Sudan University of Sciences

and Technology

College of Engineering

School of Electrical and Nuclear

Engineering

PV Grid-Connected System

نظام الطاقة الشمسية المتصلة بالشبكة

A Project Submitted In Partial Fulfillment for the Requirement of the Degree of B.Sc. (Honor) In Electrical Engineering

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بسم الله الرحمن الرحيم

" وَسَخَّرَ لَكُمُ الشَّمْسَ وَالْقَمَرَ دَائِبَيْنِ ۖ وَسَخَّرَ لَكُمُ اللَّيْلَ وَالنَّهَارَ"

إبراهيم (33)

DEDICATION

To the Martyrs of the Glorious December Revolution

To Those Who Gave Us Their Time, Love and Care

Our Parents, Our friends.

ACKNOWLEDGEMENT

Unlimited praise for Allah as the number of his creatures, the might of

himself, the weight of his throne, and the extension of his words. The work on this project has been an inspiring, over exciting, sometimes challenging, but always interesting experience. It has been made possible by many other people, who have supported us.

We would like to express our sincere gratitude to our supervisor and advisor **Ust**. **Mustafa Eltayib** for the unconditional support ever since we were under his supervision. His continuous motivation was a key element in our progress and will to do better, his relentless patience represented a strong foundation for the success of the project and his immense knowledge was always a boost, bonus and huge advantage.

ABSTRACT

As renewable energy becomes a more suitable choice for energy production, more information on how different technologies will behave needs to be available. This project follows through the design of a grid connected photovoltaic system, in the hope to discover and determine to what extent the energy produced can satisfy the specific targeted load. Adopting the grid connected methodology allows for making use of the existing utility grid which exempts the enormous cost of batteries. This project is based on a combination of hand calculations and software modeling of the grid connected PV system. Modeling the grid connected PV system is carried out by using PVsyst software for the study, sizing and data analysis of the system. Another side of modeling the PV system, E-TAP software is used to study the power flow analysis in the existing grid. The simulation results ensured the effectiveness of the proposed grid connected PV system in sufficiently meeting the SUST Complex of Medical Colleges demand.

المستخلص

نظرًا لأن الطاقة المتجددة أصبحت خياراً أكثر ملاءمة لإنتاج الطاقة ، يجب توفير مزيد من المعلومات حول كيفية تصرف التقنيات المختلفة. تتبع هذه الأطروحة من خلال تصميم نظام كهروضوئي متصل بالشبكة ، على أمل اكتشاف وتحديد مدى قدرة الطاقة المنتجة على تلبية الحمل المستهدف المحدد. يتيح اعتماد منهجية التوصيل بالشبكة الاستفادة من شبكة المرافق الحالية التي تعفي التكلفة الهائلة للبطاريات. تعتمد هذه الأطروحة على مجموعة من الحسابات اليدوية والنمذجة البرمجية للنظام الكهروضوئي المتصل بالشبكة. يتم تنفيذ نمذجة النظام الكهروضوئي المتصل بالشبكة باستخدام برنامج بي في سيست لدراسة النظام وتحجيمه وتحليل بياناته جانب آخر لنمذجة النظام الكهروضوئي، يتم استخدام برنامج اي تاب لدراسة تدفق الطاقة في الشبكة الحالية ضمنت نتائج المحاكاة فعالية النظام الكهروضوئي المتصل بالشبكة المقترح في تلبية الطلب المستهدف بشكل كاف.

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LIST OF ABBREVIATIONS

PV	Photovoltaic
DC	Direct Current
AC	Alternating Current
E-TAP	Electrical Transient and Analysis program
CSI	Crystalline Silicon
kW	Kilowatt
kWh	Kilowatt hour
V_{OC}	Open Circuit Voltage
I_{SC}	Short Circuit Current
NASA	National Aeronautics and Space Administration
CdTe	Cadmium Telluride
CB	Circuit Breaker

CHAPTER ONE

INTRODUCTION

1.1 Overview

Energy is the major source for the economic development of any country. In case of the developing country like Sudan, shortage of electricity work as a barrier for development. In recent years, Sudan's energy consumption has been increasing at a relatively fast rate due to population growth and economic development. Rapid growth of the Sudanese economy places heavy demand of electric power.

Presently most of the electric demand fulfilled by coal power plants and creates pressure on fossils fuel. Coal-based power generation is characterized by local and regional environmental degradation as well as greenhouse gas emissions, leading to climate change. Thus, there is need of enhance energy security along with reducing greenhouse gas emissions.

Renewable energy is one of the environmentally friendly sources of energy. In present energy scenario harnessing of renewable potential in effective manner is becoming need of the era, which can provide sustainable power supply as well as mitigate the negative environmental impact due to fossil fuel.[1]

Moreover, the emissions from the fossil fuel use increasingly determine another fundamental limitation on their continued use, so the need for suitable alternate is required. The renewable energy is the energy that comes from resources which are naturally replenished on human time scale. Such as solar, wind, hydro, geothermal and tides. Solar energy is the energy generated from the sun light that reaches earth surface and used as heat or captured using photovoltaic solar panels.[2]

Electricity generation from solar photovoltaic technology globally has increased tremendously over the past 20 years. From an average annual demand of only 21MW in 1985, it grew to 1460MW in 2005 and 1744MW in 2006 [1], with cumulative global deployment estimated at 7.204GW in the same year. Solar energy utilization in power supply is expected to reach 119TWh in 2030 and over 80% of this is projected to come from photovoltaic, with the rest coming from solar thermal power plants [3].

Grid-connected photovoltaic systems are designed to operate in parallel with the electric utility grid as shown. There are two general types of electrical designs for PV power systems: systems that interact with the utility power grid and have no battery backup capability, and systems that interact and include battery backup as well. The latter type of system incorporates energy storage in the form of a battery to keep “critical load” circuits operating during utility outage. When an outage occurs, the unit disconnects from the utility and powers specific circuits of the load. If the outage occurs in daylight, the PV array is able to assist the load in supplying the loads.[4]

1.2 Problem Statement

Sudan is a country located in northeastern of Africa, on the real side the country faces a serious problem of instability and shortage of electricity supply especially in the capital and the main big cities. The hydro-power generators which is the largest amount of generation in the country, could not feed their rated electricity supply mainly in the rainy season (June to October) because of the accumulation of the mud in the dams. There are some other factors that make the problems of electricity blackouts and unsustainable supply in the whole country, such as the increase of population, industries and building density.

Therefore every institution or householders capable of handling the cost of renewable energy must install a PV or any suitable system to maintain a sustainable supply without any disturbance in their system to insure the continuity of supply to supply their electrical needs. The purpose of this project is to design a PV connected system to supply Sudan University of Science and Technology (SUST) Complex of Medical Colleges with sustainable electrical supply.

1.3 Objectives

The main objectives of the project are illustrated in several points as shown:

- Design a suitable PV connected system between the PV array and utility grid, for SUST Complex of Medical Colleges to maintain a sustainable electrical supply.
- Decreasing the cost of electricity in long term while continual electricity supply is guaranteed.
- Reducing the load pressure on the utility grid so that it's become available for others that cannot afford an alternative option for energy.
- Future plans for alternative energy to improve life style with green clean energy.

1.4 Methodology

The methodology used for solving this problem is to design a PV system that can be suitable to connect the load of the building to PV array to make it the supply , when the PV grid goes down due to any damage the load will automatically switch to the utility grid the through the A.T.S to make the utility grid the main source that provide the Grid tie inverter with reasonable output properties to feed the load. The whole system was simulated and implemented using E-TAP software.

1.5 Project Layout

This project is organized into five chapters and several appendices as following;

Chapter 1 (Introduction): This chapter explains the overview of Renewable energy generally. Also, explain the objective of this project.

Chapter 2 (Literature Review): This chapter provides description and explanation of solar systems and their components.

Chapter 3 (Methodology): This chapter provides full description of the method used to design the system.

Chapter 4 (PV connected system design with simulation result): This chapter contains the design steps for the solar system and contains the simulation using ETAP program, list of results that have been obtained in this chapter and comments on them.

Chapter 5 (Conclusion and future recommendations): This chapter summarizes the work that has been done in this project also it contains future recommendations to be done In order to improve the system performance in future.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Solar power is the conversion of energy from sunlight into electricity, either directly using photovoltaic (PV), indirectly using concentrated solar power, or a combination. Concentrated solar power systems use lenses or mirrors and solar tracking systems to focus a large area of sunlight into a small beam. Photovoltaic cells convert light into an electric current using the photovoltaic effect.

Solar energy is the energy comes from sunlight radiation to earth surface captured the energy of the sun using the photovoltaic panels (PV).it consists of an arrangement of several components, including solar panels to absorb and convert sunlight into electricity, a solar inverter to change the electric current from DC to AC. It splits into two types of systems stand-alone and grid tied [5].

Figure 2.1 shows how sun light converts to electricity using PV module.

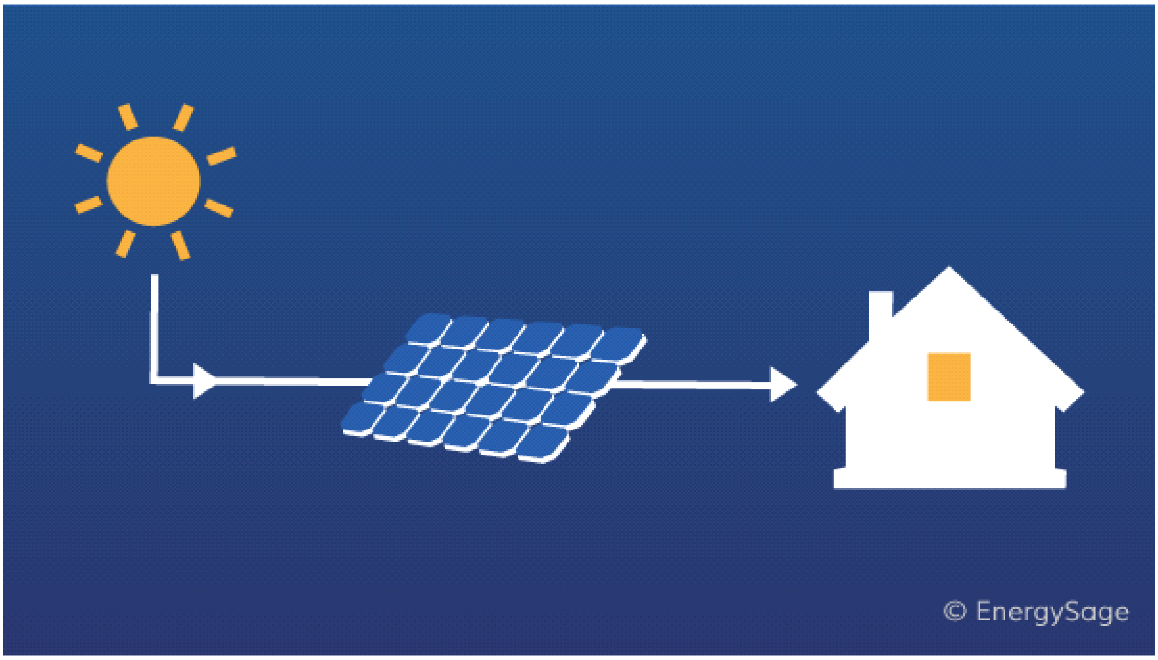

Figure 2.1: Conversion of sun light using photovoltaic

2.2 Solar Energy

Solar energy contains a direct component, which is light from the solar beam, and a diffuse component, which is light that has been scattered by the atmosphere. This distinction is important because only the direct solar component can be effectively focused by mirrors or lenses.

2.2.1 Advantages of Solar Energy

Solar energy has several advantages that make the process efficient and beneficial for generating and producing electricity through conversion of sun light. Which they must be discussed briefly:

1. Solar energy is the world's major renewable energy source and is available everywhere in different countries.
2. Photovoltaic panels do not have any moving parts, operate silently and generate no emissions.
3. The solar technology is highly modular and can be easily scaled to provide the required power for different loads.
4. Solar electric generation is economically competitive where grid connection or fuel transport is difficult, costly or impossible, such as satellites and island communities.
5. Once the initial capital cost of building a solar power plant has been met, operating costs are low when compared to conventional power technologies.
6. They are applicable for low-power uses such as solar powered garden lights and battery chargers [6].

2.2.2 Photovoltaic

Photovoltaic (PV) is the method of generating electrical power by Converting solar radiation into direct current electricity using semiconductors and an effect called the photovoltaic effect. To generate electricity and make use of it using the Photovoltaic effect, an electrical device is needed to do the conversion process of light into electricity called the Photovoltaic Cell (also called the Solar Cell).

- **Photovoltaic Effect**

The photoelectric effect was first noted by a French physicist, Edmund Becquerel, in 1839, who found that certain materials would produce small amounts of electric current when exposed to light. Albert Einstein won a Nobel Prize in 1921 due to his description of the nature of light and the photoelectric effect on which photovoltaic technology is based. In simple terms, the photovoltaic effect describes the conversion of light into an electric current. To describe this mechanism more formally, it is best to think of light in terms of a stream of photons where each photon carries one quantum of energy[7].photovoltaic effect illustrated in figure 2.2 below.

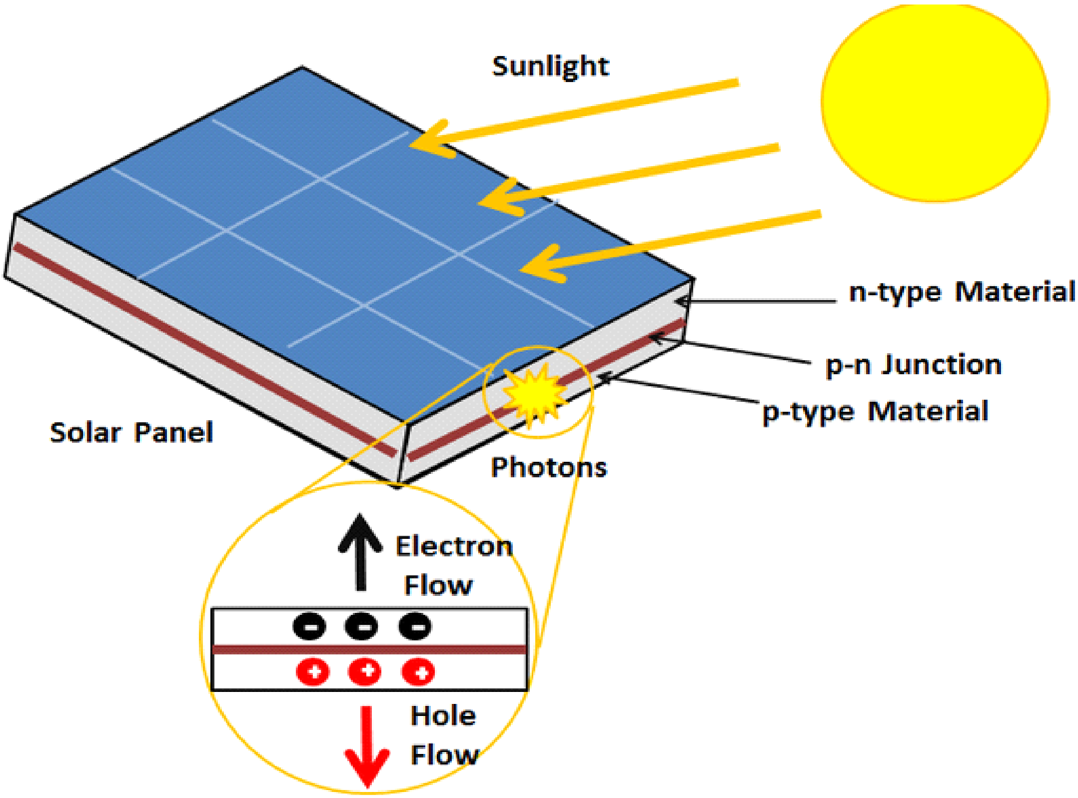

Figure 2.2: PV Effect

- **Photovoltaic Cell**

Photovoltaic cell or solar cell is a device which converts the light energy into electrical energy. When light is allowed to fall on this cell, the cell generates a voltage across its terminals. This voltage increases with the increase in light intensity. The cell is so designed that a large area is exposed to light which enhances the voltage generation across the two terminals of the cell.

The solar cell essentially consists of a silicon PN junction diode with a glass window on top surface layer of P material is made extremely thin so, that incident light photons may easily reach the PN junction. When these photons collide with valence electrons, they comport them sufficient energy as to leave their parent atoms. In this way free electrons and holes are generated on both sides of the junction. Due to these holes and electrons current is produced. This current is directly proportional to the illumination, and also depends on the size of the surface area being illuminated [7]. Figure 2.3 shows the solar cell.

Figure 2.3: Solar Cell

The P-Type material is made very thin and wide so that the incident light photon may easily reach to PN junction. The P nickel plated ring around the P layer acts as the positive output terminals (anode), and the metal contact at the bottom acts as a Cathode. Silicon and germanium are the most widely usas semiconductors materials for solar cells, although gallium arsenide, Indium arsenide and Cadmium arsenide are also being used nowadays. In a crystal of pure silicon, the atoms form a lattice. These atoms, like any others, have nucleus which includes positive charged protons, while around the nucleus are negatively charged electrons in layers or shells. The outer shell of electrons is not full, so neighboring atoms share electrons and holds each other together in the crystal. These electrons are held quite firmly in place and do not readily move around. However, the pure silicon crystal can be "doped" with a different element (i.e. small amounts of an "impurity" are added). If the doping is done with an element that has more electrons in its outer shell than silicon, there will be negatively charged electrons that are free to move around, and this is called "n-type" silicon. This material will conduct electricity much better than pure silicon as these spare electrons are free to move, then semiconductor is created. The crystal does not have an overall negative charge, however as the negative electrons are still balanced by positive protons in the nucleus. If instead, the silicon is doped with an element having fewer electrons in its outer shell, there will be an overall shortage of electrons, and the material will be p-type silicon. The minute areas where electrons are effectively missing are called holes, and these holes can also freely move around.

In a solar cell, there will be both n-type and p-type silicon in contact with each other. Electrons will move across from the n-type to the p-type at their junction as they will be attracted to the nearby holes. Once this has happened at the junction, this area acts a barrier, stopping further electrons moving across and an electric field exists across the junction. Figure 2.3 shows the silicon P-N junction

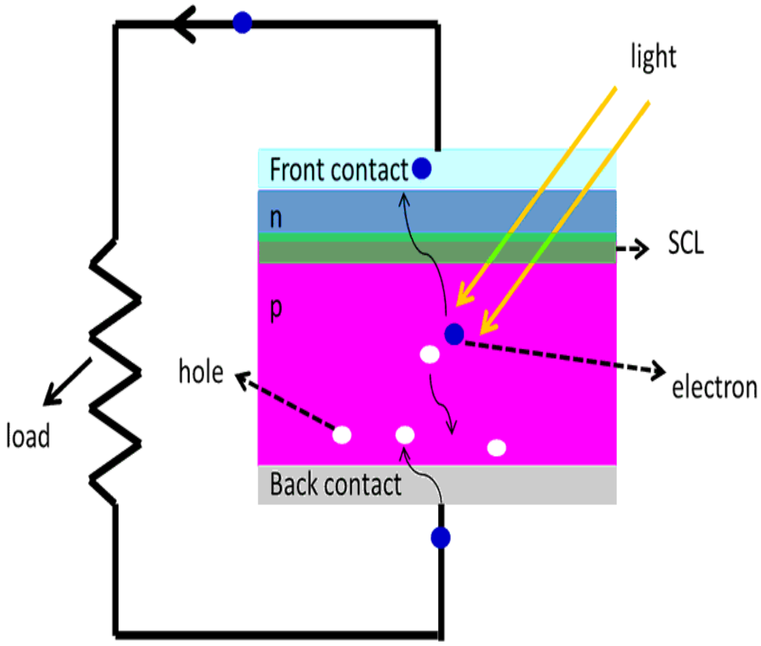

Figure 2.4: Silicon P-N Junction

If light energy is absorbed by the cell, the energy will push electrons across the junction and, if an electrical circuit is made between the two silicon types, the electrons will flow through it, back to where they came from, and continue to do so. The flow of electrons (in other words, the electric current) can be made to work on the way round (i.e. charging batteries). This type of cell may be 15-20 % efficient, partly due to the silicon wafers not absorbing all the light energy.

A more sophisticated type of cell, known as a Multi-Junction Cell, may have further wafer pairs above or below, using different doping chemicals, each able to absorb different wavelengths of light.[8]

2.2.3 Photovoltaic System

A PV system is the system that uses the photovoltaic effect to convert the solar radiation into electricity depending on the PV effect. PV system in its simplest form may contain an array of PV modules, one or more DC to AC power converter (inverter), electrical wiring, and either batteries with a charge controller or no batteries to store energy. Solar systems can be small PV system which is capable of providing enough AC electricity to power a single home, or even an isolated device in the form of AC or DC electric (rooftop systems), or it can be large grid connected PV power system capable of providing an energy supply for multiple consumers, or even off-grid plants to supply villages or small towns.

- **Stand-alone system**

Electricity generation system from solar that composed of the PV panels capture the energy from sun light the panels must be enough to cover the power needed. Using a charge controller to have a suitable DC to charge the battery, to ensure the use of the energy produced in the absence of sunlight and a battery bank for storage until energy needed by the load. It will produce a fine DC current to the inverter for conversion to AC. The main use of stand-alone systems is that it used in applications in the rural and the remote areas of the development countries in telecommunication towers and water pumps and the lightning uses, which can consider as a social benefit for this type of systems. Although there was a price reduction of the PV panels cost and the inverters involved, the batteries cost is the main concern in off grid (stand-alone) systems that it stays expensive specially if energy stored in terms of kilowatts or megawatts which increase the size of the batteries, they should be replaced in approximately every ten years and require regular maintenance, which is required more investments in the application of off grid systems. A stand-alone system is shown in Figure 2.5 below.

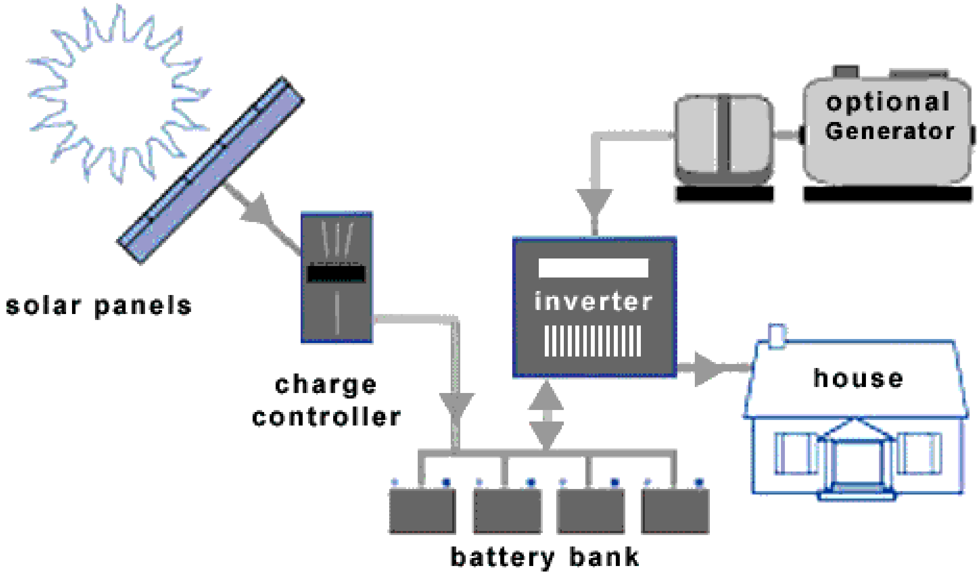

Figure 2.5: OFF-Grid System

- **Grid tied system:**

The simplest and most cost effective PV design is the "Grid-Tied" also sometimes called (utility-interactive) system. Solar system composed of PV solar panels, inverter, and load as in stand-alone systems but the difference is that the inverter used in this system called “Grid tie inverter “and it is a power electronic device which converts the direct current into the alternating current. (GTI) is a special inverter has the ability to synchronize voltage and frequency with the main grid parameters. There is not battery storage to store the energy, it is consumed immediately and the excess power transferred to the grid which can considered as battery storage “virtual battery” without the need for maintenance regularly or replacement in every decade. The grid is used to store your power for you for further use at night and during cloudy days or can be sold to the utility company with “net metering” technique that consider a power meter to measure the power in both directions from the grid to the appliances and vice versa which result in reduction of the electricity bill. Moreover, it does not require any rewiring which reduce the installation cost. The weakness in grid tied system that it does not supply electricity to the electrical appliances during a power outage as the utility company wants to do some repairs in the transmission lines for the safety of the workers or during brownout the power waveform fluctuate the system shutdown and blocks the supply to the appliances. A typical grid tied system is shown in Figure 2.6 below.

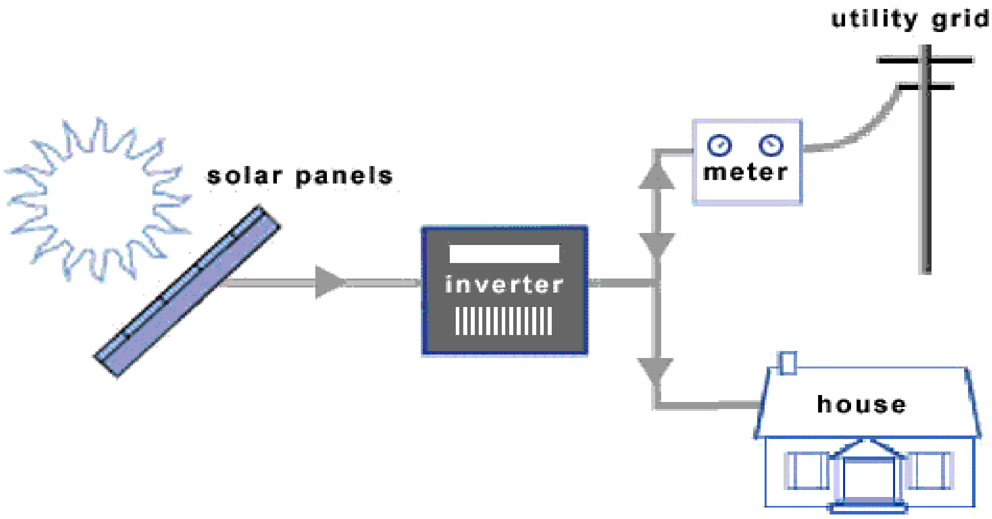

Figure 2.6: Grid tied system

2.2.4 Photovoltaic System Components

PV systems with their different sizes, applications and usages-usually consist of the following components:

- **Photovoltaic Modules**

A PV module is a group of solar PV cells connected in series or parallel in one oriented plane to construct one panel. Each module is rated by its DC output. The PV module is considered as the main component of the PV system, as it's converts the sun light into DC current. A typical PV module is shown in Figure 2.7.

Figure 2.7: PV module

PV modules often have a sheet of glass on the front (sun up) side, allowing light to pass while protecting the semiconductor wafers from abrasion and impact due to wind-driven debris, rain and hail. Solar cells are also usually connected in series in modules, creating an additive voltage while connecting cells in parallel will yield a higher current. However, very significant problems exist with parallel connections. For example, shadow effects can shut down the weaker (less illuminated) parallel string (a number of series connected cells) causing substantial power loss. Although modules can be interconnected to create an array with the desired peak DC voltage and loading current capacity. By far, the most prevalent bulk material for solar cells is crystalline silicon (CSI), also known as "solar grade silicon". Bulk silicon is separated into multiple categories according to crystalline and crystal size in the resulting ingot, ribbon, or wafer. Figure 2.8 shows the PV (cell-module-array).

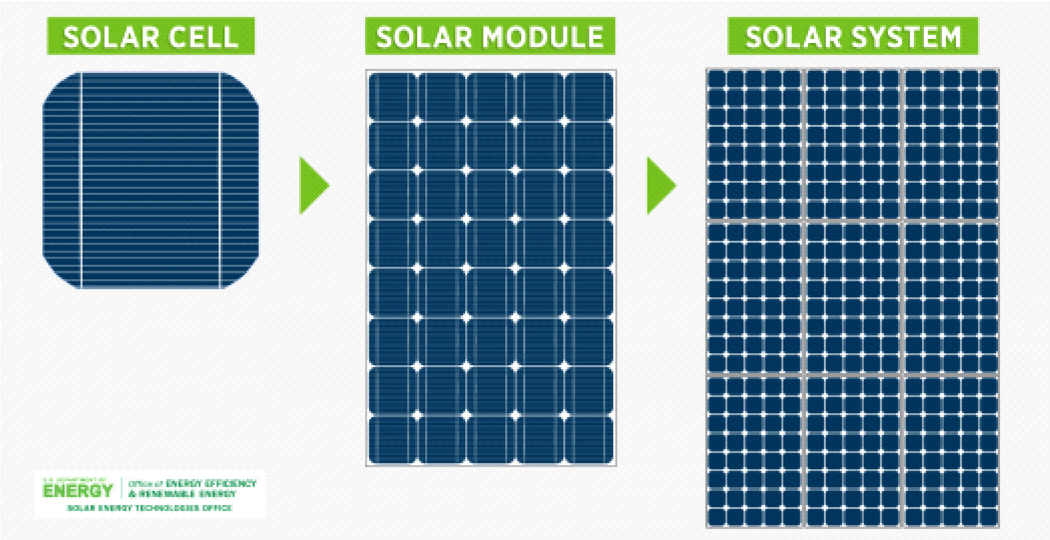

Figure 2.8: PV (Cell – Module – Array)

There are four main types of photovoltaic solar panels for both commercial and residential use. They are:

i. Mon- crystalline.
ii. Polycrystalline.
iii. Amorphous Silicon.
iv. Mono-like Multi-crystalline.

All four types of solar panels have both advantages and disadvantages depending on the user's budget, the size and type of environment where they are used and the expected output of the system

a) Mono-crystalline Cells:

Made of large silicon crystal, single-crystal wafer cells tend to be expensive, and because they are cut from cylindrical ingots, do not completely cover a square solar cell module without a substantial waste of refined silicon. Hence most (CSI) panels have uncovered gaps at the four corners of the cells.[9]

b) Polycrystalline Cells:

Also called multi-crystalline silicon (poly-Si or mc-Si). Characterized by its shattered glass look because of the manufacturing process of using multiple silicon crystals. They are made from cast square ingots, large blocks of molten silicon carefully cooled and solidified. Poly-Silicon cells are less expensive to produce than single crystal silicon cells, but are less efficient.

c) Amorphous Silicon Cells:

These panels can be thin and flexible which is why they are commonly referred to as "Thin Film" solar panels. Amorphous silicon solar panels are common for building integrated photovoltaic applications because of their many application options and aesthetics. They are cheaper and are not affected by shading. Drawbacks are low efficiency; loss of wattage per sq. ft. installed and heat retention. They can be manufactured using silicon, copper indium dieseline (CIS) or cadmium telluride (CDTE).[9]

d) Mono-like Multi-crystalline Cells:

Developed in the 2000s and introduced commercially around 2009, mono-like multi, or cast-mono, uses existing polycrystalline casting chambers with small "seeds" of mono material. The result is a bulk mono-like material with poly around the outsides. When sawn apart for processing, the inner sections are high-efficiency mono-like cells (but square instead of "clipped"), while the outer edges are sold off as conventional poly. The result is line that produces mono-like cells at poly-like prices. [9]

- **Batteries**

In photovoltaic power systems, the electrical energy produced by the PV panels cannot always be used directly. As the demand from the load does not always equal the solar panel capacity. Battery banks are generally used to store electrical energy when it’s not being used. PV systems increasingly use rechargeable batteries to store a surplus to be later used at night. Batteries used for grid-storage also stabilize the electrical grid by leveling out peak loads, and play an important role in a smart grid, as they can charge during periods of low demand and feed their stored energy into the grid when demand is high. Common battery technologies used in today's PV systems include, the valve regulated lead-acid battery a modified version of the conventional lead–acid battery, nickel– cadmium and lithium-ion batteries. Compared to the other types, lead-acid batteries have a shorter lifetime and lower energy density. However, due to their high reliability, low self-discharge as well as low investment and maintenance costs, they are currently the predominant technology used in small-scale, residential PV systems, as lithium-ion batteries are still being developed and about 3.5 times as expensive as lead-acid batteries. Furthermore, as storage devices for PV systems are used stationary, the lower energy and power density and therefore higher weight of lead-acid batteries are not as critical as, for example, in electric transportation [10].

Other rechargeable batteries that are considered for distributed PV systems include sodium–sulfur and vanadium redox batteries, two prominent types of a molten salt and a flow battery, respectively. Batteries that are able to handle the constant charging and discharging are known as deep-cycle batteries. Batteries need to have a good charging efficiency, low charging currents and low self-discharge. Under ideal conditions a new deep-cycle battery would be 90% efficient.

The important characteristics to look for are:

i) Capacity

ii) Cycle life / price / performance

iii) Size and space requirements

iv) Efficiency

v) Self-discharge rate

vi) Installation - vertical or horizontal

vii) Environmental - will batteries be placed in high temperatures,

viii) Near water supplies or in wildlife parks … etc.

- **Inverter**

A power inverter, or inverter, is an electronic device or circuitry that changes direct current (DC) to alternating current (AC). The input voltage, output voltage, frequency, and overall power handling depend on the design of the specific device or circuitry. The inverter does not produce any power; the power is provided by the DC source .The DC input to the inverter can be from any of the following sources: • Rectified DC output of the variable speed wind power system or generators. • DC output of the photovoltaic power modules. • DC output of the battery used in photovoltaic power system.

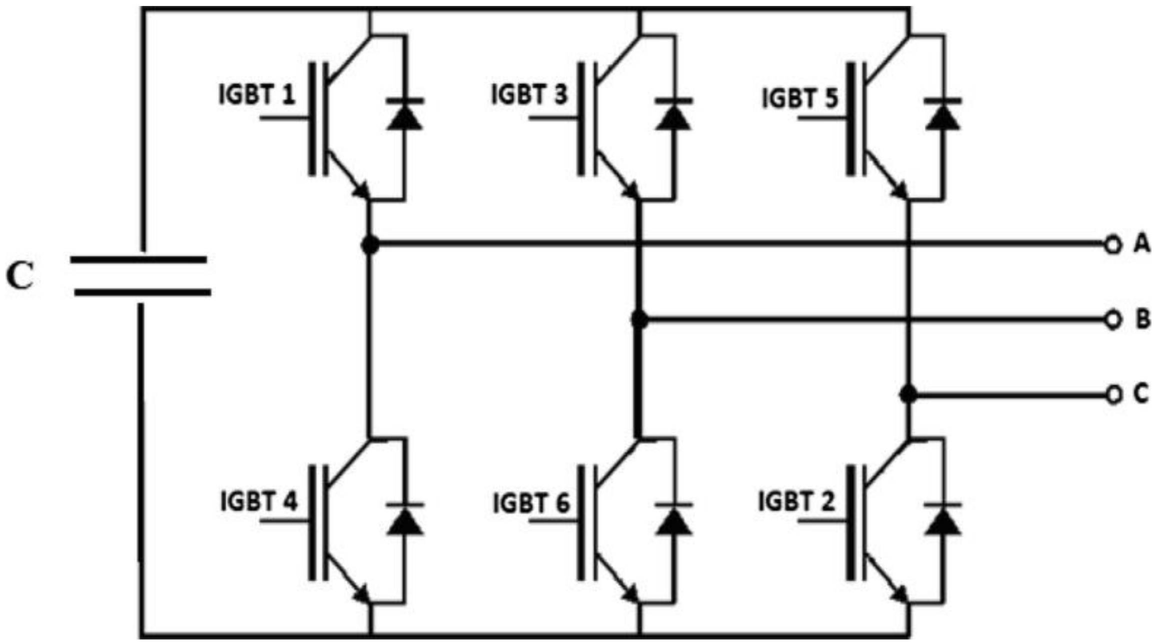

Figure 2.9: Three Phase Inverter Circuit

Mainly Solar inverters may be classified into three broad types:

a) Stand-alone inverters:

Used in isolated systems where the inverter draws its DC energy from batteries charged by PV arrays. Many stand-alone inverters also incorporate integral battery chargers to recharge the battery from an AC source, when available. Normally these do not interface in any way with the utility grid.

b) Grid-tie inverters:

Which 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, and this the type we are using in our project.

c) Battery backup inverters:

Are special inverters which are designed to draw energy from a battery, manage the battery charge via an onboard charger, and export excess energy to the utility grid. These inverters are capable of supplying AC energy to selected loads during a utility outage.[11]

- **Charge Controller**

The charge controller is a necessary part of any power system that charges batteries, whether the power source is PV, wind, hydro, fuel, or utility grid. Its purpose is to keep the batteries properly fed and safe for the long term. A charge controller is an electronic voltage regulator, used in off-grid systems and grid-tie systems with battery backup that controls the flow of power from the charging source to the battery. The charge controller automatically tapers, stops, or diverts the charge when batteries become fully charged. The most important feature of charge controller is to measure the battery voltage and protects the battery against the overcharging. This can be achieved by the following ways: Switching off the source when the charge cut-out voltage is exceeded. Short-circuiting the PV array with a shunt controller and adjusting the voltage. The reserve diode which prevents the battery to be discharged via the array during low irradiation level is integrated to the charge controller. Operation of batteries over long time of operation requires a charge controller to be flexible. The charge cut-off and discharge cut-off voltages are dependent on the state of charge of the battery.[12]

The main jobs of the charge controller are:

1- Allow the optimum charge for the battery.

2- Protect the battery from the overcharge.

3- Prevent the battery from unwanted discharge and from deep discharge.

4- Get information of state of charge of batteries

CHAPTER THREE

MOTHODOLOGY

3.1 Introduction

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 two principal classifications are grid-connected or utility-interactive systems and stand-alone 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.[13]

3.2 System Sizing

System sizing is the process for determining the required number of panels and size of the inverter needed for the medical campus of Sudan University of Science and Technology.

As mentioned in the previous chapters, solar PV power is a concept of generating electricity from the sun light and converting it to the AC energy that we use in our daily lives. PV modules are installed on fixed metallic support structures arranged in long rows, adequately spaced themselves, facing south (in the Northern Hemisphere) with an appropriate tilt, or deployed on tracking devices to follow the sun. In this chapter explanation of the methodology to design a PV connected system, in order to apply it in SUST Complex of Medical Colleges.

In a brief description of the design, PV modules are electrically connected together in series or parallel configurations and then this connection must be connected to the inverter in order to provide the AC load with sufficient power to cover the consumption of the load.

The unavailability of the sun during cloudy days and winter conditions are taken into account.

3.2.1 Load Estimation

The first step to design PV solar system is to calculate the total demand or total energy consumption (in Watt-hour per day) of all the loads that needs to be supplied by the solar system .This can be done by using table 3.1 to know the hourly consumption of each floor in the building, in order to calculate the daily consumption of each floor and external loads as illustrated in table 3.1.

Table 3.1: Electrical loads in the campus

Floor	Lighting / w	Fans/ w	Total / w
Ground floor	11672	4686	16385
First floor	12668	5326	18294
Second floor	14588	3120	17708
Third floor	9560	3692	13252
Fourth floor	7080	2972	10052
Fifth floor	8236	3018	11254
External loads	5010	2854	7864

3.2.2 PV Array Sizing

After finding out the total demand (watt-hour/day), certain calculation must be done to absorb the total energy required from the PV module. This is done by multiplying the total load demand times 1.25 (the energy loss in the system) which increase the system size by 25% and multiplying them by working hours of the system then dividing the output by the worst case scenario of sun insolation received in Khartoum, to find out PV array size as illustrated in equation 3.1 below.

This loss of energy occurs due to the temperature, shadows, and wiring and connection losses. Total losses around 30%, so the panel will produce enough (W-h/day) for the load plus more energy to cover the losses. Hence it will have to produce about 130% of the energy required by the load. [14]

All these data will be used in PVsyst and E-TAP simulation software in order to get results and reports.

Number of PV modules should be calculated by dividing the array size peak power by the peak power of a single module as illustrated in equation 3.2 below.

$$PV\ Array\ \ size = \frac{total\ demand\ (kWh/day) \times working\ hours\ of\ the\ total\ applinces \times 1.25}{sun\ inolation\ (kWh/m^2/day)} \quad (3.1)$$

$$Number\ of\ modules = \frac{PV\ system\ power\ (watt)}{Module\ power} \quad (3.2)$$

3.2.3 Inverter Sizing

An inverter is used in the system where AC power output is needed. A DC to AC inverter as it's clear from its name converts the DC output from the solar a modules into an AC that can be fed into a commercial electrical grid or institutions and residential houses. An example of solar inverter is shown in figure 3.1 below.

For on-grid systems an inverter size must be 25-30 % larger than the total watts of loads of the campus as illustrated in equation 3.3. The input rating of the inverter should never be lower than the total watts of appliances.

$$Inverter\ size\ = Total\ watt\ of\ applinces \times 1.25 \qquad (3.3)$$

Figure 3.1: Solar inverter

CHAPTER FOUR

DESIGN AND SIMULATION

4.1 Location Radiation Intensity

Sudan has a special location in the world due its latitude and longitude, it has a high UV radiation and sun insolation which it could generate a huge amount of solar energy.

Since the solar plant was suggested to be at a location of 15.38 latitude and 32.28 longitudes, Sudan Horizontal Irradiation Map has been illustrated in APPENDIX A below. And for more specific data for monthly radiation thanks to NASA radiation data shown in figure 4.1 below.

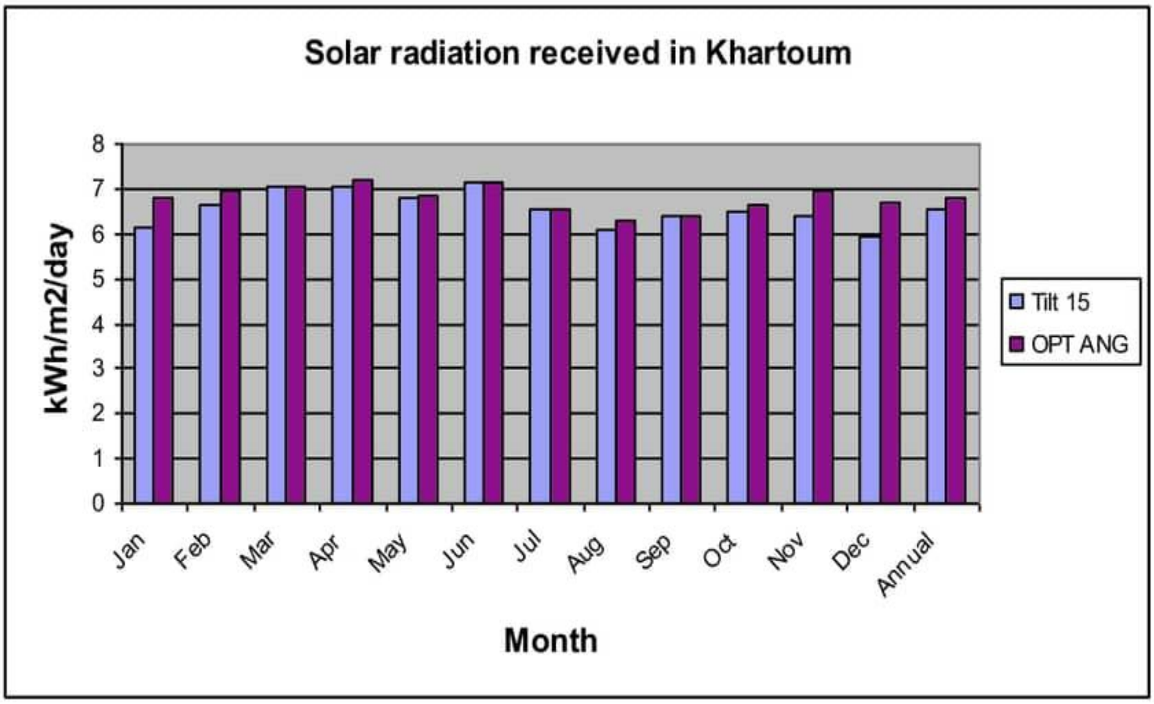

Figure 4.1: Monthly solar radiation received in Khartoum

4.2 System Design

Grid-connected PV systems (Grid-Tie) are the most effective choice among the various PV systems, whether they are stand-alone or hybrid systems, especially in the case of reliable utility (low probability of power outage). These types of systems have no backup batteries and thus totally dependent on the utility grid. A full design of PV grid connected system introduced below.

4.2.1 Load Calculation

According to the description of the campus building loads estimation above in table 3.1 to find the total energy needed to operate the institutions per day, certain calculation as follows in table 4.1:

Table 4.1: Load Calculations

Floor	Lighting / w	Fans/ w	Total / w	Hours
Ground floor	11672	4686	16385	8
First floor	12668	5326	18294	8
Second floor	14588	3120	17708	8
Third floor	9560	3692	13252	8
Fourth floor	7080	2972	10052	8
Fifth floor	8236	3018	11254	8
External loads	5010	2854	7864	8

4.2.2 PV Array Sizing

The panel generation factor is taken by the worst case scenario of the monthly insolation ratio which is in December, and equals to 6 $kWh/m^2/day$. The working hours of the complex are founded about 8 hours from 8 am to 4 pm and the average monthly sun radiation calculated from figure 4.1 above.

Total watts of the building of all floors = 94502 watt

Total demand = 94502*8 = 756.064 kWh

PV size = 756064*1.25/6 = 157500 $watt/m^2$ (3.1)

According to the module specification sheet illustrated in table 4.2 below the peak power of the module was founded.

Table 4.2: PV Module data sheet

Module name	SUNPOWER
Peak Power	450 watt
Power Tolerance	+5/0%
Panel Efficiency	22.2%
Rated Voltage	44 V
Rated Current	10.2 A
Open-Circuit Voltage (V_{oc})	51.9 V
Short-Circuit Current (I_{sc})	11 A

Number of PV module = 157500/450 = 350 module (3.2)

4.2.3 Inverter sizing

According to equation (3.3) inverter sizing must calculated from table 4.3 inverter data sheet below.

Table 4.3: Inverter data sheet

Model Name	TRIO-20.0-27.6-TL-OUTD
Rated Voltage	320/480 V AC
Output frequency	50 Hz / 60 Hz
PV voltage range	400 V
Max. input current	45.0 A
Output current	33 A
Max. efficiency	98.2%

Inverter size = 94500*1.25 = 118.125 KW. (3.3)

The size of the inverter will divided into 6 small inverters, and that will be commercial types. So dividing the 118.125 Kw by 6 small inverters equals about 20 kW per inverter.

A 20-27 kW, 3-phase inverter is recommended to be used for each group. Specifications are attached in APPENDIX B2.

4.2.4 Installation

The PV panels connection method series also called strings which in this case divided into 4-6 strings which string have 10-15 module except the last string have 13 module in series, then the four strings will be connected in parallel taking the voltages and current into consideration.

If the output voltage and current from a single module is smaller than desired, the modules can be connected into arrays. The connection method depends on which variable that needs to be increased. For a higher output voltage the modules must be connected in series, while connecting them in parallel in turn gives higher currents. It is important to know the rating of each module when creating an array. This process has been done by PVsyst program as illustrated below.

2.3 Simulation

The simulation results have been performed through PVsyst and E-TAP software environment. Results has shown good agreement with experimental data, whether for the whole operating system. The significant results are reported in order to show the effectiveness of the simulation model to predict energy generation for such PV system.

4.3.1 PVsyst Software

PVsyst 7.0 is a PC software package for the study, sizing and data analysis of complete PV systems. It deals with grid-connected, stand-alone, pumping and DC-grid (public transportation) PV systems. It includes extensive meter and PV systems components databases and comprehensive solar energy tools. Results of simulation reports illustrated in figures below.

Figure 4.1 shows the suitable tilt angle for the location of the project.

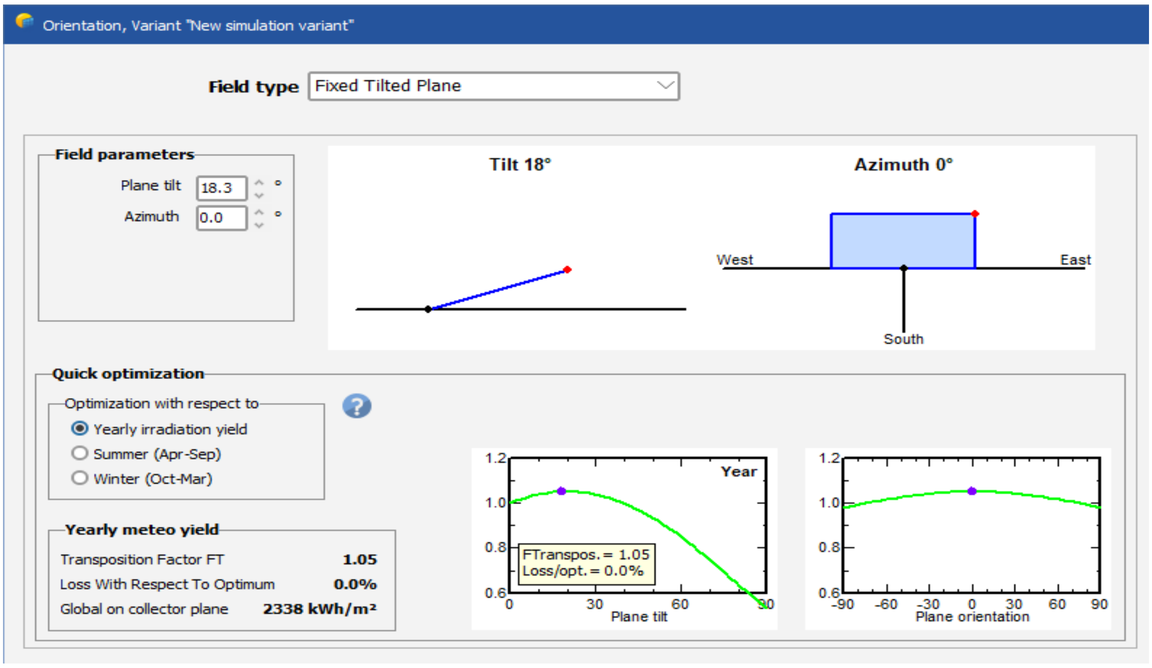

Figure 4.1: Tilt angle

Figure 4.2 shows the PV array design below.

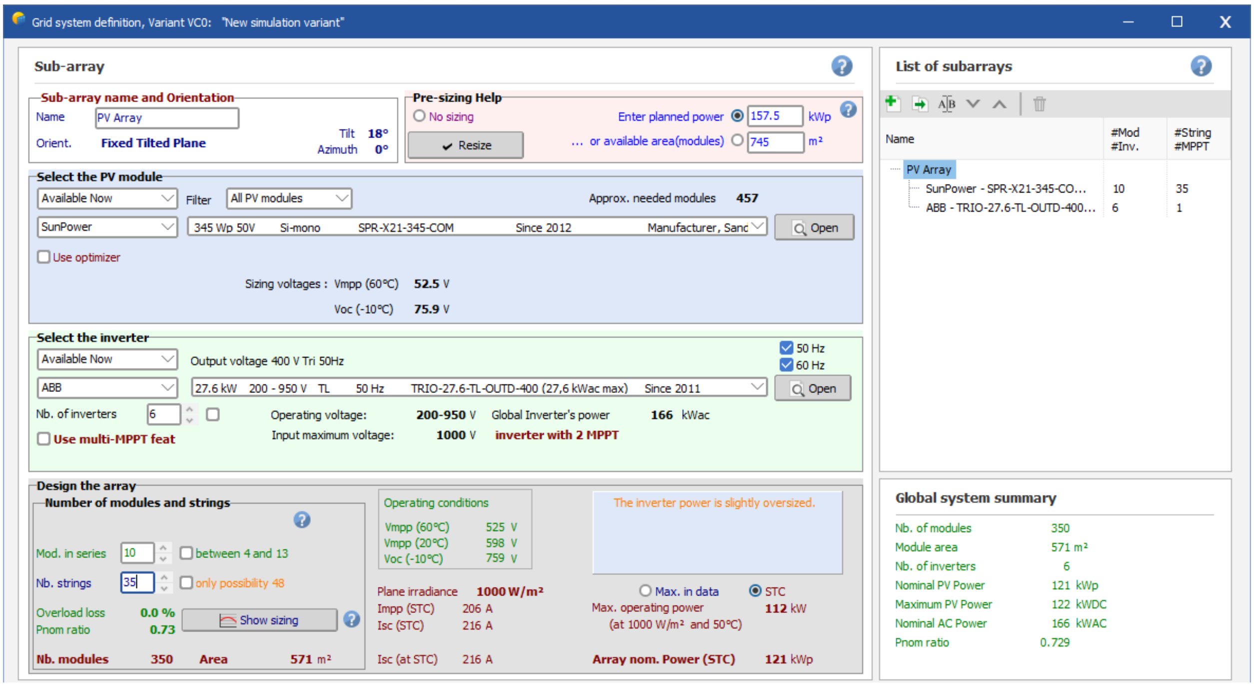

Figure 4.2: PV array design

Figure 4.3 shows report of simulation of the system parameters.

PVSYST 7.0.16		07/11/20	Page 1/6

Grid-Connected System: Simulation parameters

Project :	**graduation Project**			
Geographical Site	**Khartoum**		Country	**Sudan**
Situation	Latitude	15.60° N	Longitude	32.55° E
Time defined as	Legal Time	Time zone UT+2	Altitude	380 m
	Albedo	0.20		
Meteo data:	**Khartoum**	MeteoNorm 7.2 station - Synthetic		
Simulation variant :	**New simulation variant**			
	Simulation date	07/11/20 11h21		
Simulation parameters	System type	**No 3D scene defined, no shadings**		
Collector Plane Orientation	Tilt	18°	Azimuth	0°
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
			Circumsolar	separate
Horizon	Free Horizon			
Near Shadings	No Shadings			
User's needs :	Unlimited load (grid)			
PV Array Characteristics				
PV module Si-mono	Model	**SPR-X21-345-COM**		
Original PVsyst database	Manufacturer	Generic		
Number of PV modules	In series	10 modules	In parallel	35 strings
Total number of PV modules	nb. modules	350	Unit Nom. Power	345 Wp
Array global power	Nominal (STC)	**121 kWp**	At operating cond.	112 kWp (50°C)
Array operating characteristics (50°C)	U mpp	543 V	I mpp	206 A
Total area	Module area	**571 m²**	Cell area	515 m²
Inverter	Model	**TRIO-27.6-TL-OUTD-400 (27,6 kWac max)**		
Original PVsyst database	Manufacturer	Generic		
Characteristics	Unit Nom. Power	**27.6 kWac**	Oper. Voltage	200-950 V
Inverter pack	Total power	**166 kWac**	Pnom ratio	0.73
	Nb. of inverters	6 units		
Total	Total power	**166 kWac**	Pnom ratio	0.73
PV Array loss factors				
Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	43 mΩ	Loss Fraction	1.5 % at STC
Module Quality Loss			Loss Fraction	1.0 %
Module mismatch losses			Loss Fraction	2.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %

Incidence effect (IAM): User defined profile

0°	50°	60°	65°	70°	75°	82°	88°	90°
1.000	1.000	0.990	0.970	0.940	0.890	0.770	0.620	0.000

Figure 4.3: Report of system parameters

Figure 4.4 shows report of PV system main results.

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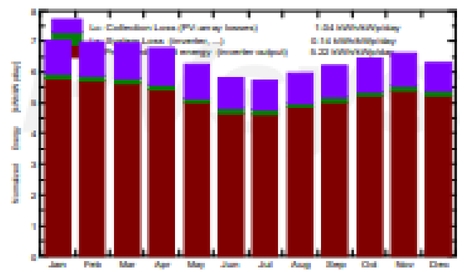
Grid-Connected System: Main results

Project : **graduation Project**
Simulation variant : **New simulation variant**

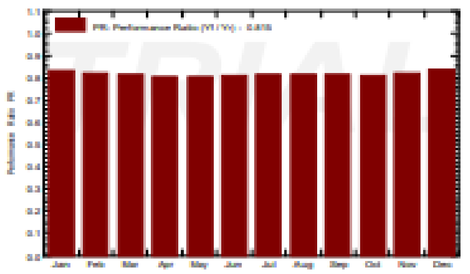
Main system parameters	System type	**No 3D scene defined, no shadings**		
PV Field Orientation	tilt	18°	azimuth	0°
PV modules	Model	SPR-X21-345-COM	Pnom	345 Wp
PV Array	Nb. of modules	350	Pnom total	**121 kWp**
Inverter		TRIO-27.6-TL-OUTD-400 (27,6 kWac max)	Pnom	27.60 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**166 kW ac**
User's needs		Unlimited load (grid)		

Main simulation results				
System Production	**Produced Energy**	**230.1 MWh/year**	Specific prod.	1906 kWh/kWp/year
	Performance Ratio PR	81.54 %		
Investment	Global	0.00 EUR	Specific	0.00 EUR/Wp
Yearly cost	Annuities	0.00 EUR/yr	Running Costs	0.00 EUR/yr
LCOE		**0.00 EUR/kWh**	Payback period	**Unprofitable**

Normalized productions (per installed kWp): Nominal power 121 kWp



Performance Ratio PR



New simulation variant

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR ratio
January	177.6	36.40	24.50	216.9	215.7	22.27	21.69	0.828
February	170.9	47.60	26.20	194.8	193.7	19.87	19.33	0.822
March	202.9	64.80	29.30	214.6	213.2	21.65	21.06	0.813
April	207.2	71.40	33.10	203.6	201.8	20.30	19.75	0.803
May	209.3	81.60	35.00	194.0	191.9	19.30	18.77	0.801
June	191.8	82.50	34.60	173.9	172.0	17.44	16.96	0.808
July	192.1	87.90	32.70	176.9	175.0	17.88	17.39	0.814
August	191.3	92.50	31.70	184.4	182.7	18.68	18.17	0.816
September	181.4	73.00	32.30	186.2	184.7	18.76	18.25	0.812
October	180.5	68.00	32.60	199.4	197.9	20.04	19.52	0.811
November	165.2	44.10	28.40	197.6	196.2	20.10	19.59	0.821
December	157.3	39.80	24.19	195.0	193.8	20.17	19.65	0.835
Year	2227.5	789.60	30.40	2337.4	2318.7	236.45	230.14	0.815

Legends:
- GlobHor: Global horizontal irradiation
- DiffHor: Horizontal diffuse irradiation
- T_Amb: T amb.
- GlobInc: Global incident in coll. plane
- GlobEff: Effective Global, corr. for IAM and shadings
- EArray: Effective energy at the output of the array
- E_Grid: Energy injected into grid
- PR: Performance Ratio

PVsyst Evaluation mode

Figure 4.4: Main results

Figure 4.5 shows the losses diagram of the system.

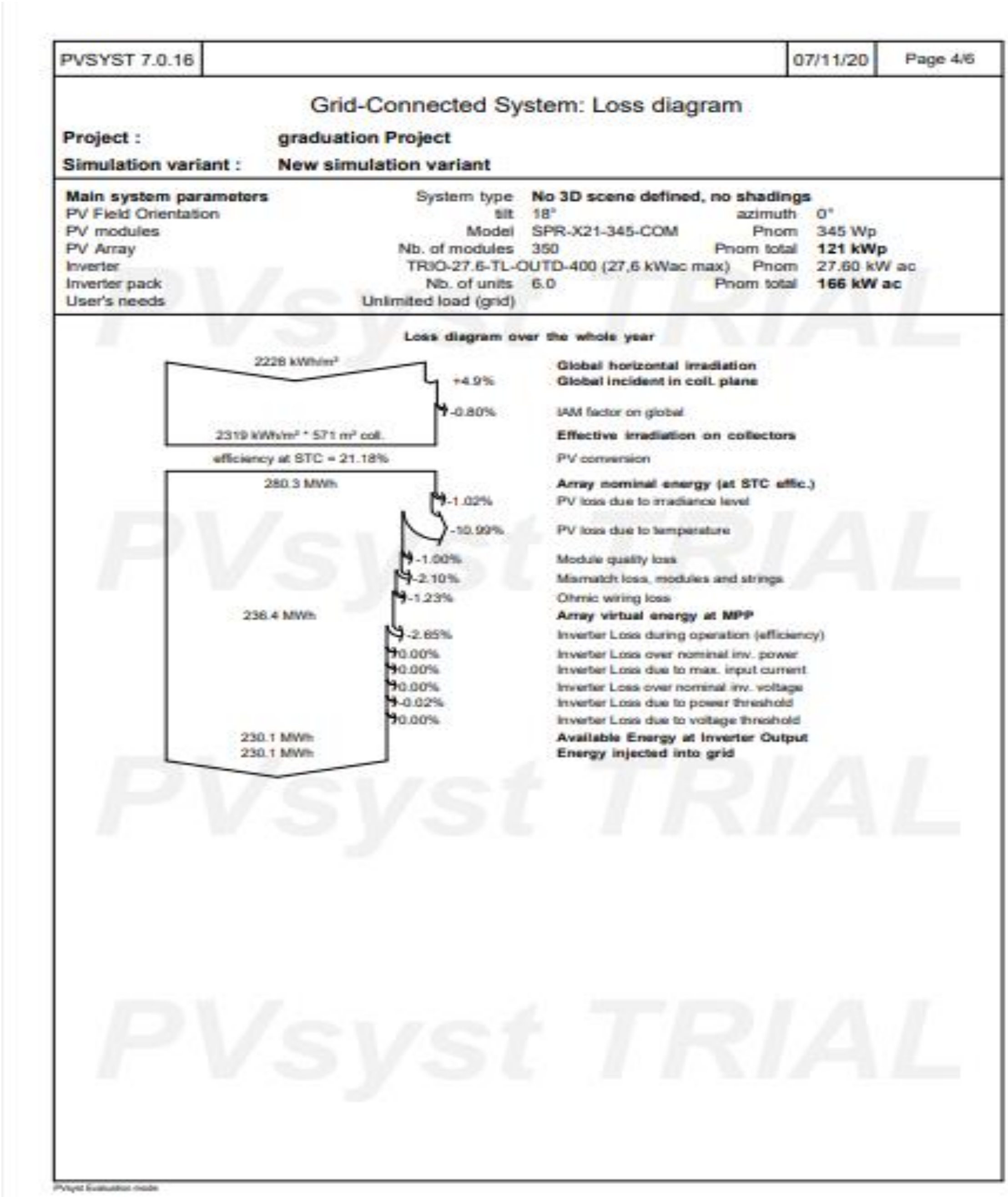


Figure 4.5: Losses diagram

4.3.2 (E-TAP) Software

Power systems analysis and simulation software are commonly used in electrical engineering practice. Initially, they were used to quickly solve the non-linear load flow problem and calculate short circuit currents, but their use has been extended. Extension includes many other areas such as power system stability, protection and coordination, contingency

/reliability, economic modeling, etc. The most common software packages used for power systems analysis are MATLAB, ETAP, PSAT, etc. E-TAP is the most comprehensive electrical engineering software solution for the design, simulation, operation, and automation of generation, transmission, distribution, and industrial power systems in this project ETAP is used to simulate the Grid tied system.

Simulation results

The ETAP Load Flow Analysis module calculates the bus voltages, branch power factors, currents, and power flows throughout the electrical system. ETAP allows for swing, voltage regulated, and unregulated power sources with multiple power grids and generator connections. It is capable of performing analysis on both radial and loop systems.

SUST Complex of Medical Colleges Load Flow Analysis illustrated in figure 4.7 below.

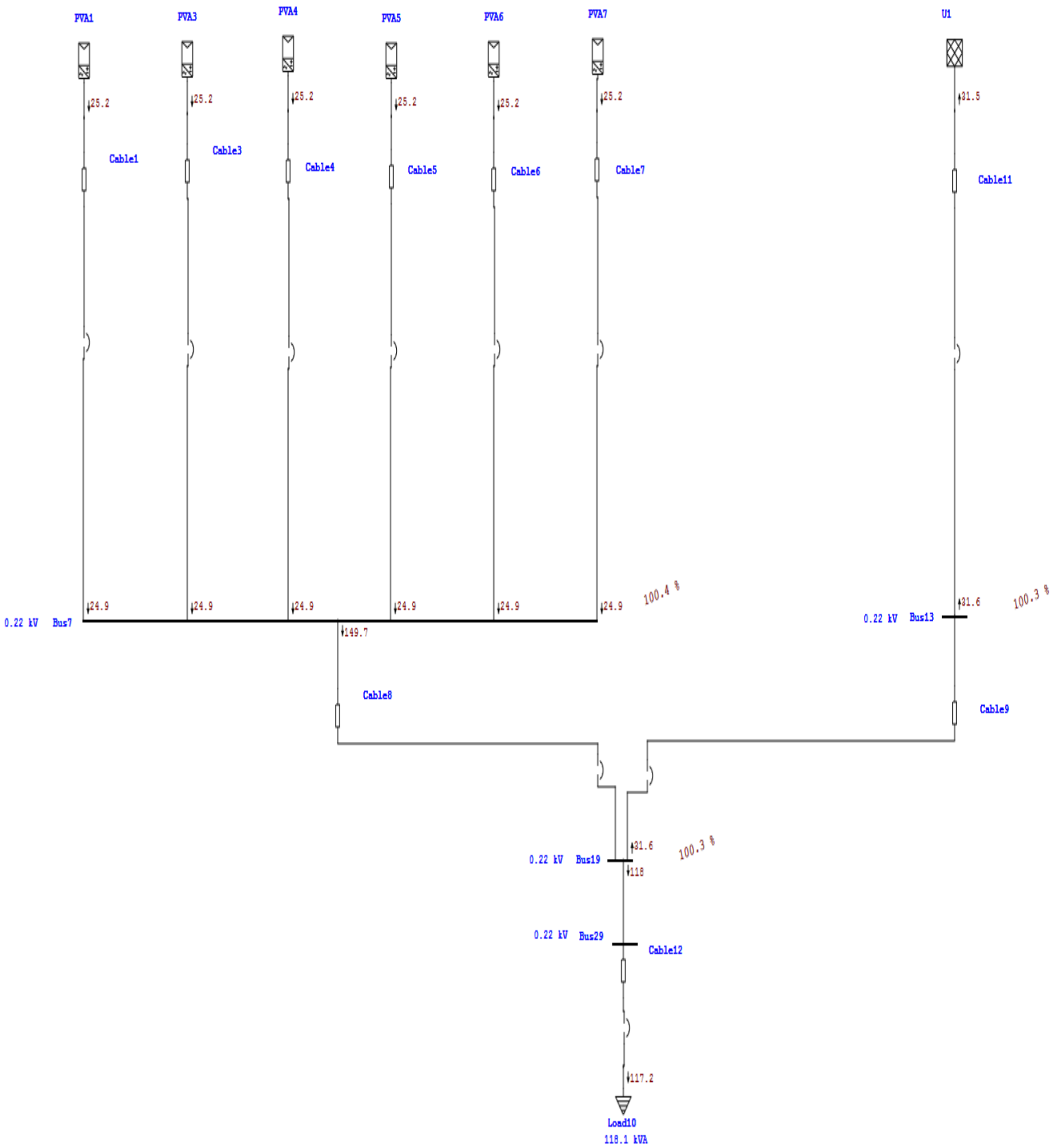


Figure 4.7 Load flow analysis simulation for SUST Complex of Medical Colleges

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The main goal of this project is to design a circuit that can feed the load demand of 756 kWh/day with sustainable power supply during peak demand working hours of the day which is 8 hours/day with costless green energy in long term, when there any disturbance in the PV grid the CB switch the load to utility grid to maintain continuity of supply.

As design was successfully obtained and satisfactory results gained from PVsyst and E-TAP software for SUST complex of Medical Colleges.

5.2 Recommendations

The national electricity grid covers only 40% of the country so alternative resources such as renewable energy should be taken in consideration. It is suggested that future plans may help the country in industrial growth and economically developed.

Reduce appliances to the less power consuming type to minimize load consumption. This project is suitable for residential institutions and not recommended for short time projects economically.

5.3 Future work

Sudan has a unique geographic location that gives it the ability to efficiently use the solar radiation as a source of power. So we must get the best of this property by concentrating upcoming researches in this field to obtain more solar plant to supply the huge demand of electricity due to the growth of population.

Upcoming researchers must study how to reduce installation cost and reduce the losses of the system by keeping up with the upcoming updates and trends.

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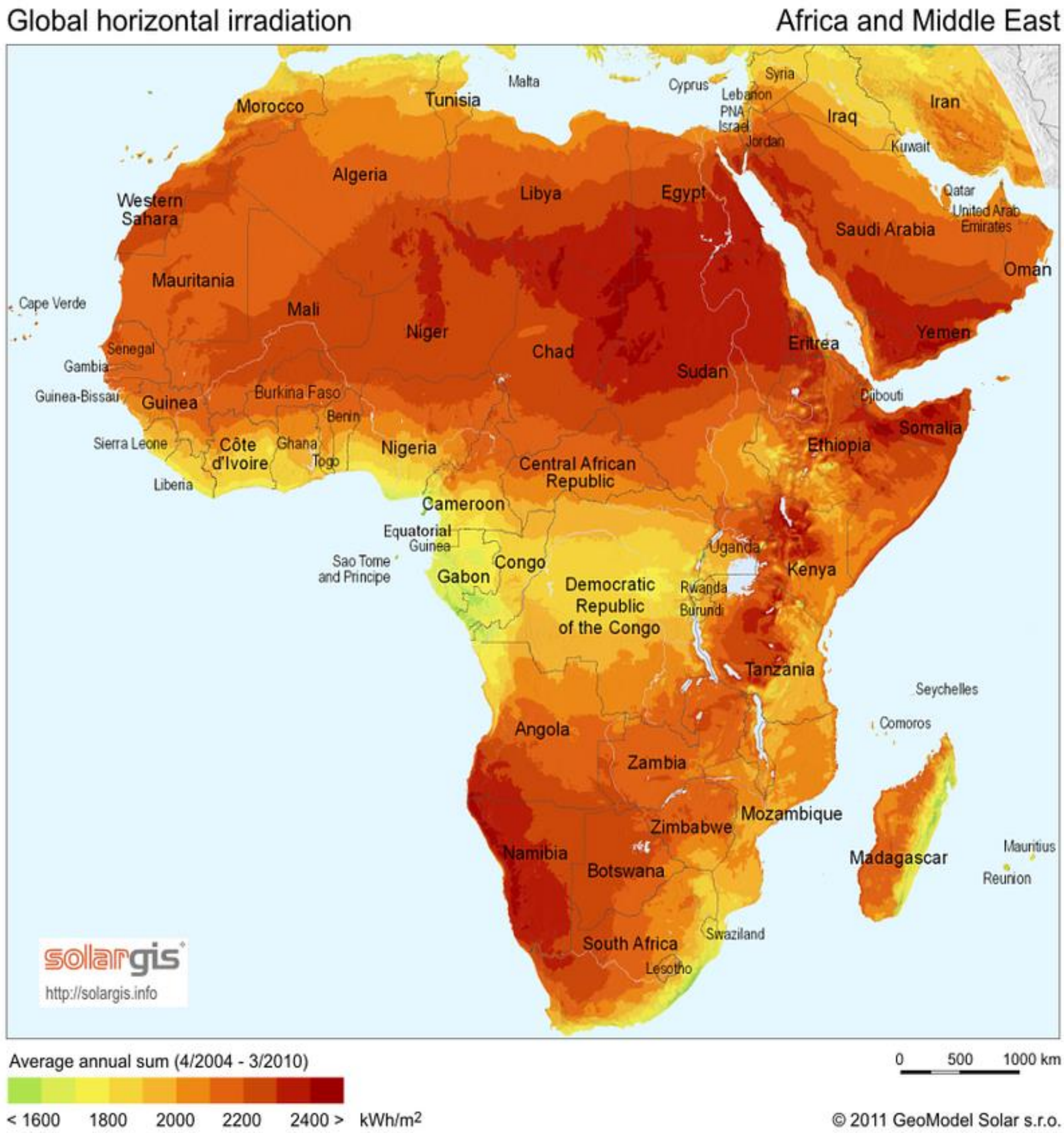
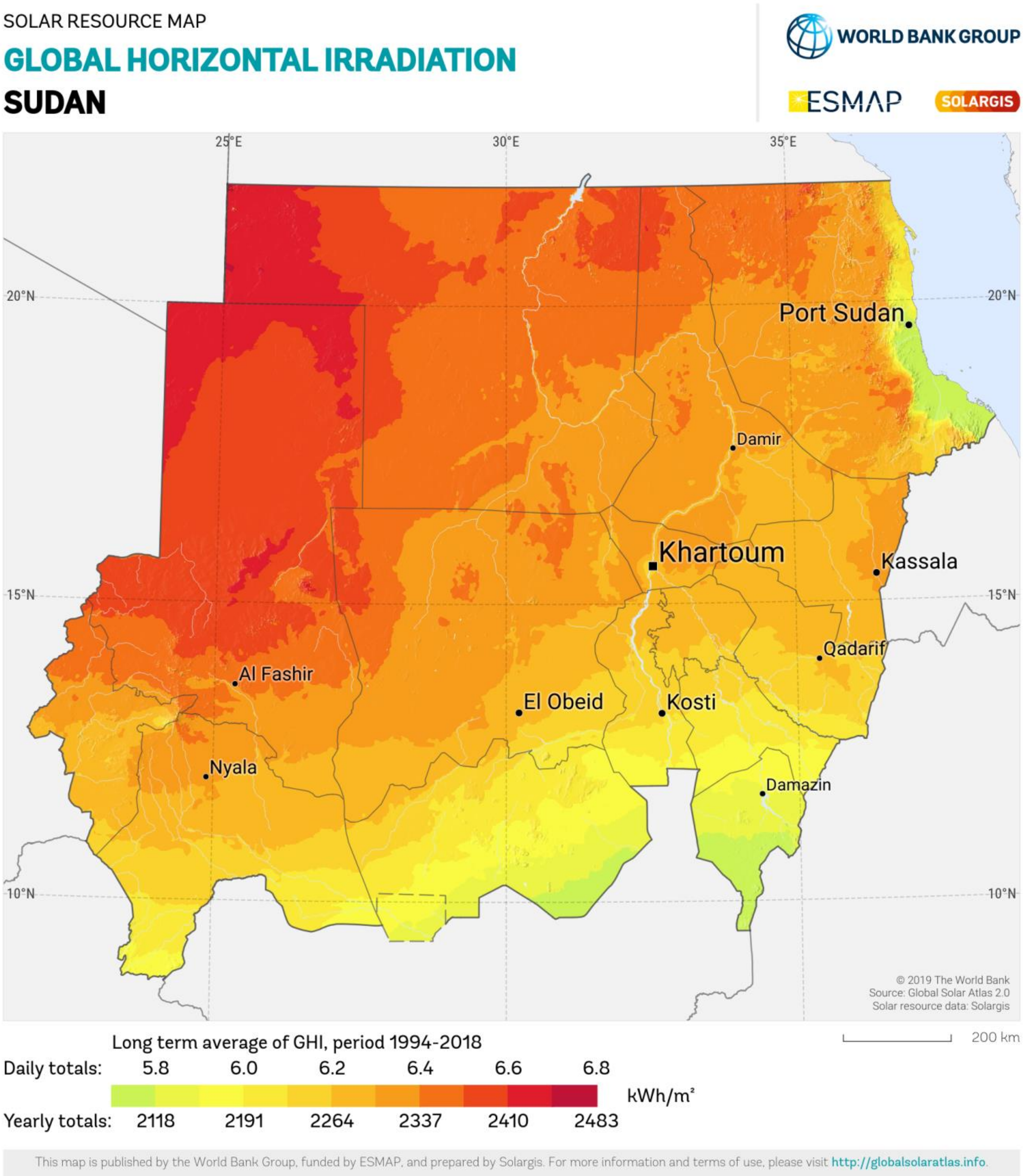
APPENDIX A



A1: AFRICA Horizantal Irradiation



A2: SUDAN Horizontal Irradiation

APPENDIX B

B1: SUNPOWER A-Series PV Module

B2: ABB 3-Phase Inverter