DESIGN OF A STANDALONE SOLAR POWER SYSTEM FOR FOUR OFFICES IN ELECTRICAL/ELECTRONIC DEPARTMENT

BY

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A PROJECT SUBMITTED TO THE DEPARTMENT OF ELECTRICAL/ELECTRONIC ENGINEERING, FACULTY OF ENGINEERING, UNIVERSITY OF BENIN, BENIN CITY.

IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF BACHELOR OF ENGINEERING (B.ENG) DEGREE.

JULY, 2021.

CERTIFICATION

This is to certify this project was carried out by **ISRAEL AZEKHUORIA** with matriculation number: **ENG1503794,** for the reward of Bachelor of engineering in Electrical/Electronic Engineering, University of Benin, Benin city, under my supervision.

__________________ _________________

Engr. N. S. Idiagi **Date**

Project Supervisor

______________________ __________________

Prof. (Mrs.) P.E Orukpe **Date**

Head of Department

DEDICATION

This project work is dedicated to God Almighty for his strength and Inspiration bestowed on me in completing this work. This work is also dedicated to my parents, Mr. and Mrs. Azekhuoria and my siblings for their love and support towards the pursuit of academic excellence.

To my project Supervisor, who guided and directed me throughout the project duration and lastly to my project members for the immerse and unrelenting effort made to ensure this project was a successful one despite the challenges and the distancing pose to us during this covid-19 period.

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I owe a lot to my project supervisor Engr. N.S Idiagi, who sought make my project worthwhile. I am thankful for your guidance a Fatherly support. My appreciation also goes to my parents for giving enthusiasm, encouragement and assistance, to ensure that I accomplish this work.

My sincere appreciation to my Head of Department, Prof Mrs P. Orukpe, and will also like to thank Prof Igbinovia, Prof S. Ike, Engr. N. Bello, Engr. J.J Onwah, Engr. E. Uwuigbe, Engr. Prophet Aikhoje, Engr. A. Dauda, Engr. G. O. Imhabekhai and other academic staff for imparting in me the knowledge and wisdom needed in making my academic experience highly educating.

This acknowledgement will not be complete without herein my deepest gratitude to Almighty God Who in His great mercy sustains me.

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ABBREVATIONS

SAPS	-	Stand Alone Power systems
MPPT	-	Maximum Power Point Tracker
AC	-	Alternating Current
DC	-	Direct Current
PV	-	Photo Voltaic
SPV	-	Solar Photo Voltaic
Ah	-	Ampere – Hooves
MW	-	Mega – Watts
NERC	-	Nigerian Electricity Regulatory Commission
DISCOs	-	Distribution Companies
IMF	-	International Monetary Fund
EEE	-	Electrical/Electronic Engineering
DIMNSP	-	Design and Installation Manual, New society Publishers

ABSTRACT

The amount of sunlight that strikes the earth’s surface in an hour and a half is enough to handle the entire world’s energy consumption for a full year. Solar Power Technology is one of the major types of green and renewable energy. They are used to convert sunlight into electrical energy either through photovoltaic (PV) panels or through mirrors that concentrate solar radiation. This energy can be used to generate electricity or be stored in batteries or thermal storage. This project is titled “The Design of a Standalone Solar Power System for Four Offices in Electrical/Electronic Department”. The project aims to design and install a Standalone Solar system to provide power supply for the critical loads present in four offices in Electrical/Electronic department, University of Benin.

The methodology employed in this project was to calculate and estimate the electrical loads and critical loads in the four offices in Electrical/Electronic department, the sizing and installation of solar panels, batteries, inverter and charge controller, and lastly the test results and maintenance procedures carried out after the installation.

This PV system consist of 3.5KVA 220V inverter at 50Hz which incorporates 14 300W-Solar panels all connected in parallel, 2 deep cycle batteries rated 200Ah, 12V connected in series and a 12V 200Amps charge controller. The system was designed to assess the total electric power demand. During the day the output from the PV charges the batteries and feed the load and when power failure occurs from the grid, the stored energy in the battery is again supplied back to the load in order to ensure there is always availability of power in the office.

CHAPTER ONE

INTRODUCTION

1.1 Background of Study

Electricity is one of the major frontiers of a country development; it is an essential part of modern life and important to any country economy. It plays a major role on every aspect of our socio-economic life. It is used in residential buildings, commercial buildings, and industrial buildings. The essence of electricity generation is for its utilization for the benefit of mankind (Ogbimi et al, 2015). The increase in electric energy demand has a linear relationship with the increase in population, urbanization and industrialization. An emerging means of generating electricity is through the solar photovoltaic cells installation, not much research and development have been carried out on it and associated devices (Adeyemo, 2013).

Solar panels are a form of photoelectric or thermoelectric processes of conversion of solar energy directly to electrical energy. A solar panel generates electricity using the photovoltaic effect, a phenomenon discovered in 1839 when Edmond Becquerel, a French physicist, observed that certain materials produced an electric current when exposed to light. Solar panels impact in power generation and in residential architecture has not been too encouraging in Nigeria. This may be due to the awareness, cost and technology (Aminu, 2011). A large number of Nigerians are unaware that the solar PV can power a whole building and not limited to street light with which they are conversant. The inadequate and unreliability of power is a daily experience in Nigeria. It has crippled the agricultural, industrial, educational and mining sectors and impedes Nigeria's ongoing economic development. It also costs the country an enormous amount of money in providing reliable alternatives for utilization which includes; generators, stand-alone solar power, etc.

The Nigeria energy supply crisis causes the ongoing failure of the Nigeria power sector to provide adequate electricity supply to domestic households and industrial producers despite a rapidly growing economy. Currently, Nigeria with over 200millions population, only 40% of Nigeria's population is connected to the energy grid whilst power supply difficulties are experienced around 60% of the time (Aliyu, 2013). The average daily power supply is estimated at three hours (PWC, 2016), although several days can go by without any power supply at all. Power cuts or restoration are neither announced, leading to calls for a load shedding schedule during the COVID-19 lockdowns to aid fair distribution and predictability (Oguguo, 2020). According to Ohunakin et al (2013), variability and intermittency of radiation, lack of awareness and information, high initial investment cost, grid unreliability, operation & maintenance cost, government policy & incentives, ineffective quality control of products, insecurity of solar plant infrastructure and competition with land use are some of the challenges facing the utilization of solar energy system in Nigeria. Awogbemi et al. (2011) evaluated solar energy, hydropower and wind energy which are the major renewable energy sources in Nigeria and opined that major constraints to the expansion of solar utilization in Nigeria are cost, unfriendly government policy, solar technologies are not manufactured locally. Low level of public awareness, financial constraint, the high cost of energy infrastructure and technological incapability were listed by Akinbami (2001) in a study of renewable energy resources and technologies in Nigeria.

Solar panels or, more accurately, photovoltaic solar panels generate electricity from the sun. Ninety-three million miles from Earth, our sun is 333,000 times the size of our planet. With a diameter of 865,000 miles, a surface temperature of 5,600°C (over 10,000°F) and a core temperature of 15,000,000°C, it is a huge mass of constant nuclear activity. Directly or indirectly, our sun provides all the power we need to exist and supports all life forms. The sun drives our climate and our weather. It's a huge energy source. The amount of solar energy the Earth receives on a sunny day is capable of generating around 200,000 times the total daily amount of energy required to power our planet. The abundance of solar energy is only limited by the methods of collection, storage and conversion into heat and electrical energy. This, however, is slowly becoming more and more accessible as solar power technology advances and costs steadily go down.

In order to increase the energy production in Nigeria, government should invest in Solar Power. With the large amount of insolation coming from the sun, the Nigeria Government can help in the mass production of solar plants and the distribution of solar system for households and businesses. The solar power system can help in electrifying 5millions households and which can be a great way of increasing the energy supply in the country.

1.2 Statement of Problem

The problem we wish to solve with this project is the inadequate and unreliability of power system in the University of Benin, Benin City, Nigeria. The inadequate supply of power has become a daily experience in the lives of every Nigerians. This great power crisis has been identified as a major obstacle to all sectors of the country and slowing the economic development of the country. The country's epileptic power supply has become a hindrance in large and small Scale Businesses across the country and even in academic activities in the country. Lack of access to reliable power supply have cost Nigeria enormous estimated amount of $29 billion a year (Samuel Ayokunle, 2019).

1.3 Aim

The aim of this project is to design a Standalone Solar Power System for powering four offices in Electrical/Electronic Engineering Department.

1.4 Objectives

The following are the objectives of this project. The design will include;

I. To identify all the loads in the four offices in Electrical/Electronic Departmental Building.

II. To calculate and estimate the electrical loads in the four offices in Electrical/Electronic Department.

III. To calculate and estimate the critical loads in the four offices in Electrical/Electronic Department.

IV. Sizing of the solar panel, battery and inverter required in the department.

V. To design for Solar PV.

1.5 Methodology

The design and installation will be undertaken at the four offices in Electrical/Electronic department where extensive literature review was carried out for the solar power system.

a. The calculations and estimation of the electrical loads in the four offices in Electrical/Electronic department will be carried out
b. The calculation of the essential or critical load will be taken note of.
c. Sizing of the solar panels, battery and inverter will be done by determining the required daily average energy demand for the critical or essential load needed.
d. The design of the charge controller will be carried out
e. Installation of the solar panel, battery and inverter will be carried out.
f. Testing and maintenance procedures will be done after the installation.

1.6 Scope of Work

This project involves designing of solar PV powered energy for powering four offices in electrical/electronic engineering department. This work will provide solar PV unit that will power the following electrical appliances such as fans, electric bulbs, computers, coffee makers, sockets and electrical extensions, etc. During the day the batteries are charged by the energy from the sun through the solar PV panels through the charge controller. The stored energy in the batteries which are in DC form is converted in to the AC form that is required to power the electrical appliances in the electrical department.

1.7 Relevance of the Work

The importance of this work cannot be overemphasized, the following relevance are listed below;

a. To Curb the problem unavailability of power supply

b. To increase efficiency in energy consumption

CHAPTER TWO

LITERATURE REVIEWS

The literature review is an overview of the previous work that has been conducted and published on this topic. It comprises theories, developments, and components from journals, textbooks and other relevant materials that form the basis for the design and construction of Stand Alone PV systems. The basics working principles and its Characteristics operations will be discussed.

2.1 Principles of Solar Power Supply System

Renewable energy is a phrase that is loosely used to describe any form of electric energy generated from resources other than fossil and nuclear fuels. Renewable energy resources include hydropower, wind, solar, wave and tide, geothermal and hydrogen. The Sun is the source of all those renewable energies with exception of geothermal and tidal energy. These resources produce much less pollution than burning fossil fuels and are constantly replenished and thus called renewable. The Sun is the primary source of energy in solar systems; the earth receives 90 % of its total energy from the Sun.

Photovoltaics offer consumers the ability to generate electricity in a clean, quiet and reliable way. Photovoltaic systems are comprised of photovoltaic cells, devices that convert light energy directly into electricity. Because the source of light is usually the Sun and are often called solar cells. The word photovoltaic comes from "photo," meaning light, and "voltaic," which refers to producing electricity. Therefore, the photovoltaic process is "producing electricity directly from sunlight." Photovoltaics are often referred to as PV. For some applications where small amounts of electricity are required like emergency call boxes, PV systems are often cost justified even when grid electricity is not very far away. When applications require larger amounts of electricity and are located away from existing power lines, photovoltaic systems can in many cases offer the least expensive, most viable option. In use today on street lights, gate openers and other low power tasks, photovoltaics are gaining popularity in Nigeria and around the world as their price declines and efficiency increases.

A Stand-Alone Electric Solar System (ESS) does not have a connection to the electricity "mains" ("grid"). ESS varies widely in size and application from wristwatches or calculators to remote buildings or spacecraft. If the load is to be supplied independently of solar insulation, the generated power is stored and buffered with a battery. In non-portable applications where weight is not an issue, such as in buildings, lead acid batteries are most commonly used for their low cost. A charge controller may be incorporated in the system to avoid battery damage by excessive charging or discharging and 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. In domestic applications, the most relevant technology for stand-alone operation is a conventional battery system (as commonly used with PV systems), although flywheel storage may have a role as products become cheaper. However, in general, it may be assumed that, for grid-parallel operation, the grid itself is the "battery" as regards mass electrical storage, some home owners in the world are turning to PV as a clean and reliable energy source even though it is often more expensive than power available from their electric utility. These home owners can supplement their energy needs with electricity from their local utility when their PV system is not supplying enough energy (at nighttime and on cloudy days) and can export excessive electricity back to their local utility when their PV system is generating more energy than is needed. For locations that are "off the grid" meaning they are far from, or do not use, existing power lines PV systems can be used to power water pumps, electric fences or even an entire household. While PV systems may require a substantial investment, it can be cheaper than paying the costs associated with extending the electric utility grid. Power systems are most often used to power DC appliances in boats and cabins, as well as farm ranch appliances like cattle gates and rural telecommunications systems when utility power is not accessible. DC solar power is less expensive than AC solar power because an inverter is not required to convert the electricity produced by solar panels and stored in batteries from DC to AC. While AC off-grid solar power systems are more expensive because of the cost of the inverter. The addition of an inverter allows this system to convert DC electrical current coming from the batteries into AC or alternating current, AC is the standard form of electricity for anything that "plugs in" to utility power and is the appropriate current for common household appliances. There are many advantages of ESS. Among the advantages are suitable for location where connection to the grid is too expensive or not possible, uninterrupted power protection from power cuts and the ability to power independently in all conditions, reduction in energy bills and maximize the use of alternative energy, uses green alternatives alongside traditional options (eco-friendly) and the last advantage is adaptable and expandable to changing living and business uses. Therefore, the purpose of this project is to study the reliability a factor of the Stand-Alone Electric Solar System (ESS) applies for a domestic house without utility supply.

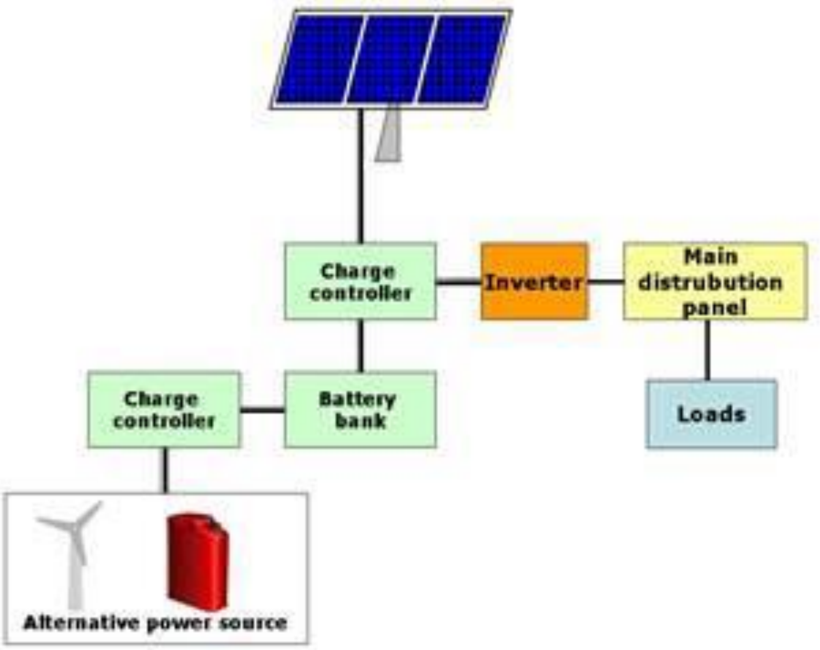


Figure 2.1 A block diagram of a grid type PV system

2.2 Reviews of Similar Work on Solar Power System

Kai Kappner (2011), did a study that shows the feed-in tariff engineering and economic benefits of photovoltaic system for residential sector in Malaysia. It will be implemented in the year 2011 in accordance with the Tenth Malaysian Plan under the New Renewable Energy Policy. With the Feed in Tariff, firstly, need to apply for an account. Second, a renewable energy generator installed such as wind turbine or solar photovoltaic (PV) system. The renewable energy generator is installed together with a special two net metering system in our home.

David Bollinger (2007) carried out a study about applications of solar energy to power stand-alone area and street lighting. One of the earliest studies was conducted by the Parks and Recreation Department of Albuquerque, New Mexico. The design of the system used two 50W photovoltaic panels with a 35W low pressure sodium lamp. The stand-alone systems were designed to last for six hours a night and used a boost converter due to the design of a working maximum power point tracker was still in the development stage. The results of the study showed the potential of using solar energy to power street lights, and built the groundwork for future designs. Isolated parts of the world are ideal places to study the abilities of stand-alone lighting systems due to the lack of electricity to those regions.

Ge, et al. (2008) Previous researches are available on how to construct alternative energy systems, combine them into the traditional power grid, and how to size the storage volume or the energy source capacity to meet the loads' needs. The impact of the alternative energy on the traditional power grid is also examined in order to improve systems' stability, but most of the design rules are based on the "meeting the need" strategy, not based on the reliability. There are also some results available, for reliability evaluation of alternative energy systems, these papers, wind, photovoltaic, or their hybrid system were evaluated, to calculate the reliability indices at the generation and transmission level. These indices are very useful for the planning and operation. However, these studies are based on high level performance studies, and do not give a clear guide on how to improve the system's reliability during design phase.

Jasvir Singh (2010). This study about Study and Design of Grid Connected Solar Photovoltaic System. These systems are connected to a broader electricity network. The PV system is connected to the utility grid using a high quality inverter, which converts DC power from the solar array into AC power that conforms to the grids electrical requirements. During the day, the solar electricity generated by the system is either used immediately or sold off to electricity supply companies. In the evening, when the system is unable to supply immediate power, electricity can be bought back from the network. From the previous study that have been done by the several researches, it can be concluded that the solar system is the main alternative source of concern from various parties. This can be seen from this that a lot of research before making the study of photovoltaic systems. In addition, demand for electricity from TNB is increasing. Lack of resources and higher prices require further research on the reliability of the ESS as a backup power supply or the mains supply, replace the existing systems for the domestic sector in Malaysia.

Hussein Kazem (2013) presented an optimal sizing design method for a standalone PV system in remote areas in Sohar – Oman. The proposed model in term of low cost and good performance look to find PV tilt angle and size of the system. Hourly measured meteorological data and load demand has been simulated by MATLAB where Numerical methods used in optimization. The optimization used to find the PV tilt angle and size, also the storage battery capacity was implemented, the results show that must be adjusted twice a year. The average daily load demand is 6.13 kWh daily, with a peak power of 520 W and the cost of the energy of 0.196 USD/kWh.

Souissi et al. (2010) planned an optimization solution of a renewable energy hybrid system through Homer software for Tunisian rural areas. The Hybrid systems considers combination of different energy sources like PV/battery, wind/battery, wind/PV /diesel/battery, wind/PV/battery, etc. Specific climatic data Hawaria area in Tunisia was used as input. To satisfy load demand renewable energy may have interruption and so the diesel generator combined with a wind PV-battery hybrid system where it is used as auxiliary source to ensure a more reliable supply without interruption. The optimal configuration for the reliable load supply hybrid system (wind/PV/diesel/battery) that considered the Review and design of a standalone PV system performance Ali et al. (2010) meteorological data changes is deduced from two selected optimal configurations: (diesel/battery) and (wind/PV/battery). The optimal configuration for the wind/PV/battery system is composed of 8 kW PV panel, 2 wind turbines, 118 batteries & 12 kW power converters. The total Net Present Cost (NPC) is USD 189.559 and the cost of energy produced is USD 0.540 per kWh. The optimal configuration for the diesel / battery is composed of 5 kW diesel generator, 18 batteries and 2 kW power converters. It's total NPC is USD134.747, its cost energy produced is USD 0.382 per kWh and the diesel 11.269 L. For the wind/PV/diesel generator/battery with load of 85 kWh/d the optimal configuration is consists of 8 kW panel PV, 2 wind turbines, 118 batteries, 5 kW diesel generators & 12 kW power converters. After having determined the optimal configuration of the hybrid wind-PV-battery system in terms of reliability and economy, authors showed the effect of the climatic change on the reliable supply of the load and proved that the diesel generator, as buck-up source, with the hybrid wind/PV/battery system combination is a great solution to a reliable supply without interruption of the load under the climatic data change.

Zeinab et al. (2012) discussed a sustainable renewable energy efficient system used for domestic demand in Khartoum, Sudan. The proposed technique relied on the collection of wind speed, basic solar radiation and other required input data, then Homer software used to design a hybrid optimization simulation model. The proposed model had a load of 54 kWh per day, and 5.3 kW as its peak. The cost of the PV module including installation has been considered as 220 SP/W for Sudan. The optimum system found to be wind/PV combination for 50 homes instead of single home system moreover, based on the conducted analysis the project's life time has been measured to be 25 years, while the annual real interest rate is chosen at 4%. The load consumed by the users is of low maintenance and operation cost, the author claimed that the system has been planned for single and multiple home users like 10 to 25. For optimization software HOMER has been used in designs and evaluating of both grid-connected and off-grid power systems for a range of applications.

Ajao et al. (2011) investigated the hybrid/solar power generation cost benefit relative to use in Nigeria. The wind/solar hybrid system cost benefit analysis has been done through Homer software and compared with utility supply. The national grid power is the least luxurious option but, it may not be available rural area. Hence renewable energy sources could be the best option for rural area. The author claimed that best system used has 0.05–0.4 kW PV array with 0.4 kW DC FD series wind turbine, (0.1 – 1.5 kW) converter, and (200 Ah / 12 V, bank size: 1-8 batteries, vision 6 FM200D) battery. HOMER's result gave a total NPC of USD 4251 and a Cost of Energy (CoE) of USD1.74 per. Singhal and Singh [6] suggested a renewable energy based alternative to diesel generators for electricity supply using Neil Island in Andaman Island (India) as a case study. In their work they considered power supply for 6 hours in the evening and the study evaluates the feasibility of an alternative, without reporting a real-life diesel-generation replacement case.

Dorji et al. (2013) used Homer energy software to analyze the possible options for electrification of a few of remote settlements in the Kingdom of Bhutan, a small neighboring country of India. A harsh mountainous terrain with many settlements scattered all over the place makes a grid connection impossible in most of the cases. In the work, they considered energy needs of households, available renewable resources and current policies and programs on rural electrification. The study revealed that renewable technologies such as wind-battery or PV-battery can be considered as alternatives to grid connections. The study also shows that the most economical approach differs from site to site. Chakrabarti and Chakrabarty presented the analysis of solar PV for an island in Sagar Dweep, India.

In the work, they considered PV and grid extensions as alternative systems and evaluated the options from economic and environmental perspectives. The work shows that grid extension over long distances is not cost-effective.

Sen and Bhattacharyya presented Off grid electricity generation with renewable energy technologies in India using HOMER software. In their work, they stressed on the importance of providing reliable and cost-effective electricity to about 1.3 billion people who live without electricity. They emphasize that in many cases extension of the main grid to the area is difficult, thereby recommending off grid electrification as an alternative. They also recommended the use of multiple sources of energy to provide adequate energy to the customers. Analysis of various system configurations and orientations of grid-connected PV systems was performed.

The authors presented a paper on grid-connected PV systems for residential houses with energy storage, and studied the relation between storage size and energy flow to the grid in Belgium. Anagreh et al. (2009) presented an investigation of the solar energy potential for seven sites in Jordan and concluded that Jordan has a great solar energy potential which motivates the utilization of stand-alone or grid-connected solar energy systems. A study of a grid-connected PV system in Hong Kong was presented. Most of these studies from the literature are hypothetical in nature, they involved interconnection of solar PV and grid supply using net meter for selling excess to the grid or buying deficit from the grid. This practice of interconnection of grid and PV still remains impracticable in most of the countries due to unreliability and complexity of the main grid. There is no study that has considered supplying the essential load (light loads) which may be continuous with solar photovoltaic and heavy load which may be discontinuous with the mains grid so as to overcome the challenges of high initial capital cost in harnessing solar energy for electric power generation. This paper tries to explore this knowledge so as to encourage the use of renewable energy (solar energy) especially in the office building and also to encourage the general public to go for solar power plant as a cost effective and economical system even without the incentives.

2.3 Principal Components of the System

2.3.1 Solar Panel

Solar panel is used colloquially for photovoltaic (PV) module. A PV module is an assembly of photo-voltaic cells mounted in a framework for installation. Photovoltaic cells use sunlight as a source of energy and generate direct current electricity. A collection of PV modules is called a PV Panel and a system of panels is an Array. Arrays of a photovoltaic system supply solar electricity to electrical equipment. Photovoltaic modules use light energy (photons) from the sun electricity through the photovoltaic effect. Most modules use wafer-based crystalline silicon cells or thin-film cells. The structural (load carrying) member of a module can be either the top layer or the back layer. Cells must be protected from mechanical damage and moisture.

Most solar panels are made up of individual solar cells, connected together. The cells are connected electrically in series one to another to the desired voltage and then in parallel to increase amperage. The wattage of the module is the mathematical product of the voltage and the amperage of the module. A typical solar cell will only produce around half a volt, so by connecting them together in series inside the panel, a more useful voltage is achieved. Most small solar panels – rated 150Wp or below – are rated as 12-volt solar panels, whilst larger solar panels are 24-volt panels. A 12-volt solar panel produces around 14–18 volts when put under load. This allows a single solar panel to charge up a 12volt battery. Incidentally, if you connect a voltmeter up to a solar panel when it is not under load, you may well see voltage readings of up to 26 volts. This is normal in an 'open circuit' on a solar panel. As soon as you connect the solar panel into a circuit, this voltage level will drop to around 14–18 volts. Solar panels can be linked together to create a solar array. Connecting multiple panels together allows you to produce a higher current or to run at a higher voltage: Connecting panels in series makes an array run at higher voltages. Typically, 12, 24 or 48 volts in a stand-alone system, several hundred volts in a grid-tie system connecting the panels in parallel allows a solar array to produce more power while maintaining the same voltage as the individual panels. When you connect multiple panels together, the power of the overall system increases, irrespective of whether they are connected in series or in parallel; In a solar array where the solar panels are connected in series, you add the voltages of each panel together and add the wattage of each panel together to calculate the maximum amount of power and voltage the solar array will generate.

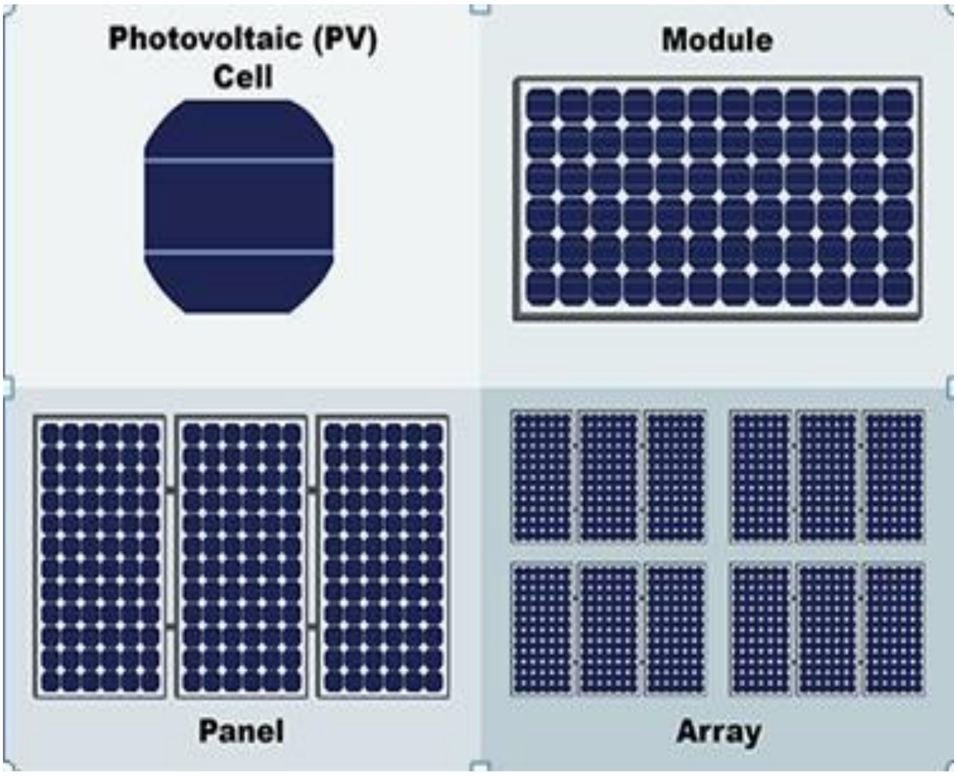


Figure 2.2: A relationship between solar cell, module and array

2.3.1.1 Types of Solar Panels

There are three types of solar panels and each one has its unique way and has a different aesthetic appearance.

2.3.1.1.1 Monocrystalline Solar Cells

Monocrystalline solar panels are the oldest type of solar panel and the most developed. The monocrystalline solar cells are also known as single crystalline cells. These solar panels are made up from about 40 of monocrystalline solar cells. These solar cells are made from pure silicon, which makes them the most efficient material for the conversion of sunlight into energy (Ana et al. 2014).

In the manufacturing process (called the Czochraliski method), a silicon crystal is placed in a vat of molten silicon. The crystal is then pulled out of the vat very slowly, allowing for the molten silicon to form a solid crystal shell around it called an ingot. The ingot is then sliced thinly into silicon wafers. The wafer is made into the cell and then the cells are assembled together to form a solar panel.

Monocrystalline cells are also the most space-efficient form of silicon solar cell. They also have the advantage of being the ones that last the longest out of all the silicon-based solar cells. In fact, many manufacturers will offer warranties of up to 25 years on this type of system – a warranty that lasts half of their expected life (Abdelkader et al. 2014).

Monocrystalline solar cells appear black because of the way sunlight interacts with pure silicon. While the cells black, there’s a variety of colors and designs for the back sheets and frames. The monocrystalline cells are shaped like a square with the corners removed, so there are small gaps between the cells. Monocrystalline cells are the most expensive option out of all of the silicon solar cell types, mostly because the four-sided cutting system results in a large amount of waste and they have a high power output, occupy less space, and last the longest. Below are some of the advantages of monocrystalline solar cells;

- They have the highest level of efficiency at 15-20%
- They require less space compared to other types due to their high efficiency
- Manufacturers state that this form of solar cell lasts the longest, with most giving them a 25-year warranty.
- They perform better in low levels of sunlight, making them ideal for cloudy areas

Here are some of the disadvantages to monocrystalline solar cells:

- They are the most expensive solar cells on the market, and so not in everyone's price range
- The performance levels tend to suffer from an increase in temperature. However, it is a small loss when compared to other forms of solar cell
- There is a lot of waste material when the silicon is cut during manufacture

Figure 2.3: A monocrystalline PV module

2.3.1.1.2 Polycrystalline Solar Cells

Polycrystalline solar panels are a newer development, but they are rising quickly in popularity and efficiency. The polycrystalline solar cells are also known as poly-silicon and multi-silicon cells. Just like monocrystalline cells, polycrystalline cells are made from silicon. But polycrystalline cells are made from fragments of the silicon crystal melted together. During the manufacturing process, the silicon crystal is placed in a vat of molten silicon. Instead of pulling it out slowly, this crystal is allowed to fragment and then cool. Then once the new crystal is cooled in its mold, the fragmented silicon is thinly sliced into polycrystalline solar wafers. These wafers are assembled together to form a polycrystalline panel.

One of the benefits of this process is that the solar cells become much more affordable. This is because hardly any silicon is wasted during the manufacturing process. However, they are less efficient than monocrystalline solar cells, and also require a lot more space. This is due to the fact that they have lower levels of purity than the single crystalline cell models.

Polycrystalline also has a lower tolerance for heat than monocrystalline. This means that they are unable to function as efficiently in high temperatures. This can be a massive disadvantage in areas with hot climates. They are made by melting raw silicon, which is a faster and cheaper process than that used for Polycrystalline panels (AbdelKader et al. 2014).

Figure 2.4: A polycrystalline PV module

Polycrystalline cells are blue in color because of the way sunlight reflects on the crystals. Sunlight reflects off of silicon fragments differently than it does with a pure silicon cell. Usually the back frames and frames are silver with polycrystalline, but there can be variation. The shape of the cell is a square, and there are no gaps between corners of cells. Some of the advantages of polycrystalline solar cells are listed below:

- The manufacturing process is cheaper and easier than the monocrystalline cells
- It avoids silicon waste

Here are some of the disadvantages to polycrystalline solar cells:

- High temperatures have less negative effects on efficiency compared with monocrystalline cells. This makes the polycrystalline cells more attractive to people in warmer areas as the price is lower

- Efficiency is only around 13-16% due to low levels of silicon purity. So they are not the most efficient on the market
- They have lower output rates which make them less space efficient. So more roof space is needed for installation.

2.3.1.1.3 Thin-Film Solar Cells

Thin-film solar panels are an extremely new development in the solar panel industry. The most distinguishing feature of thin-film panels is that they aren't always made from silicon. They can be made from a variety of materials, including cadmium telluride (CdTe), amorphous silicon (a-Si), and Copper Indium Gallium Selenide (CIGS). Thin-film panels are easy to identify by their thin appearance. These panels are approximately 350 times thinner than those that use silicon wafers. But thin-film frames can be large sometimes, and that can make the appearance of the entire solar system comparable to that of a monocrystalline or polycrystalline system. Thin-film cells can be black or blue, depending on the material they were made from. These solar cells are created by placing the main material between thin sheets of conductive material with a layer of glass on top for protection. The a-Si panels do use silicon, but they use non-crystalline silicon and are also topped with glass. These types of solar panels are the easiest to produce and economies of scale make them cheaper than the alternatives due to less material being needed for its production (Ana et al. 2014).

Figure 2.5: A thin solar PV module

They are also flexible—which opens a lot of opportunities for alternative applications—and is less affected by high temperatures. The main issue is that they take up a lot of space, generally making them unsuitable for residential installations. Moreover, they carry the shortest warranties because their lifespan is shorter than the mono- and polycrystalline types of solar panels. However, they can be a good option to choose among the different types of solar panels where a lot of space is available.

2.3.1.2 Series and Parallel Connection of a PV Panel

2.3.1.2.1 Connecting in Series

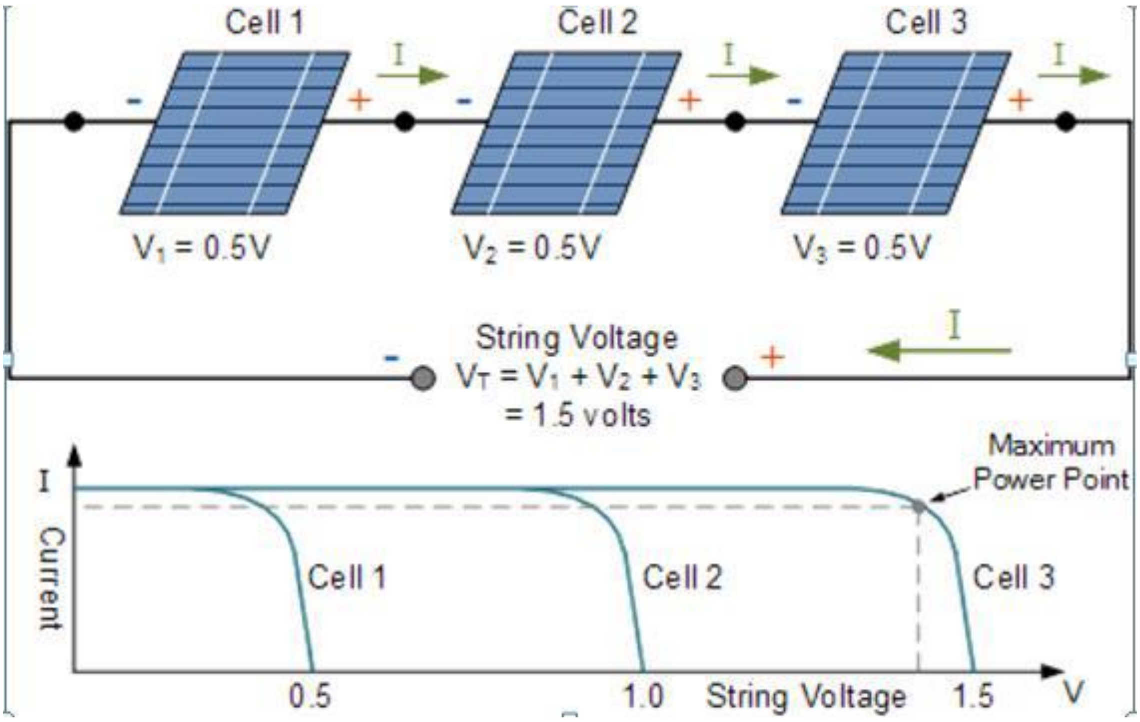
When installing solar panels in series, the voltage adds up, but the current stays the same for all of the elements. So, if you connect two solar panels with a rated voltage of 40 volts and rated amperage of 5 amps in series, the voltage of the series would be 80 volts, while the amperage would remain at 5 amps. Putting panels in series makes it so the voltage of the array increases. This is important, because a solar power system needs to operate at a certain voltage in order for the inverter to work properly.

There are some major benefits to connecting solar panels in series. First, it allows you to get away with smaller wiring (since the current stays the same), which saves you quite a bit of expense and effort during the installation.

And second, you can have very long wire runs (from your solar panels on your roof to the inverter on the side of your house, for instance) without losing too much electricity. For these reasons, most solar panels on homes today are, at least partially, connected in series.

There is one issue with connecting in series, however. If you remember our Christmas lights example from above, you can imagine the drawbacks to wiring your solar panels in a similar way. If one solar panel goes out or is shaded, then the entire system's production drops drastically. Shading decreases production in any system and that's why installers typically avoid areas of your roof where nearby trees, shrubs, buildings, satellites, chimneys, or anything else could get in the way.

Figure 2.6: Series Connection of a PV panel



2.3.1.2.2 Connecting in Parallel

When solar panels are wired in parallel, the positive terminal from one panel is connected to the positive terminal of another panel and the negative terminals of the two panels are connected together. The positive wires are connected to a positive connector within a combiner box, and the negative wires are connected to the negative connector. When multiple panels are wired in parallel, it is called a PV output circuit. Using our same example of 5 panels, each rated at 12V and 5A, if you connected them in parallel, you'd still have 12V but now 25A.

Connecting panels in parallel requires heavier wire to handle the higher current (25A vs 5A in the examples above) and you need more wire to make all the connections to the different panels. It's more difficult and costly to run these large wires to connect your solar panels to a distant inverter (like is typically found in residential situations).

Off-grid systems have a bit more flexibility and solar owners will sometimes connect their panels in parallel to meet their battery needs (12V solar system to charge a 12V battery, for example).

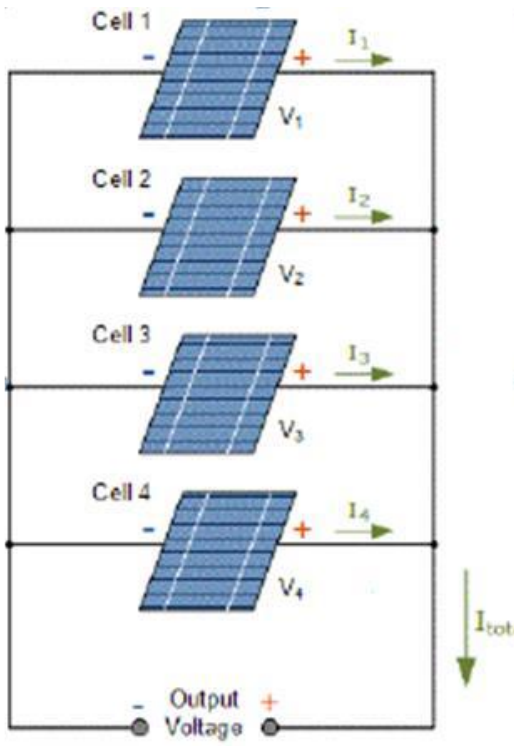


Figure 2.7: Parallel Connection of a PV panel

2.3.1.3 Review of Similar Work on Solar Panels

There has been a lot of research work carried by different set of individuals around on how solar panel works.

Ana et al. (2014) carried out a Photovoltaic Modules Performance- Comparative study which aim was to monitor the performance for two photovoltaic panels mounted in the same climatic conditions, the same tilt and the same characteristics, but with different photovoltaic cells which were mono-crystalline and polycrystalline photovoltaic cells.

This study was carried out within the period of January – September, 2014 and it was observed that mono crystalline photovoltaic panel provide a higher quantity of electricity than polycrystalline photovoltaic panel as it was found that the photovoltaic panels with mono crystalline silicon cells are able to convert a greater amount of solar energy into electricity compared to panels that were constructed with polycrystalline silicon cells of the same power. It was also observed that monocrystalline silicon photovoltaic cells have a good functionality and a higher collective power than the polycrystalline photovoltaic panel.

2.3.2 Solar Batteries

Batteries are important element in any stand Alone PV system but can be optional depending upon the design. Batteries are used to store the solar produced electricity for night time or emergency use during the day. Depending upon the solar array configuration, battery banks can be of 12V, 24V or 48V and many hundreds of amperes in total.

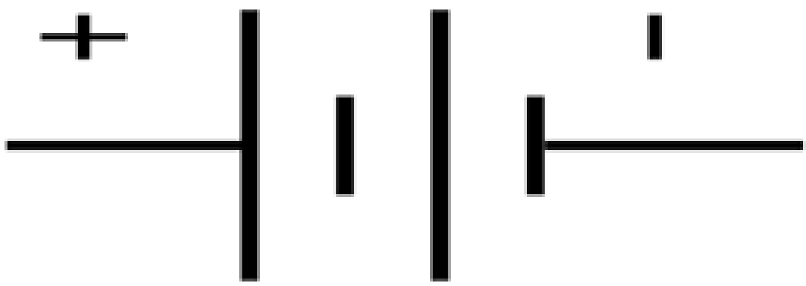


Figure 2.8: Symbol for battery

Solar panels rarely power electrical equipment directly. This is because the amount of power the solar array collects varies depending on the strength of the sunlight. This makes the power source too variable for most electrical equipment to cope with. If you are storing your solar energy, such as in a stand-alone or grid-fallback system, this energy is stored in batteries. As well as allowing flexibility as to when you use your energy, the batteries provide a constant power source for your electrical equipment. There are different battery technologies available for solar energy storage. Traditionally, ‘deep cycle’ lead acid batteries have been used. These batteries look similar to car batteries but have a different internal design. This design allows them to be heavily discharged and recharged several hundred times over. Most lead acid batteries are 6-volt or 12-volt batteries and, like solar panels, these can be connected together to form a larger battery bank. Like solar panels, multiple batteries used in series increase the capacity and the voltage of a battery bank. Multiple batteries connected in parallel increase the capacity whilst keeping the voltage the same.

2.3.2.1 Type of Batteries

There are four types of battery used in connection with storing electricity from solar power systems.

2.3.2.1.1 Lead-Acid Batteries

Lead acid batteries are the most commonly used type of battery in photovoltaic systems. Although lead acid batteries have a low energy density, only moderate efficiency and high maintenance requirements, they also have a long lifetime and low cost compared to other battery types.

Lead acid batteries are a low cost reliable power workhorse used in heavy duty applications. They are usually very large and because of their weight, they’re always used in non-portable applications such as solar panel energy storage, vehicle ignition and lights, backup power and load leveling in power generation/distribution. One of the singular advantages of lead acid batteries is that they are the most commonly used form of battery for most rechargeable battery applications and therefore have a well-established, mature technology base.

Lead acid batteries have very low energy to volume and energy to weight ratios but it has a relatively large power to weight ratio and as a result can supply huge surge currents when needed. These attributes alongside its low cost makes these batteries attractive for use in several high current applications like powering automobile starter motors and for storage in backup power supplies (ESST, 2014). A lead acid battery consists of a negative electrode made of spongy or porous lead. The lead is porous to facilitate the formation and dissolution of lead. The positive electrode consists of lead oxide. Both electrodes are immersed in a electrolytic solution of sulfuric acid and water. In case the electrodes come into contact with each other through physical movement of the battery or through changes in thickness of the electrodes, an electrically insulating, but chemically permeable membrane separates the two electrodes. This membrane also prevents electrical shorting through the electrolyte. Lead acid batteries have some advantage and limitations which are highlighted below.

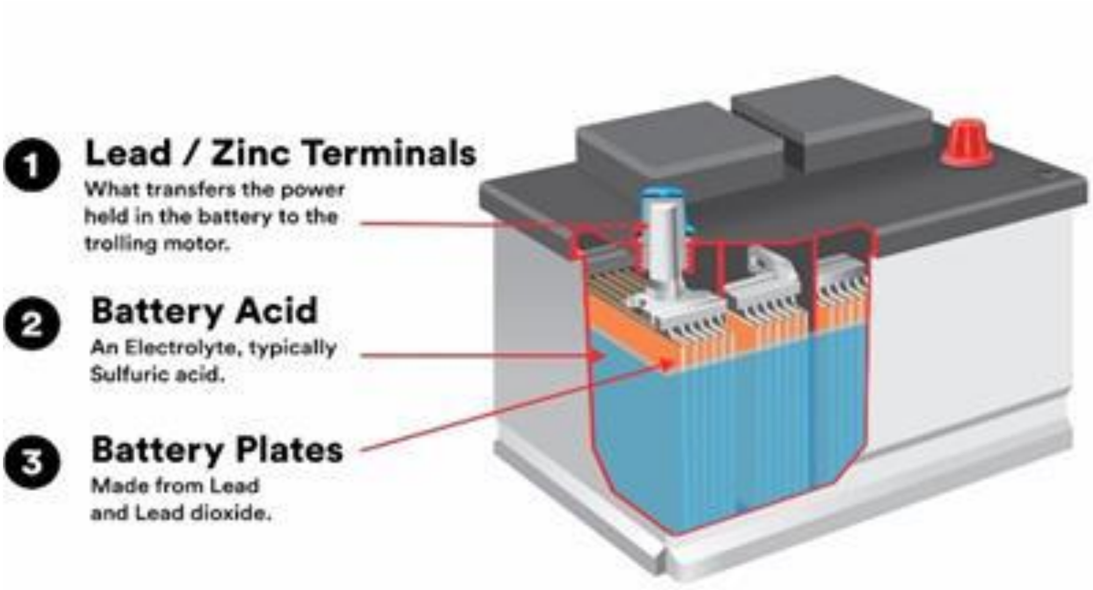


Figure 2.9: Lead acid battery

Here are the advantages of lead acid batteries;

- Lead Acid is inexpensive and simple to manufacture.
- The self – discharge is among the lowest of rechargeable battery systems.
- Capable of high discharge rates
- Lead acid is durable and provides dependable service.

Limitations of lead acid battery are;

- Low energy density – poor weight to energy ratio limits use to stationary and wheeled applications.
- Cannot be stored in a discharged condition, the cell voltage should never drop below 2.10V.

- Allow only a limited number of full discharge cycles – well suited for standby applications that require only occasional deep discharges.
- Lead content and electrolyte make the battery environmental unfriendly.
- Thermal runaway can occur if improperly charged.

2.3.2.1.2 Lithium-Ion Batteries

Lithium-ion batteries are a type of rechargeable battery in which lithium ions from the negative electrode migrate to the positive electrode during discharge and migrate back to the negative electrode when the battery is being charged. Li-ion batteries use an intercalated lithium compound as one electrode material, compared to the metallic lithium used in non-rechargeable lithium batteries. Lithium ion batteries have some advantages and limitations which are highlighted below.

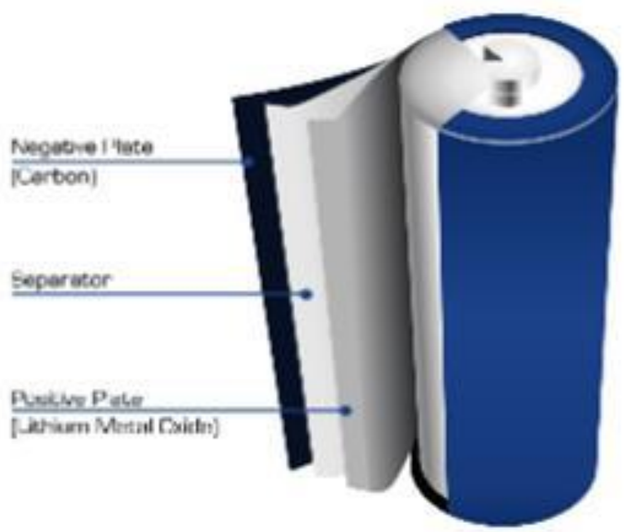


Figure 2.10: Lithium-ion battery

- High energy density potential for yet higher capacities
- Does not need prolonged priming when new, one regular charge is all that’s needed.
- Specialty cells can provide very high current to applications such as power tools.

- Low maintenance – no periodic discharge is needed; there is no memory.

Here are the following Limitations

- Requires protection circuit to maintain voltage and current within safe limits
- Subject to aging, even if not in use – storage in a cool place at 40% charge reduces the aging effect.
- Lithium ion batteries are expensive to manufacture, about 40% higher in cost than nickel-cadmium.

2.3.2.1.3 Nickel-Metal Hydride Batteries

A nickel metal hydride battery (NiMH or Ni-MH) is a type of rechargeable battery. The chemical reaction at the positive electrode is similar to that of the nickel cadmium cell (NiCd), with both using nickel oxide hydroxide (NiOOH). However, the negative electrodes use a hydrogen absorbing alloy instead of cadmium. NiMH batteries can have two to three times the capacity of NiCd batteries of the same size, with significantly higher energy density, although much less than lithium –ion batteries. Unlike the NiCad chemistry, batteries based on the NiMH chemistry are not susceptible to the ―memory effect that NiCad experience. The advantage and limitations of Nickel metal hydride are highlighted below.

Figure 2.11: Ni-MH Battery

- The nickel metal hydride battery has potential for yet higher energy densities
- Less prone to memory than the Ni-Cd
- Simple storage and transportation conditions are not subject to regulatory control
- 30 - 40% higher capacity over a standard Ni-Cd

Here are the limitations of NiMH

- Limited service life; deep discharge reduces service life
- Requires complex charge algorithm. Sensitive to overcharge
- Does not absorb overcharge well; trickle charge must be kept low
- Generates heat during fast charge and high-load discharge
- High self-discharge

2.3.2.1.4 Nickel-Cadmium Batteries

The nickel–cadmium battery (NiCd battery or NiCad battery) is a type of rechargeable battery which is developed using nickel oxide hydroxide and metallic cadmium as electrodes. Ni-Cd batteries excel at maintaining voltage and holding charge when not in use. However, NI-Cd batteries easily fall a victim of the dreaded ―memory‖ effect when a partially charged battery is recharged, lowering the future capacity of the battery. In comparison with other types of rechargeable cells, Ni-Cd batteries offer good life cycle and performance at low temperatures with a fair capacity (Energy Storage Systems Technologies, 2014).

Their most significant advantage will be their ability to deliver their full rated capacity at high discharge rates. They are available in different sizes including the sizes used for alkaline batteries, AAA to D. Ni-Cd cells are used individual or assembled in packs of two or more cells. The small packs are used in portable devices, electronics and toys while the bigger ones find application in aircraft starting batteries, electric vehicles and standby power supply. The advantage and limitations of Nickel metal hydride are highlighted below.

- Rugged, high cycle count with proper maintenance
- Only battery that can be ultra-fast charged with little stress
- Simple storage and transportation; not subject to regulatory control
- Good low-temperature performance

Here are the limitations of Nickel metal hydride

- Relatively low specific energy compared with newer systems
- Memory effect; needs periodic full discharges and can be rejuvenated
- Cadmium is a toxic metal. Cannot be disposed of in landfills
- High self-discharge; needs recharging after storage

- Low cell voltage of 1.20V requires many cells to achieve high voltage

2.3.2.2 Selecting the Right Battery for Your Application

Below are some factors to consider when selecting the right type of battery for your project.

- **Power Density:** Maximum rate of energy discharge per unit mass or volume. Low power: laptop, iPod. High power: power tools.
- **Energy Density:** The energy density is the total amount of energy that can be stored per unit mass or volume. This determines how long your device stays on before it needs a recharge.
- **Life cycle durability:** The stability of energy density and power density of a battery with repeated cycling (charging and discharging) is needed for the long battery life required by most applications.
- **Cost:** Cost is an important part of any engineering decisions you will be making. It is important that the cost of your battery choice is commensurate with its performance and will not increase the overall cost of the project abnormally.
- **Safety**: It is important to consider the temperature at which the device you are building will work. At high temperatures, certain battery components will breakdown and can undergo exothermic reactions. High temperatures generally reduce the performance of most batteries.

2.3.2.3 Battery Connections

Batteries can either be connected in series or parallel connections.

- **Battery Connection in Series:** Battery is connected in series to add the voltage of the two batteries**,** but it keeps the same amperage rating (Amp hour). To connect batteries in series, two jumper wire is used to connect negative terminal of the first battery to the positive terminal of the second battery and used another cable to connect the open positive and negative terminals to your application.

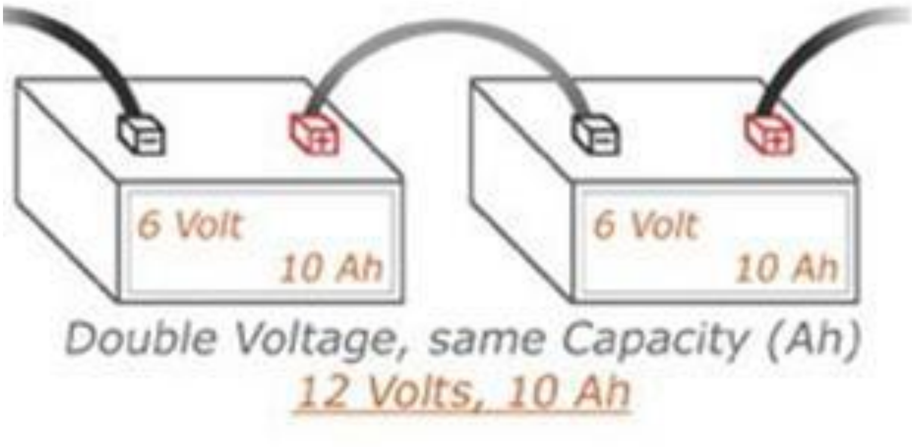


Figure 2.12: Batteries connected in series

- **Battery Connection in Parallel:** Battery connected in parallel will increase the current rating but the voltage will stay the same. To connect batteries in parallel, use a jumper wire to connect both the positive terminals and another jumper wire to connect both the negative terminals of both batteries to each other.

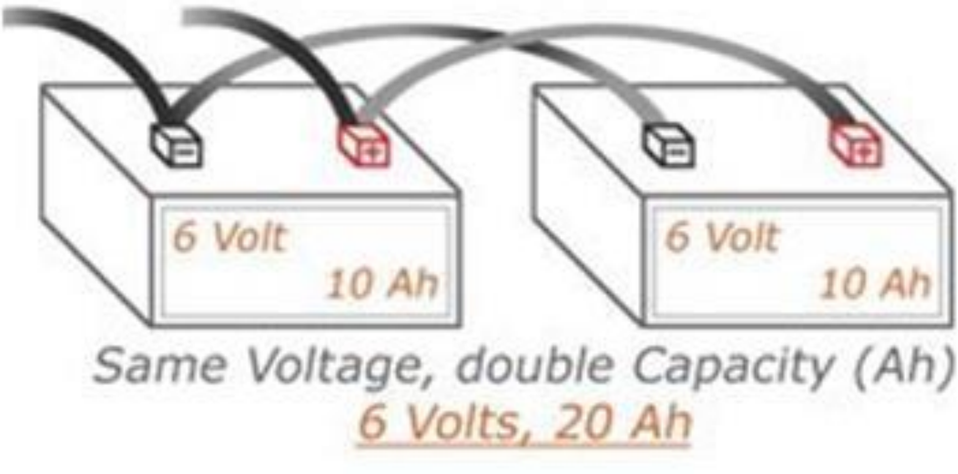


Figure 2.13: Batteries connected in parallel

2.3.3 Charge Controller

The terms "charge controller" or "charge regulator" may refer to either a stand-alone device, or to control circuitry integrated within a battery pack, battery-powered device, or battery charger (DOE, 2007). A charge controller regulates and controls the output from the solar array to prevent the batteries from being over charged (or over discharged) by dissipating the excess power into a bad resistance. Charge controllers within a SPV system are optional but it is a good idea to have one for safety reasons. Many solar controllers also include an LCD status screen so you can check the current battery charge and see how much power the solar array is generating. It ensures that the deep cycle batteries are not overcharging during the day and that the power doesn’t run backwards to the solar panels overnight and drains the batteries. Some charge controllers are available with the additional capabilities, like lighting and load control, but managing the power is its primary job.

Figure 2.14: A charge controller connected to a solar panel

2.3.3.1 Types of Charge Controller

A solar charge controller is available in two different types, PWM and MPPT. How they perform in a system is very different from each other.

- PWM solar Charge Controller
- MPPT Solar Charge Controller

2.3.3.1.1 PWM Solar Charge Controller

A PWM solar charge controller stands for “Pulse Width Modulation”. The controller checks the state of charge on the battery between pulses and adjusts itself each time (Brown 2006). These operate by making a connection directly from the solar array to the battery bank. During bulk charging, when there is a continuous connection from the array to the battery bank, the array output voltage is pulled down to the battery voltage. As the battery charges, the voltage of the battery rises, so the voltage output of the solar panel rises as well, using more of the solar power as it charges. As a result, there is needed to make sure it matches the nominal voltage of the solar array with the voltage of the battery bank. For Example, we refer to a 12V solar panel, that mean panel that is designed to work with a 12V battery. The actual voltage of a 12V solar panel, when connected to a load, is close to 18Vmp (Volts at Maximum Power). This is because a higher voltage sources is required to charge a battery. If the battery and the solar panel both started at the same voltage, the battery would not charge.

A 12V solar panel can charge a 12V battery. A 24V solar panel or solar array (two 12V panels wired in series) is needed for a 24V battery bank, and 48V array is needed for 48V bank. If you try to charge a 12V battery with a 24V solar panel, you will be throwing over half of the panel’s power away. If you try to charge a 24V battery bank with a 12V solar panel, you will be throwing away 100% of the panel’s potential and may actually drain the battery as well.

2.3.1.1.2 MPPT Solar Charge Controller

An MPPT solar charge controller stands for “Maximum Power Point Tracking”. It will measure the voltage of the panel and down-converts the PV voltage to the battery voltage. Because power into the charge controller equal power out of the charge controller, when the voltage is dropped to match the battery bank, the current is raised, so you are using more of the available power from the panel. It can use higher voltage solar array than battery, like the 60 cell nominal 20V grid-tie solar panels that are more readily available. With a 20V solar panel, it charges a 12V battery bank, on two in series can charge up to a 24V battery bank, and three in series can charge up to a 48V battery bank. This opens up a whole wide range of solar panels that now can be used for your off grid solar system.

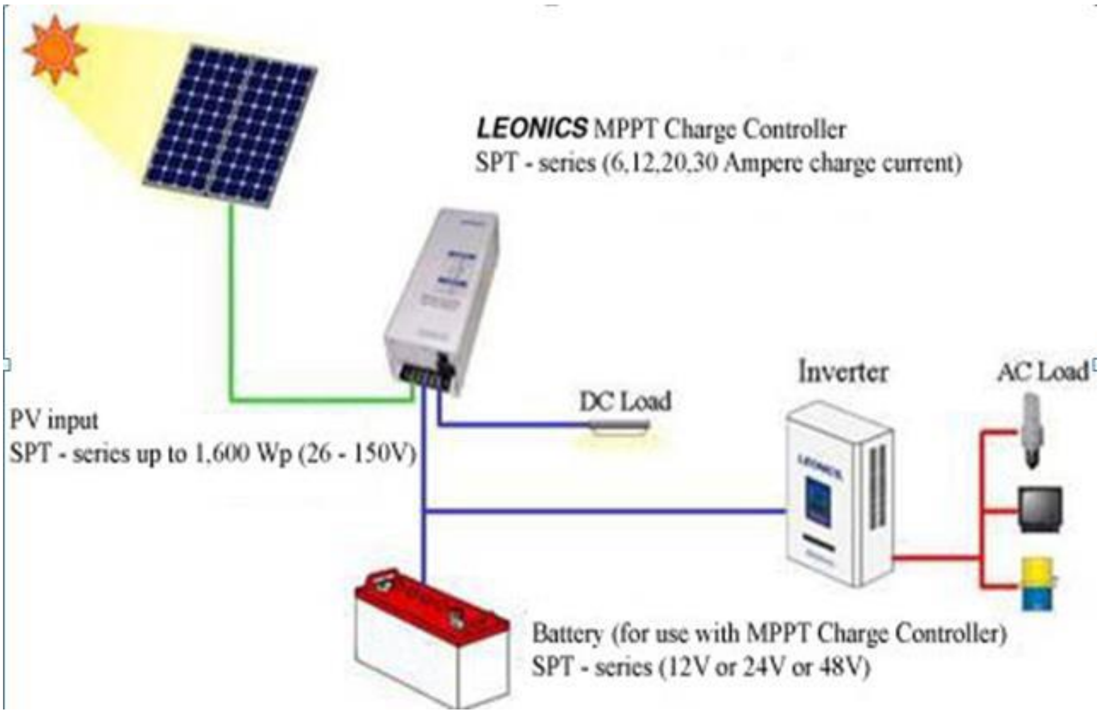


Figure 2.15: General Configuration of the MPPT solar charge controller

2.3.3.2 Features of a Solar Charge Controller

- Multistage Charging of battery bank – changes to the amount of power set to the batteries based on charge level, for healthier batteries.
- Reverse current protection – stops the solar panels from draining the batteries at night when there is no power coming from the solar panels.
- Low voltage disconnects – turns off attached load when the battery is low and turns it back on when battery is charged back up.
- Lighting control – turns attached light on and off based on dusk and dawn. Many controllers are configurable, allowing settings for a few hours all night or somewhere in between.
- Display may show voltage of battery bank, state of charge, amps coming in from solar panel.

2.3.3.3 Review of Similar Works on Charge Controller

Yuncong et al. (2011) presented an analogue maximum power point tracking (MPPT) controller for a photovoltaic (PV) solar system that utilizes the load current to achieve maximum output power from the solar panel. Comparing to the existing MPPT controller circuitry which requires multiplication of the sensed PV panel voltage and current to yield panel power, the cost and size of the proposed circuit was reduced. The tracking performance of the proposed MPPT controller was validated by simulation results.

Prodanvic et al. (2003) designed a filter and a complementary controller for a three phase inverter that rejects grid disturbance, maintains good waveform quality and achieve real and reactive power control. A full discrete- time controller design has been presented and validated with experimental results using DSP implementation. Both voltage-mode and current-mode control has been chosen for its advantages in respect to rejection by the current control loop of harmonic distortion present in the grid. The power quality has been demonstrated with time and frequency domain results showing the high quality of the currents injected into the voltage grids.

2.3.4 Solar Inverter

Inverter are used to convert the 12V, 24V, or 48 Volts direct current (DC) power from the solar array and batteries into an alternating current (AC) electricity and power of either 120 VAC or 240 VAC for use in the home or offices to power AC mains appliances such as Printers, Fans, TV's, washing machines, freezers etc. A Solar inverter is similar to a normal electric inverter but uses the energy of the Sun i.e. solar energy (Olanrewaju et al. 2016). An inverter for stand-alone systems is a different piece of equipment to a grid-tie solar inverter. With a grid-tie inverter, your power is feeding into the grid and has to work in conjunction with the grid. The inverter connects directly to your solar panels and switches off when the solar panels no longer produce enough energy. With a stand-alone system, your power is entirely separate from the grid. The inverter connects to your battery bank and switches off when the battery bank is running low on charge.

2.3.4.1 Types of Solar Inverter

Solar inverters may be classified into three broad types:

- Stand-alone Inverters
- Grid-tie inverters
- Intelligent hybrid inverters

2.3.4.1.1 Stand-Alone or Off-Grid Inverter

Stand-alone inverters are used in isolated system where the inverter draws its DC energy from batteries charged by photovoltaic arrays. Many stand-alone inverters also incorporate integral battery chargers to replenish the battery from an AC source, when available. This battery panel is charged by solar panels. Several such inverters have integrated with basic battery chargers which can be used to boost the battery from an AC power source. (Olanrewaju et al. 2016). Normally these do not interface in any way with the utility grid and as such are not required to have anti-islanding protection.

The system which utilizes only solar electric energy as main source of energy is referred as standalone solar electrical system. There are many locations on this earth where no source of electricity is available. At these locations standalone solar electrical system can be the ideal source of electricity. The main advantage of this system is that it does not depend on grid or any other source of electricity.

Selecting an inverter for a power system based on the maximum load considered to be powered, the maximum surge required, output voltage required, input battery voltage and optional features needed. High quality stand-alone inverters are available in sizes from 100 watts, for powering computers and fax machines etc. from car, to 8000 watts for powering an entire house or small commercial operation. The size of an inverter is measured by its maximum continuous output in watts. This rating must be larger than the total wattage of all of the AC loads planned to run at one time. The size of the inverter can be minimized if the number and size of the AC loads is kept under control. Wattage of most AC loads can be determined from a tag or label on the appliance, usually located near when the power cord enters or from the owner’s manual. If the inverter is expected to run induction motors like the ones found in automatic washers, dryers, dishwashers, and large power tools, it periods of time while these motors start.

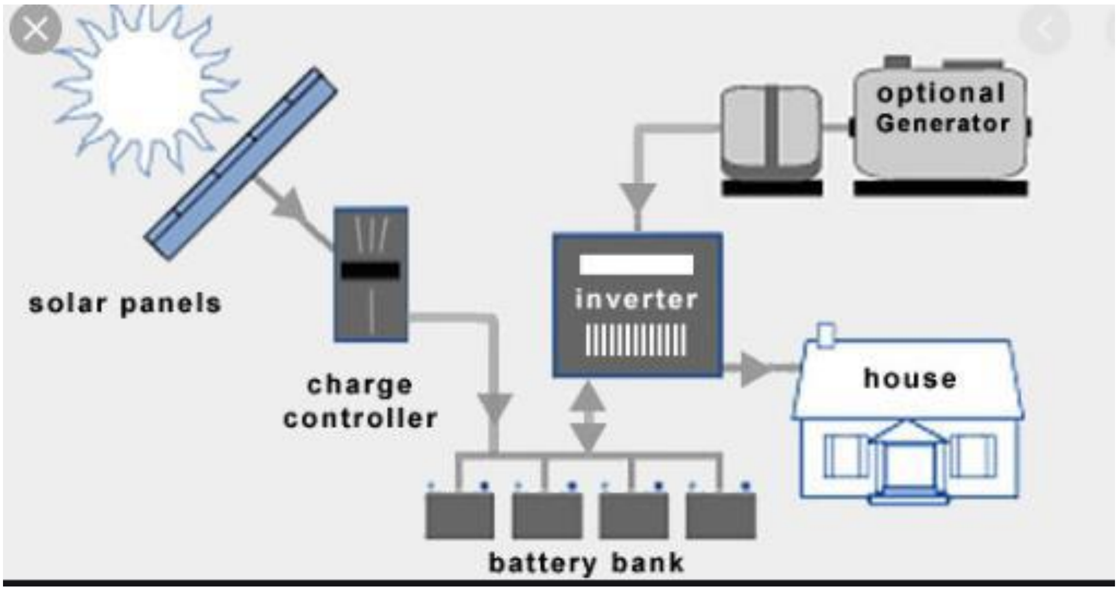


Figure 2.16: Interconnection of a Stand-alone Inverter

Stand –alone inverters are available with three basic power output waveforms:

- Square wave inverters
- Sine wave inverters
- Pure sine wave

- **Square Wave Inverter:** They have the lowest cost and efficiency. Modified square wave output is an economical choice in power systems where waveform is not critical. Their high surge capacity allows them to start large motors while their high efficiency makes them economical with power when running small loads like a stereo or a small light. They can power most lighting, televisions, appliances and computers very well. However, this type of inverter may destroy some low cost rechargeable tools and flashlights and their waveform will not allow many laser printers, copiers, light dimmers and some variable speed tools to operate. Some audio equipment will have a background buzz that may be annoying to music connoisseurs.

- **Sine Wave Inverter:** They are slightly higher cost, but they can operate almost anything that can be operated on utility power. They range in size from 150 watts for small applications to 200,000 watts that can run a small village. A sine wave is what you get from your local utility company and (usually) from a generator. This is because it is generated by rotating AC machinery and sine waves are a natural product of rotating AC machinery. The major advantage of a sine wave inverter is that all of the equipment which is sold on the market is designed for a sine wave. This guarantees that the equipment will work to its full specifications. Some appliances, such as motors and microwave ovens will only produce full output with sine wave power. A few appliances, such as bread makers, light dimmers, and some battery chargers require a sine wave to work at all. Sine wave inverters are always more expensive - from 2 to 3 times as much.
- **Pure Sine Waves Inverter:** synchronous inverters and utility companies deliver a pure sine wave. A modified pure sine wave inverter actually has a waveform more like a square wave, but with an extra step or so. A modified sine wave inverter will work fine with most equipment, although the efficiency or power will be reduced with some. Motors, such as refrigerator motor, pumps, fans etc will use more power from the inverter due to lower efficiency. Most motors will use about 20% more power. This is because a fair percentage of a modified sine wave is higher frequencies - that is, not 60 Hz - so the motors cannot use it. Some fluorescent lights will not operate quite as bright, and some may buzz or make annoying humming noises. Appliances with electronic timers and/or digital clocks will often not operate correctly. Many appliances get their timing from the line power - basically, they take the 60 Hz (cycles per second) and divide it down to 1 per second or whatever is needed.

  Because the modified sine wave is noisier and rougher than a pure sine wave, clocks and timers may run faster or not work at all. They also have some parts of the wave that are not 60 Hz, which can make clocks run fast. Items such as bread makers and light dimmers may not work at all - in many cases appliances that use electronic temperature controls will not control. The most common is on such things as variable speed drills will only have two speeds - on and off.

2.3.4.1.2 Grid Tie Inverter

Grid tie inverters are used to match phase with a utility supplied sine wave. Grid tie inverters are designed to shut down automatically upon loss of utility supply, for safety reasons. They do not provide backup power during utility outages. This all happens while your home (or solar powered building) remains dependent on the local grid, or utility. This is different from off-grid systems, which means that your power is not hooked up or dependent on any other utility power. Grid tie inverters require their system to be installed with anti-islanding protection. Islanding is a process where grid tie inverters are fooled that a utility grid is still functioning even if it has been turned off. It takes place due to load circuits that resonate in the electrical system.

The key role of the grid-interactive or synchronous inverters or simply the grid-tie inverter (GTI) is to synchronize the phase, voltage, and frequency of the power line with that of the grid. Solar grid-tie inverters are designed to quickly disconnect from the grid if the utility grid goes down. This is an NEC (National Electrical Code) requirement that ensures that in the event of a blackout, the grid tie inverter will shut down to prevent the energy it produces from harming any line workers who are sent to fix the power grid.

Grid-tie inverters that are available on the market today use a number of different technologies. The inverters may use the newer high-frequency transformers, conventional low-frequency transformers, or no transformer. Instead of converting direct current directly to 120 or 240 volts AC, high-frequency transformers employ a computerized multi-step process that involves converting the power to high-frequency AC and then back to DC and then to the final AC output voltage (DIMNSP 2004).

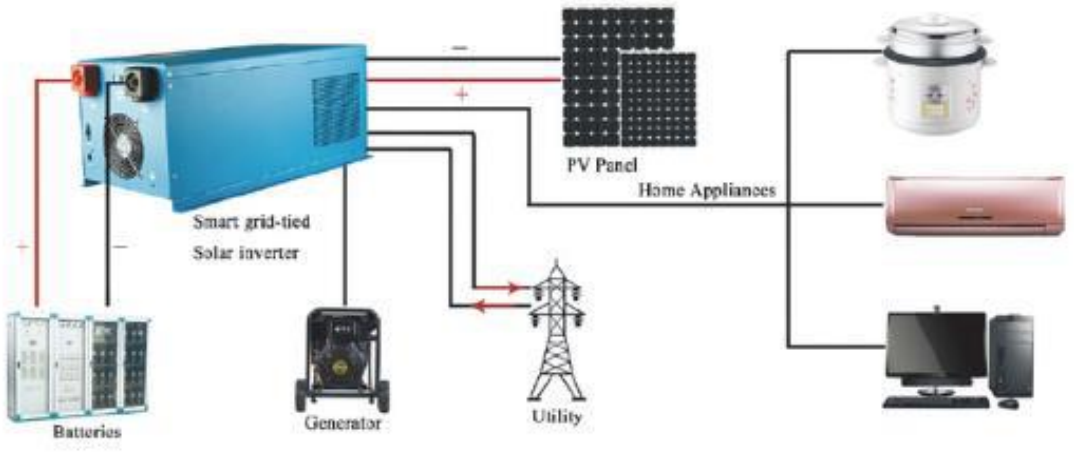


Figure 2.17: Interconnection of a smart grid inverter

2.3.4.1.3 Intelligent Hybrid or Smart Grid Inverter

Intelligent Hybrid inverters manage photovoltaic array, battery storage and utility grid, which are all coupled directly to the unit. These modern all-in-one systems are usually highly versatile and can be used for grid-tie, stand-alone or backup applications but their primary function is self-consumption with the use of storage. An intelligent hybrid inverter or smart grid inverter is a trending generation of inverter for solar applications using renewable energy for home consumption, especially for solar photovoltaic installations. Some see this as a new technology, however in some parts of the world the application of such products has been around since the 1990s. Electricity from solar panels is generated only during the day, with peak generation around midday. Generation fluctuates and may not be synchronized with a load's electricity consumption. To overcome this gap between what is produced and what is consumed during the evening, when there is no solar electricity production, it is necessary to store energy for later use and manage energy storage and consumption with an intelligent hybrid (smart grid) inverter. With the development of systems that include renewable energy sources and rising electricity prices, private companies and research laboratories have developed smart inverters for synchronizing energy production and consumption (Olanrewaju et al. 2016).

The Function of a (smart-grid) is enabling selection and orientation of renewable energy, energy from the grid and energy storage based on consumption. Unlike conventional inverters, rather than systematically storing energy in batteries (with significant loss of yield >20%) Smart grid inverters store energy only when necessary, e.g. when there is more production than consumption. This system also allows choosing whether electricity from photovoltaic panels should be stored or consumed through an internal intelligent apparatus control unit. This is possible through a technique that adds different energy sources (phase coupling: on-grid or grid-tie techniques) and the management of stored electricity in the battery (off grid technology). Hybrid inverters therefore operate on grid (grid-tie) as well as off-grid, hybrid (both on-grid and off-grid at the same time) and Backup (in case of a black out). According to the E.R.D.F. (French Electric Network) smart inverters are the future of photovoltaic solar panel installations dedicated to energy self-use, or auto-consumption of energy. The technology has different functions which include;

- Battery based off-grid inverters being further developed for on-grid connection (sometimes also referred to as multi-mode inverters)
- Use in off-grid mode (without network) with the possibility of linking to a generator. The inverter must be connected to a battery bank and must have true off-grid capabilities – not all Hybrid inverters are created equal or can be used in off-grid applications.
- Use in on-grid or grid-tie (connected to the network) with the possibility of selling energy or excess energy. There is a need to have the norm compliance of protection and decoupling (DIN VDE 0126.1).

- Use in hybrid mode the inverter functions with a battery bank, but also connected to the grid. This dual functionality is the highlight of hybrid inverters that hence enable energy management (smart grid).

- Use in Backup mode, or storage mode prevents blackouts by switching from on-grid mode to off-grid mode at the moment of a grid outage, thereby eliminates network cuts.

2.3.4.2 Components of Solar Inverters

1. **Magnetics Components:** It includes the inductor and the transformer to filter the wave shapes and smoother them, and bring ac voltages to the correct levels for grid interconnection. They also provide isolation between the dc circuits and the ac grid.
2. **Capacitors Components:** They are used to filter ripple contents (undesirable phenomenon due to semi-conductor switching) on dc lines. It is also being used to keep the dc bus voltage stable and minimize losses between the PV array and the inverter.
3. **Solid State Switches:** It is used in transformer-based inverters to adjust voltage levels as needed by the topology and to provide galvanic isolation between the solar dc input on one side and the inverter's ac output to the grid on the other. Single stage products like 60 Hz transformer-based string inverters typically use an H-bridge for inversion from dc to ac, Diagram below shows all the key components in a single stage inverter, including the H-bridge circuit. The switches at the far left represent the power semiconductor switches. By alternately closing the top left and bottom right switches, then the top right and bottom left switches, the dc voltage is inverted from positive to negative, creating a rectangular ac waveform.

2.3.4.3 Benefits of Solar Inverters

The main benefits of solar inverter include the following.

1. By using solar products, we can save money by reducing electricity bills
2. Maintenance is easy as they work well even with usual maintenance.
3. These are multifunctional devices as they preprogrammed to alter DC to AC which assists large energy consumers.
4. Solar energy decreases the greenhouse effect as well as abnormal weather change.

2.3.4.4 Limitations of Solar Inverters

1. Sunlight is necessary to generate sufficient electricity.
2. This kind of inverters is expensive to afford.
3. It requires a huge space for installation.
4. It requires a battery to work at night time to provide proper electricity to the home, commercial, etc.

2.3.4.5 Reviews of Similar Works on Solar Inverters

Ekwuribe et al (2016) constructed and designed a 2.5KVA photovoltaic Inverter using a 21/400 wound transformer, An SG3524N PMW fixed frequency voltage regulator controller, MOSFET transistors, five 80W/18A solar panel, three 200AH deep cycle battery and a charge controller to monitor the output of the battery for safety. The battery is connected to the inverter circuit to generate 220V alternating current in its output via a step-up transformer. The Inverter uses the SG 3524N IC chip fixed frequency Pulse-Width-Modulator (PMW) Voltage regulator controller. The designed oscillation period is set a 50% duty circle or 0.02 seconds to match the frequency of loads connected to it.

Lane-Fox (1970) designed a circuit which consisted of two power transistors which were connected in switching mode and controlled by an oscillator from a 9v source (battery) to a 120v ac output through a transformer secondary (Andrew, 1998). The problems with this circuit are:

i Very low load current (in the order of milliamps).

ii Poor power efficiency

Jacob (1986) designed and constructed a dc- to-ac converter that yielded an output power of 6KVA, 220V AC and 50Hz with efficiency of 93.5%. This solved the problem of low output power and poor efficiency encountered by Lane-Fox's circuit. Everson, a manufacturing company which produces Uninterrupted Power Supplies (UPS) designed an inverter circuit that gave a 4KVA output, 270V AC 50Hz and an efficiency of 95% in the year 2000. This was a huge achievement in the design of inverters and uninterrupted power supplies (Andrew, 1998). The function of a (smart-grid) is enabling selection and orientation of renewable energy, energy from the grid and energy storage based on consumption. Unlike conventional inverters, rather than systematically storing energy in batteries (with significant loss of yield >20%) Smart grid inverters store energy only when necessary, e.g. when there is more production than consumption. This system also allows choosing whether electricity from photovoltaic panels should be stored or consumed through an internal intelligent apparatus control unit. This is possible through a technique that adds different energy sources (phase coupling: on-grid or grid-tie techniques) and the management of stored electricity in the battery (off grid technology). Hybrid inverters therefore operate on grid (grid-tie) as well as off-grid, hybrid (both on-grid and 16 off-grid at the same time) and Backup (in case of a black out). According to the E.R.D.F. (French Electric Network) smart inverters are the future of photovoltaic solar panel installations dedicated to energy self-use, or auto-consumption of energy. The technology has different functions which include;

- Battery based off-grid inverters being further developed for on-grid connection (sometimes also referred to as multi-mode inverters)

- Use in off-grid mode (without network) with the possibility of linking to a generator. The inverter must be connected to a battery bank and must have true off-grid capabilities – not all Hybrid inverters are created equal or can be used in off-grid applications.

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- Use in Backup mode, or storage mode prevents blackouts by switching from on-grid mode to off-grid mode at the moment of a grid outage, thereby eliminates network cuts.

CHAPTER THREE

THE DESIGN PROCESS OF SOLAR PHOTOVALTIC SYSTEM

This chapter deals with the design and calculations for a solar PV powered energy system efficient for lighting four offices in electrical/electronic engineering department. This analysis involves calculations carried out in the course of the project design and implementation. It shows how the component values were arrived at and the reasons for choice of components. The steps taken in order to achieve this design are as follows;

3.1 Steps in Carrying Out the Design of a Standalone Power System

There are seven steps in the design of every successful solar electric installation:

- Scope the project
- Calculate the amount of energy you need
- Calculate the amount of solar energy available
- Survey your site
- Design and Size up the solar electric system
- Select the right components and work out full costs
- Produce the detailed design

3.1.1 Scoping the Project

As with any project, before you start, you need to know what you want to achieve. In fact, it is one of the most important parts of the whole project. Get it wrong and you will end up with a system that will not do what you need it to. It is usually best to keep your scope simple to start with. You can then flesh it out with more detail later. Here are some examples of a suitable scope:

- To power a light and a burglar alarm in a shed on an allotment
- To provide power for lighting, a kettle, a radio and some handheld power tools in a workshop that has no conventional electrical connection
- To provide enough power for lighting, refrigeration and a TV in a holiday caravan
- To provide lighting and power to run four laptop computers and the telephone system in an office during a power cut
- To provide an off-grid holiday home with its entire electricity requirements
- To run an electric car entirely on solar energy

3.1.2 Calculating the amount of energy

Producing a power analysis, the next step is to investigate your power requirements by carrying out a power analysis, where you measure your power consumption in watt-hours. You can find out the wattage of household appliances in one of four ways:

- Check the rear of the appliance, or on the power supply
- Check the product manual
- Measure the watts using a watt meter
- Find a ballpark figure for similar items

Often a power supply will show an output current in amps rather than the number of watts the device consumes. If the power supply also shows the output voltage, you can work out the wattage by multiplying the voltage by the current (amps): Power (watts) = Volts x Current (amps). For example, if you have a mobile phone charger that uses 1.2 amps at 5 volts, you can multiply 1.2 amps by 5 volts to work out the number of watts. In this example, it equals 6 watts of power. If I plugged this charger in for one hour, I would use 6 watt-hours of energy.

A watt meter, like the example shown above, is a useful tool for measuring the energy requirements of any device that runs on high-voltage AC power from the grid. The watt meter plugs into the wall socket and the appliance plugs into the watt meter. An LCD display on the watt meter then displays the amount of power the device is using. This is the most accurate way of measuring your true power consumption.

3.1.3 Calculating Solar Energy

What is solar energy? Solar energy is a combination of the hours of sunlight you get at your site and the strength of that sunlight. This varies depending on the time of year and where you live. This combination of hours and strength of sunlight is called solar insolation or solar irradiance, and the results can be expressed as watts per square meter (W/m^2) or, more usefully, in kilowatt-hours per square meter spread over the period of a day ($kWh/m^2/day$). One square meter is equal to 9.9 square feet.

3.1.4 Surveying Your Site

The site survey is one of the most important aspects of designing a successful solar system. It will identify whether or not your site is suitable for solar. If it is, the survey identifies the ideal position to install your system, ensuring that you get the best value for money and the best possible performance. For a solar electric system to work well, we need the site survey to answer two questions:

- Is there anywhere on the site that is suitable for positioning my solar array?
- Do nearby obstacles such as trees and buildings shade out too much sunlight?

It is vitally important that you answer these questions. The number one reason for solar energy failing to reach expectations is obstacles blocking out sunlight, which dramatically reduces the efficiency of the system. To answer this second question, we need to be able to plot the position of the sun through the sky at different times of the year. During the rainy season, the sun hours is fewer than it is during the dry season. It is important to ensure that the solar array can receive direct sunlight throughout the day during the rainy season. What you will need You will need a compass, a protractor, a spirit level and a tape measure. Inevitably a ladder is required if you are planning to mount the solar array on a roof.

A camera can also be extremely useful for photographing the site. If you have an iPhone or an Android cell phone, you can also download some cheap software that will help you identify the path of the sun across the sky and assist with obstacle analysis. I also find it useful to get some large cardboard boxes.

First impressions When you first arrive on the site, the first thing to check is that the layout of the site gives it access to sunlight. We will use a more scientific approach for checking for shade later, but a quick look first often highlights problems without needing to carry out a more in-depth survey. Positioning the solar array Your next task is to identify the best location to position your solar array. Whilst you may already have a good idea where you want to install your solar panels, it is always a good idea to consider all the different options available to you. As we discovered in the last chapter, solar arrays perform at their best when tilted towards the sun. If you are planning to install solar energy for a building, then the roof of the building can often be a suitable place to install the solar array. This is effective where the roof is south-facing or where the roof is flat and you can fit the panels using angled mountings. Other alternatives are to mount solar panels on a wall. This can work well with longer, slimmer panels that can be mounted at an angle without protruding too far out from the wall itself. Shading issues on roofs Sometimes, roofs can have shading issues of their own. Chimneys, television aerials and satellite dishes or vents in the roof can either cause problems with fitting the solar panels in the first place, or can cast shade across the solar panels at different times of the day. Sometimes, these problems are easily resolved, moving an aerial is a relatively straightforward job, for example. However, if there is a chimney on the roof that is likely to cast a shadow across your solar panels, you will need to ensure sufficient space between your panels and the chimney to ensure that shadows are kept to an absolute minimum.

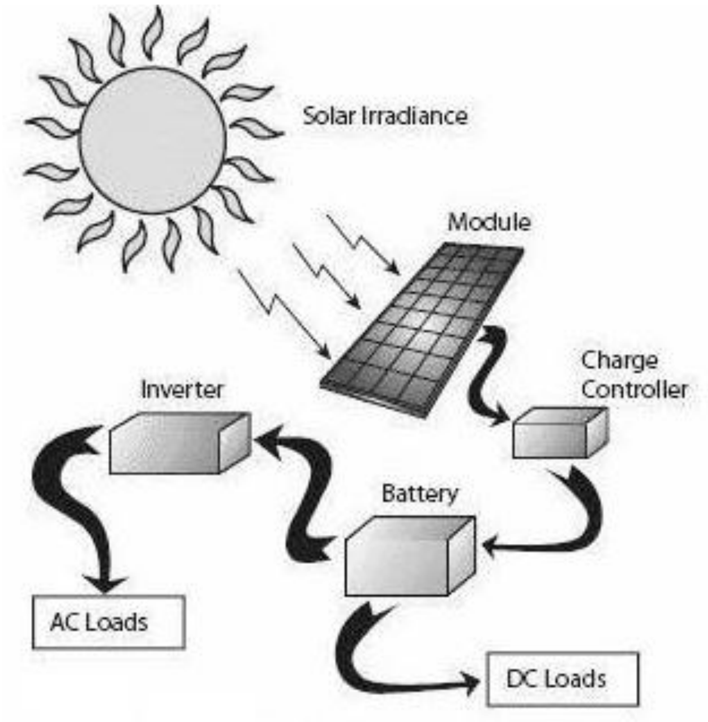

Figure 3.18: Photovoltaic system

The photovoltaic systems are classified according to how the system components connected to other power sources such as standalone (SA) and utility-interactive (UI) systems.

In a stand-alone system depicted in the Figure above, the system is designed to operate independent of the electric utility grid, and is generally designed and sized to supply certain DC- and/or AC electrical load.

3.2 Load Audit of All Electrical Loads for Four Offices in Electrical/Electronic Department Building of the University of Benin

Before designing the photo-voltaic (PV) system to power the critical loads, the energy of the critical load has to be determined. The critical loads require continuous operations for a time period and their energy demand were determined by conducting load audit.

Table 3.1: The Critical Load Rating of the Load to be Connected to the PV System

S/N	LOCATIONS (OFFICES)	CRITICAL LOAD	QTY	WATT (AC)	TOTAL WATT (AC)	USE H/D	WATT.HOUR (AC)
1	OFFICE 1 (PROF S.O IGBINOVIA)	TELEVISION	1	75	75	8	600
		ELECTRIC FAN	1	70	70	7	490
		ELECTIC BULB	1	15	15	8	120
		13Amps SOCKET	2	200	400	8	3200
				TOTAL WATT	560	TOTAL AVERAGE ENERGY	4410
2	OFFICE 2 (PROF S.O IKE)	TELEVISION	1	75	75	8	600
		ELECTRIC FAN	1	70	70	7	490
		ELECTRIC BULB	1	15	15	8	120
		13Amps SOCKET	2	200	400	8	3200
				TOTAL WATT	560	TOTAL AVERAGE ENERGY	4410
3	OFFICE 3	TELEVISION	1	75	75	8	600

	(ENGR.G.O IMABEKHA)	ELECTRIC FAN	1	70	70	8	490
		ELECTRIC BULB	1	15	15	8	120
		13 Amps SOCKET	2	200	400	8	3200
				TOTAL WATT	560	TOTAL ENERGY CONSUMED	4410
	OFFICE 19 (ENGR N.S IDIAGI)	TELEVISION	1	75	75	8	600
		ELECTRIC FAN	1	70	70	8	490
		ELECTRIC BULB	1	15	15	8	120
		13 Amps SOCKET	2	200	400	8	3200
				TOTAL WATT	560	TOTAL ENERGY CONSUMED	4410
TOTAL WATT FOR THE FOUR OFFICES = 2240Watt TOTAL ENERGY CONSUMED FOR THE FOUR OFFICE = 17640Watt							

Table 3.1 above reveals the total critical load consumed by all the four offices during the working hours of the day 8am – 4pm, which is 8hrs per day between Monday to Friday.

3.3. Design and Sizing of the Photovoltaic (PV) System

3.3.1 Design and Sizing of the Photovoltaic Module (Solar Panel)

A Felicity Mono-Crystalline PV panel is chosen for this design and its specification is given as;

- Power Output, P_{out} =300W
- Current Maximum Power, I_{mp} = 9.2A
- Voltage Maximum Power, V_{mp} = 32.7V
- Short Circuit Current, I_{sc} = 10.23A
- Open Circuit Voltage, V_{oc} = 40.1V
- Module dimension = 1960× 990× 42 mm
- Cell technology = Monocrystalline
- Maximum system voltage = 1000V DC

3.3.2 Design and Sizing of the Inverter

The power of devices that may run at the same time is

$Power_{total}$ = 2240 watt

Inverter is 25% greater than the total load

Inverter Allowance (I.A) $= P_{total} \times \frac{25}{100}$

I.A $= 2240 \times 0.25 = 560$ watt.

Recommended size of inverter = $Power_{total}$ + I.A = 2240 + 560 = 2800 watt

Alternative Method

Recommended size of inverter = $Power_{total} \times$ Safety factor

Where safety factor = 1.25.

Inverter size = 2240 × 1.25 = 2800 watt

Inverter size in KVA = $\frac{P}{\cos x}$ (1)

Power factor of the device = Efficiency of inverter = 0.8

Inverter size in VA = $\frac{2800}{0.8}$ = 3500VA

Approximately 3.5KVA

The daily energy requirement from the solar array can be determined as follows

$$E_{required} = \frac{daily\ average\ consumption}{product\ of\ component's\ efficiencies} = \frac{E}{N_{overall}} \quad (2)$$

$$E_{required} = \frac{17640}{0.8} = 22.05KWh$$

To obtain the peak power, the previous result is divided by the average sun hours per day for the geographical location T_{min}.

$$P_{peak} = \frac{daily\ energy\ requirement}{minimum\ peak\ sun\text{-}hours\ per\ day} \quad (3)$$

$$P_{peak} = \frac{22.05}{5.5} = 4KW$$

The total current needed can be calculated by dividing the peak power by the maximum power DC voltage of the system.

$$I_{dc} = \frac{peak\ power}{System\ Dc\ Voltage} = \frac{P_{peak}}{V_{dc}} \quad (4)$$

$I_{dc} = \frac{4000}{32.7} = 122.3$Amps

Approximately = 122Amps

Modules must be connected in series and parallel according to the need to meet the desired voltage and current in accordance with:

First, the number of parallel modules which equals the whole modules current divided by the rated current of one module I_{rated}.

$$N_p \quad = \quad \frac{Whole\ Module\ Current}{rated\ current\ of\ one\ module} = \frac{I_{dc}}{I_{rated}} \qquad (5)$$

$N_p = \frac{122}{9.2} = 14$ panels.

Second, the number of series modules which equals the DC voltage of the system divided by the rated voltage of each module V_{rated}.

$$N_s \quad = \quad \frac{system\ Dc\ voltrage}{module\ rated\ voltage} = \frac{V_{dc}}{V_{rated}} \qquad (6)$$

$N_s = \frac{24}{24} = 1$

Finally, the total number of modules N_m equals the series modules multiplied by the parallel ones:

$$N_m = N_s \times N_p \qquad (7)$$

$N_m = 1 \times 14 = 14$ panels

3.3.3 Sizing of the Battery Bank

Total Average Energy Use = 17640Wh

Days of autonomy or the no-sun days = 3days

(According to the selected battery NST 200AH, 12V)

The amount of energy storage required is, $E_{rough} = 17640 \times 3 = 52920$Wh

$$Energy_{safe} = \frac{energy\ storage\ required}{maximum\ depth\ of\ discharge} = \frac{E_{rough}}{MDOD}$$

$$Energy_{safe} = \frac{52920}{0.75} \text{Wh} = 70560\text{Wh}$$

At this moment, we need to make a decision regarding the rated voltage of each battery V_b to be used in the battery bank. The capacity of the battery bank needed in ampere-hours can be evaluated by dividing the safe energy storage required by the DC voltage of one of the batteries selected:

$$C = \frac{Energy_{safe}}{V_b} = \frac{70560}{12} = 5880Ah \quad (8)$$

The total number of batteries is obtained by:

$$N_{battery} = \frac{C}{Cb} \quad (9)$$

$$N_{battery} = \frac{5880}{200} = 30 \text{ batteries}$$

The connection of the battery bank can be then easily figured out. The number of batteries in series equals the DC voltage of the system divided by the voltage rating of one of the batteries selected:

$$N_s = \frac{V_{dc}}{V_b}$$

$$N_s = \frac{24}{12} = 2$$

Then number of parallel paths N_p is obtained by dividing the total number of batteries by the number of batteries connected in series:

$$N_p = \frac{30}{2} = 15 \text{ parallel branches}$$

3.3.4 Sizing of the Charge Controller

When sizing a charge controller, we take account of the safety which is 1.25 according to standard practice.

The solar charge controller rating is given as

$I = I_{sc} \times N_p \times F_{safe}$

$I = 10.23 \times 14 \times 1.25 = 179$Amps

Hence, for the department, our solar system would be needing a charge controller of rating 12V, 200A

To determine the number of charge controller according to the selected controller equals to

$N_{controller} = \frac{I}{Amps\ of\ each\ controller}$

No of controller $= \frac{179}{200} = 0.89$

Approximately = 1 charge controller.

3.3.5 Sizing of the Inverter Battery Circuit Breaker Rating

According to the selected inverter 3.5KVA/24V, the maximum charging current rating = 21Amps

Therefore,

Circuit Breaker Rating = 145% × maximum current rating

Circuit Breaker Rating $= \frac{145}{100} \times 21 = 30.45$A

The circuit breaker rating needed for the inverter battery would be = 31Amps

3.3.6 Sizing of the Solar Panel Circuit Breaker

The solar panel array has a short circuit I_{sc} of 10.23A. The number of solar panel connected in parallel is 15.

Panel Circuit Breaker Rating = 145% × Solar Panel in parrallel × I_{sc}

Panel Circuit Breaker Rating $= \frac{145}{100} \times 14 \times 10.23 = 207.7$A

The Circuit Breaker Rating needed for the solar panel would be 250A

3.3.7 Cable Sizing

In order to determine the cable size that would be required for the inverter, solar panel and battery to power the offices, we take into account the amount of voltage and current required for each of the component. Then, we try to determine the best cable size for them by using the cable gauge chart as shown in table 3.2

Table 3.2: Cable Gauge Chart

Cable Cross Sectional Area	2 cables, single phase AC or DC		3 or 4 cables, three phase AC	
	Current Carrying Capacity	Volt drop per ampere per meter	Current carrying capacity	Volt drop per ampere per meter
mm^2	A	mV	A	mV
1.0	14	42	12	37
1.5	17	28	14	24
2.5	24	17	21	15
4	32	11	29	9.2
6	45	7.1	37	6.2
10	55	4.2	1	3.7
16	74	2.7	6	2.7
25	97	1.7	7	1.5
35	119	1.3	06	1.1
50	145	0.97 AC 0.91 DC	25	0.84
70	185	0.71 AC 0.63 DC	60	0.62
95	230	0.56 AC 0.45 DC	95	0.48
120	260	0.48 AC 0.36 DC	20	0.42

3.3.8 Solar Panel Cable Sizing

In order to get the total DC current for the PV module, it is given as

DC current = Short circuit current (I_{sc}) of the PV module × Module in parallel

DC current = 10.23 ×14 = 143.22A

We have to determine the cable size which we shall check from the cable chart in table 3.1, from the cable chart, 70mm^2 multiple stranded DC cable is suitable with a current capacity 143.22A of and volt drop of 0.71mV. We assume a distance of 15m from the point of installing our PV to where the circuit breaker is connected.

Voltage drop for a distance 15m = $\frac{185\times15\times0.62}{1000}$ = 1.72V

Since we have 14 PV module and each connected in parallel. But the permissible voltage drop of the cable should be less than 2.5% of parallel PV connected PV module that is

Voltage of the parallel connected module = 32.7 × 2 = 65.4V

2.5% of 65.4V = 1.64V

Since the voltage drop for the 15m distance is less than the permissible voltage drop therefore we make use of 70mm^2 DC cable.

3.3.9 Battery Cable Sizing

Inverter rating = 2800Watt/24V

Battery's voltage = 12V

Maximum current for the cable = $\frac{inverter's\ wattage\ \times safety\ factor}{battery\ voltage}$ = $\frac{2800W\ \times1.25}{24V}$ = 146Amps

From our gauge chart in Table 3.2 the recommended size of battery cable = 70mm^2

CHAPTER FOUR

INSTALLATION, TESTING AND RESULT

4.1 Solar Panel Installation

In this chapter, how to install the solar PV system will be highlighted and the tools required. The testing operation was carried out and the result gotten is also stated. The precaution taken during the installation and the bill of quantity is stated. The process of installation is highlighted below;

1. The solar racks which will serve as the base of the solar panel are first mounted on the roof of computer department building.
2. The solar panels are then tilted in order to get the maximum amount of sunlight. Since the sun rise in the east and set in the west, the solar panel are placed in the north-south direction and titled at an angle between 18^o-36^o
3. The solar modules are then mounted on the solar rack where it is then screwed properly with bolts and nuts, where out of the 10 solar modules, 5 solar modules are each connected in parallel before finally connected in series in order to get a total of 75V.
4. For the charge controller, we are going to use an MPPT charge controller. It has 6 terminals, two (2) terminals for the solar panel, two (2) for battery and two (2) for any DC load.
5. The charge controller is then connected to the solar panel where the positive terminal of the solar panel is connected to the positive terminal of the charge controller and the negative terminal of the solar panel is connected to the negative terminal of the charge controller.
6. For the batteries, two batteries are connected in series (positive terminal of a battery unit is connected to the negative terminal of another battery unit) in order to get 24V.

7. The charge controller is then connected to the battery where the positive terminal of the solar panel is connected to the positive terminal of the charge controller and the negative terminal of the battery is connected to the negative terminal of the charge controller.
8. The battery terminals are also connected to the 3.5KVA inverter. The wire of the inverter will then be connected to the distribution board connected to the live wire of the distribution board and the negative wire is connected to the neutral wire of the distribution board.

4.2 Precautions Taken During the Installation

1. The circuit connections were tested to ensure that there is no direct connection between the positive and negative rails before powering the circuit to avoid short circuit (bridging).
2. During the connection of cables from each equipment, tight connections were ensured.

4.3 Choice of Tools

The following tools were used during the installation;

- Digital multi-meter
- Screwdrivers
- Pliers
- Spanners

4.4 Choice of Materials

The number of solar panel required for a specific power output is determined by the average daily load requirement of the house, the climate and peak sunlight in the department, the amount of energy the battery can store, the wattage of the chosen solar panel as well as the efficiency of the panel.

4.5 Bill of Engineering Materials and Evaluation

After the testing and sizing of the PV module, battery, inverter and other components required to provide back-up power for the department. The following estimate was made and shown in table

Table 4. 1: Bill of Engineering Materials and Evaluation

S/N	ITEM	QUANTITY	UNIT RATE	TOTAL AMOUNT(#)
1	Digital multimeter	1	600	600
2	Screws	50	20	2,000
3	Control Switch	1	1	6,000
4	Tape	2	100	200
5	12V/200AH battery	2	90,000	180,000
6	3.5KVA inverter	1	250,000	250,000
7	300W monocrystalline solar panel	2	50,000	100,000
8	Charge Controller	1	20,000	20,000
9	Connecting wire	28 yards	500	1,400
10	Trunking pipe	4	250	1000
11	Change over	1	3,500	3,500
12	Connector(100A)	4	800	3,200
13	$35mm^2$	1 coil	-	5,000
14	$16mm^2$	1 coil	-	5,000
15	$10mm^2$	1 coil	-	5,000
16	miscellaneous			20,000
	Total			602,900

Table 4. 2: Different Test Result Carried out with the Solar PV Module

S/N	TEST	VOLTAGE VALUE	CURRENT VALUE	TEMPERATURE
1	Open circuit test of panel	37.2	-	$60^{O}C$
2	Short circuit test of panel	-	8.93	$60^{O}C$
3	On-load	34.5	8.5	$60^{O}C$

4.6 Results

It was observed that during the noon time at between 12pm -3pm of the day the open circuit and short circuit readings was higher compared to the early hour of the day. At noon time during hot weather when the temperature was extremely high, the charging current supplied to the battery from the solar panel was high, hence making the battery to become fully charge on time. During short circuit test of the solar array of more than one panel, care was taken and the reading was taken as fast as possible to prevent damage of one or more solar cells as the current produced by the panel was high.

We noted that when the panel where tilted at angle between 20 to 45 degree with no obstruction on the solar cells, a higher and accurate reading was obtained thereby increasing the efficiency and power output of the panel.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The main objective of installing a solar power system, with uninterruptible power supply (inverter) for the above mentioned offices in Electrical/Electronic department, University of Benin was successful. The system uses the storage battery as the main power source supported by the solar PV module and with mains supply as back-up. The design and installation was based on the need of an alternative power supply to the department of Electrical/Electronic Engineering.

Also, as shown in the techno-economic section, although the initial cost implication of having this solar home setup may be huge, but compared to using petrol or diesel generators over a twenty-five (25) year period, the department would not only break-even but little or no maintenance may be required by the solar system during the entire period. In contrast a petrol or diesel generator may not even last that long as efficiency decreases as utilization increases meanwhile the solar panels have typical life-spans of up to forty (40) years and may even last longer with proper maintenance.

The variances in solar radiation can cause huge difference in the system size. This is because the solar radiation gives the available sun hours. If sun hours are low, then a bigger system is required. From the results section it can be observed that the location of the system plays a great part in sizing. The areas that have low solar radiation require more PV modules and batteries. It is vital that accurate information on solar radiation is obtained to avoid over sizing or under sizing of the system.

It can also be noted that the size of the inverter and charge controller do not change with location. This is because their sizing only depends on the loads connected. It is important that accurate load and component data is taken from manufacturer's data sheets to ensure accuracy in the calculations.

The objectives of the project were achieved as well as the comprehensive understanding of PV systems. The system sizing technique presented is consistent and is recommended for Grid fallback.

5.2 Recommendation

It is a highly recommended that stand alone photovoltaic system designers adopt this design as it incorporates all the aspects of system sizing and also any unforeseen losses in power due to equipment. The design is also simple to use and quite straight forward. Some practical recommendations for designing, installing, and operating stand-alone PV systems are;

1. Keep the design simple - Complexity lowers reliability and increases maintenance cost.
2. Understand system availability - Achieving 99+ percent availability with any energy system is expensive.
3. Be thorough but realistic, when estimating the load - A 25 percent safety factor can cost a great deal of money.
4. Cross-check weather sources - Errors in solar resource estimates can cause disappointing system performance. The system may be undersized or oversized and this means that it will not meet requirements.
5. Know the installation site before designing the system - A site visit is recommended for good planning of component placement, wire runs, shading, and terrain peculiarities.
6. Install the system carefully - Make each connection as if it had to last 30 years. Use the right tools and technique. The system reliability is no higher than its weakest connection.
7. Safety first and last – Do not take shortcuts that might endanger life or property. Comply with local and national building and electrical codes.
8. Plan periodic maintenance - PV systems have an enviable record for unattended operation, but no system works forever without some care. Routine maintenance is important to increase the life span of this system.

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