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Product Configuration for Photovoltaic Systems in Developing Countries

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Abstract: Demand and supply of electricity have always been problematic in developing economies. Poor infrastructure because of weak government policies has compounded the problem thus making it difficult for businesses to operate uninterrupted. As a result, households and businesses have no choice than to take matters in their own hands. The paper uses Ghana (a West African country) as the focus of study

The main objective is to develop various solar photovoltaic (solar PV) configurations for households and businesses in developing economies. The proposed research question is set as, 'how can product configuration support reduction and improvement of the energy predicament in developing economies?' The possibilities include standalone, backup or hybrid systems with a focus on off grid solutions. As a limitation, this paper confines its choices to backup systems because of the current distribution of electricity in Ghana. The empirical background provides insight into existing energy condition and the renewable energy plans in Ghana [6,11,17,18].

The method applied in this paper includes focus group study and a survey. The focus group session utilized some African students living in Finland while the main survey utilized a sample frame in Ghana to arrive at the desired conclusion. Some 102 respondents answered questionnaire via Google Form. From the outcome, the most common areas of use for solar PV included lighting, some household and office appliances with varied configurations. The study confirms the inadequate supply of electricity in Ghana and proposed solar PV systems as a viable alternative.

Keywords: Solar photovoltaic systems, product configuration, developing economies, Ghana.

1. INTRODUCTION

The current annual energy consumption in developing countries is at a ratio of 5 to 1 when compared to developed countries [5]. Nevertheless, the number of people having problem-accessing electricity in the world is growing mostly in developing economies such as sub-Saharan Africa and South Asia [19]. Ghana, whose major source of electricity generation and supply depends on hydroelectric power (HEP), is not exempted from this limited supply phenomenon plaguing the region [17,18]. Therefore, there is a need to create sustainable electricity access for developing countries. Achieving sustainable electricity requires efficient use of technology but more importantly rational use of energy resources.

The existing limited electricity production and supply in Ghana is an issue of concern. Concentrating on solar PV configurations offers households and businesses the options of a *standalone*, *backup* or *hybrid systems* [17]. Nevertheless, the paper restricts its choices to *backup systems* to help prepare consumers from the unreliability of electricity supply in Ghana. The research question is proposed as: *how can product configuration support reduction and improvement of the energy predicament in developing economies?*

The planning of the research includes efficiency, openness, privacy protection, usefulness, validity, reliability, proper schedule and objectivity. The objective is to ascertain how different configurations of solar PV systems would help both households and businesses in developing economies to increase their day-to-day activities, value, and reduce emission, as well as improve quality of life in general. Although, there are different sources of renewable energy which the case country Ghana can utilize to achieve sustainable energy consumption, this paper focuses mainly on photovoltaic systems. For this paper, the configuration of photovoltaic systems will create an opportunity to address the aforementioned phenomenon, nevertheless, due to limited data; the focus of the paper examines only *backup system*. According to Ndzibah [17], there is a second and a third type known as *standalone* (for those with no access to the grid) and *hybrid system* (for those using both the grid and other sources of renewable energy simultaneously). It is also important to mention that the data collected are mainly from the capital of the case country Accra, Ghana. This is because the research focuses on how to improve daily activities for household and businesses in the urban center.

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. Configuration of PV systems in Developing countries varies depending on the use. The

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energy source from the PV system to the load(s) could be used for either lighting, home appliances (e.g. TV or radio) or for businesses such as refrigeration in the case of an urban area. Although in recent times, PV system configurations in developing countries are mainly in use in the rural health care sectors. For this reason, the National Renewable Energy Laboratory (NREL) has created a framework for the development of PV system configuration specifically for the rural health clinics (NREL). Furthermore, the International Energy Agency (IEA) under the Photovoltaic Power System (PVPS) program for developing countries offer an insight into updated technical solutions and recommendation on the designs and component selection for the configuration of PV systems for health facilities [12]. Even with the increase of PV system configuration in rural health care, some middle class in the developing countries such as Ghana, can now afford to install PV system in either their businesses and homes [16]

The configuration of PV systems often depends on the type of usage. For instance, configuration of PV system can be for vaccine refrigeration, medical equipment (e.g. microscope, centrifuge etc.) or the sterilization of medical equipment in rural health care in countries such as Nigeria, Bangladesh, Egypt, Rwanda, Namibia and Ghana as standalone system. The standalone system are adapted in combination with other source of renewable energy such as wind or hydro dam to form a hybrid system [12,21].

Configuration of PV system in developing countries could be just a solar array(s) and a load(s) (usually affordable) or a solar array(s), load(s), charge controller and energy storage device such a battery or solar array(s), load(s), battery, charge controller and inverter (could be more expensive) [12,16,18].

The research focused mainly on benefit of solar PV system configuration in developing countries with Ghana as a case country. Although the researcher explained briefly other forms of solar PV configuration, the main area of interest was the backup system and how it can help improve businesses outcome in the urban area. This is because of the rationing of electricity in the case country due to low electricity output from the national dam. Nevertheless, the case country is trying to improve this outcome by investing into other sources of electricity such as natural gas plant, power plant and in some cases renewable energy such as wind and solar [10,14].

Photovoltaic Systems

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 accounts for the majority of capacity additions in power generation today. 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 [17,18,21].

The term “photovoltaic” is from 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 [17,21].

Photovoltaic 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. Furthermore, photovoltaic serves as the power source for calculators, watches, remote buildings, satellites and space vehicles. The use of photovoltaics have facilitated the commissioning of, in some area, megawatt-scale power plants to support electricity production [17,18].

Although, photovoltaic systems provide clean energy, they also have their pros and cons when compare with generators or power plants, photovoltaic system does not use fossil fuel, therefore there is no greenhouse gases (henceforth 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 [17,18].

These subsidies are in a form of Feed in Tariffs (FITs), tax credits, low interest rates etc. Solar energy has irregular supply of sun light due to weather condition, day and night and this leads to unpredictability. This limitation requires storage

systems such as battery used in conjunction with photovoltaic systems. The initial cost involved is high. Although some get government subsidies, others do not. 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 thus adding up to the already expensive initial cost of system [18].

Solar PV system is a setup of components intended to supply electric power for numerous purposes, using the sun as the power source. Though there are other kinds of solar PV installations such as grid and off-grid connected systems, this paper, limits discussions to off-grid solution with the focus is on *backup* systems. Solar PV systems includes of the following components [17,18]:

Photovoltaic Modules

A solar cell is made from silicon - semiconductor. Silicon is the second most abundant element on earth found in quartz and sand. The solar cells are the unit which converts sunlight to electricity thus the name photovoltaic [17,21].

Charge Controller

This stops solar PV modules from overcharging and over discharging the battery. It is noteworthy that without the charge controller, the additional voltage can damage the batteries [17,21].

Inverters

Converts direct current (DC) from solar PV panels and or batteries into alternating current (AC) for powering appliances. The AC of 220V is the preferred standard in most developing countries. Although, the voltage output of individual batteries varies from 3V - 48V and beyond, the application of the inverters are the same [17,21].

Battery

The battery functions as a storage device for the electric current generated by the solar cells. The stored current acts as backup power during electricity disruption (or black outs) or in the case of a hybrid system, to regulate the shared sources of power to different appliance according to the specific needs of the user. In this instance some heavy duty appliances could use the grid source while light load appliances can use the electricity supplied by the solar PV unit [17,21].

Load

This represents the home and business electrical appliances that use the energy produced by the photovoltaic system. The loads and their energy consumption varies due to the type of appliances be it either DC or AC. Examples of load include light bulb, fan, printer, computer, TV, stereo, and refrigerator just to mention a few [17].

Photovoltaic Product Configurations

Solar PV has gained a lot of popularity over the years; we can see significant increases in both production and installation of varied units and more so the unit cost is reducing rapidly [22].

Product configuration in this paper is the methods of adapting a complete solar PV unit to meet the requirements of a particular customer. The parts that making up a solar PV unit comprises of different components: panels, charge controller, batteries and inverter, services, and or software [2,10,14,17,18]. The general classification for PV systems is its usage and connectivity either on or off grid. This paper focuses on off-grid solution with special emphasis on *backup* configuration [17]. Nevertheless, a there is also the standalone configuration which is useful for remote areas and rural communities with no access to electricity and "*hybrid*" configuration allow a user utilize both grid and solar PV system concurrently with the grid connecting to energy intensive consumption appliances [17].

The application of Solar PV systems depends on different usage conditions. Some reasons includes but not limited to reduction in cost of energy, reducing carbon footprint of users and limiting dependence on electricity from the grid. In the case of reducing cost of energy, applications may differ depending on the place of use i.e. household, commercial or industrial units. These different uses require various configurations to address individual needs. For instance, in a typical back up configuration, depending on whether it is for household use or business use the configuration can be usage specific: *for only lighting*, *for refrigeration*, or in some cases for television or computer. Figure 1 shows the relationship between different configuration segments when a backup system is considered for either a home or business.

Ghana as a Developing Economy

To have practical examples and key application of the configuration of Solar PV, Ghana, a West African

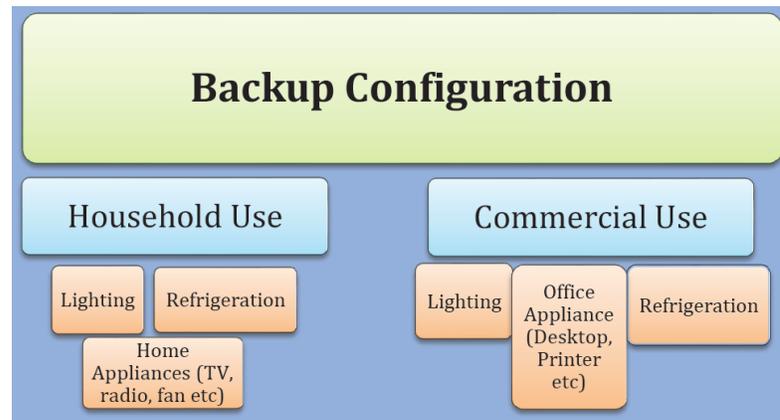


Figure 1: A configuration segment of a solar PV system (adapted from [18]).

state with a population estimate of 28 million is a good example of a developing economy. Ghana falls into the set criteria of a developing economy since it has the high –risk tendencies in relation to international business as well as having a clear limitation in terms of economic and technological advancement [17].

MATERIALS AND METHODS

In order 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. Thus, data collection method utilized was both primary and secondary.

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. Application of secondary data 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. Utilizing previous publications and articles helped to ascertain better understanding of the technology, components and configuration of photovoltaic systems. Furthermore, Ndzibah [17]; explained that primary data are preferred when developing new theories, proposals and models.

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, a number of Ghanaians studying in Finland helped by providing opinions through which the survey questionnaire was formulated. 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 data collected helped to re-define further questions for the second stage of data collection. The second stage includes an online questionnaire. The design and implementation of the questionnaire was through Google Form. The target respondents for the questionnaire were individuals with various occupational backgrounds in Ghana. The next part of the process was the data analysis.

The data collection and its subsequent analysis is through a transparent process, through confidentiality of the identity of respondents as well as in a responsible way by informing the respondents of the reasons for the collection and maintaining a high level of confidentiality thus building trust and openness. 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 GHG in Ghana would be the use of photovoltaic energy to replace generators.

The use of generators for electricity during disruption of power in the urban cities is common. 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.

What are viable solution for this problem?

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

What is photovoltaic system as well as its potential for electricity production?

The researcher observed participants lacked understanding of the term "photovoltaic system". However, they understood the term solar energy. 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, as well as circulation of printed materials. Another form could be the use of television or other electronic device such as the mobile phone.

The focus group uses content analysis throughout. According to Abrahamson M. (1983) [1], content analysis can successfully help examine almost all type of communication i.e. written, spoken or visual. [4]; 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, using descriptive analysis helps 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. The utilization of pie chart and histogram gave a pictorial representation of the findings.

Reliability and validity of any research is very important thus the need for critical examination and evaluation. Reliability is a major concern when measuring and testing attributes, because random or systematic errors influences the data measurements [18]. On the other hand, validity adds meaning to the research. Random errors can influence measurements especially if the sample contains small number of items to many ways [11].

According to Maylor & Blackmon (2005) [13]; 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 [17]. Miller M.J. (2014) [15]; 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 from highly respectable scientific journals and publications. The selection of the participants in the focus group study was a representation of 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, there was a discussion of the various energy systems together with the capacity and the future projections planned by the case country. In order to reflect the various representation of the case country, the researcher sent the questionnaire to different individual 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 order to add to the validity of the research, feedback from the first few despondences allowed the researcher to adjust the questionnaire.

The methodology applied in this paper is focus group followed by a survey questionnaire. Some eight (8) Ghanaian students living in Finland brainstormed on the topic followed by triangulation of the discussion and derivative points for designing the survey questionnaire. The survey conducted in Ghana was through questionnaire sent to 102 respondents through an online survey portal: Google Form. Table 1 and Figure 2 shows the distribution of respondents and percentage of households to commercial users respectively. The following questions *addresses the issue on product configuration*:

Question 1: *How will product configuration reduce the energy predicament facing developing economies and as an example Ghana?*

Question 2: *What measure can help reduce the carbon footprint at the end of the product life cycle?*

Table 1: Distribution of Respondents

	Frequency	Percentage (%)	
		Yes	No
Household	66	39.4	60.6
Commercial	36	47.2	52.8
Total	102		

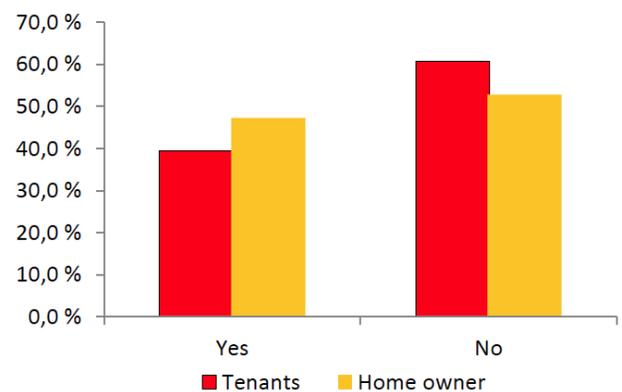


Figure 2: Percentage of commercial owners.

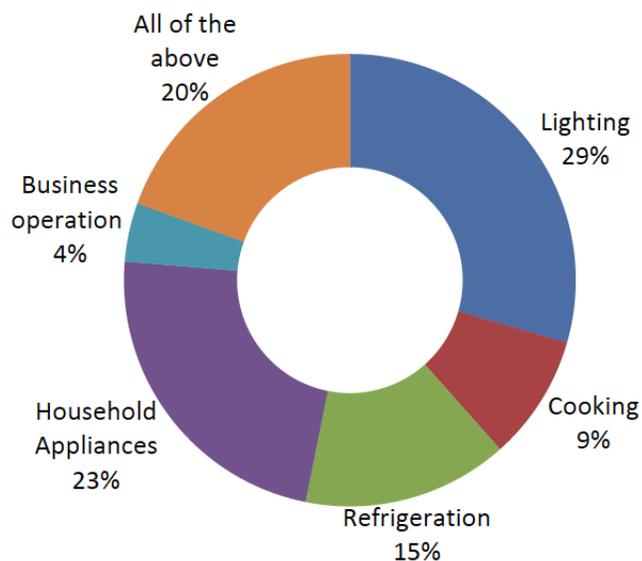
The data collected were evaluated using Microsoft office, particularly Microsoft Excel spreadsheet for easy and practical calculation and presentation of the responds. The application of histogram gave a pictographic representation of the findings. The reliability and validity focuses on the techniques of secondary data collection, which complimented the focus group study and the final questionnaire.

RESULTS AND DISCUSSIONS

In answering the first research question this paper learned that, in the case of Ghana, the concern conveyed by respondents comprised *affordability*, *accessibility* and *reliability*. In earlier study, these terms are explained as follows; affordability as the ability to pay for a solar unit. Furthermore, accessibility is the availability of the solar PV systems at notable places to help potential customers feel it, ask questions and get needed assistance in understanding the rudimentary usage of the unit as well as reliability being the durability of the system. The aforementioned parameters were essential priority to the respondents [16].

The second question which examines the measures to be put in place to reduce the carbon footprint at the end of the unit's life cycle revealed that the majority of the respondents had not thought ahead of such issues as to how and where to dispose of the unit after it has reached its useful end. Queries made to solar PV entrepreneurs in Ghana proved that be it direct or indirect, there is no current process in place for the proper disposal of the individual component at the end of the products' life cycle, due to the infantile stage of the industry especially in developing economies. Enquiry into the issue in Ghana shows that the government is yet to provide a suitable infrastructure or policy framework to address the issue. This suggests that there has not been a long term plan on issues of recycling which will definitely result in untold problems in the imaginable future.

With this in mind, the researcher wanted to know for what and why Ghanaians would like to use solar photovoltaic energy. Knowledge of the purpose of usage could help address the proper ways of configuring a system to meet the household or commercial requirement of the end user. The below image shows the various ways Ghanaians would like to adopt and use solar photovoltaic energy.



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 household appliances. The household 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, for confirmation or rejection 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 of the questions asked (see pre-assumption 3). Table 2 below shows these findings and their status. Most of the researcher's pre-assumptions were justified by the findings. It was clear that Ghanaians 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 2: Synthesis of the Findings

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

The rejection of pre-assumption number 3; proves 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 proved not completely rejected. This is because majority of Ghanaians 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.

CONCLUSIONS

The objective of the study was to look at product configuration of solar PV systems. From the result, the

most common areas of use for solar PV are for lighting, household as well as different configurations for office appliances. The study further provide an insight into the existing energy difficulties faced by a lot of developing economies particularly sub-Sahara Africa [11]. The observation is that some of the governments in developing economies were alert of the irregularity of electricity supply and to solve this, some measures have to be in place. Some of these measures include the banning of incandescent light bulb and its replacement with compact fluorescent (CFL) light bulb, which consumes less energy in the case of Ghana. The general population is now adopting energy efficient refrigerant products.

The proposed contribution in this paper is the promotion and diffusion of solar PV in terms of system configuration as an alternative to other sources of electricity. This contribution was because of the conclusions drawn from both the focus group studies and the survey where majority of respondents prefer this type of renewable energy source. Furthermore, the configuration of Solar PV systems is dependent on the needs of household or commercial entity.

The configuration categories for solar PV systems includes households, or business with varying degrees of usage capacities in each category. In the case of Ghana, the most notable usage was for lighting, refrigeration and other basic household appliances including radios and television. With this in mind, photovoltaic system configurations were design using the components basic technical parameters. These configurations focused on using solar PV as a backup system. The outcome is to 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" [3]. 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 [17]. Ndzibah E. (2013) [17]; 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, it is possible to replicate the findings and results to other developing countries thereby improving their electrification problems.

For commendations, the paper suggest appropriate services such as recycling center that will be able to separate key element such as metals and plastic in components such as panels, charge controller and inverter. Moreover, such services should be able to properly dismantle and reuse solar PV panels. As an advantage, future components could adopt recyclable and biodegradable materials as the main raw materials for building solar PV unit.

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