Sudan University of Science &Technology

College of Graduate Studies

Sizing of Photovoltaic System

A Case Study: Health Centre at Kenana Agricultural Area Seven

حجم سعة المنظومة الشمسية

دراسة حالة : مركز صحى القرية 7 بشركة سكر كنانة

A Thesis Submitted in Partial Fulfillment for the requirements
for the degree of M.Sc. in Mechatronics Engineering

By

IDRIS ELTAYEB ABDALDAIM MOHAMMED

Supervisor

Dr. ZAKARIA ANWAR ZAKARIA

December 2016

بسم الله الرحمن الرحيم

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الآية

قال تعالى

{ هُوَ الَّذِي جَعَلَ الشَّمْسَ ضِيَاءً وَالْقَمَرَ
نُورًا وَقَدَّرَهُ مَنَازِلَ لِتَعْلَمُوا عَدَدَ
السِّنِينَ وَالْحِسَابَ مَا خَلَقَ اللَّهُ ذَلِكَ
إِلَّا بِالْحَقِّ يُفَصِّلُ الْآيَاتِ لِقَوْمٍ
يَعْلَمُونَ (5) إِنَّ فِي اخْتِلَافِ اللَّيْلِ
وَالنَّهَارِ وَمَا خَلَقَ اللَّهُ فِي السَّمَوَاتِ
وَالْأَرْضِ لَآيَاتٍ لِقَوْمٍ يَتَّقُونَ (6)}

صدق الله العظيم
سورة يونس الآيات 5- 6

Dedication

I would like to dedicate this thesis to

My Parents

My Family

My Friends

And

My Colleagues Whom Have Supported Me during This Work.

Acknowledgement

I would like to acknowledge the valuable guidance, encouragement and assistance provided by my supervisor; Dr. Zakaria Anwar Zakaria during the thesis process and development of this document. I also would like to recognize Kenana Sugar Company, power distribution section for providing me all the information about Area seven solar project without which it could have been very difficult to achieve the results obtained.

I am also grateful to my colleagues for being friendly and having contributed to a good working environment.

Abstract

Rural health service is an important national and international priority. However, the availability of electricity to support proper rural health services is less than adequate in many countries. In recent years the development of reasonably priced and reliable energy systems has made it possible to provide vaccines and other basic health care services in remote areas. A number of international, national, local institutions and private companies are now deploying renewable energy systems to rural communities in the developing world where health care in rural areas is a national priority.

This thesis presents a study and sizing of a complete stand-alone photovoltaic (PV) system for providing the electrical loads in an emergency health clinic according to their energy requirements. Typical energy consumption daily profiles for Kenana area seven health center. The PV system is optimally sized to be an optimal economic system. Computer software is used to sizing and optimization tool to determine the size of photovoltaic system components, system corresponding produced electrical energy. The results were 74 solar modules (200watt), 32 batteries (12V, 180Ah), 1 Inverter (4825w, 48Vdc, 230Vac) and 1 charge controller (80A, 48Vdc). The results show that the sizing of PV stand-alone system depends on the load data, the solar resource data and system components.

المستخلص

أهمية الخدمات الصحية في المناطق الريفية تجد أولوية محلية وعالمية ومع ذلك فإن وجود الكهرباء لدعم الخدمات الصحية في المناطق الريفية غير كافئ في كثير من الـــدول. أدى التطور في الوقت الحالي إلى امكانية توفير وموثوقية الطاقة مما أدى الى إمكانية وجود اللقاحات الطبية والخدمات الصحية الأساسية في المناطق الريفيـــة. وهنـــاك عـــدة معاهـــد وشركات محلية وعالمية في الوقت الحالي بصدد توفير نظم الطاقة المتجـــددة للمجتمعـــات الريفية في الدول النامية لاستخدامها في المراكز الصحية الريفية.

هذه الاطروحة تقدم دراسة وتحديد سعات خلايا الطاقة الشمـــسية المطلوبـــة لمركـــز صحى على حسب الطاقة الكهربائية المطلوبة ، وبالتحديد الطاقة الكهربائية المـــستهلكة فـــي مركز صحى القرية 7 في شركة سكر كنانة.

الخلايا الشمسية حددت بشكل مثالي لتكون عالية الموثوقية. تـــم اســـتخدام برنـــامج كمبيوتر لتحديد سعات مكونات نظام الطاقة الشمسية وتقدير كمية الطاقة الشمـــسية المنتجـــة بواسطة الخلايا. النتائج كانت 74 خلية 200 واط ، 32 بطارية 180امبيـــر 12 فولـــت، 1 محول من تيار مباشر لتيار مستمر 4825 واط ، 1 متحكم شحن تيار مباشر 80 امبير. من النتائج يظهر ان تحديد سعة الخلايا الشمسية المطلوبة يعتمد على بيانات الأحمال للمعـــدات الكهربائية ومعلومات قوة إشعاع الطاقة الشمسية في المنطقة ومكونات نظام الطاقة الشمسية.

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List of Abbreviations and Symbols

PV	:	Photovoltaic
DC	:	Direct current
KSC	:	Kenana Sugar Company
P	:	Positive
N	:	Negative
AC	:	Alternating Current
STC	:	Standard Test Condition
BOS	:	Balance of System
PCU	:	Power Conditioning Unit
MPPT	:	Maximum Power Point Tracking
V	:	Volt
I	:	Current
RE	:	Renewable Energy
FLA	:	Flooded Lead Acid
AGM	:	Absorbent Glass Mat
DOD	:	Depth of Discharge
CC	:	Charge Controller
PWM	:	Pulse Width Modulated
GTI	:	Grid Tied Inverter
TV	:	Television
KW	:	Kilowatt
WP	:	Watt Peak
PSH	:	Peak Solar Hours
NS	:	No of Series
VS	:	System Voltage
VRLA	:	Valve Regulated Lead Acid
Ah	:	Ampere hours

Hz	:	Hertz
SHS	:	Solar Home System
HVD	:	High Voltage Disconnect
LVD	:	Low Voltage Disconnect
LED	:	Light Emitter Diode

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CHAPTER ONE

Introduction

1.1 Overview

Photovoltaic (PV) Solar Systems generate electricity from sunlight collected by solar modules or panels. Energy generated by this method can be used to supply direct power to electrical equipment; also it can be stored in batteries to supply indirect power. In set of a battery, PV systems are better for handling small to medium sized loads in locations where network of electricity is not available. They are highly modular, so it is easy to modify the system to the needs and add units if power required increases. PV systems are calmness and produce no emissions. Photovoltaic systems provide direct current (DC) power, Inverters, which convert this DC power to AC power, must be added to almost systems powering medical equipment's used in small or higher health clinics.

1.2 Problem statement

Electricity is more essential commodity in remote healthcare facilities. Modern improvements in the allocation of vaccines and other cold chain-dependent subsistence, treatments and services worldwide, have introduced new demands for electricity in sites with little or no access to reliable electrical power. Fridge and electronic diagnostic apparatus are part of the standard of care in many provincial clinics throughout the world. If the cold chain is inoperable when supplies arrive, vaccines, blood, and other medicines may go to waste. If a health centers without lights, patients arriving at night must wait until morning to receive care. Selecting an appropriate source of reliable and sustainable energy can help mitigate some of the challenges inherent in operating a health facility in the developing countries.

This thesis study the sizing of PV for agricultural area seven located in an extension eastern side of the existing Kenana sugar company fields. Agricultural area seven is a small community composed of an administrative building, a health center, and three types of housing.

Some reasons that let Kenana use solar system to supply agricultural area seven:

- Area -7 around 50km away from Kenana electrical network, if required to feed power to area -7, need a lot of capital budget.
- Minimize the operation and maintenance.
- Large amount of solar energy available in area-7 location.
- Didn't depend on any outside backup sources.
- Low cost for operation and running.
- Maximum stable and continuous power supply.
- Save Kenana resources.

1.3 Objectives

The sizing of photovoltaic system for health centre at Kenana agricultural area seven is the main objective of this thesis, which some established practices had chosen to be used as the basis of the PV model and the other objectives are:

- To calculate power consumption demands, total Watt-hours per day for each appliance used, and the total Watt-hours per day needed from the PV modules.
- To size the PV modules, inverter, bank of batteries and solar charge controller sizing.
- Utilization available package.

1.4 Methodology

The system sized by calculation of power consumption demand required by health centre according to power demand and peak power. The PV modules, inverter, batteries and solar charge controller were sizing with ability to extension in future. Computer program is developed for sizing the photovoltaic system used in this thesis and it can be used to sizing other similar photovoltaic system, the programs calculate the PV required panels, required batteries, required charge controller and inverter when the value of calculated watts is entered.

1.5 Thesis outlines

This thesis consists of five chapters, chapter one has presented an introduction of Photovoltaic (PV) Solar Systems and background, importance, methodology, objectives and overview of the thesis. In chapter two a literature survey about the solar cells, their types and technology and their basic applications has been presented. Chapter three concerned with the calculation of power consumption demands of health centre, size of PV modules, Inverter sizing, battery sizing and solar charge controller sizing. Chapter four concerned with the sizing of photovoltaic required by health centre and the result discussions. Chapter five represent conclusion and recommendations for further study.

CHAPTER TWO

Literature Review

2.1 PV Theoretical background

The word photovoltaic is come from two different words; the word photo from the Greek meaning light and the word 'voltaic' from the name of the Italian scientist, Volta, who studied electricity. This explains what a PV system does: it converts sun light energy into electrical energy. The first photovoltaic cells were produced in the last of 1950s, and throughout ten years were principally used to provide electrical power for earth-orbiting satellites [1].

The developing in manufacturing, performance and quality of PV panels helped to reduce costs and opened up a number of opportunities for powering remote earthly applications, including battery charging for navigational aids, signals, telecommunications equipment and other critical low-power needs. Today, the industry’s production of PV modules is growing at approximately 25% annually, and major programs in the U.S., Japan and Europe are rapidly accelerating the application of PV systems on buildings and interconnection to utility networks.

Although solar electricity producing appliances have been around for over 50 years, solar electricity appliances, often referred to as photovoltaic or PV, are still considered cutting edge technology. The promise of clean, cheap, and abundant electricity from the sun has been the dream of many scientists and businesses. As a result each year a number of discoveries and advances for this technology have been made.

This background has been written to cover some of the basic concepts, components, fundamental and fabrication techniques and uses of photovoltaic [3].

Photovoltaic systems have a number of unique advantages over conventional power generating technologies; PV systems can be designed for a variety of applications and operational requirements, and can be used for either centralized or distributed power generation. PV systems have no moving parts, are modular, easily expandable and even transportable in some cases. Energy independence and environmental compatibility are two attractive features of PV systems. The fuel (sunlight) is free, and no noise or pollution is created from operating PV systems. In general, PV systems that are well designed and properly installed require minimal maintenance and have long service life time.

Solar photovoltaic generation is one of the most environmental friendly methods of generating electricity and a lot of work has been done in this field since the solar PV cell was invented. In this chapter reviews literature on works and sizing of solar photovoltaic generating systems [5].

2.1.1 Fabrication of PV Cells

The process of fabricating classic single- and polycrystalline silicon PV cells begins with very pure semiconductor-grade poly silicon - a material processed from quartz and used excessively throughout the electronics industry. The poly silicon is then heated to melting temperature, and trace amounts of boron are added to the melt to create a P-type semiconductor material. Next, an ingot, or block of silicon is formed, commonly using one of two methods [2].

(i) By growing a pure crystalline silicon ingot from a seed crystal drawn from the molten poly silicon or

(ii) By casting the molten poly silicon in a block, creating a polycrystalline silicon material.

Individual wafers are then sliced from the ingots using wire saws and then subjected to a surface etching process. After the wafers are cleaned, they are placed in a phosphorus diffusion furnace, creating a thin N-type semiconductor layer around the entire outer surface of the cell. Next, an anti-reflective coating is applied to the top surface of the cell, and electrical contacts are imprinted on the top (negative) surface of the cell. An aluminized conductive material is deposited on the back (positive) surface of each cell, restoring the P-type properties of the back surface by displacing the diffused phosphorus layer. Each cell is then electrically tested, sorted based on current output, and electrically connected to other cells to form cell circuits for assembly in PV modules.

2.1.2 Thin Film Photovoltaic

Thin-film photovoltaic modules are produced by depositing ultra-thin layers of semiconductor material on a glass or thin stainless-steel substrate in a vacuum chamber. A laser-scribing process is used to separate and weld the electrical connections between individual cells in a module. Thin-film photovoltaic materials presenting great promise for reducing the materials requirements and manufacturing costs of PV modules and systems [3].

2.1.3 Cells, Modules and Array

Photovoltaic cells are connected electrically in series and/or parallel circuits to produce higher voltages, currents and power levels. Photovoltaic modules composed of PV cell circuits sealed in an environmentally protective laminate, and are the fundamental building blocks of PV systems. Photovoltaic panels involve one or more PV modules assembled as a pre-wired, field-installable unit. A photovoltaic array is the complete power-generating unit, consisting of any number of PV modules and panels. Figure (2.1) shows PV Cell, Panel (Module) and Array.

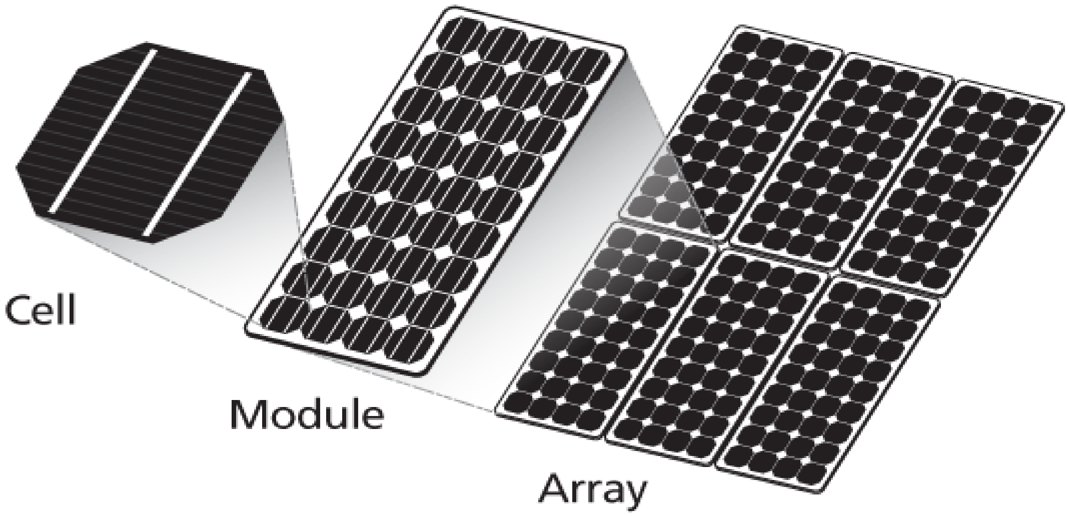


Fig. (2.1): PV cell, Module and Array

The performance of PV modules and arrays are generally rated according to their maximum DC power output (watts) under Standard Test Conditions (STC). Standard Test Conditions are defined by a module operating temperature of 25º C (77º F), and incident solar irradiance level of 1000 W/m^2 and under Air Mass 1.5 spectral distribution. Since these conditions are not always typical of how PV modules and arrays operate in the field, actual performance is usually 85 to 90 percent of the STC rating.

Today's photovoltaic modules are extremely safe and reliable products, with minimal failure rates and projected service lifetimes of 20 to 30 years. Most major manufacturers offer warranties of 20 or more years for maintaining a high percentage of initial rated power output. When selecting PV modules, look for the product listing, qualification testing and warranty information in the module manufacturer's specifications [4].

2.1.4 Work of PV Cell

A typical silicon PV cell is composed of a thin wafer consisting of an ultra-thin layer of phosphorus-doped (N-type) silicon on top of a thicker layer of boron-doped (P-type) silicon. An electrical field is created near the top surface of the cell where these two materials are in contact, called the P-N junction. The sunlight strikes the surface of a PV cell; this electrical field provides momentum and direction to light-stimulated electrons, resulting in a flow of current when the solar cell is connected to an electrical load.

Regardless of size, a typical silicon PV cell produces about 0.5 – 0.6 volt DC under open-circuit, no-load conditions. The current (and power) output of a PV cell depends on its efficiency and size (surface area), and is proportional to the intensity of sunlight striking the surface of the cell. Under peak sunlight conditions, a typical commercial PV cell with a surface area of 160 cm^2 (~25 in^2) will produce about 2 watts peak power. If the sunlight intensity were 40 percent of peak, this cell would produce about 0.8 watts. Figure (2.2) shows the PV cell works.

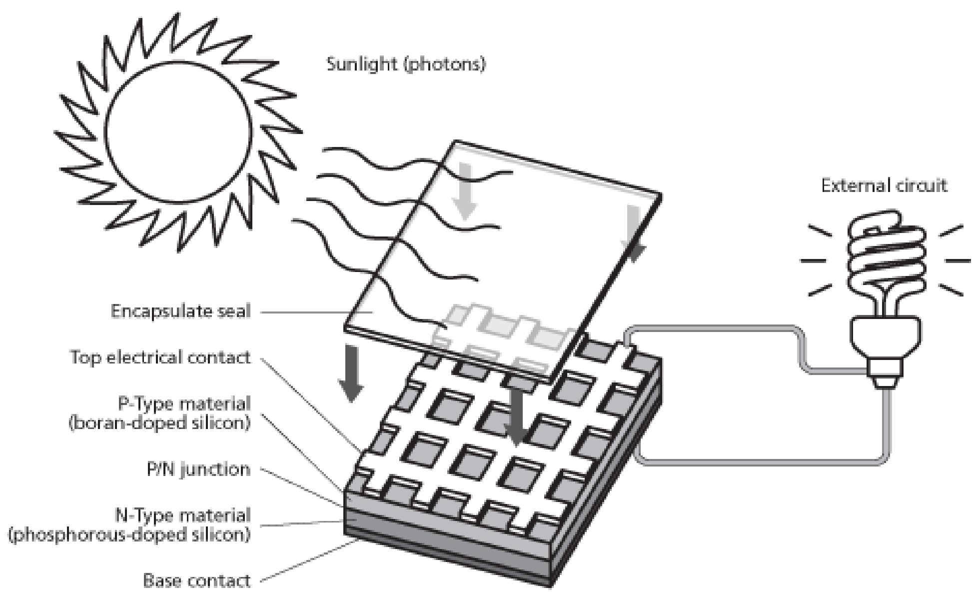


Fig. (2.2): Diagram of a photovoltaic cell.

2.1.5 Work of PV System

PV systems are like any other electrical power generating systems; just the equipment used is different than that used for conventional electromechanical generating systems. Although a PV array produces power when exposed to sunlight, a number of other components are required to properly conduct, control, convert, distribute, and store the energy produced by the array.

Depending on the functional and operational requirements of the system, the specific components required may include major components such as a DC-AC power inverter, battery bank, battery charge controller, auxiliary energy sources and sometimes the specified electrical load (appliances). In addition, an assortment of balance of system (BOS) hardware, including wiring, over current, surge protection and disconnect devices, and other power processing equipments. Figure (2.3) shows the work of PV system.

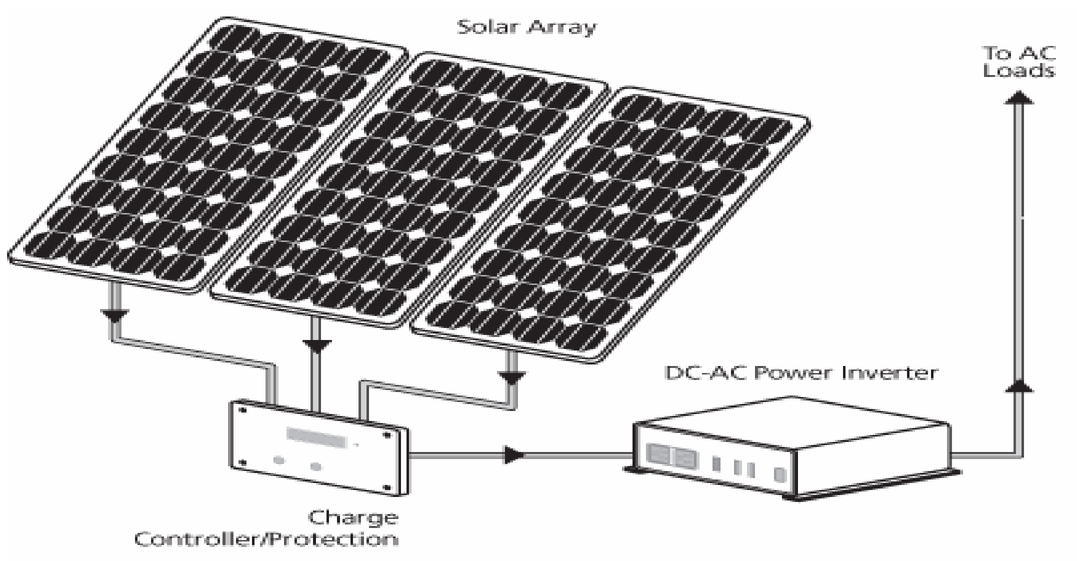


Fig.(2.3): PV / Solar System

2.1.6 PV Systems of batteries

Batteries are used in PV systems for the purpose of storing energy produced by the PV array during the day, and to supply it to electrical loads as needed (during the night and periods of cloudy weather). Other reasons batteries are used in PV systems are to operate the PV array near its maximum power point, to power electrical loads at stable voltages, and to supply surge currents to electrical loads and inverters. In most cases, a battery charge controller is used in these systems to protect the battery from overcharge and over discharge.

2.1.7 Types of PV System

Photovoltaic power systems are generally classified according to their functional and operational requirements, their component configurations, and how the equipment is connected to other power sources and electrical loads. The principal classifications are stand-alone systems, grid-connected systems and hybrid systems. Photovoltaic systems can be designed to provide DC and/or AC power service, can operate interconnected with or independent of the utility grid, and can be connected with other energy sources and energy storage systems.

2.1.7.1 Stand-Alone Photovoltaic Systems

Stand-alone PV systems are designed to operate independent of the electric utility grid, and are generally designed and sized to supply certain DC and/or AC electrical loads. These types of systems may be powered by a PV array only figure (2.4). The simplest type of stand-alone PV system is a direct-coupled system, where the DC output of a PV module or array is directly connected to a DC load figure (2.5).

Since there is no electrical energy storage (batteries) in direct-coupled systems, the load only operates during sunlight hours, making these designs suitable for common applications such as ventilation fans, water pumps, and small circulation pumps for solar thermal water heating systems. Matching the impedance of the electrical load to the maximum power output of the PV array is a critical part of designing well-performing direct-coupled system. For certain loads such as positive-displacement water pumps, a type of electronic DC-DC converter, called a maximum power point tracker (MPPT), and is used between the array and load to help better utilize the available array maximum power output. In many stand-alone PV systems, batteries are used for energy storage; Figure (2.6) shows a diagram of a typical stand-alone PV system powering DC and AC loads.

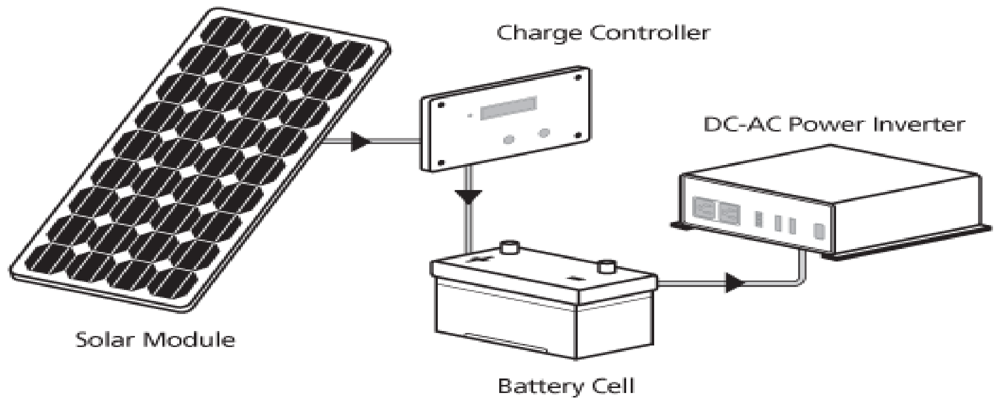


Fig.(2.4): Stand-Alone Photovoltaic Systems

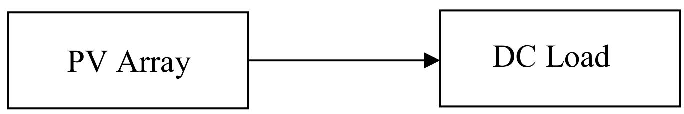


Fig.(2.5): Direct-coupled PV systems.

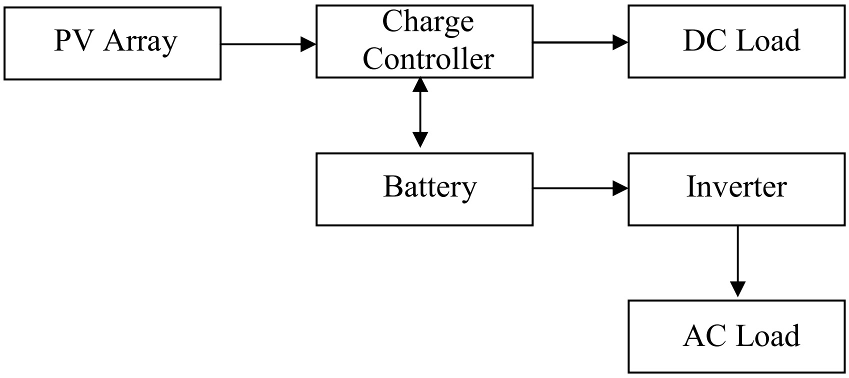


Fig. (2.6): Diagram of stand-alone PV system with battery storage powering DC and AC loads.

2.1.7.2 Grid-connected PV systems

Grid-connected PV systems are designed to operate in parallel interconnected with the electric utility grid. The primary component in grid-connected PV systems is the inverter, or power conditioning unit (PCU). The PCU converts the DC power produced by the PV array into AC power consistent with the voltage and power quality requirements of the utility grid, and automatically stops supplying power to the grid when the utility grid is not energized. A bi-directional interface is made between the PV system AC output circuits and the electric utility network, typically at an on-site distribution panel or service entrance. This allows the AC power produced by the PV system to either supply on-site electrical loads or to back-feed the grid. At night and during the electrical loads are greater than the PV system output, the balance of power required by the loads is received from the electric utility [12]. The safety feature is required in all grid-connected PV systems, and ensures that the PV system will not continue to operate and feed back into the utility grid when the grid is down for service or repair. Figure (2.7) show the grid connected PV system.

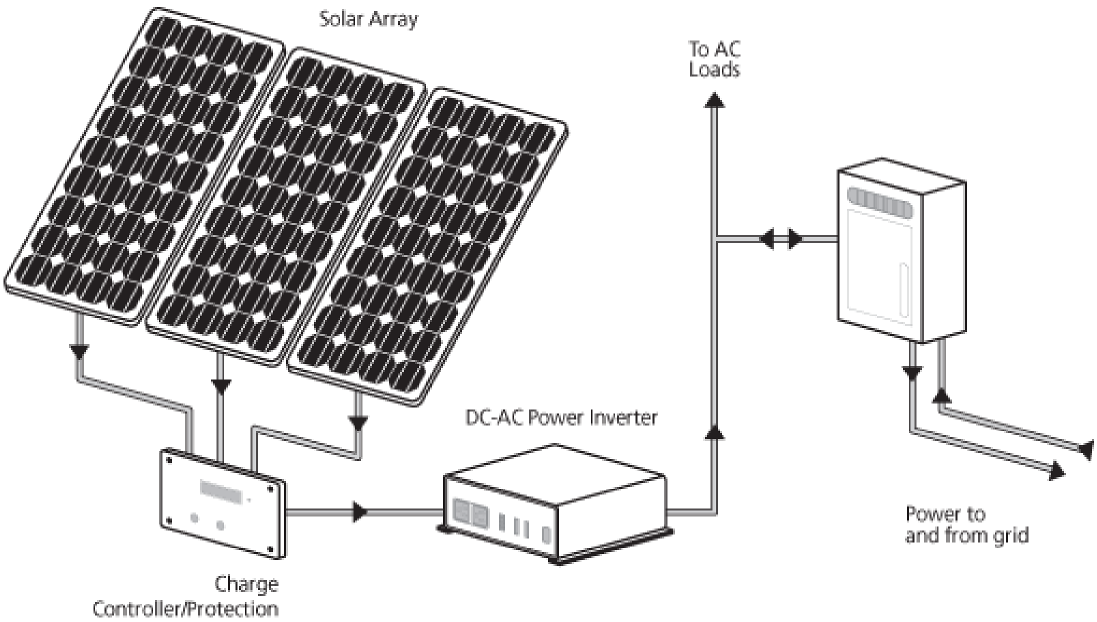


Fig.(2.7): Grid connected PV system

2.1.7.3 Solar Hybrid Power Systems

Solar hybrid power systems are system that combines solar power from a photovoltaic system with another power generating energy source such as Diesel generator, Wind or Grid. As solar energy is fluctuating, and the generation capacity of the diesel generator is limited to a certain range, it is often a viable option to include battery storage in order to optimize solar contribution to the overall generation of the hybrid system.

Another solar hybrid includes solar wind systems. The combination of wind and solar has the advantage that the two sources complement each other because the peak operating times for each system occur at different times of the day and year. The power generation of such a hybrid system is more constant and fluctuates less than each of the two component subsystems [9].

2.2 Sizing of a Solar Photovoltaic System

The components of photovoltaic and their sizes are very important in sizing the system because they determine the type and capacity of the system.

In order to determine the sizes of the components forming the solar photovoltaic system, consideration has to be made of the daily energy demand and daily peak power including the standby power consumed by idle equipment. The demand can then be matched with the solar radiation available on site. However for situations in most parts of Africa and especially within the tropics, where annual average solar insulation is between 4 to 6.4 kWh/m^2/day and solar irradiance of 1.25 kW/m^2 is a common occurrence. It is therefore important to consider general weather conditions and obtain accurate load data to sizing a solar photovoltaic system [6]. In this thesis annual isolation data is used for sizing PV system.

2. 3 Daily Electrical Energy Demand

The daily electrical energy demand is the amount of electrical energy that is required by the consumer to be supplied by the solar PV electricity generation system. Daily energy demand has been estimated by taking the ratings of electrical appliances that are used in a day and the time that they are used during the day or night time. The information then forms a load list which multiplied by the duty cycle of each appliance provides the kWh consumed in a day. A calculation of the individual appliance energy demands gave the estimated energy demand of the site under consideration random variability will create annual realistic load profiles because the daily energy demand is never the same for different days. Otherwise be very expensive and time consuming to collect actual annual daily energy demand data which still not exactly replicate in the subsequent years. Using monthly average solar insulation data also achieves more accurate results compared to using a single annual data [6].

2.4 Solar PV Array Sizing

The solar PV array is the energy gateway into the entire solar photovoltaic system, the good performance is important for the reliability of the system. The output of the solar PV array is affected by many factors like irradiance and temperature so for designing a solar photovoltaic array, these factors require consideration so that the designer can achieve acceptable and accurate results. In these factors, there are tradeoffs which also define the best achievable accuracy in the design. These derating factors must be considered because they adversely affect the performance of the solar PV array, battery storage and the power conversion components.

2.4.1 Types and Performance of Modules

There are mainly three types of solar PV module cells; those made from silicon semiconductors, chemical compounds and organic materials. The silicon cells are produced from either crystalline silicon or amorphous silicon. The crystalline silicon cells are cut from silicon ingots and can be of mono crystalline or polycrystalline form, whereas the amorphous silicon cells are produced from a non-crystalline structure material. The other types of solar cells are the dye sensitized cells that are currently under research but have low efficiencies and degrade very first. Research is under way to improve their efficiencies and reduce the effects of degradation. The silicon crystalline and amorphous silicon modules are the most common because they are the earliest technologies, first generation of PV cells and also have the best cell efficiencies so far. Furthermore, in the silicon types of modules, the mono crystalline type has the highest cell efficiency followed by the polycrystalline and lastly the thin film amorphous silicon. To selecting solar PV modules, their cell efficiency is not a major factor because modules of the same rating will produce the same rated power output but will only difference in their physical sizes. Therefore the main factors to be considered are cost, physical size and manufacturing standards for durability and reliability. This is done by making sure that the modules to be used have detailed technical data sheets [7].

Solar arrays are made of modules connected in a series-parallel formation depending on the power and voltage requirements. When an array is exposed to the sun, the same current flows through all series connected cells and the same voltage is across all the parallel connected cells. The resultant I-V curve of the array is an integration of the I-V curves of all the cells in series and parallel. Figure (2.8) shows the I-V curve for 200W PV module.

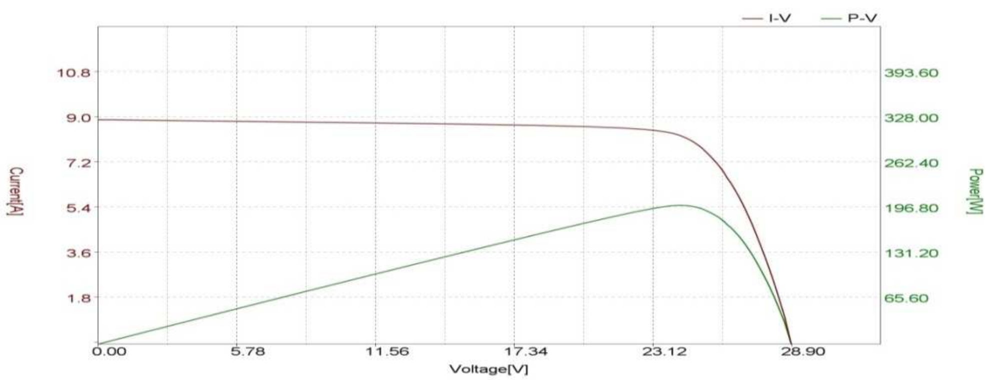


Fig. (2.8): Current, Voltage (I-V) Curves of a Solar PV Module

2.4.2 Orientation of the Solar PV Array and the Tilt Angle

The solar PV array slope or angle of tilt is the angle formed by the array with reference to the horizontal earth surface when mounted. The slope will vary depending on the location of mounting the array. Studies show that common practice of mounting solar modules is to have them at a fixed angle with reference to the ground because it is the simplest and cheapest option. Such fixed orientations normally adopt the latitude of the location as the angle of tilt with the right azimuth. An angle of tilt equal to the latitude of the location and the right azimuth will enable the solar array to extract maximum irradiation between 10 AM and 4.30 PM in most locations. In schemes where the angle of tilt is made equal to the latitude, the systems achieve better annual solar PV energy production compared to other arbitrarily fixed angles [6]. The researchers recommended the angle values shown in Table (2.1) for fixed tilt angles schemes.

Table (2.1): Recommended Fixed Angles for Solar Modules

Latitude Angle	Recommended angle
Latitude < 15 degrees	15 degrees
15 degrees < Latitude < 20 degrees	Latitude
20 degrees < Latitude < 35 degrees	Latitude + 10 degrees
35 degrees < Latitude	Latitude +15 degrees

2.4.3 Effects of Shading on Arrays

A solar PV array performs by generating electricity well when it receives direct irradiation from the sun. If the sun is obstructed or shaded to the array, the output of the array is reduced proportional to the amount of shading. The cells are in series in a module so, while the cell is shaded, the bypass diode conduct but the output current is greatly reduced. Figure (2.9) shows how the current flow in 12V module of 36 cells.

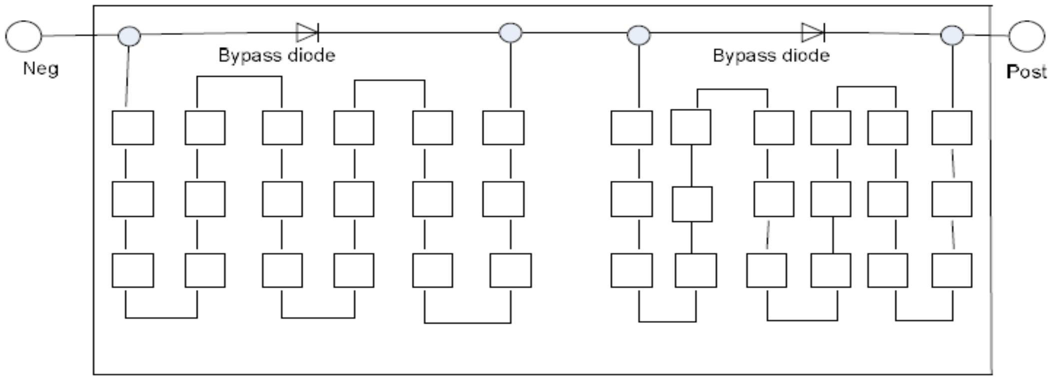


Fig. (2.9): 36 cells solar PV modules with two bypass diode.

2.4.4 Effects of Temperature and Irradiance

The performance of the solar PV array normally depends on the amount of irradiance reaching the array surface. This also causes heating on the solar cells of the array as the day progresses and affects the output voltage of the module. When irradiance reaching the module is reduced, the output current and hence the power is reduced. The effects of reduced irradiance where current is greatly affected while the voltage is affected slightly. Extreme high temperatures also reduce the lifespan of the modules by fast weathering.

If the effects of temperature are not clearly accommodated in the design of a solar PV array then a temperature derating factor is also applied. On the cell temperature characteristics, temperature adversely affects the power output of the solar cell by reducing the output voltage of the array. At lower temperatures, more power can be extracted from the solar cell with the same solar isolation. But as the temperature increases from 25°C to 75°C, the power output is reduced for the same solar insulation. Therefore, this trend makes the cell temperature a major factor to be considered for designing a Solar PV system [10].

2.4.5 Other Minor Derating Factors

Minor derating factors are factors whose effects also reduce the output of the array but the effects could be controlled or extirpate during design and sizing. These are factors like; aging, which can be controlled by timely replacement of modules, dust, which can be minimized by tilting the modules, wiring, which can be reduced by using the right size of conductors and mismatch, which can be eradicated by using modules from the same manufacturing standards [15]. Therewith these factors are controllable; they still affect many solar PV systems because of lack of proper consideration during design and sizing. Table (2.2) shows most of the derating factors that are used in design and sizing.

Table (2.2): Derating Factors for Solar PV Modules Sizing

Derating Due to	Factor Percentage
Mismatch	0.98
Efficiency	0.95
Dust	0.97
Shading	0.99
Wiring	0.98
Temperature	0.96
Aging	0.98

2.5 The Solar Photovoltaic System Bus Voltage

The solar PV system voltage is the Direct Current (DC) bus voltage at which the solar array, the battery bank and the system power inverter are operated. Depending on the power output of the system, the system voltage could be in the range 12 V up to 500 VDC. The battery bank is normally formed by individual batteries at 2 V, 6 V or12 VDC depending on the preference of the sizing and the allowable voltage drops in the DC circuit. So the total number of individual batteries that a designer will need to complete the battery bank will be determined by the system voltage and the total ampere hour capacity required by the system. Most of the time, the battery bank ampere hour capacity is held at safe levels so that the system voltage increases as the power increases. In this study 48 VDC system bus voltage is used [12].

2.6 Battery Storage System

The battery storage system is so far the most efficient and readily available method of storing electrical energy in Renewable Energy (RE) systems. Batteries are used to store electrical energy in renewable solar PV energy schemes because the source of energy is only available for part of the day. There are three major types of batteries popularly used in RE systems studies namely; the flooded lead acid (FLA) battery, Sealed Absorbent Glass Mat (AGM) battery and the sealed Gel cell battery. All the three types of batteries can be manufactured as deep cycled or duty cycled battery types for use in RE schemes. Such duty cycled batteries are capable of holding charge for long periods and also Withstanding deeper discharge cycles of up to 80% of their charge capacity as compared to the shallow discharge types. They are also able to withstand cruel weather conditions like high and low ambient temperature. Among the three types, the AGM and Gel cell batteries are more expensive on initial capital cost but are almost maintenance free compared to the FLA types of batteries. The advantages of the AGM and Gel batteries outweigh their initial capital cost and so they are preferred to the FLA for use in RE systems. Among the last two types, the Absorbent Glass Mat type is the most popular type in renewable systems because of its performance, long life and reliability.

For sizing PV system before determining the size of the battery bank, there are factors that must be considered so as to get the right size of battery bank. These factors are; the daily energy demand, number of days of autonomy, depth of discharge (DOD), ambient temperature of the location and system bus voltage.

The daily electrical energy demand of a consumer, as stated previously, is the amount of energy that will be required by the consumer for the whole day and must be supplied by the solar PV system every day. This demand can be estimated by taking the ratings of electrical appliances that are used, and the period that is used in a day as it's done for the solar PV array sizing. Then daily ampere hour capacity rating of the battery is obtained by dividing the daily energy demand by the system voltage. The number of days of autonomy is the number of days in a row weather that user of solar PV energy will need to draw energy from the battery bank without recharging the bank. In other words these are the number of consecutive "cloudy" days when the sky is not clear and the output of the solar PV array is very low. The accurate number of the days of autonomy is difficult to predict but an estimate could be obtained from a weather website /station or local weather station.

The battery depth of discharge is the limit of electrical energy capacity in ampere hours at the rated bus voltage that can be withdrawn from the battery in one full cycle. The depth of discharge is normally expressed as a percentage of the total charge capacity. A battery is fully charged when it attains its rated ampere-hour capacity and the cell voltage is 14.4 volts DC. The same battery is fully discharged if the cell voltage reduces to 9.6 volts and has 20% its rated ampere hour capacity.

Battery discharge states can either be shallow or deep. A shallow discharge state when the depth of discharge does not exceed 20% of the battery rated capacity after discharge. Whereas a deep discharge state is the DOD does not exceed 80% of battery rated capacity after discharge. Deep battery discharges normally shorten the life of the batteries because they reduce the charging cycles. This is the main reason why battery manufactures recommend that batteries should never be discharged below 50% of their rated ampere hour capacity rating. The shallower the level of the cycle DOD the longer will be the battery life. A safe DOD for a battery is 20% of its full capacity rating every day [8].

2.7 Battery Charge Controller

A battery charge controller (CC) is a component that is used between the solar PV module and the battery to switch ON and OFF the battery charging process. Charge controllers keep the batteries fully charged so as to protect them from exceeding charge and discharge levels. Most charge controllers like the pulse width modulated (PWM) types, have capabilities of controlling the discharge process of the battery by disconnecting the load when a preset discharge level is attained. On the other hand, the Maximum Power Point Tracking (MPPT) charge controller has capabilities of shifting the charging point of the battery from the battery voltage to the MPPT voltage there by increasing the charging power. However this charge controller is not suitable where temperature is very high like in harsh areas.

Consequently, the choice of a CC is made considering ambient temperature and irradiance of the particular site.

Charge controllers are rated in system DC voltage and the maximum charging current of the solar PV array. Most charge controllers have two modes of charging; the boost charging mode and the trickle charging mode. The boost charge is used to charge the battery to full charge and the trickle charge mode is used to maintain the battery at full charge without getting over charged. The PWM type of CC works very well to maintain the trickle charge of batteries. However in PV systems, the charging current is totally dependent on the amount of solar irradiance so the controllers alternate from full rate to trickle charge mode during daily charging.

2.8 Solar Photovoltaic Inverter

An inverter is an electrical appliance that converts direct current electrical power to Alternating Current (AC) power. All power generating plants that generate direct current power normally need inverters to convert the power generated to alternating current power for use by alternating current rated appliances.

Solar PV inverters can be either stand alone or grid tied. Standalone inverters rely on both the battery storage system and the solar PV array for their power supply. Therefore, these inverters are less complicated because they have less control and monitoring features. On the other hand, the grid tied inverters (GTI) are used in solar PV and other RE hybrid systems that rely on both the solar PV and the grid for their power supply. Grid tied inverters are very sophisticated because apart from the power conversion features, they also incorporate control and monitoring features. Grid tied inverters usually monitor both the solar PV system and the grid so as to respond to the consumers load demand. The GTI also protect the system from grid or utility power outages by isolating the grid during outages and sometimes incorporate a metering facility to enable flexible import and export of power from and to the grid. Grid tied inverters have intelligent control devices which safely isolate or shut down the solar PV system inverter in case of extreme adverse conditions like power outages and overvoltage. The inverter converted the power to alternating current power output at 230VAC that was fed directly into the grid. Inverters are conversion devices and have efficiencies depending on the manufacturing technology [13].

2.9 Power Rating of Solar PV Inverters

Solar PV inverters are rated in the AC voltage, power they can supply, the input DC voltage and current. The choice of an inverter is normally dictated by the features the designer of the solar PV system would want to have. Inverters can be manufactured of different power ratings for both single phase and three phase power output. The input DC voltages can range from 12 V DC to 1000 V DC depending on the power output of the inverter.

The GTIs are the most superior in the market and operate at high efficiencies of up to 95% and at a near unity power factor. The frequency of these inverters is synchronized by a monitoring circuit to that of the grid. During operation, the monitoring circuit sees the GTI as a slave with reference to the grid and so makes the frequency of the GTI synchronized to that of the grid. When the grid frequency falls by 2% or rises by 2%above the pre-set frequency, the GTI is automatically isolated because the condition is similar to a grid power outage. The inverters also incorporate maximum power point tracking (MPPT) features which enable them to extract maximum power from the solar PV array. The maximum power point tracking feature enables the inverter to adjust the output power operation point in real time according to the instantaneous variation of the sun's irradiance received on the solar PV array during the day. The inverter monitors the solar array output so as to regulate its operating power point. This feature is useful when the inverter is supplied directly from the array mostly in systems without storage.

During the night, the inverter operates depending on the bus voltage thus overriding the array output which is zero at night. The grid interactive features of the GTI also enable the inverters to deliver power to the grid whenever the solar PV system has excess power from the solar PV array during the day [10].

The rating of the inverter is determined by the peak power demand of the consumer under consideration. This peak demand can be obtained using a power data logger at the site as in the battery sizing design. The designer must make sure that the inverter peak power rating will accommodate the surge power required by starting motors of all domestic rotating machines. The input voltage to the inverter sometimes rises above the expected bus voltage during peak sun hours. Therefore the input voltage rating of the inverter should be able to accommodate the voltage variations during the charging hours.

The summary of the main features of the solar photovoltaic system resource sizing methods have been reviewed. In the review many observations have been made concerning sizing methods of solar PV systems in different parts of the world. It was also noted that as technology progresses new design and sizing methods are being developed to make solar PV designs and subsequent results as accurate as possible. Lately, solar photovoltaic electricity generation has emerged as a major alternative to conventional hydro, coal, diesel, wind and geothermal methods for electricity generation.

CHAPTER THREE

Sizing of Photovoltaic System

3.1 Introduction

Solar photovoltaic system is one of renewable energy system that uses PV modules to convert sunlight into electricity. The electric power generated from PV modules can be stored or used directly, fed back into grid line or combined with one or more other electricity generators or renewable energy source, here standalone system used. Solar PV system is reliable and clean source of electricity that can suit a wide range of applications such as residence, industry, agriculture, livestock, and here used for health centre.

3.2 Major System Components

Solar PV system includes different components that must be selected according to system type, site location and applications. The major components of solar PV system are PV modules, solar charge controller, inverter, battery bank, and loads.

(i) PV Modules: converts sunlight into DC electricity.

(ii) Solar charge controller: regulates the voltage and current coming from the PV panels going to battery and prevents battery overcharging and extend the battery life.

(iii) Inverter: converts DC output of PV panels into an AC current for AC appliances or fed back into grid line.

(iv) Batteries: stores energy for supplying to electrical appliances.

(v) Load: Are electrical appliances that connected to solar PV system such as lights, TV, refrigerator, radio, etc.

For sizing the PV system the following steps are used:

3.3 Calculation of Power Consumption Demands

The first step is to collect load information in the load list or table. It's same like electrical load schedule, but is a simple for the purposes of constructing a load profile. The load profile is an estimate of the total energy demanded from a power system over a specific period of time (hours, days). The load profile incorporates a time dimension and therefore estimates the energy demand (in kWh) instead of just the instantaneous load / power (in kW).

Estimating the power demand is important for the sizing of energy storage devices, such as batteries, the required capacity depends on the total amount of energy that will be drawn by the loads. This calculation is also useful for energy efficiency applications, where it is important to make estimates of the total energy use in a system. Table (3.1) shows detail of load profile for the health centre.

Table (3.1): Calculation of total energy for each appliance used

SN.	Equipment	Quantity	Power(w)	Total Power(w)
1	Ceiling fan	10	70	700
2	Indoor lighting	20	40	800
3	Outdoor lighting	10	40	400
4	Emergency room	1	200	200
5	Small kettle	1	200	200
6	Crystal lamp	40	20	800
7	Autoclave	1	450	450
8	Desk top computer	1	100	100
9	Exhaust fan	5	10	50
10	Refrigerator	1	100	100
11	Inject printer	1	60	60
Total load (W)				3860

3.4 The Size of PV Modules

Solar panels generate free power from the sun by converting sunlight to electricity with no moving parts, zero emissions, and no maintenance. The solar panel is the first component of an electric solar energy system, is a collection of individual silicon cells that generate electricity from sunlight. The photons (light particles) produce an electrical current as they strike the surface of the thin silicon wafers. A single solar cell produces only about 1/2 (0.5) of a volt. However, a typical 12 volt panel about 25 inches by 54 inches will contain 36 cells wired in series to produce about 17 volts peak output. If the solar panel can be configured for 24 volt output, there will be 72 cells so the two 12 volt groups of 36 each can be wired in series, usually with a jumper, allowing the solar panel to output 24 volts.

Multiple solar panels can be wired in parallel to increase current capacity (more power) and wired in series to increase voltage for 24, 48, or even higher voltage systems.

Sizing of stand-alone PV system starts by estimating the energy consumption of the health centre (Table3.2) and the available solar energy radiation (Table3.3) of the selected location.

Table (3.2): Calculation of total KW-hrs per day needed from the PV modules.

	Equipment	Quantity	Power(w)	Total watts	Hours	Energy/day
1	Ceiling fan	10	70	700	24	16800
2	Indoor lighting	20	40	800	24	19200
3	Outdoor lighting	10	40	400	11	4400
4	Emergency room	1	200	200	24	4800
5	Small kettle	1	200	200	3	600
6	Crystal lamp	40	20	800	10	8000
7	Autoclave	1	450	450	5	2250
8	Desk top computer	1	100	100	24	2400
9	Exhaust fan	5	10	50	20	1000
10	Refrigerator	1	100	100	20	2000
11	Inject printer	1	60	60	5	300
Total load (W)						61750

3.4.1 Radiation Data

To optimize sizing of PV system, it is important to collect meteorological data (solar radiation and temperature) for the site under consideration, Table3.3 shows the monthly average values of global solar radiation over the (Rabak region). It is clear from the figure that solar energy incident on the region is very high especially during summer months with average daily radiation during April 7.41 KWh/m^2/day where the annual average global solar radiation is 6.06 KWh/m^2/day.

Table (3.3): The monthly average values of daily global solar radiation ($Kwh/m^2/day$) in Kenana (Rabak region).

Month	**Daily Radiation in $KWh/m^2/day$**
January	5.09
February	5.89
March	7.24
April	7.41
May	7.14
June	6.66
July	5.92
August	5.52
September	5.97
October	5.88
November	5.24
December	4.81
Yearly average	6.06

3.4.2 The Total Watt-Peak Rating Needed for PV Modules

Different size of PV modules will produce different amount of power. To find out the sizing of PV module, the total peak watt produced is needed. The peak power (W_P) produced depends on size of the PV module and climate of site location.

Required power:

$$P_{PV} = \frac{E_L}{\eta_{cable} x \eta_{reg} x \eta_{bat} x \eta_{inv}} \qquad (3.1)$$

Where E_L is the average daily load energy consumption KWh/day and typical value of efficiency of cable, regulator, battery and inverter as below:

η_{cable} = 95%

η_{reg} = 95%

η_{bat} = 80%

η_{inv} = 95%

$$P_{PV} = \frac{61.75}{0.69} = 89.5 \text{ KWh/day}$$

$$P_{peak} = \frac{P_{PV}}{PSH} \quad \text{...} \quad (3.2)$$

Where PSH is peak solar hours (hours at1kW/m^2 = kW/m^2/day)

PSH = 6.06 h/day

$$P_{peak} = \frac{89.5\text{kwh/day}}{6.06h/day} = 14.77 \text{ kw}_p$$

3.4.3 Number of PV Modules For The System

The number of modules in series (Ns) as given in Eq. (3.3) is determined by dividing the designed system voltage VS $_{system}$ (usually determined by the battery bank or the inverter) and the nominal module voltage V_{module} at Standard Test Conditions (STC).

$$N_S = \frac{V_{DC}}{V_m} = \frac{48}{24} = 2 \quad \text{...} \quad (3.3)$$

The number of strings in parallel (N_P) as given in Eq. (3.4) is determined by dividing the designed array output P_{PV} array by the selected module output P $_{module}$ max. And the number of series modules N_S.

$$N_P = \frac{P_{peak}}{P_m x Ns} = \frac{14770}{200x2} = 36.925 \approx 37 \quad \text{...} \quad (3.4)$$

The total number of modules

$N = N_S \text{ x } N_P = 2 \text{ x } 37 = 74$ Modules .... (3.5)

3.5 Battery sizing

Storage Batteries are the fuel tank of solar power system, without batteries to store energy we only have power in a day time or the generator was running. Here we describes the four basic types of batteries and provides some good tips on the care and feeding of batteries to maximize their performance and life.

(i) RV or Marine type deep cycle batteries are basically for boats and campers and are suitable for only very small systems. They can be used but do not really have the capacity for continuous service with many charge/discharge cycles for many years. Regular or Car type batteries should not be used at all because they cannot be discharged very much without internal damage. A very popular battery for small systems is the Golf Cart battery. They are somewhat more expensive than deep cycle recreational batteries but are probably the least expensive choice for a small system on a budget.

Industrial strength: Flooded, GEL, and AGM sealed batteries types are the heavier industrial type batteries. They are all also considered Deep Cycle and are usually Lead Acid types with much thicker internal plates that can withstand many deep discharge cycles these types are all designed for alternative energy systems.

(ii) Flooded batteries these are Lead acid batteries that have caps to add water. Many manufacturers make these types for Solar Energy use, they are reasonably priced and work well for many years. All flooded batteries release gas when charged and should not be used indoors. If installed in an enclosure, a venting system should be used to vent out the gases which can be explosive.

(iii) Sealed GEL batteries are not to be confused with maintenance free batteries, sealed gel batteries have no vents and will not release gas during the charging process like flooded batteries do. Venting is therefore not required and they can be used indoors. This is a big advantage because it allows the batteries to maintain a more constant temperature and perform better.

(iv) Absorbed Glass Mat batteries are the best available for Solar Power use. A woven glass mat is used between the plates to hold the electrolyte. They are leak/spill proof, do not out gas while charging, and have superior performance. They have all the advantages of the sealed gel types and are higher quality, maintain voltage better, self-discharge slower, and last longer [16].

In this project the AGM or VRLA (valve regulated lead acid batteries 12V, 180Ah) will be used for the following properties:

- The batteries can be positioned permanently in any direction except upside down.
- The encapsulation is mechanically durable and made from ABS plastic.
- Valve-regulated design with almost 100% oxygen recombination in standby applications.
- AGM = Absorbent glass matting that contains the electrolyte.
- A minimum of maintenance is required since topping up water is either necessary or possible.
- Can be used within a wide temperature range with temperature-compensated charging.
- Life expectancy class up to 10 years.

The battery type recommended for using in solar PV system is deep cycle battery (AGM, VRLA). Deep cycle battery is specifically designed for to be discharged to low energy level and rapid recharged or cycle charged and discharged day after day for many years. The battery must be large enough to store sufficient energy to operate the appliances at night and cloudy days. The size of battery calculates as follows:

$$\text{Battery Capacity (Ah)} = \frac{\text{Total Watt-hours per day used by appliances x Days of autonomy}}{\text{(Depth of Discharge x system voltage)}}$$

$$C_B = \frac{E_L x N_C}{DODxV_{DC}} \quad \ldots\ldots (3.6)$$

Where, Nc is the number of continuous cloudy days in the selected region (2 days), E_L is the load energy in Wh, DOD is the depth of discharge (0.5) and V_{DC} is the system voltage is equal to 48V.

$$C_B = \frac{61750x2}{0.5x48} = 5145.8 \text{ Ah/day}$$

The total number of battery according to available battery in site 180Ah, 12 V $= \frac{5145.8}{180} = 28.6 \approx 29$ its better 32 batteries.

For parallel and series battery connection:

$$\text{Battery size in Ah} = \frac{totalwatt}{systemvolt} = 61750/48 = 1286.5Ah \quad \ldots\ldots (3.7)$$

$$\text{Number of batteries in parallel} = \frac{batt.Ah}{Ah.rating} = 1286.5/180 = 7.14 \approx 8 \quad \ldots\ldots (3.8)$$

$$\text{Number of batteries in series} = \frac{systemvoltage}{batteryvoltage} = 48/12 = 4 \quad \ldots\ldots (3.9)$$

Total number of batteries in battery bank = number of battery in series x number of battery in parallel = 4x8 = 32 batteries.

3.6 Inverter Sizing

Unless when planning to use battery power for everything, Power Inverter will be required. The Power Inverter will be the heart of Solar Energy System, It not only converts the low voltage DC to the 220 volts AC that runs most appliances, but also can charge the batteries if connected to the utility grid or a AC generator as in the case of a totally independent stand-alone solar power system.

3.6.1 Types of Power Inverter

3.6.1.1 Square Wave Power Inverters

This is the least expensive and least desirable type. The square wave it produces is inefficient and is hard on many types of equipment.

3.6.1.2 Modified Sine Wave Power Inverters

This is probably the most popular and economical type of power inverter. It produces an AC waveform somewhere between a square wave and a pure sine wave. Sine Wave inverters are not real expensive and work well in all but the most demanding applications and even most computers work well with a Modified Sine Wave inverter. However, there are exceptions. Some appliances that use motor speed controls or that use timers may not work quite right with a Modified Sine Wave inverter. And since more and more consumer products are using speed controls & timers, I would only recommend this type of inverter for smaller installations such as a camping cabin.

3.6.1.3 True Sine Wave power inverters

A True Sine Wave power inverter produces the closest to a pure sine wave of all power inverters and in many cases produces cleaner power than the utility company itself. It will run practically any type of AC equipment and is also the most expensive. Many True Sine Wave power inverters are computer controlled and will automatically turn on and off as AC loads ask for service. The modern sine wave power inverters has a search feature and checks every couple of seconds for anything that wants AC, then it powers up automatically, Just flick on a light switch (or whatever) and it works. While the Modified Sine Wave inverter is nearly half the price of a True Sine Wave inverter, its recommend using a True Sine Wave inverter if required to supply automatic power to a normal home using a wide variety of electrical devices. Also, most appliances run more efficiently and use less power with a True Sine Wave inverter as opposed to a Modified Sine Wave power inverter.

3.6.2 Input Voltages 48V Inverter

The main consideration to deciding on the input voltage (from battery bank) of Inverter is the distance between solar panel array and battery bank. The higher the voltage, the lower the current and the smaller the (expensive) cables need to be. Of course, when decide on a system voltage, the Solar Panels, Inverter, and Battery Bank all need to use the same voltage.

3.6.3 Inverter Stacking : Using Multiple Inverters

Two inverters can be installed in a configuration known as stacking that can provide more power or higher voltage. If two compatible inverters are stacked in *series* can double the output voltage. This would be the technique to use to provide 220 volts AC. On the other hand, if configure them in *parallel*, you can double your power. Two 4000 watt inverters in parallel would give you 8000 watts (8KW) of electricity.

3.6.4 Power Inverter Considerations

The Power Inverter is connected directly to the batteries and the main AC breaker panel to supply power from the batteries to the loads (appliances). Power Inverters are available for use on 12, 24, or 48 volt battery bank configurations. Most Power Inverters can also charge the batteries if connected to the AC line, the Power Inverter transfers the AC Generator power to the loads via a relay.

For this system 3860 watt True Sine Wave power inverter will do the job. This type of inverter will run all A/C appliances and have automatic features. These higher quality Power Inverters are computer controlled and once set-up, can control our 220 volts AC, battery charging, and even auto-start compatible AC generators all automatically.

Our goal is to provide real home power, A True Sine Wave inverter is really our best choice. The extra cost, in the long run, is a good investment in performance and reliability.

The input rating of the inverter should not be lower than the total watt of appliances; the inverter must have the same nominal voltage as battery banks. For our stand-alone systems, the inverter should be large enough to handle the total amount of Watts will be used at one time. The inverter size should be about 25-30% bigger than total Watts of appliances. The size of inverter calculates as follows:

Total Watt of all appliances = 3860 W or safety, the inverter should be considered 25-30% bigger size.

The inverter size should be about 4825 W or greater. The suitable inverter is standalone inverter 5000w/48Vdc, 220vac/50Hz.

3.7 Solar Charge Controller Sizing

Since the brighter the sunlight, the more voltage solar cells produce, the excessive voltage could damage the batteries. A charge controller is used to maintain the proper charging voltage on the batteries. As the input voltage from the solar array rises, the charge controller regulates the charge to the batteries preventing any overcharging.

3.7.1 Modern Multi-Stage Charge Controllers

Most quality charge controller units have a three stage charge cycle as followings:

(i) During the Bulk stage of the charge cycle, the voltage gradually rises to the Bulk level (usually 14.4 to 14.6 volts) while the batteries draw maximum current.

(ii) During this stage the voltage is maintained at Bulk voltage level for a specified time (usually an hour) whiles the current gradually tapers off as the batteries charge up.

(iii) After the absorption time passes the voltage is lowered to float level (usually 13.4 to 13.7 volts) and the batteries draw a small maintenance current until the next cycle [13].

The relationship between the current and the voltage during the three stages of the charge cycle can be shown visually by the figure (3.1)

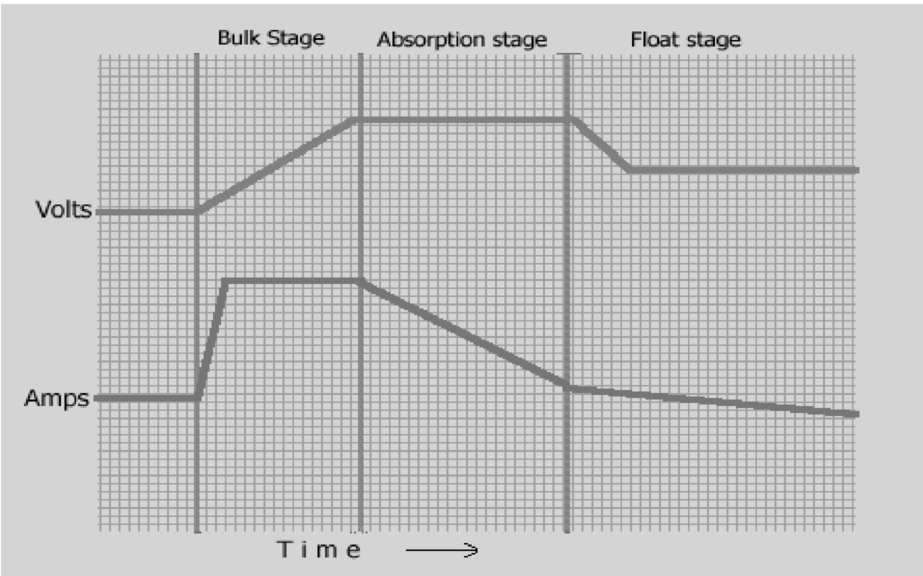


Fig.(3.1): Relationship between the current and the voltage during the three stages of the charge cycle.

3.7.2 MPPT Maximum Power Point Tracking

Most multi-stage charge controllers are Pulse Width Modulation (PWM) types. The newer Maximum Power Point Tracking (MPPT) controllers are even better. They match the output of the solar panels to the battery voltage to insure maximum charge Ampere.

The Charge Controller is installed between the Solar Panel array and the Batteries where it automatically maintains the charge on the batteries using the three stage charge cycle described above. The Power Inverter can also charge the batteries if it is connected to the AC utility grid or in the case of a standalone system [16].

The solar charge controller is typically rated against Amperage and Voltage capacities. Selected of solar charge controller depend on the voltage of PV array and batteries. The charge controller is rated by the output Amperage that they can handle, not the input current from the solar panel array. To determine the output current that the charge controller will have to handle we use the very basic formula for power (watts), which is:

Relevant parameters:

$V_{in} = V_{DC} = 48V$

$I_{in} = \frac{P_{peak}}{V_{DC}} = \frac{14770}{48} = 307.7A$

$V_{out} = V_{DC} = 48V$

$P_{out} = 3860\ W$

$I_{out} = \frac{P_{out}}{V_{out}} = \frac{3860}{48} = 80.42\ A$

still required to boost this value by 25% to take into account special conditions that could occur causing the solar panel array to produce more power than it is normally rated for (e.g. due to sunlight's reflection off of snow ,water ,extraordinarily bright conditions, etc). So, 80.42A increased by 25% is 100.25A. In this case we'd probably choose two 80 A series charge controller type.

3.8 Sizing Calculator

Computer software program is developed for sizing the photovoltaic system used in this thesis and it can be used to sizing other similar photovoltaic system ,the program calculate the PV required panels, required batteries, required charge controller and inverter when the value of calculated watts is entered.

3.9 Practices From Technical Standard For KSC

This section provides a minimum set of requirements that shall be followed in the design, specification and installation of the qualified SHS (Solar Home System). These requirements form a set of "Recommended Practices" which followed will ensure adequate levels of safety, performance, reliability and system lifetime.

3.9.1 PV Module Installation

PV module installation refers to the followings:

(a) If more than one module is used, identical models shall be used and they shall be connected in parallel and/or in series.

(b) For SHS installed permanently on a structure (in contrast with portable units):

(i) The modules must ensure waterproof sealing for the solar cells. Modules must be framed in such a way as to allow secure connection to the module mounting structure.

(ii) The mounting structure will hold the photovoltaic modules. The modules must be mounted on a support structure made of corrosion resistant material that assures stable and secure attachment.

(iii) The PV array and support structure must be able to withstand wind gusts up to 100 km/h without damage.

(iv) The structure must be mounted at a fixed angle and oriented to maximize the useful energy supplied to the user over the year (for the KSC's site, the panel should be facing south with a tilt angle of around 15 degrees with the horizon).

(v) The structure shall incorporate corrosion resistant hardware for all external connections.

(vi) The modules can be roof or ground-mounted: In case of roof-mounted modules, the mounting structure must be anchored to the building and not to the roofing material and the minimum clearance between the PV module and the roofing material must be at least 30 cm. For ground-mounted modules, it is recommended that the module mounting structure be supported on sufficiently strong metallic poles, which should be anchored in concrete or tightly packed soil at least one meter deep in the ground. The modules must be at least 5 meters off the ground. The poles and the mounting structure must be sufficiently rigid to prevent twisting by the wind.

(vii) The panel should be mounted clear of vegetation, trees and structure so as to assure that they are free of shadow throughout day light hours during each season of the year. Furthermore, if more than one panel is mounted on a support structure the panels should be mounted such that one panel will not shade the other modules.

3.9.2 Circuit Protection and Charge Controls

Circuit protection and charge controls include the following:

(a) Systems must include means to protect users and system components from the followings:

(i) Battery overcharge and excessive water loss.

(ii) Battery undercharge and excessive discharge.

(iii) Circuit protection against short circuit of any load.

(iv) Circuit protection against reverse polarity of module or battery.

(v) Circuit protection against internal shorts in charge controller, inverter or other devices.

(vi) Circuit protection against damage by the high PV open circuit voltage when it is connected to the controller without battery.

(vii) Night time discharge of the battery due to reverse current through the module.

(b) Systems shall provide appropriate protection by a charge controller incorporating a high voltage disconnect (HVD), low voltage disconnect (LVD) and circuit protection.

3.9.3 Inverters

The inverters should protect the batteries from deep discharge; the low cut off voltage should be above the voltage at the max acceptable battery depth of discharge in the range 11- 11.2 VDC, and should be auto recovery after shut down.. The inverters capacity should be chosen to satisfy all loads run at a time, taking into consideration the starting currents of some appliances.

3.9.4 System Monitoring

System monitoring includes the followings:

(i) A display (controller) to indicate when the battery is in the charging mode must be provided.

(ii) This device must indicate the batteries levels (Full - Half - Low).

(iii) The chosen device must come appropriately labeled such that the user does not have to refer to a manual to understand the existing battery condition.

3.9.5 Batteries

Required practices for batteries include the followings:

(i) Batteries should be selected to offer at least five years of useful life.

(ii) The batteries can be supplied in a dry-charged condition and all chemicals and electrolyte must be supplied in accordance with battery supplier specifications, the battery and associated containers should be packaged to handle transport down rough roads.

3.9.6 Equipment Enclosure

With regard to equipment enclosure, recommended practices comprise the followings:

(i) The batteries and charge controllers and/or inverters should be kept in properly designed protective enclosures. These enclosures should be properly vented and the face cover should be transparent to show the indicators of the equipment inside.

(ii) All parts of the compartment subject to battery acid contact must be acid resistant. This compartment must be built strong enough to accommodate all the equipment inside. Access to the battery compartment by children must be prevented.

3.9.7 Wiring

Wiring practices include the followings:

(a) Stranded and flexible insulated copper wiring must be used. Minimum acceptable cross-section area of the wire in each of the following sub-circuits, depending on the electricity current and voltage are as follows :

(i) From PV module to Charge Controller : 10.0 mm^2 and from Charge Controller to battery: 10.0 mm^2 .

(ii) From Battery to Inverter: 16.0 mm^2 .

(iii) From the Inverter to all other loads: 2.5 mm^2.

(b) All wiring must be sized to keep line voltage losses to less than 3% including each sub-circuit and to allow the circuit to operate within the capacity rating of the wire.

(c) For SHS permanently installed on a structure, all exposed wiring (with the possible exception of the module interconnects) must be in conduits and to be firmly fastened to the building structure. The cables insulation materials must resist damage by exposing to direct sunlight. Wiring through roofing, walls and other structures must be protected through the use of bushings. Wiring through roofing must form a waterproof seal.

(d) Field-installed wiring must be joined using terminal strips or screw connectors. Soldering or crimping in the field must be avoided if at all possible. Wire knots are not allowed. The rated current carrying capacity of the joint must not be less than the circuit current rating. All connections must be made in junction boxes. Fittings for lights, switches, and socket outlets may be used as junction boxes where practical.

(e) The color code should be red for line and black for neutral and yellow for earth.

(f) All cables should be ready for connection and with the compatible lugs.

3.9.8 Lamps

For the AC systems the lamps should be LED bulbs type or tube type 220Volts, 7 W to 9 W 50 Hz, or CFL lamps with the same types 220Volts, 20 W to 40 W 50 Hz, and the base should be light bulbs with standard E27 Edison screw base.

3.9.9 Switches and sockets

Each SHS should have a switch for each lamp and one socket for connecting the mobile charger or TV, both should be of high quality and life time not less than 10 years.

CHAPTER FOUR

Results and Discussions

4.1 Introduction

The photovoltaic for solar home system (SHS) is intended to provide the user with a convenient means of supplying power for most household electrical loads such as lights, TV, air coolers, ceiling fans, fridges, freezers, washing machines, and outlets for operating laptops or charging mobile phones. Each SHS consists of photovoltaic (PV) modules, charge controller(s), batteries and DC/AC inverter along with luminaries, related electronic and electrical components and mounting hardware. Additionally the SHS for the Health Centre and the Offices are expected to power the different appliances relevant to each of them. A typical SHS operates at a rated voltage of 220 Vac and provides power for the above appliances during the whole day.

Solar energy is an excellent and practical resource that can be harnessed relatively easily and effectively. This is especially where a comparatively small amount of electricity is required. For getting the best out of solar it is important to planning first and meticulous with detail is required, Only then can be assured that Solar Power Station will deliver exactly what is required [13].

This Solar Electricity Analysis for PV Sizing project provided with a feasibility study that allow to judge whether or not an off-grid solar electricity system is suitable for the project. It takes into account the electrical load and the level of solar energy available in and around Kenana region. For the purposes of this analysis, it is assumed that a suitable location for mounting solar panels, where direct sunlight is not obstructed at any point during daylight hours.

This analysis has been compiled based on load profile and site information collected by solar man company from Kenana site. Various aspects of a successful photovoltaic sizing can only be undertaken after careful analysis of requirements and surveying the site where the system is to be installed. In particular the positioning of the solar panels on the site and the overall sizing of the system are critical factors in the success of implementing a solar power system.

4.2 Solar Electricity Analysis

From the load profile for PV sizing project, the solar power systems need to power the following devices table 4.1:

Table (4.1): Energy table

Device	Power Required (watts)	Hours use per day	Total Energy (Wh/day)
Indoor lighting	800	24	19200
Emergency Room	200	24	4800
Kettle	200	3	600
Crystal Light	800	10	8000
Autoclave	450	5	2250
Desk Top	100	24	2400
Computer	50	20	1000
Exhaust Fan	100	20	2000
Inkjet Printer	60	5	300
Outdoor lighting	400	11	4400
Ceiling fan	700	24	16800

The total system energy requirement is 61750 watt-hours per day. All power is required at mains voltage. Solar energy is a combination of the hours of expected sunlight at site and the intensity of that sunlight. Solar energy varies depending on the time of year and the position of the earth relative to the sun.

This combination of hours of sunlight and intensity of sunlight is called insulation, and the results can be expressed as an average irradiance as watts per square meter (W/m^2), or as kilo-watt hours per square meter spread over the period of a day ($kWh/m^2/day$).Of course, not every day is the same and isolation figures will vary depending on the weather, a better power generation on a sunny day than on overcast day. For this reason, the batteries used to store the solar electricity generated must be large enough to be able to store enough excess energy to cover a few days of under-performance from the solar panels. The amount of solar energy captured by solar panels also varies considerably depending on the directions that the solar panels are facing. As indicated that the panel facing directly south, the panels facing in the optimum position to give the best solar performance.

For the purposes of producing a basic sizing estimation, the following efficiency values were assumed:

4.2.1 Solar Panel Power Point Efficiencies

Solar panels are rated on their 'peak power output'. Peak power on a solar panel in bright sunlight is normally generated at between 17-20 volts. However, a 12 volt battery only requires around 14 volts to charge it.

More recent solar controllers use a technology called 'Maximum Power Point Tracking' (MPPT), which converts this excess voltage into extra current at a lower voltage, thereby ensuring more power goes into the battery. The size of project means that it is recommended a MPPT controller, as this ensures greater efficiency and reduces the overall cost of the project [14].

4.2.2 Battery Storage

80% battery efficiency is assumed for the system. In other words, 80% of the energy stored in the batteries can be used by the system. New batteries should be able to exceed these figures. However, older batteries, or batteries stored at sub-optimal temperatures may provide significantly lower efficiency levels. Also assuming that batteries should not be discharged below a 50% state of charge (depth of discharge).

4.2.3 Power Inverters

61750 watt-hours of mains electricity a day is required for the sizing of photovoltaic and the solar panels generate electricity at low voltages, to increase the voltage to mains power a power inverter is required so 95% efficiency for a power inverter is chosen of this project.

4.2.4 Positioning and Installation

According to site and availability of the sun light the panels should facing south. For the purpose of this project, assumed that there are no obstacles shaded the solar panels at any time during daylight hours. In order to get the maximum efficiency out of solar installation throughout the year, the solar array should be installed for the KSC’s site, the panel should be facing south with a tilt angle of around 15 degrees with the horizon (from technical standard for KSC).

4.3 The Results

4.3.1 Panels sizing:

For sizing panels the following equations is used:

$P_{pv} = \frac{E_L}{\eta_{cable} x \eta_{reg} x \eta_{bat} x \eta_{inv}}$ To calculate required power from Photovoltaic system,

$P_{peak} = \frac{P_{PV}}{PSH}$ it's used to calculate peak power required by day Where PSH is peak solar hours (hours at1kW/m^2 = kW/m^2/day).

For calculating the total number of PV panels, the number of series and parallel is determined from the system voltage and module voltage, the total number is multiplied of parallel and series panels the result was 74 panels for the health centre, this calculation also applied in Microsoft Excel program and the same result is obtained.

4.3.2 Battery sizing

$$\text{Battery Capacity(Ah)} = \frac{\text{Total Watt-hours per day used by appliances} \times \text{Days of autonomy}}{\text{Depth of Discharge} \times \text{system voltage}}$$

For sizing battery above equation is used after calculated the total watts required per day, days of autonomy, depth of discharge and system voltage, the total capacity required was 5145.8 Ah/day the total number of batteries according to availability of batteries 180A ,12V was 29 battery by calculation but for more stability and connection to system voltage three battery were added and the total number became 32 batteries to connected to system voltage 48V to fulfil the required storage capacity for the system, when the above equation applied in Excel program the result was 28 batteries near to the calculation result.

4.3.3 Inverter Sizing

For stand-alone systems, the inverter sized according to total watt of appliances and also was large enough to handle the total amount of Watts it was 25% of total system watts and the result was 4825 and for safety of starting current for some appliance the 5000W/48VDC, 220VAC/50Hz power inverter was chosen to use in the health centre system.

4.3.4 Charge controller sizing

The solar charge controller size determined against Ampere and Voltage. According to the voltage of PV array and batteries the charge controller is selected and rated by the output ampere that can handle not the input current from the solar panel. The basic formula for power (watts) was used to determine the output ampere of charge controller which is:

$V_{out} = _{VDC} = 48V$

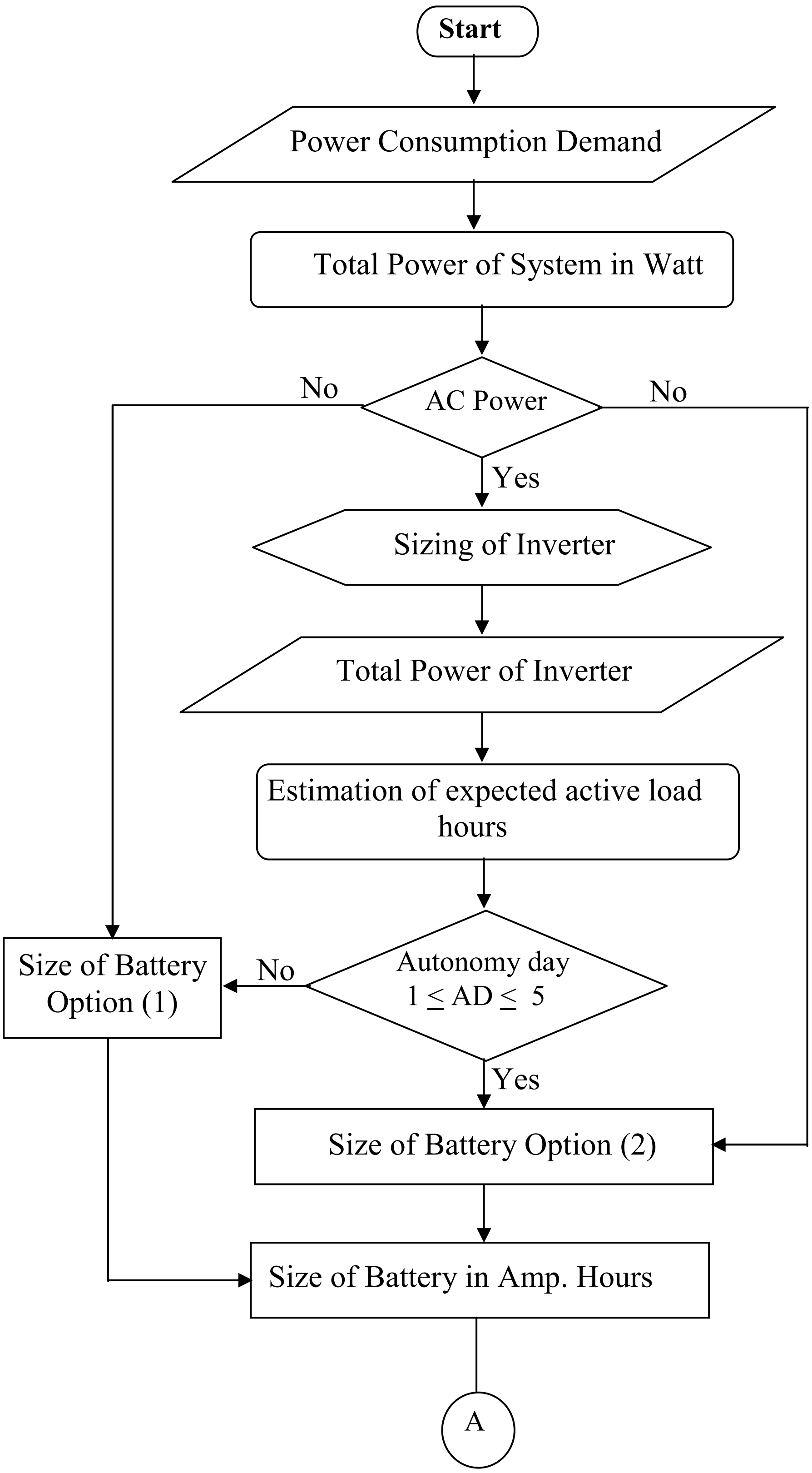
$P_{out} = 3860\ W$

$$I_{out} = \frac{P_{out}}{V_{out}} = \frac{3860}{48} = 80.42\ A$$

That value was boost by 25% to take into account special conditions that could occur causing the solar panel array to produce more power than it is normally rated. So 80.42A increased by 25% is 100.25A. In this case probably choose two 80A series charge controller type. In Microsoft Excel program the value of amperage of charge controller was 80.41A same as calculated result.

4.4 Sizing of PV System with Computer Programming

4.4.1 Flow Chart of PV System



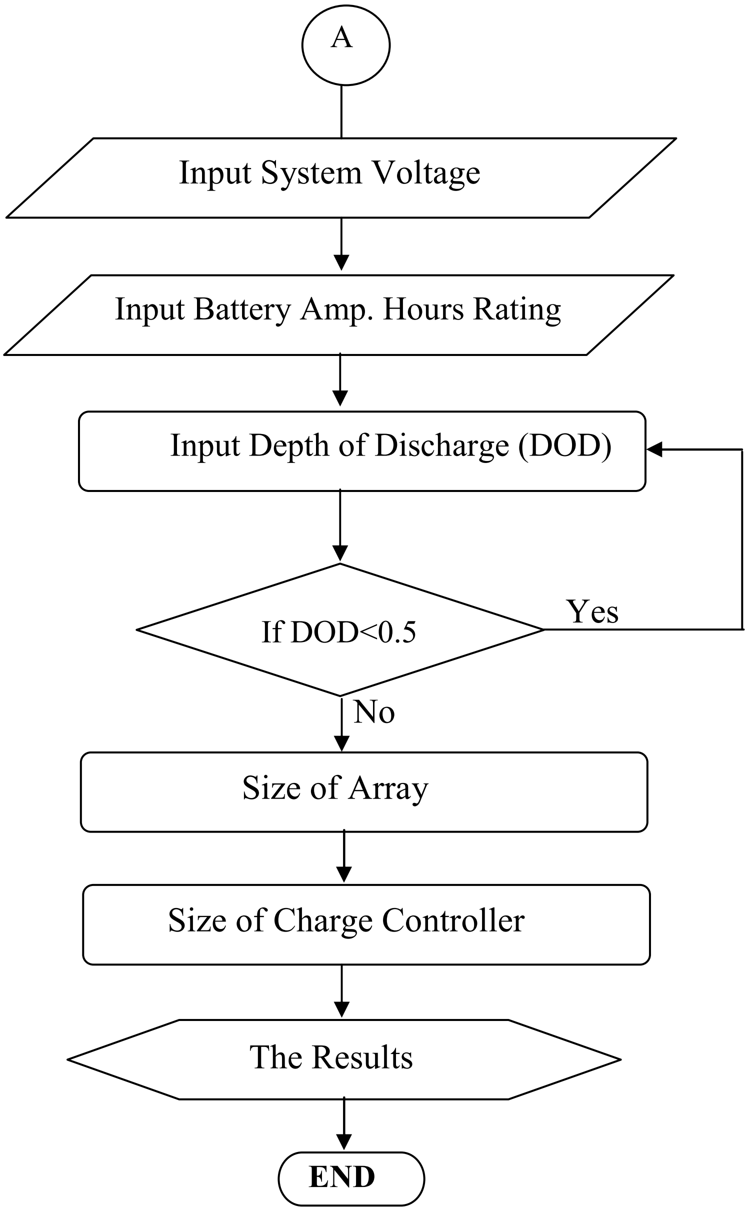


Fig.(4.1) : Flow chart of health center

4.4.2 MATLAB Program

The computer program designed to calculate the optimum sizing is based on empirical equations, which were selected after careful assessment of well tested traditional methods.

4.4.3 Matlab Result

```
pvsizing
Warning: Function call pvsizing invokes inexact match
C:\MATLAB7\work\PVSIZING.m.
 enter eta cable value.95
 enter eta regulator value>> .95
 enter eta battery value.8
 enter eta inverter value.95
 enter energy load value61750
 enter peak solar hour value6.06
 enter system voltage value48
 enter module voltage24
enter module power value200
 enter number of cloudy days2
 enter depth of discharge value.5
 enter battery ampere180
 enter battery voltage 12
 enter total watt of appliance3860

ModuleInseries =

     2
ModuleInparallel =

   37.1401

TotalNumberOfModule =

   74.2803

TotalNumberOfBattary =

   28.5880

NumberOfBattaryInParallel =

    7.1470

NumberOfBattaryInSeries =

     4

InverterSize =

        4825

ChargeControllerSizeByOutputCurrentIout =

   80.4167
```

4.5 Discussions

The sizing of a PV system for a health center at KSC, in the absence of utility power supply, was studied in this research work. The computer program designed to calculate the optimum sizing is based on empirical (formulae) equations, which were selected after careful assessment of well tested traditional methods. The results obtained were fairly acceptable and conforming with the traditional practices for the design of a similar system. The computer model was tested for sizing of similar systems.

Table (4.2): Result table

Item	Capacity	Total number
PV Panel	200 W	74
Battery	180 A	32
Inverter	5000 W	1
Charge controller	80 A	2

CHAPTER FIVE

Conclusion and Recommendations

5.1 Conclusion

In this thesis the importance of renewable energy and why we use it in remote area health centre is discussed. The word standalone refers to the fact that the system works without any connection to an established power grid. In this essay the basic concepts of the generation and storage of photovoltaic solar energy is discussed.

This essay discusses the use of solar energy for the direct production of electricity (photovoltaic solar energy). Solar energy can also be used to heat fluids (thermal solar energy) which can then be used as a heat source or to turn a turbine to generate electricity, thermal solar energy systems are beyond the scope of this essay.

The importance of renewable energy and why we use renewable energy in remote area health centre is discussed in this essay. The load profile has been created, the days of autonomy has been determined, calculation of number of solar panels , battery bank, inverters, charge controller and completed sizing of photovoltaic required for Kenana area seven health centre is discussed. Excel program has been developed for calculating the size of photovoltaic for health centre and for any photovoltaic size required only put total load, the program will till how many solar panels, batteries should be required.

5.2 Recommendations

In this thesis the photovoltaic hybrid system is recommended for Kenana Area seven health centre.

Typical hybrid solar systems are based on the following additional components:

- Charge Controller.
- Battery Bank.
- DC Disconnect (additional).
- Battery-Based Grid-Tie Inverter.
- Power Meter.

5.2.1 Photovoltaic diesel hybrid system

A photovoltaic diesel hybrid system ordinarily consists of a PV system, diesel generator and intelligent management to ensure that the amount of solar energy fed into the system exactly matches the demand at that time.

Basically, the PV system complements the diesel generator. It can supply additional energy when loads are high or relieve the generator to minimize its fuel consumption. In the future, excess energy could optionally be stored in batteries, making it possible for the hybrid system to use more solar power even at night. Intelligent management of various system components ensures optimal fuel economy and minimizes Co2 emissions.

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Appendices

Appendix A

MATLAB Program

```
etaCable = input(' enter eta cable value');
etaRegulator = input(' enter eta regulator value');
etaBattery = input(' enter eta battery value');
etaInverter = input(' enter eta inverter value');
EnergyLoad =input(' enter energy load value');
PSH = input(' enter peak solar hour value');
SystemVoltage = input(' enter system voltage value');
Vmodule = input(' enter module voltage');
Pmodule = input( 'enter module power value');
NumberOfCludyDays = input(' enter number of cloudy
days');
DepthOfDischarge = input(' enter depth of discharge
value');
While DepthOfDischarge<0.5
DepthOfDischarge = input(' Again enter depth of discharge
value');
end
BattaryAmpere = input(' enter battery ampere');
BattaryVoltage = input(' enter battery voltage ');
TotalWattOfAllAppliances = input(' enter total watt of
appliance');
Ppv =
EnergyLoad/(etaCable*etaRegulator*etaBattery*etaInverter)
;
Ppeak = Ppv/PSH;
ModuleInseries = SystemVoltage/Vmodule
ModuleInparallel = Ppeak/(Pmodule*ModuleInseries)
TotalNumberOfModule = ModuleInseries*ModuleInparallel
BattaryCapacity =
EnergyLoad*NumberOfCludyDays/(DepthOfDischarge*SystemVolt
age);
BattarySizeInAh = EnergyLoad/SystemVoltage;
TotalNumberOfBattary = BattaryCapacity/ BattaryAmpere
NumberOfBattaryInParallel = BattarySizeInAh/
BattaryAmpere
NumberOfBattaryInSeries = SystemVoltage/BattaryVoltage
TotalNumberOfBattaryInBattaryBank =
NumberOfBattaryInParallel*NumberOfBattaryInSeries;
InverterSize = 1.25*TotalWattOfAllAppliances
ChargeControllerSizeByOutputCurrentIout =
TotalWattOfAllAppliances/SystemVoltage
```