief assessment of Ghana's renewable energy policies will be discussed.

Chapter 3 starts with the introduction of photovoltaic. This will examine key aspect of photovoltaic technology. Furthermore, the concept of product configuration with relation to product design will be evaluated and discussed. Finally, a look at the different photovoltaic systems which includes standalone, backup and hybrid will be introduced including basic technical parameters for photovoltaic systems components.

Chapter 4 examines the research methodologies approach used in this study to establish meaningful and reliable conclusion. This study will use a hybrid research approach. A hybrid research approach uses both qualitative and quantitative methods (Ndzibah 2013; Burns & Bush 2000: 230, 231). This type of research will help develop and evaluate key findings.

Chapter 5 looks at the research findings and analysis. The researcher pre-assumptions were also examined.

Chapter 6 will draw conclusion to the study by presenting a summary analysis and findings. Finally, recommendations will be suggested on how Ghana can improve their energy problems. These recommendations can be used by developing economies to also improve the energy problems thereby leading to economic and social development.

2. CASE COUNTRY BACKGROUND

This chapter will look at the historical, political and technical backdrop of Ghana's energy systems since independence. A review of the energy systems including the various means to which Ghana generate its energy will be discussed. Finally, a look at the Ghana energy policies will be considered.

2.1 Ghana – historical, political, economy and technical administration of energy systems

Ghana is a country located in West Coast of Africa surrounded in the North by Burkina Faso, to the East by Togo and to the West by Côte d' Ivoire with the Gulf of Guinea to the South. Ghana was formally known as Gold Coast and became the first sub-Saharan African country to gain independent from the United Kingdom in 1957. The capital of Ghana is Accra though it was previously located at Cape Coast. Since independence, Ghana has endured series of coups until Lt. Jerry Rawlings took power in 1981, setting up a one party system. A new constitution was approved which brought about multiparty system to Ghana in 1992 and Mr. Rawlings won the presidential election that year. The official language is English though there are more than 79 languages and dialects spoken by the Ghanaians. Currently, the population of Ghana is about 25.5 million at a growth rate of 2.19 % (Ghana Web 2014, GoG 2013; Ndzibah 2010; Just Landed 2014).

Ghana's economy has strengthened over the last quarter century with good management; competitive business environment together with sustained reduction in poverty (CIA 2014). Ghana is blessed with natural resources and agriculture which account to about 25% of GDP while the service sectors generate 50% of GDP. Major foreign exchange is derived from gold and cocoa production. It is worth mentioning that the discovery and production of oil at the Jubilee field which commenced in 2010 will reduce Ghana's energy dependency on other nations. This is also expected to add to the national income of Ghana. As of 2013, the GDP is between 7% - 7.9% with per capita at $3,500 compared to $3,200 in 2011 and inflation is at 11% (CIA 2014; GoG 2013; Heritage 2014; Ahiataku-Togobo2012).

2.1.1 Types of energy systems, capacity and future forecast

Since Ghana got independence in 1957 from the United Kingdom, and built the first energy generating system at Akosombo (1961 – 1964 and was opened in 1965) at a cost of $258 million, the country's energy production cannot meet up with demand due to the rapid population growth and developments. Although the output power from the Akosombo dam was meant to serve only Ghana, an agreement between Togo and Benin was made to supply them electricity (Ndzibah 2010; Ndzibah 2013).

Even with the installation of additional electricity generating system (in the 1980s, 1990s and 200s), most are currently underperforming as domestic energy demand is growing at 7% annually. Figure 1 (below) shows the current energy consumption in Ghana. It's obvious that most of Ghana's energy is derived from biomass hence; there is a need to explore other sustainable sources of energy.

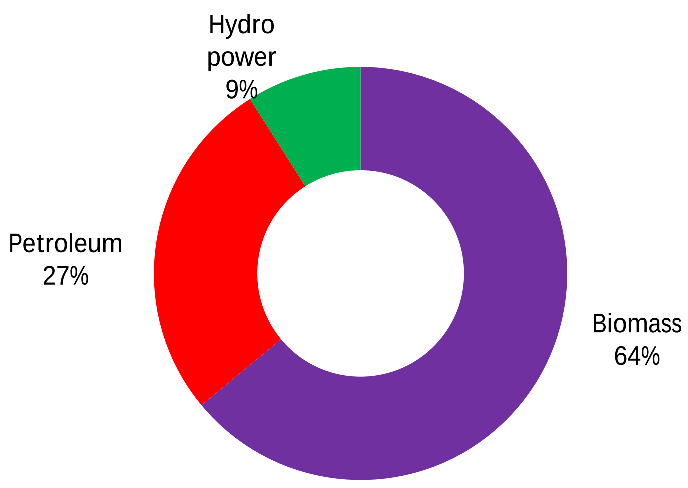


Figure 1. 2012 Energy consumption in Ghana
Adopted: Ahiataku-Togobo W. (2012)

According to Ndzibah (2013), the consumption, export and importation of electricity were approximately 5.7 billion kWh, 2.49 billion kWh and 435 million kWh, respectively while production at Akosombo and Kpong hydro power plants was 6.7 billion kWh. Nonetheless, it should be noted that there are other power plants which generate enough power to offset the net deficit of consumption, export and importation. Despite this level of electricity production, more than 9 million Ghanaians are still without power thus resorting to the use of standby generators by households and industries. Figure 2 show both power distribution networks and proposed future grids in various regions in Ghana (Kofi Agyarko 2012; Isaac Ennison 2012; CRO 2014).

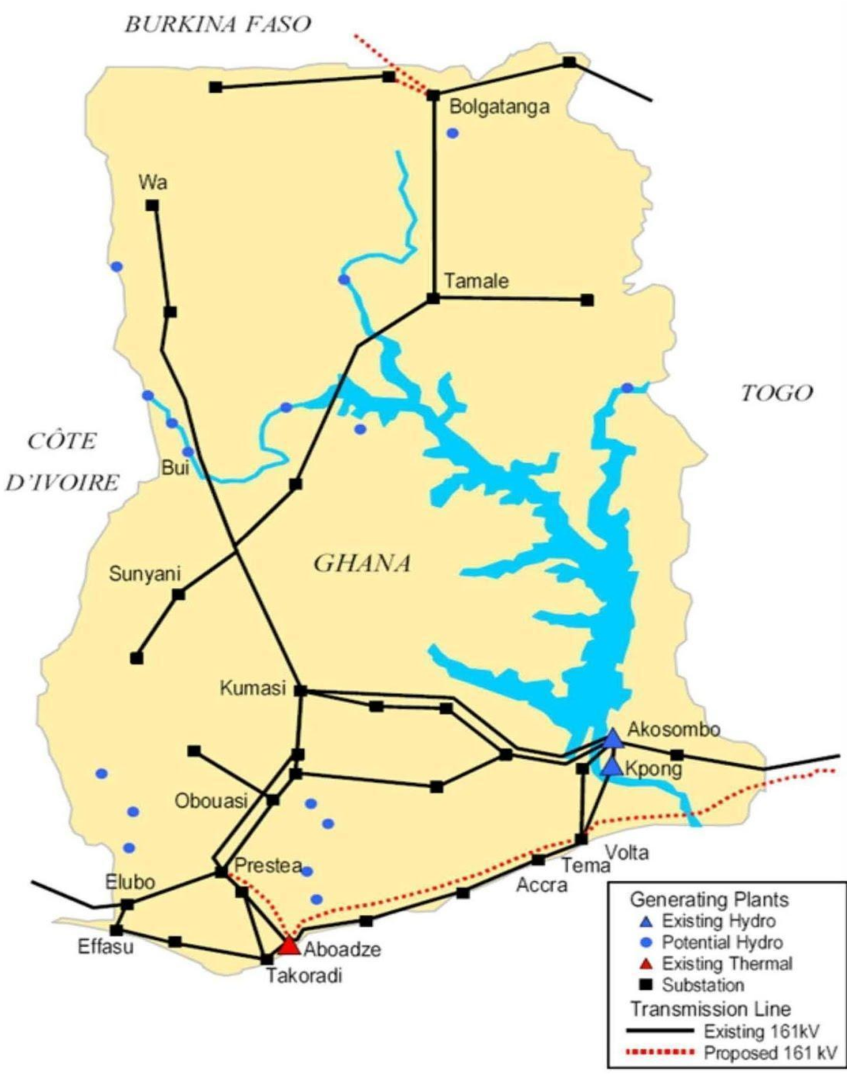


Figure 2. Volta River Authority Transmission Network
Adopted: Ndzibah (2013)

To combat the shortage, an increase power production upgrade took place in 2006 where the capacity was increased from 912 MW to 1,020 MW. Furthermore, there are numerous projects that are under construction to meet the demand and considered target set out by the government to increase the existing facility capacity to 5000 MW by 2015 from 2000 MW (see Table 1) but according to Essah (2011); this is approximately 53% less than the estimated capacity that is required to be installed in order to achieve a substantial level of electricity usage for every individual. For example, the construction of Aboadze Thermal Plant which started in 2011 at a cost of $750 million due to be completed in 2014, is expected to increase Ghana's power generation (Kofi Agyarko 2012; Isaac Ennison 2012; CRO 2014; Heritage 2014; Ahiataku-Togobo2012; Kpekpena 2014).

Table 1. Summary of potential projects to meet the 2015 targets
Adopted: EC-Ghana (2006)

ELECTRICITY EXPANSION PLAN- GENERATION MIX BY INSTALLED CAPACITY 2013–2015							
SOURCE	PLANT	Option 1 total	Percent	Option 2 total	Percent	Option 3 total	Percent
Hydro power		**1180**	**36.30 %**	**1380 -1580**	**42.60 % 45.90 %**	**1380 1580**	**42.60 % 45.90 %**
	Akosombo & Kpong	1180		1180		1180	
	Bui hydro 200–400 MW	0		200 -400		200 -400	
Thermal		**1175**	**55 %**	**1565**	**48.30 % 45.50 %**	**1565**	**48.30 % 45.50 %**
	Tapco	330		330		330	
	Tico	330		330		330	
	Tema diesel	0		0		0	
	Effasu Barge	125		125		125	
	330MW Tema GT 1	330		330		330	
	330MW Tema GT 2	330		330		330	
	Embedded Gas Gen-sets	0		120		120	
	3rd 330MW Takoradi CCGT	330		0		0	
	4th 330 MW Takoradi CCGT	0		0		0	
Renewables		**294**	**9.10 %**	**294**	**9.1 % 8.5 %**	**294**	**9.1 % 8.5 %**
	Biomass, solar, mini-hydro, etc.	10		10		10	
	Wind	200		200		200	
	Municipal Solid Wastes	80		80		80	
	Landfills	4		4		4	
Nuclear		**0**	**0 %**	**0**	**0 %**	**0**	**0 %**
	Light water reactor-IRIS-335	0	0	0	0	0	0
	Total	**3249**	**100 %**	**3239 -3439**	**100 %**	**3239 -3439**	**100 %**

Although Ghana is endowed with abundant sunlight, photovoltaic systems are yet to contribute significantly to power generation. Solar energy utilization has been limited owing to its comparatively higher cost. Figure 3 (below) show the distribution of annual solar radiation. Ghana receives very high radiation levels at a monthly average of 4.0 - 6.5kW/m^2/day. The capacity of solar photovoltaic electrification in Ghana has seen a significant growth from 0.3MWp in 1987 to 2.1MWp in 2009. Some 5,000 photovoltaic systems have been installed in remote areas by 2006 to support 15,000 homes through a

$10.9 million World Bank project. Most of the installations by the government are aimed to provide lighting for health care centers, power solar water pumps, telecommunication towers and refrigeration of vaccines. In May 2013, a 2MWp solar project was commissioned by the Volta River Authority (VRA) at Navrongo. The Navrongo Solar Power Plant is the largest grid photovoltaic plant in West Africa, besides those in Cape Verde. Furthermore, VRA is expected to install a total of 10MWp in areas such as Kaleo, Lawra and Jirapa though, they are currently looking for funding to develop the remaining 8MWp (Ghana EC 2009; Oteng-Adjei 2010; Ndzibah 2013; VRA 2013).

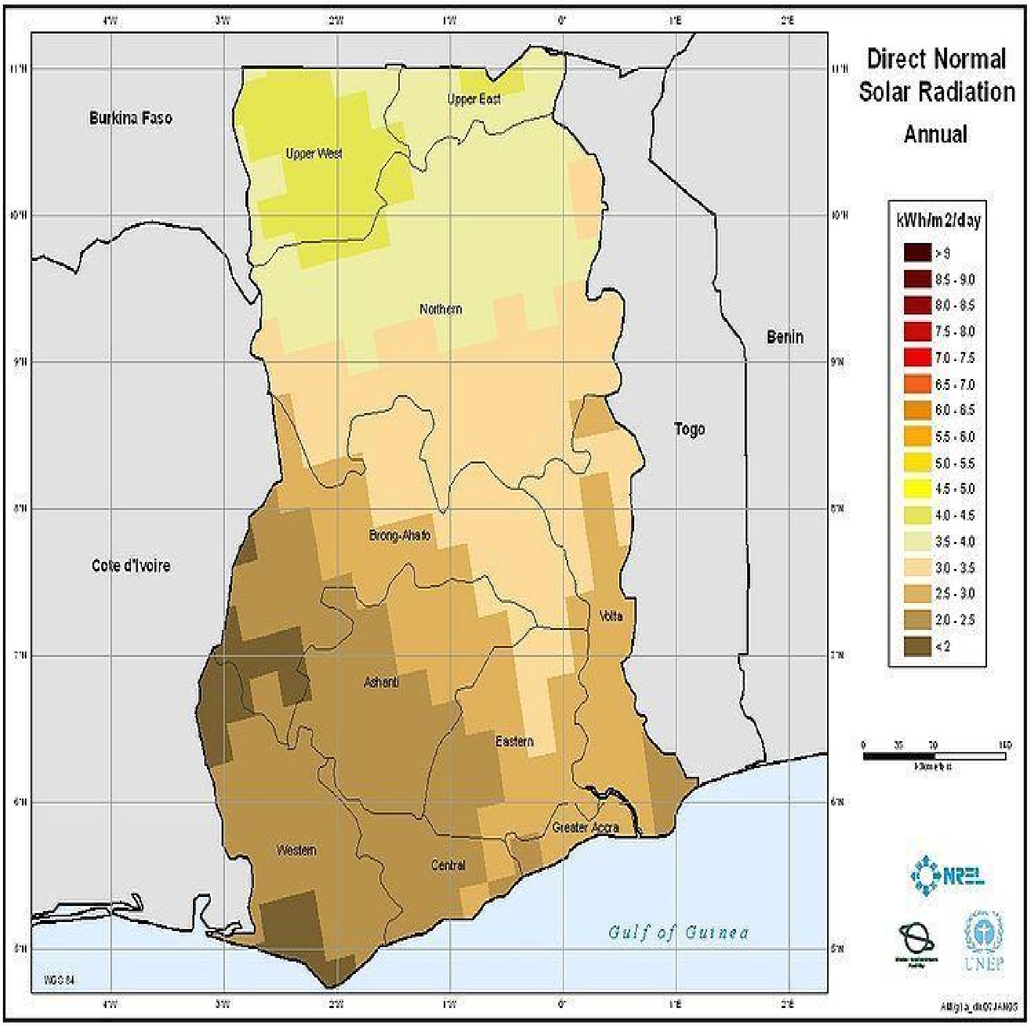


Figure 3. Solar radiation in Ghana
Adopted: NREL 2014

Other sources of energy that can help improve the electricity situation in Ghana are wind and bio energy. The wind energy power generation in Ghana is at the infant stage. Preliminary wind resources evaluations are being undertaken to select sites for the installation. The sites considered are the coastal and high elevation areas of the country. Table 2 (below) shows wind resources potential and capacities while figure 4 (below) potential areas for wind power installation in Ghana. The eastern coastlines seem promising which can generate up to 5,600MW covering about 1,128km^2 (MoE & P 2013; NREL 2014). According the VRA (2013), the first wind power project is been under construction and estimated to be completed in 2015 with an output of 150MW. Ghana's bio energy prospective is in biomass in form of charcoal and wood fuel which account for about 72% of total energy consumption. The reason is due to the fact that wood fuel is very easy to afford. Two-third (about 18.3Mha) of Ghana's land mass is covered with trees. With an annual rainfall of 1,300 – 2,200 mm, Ghana can produce 243PJ/year or 65,000GWh/year of wood fuel (MoE & P 2013; Ahiataku-Togobo 2012; Nutsukpo et al 2012).

Table 2. Gross wind resource potential of Ghana
Adopted: MoE & P (2013)

Wind Resource Utility Scale	Wind class	Wind Power at 50m (W/m^2)	Wind Speed at 50m (m/s)	Total Area Km^2	Percent Windy land	Total capacity Installed (MW)
Moderate	3	300–400	6.4 – 7.0	715	0.3	3,575
Good	4	400 – 500	7.0 – 7.5	268	0.1	1,340
Excellent	5	500 – 600	7.5 – 8.0	82	0.1	410
Excellent	6	600 – 800	8.0 – 8.8	63	0.1	315
Total				**1,128**	**0.5**	**5,640**

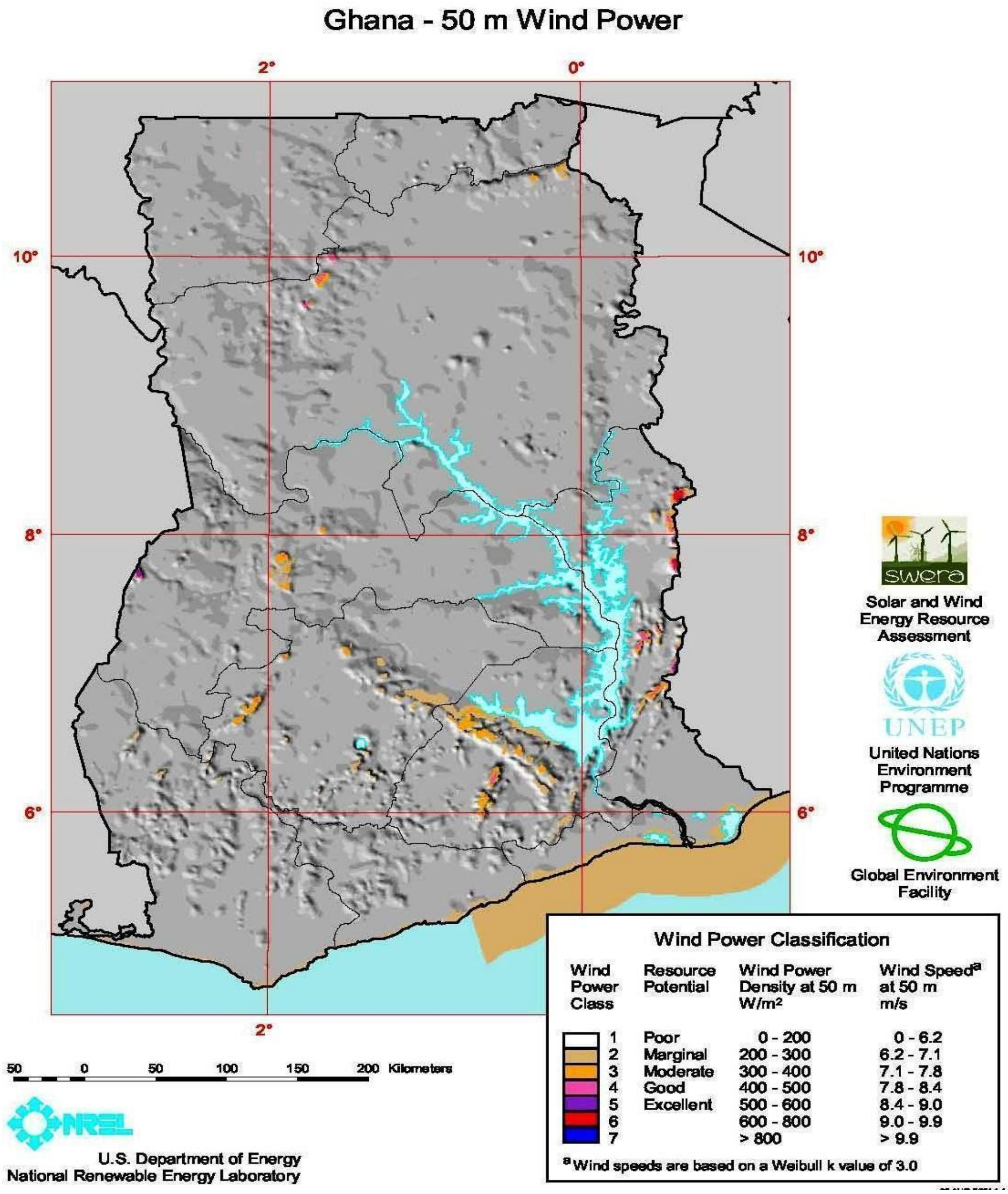


Figure 4. Ghana wind distribution
Source: NREL 2014

2.1.2 Ghana’s energy policies

In order to tackle the shortage, energy technical administrations and institutions are scrambling to increase production. The increase in demand for power generations is caused by inefficient appliances which account to 30% of total electricity generation waste. One way the government is trying to reduce the use of inefficient appliances was the introduction of *L.I. 1932 Energy Efficiency Standard and Labeling Law* which lead to the prohibition of manufacturing, sales or importation of incandescent lamps which was replaced by compact fluorescent lamps (CFLS) at a cost of $12 million and distributed to households. Also, the ban of imported used refrigerators, freezer and air conditions has led to peak savings of 124 MW power generations (Kofi Agyarko 2012; Ennison 2012; ECG 2014; NPA 2005; Hon. Owusu-Adjapong 2008; Ghana EC 2013). The various technical administrations tasked in helping reduce energy waste thereby increasing output are:

- ***Ministry of Energy (MoE)*** – to formulate, implements, monitors and evaluates energy sector policies.
- ***Energy Commission (EC)*** – regulation of the power generation as well as developing regulations for utilization of power generation systems.
- ***Electricity Company of Ghana (ECG)*** – distributing and supplying electric power
- ***Public Utilities Regulation Commission (PURC)*** – approves rates chargeable for the purchase renewable energy electricity.
- ***Forestry Commission*** – regulation of biomass plantation
- ***National Petroleum Authority*** – regulate, oversee and monitor activities in the petroleum downstream industry. Also deals with the pricing of bio-fuel and bio-fuel blends
- ***Environmental Protection Agency*** – to improve and conserve the country's environment
- ***Renewable Energy Directorate*** – oversee the implementation of renewable energy activities in the country
- ***Ghana Grid Company (GRIDCo) –*** to provide open access, non-discriminatory, reliable, secure, and efficient electricity transmission services and wholesale market operations to meet customer and stakeholder expectations within Ghana and the West African

The Ministry of Ghana in 2001, drafted an energy sector policy framework as a platform towards the development of the energy sector. A review of this policy was conducted in 2006 by key stakeholders and revised to meet Growth and Poverty Reduction Strategy II known as GPRS II. These policies are design to help improve the current challenges facing the energy sector in Ghana. It was noted in the report that Ghana is rich with various energy resources such as biomass, hydrocarbons, hydropower, solar and wind. Also, Ghana has the capacity to produce bio-fuel and nuclear energy. The energy policies cover a wide range of issues. These issues are classifies based on the energy sub-sectors such as power sub-sector, petroleum subsector, renewable energy subsector (just to mention a few) (Ndzibah 2010; Ndzibah 2013; MoE-Ghana 2009; Ennison 2012).

Regarding the power sub-sector, there is a plan to increase power generation by installing 5,000 MW to improve universal affordability by 2015. Petroleum sub-sector policy goal is to “ensure the sustainability exploration of the country’s oil and gas endowment and the judicious management of the oil and gas revenue for the overall benefit of Ghanaians as well as a commitment of indigenization of knowledge, expertise and technology”. As for the renewable energy sub-sector policy, some of the challenges are how to reverse and improve the production and use of wood fuel resources, improving the production of biomass and how to reduce the high cost in both solar and wind energy production. As part of observation, it was clear that energy efficiency and conservation policy will help improve production and transportation which will reduce wastage hence, benefitting the national economy. Finally, in the managing the future, there is a need to address energy management as well as to mobilize future investments in the energy sector (MoE 2007; MoE, 2009; Essah 2011; Norton Rose Fulbright 2013).

2.2 Renewable energy policies in Ghana

Renewable energy sources have been identified as a means capable with significant role in the nation’s energy portfolio. In 2010, the industrial, residential and commercial sectors accounted for 46%, 40% and 14% respectively of the total electricity end-use in

Ghana. Currently, 90-95% of the Ghana's energy is obtained from wood fuel with biomass accounting to more than 60%, 5-10% hydro and less than 1% from photovoltaic energy. Due to limited renewable energy source in Ghana, in December 2011, renewable energy law was promulgated. The Renewable Energy Act is meant to provide development, management and utilization of renewable energy sources for the production of both heat and power in an efficient and environmental way. The law explained renewable energy as energy sourced from non-depleting sources and these includes wind, bioenergy, solar, geothermal, ocean energy and hydro power (with capacity not more than 100MW). As part of this policy, the government plans to decentralize electricity supply by breaking the monopoly by the public sector to improve regulatory transparency (Ndzibah 2013; Ennison 2012; Kpekpena 2014).

Furthermore, the creation of Strategic National Energy Plan (SNEP) for 2006 - 2020 also adds to the government determination to improve the use of renewable energy. This policy focuses on import and usage of renewable energy products in the Ghana and the connection to international renewable energy sector. Additionally, this policy aim at reducing wood fuel energy consumption by 30% by 2015 and further by 2020. Also, the use of biogas should increase its share to 1% by 2015 and 2% by 2020 with limit to hotels, restaurants and institutional kitchens. Due to the international connections, Ghana has signed international environmental protocol notable, the United Nation's Millennium Development Goals (UNMDG) among others to eradicate poverty and hunger by promoting sustainable energy, environmental policies and to protect future generations (REEGLE 2014; ECOWREX 2011; REEEP 2009; Ndzibah 2013; Ghana-EC 2009)

The creation of Independent Power Producers (IPPs) with the recognitions by the government of Ghana has a great importance to the achievement of these international and domestic expansion objectives. According to Norton Rose Fulbright (2013), one of the disincentives to private sector investment in power generation projects in Ghana was the succeeding level of tariffs, which were considered to be too low to be economic due to the fact that most of the nation's energy is derived from hydropower projects which has very low cost per kilowatt hour compare to thermal power projects. Table 3 below shows the effective Feed-in-Tariffs (FIT) implemented by the Ghanaian government.

Table 3. Feed-in-Tariff from September 2013
Adopted: ECREEE 2014

Renewable energy Technology	**FIT Effective 1st September 2013 (GHp/kWh)**
Wind	32.1085
Solar	40.2100
Hydro ≤ 10MW	26.5574
Hydro (10MW>≤ 100MW)	22.7436
Landfill Gas	31.4696
Sewage Gas	31.4696
Biomass	31.4696

In order to encourage investors, the Public Utilities Regulation Commission (PURC) have been increasing tariffs aim at cost wistful although there is pressure to keep consumer tariffs low, which hampers the establishment of fully cost-reflective tariffs that would support IPPs. As part of the Renewable Energy Act 2011, Act 832 gives PURC the responsibility to set the Feed-In-Tariff (FIT). The Act stated that the pricing mechanism for Renewable Energy Technology in Ghana and FIT rate for electricity generated from renewable energy sources shall be guaranteed for a period of ten (10) years and subsequently be subject to review every two years” (Ennison 2012; ECREEE 2014).

3. TECHNOLOGY AND PRODUCT CONFIGURATION

This section of the research defines photovoltaic technologies and its development, types and components involved in the installation process as well as an in-depth analysis of various configurations. The introduction of an off grid solution in product configurations add value to the varied segments be it standalone, backup, or hybrid system suitable for either households or SMEs.

3.1 Photovoltaic technologies: definition, development, types and installed capacity

Renewable energy technologies can help countries meet their policy goals for secure, reliable and affordable energy to expand electricity access and promote economic development. Although there are other sources of energy, renewable energy is being adopted and account for the majority of capacity additions in power generation today (IRENA 2012). Photovoltaic technology is one of the essential forms of renewable energy that will help offset the deficit created by the demand and supply of electric energy in most developing economy. Furthermore, such reliable technology has a significant potential for long-term growth in nearly all regions (IEA & OECD 2010).

The Photovoltaic Sustainable Resources (2014) defines the term “photovoltaic” with two words – “*photo*” which means light (*photon*) and “*voltaic*” which means voltage (“*volt*” – unit of electric potential). The way photovoltaic systems generates electricity process is no different from the way plants converts sunlight or the energy from the sun to store food (see also - Green Peace & EPIA 2011).

According to the World Energy Council (2007), photovoltaic conversion “*is the direct conversion of sunlight into electricity with no intervening heat engine*”. Photovoltaic devices are rugged and simple in design and need very little maintenance. As such, the major advantage of solar photovoltaic is the ability to assemble a *stand-alone system* to give outputs from microwatts to megawatts. For this reason, they have been used as the power source for calculators, watches, remote buildings, satellites and space vehicles. In some area, megawatt-scale power plants have been commissioned and constructed to support electricity production (Viessmann 2009; IEA PVPS 2013).

The history and development of solar technology started from the 17th Century B.C. with the magnifying glass and the first solar collector in 1767.The first solar cells was made from selenium wafers by Charles Fritts in 1883 but the phenomenon known as the *photovoltaic effect* was discovered by Edmund Bacquerel in 1839. The development of photovoltaic technology started in the 1950's but gain more attention in the 1960's with NASA's space program. Since then, the technology has been improved and today some of the largest rooftop and solar farms for power generation are in operation (EERE 2014; The Solar Cooking 2014; Masson 2013; IEA-PVPS 2013; Dahl T. 2012).

A collection of photovoltaic cells make up a single modular unit. These cells are sometimes known as ***solar cells***; which convert light into electricity through a semiconductor material (e.g. silicon) (Howard 2005; Fernandes et al 2014). According to Ndzibah (2013), photovoltaic design platform is a semiconductor device prepared from silicon. Monocrystalline and polycrystalline are the two most common crystalline silicon solar cells while others models are made from ribbon, thin film technologies, and concentrating photovoltaic (CPV) all with varying output capacity (Evo Energy 2012; EPVTP 2011).

Even though the installations and procurement of photovoltaic systems are expensive, the prices have been falling as a result of many manufacturers in the market and the advancement in technology. Figure 5 (below) shows the annual growth of photovoltaic installations around the world. Although, there is a need for further research and development to improve the efficiency of all types of cells.(Viessmann 2009; RENI 2012; Mitavachan et al 2011; IEA PVPS 2013).

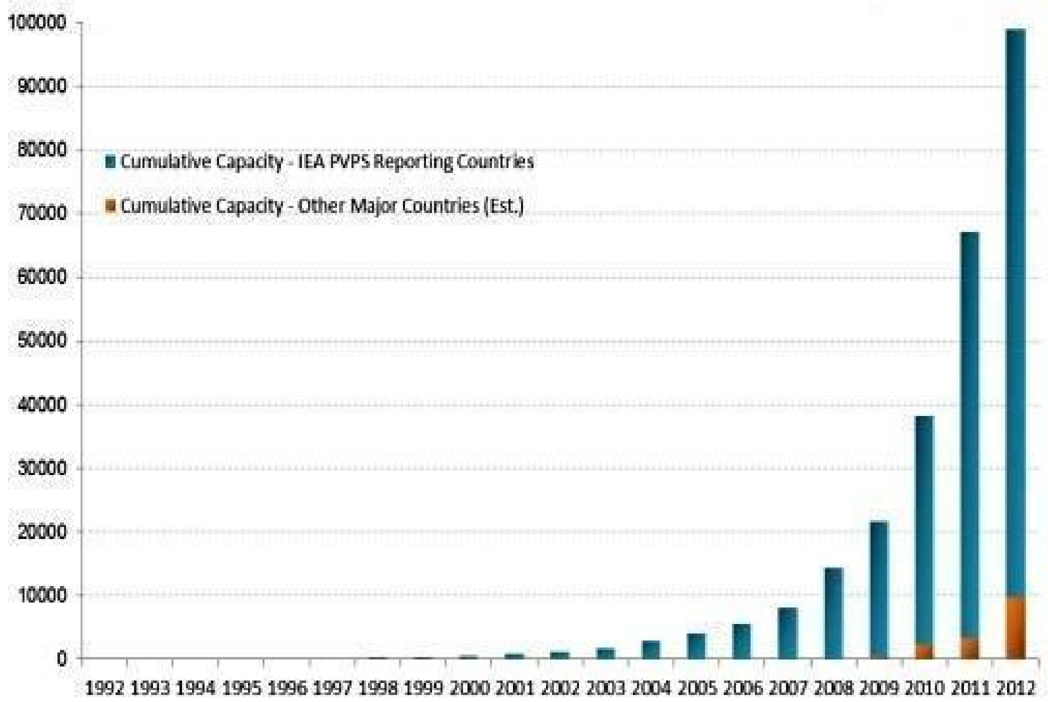


Figure 5. Annual evolution of PV capacity
Source: IEA PVPS 2013

The efficiency of photovoltaic module is important during decision making process for the purchasing and installation of a photovoltaic system. This is because the power output of photovoltaic panels are not the same hence the prices. Figure 11 below shows advancement in photovoltaic development by different companies and research groups since 1975. Furthermore, more research needed to increase and optimise maximum power output using these photovoltaic technologies (Laser Focus World 2010).

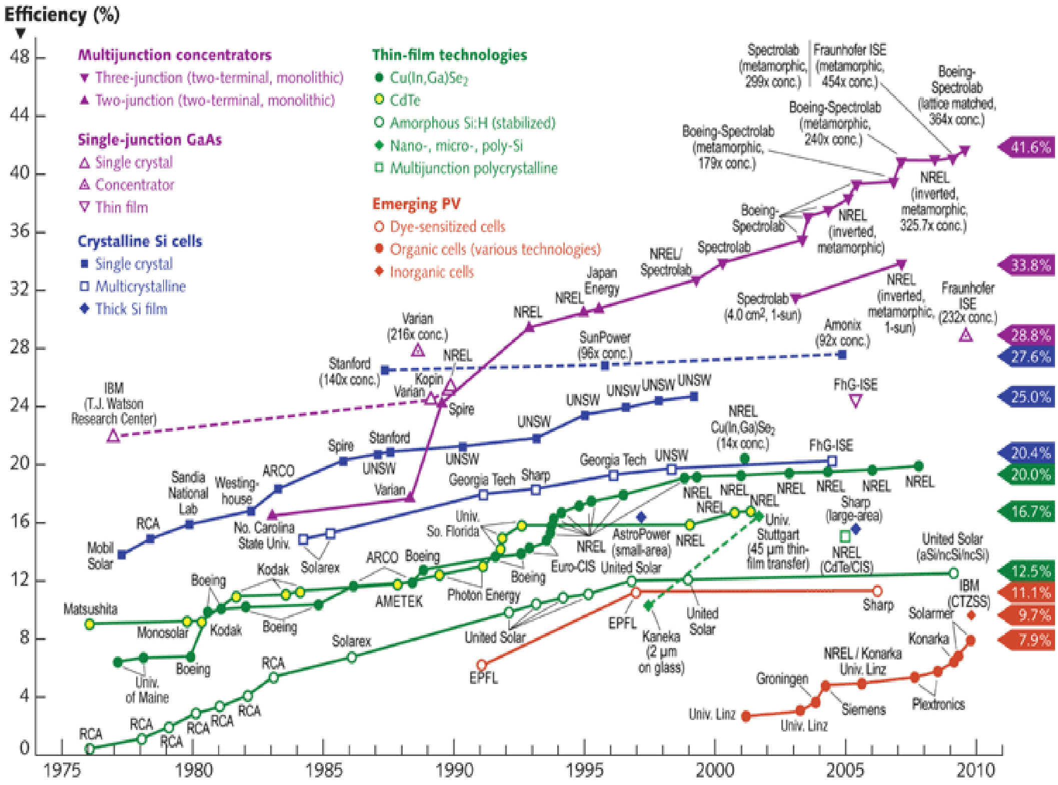


Figure 6. Photovoltaic efficiency in converting light to electricity
Source: Laser Focus World (2010)

Pros and Cons of photovoltaic technologies

As the demand for energy grows especially in non-OECD nations, many are thinking about the adoption of alternative means of generating electricity (EIA 2013). Photovoltaic systems could be an ideal choice since the source of fuel is naturally free and abundant (Green D. 2012).

Photovoltaic systems provide clean energy. When compare with generators or power plants, photovoltaic system does not use fossil fuel, therefore there is no GHG; making it an environmental friendly source of energy. Unlike power plants and generator, photovoltaic systems do not make noise making them suitable for both urban and residential use. The high cost of photovoltaic system often makes it difficult for people to invest but in recent time, most government provides subsidies for the installation.

These subsidies are in a form of Feed in Tariffs (FITs), tax credits, low interest rates etc. (IEA 2012; Green 2012; Rio & Mir-Artigues 2014; CEC 2008).

Solar energy is subjected to irregular supply of sun light due to weather condition, day and night and this leads to unpredictability. As a result of this limitation, storage systems such as battery are used in photovoltaic systems. The initial cost involve is high. Even though in some country subsidies are provided, this is not a common practice in other countries. The efficiency of photovoltaic panels (between 14% - 25%) is too low compare to other renewable energy systems. Furthermore, the cost of insuring the systems is high (Green 2012; Practical Action 2012).

3.2 Types of components in a photovoltaic system

Photovoltaic system may include panels, charge controller, batteries and inverters. These various components must be integrated properly to ensure safety and optimized maximum output during operation. The configurations of these components can be arranged either in series or parallel with the load either direct current (DC), alternate current (AC) or both (Whitaker et al. 2008; Mehrotra et al 2013; AIEDAM 2003; Haug et al 2012; Schimpf & Norum 2008; Zeman 2014).

Photovoltaic modules: These are made up of solar cells. A solar cell is formed from silicon - semi-conductor. Silicon is the second most abundant element on earth found in quartz and sand. These solar cells are the unit which converts sunlight to electricity. The cells are often connected together to produce voltage capable of charging 12 or 24 volt battery. A collection of cells make up photovoltaic modules which when put together forms photovoltaic arrays. These photovoltaic arrays are also made up of any support structure and inter-connection. Photovoltaic module is the building block of photovoltaic systems (Ndzibah 2013; Sustainable Resources 2014; Brooks 2014; Patel 2006).

Monocrystalline and polycrystalline silicon photovoltaic are two of the most common photovoltaic cells with an average annual growth of 40% (Goodrich et al. 2013; Dobrzanski et al. 2012). There are other types of photovoltaic cells such as amorphous silicon, cadmium telluride (CdTe) and thin film (Prida et al. 2011), figure 12 indicate the main groups of materials for the production of photovoltaic cells (Dobrzanski et al. 2012). *Monocrystalline silicon photovoltaic* are highly efficient solar cell with robust design and the highest conversion efficiency (17% - 24 %) of all the silicon solar cells while p*olycrystalline silicon photovoltaic* cell is made from large block of silicon and the cells are less efficient compare to monocrystalline (Redarc 2011; Dobrzanski et al. 2012).

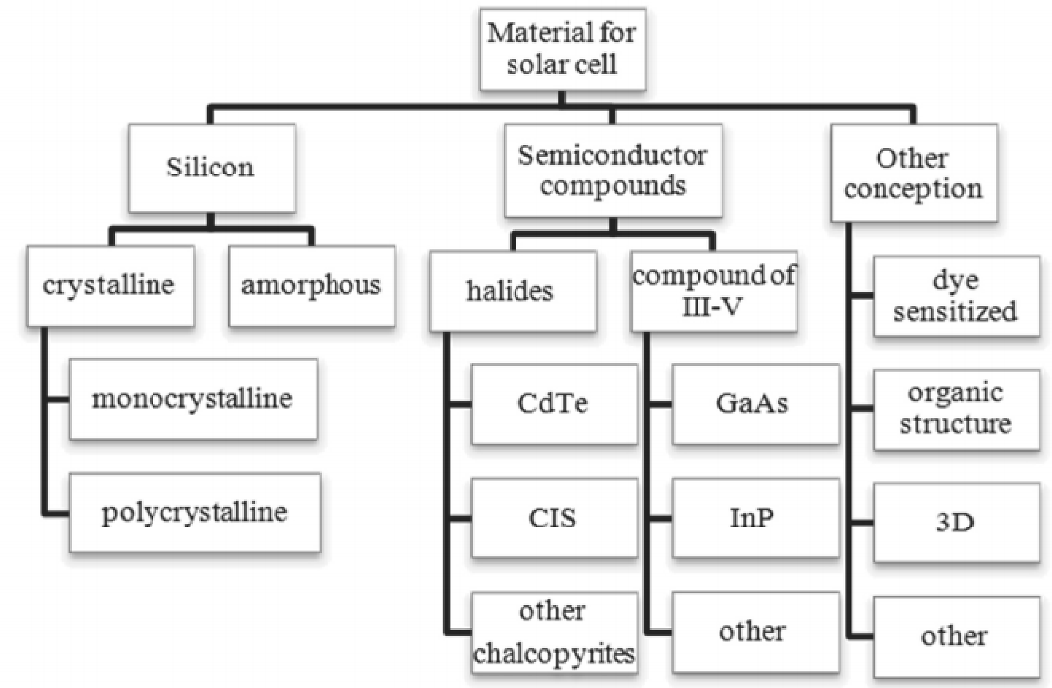
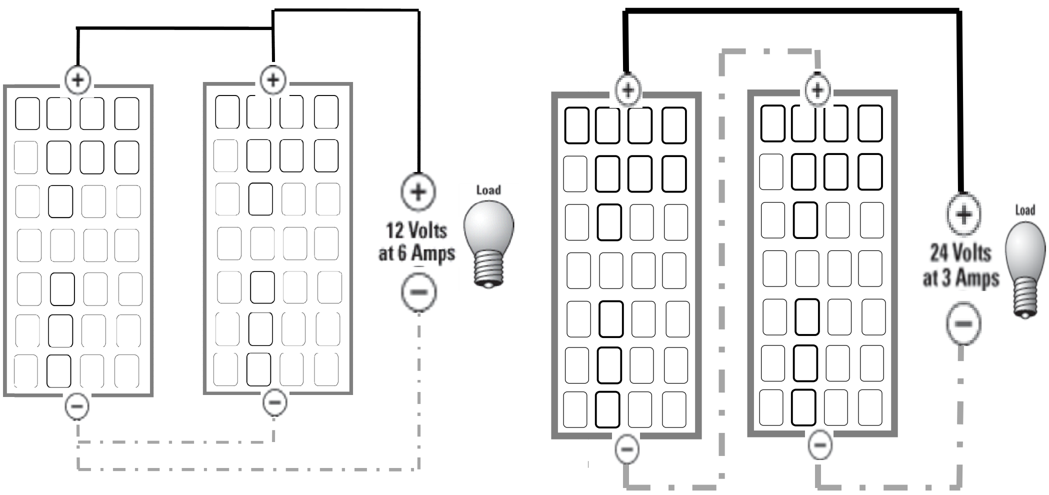


Figure 7. Classification of solar cells materials
Sources: Dobrzanski et al. 2012

Series vs. Parallel connections: Connecting photovoltaic module in series or parallel depends of the required output. Photovoltaic modules arranged in series will yield high voltage (*V*) while the one arranged in parallel yields high current (*I*) (Pearsall & Hill

2001; Obinata et al. 2010). Figure 13 A and B shows the parallel and series configuration of photovoltaic modules respectively. The configuration in both series and parallel uses two photovoltaic modules with each operating at 12VDC at 3amp. The configuration in parallel produces 12 volt at 6amp to power the load compare to the configuration in series which output voltage is double to 24 volt while the current is half at 3amp. The reason for obtaining different voltage or current output to power the load can be clarified using Ohm’s law (MSU 2014).



A: Parallel **B: Series**

Figure 8. Parallel and series connections of photovoltaic panels
Adopted: Dahl (2012)

Ohm’s law explains the relationship between current and voltage which state that the voltage passing through a circuit is directly proportional to the product of the current and resistor. This is illustrated in equation (1) (MSU 2014; Sparkfun 2014). According to Rahman et al. (2012), when a photovoltaic module is directly connected to a load, the operating point of the photovoltaic module will be at the intersection of its I–V curve. This means that the load is directly proportional to the voltage and inversely proportional to the current. Hence, resistor in equation (1) is the load.

$$\boldsymbol{V} = \boldsymbol{I} \times \boldsymbol{R} \tag{1}$$

Where:

$\boldsymbol{V} = Voltage\ (volt)$

$\boldsymbol{I} = Current\ (amp)$

$\boldsymbol{R} = Resistor\ (ohms)$

Table 4 shows how voltage and current can be calculated when configuring either a series or parallel photovoltaic system. The equations can be considered when two resistors or in this case two load.

Table 4. Photovoltaic module voltage and current calculations

Series	**Parallel**
$\boldsymbol{V_{total}} = \boldsymbol{V_1} + \boldsymbol{V_2}$	$\boldsymbol{V_{total}} = \boldsymbol{V_1} = \boldsymbol{V_2}$
$\boldsymbol{I_{total}} = \boldsymbol{I_1} = \boldsymbol{I_2}$	$\boldsymbol{I_{total}} = \boldsymbol{I_1} + \boldsymbol{I_2}$

Basic technical parameter for photovoltaic module

Photovoltaic panel calculation: The number of solar panel required in a photovoltaic system depends on the photovoltaic watts at the installation location. Since solar irradiance varies from location to location, the photovoltaic watts need to be calculated. The values obtained might vary from month-to-month. Therefore to achieve a maximum power output from the photovoltaic power, it is advisable to use the lowest photovoltaic watt for that location. There are software and web applications that can be used to obtain the exact photovoltaic watts (Budischak 2013; Marion et al 2001; Dobos 2013; Enphase Energy 2013).

The unit for photovoltaic panel is measured in kilowatt hour for every square meter in a day. This is written as $kWh/m^2/day$. This unit is sometimes called sun hours and also having unit of hours/day (h/day). According to Ndzibah (2013), the lowest photovoltaic watts or sun hour for Greater Accra is $4.35\ kWh/m^2/day$. The variations in solar irradiation are caused by topography, humidity and clouds. Greater Accra is used due to existence of valid working examples which provides more parameters. We can calculate how many panels are needed to power the load in the Greater Accra, the capital of Ghana. Assuming the panel operate at $100\ watts$ at full sunlight, the energy produced (kWh/day) by one panel will be:

$$\rightarrow \frac{4.35 hrs}{day} \times \frac{100\ \cancel{watts}}{1\ solar\ panel} \times \frac{1\ kilowatt}{1000\ \cancel{watts}} = \frac{\frac{0.435\ kWh}{day}}{1\ solar\ panel}$$

$$= 0.435 \text{kWh/day/panel}$$

Assuming the total energy required by the load was $0.4\ \text{kWh/day}$, the total number of panel needed can be obtained as follows:

$$\rightarrow \frac{0.4\ kWh}{day} \div \frac{\frac{0.435\ kWh}{day}}{panel} = \frac{0.4\ \cancel{kWh}}{\cancel{day}} \times \frac{\cancel{day}\ /panel}{0.435\ \cancel{kWh}} = 0.9195\ panel \sim 1\ panel$$

Photovoltaic Inverters: Inverters plays a major role in the configuration of photovoltaic systems. Photovoltaic inverter converts direct current (DC) from photovoltaic panels or modules into utility frequency alternating current (AC) which can be fed to appliances.

Therefore, any unit that can convert a 12-volt battery or a direct solar current to 220/230 volt electricity is an inverter. According to Hills and Pearsall (2001), inverters used in standalone are capable of “operating independently from a utility grip and uses an internal frequency generator to obtain the correct output frequency (50/60 Hz)” but this is different when it comes to grid-connected. Generally, inverters have efficiencies ranging from 90% to 96% for full load and from 85% to 95% for 10% load (especially for loads that need surge voltage) (Ndzibah 2013; Hill & Pearsall 2001; Zeman 2014).

There are basically two types of inverters – *pure sine wave* (PSW) inverter and *modified sine wave* (MSW) inverter. However, it is worth mentioning that in recent years, the *module-integrated inverter* has been developed to be positioned on the back of a module and converting the electrical output from a single module and specifically designed for grid-connected applications. The PSW with total harmonic distortion (THD) is used to operate sensitive electronic devices needed for clean, near-sine-wave outputs for instruments like medical equipment and other critical applications with an embedded motorized system whereas MSW designed to satisfy the efficiency of photovoltaic system at a less cost when compared to PSW. MSW is used in a wide variety of loads, electronics and household items such as TV, computer and satellite (Hahn 2006; Wilson 2011; Turna 2011; Hill & Pearsall 2001).

Basic technical parameter for an inverter

Inverter input power: The basic function of the inverter is to convert DC power produced by the photovoltaic modules to AC in other to power electrical loads. This is done by switching on and off the power transistors at high frequency to obtain power from the photovoltaic modules during their maximum power output (Patel 1999; Gilbert 2004). According to Budischak (2013), the efficiency of inverter ($\eta_{inverter}$) can be obtained using the following equation:

$$\boldsymbol{\eta_{inverter}} = \frac{Output\ power}{Input\ power} \rightarrow \boldsymbol{input\ power} = \frac{Output\ power}{\eta_{inverter}} \qquad (2)$$

Where:

$$\boldsymbol{\eta} = Efficiency$$

Khatib et al. (2012) explained that equation (2) can be used when the loss produced by the inverter during output is not considered. This loss is not constant and can depend on many conditions making it difficult to be calculated. Therefore, an alternative model for inverter efficiency needs to be developed in order to estimate the inverter's exact output power.

For example, assuming the inverter has an efficiency of 55% with an output of 100 watts. Using the (2), the input power of the inverter will be:

$$\boldsymbol{input\ power} = \frac{Output\ power}{\eta_{inverter}} = \frac{100 watts}{55\%} = 181.8\ watts$$

The input power of 200 watts does not mean that is the maximum. All inverters come with a rated maximum input or upper limit rating which varies depending on type and manufacture (Chiasson et al 2005; Bower et al. 2004; Tolbert et al. 2000).

Photovoltaic Charge controller: For a prolonged battery life, a charge controller is needed. This is because charge controller help sense the battery voltage by reducing and stopping charged current when the voltage is too high. Charge controllers also prevent photovoltaic modules from overcharging the battery and over discharging during operation of the system. Without the charge controller, the excessive voltage could easily damage the batteries (Ndzibah 2013; Sustainable Resources 2014; Solar Direct 2014).

Basic technical parameter for charge controller

Charge controller amperage: Charge controllers are rated and sized by the solar panel array current and the system voltage. The most common are 12, 24, and 48 volt charge controllers. The amperage ratings normally run from 1 amp to 60 amps while the voltage is between 6 and 60 volts (PV Depot 2014).

From equation 2, the voltage passing through the inverter was calculated. According to Rahman et al. (2012), for any given set of operational conditions, cells have a single operating point where the values of the current (*I*) and voltage (*V*) result in a maximum power output. These values correspond to a particular load resistance which can be represented using $\boldsymbol{R} = \frac{\boldsymbol{V}}{\boldsymbol{I}}$ as specified by Ohm's Law. To obtain the amperage using basic circuit theory, the following equation needs to be utilized:

$$\boldsymbol{P} = \boldsymbol{I} \times \boldsymbol{V} \tag{3}$$

Where:

$\boldsymbol{P} = Power\ (watts)$

$\boldsymbol{I} = Current\ (amp)$

$\boldsymbol{V} = Voltage\ (volt)$

Therefore, the power can be calculated. Assuming the charge controller is operating at 24 volt with an amperage of 10 amps and an efficiency of 100%:

$$\boldsymbol{P} = I \times V = 24 \times 10 = 240\ watts$$

Battery: The battery serves as a storage device for the voltage generated by the solar cells. They are the simplest means of storing electricity and are essential in standalone, backup and hybrid configurations (Harrington et al. 1992). The stored voltage are later used during power disruption or to power some appliances while the electricity from the grid is used for equipment or appliances that required more energy to operate (Ndzibah 2013; Sustainable Resources 2014). The life cycle of a battery is related to the depth-of-discharge (Dunlop & Farhi 2001; Spiers & Royer 1998). The capacity of a battery is rated in amp-hour (Ah) at a given voltage e.g. 220Ah at 6 volts. One amp delivered for 1 hour is equivalent to 1 amp-hour. According to Zeman (2014), there are some factors needed to be considered before purchasing a battery for use in a photovoltaic system. These are:

- Operating temperature range (e.g.: -15°C to 50°C)
- Self-discharge rate (% per month)
- Required frequency for topping up the electrolyte
- Cycle life to 80% depth of discharge (DOD)
- Charge efficiency from 20% discharged
- Capacity (Ah) at 10hr and 100hr rates (C10 & C100)
- Resistance to overcharging
- Cost

There are two types of batteries – *lead-acid batteries* and *alkaline batteries*. Lead-acid batteries are of three kinds – *flooded lead-acid*, *gelled electrolyte* and *absorbed glass mat* (AGM). Gelled electrolyte and absorbed glass mat are known as *sealed* or *valve-regulated lead-acid* (VRLA) batteries. This is because they do not need additional water unlike the flooded lead-acid batteries. Instead, valves are installed in each cell to prevent build-ups of gases which is caused by excessive overcharge. This type of problem is rectifiable in flooded lead-acid batteries due to the fact that it is not sealed and water can be added. Lead-acid batteries are the most common used in photovoltaic configurations (Zeman 2014; Spiers & Royer 1998; EMTC 1981). According to Dunlop & Farhi (2001); alkaline batteries are often used in extreme climate conditions. The two most commonly used are nickel-cadmium and nickel-metal-hydride. However, they are expensive due to the lack of availability (see also Medved et al. 2011). In developing country such as Ghana gelled electrolyte batteries is highly recommended. This is gelled electrolyte batteries has been known to be very efficient due to its ability to withstand high temperature

Batteries can be connected in series, parallel or series/parallel depending on the configuration in mind (Baghzouz 2014; Medved et al. 2011). The principle of Ohm's law can be applied to batteries. Voltage calculation using Ohm's law can be applied to batteries connected in series or parallel (Dahl 2012). Example, the total voltage in a configuration of 6 batteries in series with each measuring 2VDC will yield 12V. When compared to 2 batteries configured in parallel with each one measuring 12VDC, the output will be the same i.e. 12V.

Basic technical parameter for battery

Number of batteries: The number of batteries depends on the amount of energy needed to power the load. Assuming the total energy needed to power the load for $4\,hours$ every day was 0.4 kWh/day and the battery is 10Ah at 12 volts while the load uses the energy for 3 days:

$$\rightarrow \frac{0.4\,kWh}{\cancel{day}} \times 3\,\cancel{days} = 1.2\,kWh$$

But since the battery is measure in *amp hours*, ohms law can be used to calculate current (amp hour) using equation (3):

$$\boldsymbol{I} = \frac{P}{V} = \frac{1.2\,kWh}{12\,volt} = 0.1\,kAh \times \frac{1000\,Ah}{1\,kAh} = 100\,amphours$$

Finally, it’s worth mentioning that every photovoltaic system must have a load. The load also known as *electrical loads* could be either household appliances or industrial equipment. According to Macomber et al. (1981), the cost and size of a photovoltaic system is directly proportional to the energy requirements of the loads to be served. Additionally, the peak demand and energy requirements must be appraised as best as possible, to prevent unreasonably over sizing the power system and cost. Energy efficient loads contribute enormously to the overall efficiency and economy of the system. Table 5 shows some of the typical power consumption appliances and the amount of power needed to operate them. The load can be DC, AC or both. The load can be either connected directly (in the case of a water pump system) or indirectly (in the case of a radio). However, the utilization of DC load can reduce the installation cost. This is because frequency converters and inverters will not be required adding needed array capacity (Hansen et al. 2000; Zeman 2014; Ode 2014; Ndzibah 2013; Baghzouz 2014).

Table 5. Power consumption of home appliances

Home Appliances	**DC (*watts*)**	**AC (*watts*)**
Compact Fluorescent light	4 – 12	9 – 100
Stereo / Tape Player	10 – 50	10 – 100
Ceiling Fan	20 – 60	24 – 100
Television (48cm, colour)	40 – 50	60 – 85
Computer (Laptop)	20 – 50	60 – 90
Air-condition	250 – 1000	750 – 3500
Refrigerator	16 – 97	500 – 2200

Basic technical parameter for load

Load energy usage: Various loads use different energy and they could be either *DC* or *AC*. AC loads consume more energy than DC loads as seen in table 13. These loads are also known as *appliances* (Zeman 2014). The load energy usage is the amounts of energy required to power or operate a load or appliance taking into consideration for how long an appliance will be powered on when it is connected to a photovoltaic system. The energy consumed by a load or appliance is measured in kilowatts hour (*kWh*) i.e. the unit of energy (Packer 2011; OECD/IEA 2010). Therefore, assuming the load is a light bulb and consumes 100 watts for 4 hours every day all year round. This needs to be converted to the amount of energy the bulb will use in a day. This can be done by converting the 100 watts to kilowatts and multiply it by the hours.

$$1\cancel{00}\ \cancel{watts} = \frac{1\ kilowatt}{10\cancel{00}\ \cancel{watts}} \times \frac{4\ hours}{day} = \frac{0.4\ kWh}{day}$$

This means that the amount of energy consumed by the bulb in a day will be *0.4 kWh*. With this in mind, the amount of energy the charge controller can supply to the inverter can be calculated using equation (2) but instead of power, energy is used. Note that the output energy in now the amount of energy consumed by the bulb.

$$\rightarrow \boldsymbol{input\ energy} = \frac{Output\ \text{energy}}{\eta_{inverter}} = \frac{\frac{0.4\ kWh}{day}}{55\%} = 0.73\ \text{kWh/day}$$

Figure 15 gives a summary of all the basic technical parameters. These basic technical parameters can be used to configure either as standalone, backup or hybrid depending on market segment. Note that other parameters such as the type and efficiency of the components were not taken into consideration during the calculation. These and many more parameters could affect the outcome of the results when the calculations are done in the field or the location where they need to be installed.

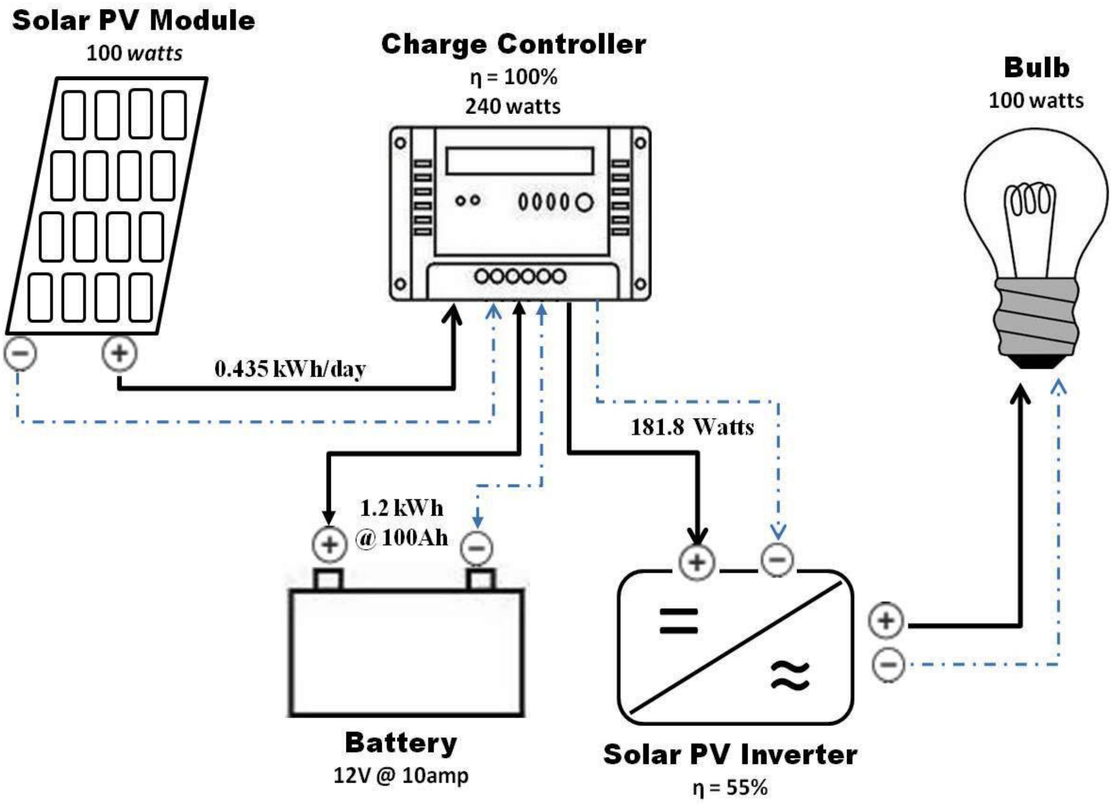


Figure 9. Summary of technical parameters

3.3 Configuration of photovoltaic systems: Standalone, Backup and Hybrid

The interest in photovoltaic is greater than ever and thus, an increase in the installation of photovoltaic systems. The installations of photovoltaic systems are getting larger and the interactive with utility grid is growing (Whitaker et al. 2008). For this reason, there are various types of photovoltaic systems and configurations. This section of the research will look at the various photovoltaic configurations. The way the parts are put together or arranged is referred to as *configuration* (Merriam Webster 2014).

Product configuration is a way of modifying a product or components to meet the needs of a particular customer. The components that make up a photovoltaic system consist of mechanical parts, services, and or software. There are different types of photovoltaic configuration and for this research, *standalone*; *backup* and *hybrid* (Ndzibah 2013) will be the main focus. Although, there are other classification of photovoltaic systems other than the one mentioned earlier. According to EMA & BCA (2009), there are two types of systems:

- *Grid- Connected*: these are systems whereby photovoltaic system is connected to the utility grid. They often contain photovoltaic panels, solar inverters, maximum power point tracking (MPPT) and grid connection equipment (Schimpf & Norum 2008).
- *Off-Grid Connected*: as the name implies, these types of systems are relevant for areas not connected to the utility grid. Generally, these are installed in isolated areas. Although, they may also be installed within the city (in areas deemed too expensive to extend electricity). This is often known as standalone photovoltaic system (EMA & BCA 2009).

Whitaker et al. (2008) further explained that, grid-connected can also be classified as:

- *Grid connected with storage*: this type of system allows solar energy to be stored, thus increasing self-consumption thereby reducing purchase of power from the grid whereas;
- *Grid connected without storage*: this type of photovoltaic system does not have any storage system therefore rely on the power grid when there is disruption in solar energy from the photovoltaic panel due to bad weather conditions.

Standalone Systems: This type of system is used by people who have no access to the national electric grid. This means that electrification is solely generated from photovoltaic system. This could also be classified as an *off-grid system* (Whitaker et al. 2008; Ndzibah 2013). According to Macomber et al. (1981) a stand-alone electrical system can be self-sufficient system which contains an array field, power conditioning and control; battery storage, instrumentation and dc loads. However, a standalone system may or may not have energy storage. The capacity of the battery must be enough to handle the load(s) it intended to serve (Medved et al. 2011; Spiers & Royer 1998; Solar Direct 2014).

Backup Systems: is recommended for those who have access to the national grid but are ready to use the photovoltaic system instead of a diesel or petrol powered generator in case of a power outage (Ndzibah 2013). This type of system could be classified as *grid-connected with storage* (Whitaker et al. 2008).

Hybrid system, differ from standalone systems. This type of photovoltaic system is recommended for specific households or businesses with enormous energy requirement. Figure 14 shows a hybrid system with an auxiliary power source. According to Hristov (2014), hybrid signifies a photovoltaic system that is used in conjunction with one or more auxiliary sources of power. This means secondary sources of power such as wind or hydroelectric is used. However, many modern hybrid photovoltaic systems uses fossil fuelled generator or utility grid.

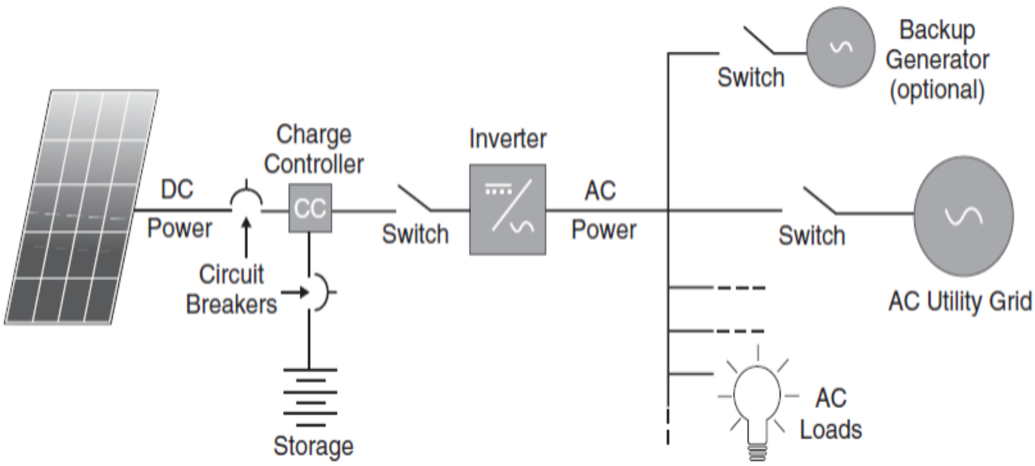


Figure 10. Hybrid system with an auxiliary power source
Source: Hristov H. (2014)

For such requirements, key appliances are connected to the grid while the photovoltaic unit powers other equipment or machineries. The design of a hybrid system should take into account the inverter capacity. This must correspond to the required energy consumption (Ndzibah 2013; SMA 2014).

Configuration segments

Photovoltaic systems are often used for many reasons. Some of these reasons includes; reduce energy cost, reduce GHG footprint and limit reliance on electricity suppliers. These may be regarded as external factors since the main application may differ depending on either in a house, business or factory. These different applications necessitate varied configuration segments. According to Ndzibah (2013), a segment could either be standalone, backup or hybrid. Nevertheless, the configuration for each of the segments may vary depending on the application. For example, one might configure a photovoltaic system for only lighting (see fig. 11) or for refrigeration while others might use it to power all the appliances (radio, TV, computer). Figure 16 shows the relationship between different configuration segments when a backup system is considered for either a home or business.

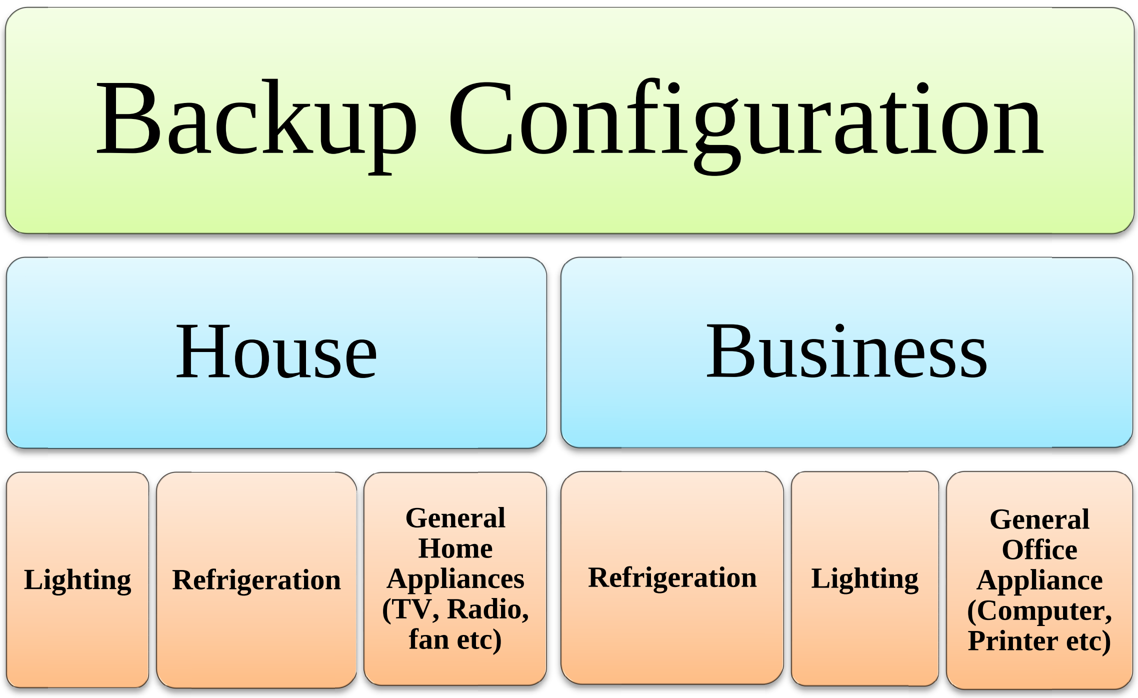


Figure 11. A configuration segment of a photovoltaic system

Designing a simple photovoltaic system

According to Clean Energy Council (2008), when designing a photovoltaic system, there are some things which need to be considered, these include the electricity demand, location, budget and rebate. The electricity demand focuses on how much electricity is used. Furthermore, the budget and the rebate are equally important when it come to financing. More so, the rebate could help reduce the financial burden. With this said, there are some calculation needed to be considered when designing a photovoltaic system. According to Budischak (2013) these include:

- *The amount of energy the load(s) will consume (kwh/day).*
- *The number of solar panels needed to provide the required energy to power the load at a particular location as well as its average peak/lean hour.*
- *Calculating the number of batteries the system will need when there is little or no sunlight.*
- *The output power to the inverter when the load is on. This help to determine the inverter capacity required for the systems.*
- *The amperage the charge controller supplied to the inverter to decide the wattage capacity of charge controller.*

Considering the limitation of the research, an example of a segment configuration for a household in Ghana will be given based on a backup system. Assuming the household uses a bulb, ceiling fan, TV, stereo and refrigerator, the total energy of all these appliances need to be calculated. Table 5 shows an average household in Ghana with the appliances and their total capacity using equation 4. These appliances are used at different hours of the day. The type of bulb used in this configuration is a compact fluorescent (CFL) light bulb due to the fact that incandescent bulbs are not allowed in Ghana. This is because Ghana energy policy toward efficiency required the use of CFL bulbs in other to reduce electricity consumption, reduce blowout and transformer overloads. This made Ghana the first country in Africa to take such action (Fuseini 2011). This configuration is for a household with a family of 4.

According to Essah (2011), the basic energy needs of a person in a country (such as Ghana) can be obtained via installed capacity of a generated source which forms the fundamental basic requirement of all developed nations. For this reason, there is a need to obtain the net actual demand and net supply to help arrive at the net deficit of electricity required to meet the needs of the population of Ghana. This can be achieved using the following basic equations. It is good to note that these equations do not take into consideration loss of energy due to inefficiency of the appliances:

Daily:

$$D_a \; P_w \, C_{ons} = AR \times Q \times hours \; (per \; day) \qquad (4)$$

Annual:

$$A_{nn} \, P_w \, C_{ons} = \frac{D_a \, P_w C_{ons} \times Days \; of \; the \; year}{1000} \qquad (5)$$

Where:

$D_a \; P_w \, C_{ons} = Daily \; Power \; Consumption; \; (Wh/day)$

$A_{nn} \, P_w \, C_{ons} = Annual \; Power \; Consumption; (kWh/year)$

$AR = Appliance \; Ratings; (Watts)$

$Q = Quantity \; of \; appliance$

Table 6. Estimated energy consumption for a household in Ghana

Appliance	**Appliance Rating (*watts*)**	**Quantity**	**Hours (per day)**	**Total Capacity (*Wh/day*)**
Bulb (CFL)	12	4	4	192
Ceiling Fan	50	2	4	400
Stereo	40	1	3	120
TV	75	1	5	375
Refrigerator / Freezer	350	1	6	2100
Total				**3187**

Using equation (4), the total energy consumed by the household in a day is 3187Wh/day. This can be approximated to 3.19kWh/day. Assuming the household decided to use a 100 watt photovoltaic panel with a sun hour of 4.35hours/day, the energy produced by the panel is calculated as:

$$\rightarrow \frac{4.35 hrs}{day} \times \frac{100\ \cancel{watts}}{1\ solar\ panel} \times \frac{1\ kilowatt}{1000\ \cancel{watts}} = \frac{\frac{0.435\ kWh}{day}}{1\ solar\ panel}$$

$$= 0.435\text{kWh/day/panel}$$

But the total energy consumed by the household appliance was 3.19kWh/day, therefore the total number of panel needed can be obtained as follows:

$$\rightarrow \frac{3.19\ kWh}{day} \div \frac{\frac{0.435\ kWh}{day}}{panel} = \frac{3.2\ \cancel{kWh}}{\cancel{day}} \times \frac{\cancel{day}\ /panel}{0.435\ \cancel{kWh}} = 7.33\ panels \sim 7\ panels$$

Therefore, the total capacity of the photovoltaic panel is 700 watts while the energy produce will be 3.199kWh/day. With the capacity and energy of the panels calculated, there is a need to decide which storage medium the household will use when there is limited or no sun light. The suggested storage medium will be a battery specifically gel battery. Gel batteries are known for its durability and toughness to withstand high temperature. Since the total power consumption by the appliances is 3.19kWh/day, the capacity of the battery needed to support the load can be obtained using equation 3. If a 12V 250Ah battery is used, the amperage of the battery will be:

$$\rightarrow \boldsymbol{I} = \frac{P}{V} = \frac{3.19\ kWh}{12\ volt} = 0.266\ \cancel{kAh} \times \frac{1000\ amphour}{1\ \cancel{kAh}} = 266\ amphours$$

The quantity of batteries can be calculated since a 250Ah battery is used:

$$\rightarrow \frac{266\ \cancel{Ah}}{250\ \cancel{Ah}} = 1.06 \sim 1\ batteries$$

The final calculation shows that one gel battery can be used to produce the energy required to operate the loads. With the number and capacity of both the photovoltaic panels and the battery calculated, it is possible to determine the type of charge controller. For this configuration, a Maximum Power Point Tracking (MPPT) charge controller will be used. This help the system to automatically and efficiently convert higher voltage down to the lower voltage produced by the photovoltaic panel. With this type of charge controller, the size of the photovoltaic panel can be increase without having to buy new one. But according to PV Depot (2014), one fundamental advantage to having a higher voltage solar panel array is that smaller gauge wiring can be used to the charge controller.

MPPT charge controller is rated by their output amperage rather than the input current from the photovoltaic panel. Since the battery is operating at 12V, the capacity or size of the charge controller can be calculated. To determine the output current, equation 3 is used.

$$\rightarrow \boldsymbol{I} = \frac{P_{panels}}{V} = \frac{700\ watts}{12\ volt} = 58.33\ amps$$

But due to special conditions that can lead to possible power surge, the value of current obtained need to be increased by 25%. Therefore, 58.33A increased by 25% is 72.91A. With this value, an 80A MPPT Charge Controller, like Outback Power's MX80 can be used.

According to Peacock (2013), inverters are rated in "DC input" and "AC output". For this reason, it is very important that the inverter is also rated to suit the output of the photovoltaic panels in DC. This is because inverter needs to be able to handle the maximum power that the solar power system can generate and to be able to power the load. With the total capacity of the load at 3,19kWh/day, and inverter with a capacity of 3kW will be enough to power the load. Although it is good to note that in some cases, not all the load will be power on while is some case all will be on simultaneously. In the case where the loads are not going to be used simultaneously, a lower capacity of the inverter can be used. According to Clean Energy Council (2012), the following must also be considered when choosing photovoltaic system inverter:

a) nominal AC power output cannot be less than 75% of the peak power and
b) the maximum power output of the photovoltaic panel or the load should not be outside the inverter manufacturers maximum input power specification.

Therefore, the chosen inverter’s nominal AC power output should be enough for this system configuration because the manufacturer’s nominal output is not more than the maximum power output of the photovoltaic panel. Figure 12 below shows a summary of the final configuration using the basic technical calculation.

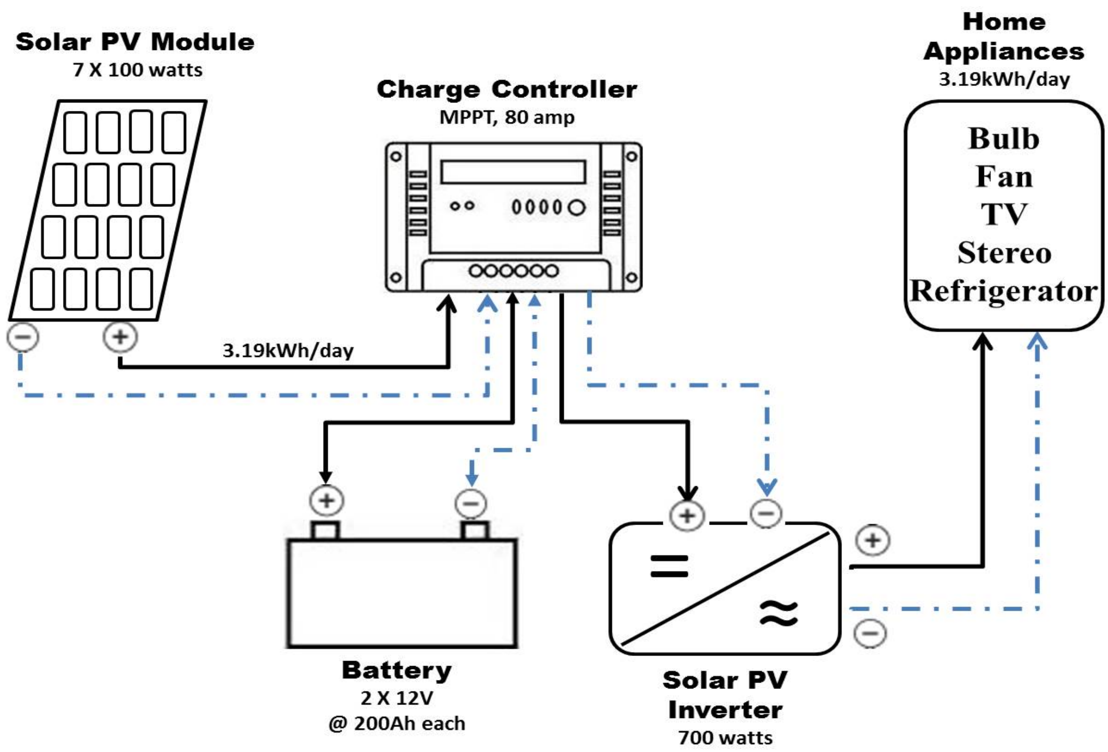


Figure 12. Configuration of a simple backup system for a household

4. RESEARCH METHODOLOGIES

This chapter examines the research methodologies used in this study to establish meaningful and reliable conclusion. This study will use a hybrid research approach; this approach uses both qualitative and quantitative methods (Ndzibah 2013; Burns & Bush 2000: 230, 231). This type of method will help develop and evaluate key findings.

According to Fischler (2014), "research" is a process of steps used to collect and analyze information in order to increase our understanding of a topic or issue". Qualitative and quantitative research differs in the procedure rather than "quality". In some cases, qualitative data can be quantified. For this reason, qualitative and quantitative methods can be said not to be mutually exclusive due to the difference in emphasis and objective of the study (Ghauri & Gronhaug 2005).

The aim of using a hybrid research is to gather an in-depth understanding of the research question. The descriptive nature of qualitative research and the analysis of qualitative research will provide help to establish clearer and meaningful data collection, its analysis and interpretation. Qualitative research involves examining and reflecting on the less tangible aspects of a research subject such as values, attitudes and perceptions. Additionally, qualitative help solve topics from the perspective of a local population obtaining culturally specific information about particular populations. Some of the methods involve in collecting qualitative data includes observation, focus groups and case studies (Hafner 2012; Gazette 2014). Qualitative research is inductive, making it easier for researchers to develop abstractions, hypotheses, concepts and theories. This helps investigates the "*why*" and "*how*" of decision making as well as answering the question: "*what*", "*where*", and "*when*" (Merriam 1988; Creswell 1994).

According to Colin Neville (2007), quantitative research is the collecting and analyzing numerical data which concentrates on measuring the scale, range, frequency etc. of a phenomenon. Quantitative research often uses mathematical based methods (SAGE 2010). Furthermore, Colby (2010) define quantitative research as the manipulation of numbers to make claims, provide evidence, describe phenomena, determine relationships, or determine causation. He further explains that qualitative research uses a systematic way of collecting, interpreting and reporting data to maintain consistency across different contexts. This means that this type of research can be used for make predictions about the research in question, opinion, phenomena or experiments.

The researcher uses focus group study and questionnaire. A focus group is defined as group of interacting individuals having some common interest or characteristics, brought together by a moderator, who uses the group and its interaction as a way to gain information about a specific or focused issue (Marczak & Sewell 2014). Focus group was use in other to know how well people are familiar with photovoltaic systems. Most importantly, how photovoltaic system work and the various components involve in a typical photovoltaic configuration. Furthermore, questionnaire and secondary data helps the researcher to understand the level of energy consumption and the problem facing Ghana's electrification output. This helps the researcher to identify how the electricity are used, the cost of electricity, where they are used (home or office), for how many hours and the devices or appliances that they often use. These questions help the researcher to evaluate and access which of the various configurations can be recommended based on the consumption patterns of electricity.

4.1 Data collection

In other to present the advantages of product configuration of photovoltaic system, there is a need to understand how well the Ghanaian society is aware of the importance of photovoltaic systems and its various configurations. This section will explain how data was collected and the tool used for analysis. For effective data collection, primary and secondary data collection methods will be adopted.

According to Harvard Gazette (2014), primary data are self-generated and consist of experimental designs, case studies, survey data, focus groups and participant observation while secondary data refer to already existing data which can be raw or processed making secondary data the most used in international studies. Secondary data was used to evaluate and investigate the current energy situation in Ghana. This help to identify the problems; collecting and analyzing records to generate solutions. The researcher employs two stages of primary data collection. The first stage was the use of focus group. The information obtained from the first stage made it possible to readjust the questions for the second stage which was in the form of questionnaire. Secondary data contributed to the understanding of both the theoretical and practical nature of photovoltaic systems. Previous published publications and articles were used to ascertain better understanding of the technology, components and configuration of photovoltaic systems. Furthermore, Ndzibah (2013) explained that primary data are preferred when new theories, proposals and models are being developed. Research data can be obtained via a variety of ways depending on the nature of the research.

The researcher used focus group to gather primary information from members of a clearly defined target audience to promote self-disclosure among participants. Due to lack of funding to visit the case country for data collection, selected Africans studying in Finland were used for this study providing opinions through the view of the population. These students are of different background as well as studying in different discipline. The areas of study include information technology, international business, hotel and restaurant management, nursing and energy and environmental engineering. The focus group was conducted with eight African students, living and studying in Vaasa. The data collected helped to re-define further questions which were used for the second stage of data collection. The second stage involves an online questionnaire. This questionnaire was developed using Google Form. The questionnaire was sent to individuals with various occupational backgrounds in Ghana. The data collected were analyzed and the result is presented in Chapter 4.2.

The planning of the research followed basic principle of good research study. These include efficiency, openness, privacy protection, usefulness, validity, reliability, proper schedule and objectivity. The validity and reliability of the research is presented in chapter 4.3.The following were the objective of the research:

1. To give background and explain the electrification development in Ghana

2. To find out the current energy policies in Ghana.
3. To add value to current configuration standards
4. To analyze and propose a set of product configurations of photovoltaic systems in solving the energy crisis in Ghana.

In chapter 2, objective 1 and 2 were answered while chapter 3 added value and explanation to objective 3. The analysis and proposed product configuration of photovoltaic systems to solving Ghana's electrification problems is introduced in chapter 5. The efficiency and openness of the study can be explained in how the data were collected and analyzed. To do this, the respondent were informed the reason *why* the data is needed. In addition, the openness was justified by informing the respondents the findings and outcome of the study without hiding any facts. To avoid mistrust, the privacy of the respondent was kept secret. Therefore, no identity of the respondents were publish in the study nor reveal to the public. Finally, it is very important to ensure usefulness and meaningful outcome from the study by establishing various photovoltaic system configurations for different segment of the Ghanaian society.

Data collected from the focus group established some of the assumptions of the researcher. During the session, the interviewees displayed their knowledge of the importance of photovoltaic in solving the electrification problem in Ghana. It was also clear from the feedback that the best alternative to reducing Green House Gas (GHG) in Ghana will be the use of photovoltaic energy to replace generators. Generators are often used to generate electricity during disruption of power in the urban cities. This proves that the adoption of photovoltaic would be good for both industries and households. Despite the importance of photovoltaic energy, it was obvious to the researcher that the interviewees had limited knowledge of the types, components and the different configurations that exist. With knowledge obtained by the researcher during the secondary data collection, the researcher was able to educate the interviewees. Interviewees proposed future seminar or lectures for in-depth understanding of photovoltaic systems.

The following are brief summary obtained during the focus group studies. This answers provided valuable knowledge and assessment of how well the participants are familiar with the various problem facing Ghana and possible ways to prevent or improve the electrification problem.

How well are you familiar with the current electrification problems in Ghana?

It was obvious that the electrification problem is affecting all the participants. Some of whom expresses the effect it is having on them, their families and business owners in their areas. The problems include higher cost of goods and services due to the use of generators. This is because both domestic and industries rely heavily on electricity.

How do you think this problem can be solved?

Solving the electrification problem could be done by looking at alternative source of electricity such as wind energy, hydro power, bio fuel and solar energy. Other expresses the need for the government to upgrade the facilities and utilities providing electricity.

What is photovoltaic system and how can it be used to produce electricity?

The researcher observed participants lacked understanding of the term “photovoltaic system”. But when the term solar energy was used, it was clear the understood it. With abundant of daily sunlight, participants believe installing photovoltaic in home, businesses and industries could drastically reduce the dependency on the national grid.

What are the components involved in a photovoltaic system?

When asked this question, one respondent said “all you need in the solar panel then you connect it to your electricity” and the rest agreed. The researcher used this opportunity to explain the various components involve in a photovoltaic system.

What is the various configuration or types of photovoltaic systems?

None of the participants could name or explain any of the various photovoltaic configurations.

The focus group findings prove that there is need for further education and promotion. The education could be in the form of seminar or workshops. Regarding promotion, printed materials could be circulated. Another form could be the use of television or other electronic device such as the mobile phone.

4.2 Data analysis

According to the Academy for Educational Development (2006), data can be obtained from various sources and for this reason; they are present in huge amount. In other words, data analysis is a part of a process i.e. a specific procedure or method. This is justified by LeCompte & Schensul (1999) definition of data analysis which state; “data analysis is the process of reducing large amounts of collected data to make sense of them”. These data are raw and therefore needs to be translated such that it is very easy to understand (Berthold et al. 2010). Therefore, doing this often rely on the researcher’s acknowledgement of gathering enough and meaningful data to support his/her theory or hypothesis (Yin 1994: 102-104). For a reasonable data analysis, the researcher needs to limit the amount of data collected to a meaningful size (Burn et al. 2000: 488 - 490).

There are several approached to data analysis. According to Merriam (1998), these include narrative analysis, ethnographic analysis, constant comparative methods and phenomenological analysis. Other data analysis approach includes grounded theory analysis, interpretive or hermeneutics analysis, cross-cultural analysis, discourse analysis, content analysis and performance analysis (Bernard 2000). These mentioned approaches could be use either as qualitative or quantitative research. For the purpose of this research, the researcher adopted content and interpretive analysis approach.

Content analysis was used systematically during the focus group study. According to Abrahamson (1983: 286), content analysis can successfully help examine almost all type of communication i.e. written, spoken or visual. Berelson (1952) further explained that content analysis is a technique for systematic, descriptive and objective way of communication content by adding role perception and behavioral norms. Interpretive analysis on the other hand, helped to analyze the secondary data given the researcher an insight and adding to the contextual details of the sample data. Most of the secondary data used came from scientific articles published and online journals. Finally, descriptive analysis was used to describe the main characteristics of the survey questionnaire. The findings provided quantitative summaries of the sample. The approaches used helped the researcher to categorized and arrange all the data to obtain meaningful findings.

The data collected were analyzed using Microsoft office, particularly Microsoft Excel spreadsheet. This tool helps the researcher to calculate and present the finding in an easy and accessible way. Pie chart and histogram were used to give a pictorial representation of the findings. The findings are presented in chapter 5 under 5.2 Survey Analysis and Findings.

4.3 Reliability and validity of the research

Reliability and validity of any research is very important which means that the research needs to be critically examined and evaluated. Miller (2014) explain that the two most important and fundamental characteristics of any measurement procedure are reliability and validity. Reliability is a major concern when measuring and testing attributes. This is because the data obtained during a research are influenced by random or systematic errors of measurements (Rosenthal & Rosnow 1991). On the other hand, validity adds meaning to the research. There are many ways to which random errors can influence measurements especially if the sample contains small number of items (Drost 2011).

According to Maylor and Blackmon (2005: 158-159; 362), validity refers to the accuracy of conducting a research while reliability is the ability to be able to repeat the research with its associated phenomenon, producing similar or same result. Furthermore, validity captures the underlying truth of the situation rather than misleading to prevent bias and other research errors (Ndzibah 2013). Miller (2014) further define reliability as the extent to which a questionnaire, test, observation or any measurement procedure produces the same results on repeated trials while validity as the extent to which the instrument measures what it purports to measure.

The reliability in this research focuses on the methods of secondary data collection, focus group study and the questionnaire. The secondary data used were selected from highly respectable scientific journals and publications. The methods of data collection and analysis are described in the previous sub-headings. The selection of the participants in the focus group study was conducted to represent the targeted case country. The focus group provided the basis for the research questionnaire. Furthermore, the introduction of brainstorming during the focus group provided valuable information which helped the researcher to widen the basic understanding of photovoltaic technology to the respondents. To achieve an accurate outcome, the various energy systems together with the capacity and the future projections planned by the case country was discussed. In other to reflect the various representation of the case country, the researcher sent the questionnaire to different individuals with diverse background. This also added to the validity of the research. Additionally, the findings describe the objectives of the research. Proper planning and tools use in analyzing data collected help collaborate the validity of the research. In other to add to the validity of the research, feedback from the first few despondences allowed the researcher to adjust the questionnaire.

5. EMPIRICAL ANALYSIS AND FINDINGS

This section of the research is devoted to the empirical analysis of data collected. A look at the pre-assumptions is explained and compared to the final outcome from the survey while the final findings analyses were presented. The reviews of the findings are presented using tables and graphs at the end.

5.1 Empirical analysis

The main research objective of this study is to present the advantage in product configuration of photovoltaic systems for developing nations. The configuration will be based on usage segments in Ghana particularly, the urban sectors of the economy. Nevertheless, brief look at the rural sector will be considered. As a result, the main research question is “*How product configuration of photovoltaic (PV) system can help reduce and improve energy crisis in developing countries and for that fact Ghana?*” This objective is aimed at promoting independent energy production in Ghana and doing so, the dependency on fossil fuel can be reduced.

According to Zimmerman (2012), information or data gathered as a result of observation or experimentation and analyzed using scientific methods can be classified as empirical evidence. The scientific methods start by creating questions to acquire knowledge to support specific theory or hypothesis (Blakstad, 2009). In this research, the theory or hypotheses are in the form of pre-assumptions formulated by the researcher. These pre-assumptions helped generate questionnaire which were used to obtained and acquire knowledge to support or repudiate the pre-assumptions.

Pre-assumption

The electrification problem facing Ghana is one which needs to be resolved if the country need to improve the various sectors of the economy. For this reason, the idea of adopting one of the various photovoltaic system configurations can contribute in reducing this problem. The researcher pre-assumption were based on observations and conversation with individuals and groups. These took place as a result of discussing the electrification situation facing Ghana. This assumption is collaborated by Ndzibah (2013) explaining that the population of Ghana had quadrupled making demand higher that supply. The main hydroelectric dams (Akosompo & Kpong) have a combined capacity of 1,180 MW (VRA, 2013) but the demand or consumption in 2007 was 5.7 billion KWh. Some of these pre-assumptions suggest that Ghanaians especially those in the urban area are well knowledgeable about photovoltaic systems. This was not so as the researcher found out during the focus group study. Additionally, the researcher believe that solar photovoltaic will be the presume choice as a renewable option rather than the use of fossil fuel in the generation of electricity due to abundant daily radiation in Ghana. The following in a nutshell, expresses the researcher pre-assumptions based on the questionnaire. The questionnaires are independent to give the researcher clear and precise results making the outcome simple to understand.

1. *The electrification problem is affecting majority of the Ghanaian population in the urban area.*
2. *Most of the populations in the urban area are tenants.*
3. *Majority of Ghanaians in the urban area does not knows or understand the term "renewable energy".*
4. *The idea of switching or looking for alternative source of energy in Ghana will be welcome.*
5. *The preferred choice of renewable energy in Ghana would be solar photovoltaic energy.*
6. *The adaptation of solar photovoltaic system will be mostly used for all daily activities – both in homes and businesses*
7. *The average monthly electric bill for Ghanaians would be GHC20 – GHC40*

5.2 Survey analysis and findings

The demand for data in research and other studies has increased both nationally and internationally and for this reason, household surveys are conducted regularly to provide the necessary data needed to achieve relevant findings (UNESCO 2004). These data are of different type and kinds and therefore needs to be structured. According to the Statistical Services Centre of the University of Reading (2001), survey data structure can be either simple survey data or hierarchical data. This research uses the hierarchical data structure. This type of data structure uses series of questions in a form of household questionnaire.

A total number of 102 respondents participated by answering the questionnaire; out of which 58% are male and 42% female. When the data is further analysis was conducted, the researcher found out that 65% are tenants while 35% are home owners. This is illustrated in figure 14 below. Based on the number of respondent, majority of them were clear in their response when it comes to whether the current electrification problem is Ghana is affecting their household or businesses. This is because 92% agreed that they have been affected while only 8% says they have not been affected. Although, the researcher did not ask the reason why this is so but it was obvious during the group brainstorm session that majority of the population live from hand-to-mouth therefore they cannot afford to own a generator. This would have provided them electricity during disruption of power from the national grid. This is justified as shown in Figure 13 below. This figure expresses the fact that only 8.8% of the respondents could afford to pay more than GHC80 of electricity a month which is equivalent to €20 (based on exchange rate of GHC1 = €3.985). According to Numbeo (2014), the monthly average income after tax is €306.21; though 42% of the income is spent on rent.

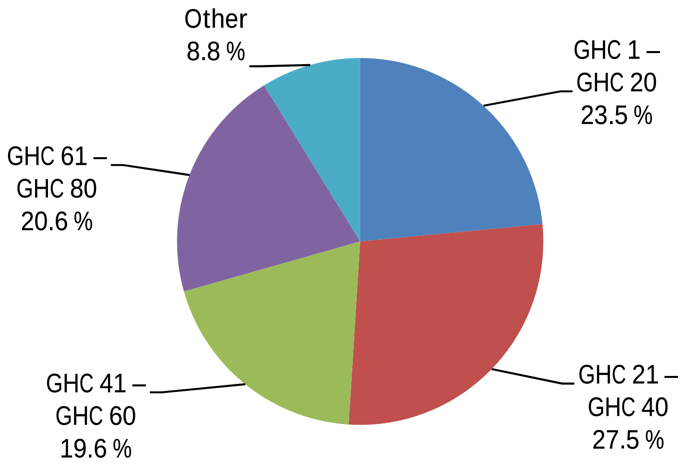


Figure 13. Average monthly electricity bill

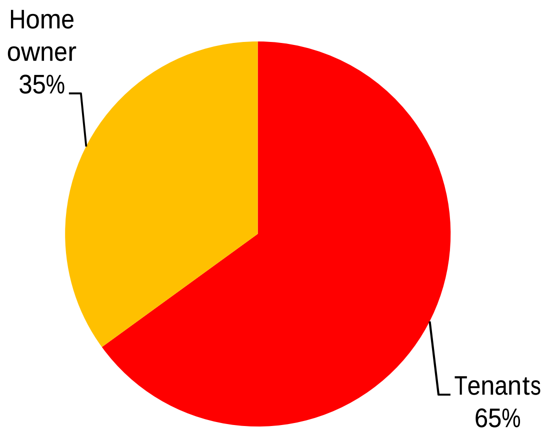


Figure 14. Percentage of tenants to homeowners

A critical look at the data shows that though there are two main groups – tenants and home owners, some of them operate their own business or businesses. The table below explains in details the distribution of tenants to home owners when asked whether they own a business or not. Figure 15 and table 7 show the numbers and percentage of respondents that owns a business respectively. When compared, it was obvious that most of the home owners engage in one type of business or the other. These types of businesses could vary from a small retail store located at their homes or petty trading which involves selling consumable items to friends and neigbours.

Table 7. Distribution of business owners

	Frequency	Percentage (%)	
		Yes	No
Tenants	66	39.4	60.6
Home Owner	36	47.2	52.8
Total	102		

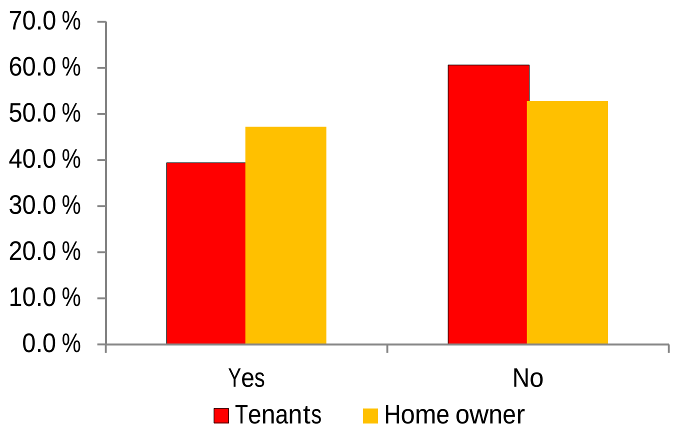


Figure 15. Percentage of business owners

Knowing that majority of Ghanaians cannot rely on the national grid; it was obvious that an alternate source would be important. Since there are many sources to which they could get their electricity, the researcher presented a number of options based on various sources of renewable energy. The finding presented in Fig 16 shows that most of the respondents would prefer solar photovoltaic as an alternate source of electricity. However, it was also clear that there are other sources which the respondents could obtain their electricity due to the abundant of solar irradiation. The researcher gave the respondents the opportunity to choose more than one of these criteria therefore these figures are not presented as a percentage of the total participants but rather on the frequency. The three highest values are 62, 71 and 82 which represent hydro power energy, others and solar photovoltaic energy respectively. The "others" option was provided to the respondent to mention other sources of energy they know leading to non-response error.

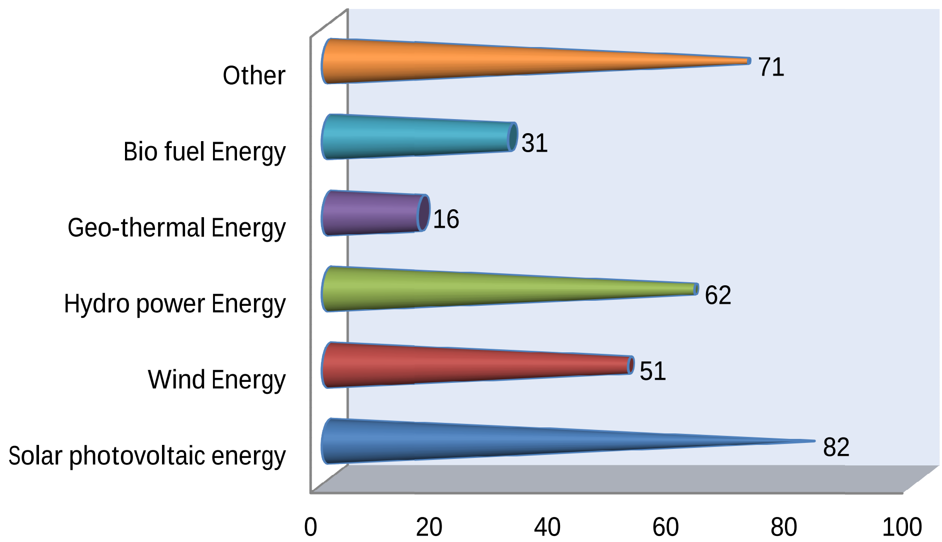


Figure 16. Various renewable energy sources

Since most of the respondents prefer solar photovoltaic energy, it was clear where and what they would use it. Solar photovoltaic is used in different applications and for different purpose. These different applications could be in or out side of homes, business and factories. In homes, they could be used for lighting or on other home appliances. With this in mind, the researcher wanted to know for what and why Ghanaians would like to use solar photovoltaic energy. Figure 17 below shows the various ways Ghanaians would like to adopt and use solar photovoltaic energy.

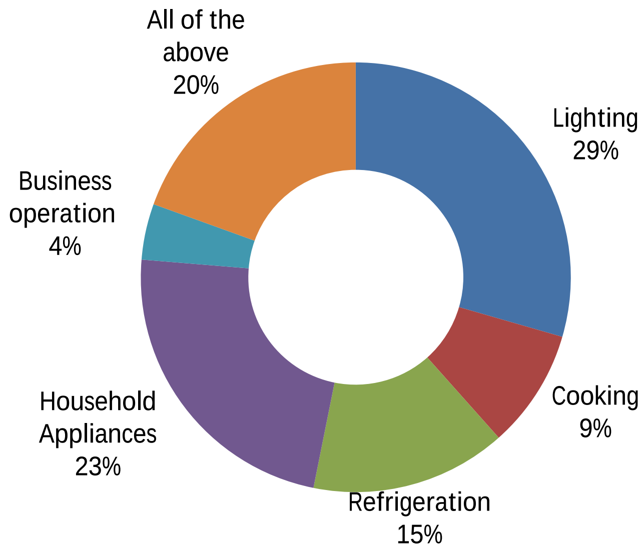


Figure 17. Percentage distribution of solar photovoltaic energy use

It is obvious that most 29% of respondents would like to use solar photovoltaic energy to provide lighting while only 4% would like to use it for their business operation. However, 23% would like to use solar photovoltaic for other house appliances. The house appliances could include refrigerator, cooking stove, radio and television although; only 15% would like to use it mainly for refrigeration.

At the beginning of the survey analysis, the researcher listed pre-assumptions which were to be confirmed or rejected by the findings. Although, it is good to point out that not all the findings supported the researcher's pre-assumption which proves that respondents are well familiar with some the questions asked (see pre-assumption 3). Table below shows this findings and their status. Most of the researcher's pre-assumptions were justified by the finding. It was clear that respondents do not like the energy crisis; therefore, they would like to use other alternative sources of electricity even though most of them live in the urban area and they are tenants.

Table 8. Synthesis of the findings

Number	Pre-assumptions	Status
1	*The electrification problem is affecting majority of the Ghanaian population in the urban area.*	Supported
2	*Most of the populations in the urban area are tenants.*	Supported
3	*Majority of Ghanaians in the urban areas doesn't know or understand the term "renewable energy".*	Rejected
4	*The idea of switching or looking for alternative source of energy in Ghana will be welcome.*	Supported
5	*The preferred choice of renewable energy in Ghana would be solar photovoltaic energy.*	Supported
6	*The adaptation of solar photovoltaic system will be mostly used for all daily activities – both in homes and businesses*	Not completely Rejected
7	*The average monthly electric bill for Ghanaians would be GHC20 – GHC40.*	Supported

Pre-assumption number 3 was rejected; proving that majority of respondents was to some degree familiar with different types and kinds of renewable energy. Nevertheless, being familiar does not imply they fully comprehend the nature and scope of such systems and their generic functions. Finally, the last pre-assumption prove not completely rejected. This is because majority of respondents would like to use it for their daily lighting though more than half plan to use it for both household appliances and to operation businesses.

6. SUMMARIES AND CONCLUSIONS

This section of the research provides a summary of both the theoretical and empirical intentions. In addition, relevant findings, recommendations and future research will be examined.

6.1 Research summary

This research commenced by looking at the current energy situation in developing nation particularly, Ghana and various institutions responsible for making decisions related to energy was examined. Like many developing nations, electrification is very important to the development of their economies. During the study, particular attention was focused on the current electrification problems and how it can be improve. This is because businesses need constant and reliable supply of electricity to improve and develop their processes. This in return provides products or services for their clients or customers. One possible observed way of improving the electrification was the use of photovoltaic systems.

The research started by examining the energy situation in developing countries with particular focus on sub-Sahara various energy sources. Definitions and the limitations of the studies were examined. The research objectives and questions were elaborated and the research dealt with the following objectives:

i. Examine the background and explain the electrification development in Ghana
ii. Explore the current energy policies in Ghana
iii. To add value to current configuration standards
iv. To analyze and propose a set of product configurations of photovoltaic systems in solving the energy crisis in Ghana.

Chapter 2 looks at the historical, political and technical frame work of Ghana's energy sector particularly the electrification issues. Additionally, the various types of energy systems as well as their capacity and future energy potentials were examined. Finally, a brief assessment of Ghana's renewable energy policies will be discussed. Particular focus was on the types of electricity generation systems and their capacities. Furthermore, the concept of product configuration particularly photovoltaic system configuration was evaluated in chapter 3. The various configurations discussed were standalone, backup and hybrid. To help further understand these configurations, background information of the various components involve in a photovoltaic system, namely, panel arrays, charge controllers, batteries, inverters and loads were examined including their basic technical parameters. Completing the chapter, a simple photovoltaic system configuration for a family of four was design by the researcher. It is important to note that this configuration only took into consideration only the basic technical information of the components.

Chapter 4 examined the research methodologies approach used in this study to establish meaningful and reliable conclusion. This research used a hybrid research approach. This type of research helped developed and evaluate key findings which was used to evaluate the researcher's pre-assumptions. Additionally, chapter presented methods and techniques for collecting data on the area of study. Although not all the researcher's pre-assumptions were supported by the findings. For example, when respondents were asked if they fully understood the term "*renewable energy*", majority said "yes" but the research pre-assumed they were not familiar with the term. These findings and many more were explained in chapter 5 which looked at the research findings and analysis. Different methods and techniques were used to represent the findings. These includes bar chat, pie chart, histograms and tables. Finally, further recommendations and suggestions on how Ghana can improve her energy problems were given. These recommendations can be replicated by other developing countries to improve their energy particularly electrification problems thereby leading to economic and social development.

6.2 Conclusion and recommendation

The goal of the research was to look at product configuration of photovoltaic systems. But to do this, there was a need to identify the energy problems facing developing countries, such as Ghana. The study further provide an insight into the current energy problems facing many developing nation particularly sub-Sahara Africa. The research findings were conclusive i.e. there are shortages of electricity in Ghana and as a result, rationing had been introduced. For this reason, the researcher looked at other means of generating electricity to solve these issues. Although it was observed that the governments of Ghana were aware of the rationing of electricity and to solve this, some measures have been put in place. Some of these measures include the banning of incandescent light bulb which was replaced with compact fluorescent (CFL) light bulb which consumes less energy. Also the introduction of Ghana refrigerator energy efficiency ratings and label has helped reduced the average refrigerator energy consumption from 1200kWh/year to 650kWh/year (Fuseini 2011). Other projects currently undertaken by the government to improve electrification situation includes Kpone Thermal Power Plant (KTPP), Takoradi 2 Thermal Power Project (T2) expansion, Takoradi 3 (T3) and Bui Hydro Power Plant (VRA 2013). Even with all these, Ghanaians still face rationing of electricity. In other to improve these problems, the researcher suggested more attention should be focus on renewable energy particularly solar energy. Although it is good to point out that the government of Ghana has commissioned two renewable projects, namely, VRA Wind Power Project and VRA Solar Power Project with a capacity of 100-150 MW and 10MWp respectively. These capacities are relatively small compare to KTPP (230MW) which will required an external source of energy. This will add additional cost to the operation of the power plant compare to using solar energy to generate clean and efficient energy.

One area of contribution by the researcher is the use of solar photovoltaic in terms of system configuration as an alternative to other sources of electricity due to the fact that Ghana is blessed with abundant sunlight. This contribution arose as a result of the findings obtained during both the focus group studies and the questionnaire where majority of respondents prefer this type of renewable energy source. Photovoltaic systems can be configured based on the needs either by an individual, household, or business. When using photovoltaic as a source of electricity, the type of load(s) should be taken into consideration. Lighting (see fig. 9) and household basic appliance (see fig. 12) are the two main loads the researcher found to be interested for Ghanaians. With this in mind, photovoltaic system configurations were design using the components basic technical parameters. These configurations focus on using photovoltaic as a backup system. This can drastically improve the rationing electricity problem facing developing countries hence, Ghana.

Although the research focuses only on product configuration of photovoltaic systems particularly backup systems, there is a need to understand other systems. For this reason, the researcher recommends reading "*Optimal Configuration for Design of Stand-Alone PV System*" by Bataineh & Dalalah (2012). As for the problem facing the financing when it comes to the installation of photovoltaic systems, the researcher recommends reading *"Marketing Mechanisms for Photovoltaic Technology in Developing Countries – Case Ghana"* by Ndzibah (2013). Ndzibah (2013) suggested various ways through which government, banks and other institutions can contribute toward the marketing and financing photovoltaic systems, making it affordable. Finally, it would be nice for the government of Ghana to start collecting daily average energy consumptions which will help in future studies. Finally, the findings and results can be replicated in other developing countries thereby improving their electrification problems.

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APPENDIXES

Appendix 1: Focus Group Questionnaire

1. How well are you familiar with the current electrification problems in Ghana?
2. How do you think this problem can be solved?
3. What is photovoltaic system and how can it be used to produce electricity?
4. What are the components involved in a photovoltaic system?
5. What is the various configuration or types of photovoltaic systems?

Appendix 2: Survey Questionnaire

Study on Product Configuration of Photovoltaic Systems in Developing Countries – Case Ghana

This questionnaire is part of a Master thesis researcher at the University of Vaasa, Finland.
The purpose is to obtain feedback to answer the research questions and key objectives.

All answers and information given will be handled confidentially.

Its takes **5 - 10** minutes to fill the questionnaire.

Respondent info: i) How old are you? _________ ii) What is your gender? **Male** or **Female**

iii) Your Occupation (s): __________

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1. Are you a business owner? **Yes** / **No**

2. Which of the following applies to you?

   a. Tenants

   b. Home owner

3. What is your average monthly electricity bill?

   a. GHC 1 – GHC 20

   b. GHC 21 – GHC 40

   c. GHC 41 – GHC 60

   d. GHC 61 – GHC 80

   e. If more than GHC 80, please specify: ________

4. Is the current electrification problem in Ghana affecting you? **Yes** or **No**

5. Do you have any knowledge about renewable energy? **Yes** or **No**

6. Which of the following renewable energy are you familiar with?

   a. Solar Photovoltaic Energy

   b. Wind Energy

   c. Hydropower Energy

   d. Geo-thermal Energy

   e. Bio fuel Energy

   f. Others, please specify: ________

7. Would you like to switch to photovoltaic energy? **Yes** or **No**

8. Which of the following would you likely use photovoltaic energy for?

   a. Lighting   b. Cooking

   c. Refrigeration   d. Household Appliances

   e. Business operation   f. All of the above