UNIVERSITY OF EDUCATION, WINNEBA

COLLEGE OF TECHNOLOGY EDUCATION, KUMASI

DESIGN OF A MINI-GRID SOLAR PHOTOVOLTAIC ELECTRICITY SYSTEM FOR MPAHIN, VILLAGE IN CENTRAL REGION

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A Thesis in the Department of ELECTRICAL/ELECTRONICS TECHNOLOGY EDUCATION, Faculty of TECHNICAL EDUCATION, submitted to School of Graduate Studies, University of Education, Winneba, in partial fulfillment of the requirement for the award of Master of Technology in (Electrical/Electronic Technology Education) degree.

OCTOBER, 2017

DECLARATION

STUDENT'S DECLARATION

I, **Kingsford Kwamina Eshun**, declare that this thesis, with the exception of quotations and reference contained in published works which have all been identified and duly acknowledged, is entirely my own original work, and it has not been submitted, either in part or whole, for another degree elsewhere.

SIGNATURE:…………………………………………

DATE:…………………………………………………

SUPERVISOR'S DELARATION

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

NAME OF SUPERVISOR: **PROF. AHMAD ADDO**

SIGNATURE:…………………………………………

DATE:…………………………………………………

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DEDICATION

To My wife Janet Eshun (Mrs.) and Children

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ABSTRACT

The aim of this research was to design a mini-grid solar photovoltaic electricity system for Mpahin village in the Central Region of Ghana. The researcher adopted the mixed method approach. The study is organized into two parts. In the first part of the study, a comprehensive interview was performed on respondents to know their economic conditions, their means of getting light and cooking, their preferred energy, their knowledge about solar energy and its impact on their lives as well as its sustainability. The researcher also made personal observations of the various facilities available in the community and the perception of the people with regard to solar energy. In the second part, a feasibility study to estimate the total space (area) required for the installation of the system and access the economics of the whole project. The study also identified various building roofs and car parks that can be used for the project based on a minimum roof area. Additionally, site analysis and meteorological analysis was undertaken to determine the energy usage capacity of Mpahin. Also solar PV information from various solar dealers both locally and internationally were contacted to determine the economic feasibility of the project. A survey was conducted to know the end-user appliances and power consumption to set an appropriate limit for the loads. The total energy consumption per day and the peak power demand was estimated and subsequently the system voltage determined. A mini grid system was designed for the community. PV-based mini-grid can contribute to increasing access to modern energy services for rural communities. This manual provides a step-by-step guide for the planning, the design, installation, operation and maintenance, testing and commissioning of PV-based mini-grid systems. The manual also incorporated some safety issues as well as financial analysis. The system configuration was chosen by considering the solar resource available, the power demand of the community, energy requirement and load variability. In the design process, various processes such as load assessment, system sizing, battery bank sizing, inverter sizing, array sizing, sizing of wires and fuses, distribution network solar energy fraction, and installation of components in a solar PV based mini-grid. All the design processes were properly elaborated with a step-by-step procedure for undertaking and completing each design process. Various calculations were done and all variables explained. The study also presented a step-by-step practical guide on the installation and mounting plan, design, and how to maintain the solar PV-Based multi-grid system. Through the analysis of the community's electricity expenditure, a spreadsheet was set up to determine the net present value (NPV) and internal rate of return (IRR), which are major indicators of whether or not a project is beneficial. The study concluded that investment in solar panels is financially positive and that switching to solar will be cost-beneficial to the community. Based on the results of this study, the study strongly recommend the use of local materials as much as possible for setting up any PV based mini-grid. It is envisaged that the implementation of the suggested energy system with other environmentally responsible interventions would support people within the Mpahin village, whose lives have been impaired with poverty, to attain their full environmental, social and economic potentials.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Energy development leads to enhancement of rural production, and food security, improvement in healthcare and standard of living in human habitats. Currently, while energy can help extricate rural communities in developing world from poverty and augment development, they can only be achieved through the enactment and implementation of effective energy policy approaches. International Energy Agency (IEA) calculations revealed that if 4% of the world's very dry desert areas were used for PV installations; the global total primary energy demand could be met (Diemuodeke, Hamilton & Addo, 2016). Following this report and considering the fact that there are huge free areas without any use, the untapped potential is already very high.

These vast areas, such as: roofs, building surfaces, fallow land and desert, could be used to support solar power generation. For example, if all suitable roofs and facades were covered with solar panels, 40% of the European Union's total foreseen electricity demand in 2020 could be covered by from PVs (EPIA-Greenpeace, 2011; 2007; EPIA, 2011; Greenpeace, 2008; IEA PVPS, 2003; IEA, 2010; Krauter, 2006).

Solar power is the conversion of sunlight into electricity, either directly using Photovoltaic (PV), or indirectly using Concentrated Solar Power (CSP). Concentrated solar power systems uses lens or mirrors and tracking systems to focus a large area of sunlight into a small beam. PV converts light into electric current using the photoelectric effect. A solar cell, or photovoltaic cell (PV), is a device that converts light into electric current using the photoelectric effect (Diemuodeke, Hamilton & Addo, 2016).

Ghana is a country that is rich in renewable energy resources such as hydro power, thermal power, biogas and solar energy. These abundant and locally available renewable energy resources can be tapped into with appropriate locally developed technologies. Generating and storing electrical energy derived from these rich local energy resources can provide for appropriate and sustainable lighting which brings potential health, education, social and economic benefits to the people who have previously lived in homes with excessive indoor air pollution. This research also compares between the use of the hydro power electrification and solar PV power for domestic use.

As the most popular renewable energy source across the globe and the one with the most consumer applications, from distributed electrical generation to domestic hot water heating, the solar industry is reaping and will continue to reap the benefits. However, cost remains critical. At the same time, consumers seem positive but perhaps misinformed about the applicability and feasibility of solar power. With greater awareness, continued installation growth, and ever-increasing environmental awareness, the solar industry is positioned for long-term, sustained growth all across the globe, despite potential short-term fluctuations (Aslani, Helo & Naaranoja, 2013).

Public perception matters because at least one of the benefits of "going solar" is reducing carbon and other emissions in electrical production. Whether for gathering support for utility-scale operations, beneficial public policies, or making individual consumer choices, the fact that solar power produces clean electricity is becoming more and more attractive (Sinha & Chandel, 2014).Of course, public perception does not exist in a vacuum, and clean energy has a lot more to offer than simply environmental improvement. Issues such as energy security and perhaps most importantly, cost, are critical. As a result, it is imperative to analyze changes in consumer choices and penetration of "clean and green" goods and services in Ghana.

1.2 Statement of the Problem

Energy is one of the most basic and crucial elements upon which to base a life and an economy nowadays. Energy is needed for daily tasks in homes, schools, hospitals, industries and countless other places.With the alarming rate of depletion of the major conventional energy resources such as Coal, Petroleum and Natural gas, coupled with the environmental degradation caused by the process of harnessing these energy sources, it has become an urgent necessity to invest in renewable energy resources that would power the future sufficiently without degrading the environment through greenhouse gas emission (Diemuodeke, Hamilton & Addo, 2016).

Population growth and economic development are leading to a continuous increase in energy demand in Ghana especially in the Western Region. At the same time conventional energy sources are diminishing amid growing global concern for the environment. These factors underline the importance of increasing the use of Renewable Energy sources. The main source of energy for Ghana is Hydro power which we get from Akosombo and the Bui Dam with the water source tapped from the Volta Lake.

In contrast to Hydro energy, solar energy is abundantly available. Solar technologies use the sun to provide heat, light, electricity, etc for domestic and industrial applications. The general concept of the technology is to receive direct solar radiation on a large area (the aperture) and concentrate it on a smaller area, the receiver.

Mpahin in Bisease-Kissi of KEEA District has enormous potential in solar energy. There is sufficient proof of Mpahin potential for extracting energy from Concentrated Solar Power (CSP), especially power on demand generation due to long sun duration hours, few cloudy days, and high-constant sun radiation (Diemuodeke, Hamilton & Addo, 2016). The potential of Concentrated Solar Power (CSP) is of special importance, as Ghana is one of the sun-belt countries with high Direct Normal Irradiance (DNI) (EPIA-Greenpeace, 2011). CSP represents a reliable and sustainable source of energy for Ghana with different outputs that can be used. This thesis studies the feasibility of CSP in Mpahin from regulatory and institutional conditions to technological characteristics and economic competitiveness under Ghanaian conditions.

1.3 Research Objectives and Questions

This research designs s multi-grid solar photovoltaic electrification project. Emphasis will be placed on:

- ❖ The benefits of the electricity for the local population.
- ❖ Site survey and present condition of rural electrification
- ❖ The sustainability of the project in terms of capacity, efficiency, dependability and cost structure of the project.

Based on the feasibility of this research, the following research questions were developed:

- ❖ What measures can be adopted to ascertain the feasibility and sustainability of electricity to the Mpahin community by making use of available and abundance of solar energy from the sun.

- What is the overall impact of a Photovoltaic (PV) generated rural electrification project in Mpahin-Ghana, regarding the benefits for the local population and its sustainability?

1.4 Case Study of the Solar Project / Significant of the Study

Mpahin in Bisease –Kissi of KEEA District is the case study for this research work. It is a small village with an adult population about Two hundred (200). Almost all the houses in the village were constructed with mud thatched and bamboo roofed, with the exception of the Odikro and very few ones whose houses had been roofed with iron sheets. The size of the village may be around 160 m square area with women and children being the dominant of the population. The major occupations of the people are subsistent farming with palm plantation, cocoa and variety of food stuffs.

Livelihood in the village is so challenging that most of the energetic ones have left for nearby communities that enjoy power from the grid. The main sources of energy are the traditional method i.e. the usage of fossil fuel. The sun shine pattern of the village is so appropriate that drying of their cocoa, cassava for kokonte and the like have been the best since the date of their settlement to date.

The study based on the households would suggest the following materials for construction, installation, testing and commissioning;

a) Length of cables and sizes to cater for the connection from main source to the households,
b) Lighting accessories and appliances that would be needed,

c) Sizes and number of PV panels needed,

d) Cost of PV panels and type,

e) Cost of other related equipments etc. etc.

f) Earthing arrangements and testing procedure(s).

The access route that leads to the village starts from Kissi in Komenda Traditional Area through Bisease as shown in the sketch below. The photographs of Mpahin village have been in shown in the study.

The source of drinking water is also a challenge to the Mpahin people. River antem is the only option for the people. It often dried up as a result of lean season. The only borehole which used to serve them is currently overgrown with thick weeds as shown in the photograph below and therefore dilapidated. There is even no latrine for the people and they only use the surrounding bushes for responding to nature's call.

It is therefore against these backgrounds that Mpahin in the south western part of Central Region is however, been considered as case study for this research work to feasibly evaluate solar energy electrification for the use of tomorrow.

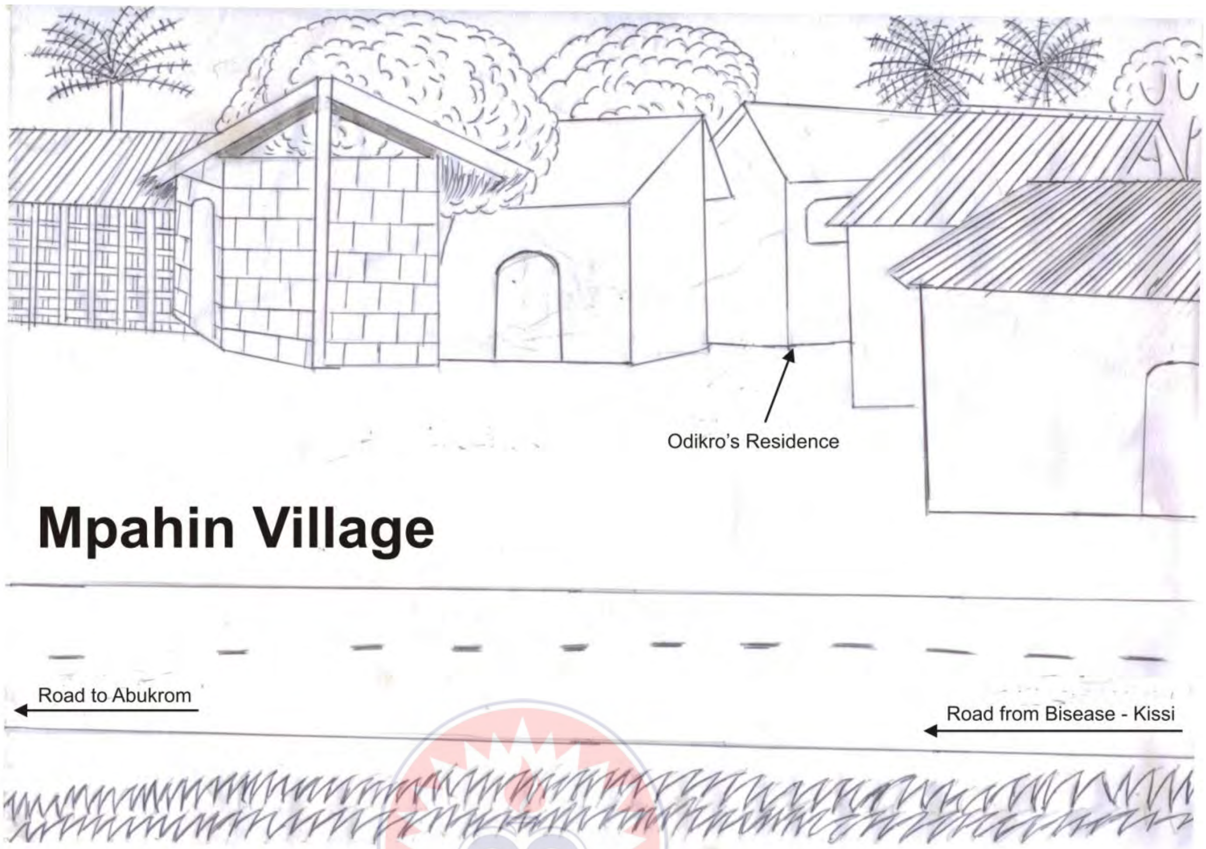


Figure 1.1: Photograph showing the sketch of Mpahin Village

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

This chapter draws attention to relevant works conducted around solar energy and its sustainability and also shows the gaps this research fills. Attention was therefore focused on how other researchers and authors have expressed their views on the topic and other related issues.The review was carried out under the conceptual and empirical reviews.

2.1 Conceptual Review

The conceptual review is organized under the following subheadings:

- Solar irradiation
- The Concept of Solar Energy Electrification
- Feasibility evaluation of Sustainable Solar Electrification Project
- Impact of Photovoltaic Generated Rural Electrification Projects in Ghana
- Measures that could be adopted to ascertain Solar Energy Sustainability

2.1.1 Solar Irradiation

The sun delivers energy to the earth by means of electromagnetic radiation. For our purposes we can assume that the radiation flows evenly distributed from a surface which is close to spherical. The sunlight covers a broad range of wavelengths from roughly 250 nm (UV) over the visible range (400-700 nm) up to several thousands of nm (IR). The radiation density is decreasing with the square of the distance. At the average distance of the earth from the sun the flux of energy amounts to 1366 W/m^2 which is called the solar constant.

On the way through the atmosphere the properties of the irradiation are slightly changed; e.g. the UV light is absorbed by the ozone layer, some parts of the IR are absorbed by water vapour and carbon dioxide. Depending on the latitude of the observer, the irradiation density is still lower due to the longer path of sunlight through the atmosphere, e.g. to below 1000 W/m^2 in Central Europe.

The total irradiated energy per year, including seasonal changes, times of overcast sky, and night time, amounts to about 1000 kWh/m^2*year in Central Europe (corresponding to 2 to 3 hours of ideal sunshine each day). The map below illustrates the worldwide distribution of the irradiation density.

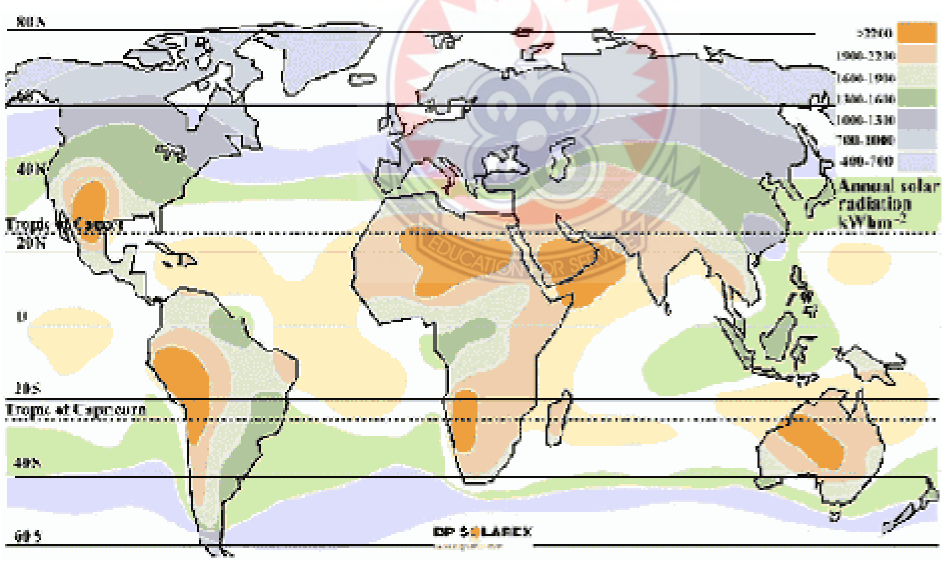


Figure 2.1: Solar irradiation map

(Source: My Solar)

For the conditions of central Europe a PV system of 1 kW_p (say an area of 10 m^2 and an efficiency of 10%) will produce approximately 900 kWh of electric energy. The expression W_p is a power rating for solar cells and modules and gives the output power under standard test conditions (AM1.5 Spectrum with 1000 W/m^2 and a cell temperature of 25ºC).

The average electricity consumption of a 4-person family is about 4000 kWh, thus, solar energy has the potential to supply the average amount of energy, even in the moderate climate of Central Europe.

Two serious drawbacks arise: The storage and the required area. Daily and seasonal availability of solar energy is often contrary to the customer's needs and not every family has access to 40 m^2 for mounting their solar modules. Nevertheless, storage solutions are being developed and if existing buildings were equipped with solar systems a considerable amount of energy could be produced even without consumption of additional area.

We can estimate the total radiated power of the sun with the law of Stefan and Boltzmann.

$P = 4 \pi r^2 \sigma \varepsilon T^4 = 3.9 \cdot 10^{26}$ W

T is the temperature (about 5800 K, see next section),r the radius of the sun ($6.9 \cdot 10^8$ m) and σ the Boltzmann constant ($5.67 \cdot 10^{-8}$ W/m^2K^4) and ε is the emissivity of the surface (assumed to be one). The power is created by nuclear fusion processes inside the core. Due to Einsteins famous law $E = mc^2$ about million tons of matter are converted to energy every single second!

The solar energy irradiated to the Earth is $5 \cdot 10^{24}$ Joule per year. This is 10 000 times the present worldwide yearly energy consumption which is estimated to $5 \cdot 10^{20}$ Joule (as of 2004). In the literature the energy consumption is frequently given in terms of Quads. The Quad is 10^{15} (one quadrillion) British Thermal Units (BTUs), where a BTU is1055 Joule (the BTU is defined as the amount of energy which increases the temperature of one pound of water by one degree Fahrenheit).

2.1.2The Concept of Solar Energy Electrification

Solar power is the conversion of sunlight into electricity, either directly using Photovoltaic (PV), or indirectly using Concentrated Solar Power (CSP).Concentrated solar power systems uses lens or mirrors and tracking systems to focus a large area of sunlight into a small beam (Lorenzo, 2000). PV converts light into electric current using the photoelectric effect. The photoelectric effect is the name given to the observation that when light is shone onto a piece of metal, a small current flows through the metal. The light gives its energy to the electrons in the atoms of the metal and allowing them to move around, producing the current. However, not all colours of light affect metals in this way. No matter how bright a red light you have, it will not produce a current in a metal, but even a very dim blue light will result in a current flowing. Einstien (a physicist), explained that, light was actually made up of lots of small packets of energy called photons that behaved like particles (UNDP, 2004).

Einstein showed that red light can't dislodge electrons because its individual photons don't have enough energy - the impacts are just not large enough to shift the electrons. However, blue light can dislodge electrons - each individual photon has more energy than the red photon. Photons of ultraviolet light, which have yet more energy, will give electrons enough energy to whizz away from the metal altogether (UNDP, 2004).

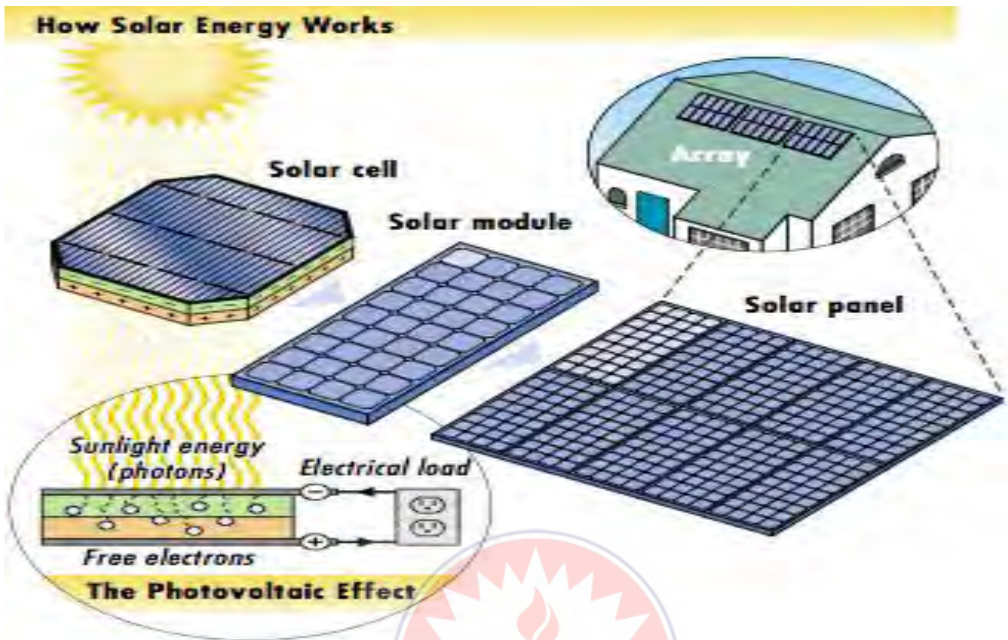


Figure 2.2: How Solar Energy Works

Solar power technology attempts to capture some solar energy and convert it to electricity to power a portion of our lifestyle. Some solar energy can also be captured as heat energy and used to heat our houses, buildings and hot water (Fishbein, 2003). Capturing the vast energy of the sun has been the dream of scientists for millennia. Unfortunately, it is not an easy thing to do economically. Part of the reason for this is that solar energy is very diffuse and it costs a lot to concentrate it into usable forms. There are two main methods of directly capturing sunlight to be used as an energy source for electricity generation (Cecelski, 2003). The first is through the use of semiconductors to convert sunlight directly into electricity. This method is known as photovoltaic (PV) solar energy. The second method involves using mirrors to concentrate sunlight onto pipes or towers containing liquid material that is used to heat steam to drive a turbine to make electricity. This method goes by the name of concentrated solar power (CSP).Photovoltaic (PV) modules are solid-state devices that convert sunlight, the most abundant energy source on the planet, directly into electricity without an intervening heat engine or rotating equipment (Cecelski, 2003). PV equipment has no moving parts and, as a result, requires minimal maintenance and has a long life. It generates electricity without producing emissions of greenhouse or any other gases and its operation is virtually silent. Photovoltaic systems can be built in virtually any size, ranging from milli-watt to megawatt, and the systems are modular, i.e., more panels can be easily added to increase output. Photovoltaic systems are highly reliable and require little maintenance (Fishbein, 2003). They can also be set up as stand-alone systems. A PV cell consists of two or more thin layers of semiconducting material, most commonly silicon. When the silicon is exposed to light, electrical charges are generated; and this can be conducted away by metal contacts as direct current. The electrical output from a single cell is small, so multiple cells are connected and encapsulated (usually glass covered) to form a module (also called a panel). The PV panel is the main building block of a PV system, and any number of panels can be connected together to give the desired electrical output. This modular structure is a considerable advantage of the PV system, where further panels can be added to an existing system as required (Diemuodeke, Hamilton & Addo, 2016).

Operating silently and without any moving parts or environmental emissions, PV systems have developed into a mature technology that has been used for fifty years in specialized applications, and grid-connected systems have been operating for over twenty years

(Obeng et al 2008). A roof-top system recoups the invested energy for its manufacturing and installation within 0.7 to 2 years and produces about 95 percent of net clean renewable energy over a 30-year service lifetime.

As new installations are growing exponentially, prices for PV systems have rapidly declined in recent years. However, they vary by markets and the system's size. In the United States, prices for utility-scale systems were around $1.77–$3.09 per watt in 2015, while prices for smaller roof-top systems in the highly penetrated German market fell below €1.90 per watt in 2015. In that market, solar panels make up for 40 to 50 percent of the overall cost, leaving the rest to installation labour and to the PV system's remaining components (Obeng et al 2008).

PV modules are designed for outdoor use under harsh conditions, such as marine, tropic, arctic, and desert environments. The PV array consists of a number of individual photovoltaic modules connected together to give a suitable current and voltage output. Common power modules have a rated power output of around 50–180 W each. As an example, a small system of 1.5–2 kWp may therefore comprise some 10–30 modules covering an area of around 15–25 m2, depending on the technology used and the orientation of the array with respect to the sun (Fishbein, 2003). Most power modules deliver direct current electricity at 12 V, whereas most common household appliances and industrial processes operate with alternating current at 240 or 415 V (Ramde et al., 2014). Therefore, an inverter is used to convert the low-voltage DC to higher-voltage AC. Other components in a typical PV system are the array mounting structure and various cables and switches needed to ensure that the PV generator can be isolated. The basic principle of a PV system is shown in Figure 2.3 as can be seen, the PV array produces electricity, which can be directed from the controller to either battery storage or a load. Whenever there is no sunshine, the battery can supply power to the load if it has a satisfactory capacity.

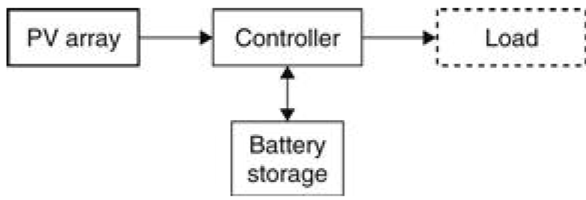


Figure 2.3: Basic principle of a PV solar energy system

2.1.2.1 Categories of PV Systems

Direct-coupled PV system / Off-grid without Battery

In a direct-coupled PV system, the PV array is connected directly to the load. Therefore, the load can operate only whenever there is solar radiation, so such a system has very limited applications. The schematic diagram of such a system is shown in Figure 2.3. A typical application of this type of system is for water pumping, i.e., the system operates as long as sunshine is available, and instead of storing electrical energy, water is usually stored.

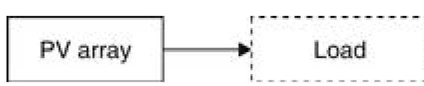


Figure 2.4: Schematic diagram of a direct-coupled PV system

Stand-alone applications / Off-grid with battery storage

Stand-alone PV systems are used in areas that are not easily accessible or have no access to an electric grid. A stand-alone system is independent of the electricity grid, with the energy produced normally being stored in batteries. A typical stand-alone system would consist of a PV module or modules, batteries, and a charge controller. An inverter may also be included in the system to convert the direct current generated by the PV modules to the alternating current form required by normal appliances.

A charge controller may be incorporated in the system to: a) avoid battery damage by excessive charging or discharging and, b) optimizing the production of the cells or modules by maximum power point tracking (MPPT). However, in simple PV systems where the PV module voltage is matched to the battery voltage, the use of MPPT electronics is generally considered unnecessary, since the battery voltage is stable enough to provide near-maximum power collection from the PV module (Ramde et al., 2014). In small devices (e.g. calculators, parking meters) only direct current (DC) is consumed. In larger systems (e.g. buildings, remote water pumps) AC is usually required. To convert the DC from the modules or batteries into AC, an inverter is used. A schematic diagram of a stand-alone system is shown in Figure 2.5. As can be seen, the system can satisfy both DC and AC loads simultaneously.

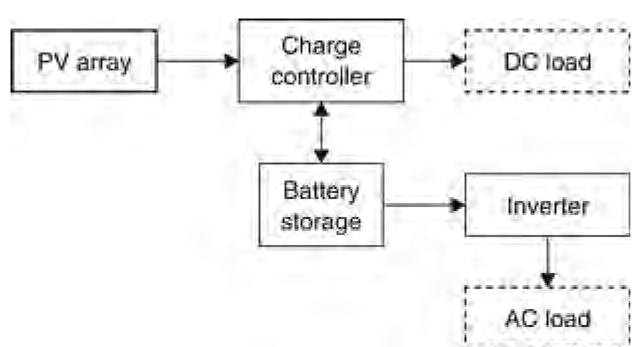


Figure 2.5: Schematic diagram of a stand-alone PV application

Grid-connection

Figure 2.6: Schematics of a typical residential PV system

A grid connected system is connected to a larger independent grid (typically the public electricity grid) and feeds energy directly into the grid. This energy may be shared by a residential or commercial building before or after the revenue measurement point. The difference being whether the credited energy production is calculated independently of the customer's energy consumption (feed-in tariff) or only on the difference of energy (net metering). Grid connected systems vary in size from residential (2-10kWp) to solar power stations (up to 10s of MWp). This is a form of decentralized electricity generation. The feeding of electricity into the grid requires the transformation of DC into AC by a special, synchronizing grid-tie inverter. In kW sized installations the DC side system voltage is as high as permitted (typically 1000V except US residential 600V) to limit ohmic losses. Most modules (72 crystalline silicon cells) generate 160W to 300W at 36 volts (Ramde et al., 2014). It is sometimes necessary or desirable to connect the modules partially in parallel rather than all in series. One set of modules connected in series is known as a 'string'.

Hybrid-connected system

In the hybrid-connected system, more than one type of electricity generator is employed. The second type of electricity generator can be renewable, such as a wind turbine, or conventional, such as a diesel engine generator or the utility grid. The diesel engine generator can also be a renewable source of electricity when the diesel engine is fed with biofuels. A schematic diagram of a hybrid-connected system is shown in Figure 2.7. Again, in this system, both DC and AC loads can be satisfied simultaneously.

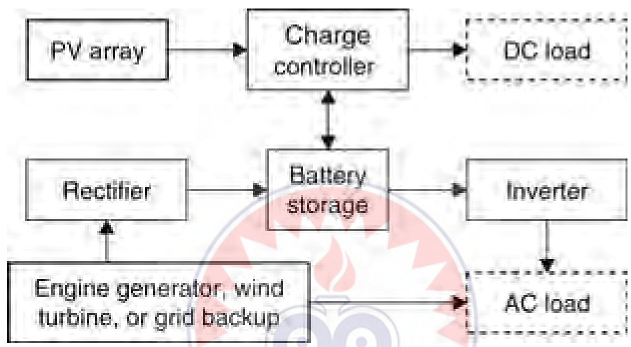


Figure 2.7: Schematic diagram of a hybrid connected system

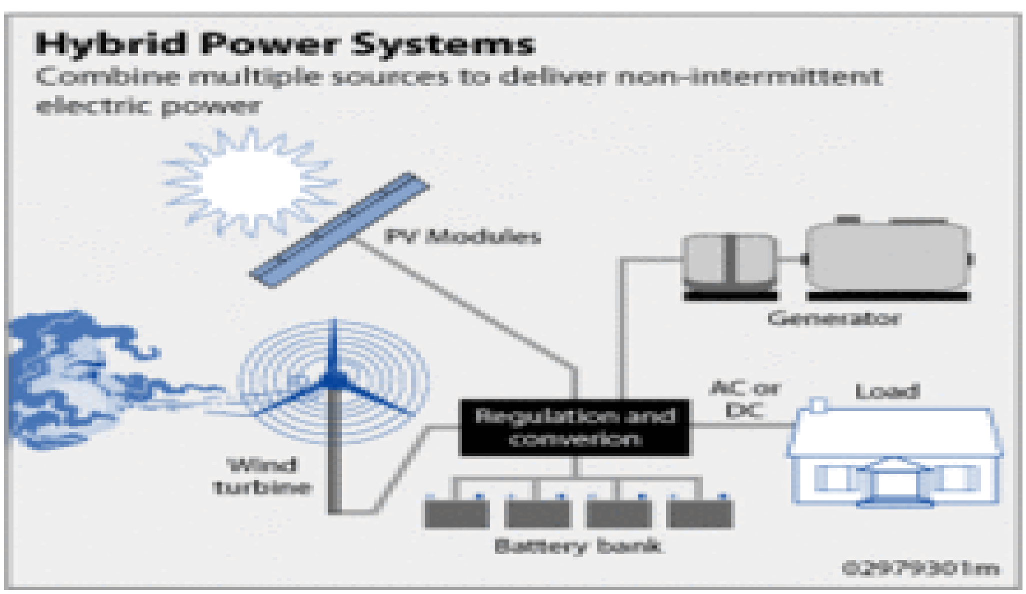


Figure 2.8: Schematics of a hybrid system

2.1.2.2 Basic PV System Components

A basic solar PV system consists of the following:

1. Solar photovoltaic modules,
2. Proper electrical disconnects and overcurrent protection systems, and
3. A string inverter or micro-inverters that change the DC generated electricity to alternating current (AC) used in most residences.

2.1.2.3 Solar Photovoltaic Modules

Conventional solar cells, normally wired in series, are encapsulated in a solar module to protect them from the weather. The module consists of a tempered glass as cover, a soft and flexible encapsulate, a rear back sheet made of a weathering and fire-resistant material and an aluminum frame around the outer edge. Electrically connected and mounted on a supporting structure, solar modules build a string of modules, often called solar panel. A solar array consists of one or many such panels. A photovoltaic array (or solar array) is a linked collection of solar panels. The power that one module can produce is seldom enough to meet requirements of a home or a business, so the modules are linked together to form an array (Martinot et. al., 2002).

2.1.2.4 Electrical Safety Disconnects

Electrical disconnects consist of additional switching that shuts off the AC power between the inverter and the grid, as well as a DC disconnect to safely interrupt the flow of electricity from the PV array to the inverter for system maintenance and troubleshooting possible system problems. These disconnects add costs and complexity to the photovoltaic system but ensure a redundancy to safety and overcurrent protection.

2.1.2.5 DC to AC inverters

A solar electric inverter is a component that converts DC electricity from the output of the PV array into grid-compliant AC electricity that is used in most homes. An inverter takes the DC power from the PV module array and causes it to oscillate until it matches the frequency of the power grid at 60 Hz (cycles per second). An inverter with ground fault protection also constantly checks for DC wiring shorts and bad connections, shutting the system down if problems are detected. If there is a power outage, the inverter will discontinue supplying electricity to the grid preventing electrical feedback to the power lines and personal injury to repair personnel. Most inverters have an efficiency of 85–96% depending on make and model. The power losses in the conversion of DC to AC as well as wire and switch-gear losses should be accounted for when determining the number of PV modules required (Cecelski, 2003).

Figure 2.9: Inverter for grid connected PV

2.1.2.6 Charge Controller

PV systems with integrated battery solutions also need a charge controller, as the varying voltage and current from the solar array requires constant adjustment to prevent damage from overcharging. Basic charge controllers may simply turn the PV panels on and off, or may meter out pulses of energy as needed, a strategy called PWM or pulse-width modulation. More advanced charge controllers will incorporate MPPT logic into their battery charging algorithms. Charge controllers may also divert energy to some purpose other than battery charging. Rather than simply shut off the free PV energy when not needed, a user may choose to heat air or water once the battery is full.

2.1.2.7 Battery

Although still expensive, PV systems increasingly use rechargeable batteries to store a surplus to be later used at night. Batteries used for grid-storage also stabilize the electrical grid by leveling out peak loads, and play an important role in a smart grid, as they can charge during periods of low demand and feed their stored energy into the grid when demand is high (Cecelski, 2003). Other rechargeable batteries that are considered for distributed PV systems include, sodium–sulphur and vanadium redox batteries, two prominent types of a molten salt and a flow battery, respectively.

2.1.2.8 Monitoring and Metering

The metering must be able to accumulate energy units in both directions and two meters must be used. Many meters accumulate bidirectional, some systems use two meters, but a unidirectional meter (with detent) will not accumulate energy from any resultant feed into the grid.

In some countries, for installations over 30 kWp a frequency and a voltage monitor with disconnection of all phases is required. This is done where more solar power is being generated than can be accommodated by the utility, and the excess cannot either be exported or stored. Grid operators historically have needed to provide transmission lines and generation capacity. Now they need to also provide storage. This is normally hydro-storage, but other means of storage are used. Initially storage was used so that base load generators could operate at full output. With variable renewable energy, storage is needed to allow power generation whenever it is available and consumption whenever it is needed. The two variables a grid operator has are storing electricity for when it is needed, or transmitting it to where it is needed. If both of those fail, installations over 30kWp can automatically shut down, although in practice all inverters maintain voltage regulation and stop supplying power if the load is inadequate (UNDP, 2004). Grid operators have the option of curtailing excess generation from large systems, although this is more commonly done with wind power than solar power, and results in a substantial loss of revenue. Three-phase inverters have the unique option of supplying reactive power which can be advantageous in matching load requirements.

Photovoltaic systems need to be monitored to detect breakdown and optimize their operation. Several photovoltaic monitoring strategies depending on the output of the installation and its nature. Monitoring can be performed on site or remotely.

2.1.3 Feasibility Evaluation of Sustainable Solar Electrification Project

Every day the sun beams an average of 60,000 EJ of energy directly to the earth. If it did not receive this energy, the earth would die. Figure 8.1 illustrates what happens to this energy: 6% is reflected by the atmosphere; 20% is reflected by the clouds; 4% is reflected by the earth's surface; 16% is absorbed by the atmosphere; 3% is absorbed by the clouds; and 51% is absorbed by the land and the oceans (Klare, 2008). Very little of the energy is actually captured. Most of what is absorbed is radiated back into space. Nevertheless, solar energy plays a crucial role in controlling the temperature of the earth. When solar insolation increases, the earth warms up and when it decreases the earth cools down. Solar insolation has the most significant impact on the earth's temperature, much larger than all the greenhouse gases combined. A very small part of the sun's energy is captured by plants and animals on the earth and used to support the growth of living organisms on the planet.

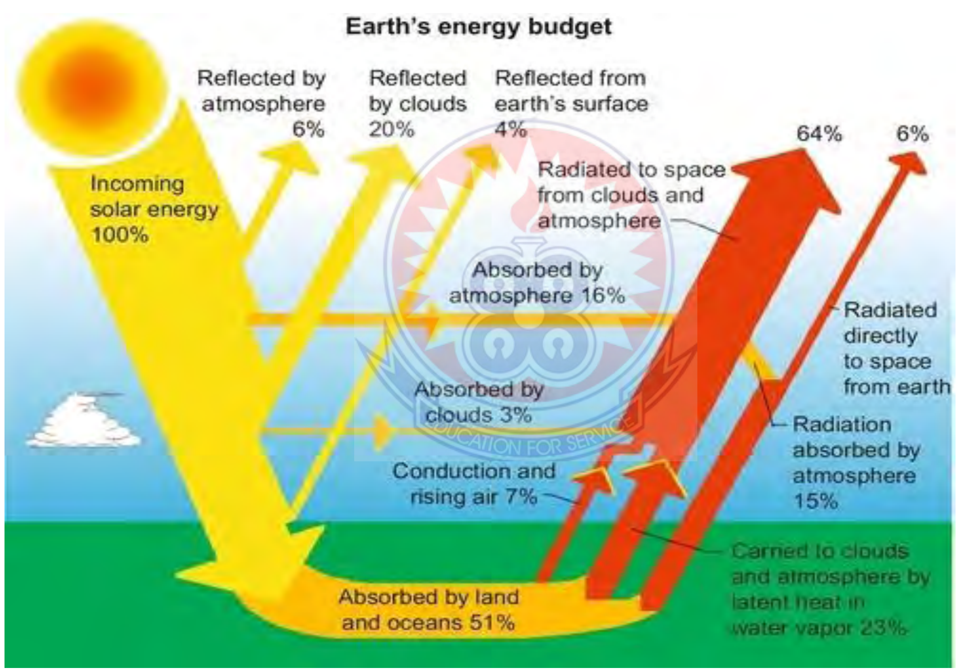


Figure 2.10: Earth's energy budget

Source: NASA

The total solar energy that reaches the upper atmosphere is 1367 W/m2. Of this, about 697 W/m2 reaches the earth's surface and is absorbed by the land and the oceans. The other 670 W/m2 is intercepted by the atmosphere and reflected or absorbed and reradiated back into space. Not all of this energy is in a form that can be captured by photovoltaic (PV) technology. By the time it reaches the earth's surface, the usable solar energy received averages about 300 W/m2. The diameter of the earth is 12,750 km (7920 miles). The surface area of the earth is 510 Tm2, of which 149 Tm2 is land and the other 361 Tm2 is ocean (NASA, 2002). The usable solar energy hitting the land area is 300 × 149 TW = 45 PW. The world uses about 500 EJ/year, which is 500/(365 × 24 × 3600) EW = 0.016 PW. A tiny fraction of the usable solar energy that is hitting the land mass of the earth could power the entire world. Put another way, if the 45 PW hitting the land was captured with 10% efficiency, it would take 0.35% of the land area to be used to capture enough solar energy to power the entire world (NASA, 2002). Of course, it is not as simple as that. Solar energy is very expensive. It is intermittent, unreliable and requires exotic materials. There are simply not enough of these materials to do the job.

2.1.4 Impact of Photovoltaic Generated Rural Electrification Projects in Ghana

In recent times efforts at the global, regional and local levels have been intensified to link energy to sustainable development and poverty reduction. It is understood that unavailability of electricity services in rural and peri-urban areas is usually associated with poverty and it is among the most serious problems confronting everybody (Lorenzo, 2000; UNDP, 2004). At the nineth session of the United Nations Commission on Sustainable Development (CSD-9) renewables and rural energy were identified among the key energy issues for sustainable human development (Chaurey et al, 2002). Several authors have provided analysis of the link between energy (electricity) and major global issues such as health, education, water, gender etc. (Cecelski, 2003; DFID, 2002; UNDP, 2004). From all these, a common key finding is that energy alone cannot initiate development and reduce poverty. It must be linked to development strategies for education, health, agriculture, infrastructure, political and economic improvements.

Within this context, the linkages of energy strategies to poverty reduction and quality of life have been under-explored. This is partly because the definition of poverty has been centered around the money metric measures of income, expenditure, or consumption. Therefore, in addition to consumption poverty, the Ghana Living Standards Survey (GLSS) considered other dimensions of poverty including lack of access to services and limited human development (Ghana Statistical Service, 2007). There is the need to include other dimensions of poverty so as to fight all aspects of it (Cecelski, 2003). This underscores the need for continuous research to deepen knowledge on the relationship between rural electrification using solar PV and energy poverty reduction in rural and peri-urban areas, where there is low access to grid-electricity. The following subsection focuses on significant issues on the link between solar PV electrification and quality of life and Solar PV electrification can improve the quality of life of rural households through positive impacts that cannot easily be expressed in monetary terms. Quality of life is simply life goals expected to be fulfilled: better education, health, access to information, indoor lighting, among others. Significant impacts of solar PV systems include better quality of light, car batteries do not have to be transported, indoor smoke and fire hazards from kerosene lanterns are reduced (Obeng et al 2008b). Furthermore solar PV electrification contributes to improve quality of life in off-grid rural communities through the direct effect of the technology on household wellbeing and enterprise income (Fishbein, 2003; Martinot et. al., 2002). It should be stressed that the gradual replacement of fossil energy electrification with renewables will not provide all the energy needs for quality of life improvements. However, there are many applications that can improve the quality of life of rural households. These include among others the replacement of kerosene lanterns and candles with solar PV lighting (Plastow & Goldstone, 2001). A survey to explore user perception about the positive linkage between rural electrification and education in Tunisia revealed that women and children especially benefited from improved access to education as a result of rural electrification (Cecelski, 2003). Although the study was not specifically on solar PV electrification, the findings may also apply to the linkage between solar PV electrification and children's extended study, particularly after sunset when lighting services are most needed. Drawing on this the following investigative question is posed: How does access to solar PV lighting in rural Ghana improve children's education? Does access to solar PV light enhance the academic performance of rural school children?

Furthermore, solar PV lighting enables access to educational media, communications in schools and at home. This increases education opportunities and allows distance learning (DFID, 2002; UNDP, 2004). If rural electrification policies, programmes and plans integrate solar PV as an alternative service for the supply of electricity services to dispersed rural populations and remote rural communities, children would have access to lighting in the evening to extend their studies. This would go in a long way to contribute to the international goal of ensuring that children everywhere will be able to complete a full course of primary schooling by 2015 - MDG Goal 2, Target 3.

Public health is a critical sector where the contribution of solar PV is much felt especially in off-grid communities. As noted earlier, the replacement of kerosene lanterns with solar PV could reduce indoor air pollution, which affects the health and wellbeing of rural families. In this regard, this study focuses on environmental health considerations, which refer to the health risks associated with environmental factors (Kishore, 2006). They fall into two broad categories, namely traditional and modern hazards (Kishore, 2006). This study examines the association between traditional forms of lighting and environmental health risks. Traditional hazards are related to poverty and lack of development (Kishore, 2006).

'The World Bank has classed indoor air pollution in developing countries among the four most critical global environmental problems' (Cecelski, 2003). Indoor air smoke contributes to respiratory infections that account for up to 20 percent of the 11 million deaths in children each year (DFID cited by UNDP, 2004). This trend if not stopped will have direct effects on future family lives of the poor since children are the future source and wealth of poor families (Fanworth, 2004). In the light of this it is important to re-emphasize the need for pragmatic policies on environmentally-friendly technologies like solar PV. When used as a substitute for a kerosene lantern solar PV can reduce the potential threat of indoor air smoke (Plastow & Goldsmith, 2001; PPIAF/AD 2002).

Typically electricity to run a motor for a grain mill can transform a manual subsistence household activity into an income-generating enterprise, or help transform a barely viable enterprise into a more sustainable one (Allderdice & Rogers, 2000). Small rural stores can also expand their inventory by adding items that can be preserved using solarpowered refrigerators (Allderdice & Rogers, 2000, Etcheverry, 2003). For example, solar PV-powered icemakers can assist village micro enterprises in fishing, sale of ice cubes and cold drinks especially in tropical countries. Solar crop drying by small electric fans that circulate air around a heated surface, can also be used to preserve crops for export. Solar PV electricity helps micro-enterprises to generate additional income by extending their working hours after dusk (Allderdice & Rogers, 2000; DFID 2002). However, there are so few published data that indicate in quantitative terms the additional incomes likely to be generated after sunset by different solar-electrified enterprises.

Securing access to water plays a strategic role in ensuring agricultural production (FAO, 2005). In this regard, solar PV water pumping can supply water for dry land irrigation. This helps to sustain the conditions under which agriculture can contribute to food security, income generation and poverty reduction. However, the lack of proper maintenance of solar PV pumps has made some rural beneficiaries abandon them at the installation sites (Van den Akker & Lamba, 2002). Addressing energy issues related to agriculture and off-farm activities can help to increase prospects for income generation in rural households/enterprises by providing energy for irrigation, food processing, food preservation and many types of manual production during evening hours (Etcheverry, 2003; Martinot, 2004). Nevertheless, a sketchy account of the ‘benefit values’ of the association between the use of solar PV and income generation is presented in the literature and therefore there is the need for further research.

2.1.5 Measures that could be Adopted to Ascertain Solar Energy Sustainability

Solar energy has started to grow but until the costs are substantially reduced it will remain a very small component of the world and the U.S. energy picture. Even though the cost has been substantially reduced over the past 50 years, it still remains a very expensive energy source. The PV effect has been known since 1839 and, despite extensive research efforts since then, solar power is still very expensive. It does not seem likely that further research efforts will make the breakthroughs that will lead to the commercialization of solar power in the foreseeable future. There is a lot of solar power waiting to be harnessed if such a breakthrough could be made; however, even if there was a way to make solar power viable, it is to be expected that this cannot be done without having a significant impact on the environment.

The optimization of a photovoltaic system for a specific environment can be complicated as issues of solar flux, soiling, and snow losses should be taken into effect. In addition, recent work has shown that spectral effects can play a role in optimal photovoltaic material selection. For example, the spectral albedo can play a significant role in output depending on the surface around the photovoltaic system and the type of solar cell material. For the weather and latitudes, typical solar panels have an average efficiency of 15%, with the best commercially available panels at 21%.

In the context of off-grid rural Ghana the issue of subsidy is relevant in the sense that about 39 percent of the population live under the US$ 1 per day poverty line (Ghana Statistical Service, 2007), and would certainly need cost reduction measures to enable them derive the full benefit offered by solar PV electrification. In view of the extensive use of subsidies in the developing member countries of the Asian Development Bank (ADB), the ADB established a policy framework on subsidies in 1996. This policy framework suggests that subsidies be provided in specific instances - on pure public goods, while private goods should not be subsidized (PPIAF/AD, 2002). However, the policy views electricity as a private good that should generally not be subsidized, except in cases where poverty is a factor or where sudden and large price increase have negative economic impacts (PPIAF/AD, 2002).

In the discourse on renewable energy technologies (RETs) the much expressed concern about subsidies is that subsidies provided for grid-extension undermines possible markets for RETs in rural areas (Russell and Bunting, 2002; Beck and Martinot, 2004; Sawin, 2004). 'Even relatively small subsidies on kerosene and diesel can discourage the use of renewable energies' (Sawin, 2004). Van den Akker and Lamba (2002) argue that without subsidies on solar water pumping for farmers in Punjab, there would be no markets in India because grid electricity prices are heavily subsidized for irrigation making the playing field unleveled. Drawing on the above, it is noted that subsidies targeted at the poor to enable them to meet their basic electricity needs from solar PV would encourage usage, sustainability and contribute to increase access to electricity services in off-grid rural areas.

2.2 Empirical Review

Ramde et al (2014), looked at the dire situation of Africa with regards to access to electricity calls for urgent measures if the continent is to develop and lift its citizens out of poverty. They advocated that the traditional grid extension approach needs to be complemented by decentralized solutions as well – particularly where these turn out to be more cost-effective. With the decreasing cost of Solar Photovoltaic (PV) technology globally, PV based mini-grid is one of the options that are available to governments and other stakeholders for accelerating access to electricity for many communities across the continent. This becomes an even more interesting proposition when viewed in the light of Africa's significant solar resources. The study came out with a technical manual intended to provide a step-by-step practical guide on how to plan, design, install, operate and maintain a solar PV-Based mini-grid that supplies electricity to an Africa village (or group of villages). The manual considers two options. The first option is solar PV with battery only mini-grid and the second option is hybrid PV-diesel with battery storage. It considers systems of sizes up to 100 kW.

Rio and Burguillo (2008) empirically analyses those benefits of solar energy by applying a conceptual and methodological framework previously developed by the authors to three renewable energy technologies in three different places in Spain. With the help of case studies, their paper shows that the contribution of renewable energy resources to the economic and social dimensions of sustainable development might be significant. Particularly important is employment creation in these areas. Although, in absolute terms, the number of jobs created may not be high, their study indicated that it may be so with respect to the existing jobs in the areas considered. The study outlined that the specific socioeconomic features of the territories, including the productive structure of the area, the relationships between the stakeholders and the involvement of the local actors in the renewable energy project may play a relevant role in this regard. Furthermore, other local (socioeconomic) sustainability aspects beyond employment creation should be considered.

Macauley et al. (2000) in the research suggest that Satellite Solar Power (SSP) is an alternative to terrestrial energy resources for electricity generation. The study considers the market for electricity from the present to 2020, roughly the year when many experts expect SSP to be technically achievable. It is found that several trends from the present to 2020 should influence decisions about the design, development, financing and operation of SSP. Second set of observations pertains specifically to challenges facing SSP. They stated that the festive immaturity of the technologies required for SSP makes it difficult to assess the validity of estimated costs and the likely competitiveness of SSP. Additionally; they added that National security and national economic considerations may discourage some countries from participating in an SSP system operated by another country or group of countries. Countries with these concerns may require equity participation in SSP, limit their reliance on SSP to only a small share of their energy portfolio, or decline use of the technology altogether. They recommended that the energy industry should be invited to be ‘at the table’ in technical and economic analysis of SSP - that is, to both participate in conducting the analysis and learn about the results. Finally, the authors identified specific topics for future research to focus on the use of SSP in terrestrial markets. SSP capabilities may be applicable to non-terrestrial systems, such as the international space station, other large orbiting platforms, lunar bases, and other activities that are used to explore and develop space.

Mulugetta, and Jackson (2000) in their study explored the complexities associated with diffusion of small scale photovoltaic systems in rural areas of developing countries, with the experience of Global Environment Facility (GEF) project of Zimbabwe. GEF has founded 41 renewable energy projects in 26developing countries to the tune of US $ 480 million by 2000 (Mulugetta, & Jackson, 2000: 1070). The authors were of the opinion that GEF programme is quite successful in achieving the targets and in creating the awareness and benefits of PV systems. It was able to take good use of subsidy and has created a good number of stakeholders. The paper also throws light on the macroeconomic problems like inflation and explains how depression will curse success of the PV industry. As a policy matter the authors stress upon the need of sustainable energy policy, political stability and more demand pull approach than technology push etc. (Mulugetta, & Jackson, 2000).

Andersson and Jacobsson (2000) opined that technological change was the driving force for development, thus policy makers have a need to understand the techno-economic dynamics. The authors gave a model, in that they said the present dynamics of solar cells was the technology and market, specifically for the long run. They also wrote that real beginning of PV technology was in 1960's, especially in US, when oil crisis occurred and due to the progress in PV technology the annual sales of PV systems have increased by 33 percent in the last decade. They also found that the target set by different countries like Europe aims 3 GWp electricity production, Japan 4.6 GWp and US 7 GWp production by 2010 (Andersson & Jacobsson, 2000: 1044). It is Japan and USA who play very important role in the PV technology and usage; thus the patents taken by these countries are highest in the world. Particularly Canon and Sanya companies of Japan and, Solaex and ECD companies of USA will act key actors in the world of PV market. As policy issues, authors have suggested that measures should be taken towards the diffusion of solar cells in terms of procurement of cells, new competing design and, at last, policy should ensure careful material and environmental management (Andersson & Jacobsson, 2000).

Alsema and Nieuwlaar (2000) in their paper analyze the energy payback time (EPBT) of PV systems by assuming 25 percent energy loss in the production. They have mentioned that EPBT is only 2 to 6 years, whereas life of the PV system is 25 to30 years. In the paper given availability of future technology of PV systems and further they have mentioned that future technology will reduce EPBT to 1.5 to 2 years (Alsema & Nieuwlaar, 2000: 1006). In the paper it is also found that CO2 emission from conventional electricity is 0.57 kg/kWh, but by PV systems emission is only 50to 60 g/kWh (pp 1007), they have also written that CO2 emission is even less in biomass and wind energy. In the policy implications the authors suggest that cost-effective technology should be developed and still life of system should be increased. Finally, the paper concludes that PV system will play an important role in the future in sustainable energy supply, especially after 2010 (Alsema & Nieuwlaar, 2000).

Biswas, Diesendorf and Bryce (2004) in the paper explore the possibility of attaining sustainable rural development in Bangladesh through fostering decentralized rural companies based on photovoltaic (PV) technologies, because authors opines that the solar electricity could be a promising business and able to generate employment opportunities to landless and marginal farmers as it is not a much seasonal businesslike agriculture (Biswas, Diesendorf & Bryce, 2004). The paper begins with the discussion on the scope of P V technologies in Bangladesh, and then tries to apply different models for sustainable rural development. In different models, the authors explain the role of the government, rebate strategy, consumers, local industries, price of solar electricity, NGO's etc. Further they explain the role of stake holders namely NGO's, training institutes, marginal agriculturist etc (Biswas, Diesendorf & Bryce, 2004: 1206). Lastly, they conclude that PV technologies used appropriately may improve the quality of life of rural people and provide income generating opportunities and also stresses on the requirement of the new model that specifically address social, economic and environmental issues.

Ciorba, Pauli and Meona (2004) analyze the potential economic impact of a demand of photovoltaic (PV) devices in terms of induced production and job creation, directly and indirectly. The authors say that implementation of PV manufacturing facilities may stimulate several economic activities helping to set up local industries and inducing more environmental development. Presently, USA and Japan are the leading countries in production of electricity from PV systems and total world electricity production through this means is about 400 MW in 2001, in business value it is 2.5 billion euro dollars (Ciorba, Pauli &Menna, 2004). Finally, the analysis concludes that PV installation has not only created direct and indirect employment but also has made an impact on the GDP growth of the country.

Hamakawa (2004) in his paper says that solar photovoltaic (PV) technology plays an important role in the sustainable development of civilization in the 21stcentury and he further mentions that the development of clean energy technology is most important task of modem science. By the mass consumption of fossil fuels, pollutants like CO2, NO2 etc will be omitted which leads to global warming. Then, the author built a model called as '3E-Trilemma\ The model illustrates cyclical correlation of the economy, energy and environment. The writer also mentions that, Asia by 2010 will import 69.2 percent fuel to meet its total demand (Hamakawa, 2004). Then, the paper deals with the key issues of PV technology and its bright future in different stages. Finally, he concludes that with PV technology, a new kind of energy revolution will take place, within next 25 years.

Khan Shinwari, Fahd Ali and Nayyar (2004) opine that solar photovoltaic systems are prohibitively expensive in terms of installation costs. Power from them is also available intermittently only when energy from the sun is available. On the other hand, the PV systems are free of the ever-rising costs of input fuel. They also incur much less operation and maintenance costs and are supposed to have a longer lifetime than, for example, a fossil fuel power plant. Thus using solar PV power looks uneconomical in the short term, but may be profitable in the long term. It is, therefore, interesting to identify the factors that can make investment in solar PV power generation acceptable. The paper also carries out a financial analysis of installing a 10 MW solar photovoltaic power generation plant for sale of electricity to a grid. It compares the level zed cost of this mode of energy generation as compared to a fossil fuel plant. It also calculates the cost of electricity generation and tariff for power from this plant. It then identifies the factors that can make the investment in a grid-scale solar PV plant more favorable than investment in other conventional and non-renewable sources.

Gullberg, Ilskog, Katyega and Kjellstrom (2005) in their paper have demonstrated the implications of introducing PV systems and compact florescent lamps in rural Tanzania. The study is based on the cost-sensitivity analysis of PV systems with traditional diesel systems with certain assumptions. The analysis says that the PV options are most expensive for the low load case, whereas traditional system is most expensive for the high load case. The papers throw the light on the environmental aspects like stoppage of cent percent CO2 emissions by using PV Systems (Gullberg, Ilskog, Katyega & Kjellstrom, 2005). Lastly, as a policy matter author suggests that from a national policy point of view, introduction of renewable technologies such as PV power kits for household use, should consider that other development goals might be over seen if infrastructure planning focuses on individual and short term needs.

CHAPTER THREE

METHODOLOGY

3.0 Introduction

This chapter outlines the research methodology employed in achieving the aims, objectives and goals of the study. It involves the study type, population, sample, sampling design, research design, data collection instrument and sources of data. The mode of establishing method of data analysis and ethical consideration are also considered.

Additionally, the chapter focuses on the quantitative and qualitative description of the sample and how it relates to the population under study. It describes and analyses the demographic characteristics of the sample. The chapter presents the results generated from the data collected from Mpahin. The researcher assessed the demographic characteristics' relation to the study variables. The data was presented with the help of tables. Through qualitative and quantitative analyses, the researcher tested and validated the preset objectives and answered the study questions.

3.1 Research Design

The research design guides the Planning and organization of the study in a way that is most possible to attain the projected goal. In choosing the research design, numerous research methods were examined. The researcher will adopt the mixed method approach. Creswell (2005), states that you conduct a mixed method study when you have both quantitative and qualitative data and both types of data together provide a better understanding of your research problem than either type by itself. The study is organized into two parts.

In the first part of the study, a comprehensive interview will be performed on respondents to know their economic conditions, their means of getting light and cooking, their preferred energy, their knowledge about solar energy and its impact on their lives as well as its sustainability. The researcher also will make personal observations of the various facilities available in the community and the perception of the people with regard to solar energy.

In the second part, a prefeasibility study (using RET Screen or other suitable software) to obtain an idea of the amount of energy that will be generated by the system, estimate the total space (area) required for the installation of the system and access the economics of the whole project. This was carried out through the following:

1. Embarking on site analysis as well as meteorological analysis to ascertain the solar radiation for the location
2. Determine the energy usage capacity of the Mpahin by gathering previous energy data from the Volta River Authority on 3 similar communities who are connected to the national grid in order to gain a better understanding of how a solar panel system would affect the overall amount of energy needed at Mpahin.
3. Obtain a land use map of the location showing the various sites that can be used for the project.
4. Identify various building roofs and car parks that can be used for the project based on a minimum roof area.
5. Obtain solar PV information from various solar dealers both locally and internationally to determine the economic feasibility of the project.

Basically, the researcher employed the quantitative research design which aims to systematically investigate and explain the survey design to elicit data on the feasibility, impact and sustainability of solar electricity on the residents of Mpahin. With surveys, questions can be asked personally through interview or questionnaire about phenomena which cannot easily be observed (Peil, 1995), and the researcher could gain the opportunity to ask many questions on the issues and thus give enough flexibility for analysis.

3.2 Population

According to Ary, Jacobs and Rezavieh (2002) cited Frempong (2011), population is used to refer to the entire group of individuals to whom the findings of a study apply. The population for the research involved pupils of Mpahin in the Central Region of Ghana. It is a small village with an adult population about four hundred (400).The size of the village may be around 160 m square area with women and children being the dominant of the population.

Figure 3.1: Mpahin Village include the Odikro's residence

Figure 3.2: The Researcher with Odikro (middle) and other two opinion leaders of Mpahin village

Figure 3.3: The drying of kokonte by direct sunshine at Mpahin

3.3 Sample and Sampling Techniques

The sample of the study was 250 participants.The random and convenience sampling techniques were used in the selection process. The convenience sampling technique employed was based on the criterion that participants were accessible throughout the period of study and thus could be easily recruited.On the other Hand, Lartey (2009) acknowledges that every member of the population has equal chance of being selected in a simple random technique.

3.4 Data Collection Instruments

Questionnaires were the core instrument employed to achieve a thorough understanding from the respondents. Most of the questions were mainly close-ended which made it easy to interpret and analyze the data. In addition to this, the questionnaires were constructed in line with the objective that it should collect precise data required to answer research question and meet the objective of a research. The questionnaire was structured, which were mostly close ended type that required the respondents to make a choice by ticking or circling the one they may opt. The questionnaires were administered to get feedbacks from respondents with regard to the feasibility, maintenance and sustainability of solar energy in their community.

A comprehensive interview was performed on respondents to know their economic conditions, their means of getting light and cooking, their preferred energy, their knowledge about solar energy and its impact on their lives as well as its sustainability. The researcher also made personal observations of the various facilities available in the community and the perception of the people with regard to solar energy.

3.5 Pre-testing

To ascertain the reliability and validity of the instrument, a pilot study was conducted to help the researcher decide whether the study was feasible and worthwhile to continue. It also provided an opportunity to assess the appropriateness and practicality of the data collection instrument. The wisdom in doing a pre-test was also to help revise questions in the guide that were apparently unclear or produced negative reactions in the subjects.

To pre-test the questionnaires meant to reveal ambiguities, poorly worded questions that were not understood, and could also indicate whether the instrument to the respondents were clear, in order to make some modification before the final administration.

The questionnaires for the study were pre-tested on 20 respondents. During the analysis of the pre-test, the researcher found out that some of the questions were irrelevant and ambiguous. This became clear due to the way the items in the questions were answered. The researcher used the responses obtained to eliminate ambiguous, non-specific items and made some modifications before the final administration.

3.6 Data Collection Procedure

In order to understand the potential needs for electricity, a questionnaire was designed to collect data from villagers in a consistent manner .It was categorized into two parts as; 1) basic data on gender, occupation, type of buildings, basic amenities, and 2) electricity use-including (i) daily activity preference and energy use ;cooking , heating water, ironing, lighting the houses or rooms and the entire community, (ii) time preference – what time these activities take place and for how long, and (iii) electrical appliances –

what kinds of appliances are used f or these activities. In order to elicit the much needed information, interviewing was determined to be the ideal method because most people could not read and write English. The questions were asked in the local language.

For participants to do their best to give realistic response to each question, they were assured confidentiality as the researcher articulated the purpose of the research for purely academic exercise. According to Kelley, Clark, Brown & Sitzia (2003), these are the most important ethical issues to adhere to when conducting a survey. Also, they were assured that all information obtained would be used for the intended purpose. The researcher was present to explain how to answer sections of the questionnaire. With open ended questions, respondents were required to indicate opinions.

The respondents were guided to answer their questionnaire instantly to avoid misplacement of the questionnaire and other excuses. Every question was thoroughly explained and all doubts were cleared. Room was given for questions and appropriate answers were given. To ensure high return rate of the questionnaires, the researcher did the administration and collection personally.

3.7 Data Analysis

Raw data collected was edited to notice and correct errors and omissions to ensure consistency and validity. Next the data was tallied item by item and input into a computer. For the purpose of data analysis, Statistical Program for Social Science software version 20 was used. Descriptive statistics, as well as frequency tables were used to elicit easy understanding.

After all the questionnaires have been returned, they were scored and coded for analysis and answering of the research questions. An item-by-item analysis of data was conducted. The percentage of the total sample responding to each question was given. The qualitative data was analyzed using thematic analysis.

The interview data were analyzed using content analysis which according to Krueger (1998) is comparing of the words used in the answers of the respondents. The researcher looked for themes and similar ideas or responses to the questions posed to the respondents of which the respondent's information or speeches were translated into specific categories for the purposes of analysis.

3.8 Ethical Consideration

As researchers, ethical consideration emerged the moment the research was planned. Seeking access to organizations and individuals, collecting, analyzing and reporting data involved some kind of consideration. In the context of research, ethics refers to the appropriateness of one's behavior in relation to the right of those who become the subject of one's work, or are affected by it. Wells (1994) defines ethics in terms of a code of behaviour appropriate to academics and the conduct of a research. The researcher therefore needed to consider ethical issues throughout the period of the research and remain sensitive to the impact of work on those whose consent we sought and who participated. Again, researchers asked for the consent of respondents before administering the questionnaire and interviewed. Finally, the researchers ensured that the information collected was used for the purpose for which it was collected and also confidential information were strictly treated as such.

3.9 Planning

Planning is an integral part of the implementation of the PV system and this involves preparation and background work to ensure good chance of success (African Energy Commission, 2014). The success of the system depends on how well the community was involved. Hence this study, engaged the community through the use of questionnaire to get an overview of the community power needs and load limits. Among the planning processes undertaken within the study are presented below:

3.9.1 Analysis of the Demographic Characteristics

According to the technical guide for the design, installation and operation of solar PV-Based mini-grid for rural electrification in Africa, demographic and socio-economic data are important baseline information to assist in projecting load growth and enable the project team to make informed suggestions in the community engagement process.

3.9.1.1 Gender

A study of the gender characteristics of the village was undertaken. This was to give the number of males and females as well as the age composition of the inhabitants within the village. This is very important since the characteristics of the inhabitants whether youthful or aged would give an overview of the future demand of energy. Table 4.1 presents the respondents by gender.

Table 3.1: Distribution of respondents by gender

	Frequency	Percent	Valid Percent
Male	102	40.8	40.8
Female	148	59.2	59.2
Total	**250**	**100.0**	**100.0**

Source: Field Data, (2017)

Table 3.1 shows that the percentage of female inhabitants at Mpahin are 59.3%while that of male inhabitants are 40.8%. This implies that females outnumber males in the village.

Table 3.2: Distribution of respondents by Age

Age group	Frequency	Percent	Valid Percent
18 - 25	55	22.2	22.2
26 - 40	85	34.2	34.2
41 and above	108	43.6	43.6
Total	**248**	**100.0**	**100.0**

Source: Field Data, (2017)

Table 3.2 reveals that 43.6% of the respondents are above 40 years, 34.2% are within the ages of 26 and 40 years while 22.2% are within the ages of 18 – 25 years. This is due to absence of any source of electrical energy which discourage the youth from staying there. In addition, the absence of electrical energy leads to limited employment making them to seek greener pastures in the cities and towns. This finding is in agreement to the Ghana Statistical Service report on the 2010 Population and Housing Census report which indicates that areas which lack basic amenities such as electricity record less youth.

3.9.2 Other Demographic Findings

Additionally, the village has an adult population about two hundred (200). Almost all the houses in the village were constructed with mud thatched and bamboo roofed, with the exception of the Odikro and very few ones whose houses had been roofed with iron sheets.

The size of the village is around 160 m square area with women and children being the dominant of the population. The major occupations of the people are subsistent farming with palm plantation, cocoa and variety of food stuffs.

3.10 Site Analysis

Given the relationship between the sunlight available in a region and a solar cell's energy output, site analysis was one of the greatest influences on the feasibility of a photovoltaic project. A research on different panels showed that panels should not be partially shaded. The researcher therefore decided to visit the site at different times of day to take detailed measurements of where shadows fell. This allowed the researcher to identify an area of the community which will be most suitable for the panels.

The primary space that would potentially be used for the solar panel array is a mostly flat. The area has an open southern exposure that makes it ideal for solar power collection. The flat nature of environment is situated in such a way that it is sunny with no shadows throughout the day, and anything mounted on it would not affect the aesthetics of the environment from most angles.

3.11 Meteorological Analyses

Gathering and summarizing meteorological data was a vital aspect for creating the site analysis.

Figure 3.4 below shows the solar radiation map of Ghana which proofs the fact that the extraction of electrical energy from the sun is 100% viable. In the case of Mpahin, this area receives a continuous sunlight radiation from 9 am to 4pm. According to the **SWERA Ghana Project report,** the Central region, receives solar irradiation of 5.011 KWh/m^2 per day, the area is very suitable for solar energy implementation.

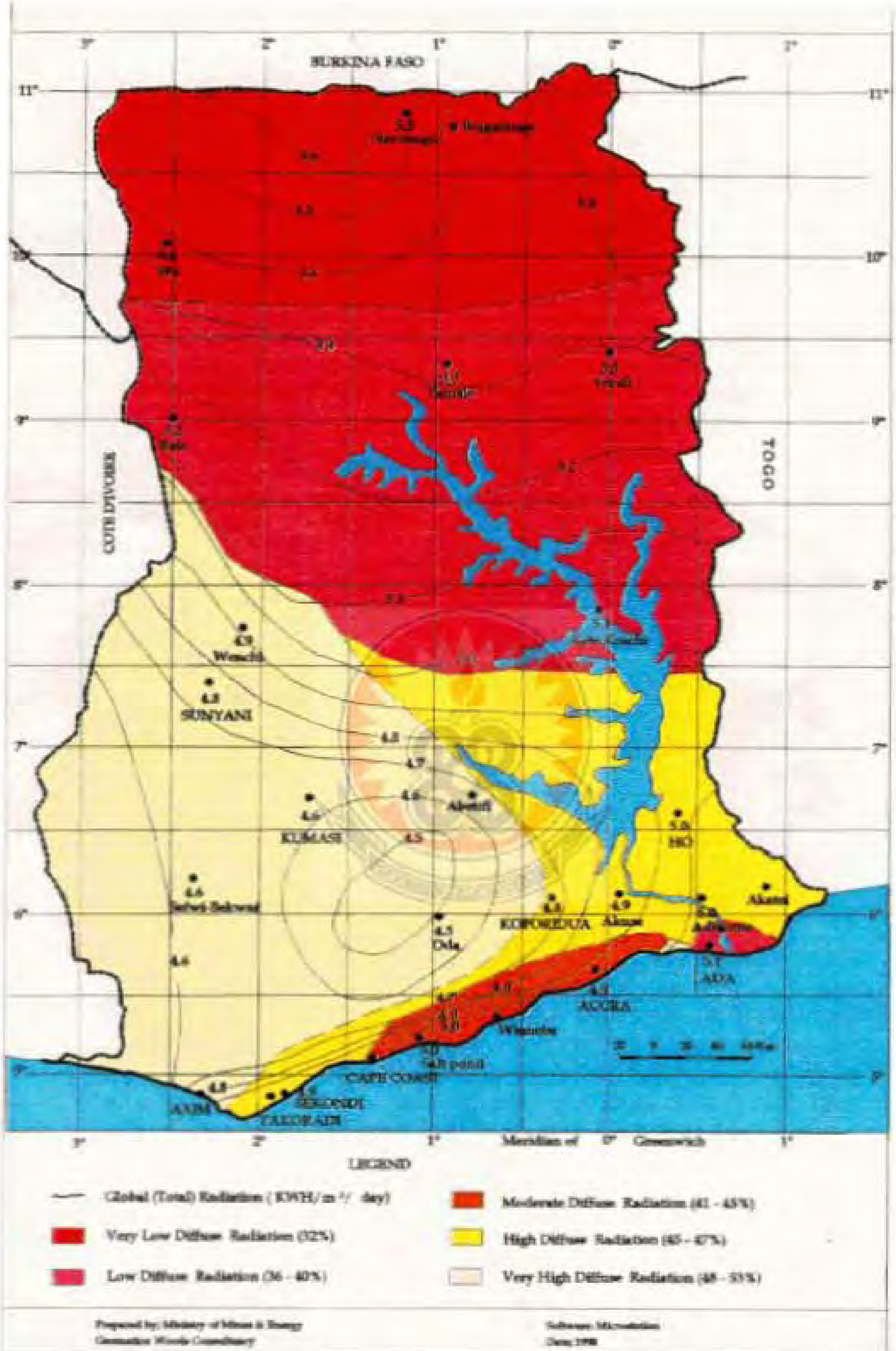


Figure 3.4: Solar radiation map of Ghana

3.12 Power Demand for the Community

The researcher found it necessary to gather previous energy data from the Volta River Authority on 3 communities (Bisease, Kwahinkrom and Abukrom) who are connected to the national grid in order to gain a better understanding of how a solar panel system would affect the overall amount of energy needed by Mpahin. Using this data, the researcher is able to summarize the trends in energy usage over the course of the year, and more importantly, compare this energy data to the estimated energy that could be produced by a solar panel installation. A table of energy usage in the 3 communities from the VRA is shown below:

Table 3.3: Energy usage

Month	**Average energy used / Day (kWh)**		
	Bisease	**Kwahinkrom**	**Abukrom**
January	12,748	11,811	10,778
February	12,689	13,009	12,456
March	12,940	13,020	12,049
April	12,929	12,123	12,339
May	12,878	10,455	11,112
June	12,797	12,445	10,790
July	12,810	10,989	11,670
August	12,821	14,001	11,829
September	12,799	12,221	12,998
October	12,806	12,209	12,829
November	12,876	13,777	12,994
December	13,032	14,064	14,032
Total	**154,125**	**150,124**	**145,876**

(Source: VRA)

Using this energy demand from these three communities, average power demand of 150,000Kwh energy is proposed.

3.13 Energy Requirements and Load Variability

The selected configuration should be able to meet the energy requirements of the rural community for the given period of time. This study realized that the average demand power stipulated (150MWh) is sufficient since Mpahin does not differ in terms of community structure such as availability of commercial activities, public activities or commercial activities.

3.14 Financial Viability

The continuous rise in fuel cost especially for diesel genset and drop in PV module cost have to be considered in selecting a financially viable configuration (African Energy Commission, 2014). The combination of solar power with diesel system can reduce the size of batteries required- which happens to be the most costly component of the system. According to a report by the National Renewable Energy Laboratory (NREL) cited by African Energy Commission (2014), installed prices of residential and commercial PV systems declined 6%–7% per year, on average, from 1998–2012, and by 6%–14% from 2011–2012, depending on system size.

CHAPTER FOUR

PRESENTATION AND DESIGN OF MINI GRID SYSTEM

4.0 Introduction

This chapter covers processes in load assessment, system sizing, battery bank sizing, inverter sizing, array sizing, sizing of wires and fuses, distribution network solar energy fraction, and installation of components in a solar PV based mini-grid.

The system configuration has to be chosen by the researcher at the beginning of the design phase. Generally, solar PV mini-grids can be grouped into three configurations:

1. Standalone PV power station
2. Hybrid PV-Diesel power station (also with batteries and partial supplement from the diesel engine)
3. PV-Grid connected station (double phase, feeding the grid with surplus power by day and take it back by night without batteries for backups)

This thesis focuses on the first configuration. Several factors have been considered in selecting configuration 1 (Standalone PV power station) as they all have merits and demerits. Some of these factors include:

4.1 Solar Resource Available

When solar irradiation in the area is low, there is usually insufficient current to charge the batteries to full capacity. It becomes necessary to supplement the current from the PV modules with current from the genset to charge the batteries to full capacity.

4.2 Power demand of the rural community e.g. Power for lighting, power for heavy equipment (food processing equipment)

In a standalone PV power station, the level of investment in the battery bank depends on the power demand of the rural community during the night; the higher the load, the higher the investment in a battery system. The Researcher considered the economics of increasing the battery capacity as against supplementing output using diesel genset.

4.3 Energy Requirements and Load Variability

The selected configuration should be able to meet the energy requirements of the rural community for the given period of time since the village is not large

4.4 Load Assessment

Additionally, the chapter presents a step-by-step practical guide on the installation and mounting plan, design, and how to maintain the solar PV-Based mini-grid that supplies electricity to Mpahin.

After the system configuration has been chosen, a load assessment must be conducted by the Researcher engineer. The purpose of load assessment to know the type of equipment, number of appliances, power ratings, duration of use, time of usage (day or night) in order to accurately size system components.

Needs of rural communities vary across different localities; some facilities and establishments common to some rural communities include but not limited to:

- Households
- Public facilities (e.g. schools, health clinics, security posts, etc.)
- Commercial activities (e.g., mobile phone charging, retails shops, etc.)
- Community water supply system
- Street lighting
- Religious hall (e.g. churches, mosques, etc.)

It is the responsibility of the researcher to conduct a survey to know what pertains in the rural community and conduct a load assessment accordingly. The following sections give details under households and street lighting only.

Table 4.1: Some Appliances Used

Appliance	Name of appliance	Rated power	Power factor	Surge factor
	CFL Bulb	11W	0.95	1
	CFL Bulb	65W	0.95	1
	CFL Bulb	85W	0.95	1
	Radio	15-30W	0.9	1
	CRT Television	65-200W	0.9	1.2
	Vaccine Refrigerator	60W	0.95	1.5
	Water pump	700-1300W	0.7	1.2
	Desktop computer	100W	0.95	1
	Ceiling fan	70W	0.8	1
	Street light	30W	0.9	1

4.4.1 Households

According to the International Energy Agency, initial threshold of electricity consumption for rural households is assumed to be 250 kilowatt-hours (kWh) per year. This calculation was based on an assumption of five people per household given a consumption of a standing fan, a mobile telephone and two compact fluorescent light bulbs.

Tanzania, Kenya and Ghana's lifeline tariff which is used to subsidize domestic customers is 50 kWh per month. In Uganda, it is limited to 30 kWh per month; Mali has lower tariffs for consumers using less than 5 Amperes and the first 50 kWh (ESMAP, 2005) (IMF: African Department, 2013). Based on these figures and the writers' discretion, an energy daily allowance of 1.7 kWh can be set for each household.

The responsibility lies on the designer embarking on the project to conduct a survey to know the end-user appliances and power consumption to set an appropriate limit for the loads. Some typical loads are shown in Table 4.2.

Table 4.2: Load Assessment

Appliance	Qty	R.P (W)	U.T (h)	E. Con. / Day	PF	A.P (VA)	SF	SP
CFL bulb	60	11	6	3960	0.95	695	1	695
Radio	10	15	4	600	1	150	1	150
Street light	3	70	6	1260	0.8	263	1	263
CRT TV	3	75	10	2250	0.9	250	1.2	300
Pump for Drinking	1	373	2	746	0.7	533	1.2	639
Computer	2	138	10	2760	0.95	291	1	295
Ceiling fan	4	40	6	960	0.8	200	1	200
TOTAL	83	722	44	12,536	6.1	2382	7.4	2542

(Source: Field Data, 2017)

NOTE: PF = Power Factor, SP = Surge Power, A.P = Apparent Power, E. Con. = Energy Consumption, UT = Usage Time, RP = Rated Power.

A.P = $\frac{QTY * RP}{PF}$

4.5 Suggested Steps for Performing Load Assessment

The system designer must involve relevant opinion leaders and town folks when conducting the load assessment. A step by step procedure for completing an effective load assessment is given in Figure. The different results from the steps presented in Figure 11, for the whole community under consideration, will be used in sizing the components (inverter, battery and array). A sample load assessment sheet has been given in Table 4.2. The formulae can be built into Microsoft excel so as to reduce the time required to compute each parameter. However the formulae must be verified to avoid errors. Because of seasonal variations in both resource and load (duration of operation) especially in some parts of the continent (northern and southern African regions), it is useful to perform a seasonal/monthly load assessment.

Example:

A load assessment for Mpahin community with 50 households, was done by a Researcher designer. The following are results from the load assessment:

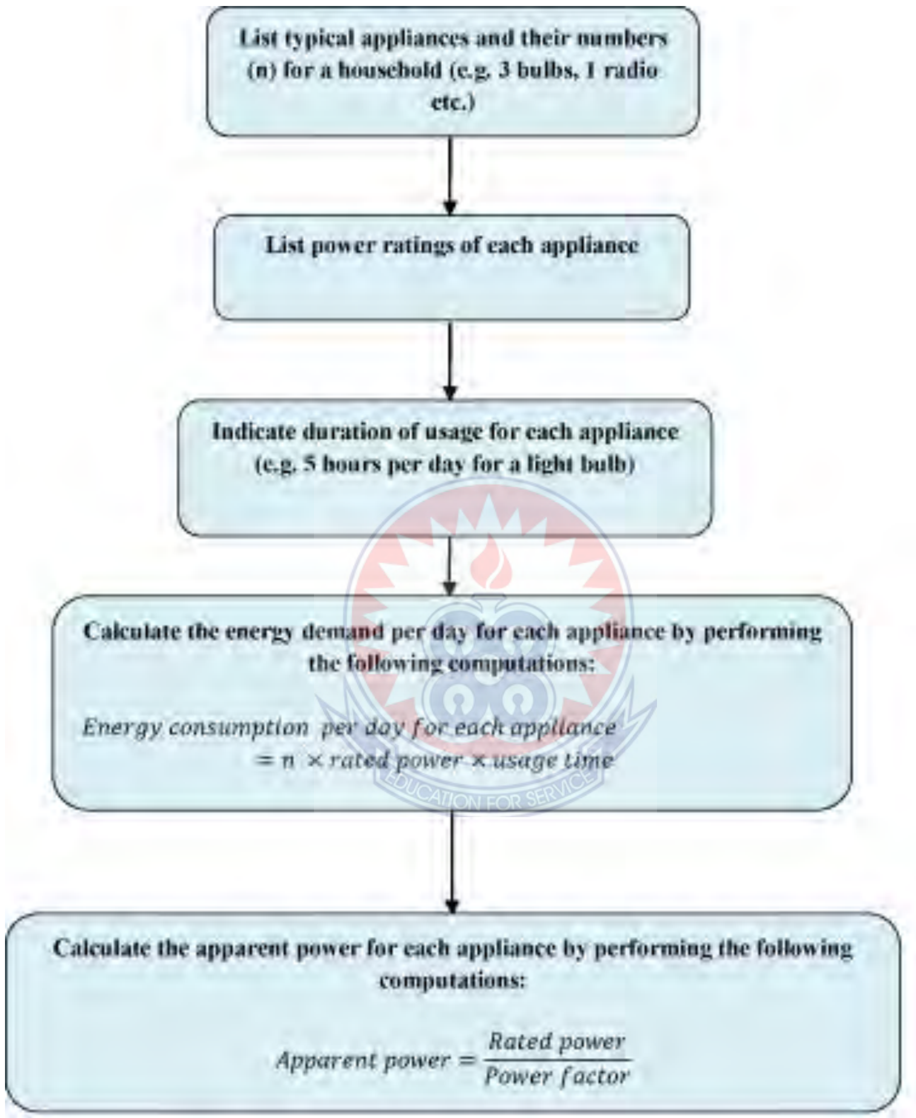


Figure 4.1: Steps in performing load assessment

Table 4.3: Example of load assessment of a village

Appliance	Quantity	Rated power (W)	Usage time (h)	Energy consumption per day (Wh)	Power factor	Apparent power (VA)	Surge factor	Surge power (VA)
CFL bulb (with capacitor)	200	11	6	13200	0.95	2316	1	2316
Radio	10	15	4	600	1	150	1	150
Street Lights (LED type)	6	70	6	2520	0.8	525	1	525
CRT Television	3	75	10	2250	0.9	250	1.2	300
Desktop computer	2	138	10	2760	0.95	291	1	291
Ceiling fan	4	40	6	960	0.8	200	1	200
Total				**22290**		**3732**		**3782**

4.6 System Sizing and Dimensioning for Stand-alone PV Power Station

4.6.1 Battery Bank Sizing

The system designer must determine the system voltage and must be based on the total energy consumption (requirement) per day (Wh) and also the peak power demand (total apparent power) (VA). One of the constraints in selecting system voltages is that, maximum continuous current drawn from the battery is not greater than 120A.

The battery voltage selected will serve as the system voltage and must be the same voltage as the inverter. Since mini-grid systems for rural electrification are relatively larger, 48 V or 120 V will be ideal compared to 12 V and 24 V systems for Solar Home Systems (SHS). However for the determination of system voltage, Figure 3.6 could be used as a guide.

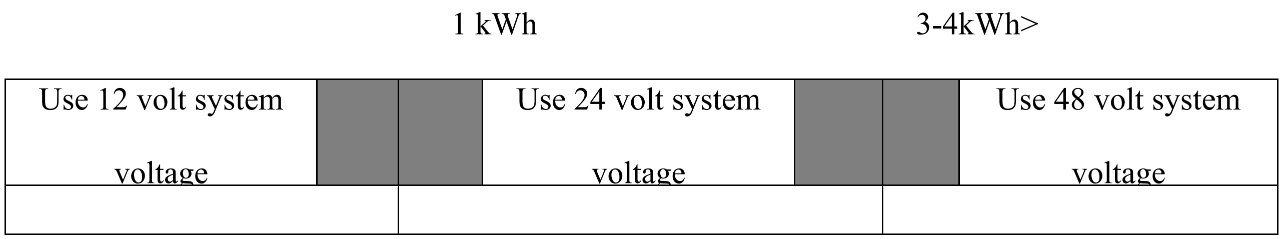


Figure 4.2: Suggested system voltage

Ideally, the battery must not be completely discharged during each cycle, else can be damaged. For optimum operation, the maximum depth of discharge of **70%** for deep-cycle lead-acid batteries can be considered. However, the system designer must refer to the manufacturer's specifications for details on the C-rating, maximum depth of discharge, amp-hour capacity, voltage, etc.

4.7 Suggested Steps for Sizing Battery Bank

A step by step procedure for determining the battery bank size has been given in Figure 4.3. The inverter efficiency used in the steps will be supplied by the manufacturer which can be read on the nameplate.

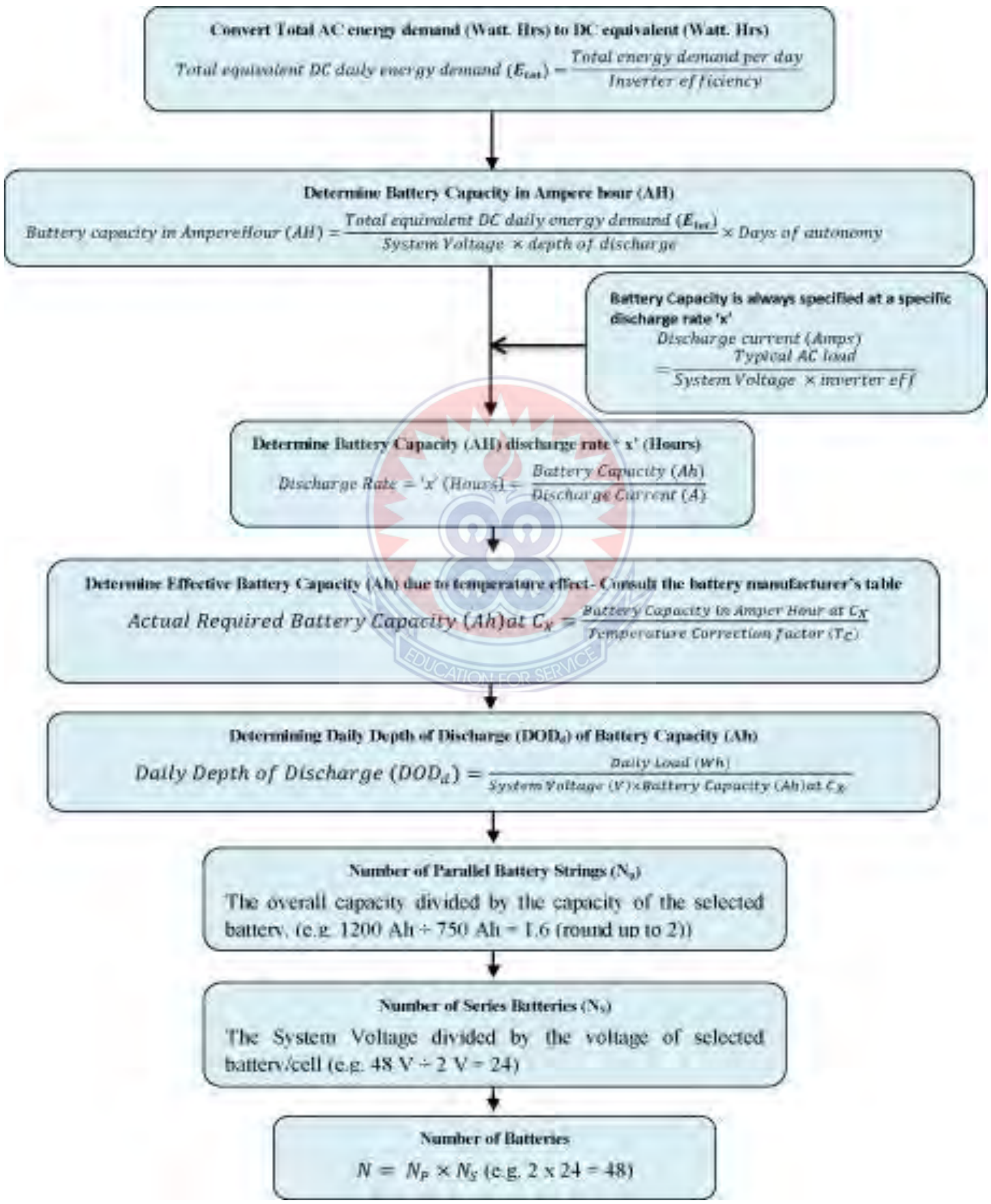


Figure 4.3: Steps to sizing battery bank

NB: Use 12/24/48 or 120 Volts as system voltage if your discharge current is less than 120 Temperature Correction Factor (T_c): the battery bank's ambient operating temperature is taken into consideration, since temperature affects a flooded lead-acid battery's internal resistance and ability to hold a charge. As temperatures fall below 25°C, battery capacity is reduced. A battery temperature multiplier table can be used. Check with the battery manufacturer for their specific correction factors.

4.7.1 Invert Sizing

The inverter size should be higher than the total apparent power of all appliances to cater for a possibility of residents adding new loads in the future. For example an inverter can be rated at 20% larger if the rural load is estimated to grow slightly below 20% over the lifecycle of the project. Avoid loading the inverter to full capacity as this may damage the inverter overtime.

If an appliance of a motor or compressor, for example community water pump, community refrigerators, electric fans, are part of the loads in the rural community then inverter selected should have a surge capacity of 3 times the nominal rating to handle surge current during starting. Also, inverters must have the same voltage with the battery bank to which it will be connected i.e. (48 V or 120 V).

4.8 Suggested Steps for Sizing Inverter

A step-by-step procedure for determining the inverter rating has been given in Figure 4.4.

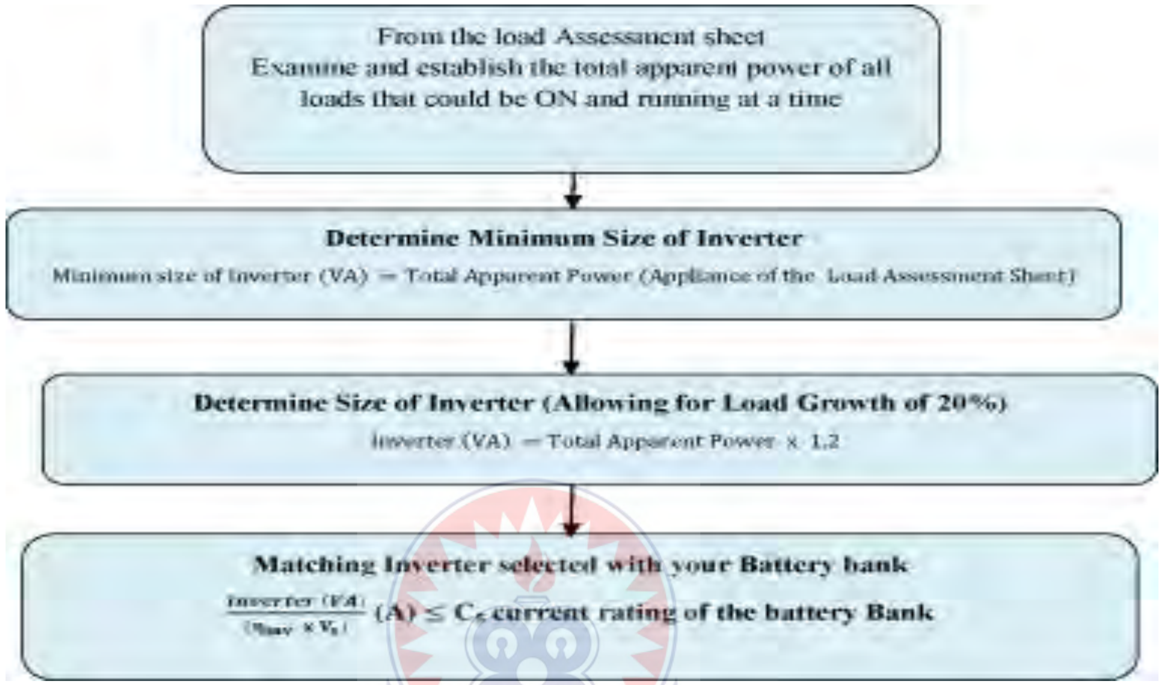


Figure 4.4: Suggested steps for sizing inverter

4.9 Inverter Selection

Inverters which meet the power requirements of the community must be tested to meet internationally certified standards and local standards and certifications such as:

IEC 62109: Safety of power converters for use in photovoltaic power systems

IEC 62093: Balance-of-system components for photovoltaic systems - Design qualification natural environments.

IEC 61683: Photovoltaic systems - Power conditioners - Procedure for measuring efficiency IEC 60068: Environmental testing

4.10 Array Sizing

A simplified step by step procedure for sizing the solar array has been given in Figure 4.4. One should note that in the calculation below, **85 %** was selected as the efficiency of regulator which regulates the current from the solar array to the battery. The responsibility lies with the system designer to infer from the regulator nameplate for the efficiency provided by the manufacturer.

The system designer should account for seasonal variations in both resource and load (duration of operation) especially in northern and southern African regions. The best practice is to select the month with the worst ratio of the solar irradiation to the load (e.g. July: irradiation = 3.67 kWh/m^2/day; Load= 167 kWh/day; Ratio = 3.67/167 = 0.022).

Table 4.4: Ratio of Irradiation to Load for a rural community

Month	Irradiation kW/m^2/day	Load kWh/day	Ratio
January	4.18	128	0.033
February	4.68	101	0.046
March	5.04	144	0.035
April	5.09	114	0.045
May	4.97	140	0.036
June	4.38	135	0.032
July	3.67	167	0.022
August	3.35	141	0.024
September	3.80	119	0.032
October	4.44	121	0.037
November	4.66	136	0.034
December	3.87	172	0.023

4.10.1 Suggested Steps for Sizing Array

This section outlines steps in sizing array for systems using standard regulator and maximum power point tracker. For both methods, the system designer must first determine module deratings due to:

- Manufacturer tolerance of the solar module
- Ambient temperature
- other site conditions e.g. dirt and efficiencies of Regulator, Battery and cabling between array and battery

4.10.2 Suggested steps for sizing array using Standard Regulator

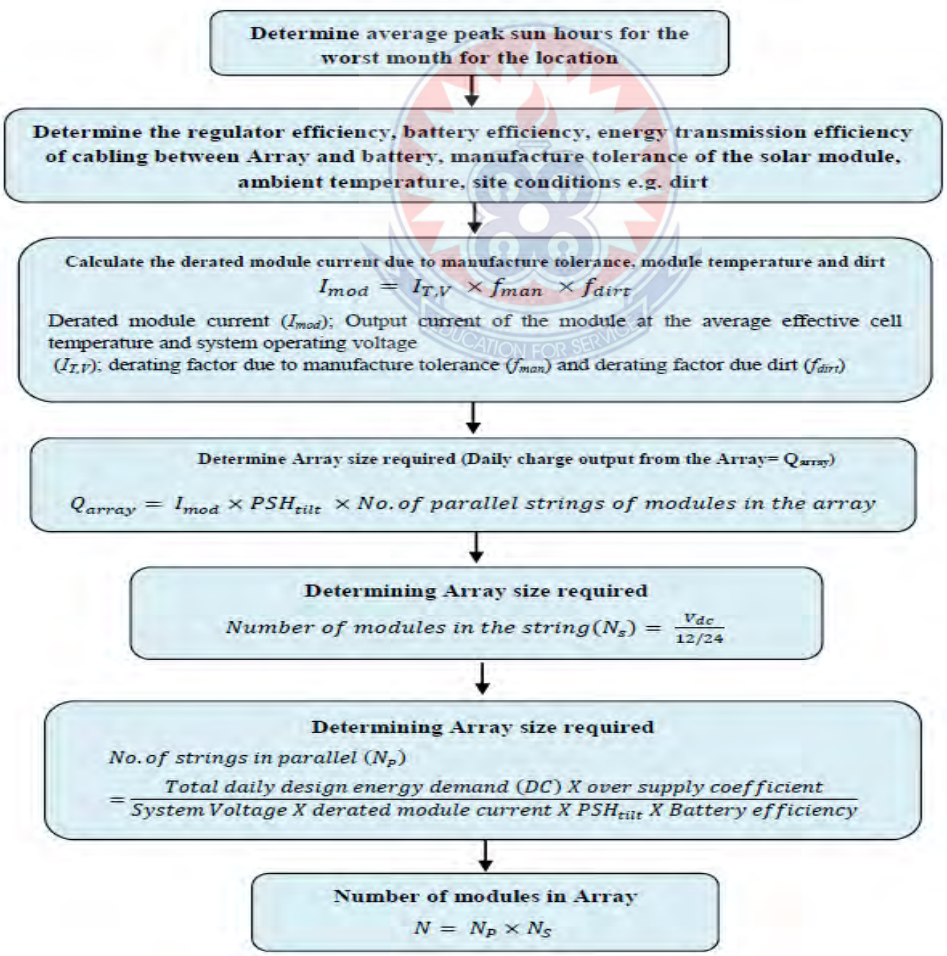


Figure 4.5: Steps for sizing array using standard regulator

4.10.3 Suggested Steps for Sizing Array using MPP Regulator

MPP: Maximum Power Point

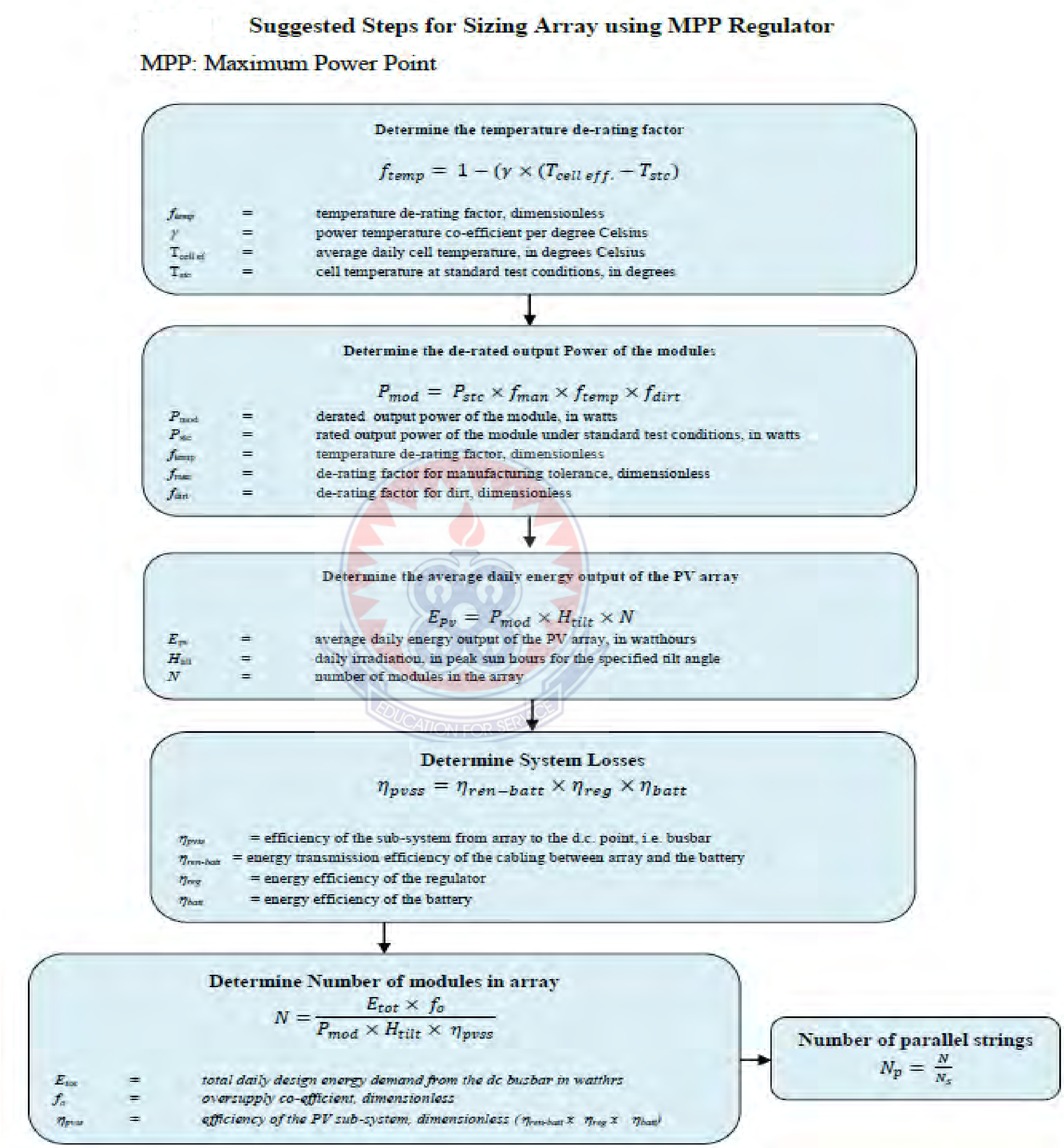


Figure 4.6: Steps for sizing using MPP Regulator

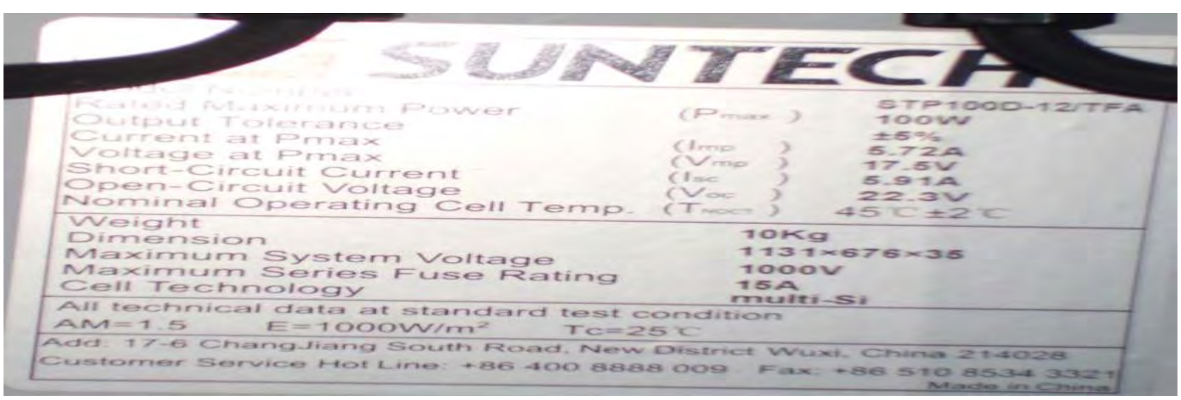
4.11 Sizing of Wires

As a good design principle, wiring should be done such that the maximum voltage drop at full power from the PV modules to the inverter is 3% **or less.** This section covers wiring from:

- PV array to combiner box
- Combiner box to charge controller
- Charge controller to batteries
- Batteries to inverter
- Inverter to AC bus bar

4.11.1 Wiring from PV array to Combiner Box

Under normal operating conditions, modules can produce higher currents and voltages than specified on the module nameplate under STC (Standard Test Conditions)[5] for instance in some regions solar radiation of more than 1000 W/m has been recorded. The short-circuit current must therefore be multiplied by a factor to account for periods where the current exceeds that value. The short-circuit current can be obtained on the module nameplate. Shown in Figure 4.7 is a typical nameplate of a module.



[5] Standard Test Conditions: 1000 W/m^{2}irradiance, 25°C CellTemperature and 1.5 Air Mass

Figure 4.7: Module nameplate

4.12 Wiring from PV Array to Combiner Box

NEC 690.8, an American code, applies a factor of 1.25 to the short-circuit current of the PV module (Isc). The conductors are then sized at 125% of the maximum circuit current or 1.56 x Isc. In order to stay within the required 3 % voltage drop from PV array to inverter, the maximum voltage drop between the PV modules and the combiner box should be kept as low as **1 - 1.5%.**

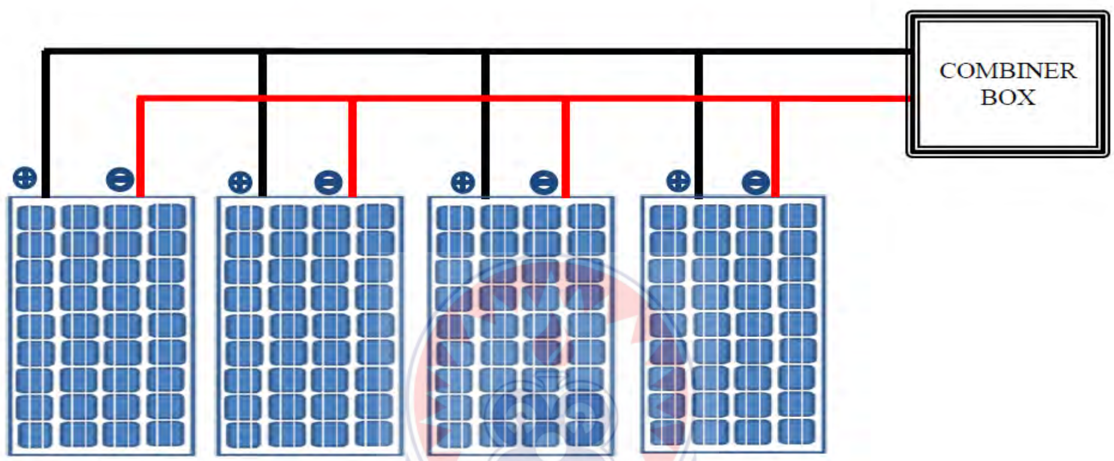


Figure 4.8: Wiring from PV array to combiner box

4.12.1 Suggested steps in sizing wires from PV array to combiner box

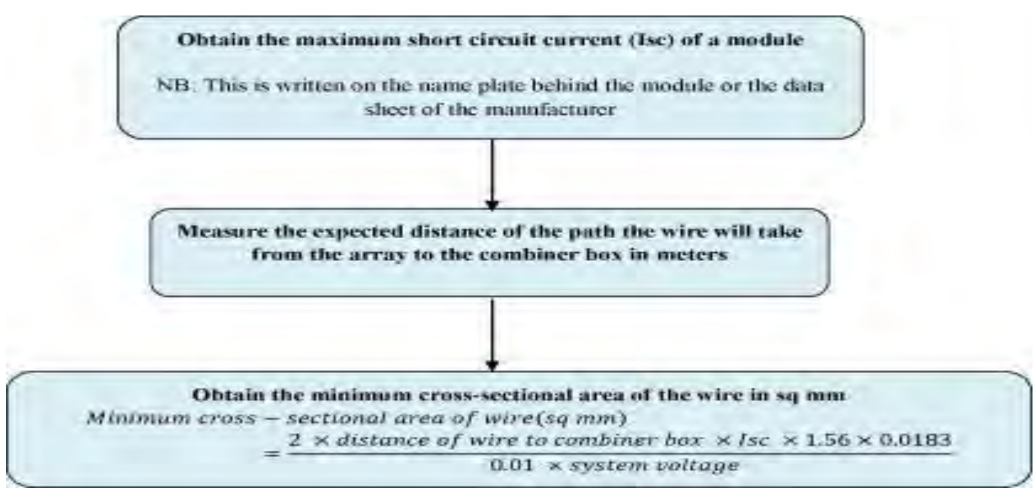


Figure 4.9: Steps to sizing wire from combiner box to charge controller

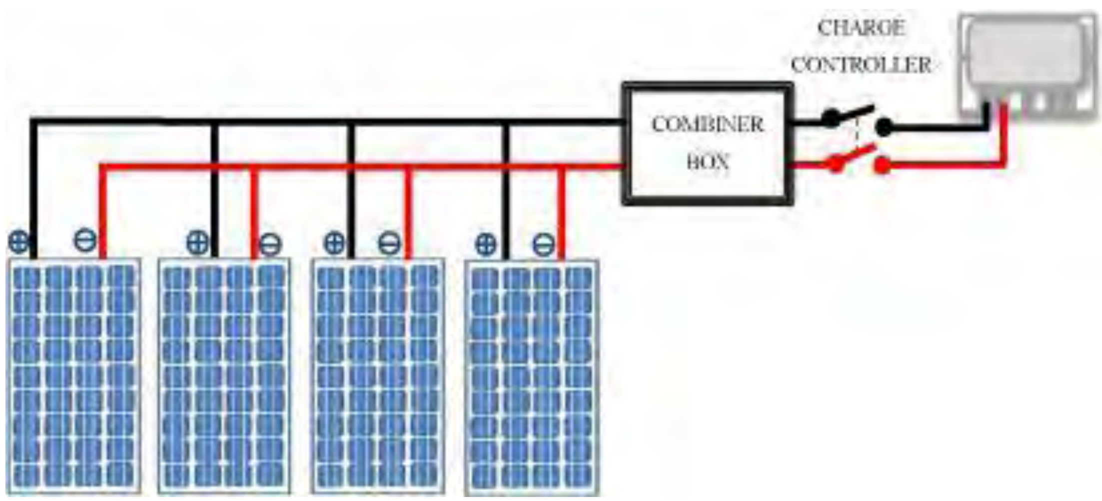


Figure 4.10: Wiring from combiner box to charge controller

4.12.2 Suggested steps to sizing wires from combiner box to charge controller

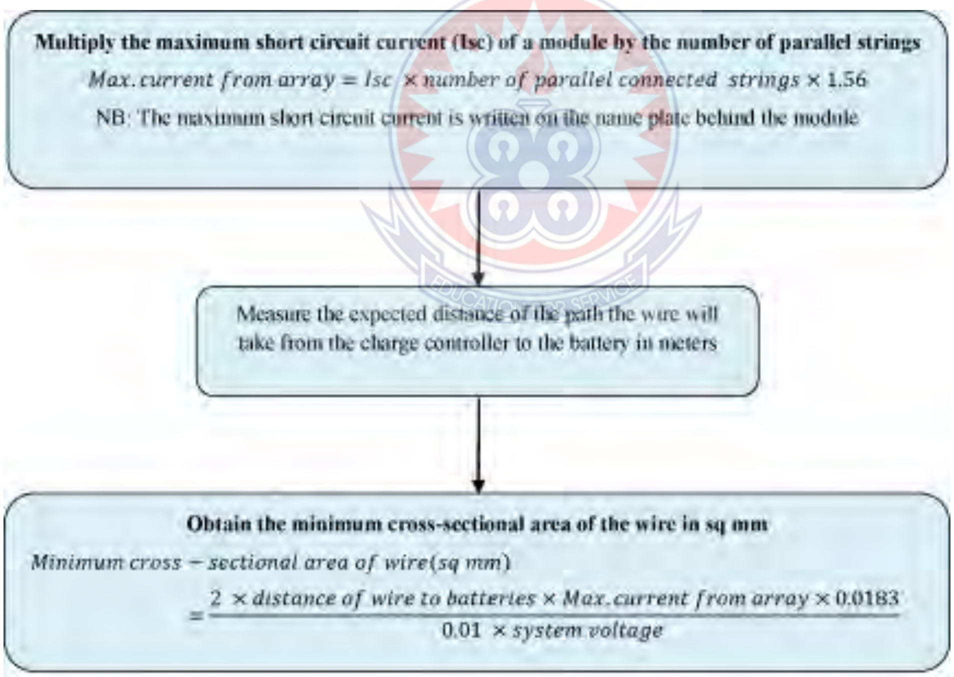


Figure 4.11: Steps to sizing wires from combiner box to charge controller

4.12.3 Wiring from Charge Controller to Batteries

It is recommended that the maximum voltage drop between the PV combiner box and the inverter should be kept below**1 - 1.5% or less.**

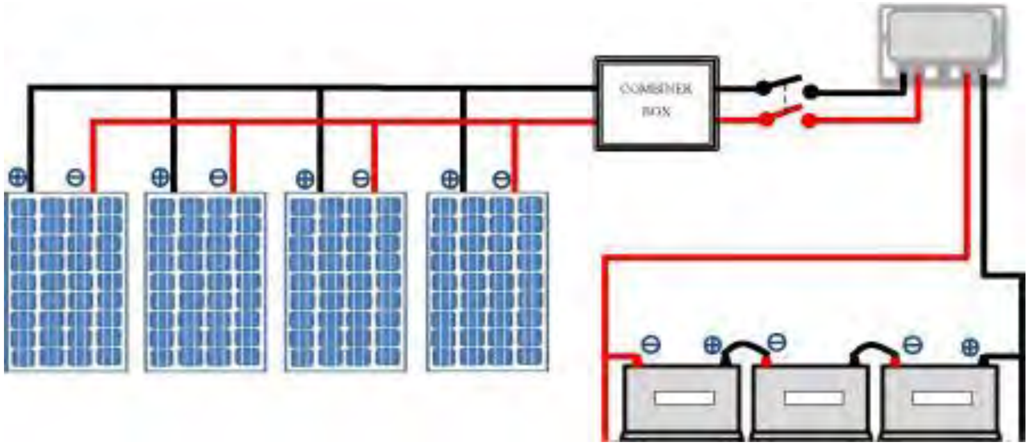


Figure 4.12: Wiring from Charge controller to batteries

A simplified step by step procedure for selecting the appropriate wire size has been given in Figures 4.12 and 4.13 using a maximum voltage drop of **1- 1.5% or less.**

4.12.4 Suggested steps to sizing wires from charge controller to batteries

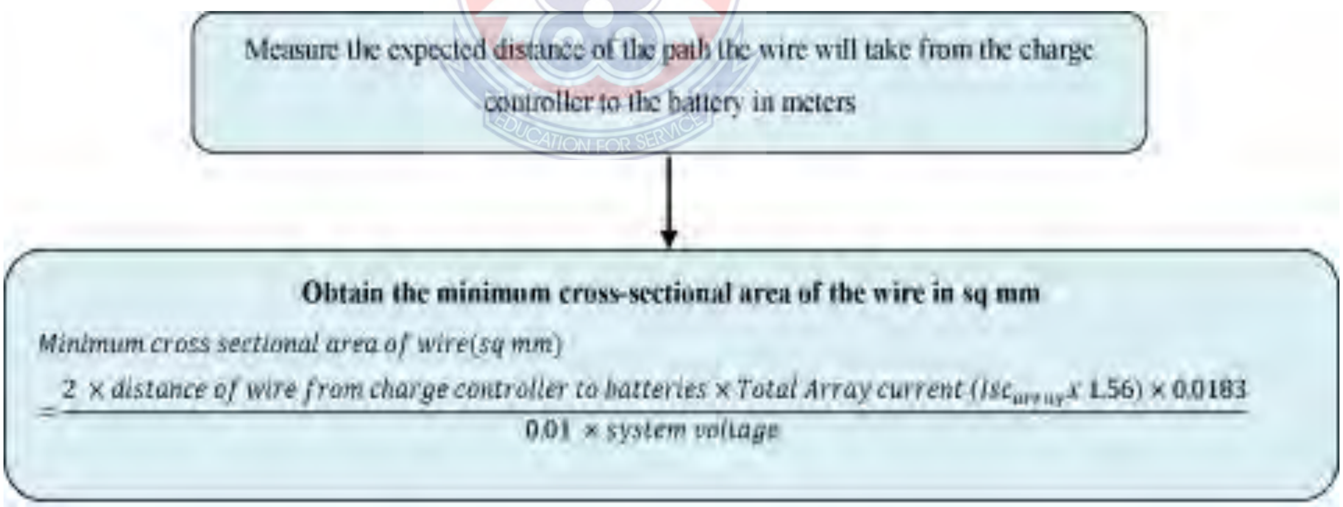


Figure 4.13: Steps to sizing wires from charge controller to batteries

4.12.5 Wiring from Batteries to Inverter (s)

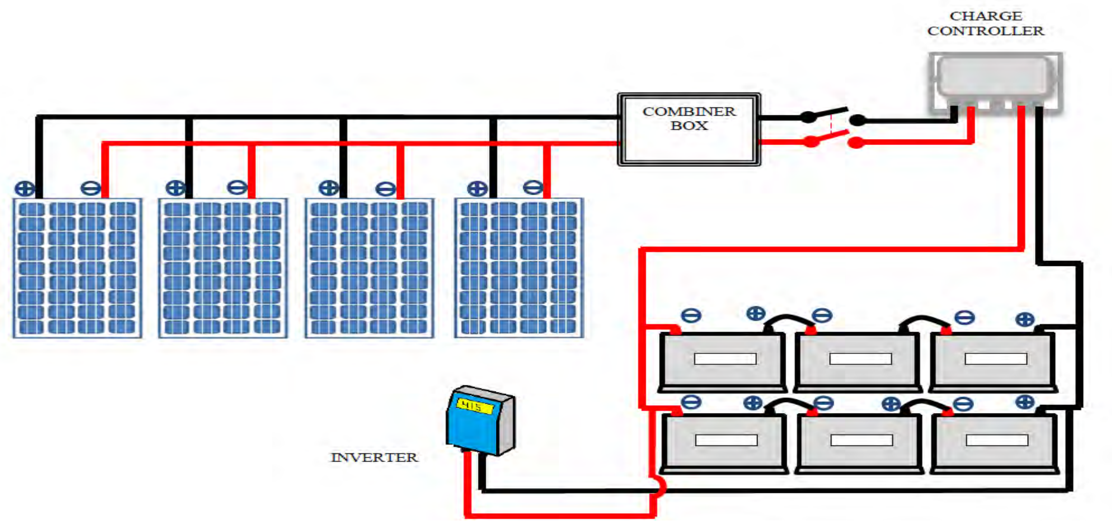


Figure 4.14: Steps to sizing wires from batteries to inverter

4.12.6 Wire Size Selection

The minimum cross-sectional area of wire obtained from the computations may not be a standard size. In such cases, the next standard wire size should be selected. Diameters commonly available on the market are 1.5, 2.5, 4, 6, 10, 16, 25, 35, 50, 70, 95, 120 and 150 (mm^2).

4.13 Sizing of Fuses

In the event of a short-circuit fault, wires can catch fire since they are exposed to the combined short circuit current of all the circuit components supplying current. Fuses are therefore required to protect cables and PV modules in the event of a short-circuit fault. However, there are some situations where fusing is not required:

- Single series string (fusing not required)
- Two Strings in Parallel (fusing not required)
- Three or more strings in parallel (fusing required)

4.13.1 Steps to sizing fuses for string protection

If the number of strings in parallel per sub array (N_p) is greater than or equal to three i.e. $N_p > 3$, the strings have to be protected using fuse links.

Steps in Figure 4.15 show how to size fuse for string protection

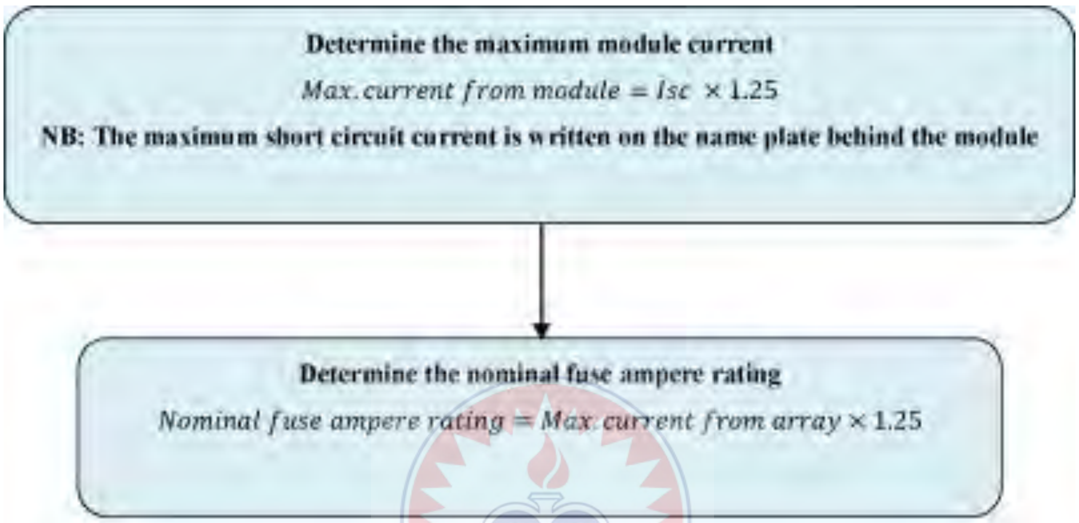


Figure 4.15: Steps to sizing string protection

4.13.2 Steps to Sizing Fuses for Array Protection

If the fuses are operating in outdoor environments and there is exposure to direct sunlight and sustained temperatures exceed 40°C then a correction factor (de-rate factor) may be applied to prevent nuisance openings. Steps in Figure 4.16 show how to obtain fuse nameplate current rating:

Determine the maximum array current

$$Max.\,current\,from\,array = Isc \times number\,of\,parallel\,connected\,strings \times 1.25$$

NB: The maximum short circuit current is written on the name plate behind the module

↓

Determine the nominal fuse ampere rating

$$Nominal\,fuse\,ampere\,rating = Max.\,current\,from\,array \times 1.25$$

↓

De-rate fuse due to abnormal ambient temperature (if required)

$$Fuse\,nameplate\,ampere\,rating = \frac{Nominal\,fuse\,ampere\,rating}{K_f}$$

NB: K_f is the temperature co-efficient. For ambient temperature of 25°C, $K_f = 1$

Figure 4.16: Steps to sizing fuse for array protection (Current rating)

Determine the maximum module voltage

$$Max.Voltage\,from\,module = 1.20 \times Open\,circuit\,voltage\,of\,one\,module$$

NB: The Open circuit voltage is written on the name plate behind the module

↓

Determine the nominal fuse voltage rating

$$Nominal\,fuse\,voltage\,rating = Max.\,voltage\,from\,module \times Number\,in\,series\,per\,string$$

Steps in Figure 4.17 show how to obtain fuse nameplate voltage rating:

Figure 4.17: Steps to sizing fuse for string protection (Voltage rating)

4.14 Distribution Network Installation Design

Step 1

The location of the power or control station should be decided at this very stage. It is recommended to locate the station at the center of the town or village if possible.

Step 2

The Load Demand of the Community should be determined from the intended or installed loads.

Step 3

The size of conductor that will be used should be selected from the manufacturers' Chart based on the power demand already known from the community.

Step 4

The pole height, one span or spacing should be agreed on with respect to the standard of the local Electricity Company in that Country.

Table 4.5: Specifications for poles

Pole Height	Basic Span	Maximum span	Weight span
8 m to 10 m	46 m	50 m	75 m

The poles shall be placed in the ground to the planting depths dictated by foundation design but not less than the following:

Planting depth = Total length of support / 6

or Planting depth = 60cm+Total length of

support / 10

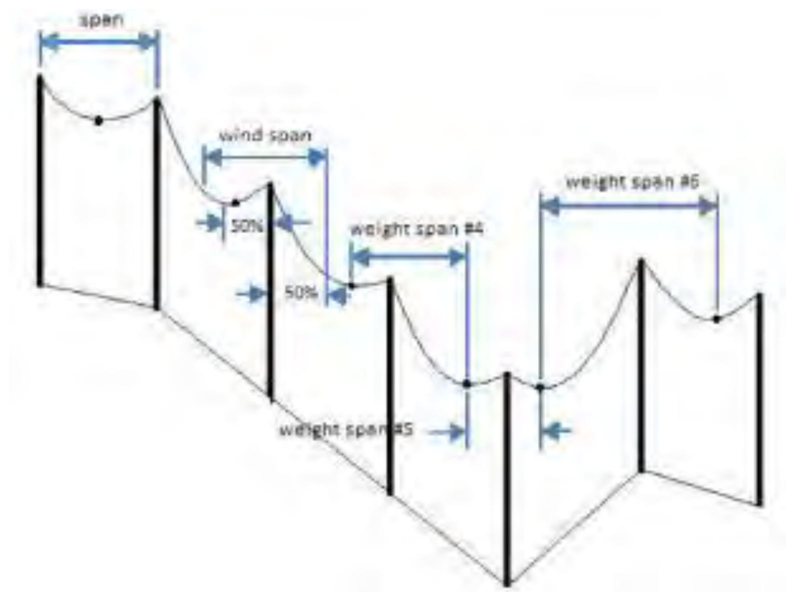


Figure 4.18: Distribution network (ECG Distribution Design Manual)

Step 5

The length and type of the conductor per feeder should be specified at this stage taking into consideration an allowable voltage drop of 5%. The type of conductor that is insulated, bare, armoured cable should be decided on at this stage. All aluminium conductors (AAC) shall be normally used because of the high conductivity and acceptable sag & tension behaviour suitable for short spans. The preferred conductor sizes for LV main lines are 50 mm^2, 120 mm^2 and 150 mm^2. The preferred conductor sizes for LV spur or branch lines are 25 mm^2 and 50 mm^2. The 25 mm^2 conductor size can also be used as main line if the load is very low.

Table 4.6: Specifications for conductors

Type (mm²)	Construction	Material	Ampacity * (Amps)	Maximum feeder length^ (km)	Diameter (mm)
25 sq.mm	7/ 2.0	Aluminium	145	0.1	6.0
50 sq.mm	7/ 3.1	Aluminium	249	0.2	9.3
120 sq.mm	19 / 2.8	Aluminium	407	0.2	14.0
150 sq.mm	19/ 3.25	Aluminium	489	0.3	16.25

(*) Ampacity quoted for ambient temperature 30°C and maximum temperature 80°C in accordance with the recommendations and methodology of IEEE 738 and IEC 1597.

Step6

Type of earthing that will be used on the distribution network, protective multiple earthing is industry standard now.

Terminologies

The Basic Span of a line is the section between two tension points.

The Weight Span is the representation of dead weight load of the conductors on pole expressed in length of the specific conductor and its unit weight.

House Wiring

4.15 Guiding steps in household wiring for solar PV based mini-grid systems

Step one

Selection of consumer unit and Miniature Circuit Breakers (MCB): The total load current or power demand should be known, this will enable one select the correct consumer unit. The rating of the consumer unit (distribution panel) should be greater than the total load current of that household.

Step two

A ten percent safety factor should be taken into consideration. Modern units do not contain fuses, but miniature mechanical circuit breakers (MCBs) have replaced them. Figure 4.19 shows a picture of an MCB. Unlike a fuse, which operates once and then must be replaced, a circuit breaker can be reset (either manually or automatically) to resume normal operation.

Figure 4.19: Miniature Circuit Breaker (MCB)

Example

For a load rating of 600 Watts and a number of specified loads 6 and a system voltage of 240 volts, the current consumed is 600/240 which gives 2.5Amperes.

But since number of specified load is 6, total current consumed by these loads is 2.5*6 which gives15 Amperes. Here one has to select 2.5 mm. Circuit breaker selection is based on 10 % safety factor, so 10 % of 15 is 1.5. 1.5 added to 15 is 16.5 Amps. So rating of breaker should be 17 Amps provided is available on the market if not use the immediate highest rating from 17. This same approach is used to select the main breaker by adding all the possible load currents on the various circuits.

Table 4.7: Suggested specifications for household wiring

Load Ratings	Type of Load	Electrical Accessories	Number of specified load	Main Conductor Size (mm^2)	Total current Consumed by Load	Circuit Breaker Capacity (A)	Safety factor (%)
Up to 100	Lights	3 Switches	6	1.5	2.5	3 (5)	10
Up to 30 W	Radio	1 Socket	1	1.5	1.408	2(5)	10
Up to 300	TV	1 Socket	1				
Up to 8 W	Mobile Phone		1				

The height for Sockets should be 450 mm from the ground while the height for light switches should be 1400 mm from the ground according to British Standard **BS 8300.**

Note

The length of conductor from the consumer unit will be determined by the dimensions of the room. The lighting circuit should also take 10 to 15 meters from the consumer unit and back.

4.16 Metering

Consumer metering for all facilities should consider rating of 5/25 Amperes, single phase (240 volts). Meters should be mounted at about 1.8 meters from the ground as per regulations in many countries. They should be equipped with a load limit which strips on overcurrent settings. This is especially necessary in cutting-off people who may be tempted to use high rating appliances such as ions and fridges. If a person can be employed to read these meters for billing then a smart meter which is much more expensive could be avoided. A prepaid meter could also be used. A prepaid meter offers a good opportunity for the consumer to budget for his energy, especially for low income or oscillating income people. Pictures of a prepayment meter and a smart meter are shown in Figure 31 and 32 respectively. Instead of meters, load limiters could also be used to do the metering at a flat rate tariff that is agreed upon by the parties involved. If customer tries to go beyond the assigned limit the miniature circuit breakers (MCB) strips and the power goes off. These load limiters can be the intelligent type that restores power back when the load falls within range again. In case they are not intelligent, the customer should be trained on how to reduce load and turn the MCB back on.

Figure 4.20: Prepaid meter

Figure 4.21: Smart meter

4.17 Sizing and Selecting Battery Charger

The maximum rate of charge of the batteries must be specified by the battery's manufacturer. This is generally rated at the 10h rate.

The maximum charge rate is:

$I_{bc} = 01 \times C_{10}$

That is, it is 10% of the C_{10} capacity of the battery.

As an example if a battery has a C_{10} capacity of 785, then the maximum charge current is 78.5amps. Therefore for system voltage of 48V, the apparent power (VA) of the battery charger is:

$$S_{bc} = I_{bc} \times V_{sys} = 78.5 \times 48 = 3768 \text{ VA}$$

4.18 Solar Energy Fraction

This term relates to how much of the daily energy demand is met by the solar PV system. For PV systems using standard regulators, calculations are based on ampere hours, and so the solar fraction is determined by the following formula:

Vdc X /mod X //tilt X ?7coul

X iVpSolar fraction = /pv = ________________________________

Etot

For PV systems using MPPT, where calculations are based on watt hours, the solar fraction is determined by the following formula:

Solar fraction = fv *Ep*\ x ?7pvss ⁼*Etot*

4.19 Materials Recommendations

- Materials used outdoors especially the wiring cables should be protected and sunlight/UV resistant
- Dissimilar metals such as steel and aluminium (e.g. mounting module to aluminium structure using steel bolt) should be isolated from one another using non-conductive shims, washers, or other methods.
- High quality fasteners should always be used and most preferred is stainless steel.

- Structural members should be either; aluminium (corrosion resistant) or hot dip galvanized. However in low corrosive environments such as deserts coated or painted steel could be employed and in very corrosive environments (marine areas) stainless steel should be used.

4.20 Installation Checklist:

The first step in the installation process is to ensure that the tools and materials required to complete the installation are transported to the site.

The Schedule of Material produced for the quotation is normally used as the basis for this checklist. Table 4.8 provides an example of installation checklist.

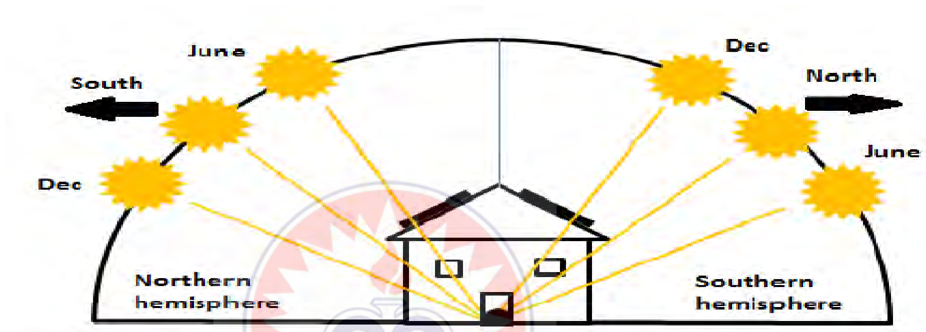
Table 4.8: Sample Installation Checklist for Centralised PV mini-grid System

Item No.	Type of Item	Number Required	Details	OK
1)	PV Module-Model ABC-100			
2)	Solar Mounting structure			
3)	Hardware for connecting module to frame			
4)	Hardware for connecting frame to roof (if required)			
5)	Cable between module & solar regulator			
6)	Conduit			
7)	Fastening hardware for cable/conduit			
8)	Solar Regulator			
9)	PV array isolator between solar array and inverter			
10)	Cable from isolator to inverter			
11)	Array Junction box (if one exist)			
12)	Inverter AC isolator			
13)	Cable between inverter and switchboard			
14)	Hardware for fastening controller to wall			
15)	Fuse/Circuit breaker between solar module/controller			
16)	Batteries			
17)	Timber (if battery floor mounted)			
18)	Battery racks/stands (if required)			
19)	Battery Box (if required)			
20)	Coverings for terminals (if required)			
21)	Cable between controller and battery			
22)	Lugs or fasteners for cable connection to battery			
23)	Inverter(s) Model PWS….			
24)	Cable between batteries and inverter			
25)	Battery Charger (if required)			
26)	Cable between charger and batteries			
27)	System Fuses or Switch Fuse			
28)	Lights for shed/battery room			
29)	Light Switches			
30)	Cable between controllers/batteries and lights			
31)	Fastening hardware for lights/switches			
32)	Fastening hardware for lighting cable			
33)	Installation Tools (recommended technician prepares a list)			

4.21 Solar Array Installation

4.21.1 Orientation of Panels

In the northern hemisphere, modules should face south, and in the southern hemisphere, modules should face north. Figure 4.22 illustrates the orientation of solar panels. The selected site must be checked for shading by trees, towers, buildings and other structures. PV arrays should be unshaded at least between the hours of 8 a.m. to 4 p.m.



Credit: Adapted from www.thesolarco.com/

Figure 4.22: Direction and angle of installation

4.21.2 Roof Mounted System

If panels are to be mounted on the roof, the roof pitch shall not exceed 35°. Recommended space between two solar modules is 5 mm considering linear thermal expansion of the module frames. For rural communities, roof mounted systems are recommended.

4.21.3 Ground Mounted Systems

The distance from ground level to the underside of solar panels shall be not be less than 250 mm and the tilt angle shall not exceed 45°. The recommended tilt angles are given in Table 4.9.

Table 4.9: Recommended tilt angles for a ground mounted (fixed) system

Site latitude in degrees	Fixed tilt angle
0°to 15°	15°
15°to 25°	Same as Latitude
25° to 30°	LATITUDE +5°
30° to 35°	LATITUDE +10°
35° to 40°	LATITUDE +15°
40°+	LATITUDE +20°

4.21.4 Roof Selection

The selected roof for mounting the PV array must meet the following requirements to ensure safety of personnel during installation, reliability of operation and increase in system life.

It should be noted that the requirement per kW of solar PV modules is about 12 m. The roof selected must have sufficient space to accommodate the arrays and have extra space for recommended module spacing of 5- 10 mm.

1. Roof area should not have holes, cracks or indentations and leakages which can serve as a safety hazard for installers.
2. Roof should be structurally strong to support weight imposed by modules and should also be easily accessible to installers to perform installation.
3. Roof area selected must be free from shading by trees or adjacent structures from 8 a.m. to 4 p.m.

4. Distance between the roof mounted PV array and the location of all system components should be close to reduce voltage drop caused by long wires.

Figures 35 and 36 respectively illustrate a typical inappropriate and a typical suitable roofs for solar PV installations

Figure 4.23: Typical roofs not appropriate for solar PV installations

Figure 4.24: Typical roof appropriate for solar PV installation

4.21.5 Array Mounting

Different methods can be used to mount the array on the roof; array and rails can be mounted vertically; array and rails can be mounted horizontally; array can be mounted horizontally while rails are vertical and array can be mounted vertically while rails are horizontal. There are commercially available mounting structures on the markets including Sharp, Conerg, and SRS mounting systems. There are two main types of mounting methods: Mounting with bolts and mounting with clamps.

Each row of modules is held to the roof for both methods using two aluminium rails and fastened to the roof using:

- L-Foot
- Standard Rail
- Mid Clamp
- Internal Splice
- End Clamp
- End cap
- M8 bolts

4.21.6 Suggested Steps to Mounting with Bolts (refer to manufacturer's mounting instructions)

Step 1: Mounting the feet and first piece of the rail

1. Mount all of the feet to the roof in the desired locations
2. On the first piece of rail, slide 10 mm bolts into the slide facing T-slot on the rail. Space the bolts out to match the foot spacing.

3. On this same piece of rail, slide 6 mm bolts into the top facing T-slot on the rail. Space the bolts out to match the panel spacing
4. Attach this first piece of rail to the feet mounted on the roof. Mount the rail to each foot with a flange nut and bolt. Hands tighten the nuts and check the level of the rail. Tighten 10 mm bolts.

Step 2: Mounting the next pieces of the rail

1) On the next piece of rail, slide 10 mm bolts into the slide facing T-slot on the rail. Space the bolts out to match the foot spacing.
2) On this same piece of rail, slide 6 mm into the top facing t-slot on the rail. Space the bolts out to match the panel spacing
3) Lay the rail on its side, with the slotted side down
4) Slide the internal splice half way into the internal cavity in the rail. It should extend approximately 150 mm into the cavity.
5) Using one self-drilling, self-tapping screw, 1 inch from the edge of the rail, secure the internal splice into the rail.
6) Loosely mount this piece of rail onto its footing.
7) By moving this second rail along its footings, the internal splice should slip into the cavity on the first rail, with the rails butting tightly and evenly together
8) Maintain rail alignment by driving one self-tapping screw through the second rail
9) Repeat procedure for the remaining rails
10) A minimum distance of 5 mm should be allowed between two modules due to linear expansion of the frames.

4.21.7 Suggested Steps to Mounting with Clamps

1) Lay the first PV module in position on the rails
2) Then slip the end clamp over the bolt, making sure it is firmly hooked over the side of the module
3) Complete the clamp assembly with a flange nut
4) Repeat with the other clamp
5) Work from the opposite side of the PV module. Assemble the mid clamps by putting a clamp on the nut, followed by the flange nut
6) Place the second PV module into position on the rails, sliding it against the first so the mid clamps are in contact with the edges of both panels
7) Repeat the procedure using mid clamps to secure each successive module
8) Secure the last module at the end of the rails using the other set of clamps

Figure 4.25: use of end clamps

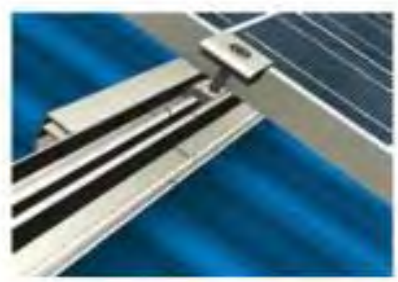


Figure 4.26: use of mid clamps

4.22 Ground Mounting

Ground mounted systems are used for very large systems in the range up around 70 MWp but for moderate systems of 100 kWp and for centralized systems for rural electrification projects equally employ ground mounting systems due to lack of suitable roof space and availability of land.

4.22.1 Ground Mounting using Piles

The most recent cost-effective and quick-to-install mounting systems on the market is where no foundation is cast, but instead stands are secured on driven piles. This method also creates array which is parallel to the ground and avoid expensive and time consuming ground-levelling works. The level of the mount can easily be set to meet the tilt angle for the location and also to a height that would very convenient for the installers.

Figure 4.27: Ground mounting using piles

4.22.2 Ground Mounting using Concrete Foundations

Foundation-based open area mounting system is the tried-and -tested mounting structure over the years. It provides convenient installation environment and Minimise use of special tools and generally keeps installation cost low

Figure 2.28: Ground mounting using concrete foundation

4.23 Array Wiring and Connection

After obtaining the number of modules to be used, they need to be wired in the appropriate configuration. Modules can be wired in series or parallel to increase voltage or to increase current respectively. To wire modules in series, connect wires from the positive terminal of one module to the negative terminal of the next module. The series wiring configuration is shown in Figure 4.29.

To wire modules in parallel, connect wires from the positive terminal of one module to the positive terminal of the next module and negative terminal of one module to the negative terminal of the next module. The parallel wiring configuration is illustrated in Figure 4.29.

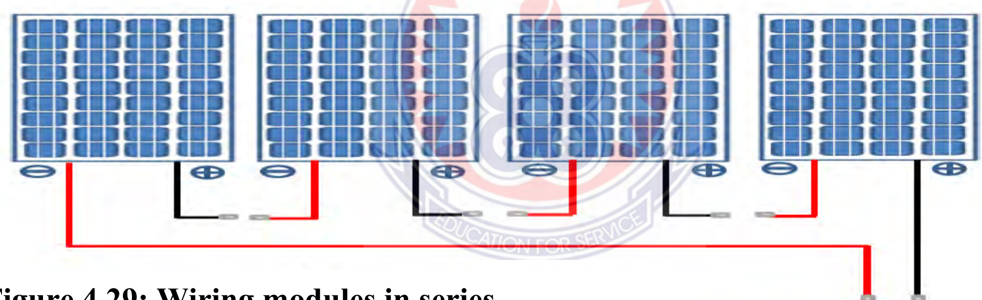


Figure 4.29: Wiring modules in series

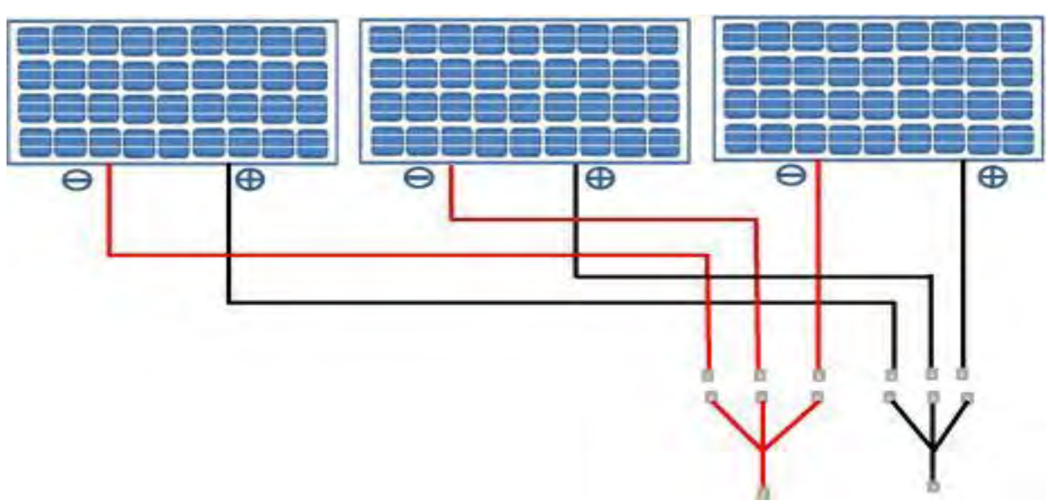


Figure 4.30: Wiring modules in parallel

Series and parallel combinations can be used to increase both panel current and voltage at the same time. The maximum number of Modules that can be connected in a series string must be calculated in accordance with applicable regulations in such a way that the specified maximum system voltage does not exceed DC 1000 V according to the safety appraisal of the IEC61730.

4.24 Grounding

All module frames and exposed metal parts must be properly grounded to avoid electrocution. The connection must be made with the hardware provided using the instructions supplied by the module manufacturer and in accordance with local electrical codes.

4.25 Charge Controller Wiring and Connection

Charge controllers are usually designed to be wall mounted. Mounting should be done on a dry surface as close to the batteries as possible. Holes are usually provided on the mounting flange for easy mounting using screws. Refer to manufacturer mounting instructions. Connections to the regulator are made at the positive (+) and negative (-) terminals. Refer to manufacturer wiring diagrams for recommended ways to connect solar panels and batteries to charge controller. The rule of thumb had been connecting the battery first before the solar array. Shown in Figure 4.31 is a typical wiring diagram.

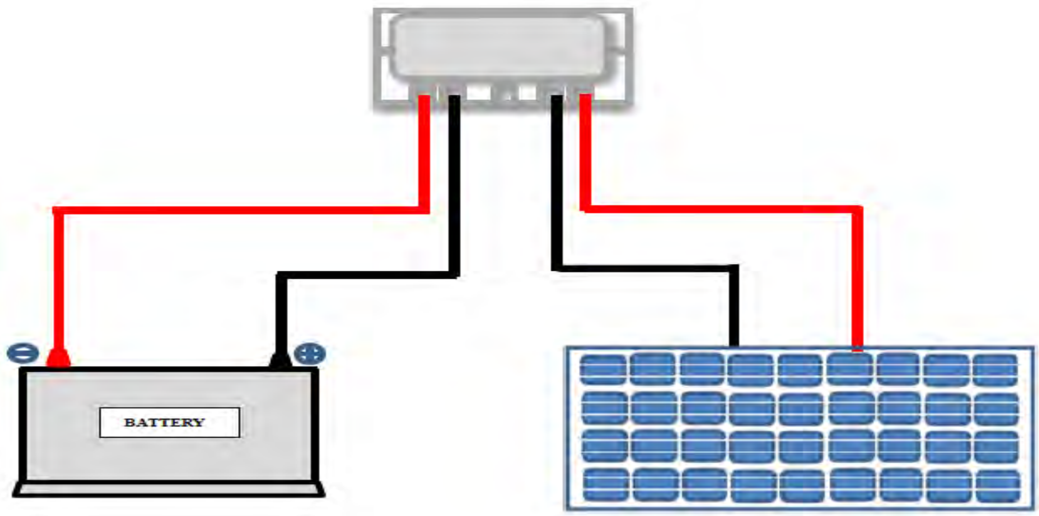


Figure 4.31: Wiring diagram

4.26 Battery Wiring

Connect batteries in parallel to increase battery capacity or in series to increase battery total voltage. To connect batteries in series, connect wires from the positive terminal of one battery to the negative terminal of the next. The series wiring configuration is shown in Figure 4.32.

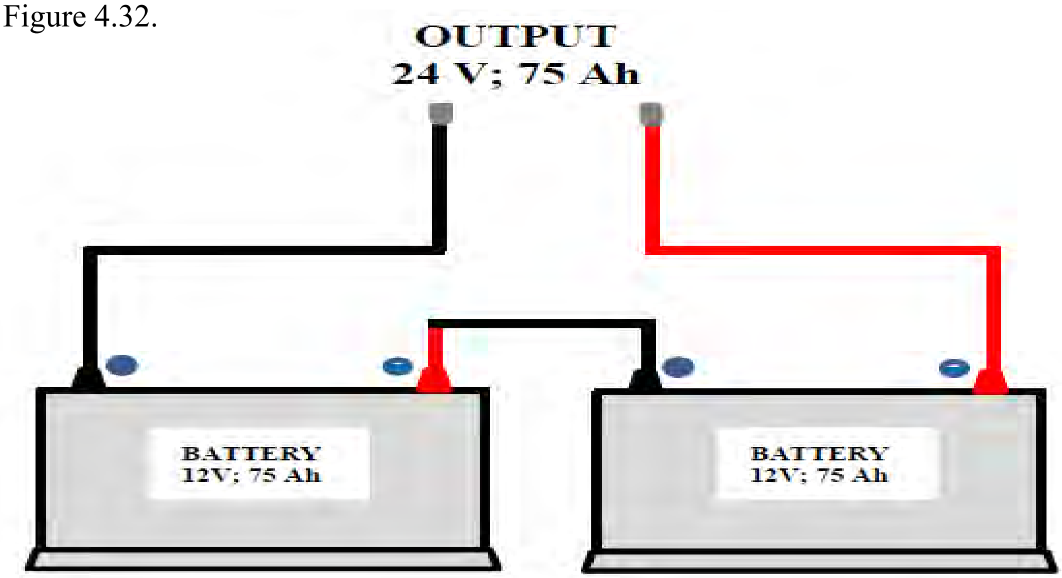


Figure 4.32: Series connection of Batteries

To wire batteries in parallel, connect wires from the positive terminal of one battery to the positive terminal of the next battery and negative terminal of one battery to the negative terminal of the next battery. The parallel wiring configuration is shown in Figure 4.33.

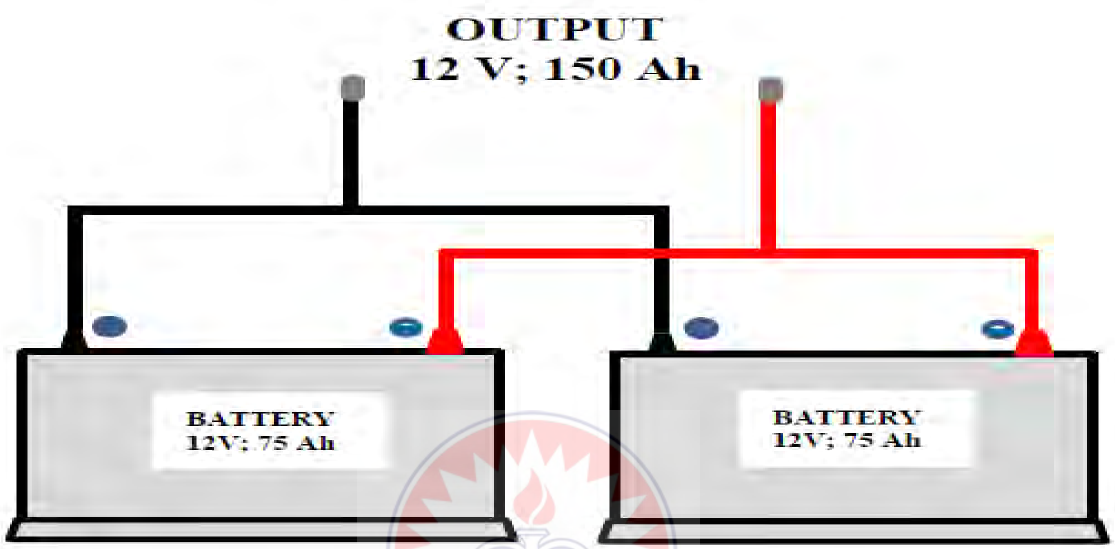


Figure 4.33: Parallel Connected Batteries

Series and parallel combinations can be combined to increase both panel current and voltage at the same time.

4.27 Battery Installation

Batteries will last for a long time depending on its type and the way they are treated. Typically some cells will deteriorate before the others, so it's better to occasionally check for bad cells in old batteries.

- Batteries need to be handled with extreme care because battery acid is corrosive which can cause skin burns, destroy clothes and furniture, damage cemented floor or cause blindness if it comes into contact with the eyes. Thus goggles and protective clothing should be worn and a funnel used when filling cells to avoid splashing.

- Safety shower and eyewash should be located near the battery area.
- Batteries should be located in ventilated areas as batteries emit explosive gases when charging and this must be allowed to escape.
- People should not smoke near batteries. Therefore a “NO SMOKING” sign should be placed in the room where battery is located.
- Battery location should not be at places with extremely high temperature or exposed to sunlight.
- Battery boxes should not be kept on the floor or concrete, but rather should be kept on either wooden, plastic pellets or non-metallic tray.

Figure 4.34: Battery mounted off the floor; source: Briganti

4.27.1 Battery safety

- Do not add tap water, acid or any other solution to the cells except de-ionised water to replace lost water during degassing.
- Overcharging of battery causes gassing which leads to the drop in level of electrolyte or release of explosive hydrogen. Thus overcharging must be checked by checking the battery state of charge regularly.

- Batteries should not be charged at a current that is more than one tenth of their rated capacity. High current causes fall in electrolyte level quickly and gassing. Charging with Low current is more efficient.
- Do not take too much energy out of battery before recharging. It is likely to destroy battery.
- If there is no controller or charge regulator, the load should be left on much longer or the modules disconnected when the battery is fully charged

4.28 Mounting Solar Modules

Solar modules should be mounted in a place where they can receive maximum solar radiation but not be shaded by trees or any obstruction. Modules should be as close as possible to the batteries, control and in a place free from vandalism and theft.

- Modules are very fragile and expensive so should be handled and transported with care.
- The backside of a module should be protected from the strike of sharp objects or heavy objects such as pliers, screw drivers, hammers etc. which can break a cell.
- Keep children well away from the system while transporting
- Do not stand, step or drill in the module.
- Overcharging of battery causes gassing which leads to the drop in level of electrolyte or release of explosive hydrogen. Thus overcharging must be checked by checking the battery state of charge regularly.
- Batteries should not be charged at a current that is more than one tenth of their rated capacity. High current causes fall in electrolyte level quickly.

- Do not take too much energy out of battery before recharging. It is likely to destroy battery.
- If there is no controller or charge regulator, the load should be left on much longer or the modules disconnected when the battery is fully charged.

4.29 Controller and Inverter Installation

The most common cause of solar system failure is the abuse of batteries by excessive discharge during bad (cloudy) weather. Solar electric systems need to be managed in order to avoid damaging the battery and other parts of the system due to overcharging and excessive discharge with the charge controller. The charge controller also notifies the user as and when the system is not functioning properly.

Battery inverters are advised if the system uses AC power and AC loads. The charge controller is connected between the solar modules and the battery to regulate the charging process.

CHAPTER FIVE

FINANCIAL AND COST ANALYSIS FOR PV-BASED MINI GRID

5.0 Introduction

Financing is one of the key sustainability issues in mini-grid operations. Among the cost associated with the system includes capital cost, operational cost and loan repayments (if loans were taken for the project). Capital cost is the cost incurred in setting up the system. It includes cost associated with planning and design, acquisition of land, PV system, poles and conductors, labour and many others.

Operational cost is cost associated with the operation and maintenance. These costs are necessary to keep the system running. If loans were taken to undertake the project, this cost need to be captured in the cost computations including the interest that the loan will incur.

5.1 Economic Feasibility of the Systems

In order to do a cost-benefit analysis of installing solar panels to power these two sister communities, the Regional branch of Volta River Authority was contacted to ascertain how much it would cost for the community to be connected to the National grid. In addition the bills of the three pilot communities (Bisease, Kwahinkrom, Abukrom) were also obtained from the Volta River Authority. These bills will provide an approximate data on how much the community would have been paying if they were connected to the national grid.

Table 5.1: Material estimate of Hydro power electrification for 500 people population

Item / Activity	Qty	Distance between poles	Unit price (GHC)	Total (GHC)
Low tension poles	80	45 – 60 m	300.00	24,000.00
High tension poles	84	45 – 60m	500.00	42,000
Conductors (LT)	80 spans	16,000m per span	2.00 x 16,000 x 80	42,000.00
Conductors (HT)	210000m	90m pole to pole	5.00 x 300m x 700m	1,050,000.00
Stays	50		60.00 x 50	3,000
Meters (single phase)	60		50.00	3000.00
Meters (3 phase)	3		100.00	300.00
Total				1,164,300

(Source: Volta River Authority)

Screenshot of total estimate of Hydro power electrification for 500 people population

Estimate for Hydro electrification for 500 people population

Section1: System size and cost		
Desired system size:	19,265	Watt
Cost per Watt:	0.4121	Cedis
Cost of Transformer	120,000.00	Cedis
Cost of other Materials	1,164,300.00	Cedis
TOTAL COST:	**1,284,300.00**	Cedis
Section 2: Installation and fees:		
Digging and planting poles:	2,460.00	Cedis
Fixing of lines, conductors etc:	2,500.00	Cedis
Installation of Transformer	255.00	Cedis
TOTAL COST:	5215.00	Cedis
OVERALL SYSTEM COST	**1,289,515.00**	Cedis
Section 3: System life and Maintenance		
System life Expecancy:	25	Years
Annual increment	15	%
Yearly Degradation:	0.5	%
Yearly Maintenance cost:	0.00	Cedis

Figure 5.1: Estimate for hydro electrification

The researcher developed an economic feasibility spreadsheet in Microsoft Excel as described in the Methodology section to aid in feasibility calculations for various scenarios. In the Methodology section we explained how the spreadsheet worked. A screenshot of the spreadsheet can be seen below.

	A	B	C	D
1	**Solar Feasibility Analysis for Mpahin**			
2				
3	**Section1: System size and cost**			
4	Desired system size:	100,000	Watt	
5	Installation Cost per Watt:	12	Cedis	
6	Inverter, battery, controller:	129,000.00	Cedis	
7	Ground mounters	27,500.00	Cedis	
8	Cost of other Materials	78,000.00	Cedis	
9	Solar Panels:	150,000.00	Cedis	
10	**TOTAL COST:**	**384,500.00**	Cedis	
11				
12	**Section 2: Installation and fees:**			
13	Digging and planting poles:	1,500.00	Cedis	
14	Fixing of lines, conductors etc:	5,500.00	Cedis	
15	Installation of Components:	1,200,000.00	Cedis	
16	**TOTAL COST:**	1,207,000.00	Cedis	
17				
18				
19	***OVERALL SYSTEM COST***	**1,591,500.00**	Cedis	
20				
21	**Section 3: System life and Maintenance**			
22	System life Expecancy:	20	years	
23	Yearly Degradation:	0.5	%	
24	Yearly Maintenance cost:		Cedis	
25				
26				
27	**Section 4: Financing**			
28	Down payment:			
29	Loan interest rate:	24	%	
30	Loan period:	20	Years	
31	Monthly Payment:	38461.25		
32	Depreciation	7	%	
33				
34	**Section 5: Analysis**			
35	Annual bill increment rate	8	%	
36	Net present value:	1,591,500.00	Cedis	
37	Monthly cash flow	75002.2	Cedis	
38				

Figure 5.2: Solar feasibility analysis

In the first section of the spreadsheet, “System Size and Cost” the researcher determined the cost per Watt of the solar panels and the cost of the inverter and other equipment. This data comes directly from our list of solar panels and our inverters.

The second section, “Installation and Fees”, describes an estimated cost for installation on a per Watt basis, an estimation of electrical inspection costs, and several other fees. The installation cost per Watt is the largest factor in determining system cost, so it must be estimated with high precision.

Section three titled “System Life and Maintenance” provides an estimation of the system life expectancy, the yearly degradation factor, and the yearly maintenance cost. To use a safe estimate of system life expectancy, we chose twenty years (even though twenty-five years is the typical warranty on solar panels). It could be the case that the system continued to work after twenty-five years; however we would rather use a conservative estimate and analyze the feasibility over the next twenty years. The yearly degradation factor is the percentage that the electricity production is decreased each year, due to several factors such as: packaging material disintegration, adhesional degradation, interconnect loss of integrity, moisture intrusion, and semiconductor device degradation. Unfortunately, an effort to collect data regarding photovoltaic degradation has not been well coordinated. There are, however, two studies that look at degradation on single and multicrystal line photovoltaics. The Sandia study, which was on multicrystal line photovoltaics, reported 0.5% degradation per year. The National Renewable Energy Laboratory reported 0.7% degradation per year on a study they did looking at single and multi-crystalline photovoltaic. The graph below shows what the overall efficiency of a solar panel would be over the course of twenty five years, assuming it started at 13% efficiency.

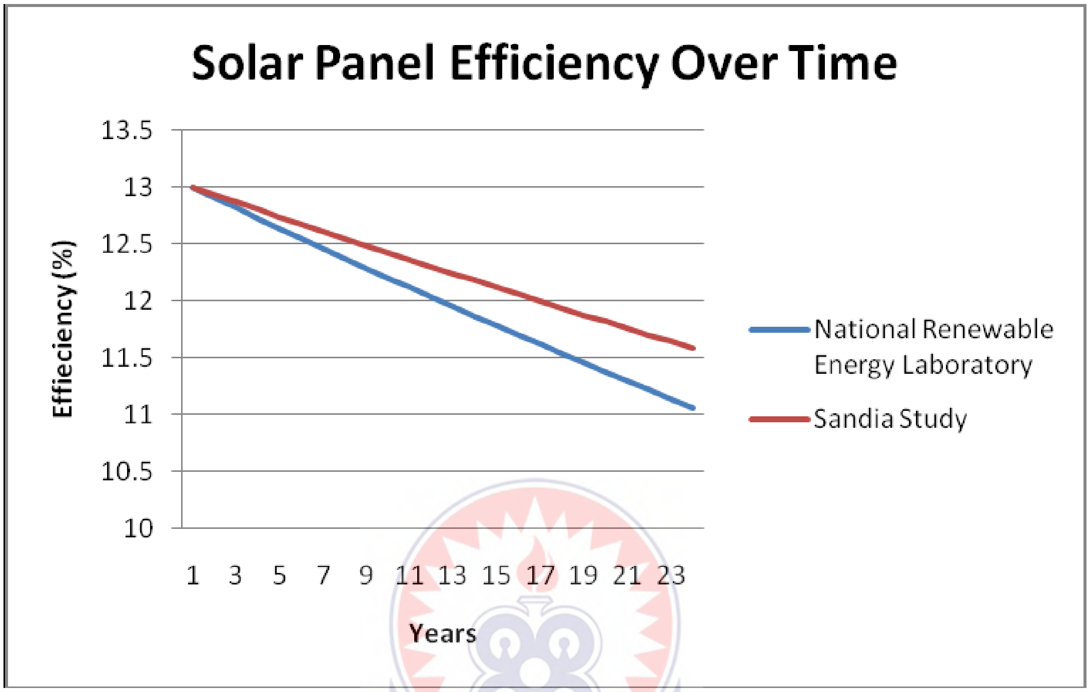


Figure 5.3: Solar panel efficiency

Based on these two studies, we have decided to use the average of their results, and estimate 0.6% annual degradation.

Because solar panels contain no moving parts maintenance costs are found to be extremely minimal. Due to the fact that the lifetime warranties of solar panels are generally found to be twenty years or more, it is unlikely that any maintenance costs will be realized within this time span. The cost of maintaining an array will generally reside in labour, not replacement parts.

Section four, "Financing" allows the option for testing how the feasibility of a system changes by using a loan. This section requires the percentage of the entire loan that the down payment makes up, the interest rate, and the loan term. It assumes that a fixed rate mortgage will be used, and calculates the monthly payment.

The last section, analysis, takes information from the previous sections to compute typical economic values such as net present value, the breakeven point, and cash flow. Net present value is determined by taking these future cash earnings and discounting them by the present value interest factor and then subtracting the initial down payment, as outlined in "ISD Module: Quantitative Methods in Economics." We can determine the break-even point by figuring out when the discounted value of future earnings is equal to the initial investment, in this case the down payment. In many cases throughout this analysis, we used adjustor percentages for different factors. This was so that we could have a more accurate economic model for the dynamic future. Taking these factors into account and having them accurate is important for the overall accuracy of our model as we look forward. The economic values determined in Section 5, Analysis, will essentially determine the economic feasibility of the project. We would not be able to recommend beginning a project that had a negative net present value, a negative cash flow, or an internal rate of return lower than that of a typical savings account.

The analysis also takes into consideration interest, monthly and annual instalments to be paid by the community assuming they go for a loan from a bank. The interest is calculated on the current bank interest rate of 24%.

Table 5.2: Estimated Cost

ITEMS	AMOUNT	UNITS
Interest	7639200	Cedis
Principal	9,230,700.00	Cedis
Monthly installment	38461.25	Cedis
Annual instalment	461535	Cedis
		Cedis
Annual sale	900,026.40	Cedis

The amount to seek the loan for is the overall system cost. This amount is multiplied by the current interest rate to arrive at the interest amount stated in figure above. The principal is the sum of the overall system cost and the interest to be accrued over the loan. This principal is divided by the number of months that will be used to offset the loan to get the monthly instalment. Annual sale is the product of the cost of electricity (current VRA rate of 0.4121 per watt is used) and the rate of charged in a year.

For the payment analysis, the researcher considered three main scenarios. The first is when the community decides to go a full cost loan to undertake the project. In this case, there is no any initial payments and the interest is calculated on the overall system cost. The second scenario is when the community decides to go for a 50% down payment plan. This is when the community pays half of the overall system cost and then go for a loan to recover the remaining amount.

The last scenario is when the community decides to undertake an overall down payment plan. In this case, the community pays off all the overall system cost to undertake the venture. An analysis of the total cash flow verses the number of years that the community can take to offset the loan in the three scenarios is shown in the figure below.

Years	Zero down payment cash flow	50% down payment cash flow	Overall down payment cash flow
1	-8,330,673.60	-3,715,323.60	900,026.40
2	-7,430,647.20	-2,815,297.20	1,800,052.80
3	-6,530,620.80	-1,915,270.80	2,700,079.20
4	-5,630,594.40	-1,015,244.40	3,600,105.60
5	-4,730,568.00	-115,218.00	4,500,132.00
6	-3,830,541.60	784,808.40	5,400,158.40
7	-2,930,515.20	1,684,834.80	6,300,184.80
8	-2,030,488.80	2,584,861.20	7,200,211.20
9	-1,130,462.40	3,484,887.60	8,100,237.60
10	-230,436.00	4,384,914.00	9,000,264.00
11	669,590.40	5,284,940.40	9,900,290.40
12	1,569,616.80	6,184,966.80	10,800,316.80
13	2,469,643.20	7,084,993.20	11,700,343.20
14	3,369,669.60	7,985,019.60	12,600,369.60
15	4,269,696.00	8,885,046.00	13,500,396.00
16	5,169,722.40	9,785,072.40	14,400,422.40
17	6,069,748.80	10,685,098.80	15,300,448.80
18	6,969,775.20	11,585,125.20	16,200,475.20
19	7,869,801.60	12,485,151.60	17,100,501.60
20	8,769,828.00	13,385,178.00	18,000,528.00
21	9,669,854.40	14,285,204.40	18,900,554.40
22	10,569,880.80	15,185,230.80	19,800,580.80
23	11,469,907.20	16,085,257.20	20,700,607.20
24	12,369,933.60	16,985,283.60	21,600,633.60
25	13,269,960.00	17,885,310.00	22,500,660.00

Figure 5.4: Cash flow payment format

For the zero down payment cash flow, the year 1 value is calculated from the principal amount (9,230,700.00) less the annual payment (900,026.040). The value is negative to indicate that it is a debit amount. Subsequent amount for every year is calculated by taking the remaining principal less the annual amount.

For the 50% down payment plan, the community pays half of the principal. Interest is then calculated on the remaining amount. Each year the amount is arrived at by taking the remaining amount less the annual instalment.

For the 100% down payment plan, the community totally offset the overall cost of the system. Any money accrued from the installation therefore becomes a credit for the community.

From the analysis, it can be observed that for a zero percent down payment plan, it will take the community 11 years to totally offset the system cost plus the loan and its interest. The community begins to enjoy a credit thereon and by the 20 years period the community had accrued a total amount of 8,769,828.00 Cedis. This money can be used to undertake other lucrative ventures that develop the community as a whole.

For a 50% down payment plan, the community offsets their loan and its interest in 6 years. The analysis is supported by the graph indicated in fig. 50 below.

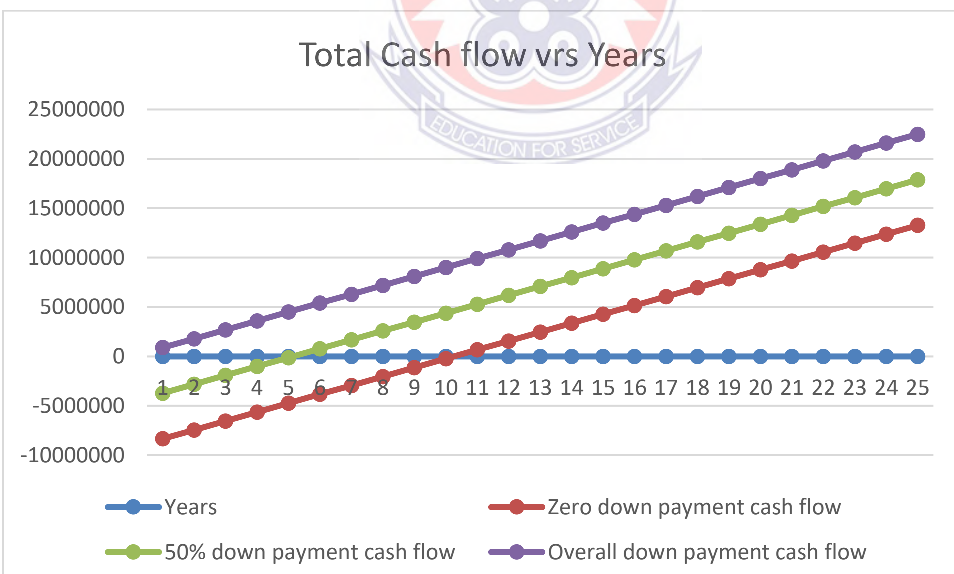


Figure 5.5: Total cash flow verses years

5.2 Social Implications

To answer the research question "What is the overall impact of a Photovoltaic (PV) generated rural electrification project in Mpahin-Ghana, regarding the benefits for the local population and its sustainability?" the researcher assessed the possible social impacts of installing a photovoltaic system on the said community. Current viewpoints on the acceptance of solar panel systems, especially the viewpoints of the community, were important to consider.

Table 5.3: Preferences for energy sources

Source	Frequency	Percentage
Hydro	35	50
Hydro and Solar	20	28.57
Solar	15	21.43

(Source: Field Data)

Table 5.3 indicates that, hydro energy is rated high as the preferred energy. This according to the researcher view is due to the availability of hydro energy in Ghana. The Akosombo and the Bui Dam constitutes more than 80% of the country's energy source. It is therefore not surprise for the inhabitants of Mpahin to rate this energy as against solar as the energy they prefer. Even though much attention and publication has not been given to solar energy, more than 21% of the inhabitants voted for this energy source while 28.57% agreed both in solar and hydro.

Table 5.4: Reasons for Hydro

Reason	Frequency	Percentage
Produces high voltage for many appliances	30	42.86
Readily accessible	23	32.86
Familiar to us	7	10
Environmentally friendly	6	8.57
Very efficient	2	2.86

(Source: Field Data, 2017)

Table 5.4 indicates respondents' view of choosing hydro energy source as their main energy preference over all other sources. About 43% of these respondents voted for this source of energy because they believe it produces high voltage for the many appliances they have. Almost 33% of the respondents preferred this energy source because it is the energy source which is readily accessible to them. Among all views, familiarity of hydro energy source counted for 10% of the sample. This outcome is not surprising per the reason stated earlier by the researcher of the familiarity of solar energy as the main source of energy in Ghana. Respondents are deceived in thinking that only hydro energy can produce the needed voltage to power heavy appliances. This is as a result of respondents awareness of this energy source shaping this mode of thinking. They tend to know more of this energy source and hence are able to give a positive feedback on it.

Table 5.5: Reasons for Solar

Reasons	Frequency	Percentage
Readily accessible	13	18.57
Cheaper	6	8.57
Environmentally friendly	8	11.43
Familiarity	4	5.71

(Source: Field Data, 2017)

Among the total respondents in the community, a little above 18% of them voted for this energy source as their preference energy source because of its availability. About 9% of the total respondents think solar energy is cheaper while a little above 11% thinks it is environmentally friendly.

The first step in this process was discovering what possible social and cultural effects would be witnessed from the installation of a photovoltaic system, as well as the extent of each effect. This is as a result of lack of education on solar energy leading to the inhabitants not having a first-hand information concerning this energy source.

Table 5.6: Social effects

Effect	Frequency	Percentage
Environmental Stewardship	42	16.8
Economic Activities	58	23.2
Impact on education	55	22
Health	45	18
Employment	50	20

In order to measure their views, we created a survey that was oriented towards the community. The survey focused on how members felt about having solar panels installed on their community. It was important to measure how the congregation felt about the installation of solar panels in general. We also wanted to access from this survey if members of the congregation felt that the social benefits of installing such a system could outweigh the economic benefits. That is, we wanted to know if the community would still install a solar panel system if there were limited or no economic incentive to do so.

5.3 Environmental Stewardship

Ghana commissioned this study of green technology as an expression of its commitment towards "environmental stewardship." For that reason, the implementation of a solar array would not only reduce greenhouse emissions, but also spread awareness to the wider community and inspire other community members to follow suit. The sun provides a tremendous resource for generating clean and sustainable electricity without toxic pollution or global warming emissions.

5.4 Economic Implications

Solar energy is not only sustainable, it is renewable and this means that we will never run out of it. It is about as natural a source of power as it is possible to generate electricity. Energy from the sun provide consistent and steady source of solar power throughout the year. This feature will boost up economic activities of the community. With the current stake of power outages, businesses are collapsing hence the need for a reliable source of energy. Energy is needed for many economic activities and the community belief this will raise the financial status of the community and help eradicate abject poverty.

5.5 Post Installation Safety

Proper care and maintenance is necessary after installation of the PV system for system durability and sustainability. So therefore some post system installation measures should be practice in order to sustain the system.

5.5.1 Starting Up the System

- Good to start system if there is no load connected because overcurrent can damage equipment.
- Inspect system before starting up.
- Check system grounding before start up.

5.5.2 Shutting down the system

- Photovoltaic modules are energized when exposed to light and therefore can produce an electrical shock therefore system modules should be covered with an opaque material to prevent electricity from being generated while disconnecting conductors.
- Disconnect all components of the system from power source.
- When disconnecting wires connected to a module that is exposed to sunlight, an electric arc may occur. Arcs can cause burns, start fires or otherwise create safety problems. Therefore exercise caution when disconnecting wiring on modules exposed to sunlight.

5.6 Cleaning Modules

- Do not sit, stand or step on module when cleaning. The glass surface may break resulting in bodily injury or stop the module from functioning.
- The top surface and outside of battery should be cleaned and the terminals greased and cleaned as this will decrease self-discharge rate of the battery.
- Do not use any chemical or detergent to clean modules just water and sponge or soft cloth in the cool of the day.

Figure 5.6: No one should sit or stand on module (source: JA solar)

5.7 Maintenance

5.7.1 Maintenance of Solar Array

- Clean modules regularly as required
- Check array structure for loose mounting connections
- Check inter-module cables and other cables for mechanical damage
- Check total array output voltage and current and compare to what would be expected under the existing conditions

5.7.2 Maintenance of Batteries

- Check electrolyte level at least once a month to ensure that it is above the plates in all cells. If it is below the plates, add distilled water to the level recommended by manufacturer
- Measure the Specific Gravity (SG) using a hydrometer under no-load. The working range of SG lies between 1.1 and 1.3; if below 1.1 hydrated plates can damage the batteries, and above 1.3 plates and grids are likely to be corroded. The SG of the electrolyte of a fully charged battery is between 1.215 and 1.28. Add distilled water to keep Specific Gravity levels within manufacturer's technical specifications.
- Charge the batteries to full capacity at least every 2 weeks. This reduces internal corrosion and degradation and helps to ensure equalization

5.8 Troubleshooting and Fault Finding

It should be appreciated that troubleshooting and fault finding are very practical skills which cannot be elaborated in written material alone. This chapter presents guidelines and some pointers that may be of assistance. The factors contributing to the development of these skills are:

- A thorough understanding of how the components work individually, and how the system, including interaction with the user, work as a whole.
- Training by the manufacturers on the individual components.
- On-the-job experience.
- Using common sense, logic and intuition to determine what might be happening with the system.

5.8.1Troubleshooting the whole system

In general the customer will complain that they do not have any power at all. This could have resulted from:

- Failure of any one (or more) particular item
- Failure of the interconnection wiring between the system components.
- The users using more power than the system was originally designed for.

In general it is good practice to develop a troubleshooting flow chart, incorporating all of the elements listed in this Unit, plus any details specific to the particular equipment used. This must identify the tasks that the user can safely perform, as well as work that must be performed by suitably qualified personnel.

It is recommended that the system maintainer undertakes individual training on the various items and therefore becomes very familiar with the equipment to be able to offer the operator excellent service when faults occur. The following sections give details on faults, possible causes and steps to follow:

5.9 Solar Array Fault Finding

Table 5.7 summarizes the fault finding procedure for the solar array.

Table 5.7: Solar array fault finding

Faults	Possible reasons	Steps to follow
Solar array not producing same current under similar light conditions as it was in the past causing low state-of-charge	Modules might be shaded by overgrown trees, new structures etc.	Look for shade over the modules between 8 a.m. to 4 p.m.
	Modules might be covered in dirt, bird droppings or are	Look for dirt, bird droppings etc. on the modules and wash
	A loose connection in the wiring system or a hot joint has occurred causing cable to	Check the combiner box and junction box for any loose wires
	Diodes have failed in some modules	Measure voltage across modules and replace faulty ones with new ones
	Regulator is faulty	Check the operation of the regulator and have it fixed or replaced

5.10 Charge Controller/Regulator Fault Finding

Many of the regulators that are available today are microprocessor controlled and can require extensive programming on commissioning. It is critical that any installer or maintainer of systems is completely familiar with the regulator they have installed or are testing.

CHAPTER SIX

SUMMARY, CONCLUSION, AND RECOMMENDATIONS

6.1 Summary

The switch to alternative energy sources to power electricity has become much more common in today's society, especially through solar energy. The installation of solar panels is advertised throughout Ghana and other countries.

PV-based mini-grid can contribute to increasing access to modern energy services for rural communities. This manual provides a step-by-step guide for the planning, the design, installation, operation and maintenance, testing and commissioning of PV-based mini-grid systems. The manual also incorporated some safety issues as well as financial analysis. It strongly recommended the use of local materials as much as possible for setting up any PV based mini-grid.

The purpose of this project was to determine if applying solar to Mpahin was going to prove cost-beneficial or detrimental. Through the analysis of the community's electricity expenditure, a spread sheet was set up to determine the net present value (NPV) and internal rate of return (IRR), which are major indicators of whether or not a project is beneficial.

The total cost of the solar panels is GH¢ **1, 591,500.00** and by year 11 the community will return to operating with a positive cash flow. This shows that the investment is financially positive and that switching to solar will be cost-beneficial.

6.2 Conclusions

The benefits of solar panel installations are numerous, ranging from green stewardship to reducing the community's monthly electricity bills. The feasibility of such a system is not determined by a financial analysis alone. Based on current prices, a solar panel system installed at Mpahin would have a ten-year payback period. We recommend that the community strongly weigh the positive impacts of solar panels alongside the economic feasibility of installation. With the present conditions, it is unlikely that a solar panel installation will lose money over the lifetime of the system; however, it requires a large capital investment. The community should monitor in the future the economic conditions using the "Simplified Economics Spreadsheet" that we have provided to get an estimate of economic feasibility of a solar power system. When it is determined that the benefits from a solar panel installation outweigh its drawbacks, such as when the cost per watt drops below a threshold price, the community should follow the procedure outlined below:

1. Form a committee of people who are interested in seeing this project carried forward.
2. Have the committee hold meetings/focus groups with interested members of the congregation to educate the congregation about solar panels and answer any concerns. The committee can use our presentation, brochure, and any of the other materials in this report.
3. Have the committee members contact three to five installers and go through the bidding process as we have outlined.

4. Use the graph "Simplified Economics Spreadsheet" with current data to determine the financial feasibility of this system.
5. After estimates have been received, the selection process can begin. After choosing an installer, the rest of the process, such as fulfilling permit obligations will be handed by the chosen installer. Hopefully, as solar panel technology continues to drop in price, the community will be able to reap the benefits of clean, renewable energy.

6.3 Recommendations

In order to promote solar PV in rural communities in Ghana and at the same time set an example for other developing countries to follow especially in West Africa the following recommendations made are that:

The systems will not always be free of shadows during parts of the day. Care should therefore be taken when selecting the number of modules in a string because the shadow could result in the maximum power point voltage at high temperatures being below the minimum operating voltage of the inverter.

Based on the results of this study, through various algorithms, such as practical steps of designing, calculation steps, diagrammatic steps and others, it is imperative that Mpahin invest in solar panels so as to attract the Youth to take to viable economic activities in order to halt them drift for greener pasture elsewhere.

Furthermore, implementing such projects is not without possible risks e.g. legal, regulatory, governance, institutional, commercial, technical, organizational, design, and implementation. Studies from other parts of the world can provide useful insights on minimizing the risks involved in such projects. The following recommendations are hereby made:

- Government should create support mechanisms to support private sector investment in mini-grid based off-grid electrification programmes using PV systems.
- A legal and regulatory framework that encourages private sector participation in ensuring access to electricity in rural areas should be introduced.
- If rural electrification has been proven to promote rural economic development, then, the demand of electricity from the rural community may eventually increase. Therefore, the result of insufficiency should be avoided by considering some level of flexibility and moderation that will cater for future extension of the system to meet growth and demand at a reduced cost.
- Rural electrification projects come with no specific standard. The local characteristics have a major influence on every project for a particular rural community for the implementation of the project. Choosing a suitable technology should be based on the assessment of mini-grid PV available.
- Government should not politicize rural electrification as it has dire consequences of not being implemented when Government changes, rather there should be a system in place that will allow the reviewing of MINI-GRID policy from time to time, updated periodically and implemented.

- The sector should have a method in place that will ensure responsibility of operation and maintenance of rural electrification projects supported by government. It should not limit electricity supply to residential application but rather promote rural development.

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