DESIGN AND EVALUATION OF A GRID CONNECTED PHOTO VOLTAIC (PV) SYSTEM: A CASE STUDY OF MOI UNIVERSITY ADMINISTRATION BLOCK

BY

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A Thesis Submitted to the School of Engineering, Department of Mechanical and Production Engineering in Partial Fulfillment of the Requirements of the Award of the Degree Master of Science in Energy Studies

(Renewable Energy Resources Option)

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MOI UNIVERSITY

2021

DECLARATION

Declaration by Candidate

I hereby declare that this thesis is my original work has not been presented to any other institution for the award of any certificate, and therefore may not be reproduced in whole or part unless with the consent of my approval or that of Moi University.

Signature: ________________________________ Date:___________________

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Reg No: TEC/PGMP/03/15

Declaration by the Supervisors

This research thesis has been submitted for examination with our approval as University supervisors.

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DEDICATION

I dedicate this work to my family for unwavering support, encouragement they gave me as I researched, their patience and understanding during the entire study period. May all Glory be to God.

ACKNOWLEDGMENT

I would like to acknowledge the invaluable guidance, encouragement and assistance provided by my supervisors; Dr. S. Talai and Dr. L. Letting during the research process and development of this thesis.

ABSTRACT

Moi University relies on utility grid whose major sources are centralized generation with petroleum, hydro and geothermal resources. With increasing students enrolment every year, the grid power is not adequate, hence frequent outages are experienced. During the occurrence, diesel generators are utilized as backup. However, fuel is expensive for its operation. Fortunately, Moi University administration block is at geographical location of 0.286°N latitude and 35.294°E longitude, where availability of solar resource is throughout the year. The average has been indicated to be 5.56 kWh/m^2/day. Therefore, the main aim of this research was to design, simulate and evaluate a grid-connected system for Moi University administration block. The specific objectives were: to evaluate the optimal values of solar resource parameters with respect to tilt and orientation; to map and collect power rating data of power consumer in the administration block; to design and simulate a grid connected PV system based on the outcome of first and second objectives and finally to evaluate the economic impact of incorporating battery bank to the grid connected system. To design an ideal grid connected PV system this study had to get ideal solar resource parameters through experimentation by varying solar panel tilt and orientation. Administration block's power demand was obtained through physical load audit and utility company bills (KPLC bills) to obtain load demand as well as identifying the amount critical load power consumption. Lastly, a grid connected system was designed, simulated at this ideal orientation and its performance evaluated by PVsyst software. The economical evaluation was done with respect to current market prices. The orientation of the building was found to be desirable for having most of its roof surface area on its longitudinal length sloping downward midway along North and South axis to forming solar plane Azimuth 159° and -21°. The obtained load was 19745 kWh per Month, with 66.24 kWh being daily critical load. The energy balance between load and available solar resource done by PVsyst yielded a feasible and economical system of 100 Kw grid-tie system with a battery bank of 2145 Ah at 48 V. This battery bank was sized to specifically support the critical load sub panel when this system intentionally island during outage. The study obtained an ideal panel orientation as -21° tilt angle and 159° azimuth angle. The designed system simulated yearly production of 265.21 mWh leading to which a savings of KES 4.3 million per year. This translated to breakeven of 2.7 years for a 100 kW grid-connected system without battery bank while 3.4 years for the same system with batteries. In conclusion, such a system with these savings on electric bills, improved power reliability, and short time of return on investment can be adopted to take advantage of abundant solar energy resources. Therefore, this study recommends a grid connected solar system not only for administration block but to the whole university to take advantage of adequate solar resource within the geographical location. Future work is needed on ways of enhancing energy efficiency and its impact on sizing solar system as alternative power supply.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS/ACRONYMS

BoP	Base of pyramid
BOS	Balance of System
DG	Distributed generation
EIA	U.S Energy informative administration
FiAH	Feed-in Approved Holder
FiT	Feed in Tariff
GDC	Geothermal Development Cooperation
IPP	Independent power producers
IPP	Independent Power Producers
IRR	Internal Rate of Return
Ken Gen	Kenya Electricity Generating Company
KESI	Kenya Electricity Supply Industry
KPLC	Kenya Power and Lighting Company
LPG	Liquefied Petroleum Gas
MoE	Ministry of Energy
MoEP	Ministry of Energy and Petroleum
MPPT	Maximum Power Point Tracking
MWh	Mega Watt Hours
MWp	Megawatts peak
NEC	National electrical code
NGO	Non-Governmental Organizations
REA	Rural Electrification authority
SLP	Solar lighting products

OPERATIONAL DEFINITION OF TERMS

Connection point — The point on the Distribution System, electrically closest to the FiAH's plant, at which FiAH generated energy is exported.

Harmonic — A sinusoidal component of a periodic wave or quantity having a frequency that is an integral multiple of the fundamental frequency.

Intentional Islanding — Permitting one or a number of distributed sources to continue operating autonomously and provide uninterrupted service to local customers and revenue to the mini-grid operator during outages on the main grid

Islanding — A condition in which a portion of the utility system that contains both load and distributed resources remains energized while isolated from the remainder of the utility system

Performance Ratio — Is a measure of the quality of a PV plant that is independent of location and it therefore often described as quality factor. The performance ratio (PR), stated as percent describes the relationship between the actual and theoretical energy outputs of the PV plant. It therefore indicates the proportion of the energy that is actually available for export to the grid after deduction of energy loss as thermal losses and conduction losses and of energy consumption for operation. The closer the PR

	value determined for a PV plant approaches 100%, the more efficiently the respective PV plant is operation.
Specific energy production	It is computed by applying a transposition model (Hay or Perez) to the horizontal hourly values. The result depends namely on the diffuse irradiance. Expressed in [kWh/kWp/year], is an indicator that allows the comparison of the system quality between installations in different locations and orientations.
Traditional networks	Are conceptualized as systems with large generators connected away from the load side, so power transfer occurs from the higher voltage level to the point of consumption at lower voltage levels.
Transpose Factor	The Transposition Factor is the ratio of the incident irradiation (GlobInc) on the plane, to the horizontal irradiation (GlobHor). I.e. what you gain (or loose) when tilting the collector plane. It may be defined in hourly, daily, monthly or yearly values.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

According to Kenyan Electricity Supply Industry (KESI), Kenya's installed capacity is at 2.3 GW with electricity generation mix of consists of hydro, geothermal, thermal and wind (energypedia.info, 2020.). The base load is supplied by the cheaper hydro and geothermal power generating plants while the peak power is supplied by the generators like diesel, thermal and gas plants. Significant of this electrical energy is consumed by industries in the urban centers.

Moi University is situated at an ideal location for solar resource throughout the year for the utilization of photovoltaic for the generation of electricity. It is closer to the equator where the sun is sun is overhead in most part of the year. The administration block is at coordinate 0.282˚N, 35.295˚ E (Figure 3.6). At the moment, the university heavily relies on utility grid whose major sources are centralized generation with petroleum, hydro, and geothermal resources therefore marred with line losses due to long line transmission and distributions. Diesel generator is used as a backup during power outages. The whole administration block consumes roughly 31756.5KWh per month with each unit going for Ksh. 16.17 making a bill of Ksh. 513502.60 per month while the whole Kesses Main campus monthly bill is Ksh. 14,895,744 according to KPLC bill of July 2018.

1.2 Utility Grid Supplying Moi University

Moi university electricity is fed by installed Lessos 2.5 MVA 33/11 substation. The substation load has increased between the year 2017 and 2018 from 11MW to 18MW presently with five evacuation feeders namely;

- Eldoret - Lessos interconnector
- Chemelil Feeder
- Fluorspar Feeder
- Kapsabet Feeder
- Lessos Feeder

Figure 1.1: Lessos 232/33 KV, Substation 23MVA TX
(KPLC, 2020.)

The Eldoret-Lessos interconnector serves Moi University, Ngeria Prisons, Kabiyet and Sangalu Dairies and others. Lessos power supply by distanced centralized generations as far as Tororo through long range transmission as Bujagali-Tororo-Lessos High Voltage power line ((REA, 2009).

1.3 Moi University Administration Building Electricity Bills

Due to numerous academic activities taking place at Moi university administration block, the bill is significantly huge (over Kshs. 760,000 per month). The administration has a significant power consumption during the day as shown by KPLC electricity bill in Table 1.1. for the period of 2nd July, 2018 – 1st August, 2019.

Table 1.1: Administration block electricity bill for 2nd July – 1st August 2018

Meter No.	Previous reading	Current reading	Reading Type	Consumption	Consumption type
040016113631	0	96	Real	96	Demand KVA
040016113631	0	94	Real	94	Demand KW
040016113631	563873	582889	Real	19016	High rate
040016113631	368516	378147	Real	9631	Low rate

*Source: **(KPLC bill)***

1.4 Kenya Government Power Planning

The second medium Plan 2013–2017 of Vision 2030, it identifies energy as one of the infrastructure enablers for Kenya's transformation into "a newly-industrializing, middle-income country providing a high quality of life to all its citizens in a clean and secure environment". Access to competitively priced, reliable, quality, safe and sustainable energy is essential for achievement of the Vision. Government have put up a 20-year feed-in-tariff for renewable resources established, as well as a zero rating of export duty and a removal of VAT on renewable equipment, the Kenyan government is actively facilitating renewable energy growth at utility scale, commercial and industrial (C&I) scale, as on-grid solution (Global Energy insights,2018).

Furthermore, parliament came up with Energy Bill 2015 with intensions to unbundle electricity transmission and distribution while liberalizing licensing of electricity generation, transmission and distribution. This reflects the changing environment of energy regulation in Kenya since it recognizes different sources of renewable energy and creates the corresponding licensing and regulatory agencies. These include the introduction of an energy and petroleum institute (which shall be responsible for the nuclear energy program) and regulation of mid-stream petroleum, areas which did not exist under the previous regulatory regime - Kenya gazette, August 2015.

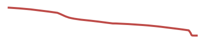
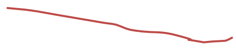
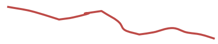
1.5 Power Line Losses State

Centralized generation exposes large regions on constant outages and huge transmission and distribution losses. This leads to 600hrs/year of outages compared to 120hrs/year in South Africa. To guard themselves, firms resort to expensive backups like diesel generators which lead to pollution (IEA, 2018). Moi University is one of the institutions with standby diesel generator as an energy solution during times of outage.

Transmission losses at about 19.45% and power theft costs Kenya power 17.5 billion annually. With such trend, KPLC was push spent Sh10 billion in a countrywide network upgrade project – Operation boresha stima – launched in August 2015. In 2014, it also had spent Sh1 billion in a programme – Boresha meme viwandani – aimed at boosting power supply in manufacturing industries (Ben Chuma, 2016).

The status quo as is for now is that government investment on renewable energy resource so far has been mostly by centralized generation systems – Garissa solar plant 55 MW and Lake Turkana wind plant 300MW will be connected to the national grid. This centralized generation comes with long range transmission and distribution which is characterized with high line losses and large area blackouts every time when a minor grid fault occurs – 25 days/year of blackout in Kenya compared to 5 days/year in South Africa (IEA Statistics). These have forced end users to invest in diesel-powered that are costly and not environmentally friendly.

Table 1.2: Failure curve of sampled countries between 1960 and 2014

Country	1960	2014	Curve
Kenya		18	
South Africa		8	
South Africa		6	
China		5	
United Kingdom	9	8	
USA	9	6	
Australia	13	5	
Austria	8	5	
Azerbaijan		14	

The power failures, averaging two days a month, rank Kenya eighth on the list of African countries that suffer the longest duration of electricity outages and power losses.

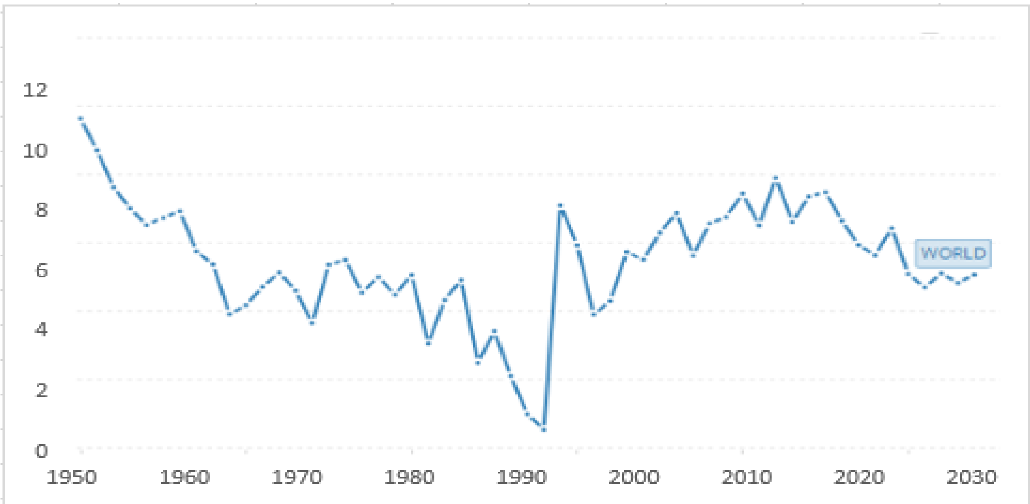


Figure 1.2: Average global power line losses between 1960 and 2014.

(Source: IEA statistics, OECD/IEA 2018)

1.6 Distributed Generator Islanding

This is a condition in which a portion of the electric utility system that contains both load and DG resources - which the utility has no control over remains energized while isolated from the remainder of the utility system. In the case of this study, Islanding will allow the designed system to power administration bock even with loss of power in the grid. This is unusual characteristics of Grid tie inverters which go off during grid failure.

The battle for electricity customers in an increasingly competitive and deregulated market environment is one of the challenges facing the electric power utilities of today. Customers expect a reliable and efficient supply of power from their utilities. One of the advantages that a DG can provide to the electric utility and to customers is the possibility of improving the continuity of supply by implementing safe intentional islands in the event of upstream utility supply outage. Implementing intentional islanding of DG in a deregulated era will have an impact on electricity market prices. This problem is considered in this thesis by solving the optimal power flow problem while accounting for islanded operation (H.H. Zeineldin).

1.7 Problem Statement

Moi university electricity is supplied by fault-prone traditional grid which gradually becoming insufficient due to rapidly expanding annual electricity demand at a rate of 13.5% as a result of rise in population and expanding economy (Megorden, 2017). Kenya population rose by 2.3% in 2018 according to Kenya national bureau of statistics. Therefore, the university suffer an average of 600 hours of blackout in a year as the rest part of the country supplied by the same grid with centralized generations.

Just like other firms, Moi University resort to diesel generators to fill the gap that come with these outages. Running diesel generators is costly. Also, its operation is not environmentally friendly and this couple up with tedious routine maintenance of the generator.

Therefore, this research aimed at designing an economical and feasible Grid-connected solar system with sized battery bank for critical loads to harness adequate solar resource of $5.56\ kWh / (m^2/day)$ available to administration block against $19000\, kWh / month$ as daytime consumption. a solution to these problems which is worsening with time to decouple part of demand from the grid through decentralized generation.

1.8 Justification of the Study

Moi University administration block has electric demand of 374.5 MWh yearly (KPLC Bill, 2018). The solar resource of this geographical resource is 5.56 sun-hours a day (Table 4.1). This solar resource can be harnessed to generate and substitute of $265.2\, MWh / Year$ electricity, hence, grid savings Ksh. 4.3M per year. Grid-connected system without batteries makes the system more economical since the batteries are the most replaceable component in the PV system making the system expensive in the long run. Furthermore, the system will raise awareness of renewable resources among the students, thus, this will attract new apprentices to engage in the PV industry and stimulate solar energy research. .

Administration offices being operational during daytime, hence, the peak load is during the day which coincides with day time irradiation of sun resource. 5.564 sun-hours of administration bock is abundant enough resource in tropical locations like in Kenya to substitute most of administration demand-19016Kwh/month during the day and 9631KWh/month during the night in July, 2018.

Furthermore, solar PV systems will improve the voltage profile in the distribution lines, thereby reducing transmission and distribution losses. This will encourage the introduction of Building Integrated Photovoltaic (BIPV) legislation that would accelerate solar PV penetration and reduce reliance on fossil fuel generators.

1.9 Objectives of Study

1.9.1General Objective

To design, simulate and evaluate a grid connected *PV* system for Moi university administration block.

1.9.2 Specific Objectives

i. To evaluate the optimal values of solar resource parameters with respect to tilt and orientation.

ii. To map and collect power rating data of power consumer in the administration block.

iii. To design and simulate a grid connected PV system for Moi university administration block based on (i) and (ii) above.

1.10 Scope of the Study

The scope of this study is limited to collection and analysis of solar insolation, loads demand data for Moi University administration block. The analyzed trends enables the sizing of a typical grid connected solar photovoltaic electricity generation system. This study does not cover energy management.

The flow plan of this thesis is as shown in Figure 1.3. The two main values that was used to obtain energy balance of the power system sized and designed are;

i. The solar resource assessment of the site is a theoretical study based on meteorological data provided by PVGIS website.

ii. To find the load power demand, a field survey of the administration block to Moi University will be conducted.

These two portions were the foundation that built a suitable PV system. To find the optimal solution, the computer software PVsyst and Sunny Design will be used, which will result in a numerical model that will end with economical evaluation of the system.

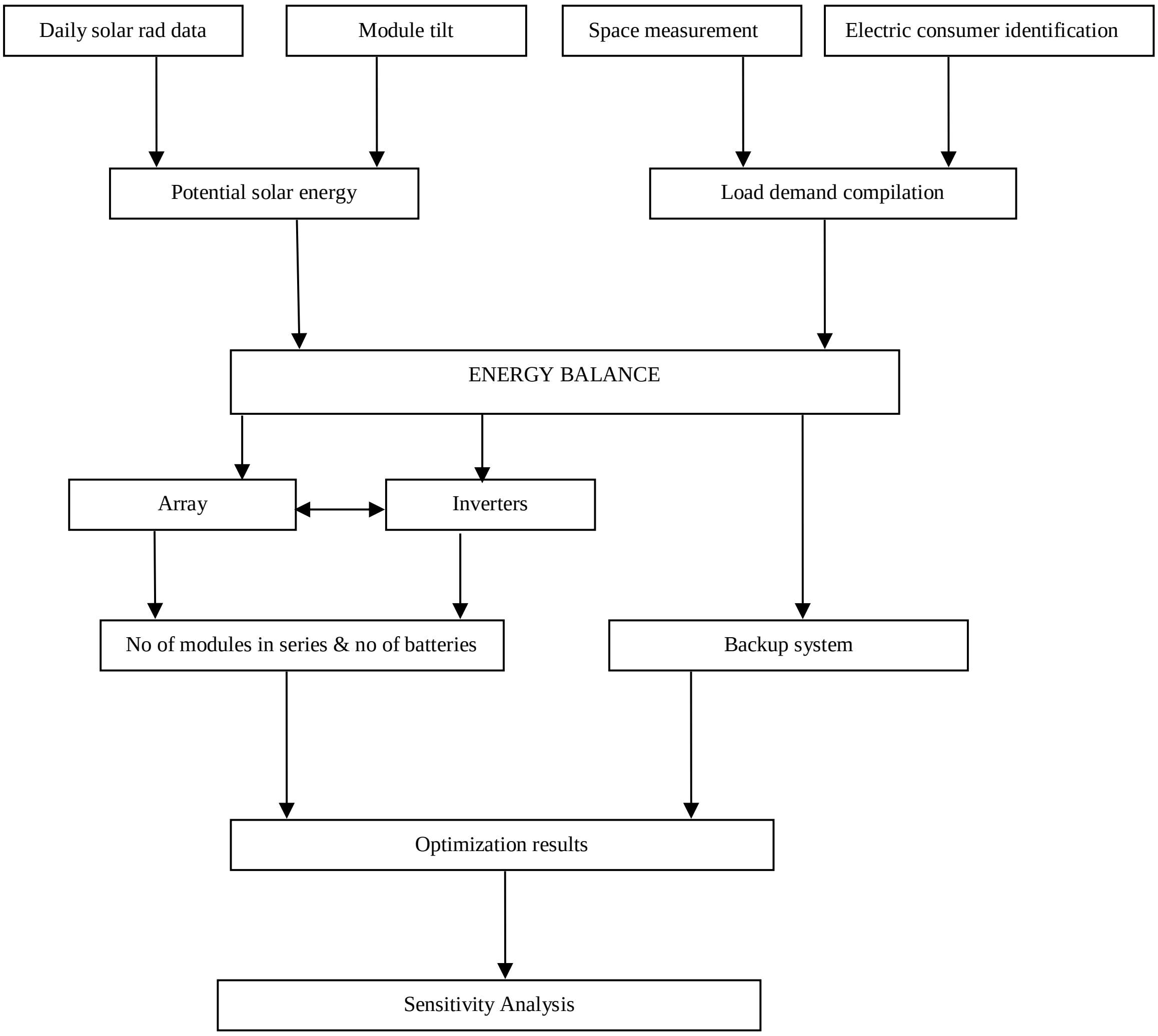


Figure 1.3: Energy balance facets structure

CHAPTER TWO

LITERATURE REVIEW

2.1 Solar Photovoltaic (PV) Technology

Historically, PV deployment has been slowed by real or perceived challenges such as high capital costs, lack of scale in manufacturing, shortage of raw materials, and balance of system (BOS) performance limitations. Recent reductions in cell prices, increased manufacturing and more aggressive policies have driven a rapid growth in installed global solar PV capacity. Annual growth in installed PV has averaged over 58% since 2006. With an installed capacity greater than 137 GWs worldwide, solar photovoltaic (PV) technology has become an increasingly relevant energy supply resource (*Rethinking Energy*, IRENA 2014).

2.2 Types of Solar Systems

The *Energy Informative* of August 14, 2013. Categorized solar photovoltaic systems depending on:

i. Connection to grid – off grid and grid tied
ii. Connection to other energy sources- hybrid mostly supplemented with genset or grid
iii. Design use- stand alone and micro grid
iv. Size- Pico solar homes system as m-kopa delights.

These are discussed as follows:

2.2.1 Off-grid solar systems

An off-grid solar system (off-the-grid, standalone) is the alternative to one that is grid-tied. For homeowners that have access to the grid, off-grid solar systems are usually out of question. It ensures access to electricity at all times, off-grid solar systems require battery storage and a backup generator (if you live off-the-grid). On top of this, a battery bank typically needs to be replaced after 10 years. Batteries are complicated, expensive and decrease overall system efficiency.

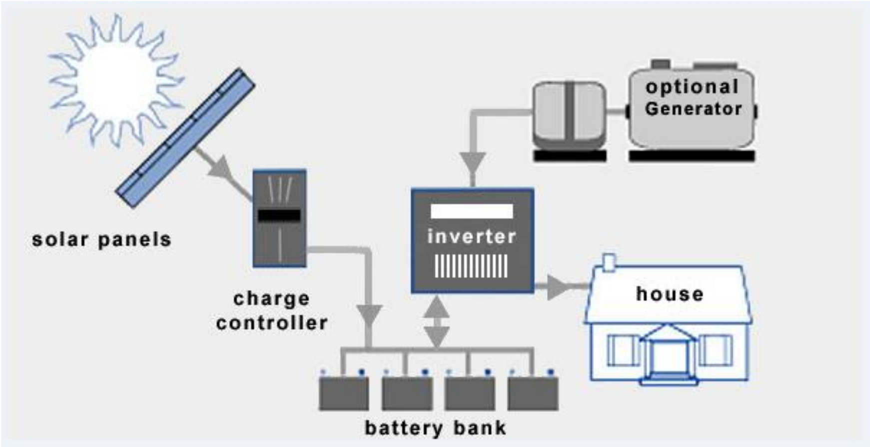


Figure 2.1 : Off-grid system (*Energy Informative*,2014.)

2.2.2 Hybrid solar systems

Hybrid solar systems combine the best from grid-tied and off-grid solar systems. They can either be referred as off-grid solar with utility backup power, or grid-tied solar with extra battery storage.

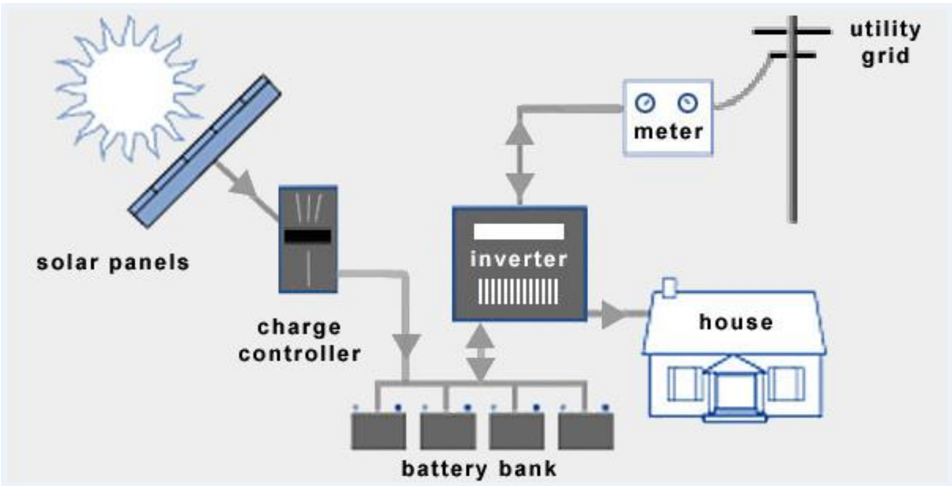


Figure 2.2: Hybrid system structure (*Energy Informative*,2014.)

2.2.3 Battery-based grid-tie inverter

Hybrid solar systems utilize batter-based grid-tie inverters. These devices combine can draw electrical power to and from battery banks, as well as synchronize with the utility grid. The bottom line is that, currently for the vast majority of homeowners, tapping the utility grid for electricity and energy storage is significantly cheaper and more practical than using battery banks and/or backup generators.

2.2.4 Grid-tied solar systems

Grid-tied, on-grid, utility-interactive, grid intertie and grid back-feeding are all terms used to describe the same concept – a solar system that is connected to the utility power grid.

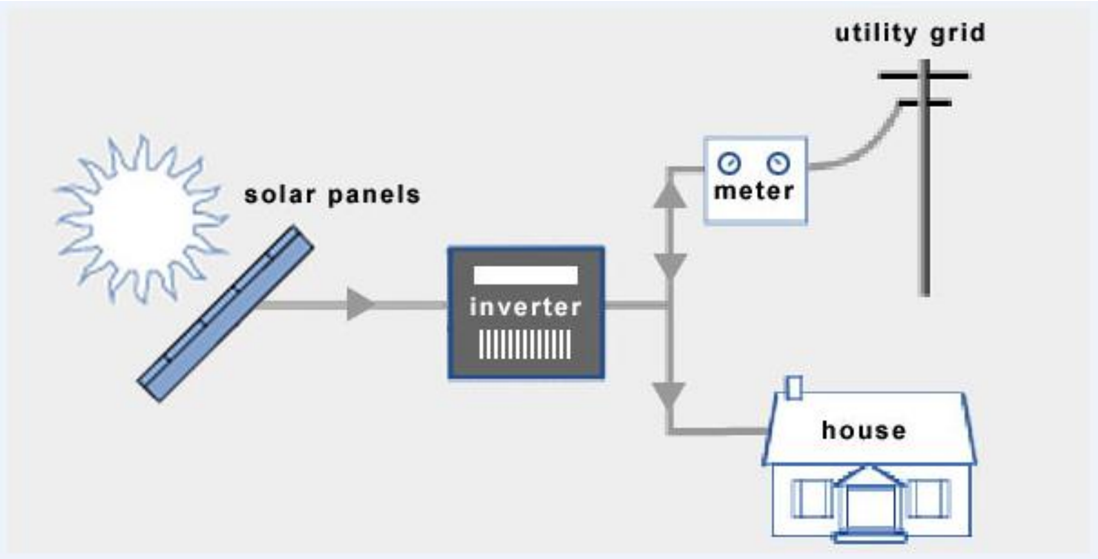


Figure 2.3: Grid tie system structure (*Energy informative*, 2014.)

Though Grid Tied Systems is used only used when the sun is available it has numerous advantages (Outback USA, 2019);

i. **Save more money with net metering**

A grid-connection will allow you to save more money with solar panels through better efficiency rates, net metering, plus lower equipment and installation costs: - Batteries, and other stand-alone equipment, are required for a fully functional off-grid solar system and add to costs as well as maintenance. Grid-tied solar systems are therefore generally cheaper and simpler to install.

The solar panels will often generate more electricity than what you are capable of consuming. With net metering, homeowners can put this excess electricity onto the utility grid instead of storing it themselves with batteries.

Net metering plays an important role in how solar power is incentivized. Without it, residential solar systems would be much less feasible from a financial point of view. Most utility companies guarantee to buy electricity from homeowners at the same rate as they sell it themselves.

ii. The utility grid is a virtual battery

Electricity has to be spent in real time. However, it can be temporarily stored as other forms of energy (e.g. chemical energy in batteries). Energy storage typically comes with significant losses. The electric power grid is in many ways also a battery, without the need for maintenance or replacements, and with much better efficiency rates. In other words, more electricity (and more money) goes to waste with conventional battery systems.

According to EIA data, national, annual electricity transmission and distribution losses average about 7% of the electricity that is transmitted in the United States. Lead-acid batteries, which are commonly used with solar panels, are only 80-90 efficient at storing energy, and their performance degrades with time.

Additional perks of being grid-tied include access to backup power from the utility grid when your solar systems stop generating electricity for one reason or another. Further, more it helps to mitigate the utility company`s peak load and as a result, the efficiency of our electrical system as a whole goes up.

2.3 Type of Feed in Grid Connected Inverters

The feeding method can be sub categorized as:

a) Direct Feed – Connection point at grid (MV to HV) and

b) Indirect Feed - Connection point at customer (only applicable for LV)

For MV, connection is to be made to a bus bar at a substation. No connection is to be made directly to an overhead line or cable.

2.4 Categories of Grid Connected System

There are two major types of grids connected solar systems. These are:

2.4.1 Central Grid-Connected PV Systems

The existing electricity system typically consists of central power stations using a variety of fuel sources such as coal, gas, hydro or diesel that provide power to end-users via transmission lines and a distribution system (Vijay K. Sood, Haytham Abedelgawad Distributed Energy Resource in Micro grid, 2019). The power station connects to the transmission lines. The power produced is consumed by end-users at their actual location such as factories, businesses and homes as in the figure 2.4.

Figure 2.4: Ground mounted grid tie PV

(Source: SMA Solar Technology AG, 2017)

2.4.2 Distributed Grid-Connected PV Systems

Grid-connected PV systems are distributed throughout the electricity grid. This is the most common type of PV system. Hence, this thesis focused on this type of PV System. Distributed grid-connected PV systems are further categorized into two kinds:

i. Commercial and

ii. Residential

Commercial systems are generally greater than 10kWp and are located on buildings such as factories, commercial businesses, office blocks and shopping centers (Vijay k. Sood, Haytham Abedelgawad Distributed Energy Resource in Microgrid, 2019). The power generated by these systems is typically consumed by the loads within the building, so no excess power is pumped to the electricity grid.

Residential systems refer to those installed on homes and are generally smaller than commercial systems, typically between 1 and 5kWp (Vijay k. Sood, Haytham Abedelgawad Distributed Energy Resource in Microgrid, 2019). The power generated by these systems is first consumed by any loads operating in the house during the day; excess power is fed into the grid providing electricity to nearby buildings.

2.5 Equipment for Grid-Tied Solar Systems

There exist differences between the equipment needed for grid-tied, off-grid and hybrid solar systems. Standard grid-tied solar systems rely on the following components:

- Grid-Tie Inverter (GTI) or Micro-Inverters
- Power Meter

2.5.1 Grid-Tie Inverter (GTI)

Role of a solar inverter is to regulate the voltage and current received from the solar panels. Direct current (DC) generated is converted into alternating current (AC), which is the type of current that is utilized by the majority of electrical appliances. In addition to this, grid-tie inverters- also known as grid-interactive or synchronous inverters, synchronize the phase and frequency of the current to fit the utility grid (nominally 50Hz). The output voltage is also adjusted slightly higher than the grid voltage in order for excess electricity to flow outwards to the grid (SMA, 2019).

2.5.1.1 Micro-Inverters

Micro-inverters go on the back of each solar panel, as opposed to one central inverter that typically takes on the entire solar array.

Micro-inverters are certainly more expensive, but in many cases yield higher efficiency rates (SMA, 2019). Home owners who are suspect to shading issues should definitely look into if micro-inverters are better in their situation.

2.5.1.2 Central inverters

These inverters are connected to a series of strings of solar panels rather to just a single string as in the String inverter. In this study, the generated DC power from a series of solar panels is connected in parallel with the output from other series of solar panels at a combiner box. The DC output from a combiner box is then connected to a single central inverter.

2.5.1.3 String inverter

This is connected to a *series* of solar panels rather than to just a single panel as in the case of micro inverters. AC current from a string inverter can then be combined with output from other String inverters. A “string” here means *series* of solar panels.

2.5.2 Power meter

Most home owners will need to replace their current power meter with one that is compatible with net metering. This device, often called a net meter or a two-way meter, is capable of measuring power going in both directions, from the grid to your house and vice versa.

2.6 Solar Insolation

The surface of the sun, with a temperature of about 5 800 Kelvin, is emitting electromagnetic radiation. The energy is spread out in the universe and when the radiation reaches the outside of the earth's atmosphere the mean energy content is 1367 W/m^2, named the solar constant. About 40% of this radiation reaches the surface of earth; the rest is reflected or absorbed by the atmosphere. The maximum radiation is about 1 100 W/m^2, this is in places near the equator, like Kenya. The energy density per unit area, W (λ), as a function of wavelength, λ, is given by

$$\boldsymbol{w(\lambda)A = 2\pi hCr^2\lambda^{-5}\left(e^{\frac{hc}{\lambda KT}} - 1\right)} \quad (0.1)$$

Where h is Planks constant (h= $6.63x10^{\wedge}(-34)\ Js$ c is speed of light in vacuum (C= $3X10^8$ m/s), k is Boltzmann's constant (K= $1.38X10^{-23}$J/K), t is temperature of blackbody in degrees Kelvin, λ is Wavelength.

2.7 The Solar Resource - Kenya

Kenya is located near the equator and has a great potential for solar power. The average irradiance is between 4 and 6 $KWh/(m^2/day$. Depending on the conversion efficiency of solar modules, 10-18% of this energy can be converted to electric energy. There exist regional and periodic differences in the solar resources of the country. Seasonally, a place like Nairobi experiences high level of solar isolation at December solstice. Similarly, sun radiation decreases between June solstice and September equinox.

On the other hand, Kisumu has a good solar radiation throughout the year- both in solstices and Equinoxes (timeanddate.com). Therefore, it is important that solar consumers to be conversant with solar resources in their area and on the long-term implications of these resources on the system they are putting up.

2.8 Components of Solar Irradiance

Radiation reaching the earth's surface is represented in a number of ways. These are explained as follows:

2.8.1 Global horizontal irradiance

This is the total amount of shortwave radiation received from above by a surface horizontal to the ground. It includes both Direct Normal irradiance (DNI)- as in Figure 2.5 and the diffuse horizontal irradiance (DHI). Where, Direct Normal irradiance is solar radiation that comes in a straight line from the direction of the sun at its current position in the sky. Figure 2.4 shows diffuse horizontal irradiance which is solar radiation that does not arrive on a direct path from the sun, but has been scattered by molecules and particles in the atmosphere and comes equally from all direction.

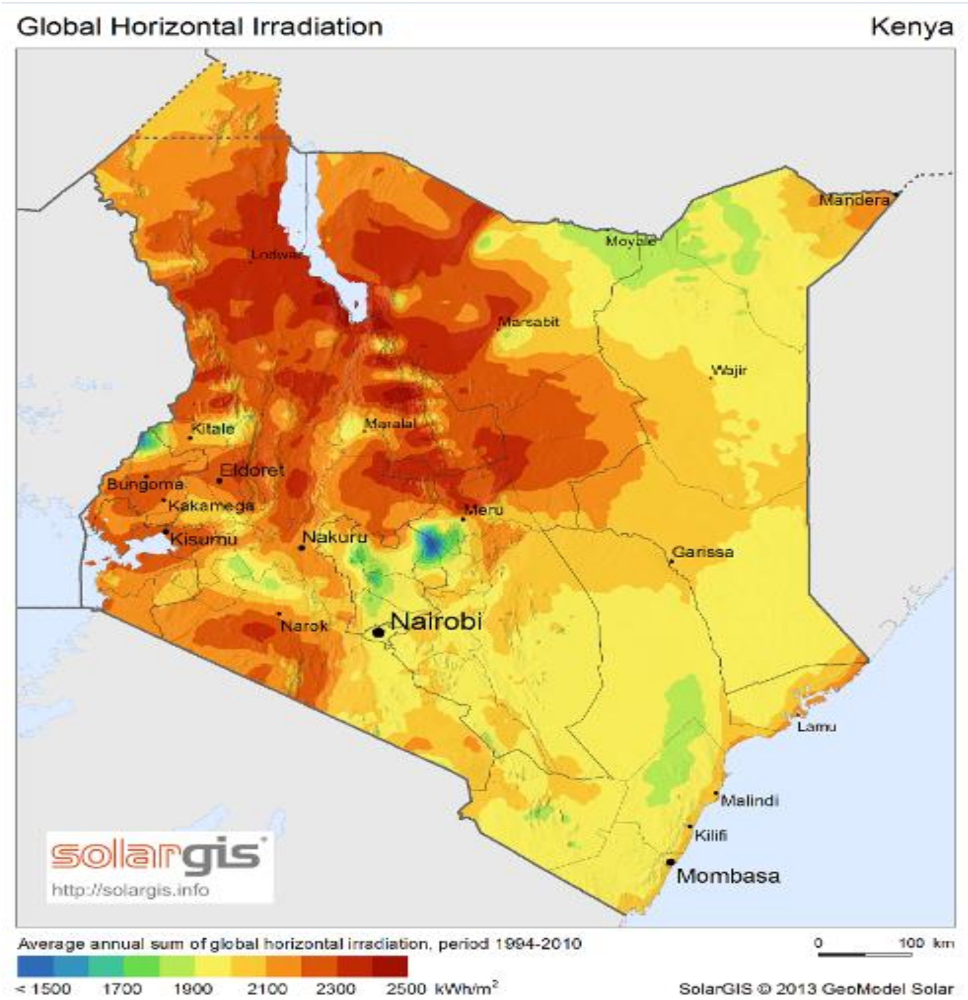


Figure 2.4: Horizontal irradiance

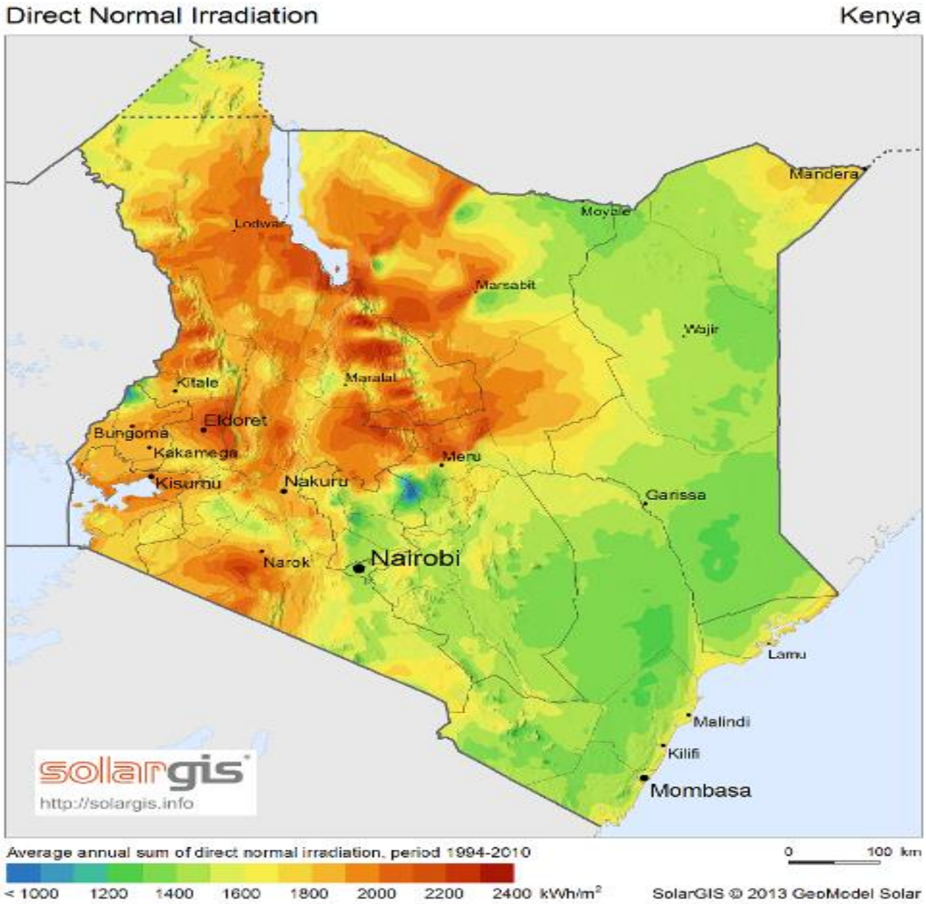


Figure 2.5: Diffuse normal irradiance.

2.9 Policy and Regulation Framework in the Solar PV Sector

The key government institution with direct influence in the solar energy sector focuses on key policy, regulation, standardization and taxation issues in the solar energy sector that have positive and negative impacts on solar PV market structure as in the Table 2.1

Table 2.1: Policies supporting solar (Source: GIZ Kenya, 2014)

Legal document	Key Policy/regulation statement	Positive Effect in the value chain	Negative Effect in the value chain
National Energy and petroleum policy, draft 2015	Tax and other concessions are planned to encourage investment in oil and gas, exploration of coal and geothermal, development of hydroelectric power as well as other forms of renewable energy such as wind, solar and biomass	Lower prices of solar products	This may shift the focus to industrial energy needs neglecting micro-level
	Uncoordinated approach in policy implementation and promotion of solar energy projects.		Drag rapid diffusion of solar PV products
	The existing FiT structure for each technology	Review of FiT to accommodate net metering shall promote SHS	
Energy (Solar photo voltaics) regulation, 2012	The regulations shall apply to a solar PV system manufacturer, importer, vendor, technician, contractor, system owner, a solar PV system installation and consumer devices	• Improve quality of solar product in the market • Consumer satisfaction	
	• Improve quality of solar product in the market • Consumer satisfaction	• Ensure traceability and reduced quacks in the market	
	Any person by himself, servant, or agent undertakes or carries out any solar PV system manufacture, import, vending or installation work without being the holder of a license then in force appropriate to the work undertaken or carried out or without being under the direction of such a license-holder;	Ensure quality of imported products	Reduced existing actors creating shock on the upward adoption trend of solar PV
Sessional paper No.4 on energy, 2004	No rigorous attempts have been made to project cost effective demand for the other renewable energy sources including solar, wind, biogas and municipal wastes.		Dragging on rapid diffusion of solar PV product
	lack of awareness on the potential opportunities and economic benefits offered by solar technologies; and,	• PAYG credit models like MKOPA have transformed the sector	
	Lack of appropriate credit and financing mechanisms to facilitate acquisition of solar technology by the rural population and urban poor.		

2.10 Status of the Kenyan Solar Market

Utilization of solar resources in Kenya begun in the 1870s, due to government's use of solar photo voltaic systems to operate broadcast installations in remote regions (ESMAP, 2016). Around 1980s, international donors and NGOs started a key role in the development of solar energy sector in Kenya to power social services, like school lighting, vaccine refrigeration and water pumping (GVEP, 2014). Later, donor role had gradually reduced over the years; paving way for private sector as from 1990s.

Today SLP entrepreneurs are leading the solar lighting industry who often relying purely on market-based models, utilizing the latest technology, and designing based on consumer tastes (Wright, 2015). Technology is improving at a rapid rate, business models such as mobile phone enabled PAYG are maturing, and the focus by industry players and market facilitators on addressing key market failures means that the SLP market is ready for a substantial inflow of private sector investment and exponential growth. The impact of heightened campaign and awareness creation by lighting Global has seen the growth of SLP to close to a million by 2014.

Most of these modern solar lighting products incorporate features such as mobile charging and consumer credit systems such as the pay-as-you-go (PAYG) (Yarime et.al, 2015).

2.11 Moi University Energy Situation

Since inception of Moi University in 1984, electricity demand has been growing up over time. A sharp rise in the number of students' enrolment - 21.3% occurred in 2011/12 due to double intake adopted by ministry of education to avoid eighteen-month break between students completing high school and joining university (commission for university education, 2014). In the academic year 2018/19 Moi university reacted to this rise in demand by stopping students from cooking in the hostels and considering putting up solar water heating solutions to all hostels to avoid use of electricity to warm water (Student notice, 2017).

2.12 Grid Connected PV Systems in Kenya

Currently, there are four grid-connected solar power plants in operation in Kenya. These include:

i. $60KWp$ Plant at a Tambuzi ltd (AHK, 2013; Hansen et al., 2015);

ii. $72kWp$ Plant installed Uhuru flower farm (Earley, 2015)

iii. $575KWp$ Plant installed at the UN compound in Nairobi (Pedersen, 2016);

iv. Plant at the SOS Children's village in Nairobi ($60KWp$) (AHK, 2013);

The first two plants financed by international donors while the other two were financed by the industrial plant owners. The existing plants were delivered on a turnkey basis by total system suppliers from abroad in cooperation with local consultancy companies and installation contractors (Dinnewell, 2014). The second plant was constructed by the UK-based company Arun Construction Services in cooperation with the local company Azimuth Power (modules from Centro solar AG and inverters from SMA Solar Systems (Hille and Franz, 2011). In the third plant, the tea farm owner commissioned the UK-based company, Solar Century, to deliver the plant, including import of key components, in cooperation with the Kenyan-based companies East African Solar Ltd. and Azimuth Power (Solar Century, 2014). An additional plant at the Strathmore University ($O.6\ MWp$), which in 2015 signed a PPA with KenGen, seems to be close to starting operation. Kenyan companies Quest works and ReSol were contracted as the total system provider and installation contractor respectively, and major components will be sourced from European and Chinese suppliers - panels from Jinko Solar while the inverters are from Solar edge. Various projects of significant scale are under development in Kenya as part of the feed-in tariff system. Currently, it offers a tariff of US$ 0.12/kWh for project developers (ERC, 2015). This includes the Garissa project (55 MW), the Samburu project (40 MW), the Green millenia Energy project (40 MW), the Alten Kenya Solar farm project (40 MW), the Nakuru project (50 MW), the Witu Solar Power project (40 MW), and the Kopere Solar Park project (17 MW), (Hansen et al., 2015; IREK, 2015).

Project planning preparation for these projects started in 2012, (ERC, 2015; Eberhard et al., 2016). Most of the projects are supported by a number of donors and development banks, like the German development agency and the World Bank.

2.13 Site Assessment

A site assessment aims to determine the location of the PV array, the roof specifications, and amount of shading, available area and other considerations.

During the site assessment the installer should collect roof tilt and orientation, roof space and strength, site coordinates, shading on location and other site specific required to optimize system design. In most urban areas, the array is located on the roof of a building, or in cases where there is a large, clear area of ground that will not be shaded.

2.13.1 Roof specifications

Orientation*:* Ideal orientation is where a module receives maximum sunlight (this is true south for the northern hemisphere or true north for the southern hemisphere). Unfortunately, when a PV array is installed on a roof its orientation is governed by the direction of the roof. Using a compass and magnetic declination data, installers should determine the orientation that the roof is facing and its bearing from the ideal orientation. The orientation of the roof will be the same as the orientation of the modules and will be required for energy yield calculations.

Tilt angle: Tilt of the modules will follow the tilt angle (or pitch) of the roof. The tilt angle should be measured using an inclinometer or an angle finder; it may also be available on architectural drawings of the building. The optimum tilt for a system is equal to the latitude of that location. In cases where the pitch of the roof is not equal to the optimum tilt angle the PV array's energy yield will be affected.

Once the tilt and orientation angles of the PV array have been determined, the designer may want to calculate their effect on energy yield. This is normally done using data tables rather than by hand; with current development, data tables are available.

Space: This is an available area to which the panel are laid. It plays a vital role as if not optimized; it limits the amount of energy that can be generated.

2.13.2 Fixed angles scheme

National Renewable Energy Laboratories (NREL) research affirmed that fixed angles for different latitudes can produce very good results as indicated in Table 2.2. However, for locations very near to the equator, the purpose of tilting the array is to enable its natural cleaning during rainy seasons to avoid dust accumulation. Furthermore, tilting the array also provides free air space under the array which enhances the cooling of the array (Solar century, 2014).

Table 2.2: Array tilt vs site latitude

Latitude	**Recommended tilt 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

(Source: National Renewable Energy Laboratories, 2009)

2.13.3 Effects of Shading on Arrays

A solar PV module reacts by generating electricity well when it receives direct radiation from the sun (Nielsen, R. 2005). When the sun is obstructed from the module, the output of the module is reduced proportional to the amount of shading (Ramaprabha, 2013). Module cell shading is either caused by trees, flying objects and even clouds. Short lasting shading does not affect the daily charging current but persistent shading reduces the daily output current of the modules.

As seen in Figure 2.6, a "soft" source, like a distant tree branch or cloud causing a diffused shade that can significantly reduce the amount of light reaching a solar panel's cells. "Hard" sources block light from reaching solar cells, such as debri or bird dropping sitting on top of the panel. Even if one full cell is hard shaded, the voltage of a solar panel drops to half in order to protect itself. When enough cells are hard shaded, the module will not convert any energy, and eventually become a significant drain of energy on the entire system over time (Boxwell, 2012).

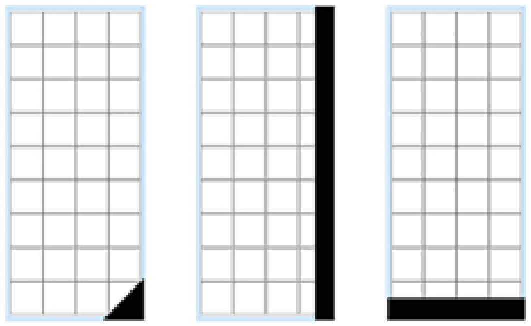


Figure 2.6 Partially shaded cell/cells (Altestore, 2014)

Partial shading on cell of a 36-cell solar panel will reduce its power output. Due to all cells are connected in a series string, the weakest cell will bring the others down to its reduced power level. Therefore, whether half of one cell is shaded, or half a row of cells is shaded, the power decrease will be the same and proportional to the percentage of area shaded that is 50 percent.

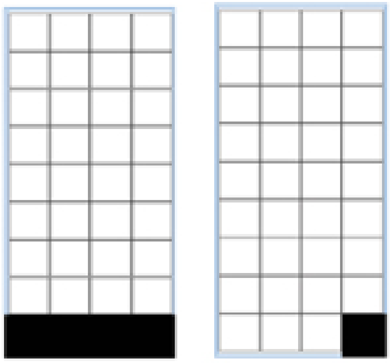


Figure 2.7: Fully shaded cell/s (GIZ 2014)

When a full cell is shaded, it uses energy produced by the remaining cells, and trigger the solar panel to protect itself. The solar panel will route the power around that series string. If one full cell in a series string is shaded, it causes the module to reduce its power level to half of its full available value (GIZ 2014). If a row of cells at the bottom of a solar panel is fully shaded, the power output may drop to zero.

In a centralized inverter system, where panels are connected in series, if one of the solar panels is shaded in an array, the rest of the panels' output reduces. So, it is important when choosing a grid connected solar power system that you often prefer the tested and true technology of a centralized inverter system with pretty good prices. But with consideration of the effects of shading, however, it's easy to understand how micro inverter and Solar Edge systems have become so popular (SolarEdge, 2016).

The use of both Solar Edge and Micro inverter systems allows each solar panel in an array to maximize power output independently, thereby maximizing a system's power generation. If one solar panel is shaded in either of these systems, the rest of the array's panels can still operate at full capacity. Solar Edge provides DC to AC power optimization for each solar panel, while micro inverters provide DC to AC optimization at the module level. Both of these systems allow solar panels to be facing different orientations giving you more design flexibility if part of your installation site is in the shade. A centralized inverter system requires panels to facing the same direction (SMA, 2019).

2.14 Effects of Temperature and Irradiance

The performance of the solar PV array normally depends on the amount of irradiance reaching the array surface (Jinko Solar, 2018.). Unfortunately, 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. Where, current is greatly affected while the voltage is affected slightly. Extreme high temperatures also reduce the lifespan of the modules by fast wear and tear. When effects of temperature are not clearly accommodated in the design of a solar PV array then a temperature derating factor is also applied.

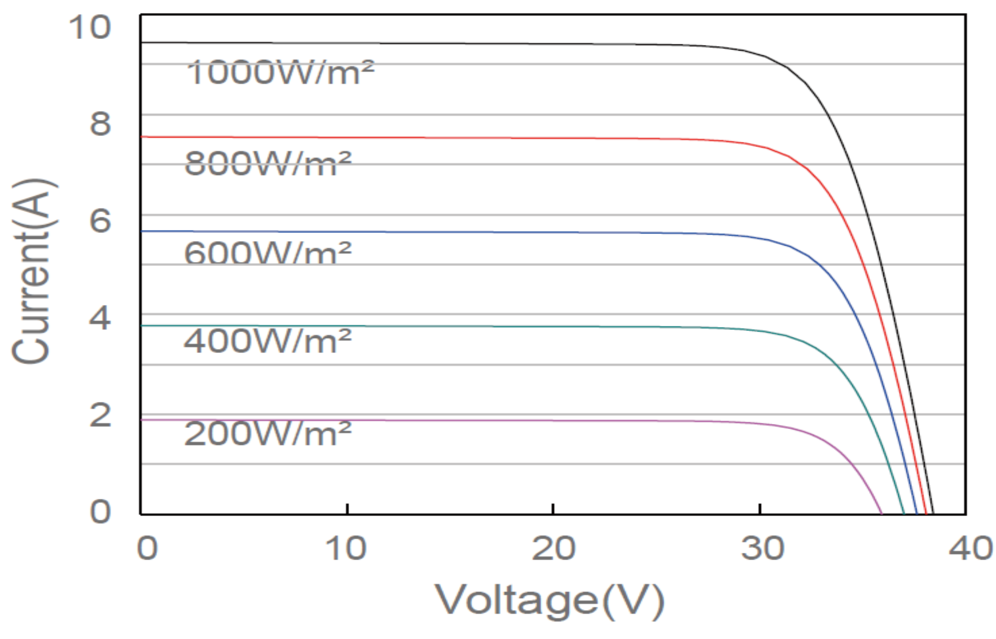


Figure 2.8: Panel I-V Curve of a module at different temperature.

(Source: Jinko Solar, 2018.)

2.15 Other Derating Factors

Table 2.3 gives the impacts on performance of these already discussed and other derating factors which are controllable. These are aging, that can be controlled by timely replacement of modules, dust can be reduced by tilting the modules, wiring can be reduced by using the right size of conductors and mismatch, can be eradicated by using modules from the same manufacturing standards.

Table 2.3: Derating factors (Rodgers CRC press London, 2010)

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

2.16 Ways to Optimize a Commercial PV System

Designers of commercial solar are increasingly using system optimization to drive performance and decrease system costs. As module and inverter prices drop, the other major opportunity to bring down system cost is by soft-cost reduction through design optimization. Design optimization improves system performance without increasing cost, which can actually impact decision on either the project will be economical or not (Michael La Marca. *project engineer*, 2015). Because of this, many designing firms are now focused on developing optimization techniques that can be applied to find the most cost-effective designs on a site-by-site basis. This is particularly common in commercial systems given that the system size is large enough to merit optimization - project price tags reach into the millions of dollars, and yet each location and customer profile is sufficiently unique to require a customized analysis. With system engineers' quest for the highest leverage design parameters, these optimization drivers consistently rise to the top (Paul Grana of Folsom Labs, 2015). The following are the various ways of optimization:

2.16.1 Module spacing and tilt

Every system designer should have a tradeoff. In the process of maximize the sunlight on each module, the designer has to tilt for maximum yield and space the modules far apart. This will reduce the number of modules that can fit in the array (Rheinlände,2004). Alternatively, the designer can place the modules closer together, and reduce the tilt in order to minimize shading. This is a tradeoff between energy density, which is maximum yield per module and power density- maximum kilowatts per square foot. On this, the industry is moving toward designs with lower tilt and narrower spacing, sacrificing energy density for improved power density (Horn, 2014). This move has been driven primarily by the advent of lower-cost modules, well explained that as hardware costs fall, it becomes efficient to use more modules and maximize the total generation from a rooftop. With ground mounted system this meant large land that could be used for agriculture is used (Ferrer-Martí et al., 2012). Also, new technologies are capitalizing on east-west racking which enables even greater power density by alternating the module tilt to fit the modules even closer on the rooftop and maximize the energy yield of the array.

A cascade of simulations can be run and an optimal configuration for each project selected. For a 2 percent drop in kWh/kWp from reducing tilt and row spacing can improve the power density by more than 20 percent (Green, 2015).

2.16.2 Azimuth Optimization

Most rooftops are not perfectly south facing. This leaves the system designer with a choice that must make- either to align the modules to the south to maximize the energy yield or face them in the direction of the building to maximize the number of modules that can fit on the roof.

Orientation choice ties in with the biggest themes facing design engineers, this is a tradeoff between energy productivity versus array power, and the time-of-day profile of energy production, which can benefit in places with (NREL, 2018). Mostly, this is not the case involved with the existing centralized solar plants system in Kenya as the main design concern amount of power being feed to the grid and not the daytime load profile. Utilities increasingly need later-afternoon production, and changing the array's azimuth can be the most cost-effective way to achieve that while with a commercial building, you can fit a bigger system by going with the building, which almost always offsets the slight reduction in energy yield that is associated with arrays that do not perfectly face south (Mayfield 2014).

2.16.3 Inverter design and shade tolerance

The new inverter topologies such as three-phase string inverters, micro-inverters and optimizers, gives commercial system engineers various options beyond standard central inverters (Ferrer-Martí et al., 2012). Micro-inverters and three-phase string inverters change the whole array design, leading to fewer DC wires and more AC wires. Furthermore, it caused change in the labor mix- these new technologies require more labor during installation but offer more modularity and easier replacement (SMA, 2015).

Also, with module-level optimization, systems can be designed closer to shade. Historically System designers eliminated any modules that are shaded. But with module prices getting down, it currently makes more sense to selectively add some of those modules back in the system, especially if they are only shaded in the small part of the day when productivity is low. Also, only recently have new software that enable detailed shade and mismatch calculations, enabling system designers to rigorously analyze the losses from shade and assess the system cost-benefit of adding modules. This is facilitated with switching to string inverters, which does a good job of minimizing the shading losses on the project (La Marca, 2015).

There is better economics for solar projects designed to enhance a system array in a finite area vs. designing solely to optimize system efficiency (Schiemann,2014). Even with a resulting increase in shading, the overall increase in energy production from the project makes for better economics for customers (IEA and World Bank, 2015).

2.16.4 A new era of system design

Sophisticated solar developers find it easy to embrace optimization techniques. They are able to deploy lower-cost solar projects without sacrificing quality- with lower hardware costs. Experienced developers, actually do the analysis and realizes that a lower tilt and tighter spacing can improve system economics significantly (Mayfield, 2015).

2.17 Simulation of Solar PV Systems

The world market has various solar database and software programs for analyzing solar photovoltaic (PV) systems, either for commercially, personal or study use (IRENA, 2018).

Solar resource information is required in all stages of the development of a PV project. Reliable solar radiation statistics is required for system siting, design, and for financing (IEA, 2015). Mostly, monthly averages, probability statistics of typical meteorological years (TMY) is sufficient. This information is sufficient also for the manufacturing industry and for policy makers defining support programs (IRENA, 2018).

Given that factors as solar irradiance, ambient temperature, shading and other derating factors are never constant, it implies that the output of the solar PV array will be varying as frequently as the parameter changes (Malerba, 2005). This means that long hand calculation cannot adequately give an accurate design where all conditions are matched. There are solar PV design software's to simplify the solar PV systems model design process like sunny design, PVSyst and HOMER which was developed by the National Renewable Energy Laboratories (NREL) of USA (NREL, 2010).

2.18 Intentional Islanding

There are instances under which islanding operation may be required, especially with the case of a mini-grid being integrated with a central grid that has history of reliability problems. The mini-grid interconnection may be made in a way that permits the mini-grid to continue operating autonomously and provide uninterrupted service to local customers and revenue to the mini-grid operator during outages on the main grid. This capability is known as intentional islanding.

The recent adoption IEEE standard 1547.4-2011 specifically looked on power systems that include intentional islanding. Implementing intentional islanding requires that the system perform various steps, reliably, in correct sequence and timing:

i. The distributed generator must identify an abnormal condition on the utility grid and disconnect a circuit breaker to separate the generator and islanded mini grid load from the main grid (Outback, 2019).

ii. On disconnecting, the distributed generator must immediately switch from "synchronized mode" to "autonomous mode" engaging controls to regulate frequency (Nelson, 2011).

In addition to the generator configuration, the settings of various protective relays are needed to be different in islanded mode. Since small generators particularly inverters typically produce less fault current than large generators on the main grid. Also, voltage or frequency tolerances need to be broader in island mode. More so, inverter-based generation may need low-voltage ride-through (LVRT) and frequency ride-through (FRT) capability to continue operating during voltage disturbances due to faults or sudden load changes, especially while the grid is transitioning to islanded mode (IEEE, 2015).

The system should continue to sense line voltage on the main grid, and when main grid power returns to stable conditions, initiate reconnection, and return to control regimes appropriate for grid-connection (Pilo, 2013).

The protective relay settings controlling intentional islanding must be selected based on the local grid operating conditions and coordinated with the utility's protective relays (Outback,2019). Separating from the main grid due to minor disturbances lead to lost opportunities for revenue generation from selling power to the utility. On the other hand remaining on for quite long and only disconnecting at more extreme disturbances on the grid can lead to cases of excessive voltage and frequency sag hence brownouts and blackouts with possible equipment damage.

In the same way, settings for condition that constitute to stable conditions on the main grid for reconnection must consider the timing and effects of re-closers, if they exist on the main grid's feeder to which the distributed generator reconnects. When a line is disconnected after a fault, a re-closer will automatically re-energize the line after a short delay (Xantrex, 2017). The distributed generator's controls must:

i. Disconnect the generator fast enough to avoid being on when a recloser energizes the circuit; and
ii. Wait to resynchronize until grid voltage and frequency are stable (typically a few cycles).

An intentionally islanded mini-grid faces, all the operational challenges of a standalone mini-grid with no connection to the grid. Specifically, the mini-grid must meet the demand and balance local load with local generating resources at all times may experience significant load growth after connecting to a central grid. This means, the original generation capacity of the mini grid may no longer be sufficient to supply all of the load in islanded mode.

This makes it important to have demand-side management strategies ready to implement on short notice. Normally, automatically opening circuit breakers to curtail large, non-critical loads or by using smart load-limiting devices on household circuits that can detect the islanded condition and respond automatically are used. Currently there is no intentionally islanded mini-grids that face this condition and have implemented these measures. In principle the same relay that opens the grid intertied breaker to initiate islanding could simultaneously send a signal to open breakers to large or non-priority loads (SMA,2015).

2.19 Inverters interconnection requirement

Solar modules produce DC and inverters are an important component of these systems. For Grid-interactive inverters, the grid controls both frequency and voltage (Victron, 2013). These inverters are designed to export power to the utility grid and incorporate many of the functions traditionally performed by protective relays, including synchronization, over/under voltage protection, and frequency protection (Malerba, 2011).

Pumping power to the utility grid requires a grid-interactive inverter. However, most grid-tie inverters cannot operate without a grid connection and will go off if one is not available- that is, they do not support intentional islanding (GIZ,2016).

A standalone inverter regulates its frequency and voltage and can operate without a grid connection. Some standalone inverters allow the grid to be used as a backup for the renewable generation while others allow the renewable generation to serve as a backup when the grid is down. However, the inverter cannot be paralleled with the grid such that either the inverter is providing power to the AC loads, or the grid is providing power as the inverter is off. These inverters have separate terminals for the grid connection and for the AC loads (Outback USA, 2019).

Some inverters can operate in both standalone and grid-interactive mode, allowing both grid export and off-grid (intentionally islanded) operation. These inverters offer the most flexibility, allowing both intentional islanding and power export. In addition to the main grid connection, some of these inverters like the SMA Sunny Island allow other inverters or small induction generators to be connected to the AC load. This feature allows the construction of AC-coupled mini-grids using a variety of energy sources. As with standalone inverters, these dual-function inverters generally have separate terminals for the grid connection and the AC loads (SMA 2012).

Multiple inverters can also be added in parallel on the AC bus to accommodate higher capacities (SMA 2012). To accommodate multiple-phase loads in larger systems, a three-phase inverter can be used, or three single-phase inverters can be networked together with one on each phase (SMA 2012). Also, large, non-critical loads can be connected separately to the utility grid and not through the inverter.

As of mid-2012, the following inverters sized for the residential market in industrialized countries were capable of both grid-tie and standalone operation (SMA 2012): Out Back Power GS, GFX, GTFX, and GVFX series; SMA Solar Technology Sunny Island (SI) series; Schneider Electric XW series; and Princeton Power Grid tied Inverter and Battery Controller (GTIB) 480-100. Rotating machines (synchronous and asynchronous generators), which generate relatively pure sine wave output using rotating magnetic fields, inverters synthesize a sine wave using solid-state electronic components. If the synthesized waveform is not exactly a true sine wave, current is introduced at frequencies that are multiples (harmonics) of 50 or 60 Hz, depending on the local utility frequency (*harmonic distortion) (*SMA, 2012*)*.

Transformer less inverters may accidentally introduce DC current into the grid, a process referred to as *DC injection*. These abnormal currents may damage utility transformers and other system components and can cause problems for other utility customers (SMA, 2012). Therefore, grid tie inverters must meet strict requirements for power quality, including limits on total harmonic distortion and DC injection.

Some small mini grids are entirely DC, with no inverters at all; for example, Mera Gao Power operates all-DC solar micro grids in 155 villages in Uttar Pradesh, India. These systems, the renewable energy source produces DC electricity, which is used to charge a battery bank to which the loads are directly connected (Sungrow, 2018). Customers must use low power LED lights and appliances specifically designed for low-voltage DC, with 12 volts the most common system voltage. These DC micro grids are very small and dissimilar to warrant interconnection with utility AC power. The low voltage distribution DC system would be difficult to adapt safely to AC power (KPLC, 2018). In any case, concerns about such systems quickly becoming obsolete may be unwarranted; considering the high fees paid by households to connect to the main grid, electrification policies that makes a community electrified even though only a small fraction of the households connected to the grid, and the intermittency of national grid power in rural areas, operators of micro grids like Mera Gao Power may find they retain a sufficient customer base even when the main grid arrives (GIZ, 2015)

2.20 Intentional Islanding Configuration Through AC-coupling

The grid-as-battery is good concept until the grid is no longer there – the grid connected inverter requires a powered grid to stay per the UL1741 requirement for safety. Without grid power to keep the GT inverter operating, the available solar power just sits on the roof unused (Altestore, 2013). During an outage, a home or business with PV electricity potentially available remains in the dark just like everyone else unconnected to grid as indicated by Figure 2.9.

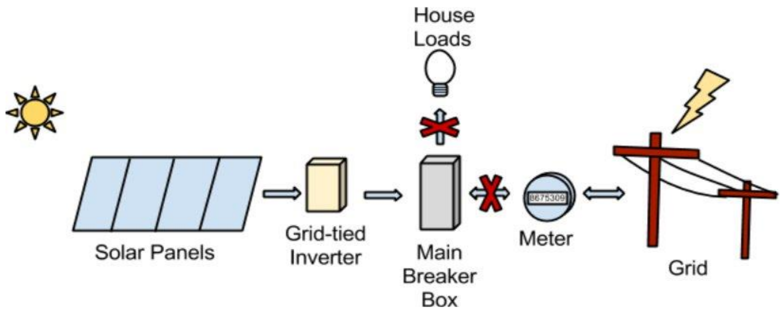


Figure 2.9: Anti-islanding of grid tie inverters

(Source: Altestore, 2013.)

Incorporating a battery-based off-grid technology to get a smarter type of grid/hybrid inverter technology is able to use PV and other renewable DC energy sources to keep the batteries charged while selling excess power to the grid. Batteries come in as link to facilitate islanding (Outback USA, 2019). It typically calls for additional load center with circuit breakers and electrical connections for the building's critical loads to create a point at which the grid-tied (GT) inverter and the battery-based (BB) inverter to couple and share their energy to the loads-power flow shown by Figure 2.10. In the normal mode of operation with grid power available, energy from the PV array flows through the GT inverter to the critical load panel, with any excess energy flowing through the load panel to the BB inverter, and then out to the grid.

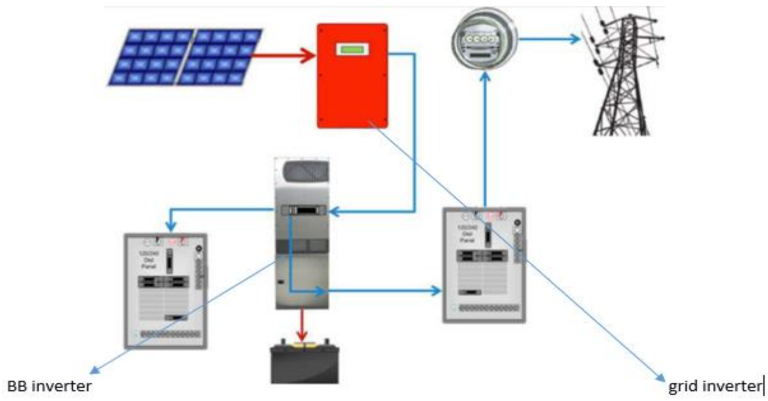


Figure 2.10: Current path when grid power is present (Source: Outback USA, 2019).

During outage time, the BB inverter activates an internal transfer switch that opens its connection to the grid. This avoids the inverter from trying to power other homes on the grid, and also, keeping energy off the power lines so that utility workers don't get electrocuted (Outback USA, 2019). The BB inverter also provides a power source to the GT inverter that keeps it online and inverting the DC power to AC power for the critical loads as shown by Figure 2.11.

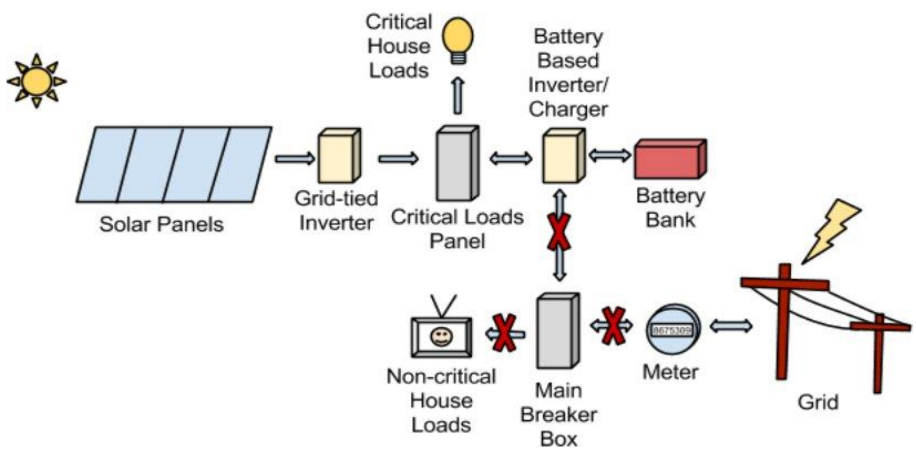


Figure 2.11: Flow of power uninterrupted to critical loads during outage
(Source: Altestore, 2017)

2.21 Guidelines for Sizing and Interacting Two Types of Inverters

There are two norms that are encouraged for a successful interaction of the two different inverters;

a) The daily critical load watt-hours shouldn't exceed 80% of the Battery bank's watt-hours (Häberlin, 2012). This assumes that the backup system will only be used a few days or perhaps a week or two per year, so discharging batteries to an 80% depth will not significantly reduce their life below what is considered the normal life cycle for a battery. The rate or speed of which the batteries are both charged and discharged will affect their overall capacity (Altestore, 2017). The slower the rate of charge or discharge, the more capacity in the battery.

b) Inverter power rating should be 1.25% of the GT inverter power rating (Altestore, 2017).

This ensures that the GT inverter does not overwhelm the charging circuitry in the Outback inverter if the load demand goes to zero and all available GT inverter power is flowing to the Outback inverter. While admittedly an unlikely scenario, for safety and equipment protection it's best to follow this guideline. Daily load or battery charging power must be lower than PV power. This prevents either the daily load demand or battery charging from exceeds the power from the PV array, or adds an optional generator to the backup system. In a situation where, available PV power exceeds load demand, requiring that the GT inverter is disconnected with an Outback remote operated circuit breaker (Figure 2.12) if the excess power begins to overcharge the batteries. In reality, the condition in a backup system whereby the available PV power is out-producing the load and battery charging demand doesn't occur. Critical loads will hardly turn off completely and many conditions, especially on cloudy days, will call for other source of power to meet load and battery charging demand (Outback USA, 2019).

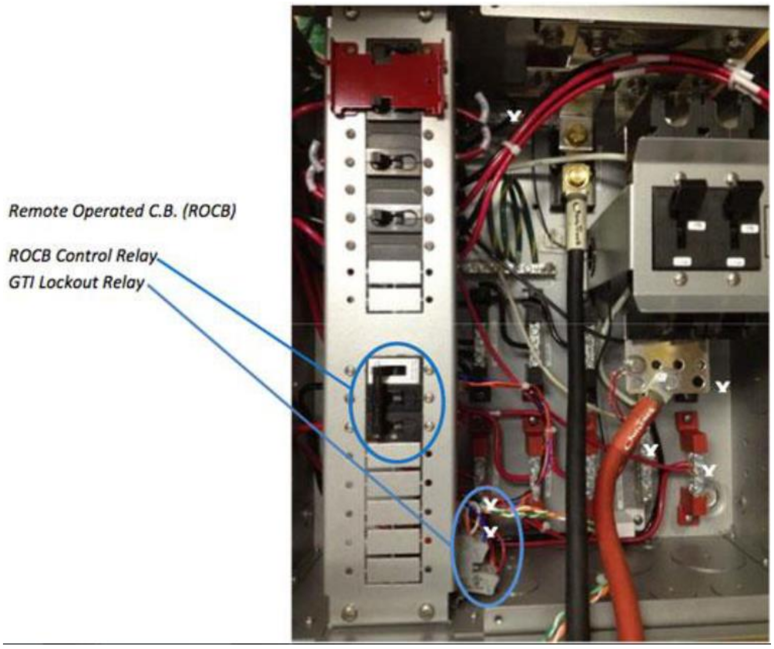


Figure 2.12: Predesigned consumer board from outback

2.22 Battery sizing

Without a well sized battery backup, the grid connected system will only supply power to loads when the grid is available. Therefore, it will not solve the fundamental problem that this research seeks to solve, therefore the battery bank is sized to supply power to critical load all times - during the day, grid failure as well as in the night.

To ease the battery specification since most batteries are rated at their 10hr, 20hr and 100hr discharge rate; a discharge rate of 20 hours will be most appropriately taken as the typical discharge rate.

The total energy that must be supplied by the battery bank is determined by the following equation 2.2;

$$E\_T = E\_dl/\eta\_inv \qquad (0.1)$$

Where;

E_T= Total energy in watt hours to be supplied by battery bank during grid failure.

E_{dl} = Total AC energy to be supplied by grid connected PV system. This is determined from estimated daily critical load as prioritized from load mapping list and allowance for future load growth.

2.23 Solar PV System Economic Analysis

There are few studies on Solar systems in Kenya considering the economical aspect of the installation. Therefore, this study was anchored on Kenyan 2030 vision on sustainable and reliable energy research by the virtue of being one of its a pillar of the vision.

In a research by the Solar Energy Foundation, the payback time of a small off-grid system was calculated as a guideline for the investment required installing the PV system (Breyer et al. 2009). It shows that the payback time of a 10 W PV module was 2 to 4 years depending on the energy usage of the household. Batteries account for 10-40% of the total capital cost for off-grid PV systems (Häberlin, 2012).

The demand for more efficient and cost-effective storage systems was high and companies around the world were doing research on solar energy storage solutions. According to Tesla Motors (2015) announced the release of a newly developed lithium-ion battery especially adapted for solar power named Power Wall. The batteries come in two models, 10 kWh weekly cycle and 7 kWh daily cycle, with a price of $ 3 500 and $ 3 000 per unit. The peak power was 3.3 kW. This low price of the new innovation creates huge opportunities for the PV industry to engage more customers (Tesa, 2015).

Much research concerning evaluation of the use of renewable resources has been conducted by using life cycle evaluations, such as energy payback time and greenhousegas emission rate (GIZ, 2018). The energy payback is the ratio of energy input compared to energy output rate. A study on *strengthening the case for recycling photovoltaics, an energy payback analysis* showed that the aluminum frame and mounting rails of the PV system was responsible for the majority of energy payback time reduction, as they have robust recycling technologies (Goe and Gaustad, 2014). Materials in the PV cell such as indium, gallium and silicon do not. Although indicators of sustainability and environmental impact was important, the economic consequences should also be highlighted since it was of major importance when it comes to influencing policy- and decision makers to develop new markets.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

The research was carried out through literature review and experimentations with an ultimate aim of coming up with better system design that harness more solar resource to generate enough power that satisfy Moi University administration block economically.

This involved finding of optimal module tilt angle and load determination. It further carried out numerical calculations and inputs. The PVsyst software was used to determine optimal system solution.

3.2 Data Collection

The specific data required were site solar insolation, geographical position, and electrical load. Solar insolation data were obtained from PVGIS and PVsyst by inputting optimal parameters of design obtained as indicated by equations (3.1) to (3.15). The information on electrical loads, and rooftop specifications such as tilt and wall orientation wall were measured.

3.3 Geographical Location

GPS Location of Moi university administration block in GPS is Latitude 0.286°N, longitude 35.294°E and altitude of 2203M as seen in Figure 3.7. The construction was such that its longitudinal length is at 21° northern drift from true East (refer Fig 3.6).

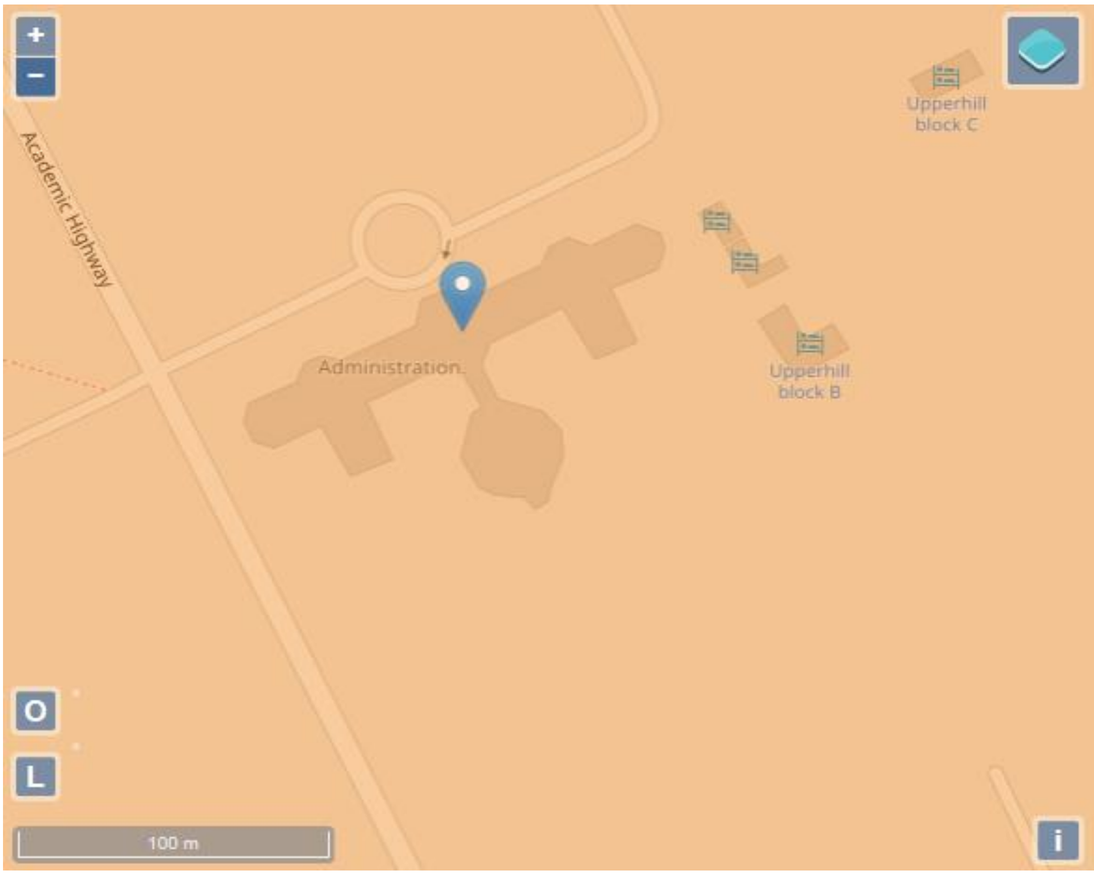


Figure 3.1: Location of Moi University Administration in GPS

3.4 Administration Block Grid Supply

From the incoming utility electric supply line, a service ring circuit of transformers if formed to serve different sections of the university. Administration block is supplied by 315 KVA TX Pole mounted at the utility transformer at Upper hill hostel.

3.5 Electricity Outages

The challenge of Kenya grid electricity system is the regular occurrence of grid failure (IRENA, 2016). This regular grid failure affects the work in the university since it depends on electricity for its production. However, no records on occurrences and duration of blackouts are kept.

3.6 Shading Analysis

In PV, shading analyzes the shading caused by surrounding objects and vegetation. In cases like analysis or design of BIPV systems, exact analysis of "shadow-voltaic" systems as overhangs, vertical shading fins and awnings are also very important in showing the overall system efficiency in harnessing the sun. Calculations were done using equations 3.1 to equation 3.3 with dimensions as in Figure 3.2 and figure 3.3

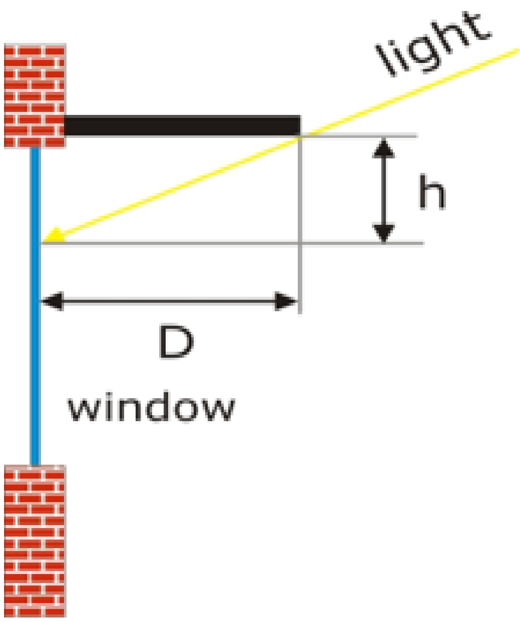


Figure 3.2: Horizontal shading device, overhang, side view

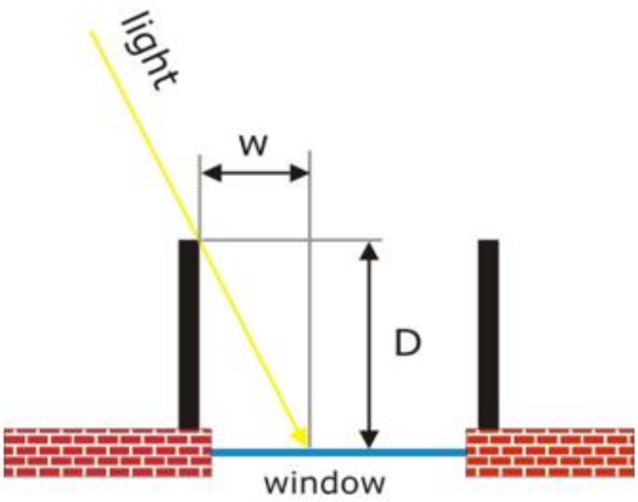


Figure 3.3: Vertical shading device, vertical fin, top view

$$(\boldsymbol{h} = (\boldsymbol{D} \cdot \tan \boldsymbol{a}))/(\cos(\boldsymbol{\phi} - \boldsymbol{\psi})) \quad (0.1)$$

$$\boldsymbol{\omega} = \boldsymbol{D} \cdot \tan(\boldsymbol{\phi} - \boldsymbol{\psi}) \quad (0.2)$$

$$\boldsymbol{\gamma} = \boldsymbol{tan}^{-1}\left(\frac{\tan \boldsymbol{a}}{\cos(\emptyset - \boldsymbol{\psi})}\right) \quad (0.3)$$

Where

D - geometry of horizontal shading device (overhang dimension)

α - sun height, Φ - solar azimuth, Ψ - plane azimuth

ω - geometry of vertical shading device (vertical fin)

γ - vertical shadow angle (VSA)

3.7 Calculation of Solar Irradiation

Solar radiation data of various forms; Monthly average values of the radiation incident on a horizontal surface $Ghorizontal$ were obtained from PVGIS Website. Simulation was done using PVSyst software.

To increase the amount of radiation intercepted, modules are often installed at an inclination angle facing south for locations in northern hemisphere, as seen in Figure 3.4. Tilting the solar array at an angle β to the incoming light increases the module output.

This study utilized PVGIS and PVSyst to simulate monthly and yearly energy output of designed system in two scenarios, namely:

i. Array with roof's tilt and orientation performance
ii. Optimized array with optimal site parameters performance

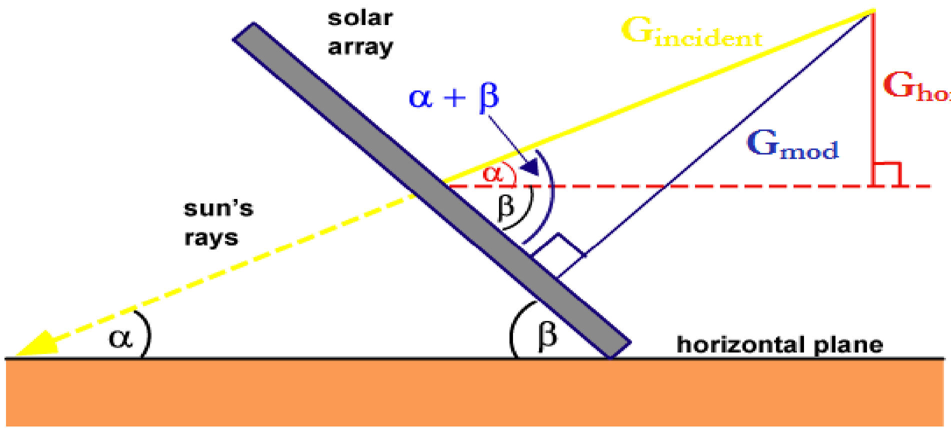


Figure 3.4: Incline surface and resource influencing parameters

(Source: PV Education, 2013).

The amount of solar radiation incident on a tilted module surface $Gmod$ was calculated with help of equations 3.4 to 3.7 (Wenham, 2011)

$$\boldsymbol{Ghorizintal = Gincident.Sin\,a} \quad (0.1)$$

$$\boldsymbol{Gmod = Gincident.Sin\,(a + \beta)} \quad (0.2)$$

Where

α: The elevation angle of the module [°],

β: The tilt angle of the module from the horizontal ground[°],

$G_{horizontal}$: Solar radiation measured on horizontal surface $[(kW\ /\ m\text{^}2\ )\ /\ day]$ and

$G_{incident}$: Solar radiation measured perpendicular to the sun $[(kW\ /\ m\text{^}2\ )\ /\ day]$.

The elevation angle of the site is specified as:

$$\alpha = 90 - \varphi + \delta \quad (0.3\ )$$

Where φ is the latitude and δ is the declination angle given as:

$$\delta = 23.45° \cdot \sin\,[360/365 * (284+d)] \quad (0.4)$$

where d is the day number of the year, 23.45° is the angle of earth axis of rotation from the ecliptic axis and 284 + d is equivalent to $d - 81$ which are the days of the year when the declination of the sun equals zero.

By using numerical methods in calculating the incoming radiation depending on the degree of tilt; the optimum angle β_{opt} can be estimated. This algorithm is based on finding the angle that gives the optimum solar radiation of each specific month. The average of all monthly optimum angles is found as the most efficient inclination for a fixed PV array.

The incident radiation varies during the year since the module is set at a fixed angle. The average annual solar radiation incident on the tilted angle β_{opt} was calculated as in equation 3.8

$$\boldsymbol{G_{opt}} = \sum_{\boldsymbol{i=1}}^{\boldsymbol{n}} \frac{\boldsymbol{G_{mod,i}}}{\boldsymbol{n}} \qquad (0.5)$$

Where:

G_{opt}: the average solar radiation at the specific month [kW/m2/day] and

n: the number of the month where n = 1 is January and n = 12 is December.

The number of daylight hours N is given by (Duffie and Beckman, 2006).

$$\boldsymbol{N} = \frac{\boldsymbol{2}}{\boldsymbol{15}} \boldsymbol{cos^{-1}}(\boldsymbol{-tan\emptyset tan\delta}) \qquad (0.6)$$

This is an important correlation for estimation of the sunlight hours. The above equations will give all underlying data needed to calculate the potential solar energy given at the site.

3.8 Experiment to Obtain Optimal Tilt Angle

The experiment was carried out with four setup each comprising of 50 W rated solar panel powering one 7W bulb as a load and two multi meters-(one measuring voltage while the other one current). Each solar panel on each setup was mounted at Azimuth angle corresponding to south fazing roof of block but different tilt angle i.e. 5°, 15°, 25°, 35° and last one set at block roof angle. Timer was used to facilitate simultaneous Voltages and current readings at the same irradiance while recording. This was conducted on a sunny day of 15th August 2019. The experiment results were not dependent on date and time but on sensibility of power with respect to tilt.as seen in Figure 3.5.

Figure 3.5: Tilt angle experiment

3.9 Investigation of Offices Load

For a sustainable and economical design of the grid connected PV system, data from two sources were collected. The first being electrical bill data from the administration block. Secondly, mapping and collection of daily watt-hour compilation of all individual electrical load as per manufacturers specifications. This facilitated the size determination of the battery-based inverter as well as battery bank size.

3.10 Roof Top Tilt and Orientation

The orientation and tilted angle of the roof was determined with the help of scan the earth software installed in a phone., The tilt and orientation were recorded when the phone was kept on parallel to the roof.

Figure 3.6: Orientation of north facing roof as captured

With the orientation of the North facing roof, the south facing roof's orientation was obvious given that it is parallel and opposite to northern facing roof.

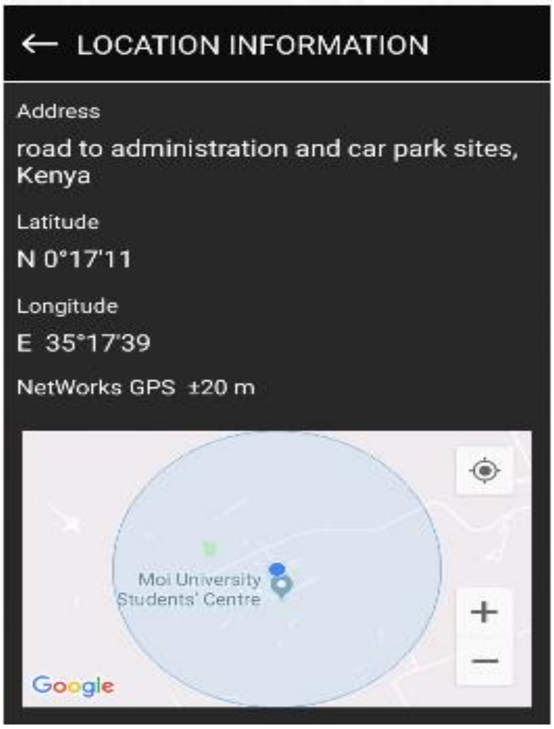


Figure 3.7: Moi Administration admin coordinate

3.11 Dimensioning of the PV System

The dimensioning involved the following:

3.11.1 Module dimensions

The PV modules were incorporated to match the load power demand. Not only the irradiated energy of the site needed to be known, but also the efficiency of the module selected for the installation. Once the load and the absorbed radiation of the site was established, the PV module area to meet the load was determined through an energy balance. A PV module generates the energy, E_{pv}, obtained by equation 3.10

$$E_{pv} = A_C . \eta_{SYS} . G_{mod} \quad (0.1)$$

Where:

A_C: the surface area of the module [m2],

η_{sys}: the total system efficiency [%] and

G_{mod}: the incident solar radiation on the tilted array [kW/m^2/day].

This energy can either be used directly to supply a primary load, as can be seen in Figure 2.11 or be accumulated in a backup battery for deferred utilization.

The total system efficiency η_{sys} considers all losses from converting solar energy into direct current electricity and then transform it into alternating current electricity, thus, it involves all the deficiencies of the components in a PV system. This ratio is given by equation 3.10 (Antony et al, 2007).

$$\boldsymbol{\eta_{sys} = \eta_{pv}.\eta_{pv-batt}.\eta_{cc}.\eta batt.\eta_{dist}.\eta_{inv}} \quad (0.2)$$

Where:

η_{pv}: efficiency of the PV modules,

$\eta_{pv\text{-}batt}$: efficiency due to voltage drop in cables,

η_{cc}: efficiency of the charge controller,

η_{batt}: efficiency of the batteries,

η_{cable}: efficiency of the distribution cables from PV battery to loads and

η_{inv}: efficiency of the inverter.

The universal index used for comparing the efficiency of solar cells from different vendors is the peak power Wp, which is estimated under Standard Test Conditions (STC). STC is equivalent with an irradiance G_{STC} of 1000 W/m^2 and a temperature T_{STC} of 25°C. The peak power of a solar cell has a direct correlation to its efficiency $\boldsymbol{\eta}_{PV}$, which is defined as the ratio of generated power to incident solar energy (Häberlin, 2012)

$$\boldsymbol{\eta_{pV} = \frac{w_p}{G_{sTC} \cdot A_C}} \quad (0.3)$$

An inverter was required to upturn DC power into AC power with a desired output voltage for utilization of conventional electrical appliances that demanded AC power.

A converter can be used instead since it can convert AC to DC and vice versa depending on the direction of power flow.

The inverter provides for low battery cut-out and cut-in operation (Messenger and Ventre, 2010). The selected inverter was needed to meet the requirements of the load as well as monitor the battery voltage.

After choosing inverter, the string size (number of modules in series) for the PV modules has to be determined. The modules can be connected either in series and/or in parallel before they are connected to the inverter.

The size of the string determines the amperage and the voltage that will be going into the inverter. The maximum number of modules allowed to be connected in series as given in equation 3.13 (Messenger and Ventre, 2010)

$$\boldsymbol{M_{m_{ax}}} = \frac{\mathbf{Vi\,m}\,\boldsymbol{ax}}{\boldsymbol{V_{oc}} + (\boldsymbol{T\,min}^{-\boldsymbol{T}}\,\boldsymbol{STC}) \cdot {}^{\boldsymbol{\Delta V_0 c}}/_{\boldsymbol{\Delta T}}} \qquad (0.4)$$

And the minimum number of modules tolerable to be connected in series is

$$\boldsymbol{M_{min}} = \frac{\mathbf{V\,i}\,\boldsymbol{min}}{\boldsymbol{V_{mp}} + (\boldsymbol{T\,max}^{-\boldsymbol{T}}\,\boldsymbol{STC}) \cdot {}^{\boldsymbol{\Delta V_{oc}}}/_{\boldsymbol{\Delta T}}} \qquad (0.5)$$

Where:

$V_{i,\,max}$: maximum inverter voltage [V],

$V_{i,\,min}$: minimum inverter voltage [V],

$V_{m\,p}$: maximum power voltage [V],

$V_{o\,c}$: open circuit voltage [V],

$\Delta V_{o\,c}/\Delta T$: temperature coefficient of V_{oc} [V/K] – Technical data for 295 W Jinko PV module,

Tmax: maximum monthly averaged temperature of Kenya (23.0°C) and

Tmin: minimum monthly averaged temperature of Kenya (12°C) according to world weather online.com.

The total number of modules has to be equal or exceed the wattage of the inverter as well as match the number of modules needed to meet the system load. The final combination also has to match the measured location area for the placement of the PV modules.

Equations (3.10) to (3.14) gives the number of modules required to meet the load and was simulated in PVSyst. Such a system can only supply power at the same time when the solar resource is present, meaning that it can function to supply critical offices during power outages.

The administration block load from the KPLC bills was accurate since previous meter reading was subtracted from current meter reading, thus, actual. The consumption and separation of high rate and low rate depicts time and night utilization respectively. With just two bills of July, 2018 and June, 2019-meter reading gave actual consumption.

The number of PV modules was found by determining the number of components needed to equal the same load during the day and battery backup that can supply night lighting with a few the critical loads of offices during power outages.

3.12 Battery Capacity Determination

The assessment of the energy required during grid failure is based on its nature and how the system operates during failure. Given that there was no data of grid failure at the university and the fact that the system is expected to supply power to some of the loads during failure, the energy needed during failure was typically fraction of total energy.

The crucial equipment that allows minimal operation during outage were considered for backup as in Figure 3.8. Every office will be backed with one 4 feet fluorescent and a desktop. Also, ethernet network is need to be available all the times. Due to the quality of Trojan batteries from USA this research used them in the design. The Trojan battery in Figure 3.8, is manufactured in USA was used. Its specifications are given in Figure 4.8.

Figure 3.8: Trojan battery

Batteries used in all solar systems are sized in Ampere hours under standard test conditions (Temp: 25^{0}C). The depth of discharge is a measure of how much of the total battery capacity has been consumed. For most batteries' manufacturers recommend the maximum allowable depth of discharge is 0.5 (50%) - 0.7 (70%) in order to get more cycles which, translate to lifespan.

The battery bank capacity was given by equation 3.15

$$C_x = G_{ft} / V_{dc} \times E_{tot} / DOD_{max} \qquad (0.1)$$

Where

C_x = battery capacity, for a specified discharge rate in ampere hours.

E_{tot} = total energy in watt hours to be supplied by battery bank during grid failure

G_{ft} = the number of days the battery bank needs supply during grid failure.

DOD_{max} = design maximum depth of discharge

3.13 Equipment's

The descriptions of equipment used were as follows:

3.13.1 Solar modules

Jinko panels model JKMS295M-60V Maxim were used for the design and their features are elaborated in table 3.1

Table 3.1: Characteristic of panels

Description	Specifications
Weight	41.90 lbs
Solar Cells	Monocrystalline PERC
Front Glass	3.2mm, Anti-Reflection Coating, High Transmission, Low Iron, Tempered Glass
Frame	Anodized Aluminum Alloy (Black)
J-Box	IP67 Rated
Output Cables	TUV 1x4.0mm², Length: 900mm or Customized

Table 3.2: Electrical Characteristics

Maximum Power (Pmax)	295 Watts
Maximum Power Voltage (Vmp)	32.40 Volts
Maximum Power Current (Imp)	9.10 Amps
Open-Circuit Voltage (Voc	39.70 Volts
Short-Circuit Current (Isc)	9.61 Amps
Module Efficiency STC	0.1802
Operating Temperature	-40°C to +85°C
Maximum System Voltage	1000VDC (IEC)
Maximum Series Fuse Rating	15 Amps
Power Tolerance	0~+3%

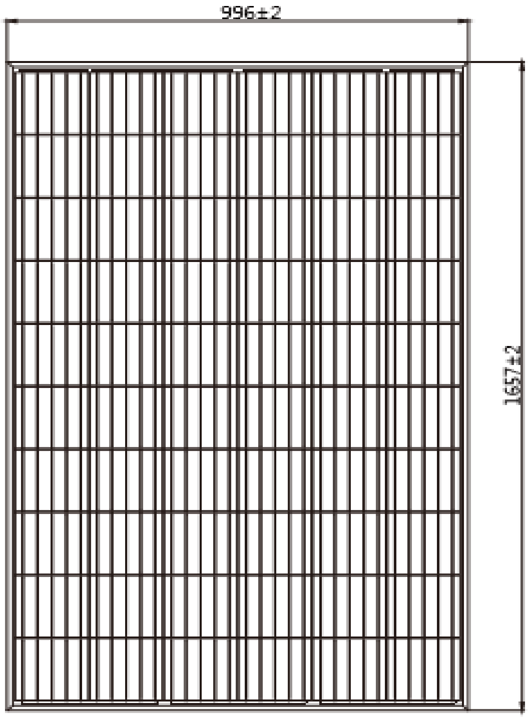


Figure 3.9: JKMS295M-60V Maxim Dimension

3.13.2 Inverter

SMA inverter from Germany- Model Sunny Tripower 25000TL-JP-30 was used as it has a well distribution- function that provide voltage regulation by controlling reactive power flow in the circuit. This facilitated renewable penetration even with their intermittent nature characterized with rapid, large and random fluctuation in supply (Ieeexpore, 2019)

Figure 3.10: Inverter

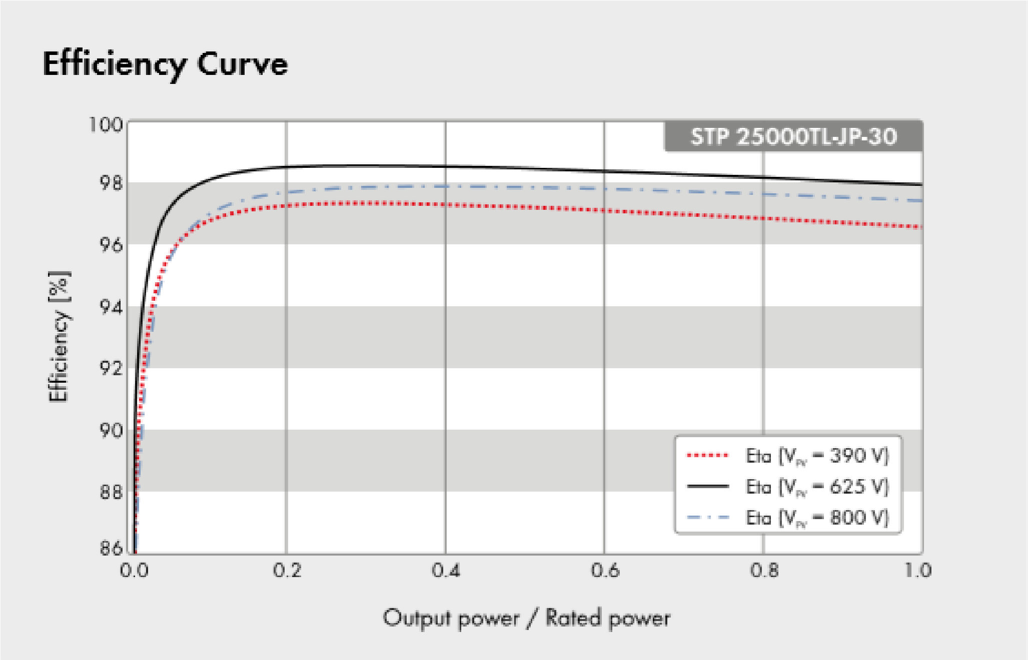


Figure 3.11: Efficiency Curve Graph (Source: SMA solar, 2015)

3.13.3 PVGIS Website

The Photovoltaic Geographical Information System (PVGIS) provides web access to:

- solar radiation and temperature data
- PV performance assessment tools

3.14 STC Standard Test Conditions of Panels

Usually, when the performance of the solar module is tested under standard conditions as;

- Irradiance 1000 W/m^2
- Module temperature $25^0\,C$
- Spectrum AM 1.5

3.15 AC Connection to Sub-panel

When a site service contains more than one panel board, the panels fed from the main service panel are referred to as subpanels. The NEC, in 705.12(D) and NEC 690.64(B) in the 2008 NEC, allows the inverter OCPD to be connected at any location in the premises wiring system, provided that the 120% of busbar and conductor ampacity limitation was observed.

Now consider the current flow at the main service panel, the 2011 NEC requires installers to calculate the sum of the supply OCPDs at the main service panel based on the rating of inverter OCPD, like in the case of 200A service board a 40-amps and not the 200-amp feeder breaker that feeds the subpanel

3.16 Sensitivity Analysis of the Investment

The research analyzed the system cost and benefit of conventional on-grid power system components, off-grid solar systems and hybrid of solar systems. For quantification and analysis, power production and consumption were kept equivalent for all the three energy systems. The model enabled end customers to make a decision based on system parameters and its corresponding results in terms of power savings. This model is a conglomeration of solar system studies and its direct impact on end customers on an annual basis.

For more precision cost benefit model, it used real time data such as current energy prices for residential systems, solar system costs from different agencies, costs of power components, construction and labor costs from solar and roofing contractors, carbon emission reduction data through different conventional sources.

PVSyst calculates the cost of the investment and will find the optimal system to meet the load. The two most important setups were evaluation of a sensitivity analysis by varying important parameters such as PV capital cost, and grid electricity price.

Once the optimal system was found, its' payback period was calculated with respect to the accumulative development of the national grid electricity price in Kenya.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents results and discussions of various findings of the study. It starts from sizing the system that meets administration block load and simulation of this system on existing site parameters.

4.2 Site Sun Path

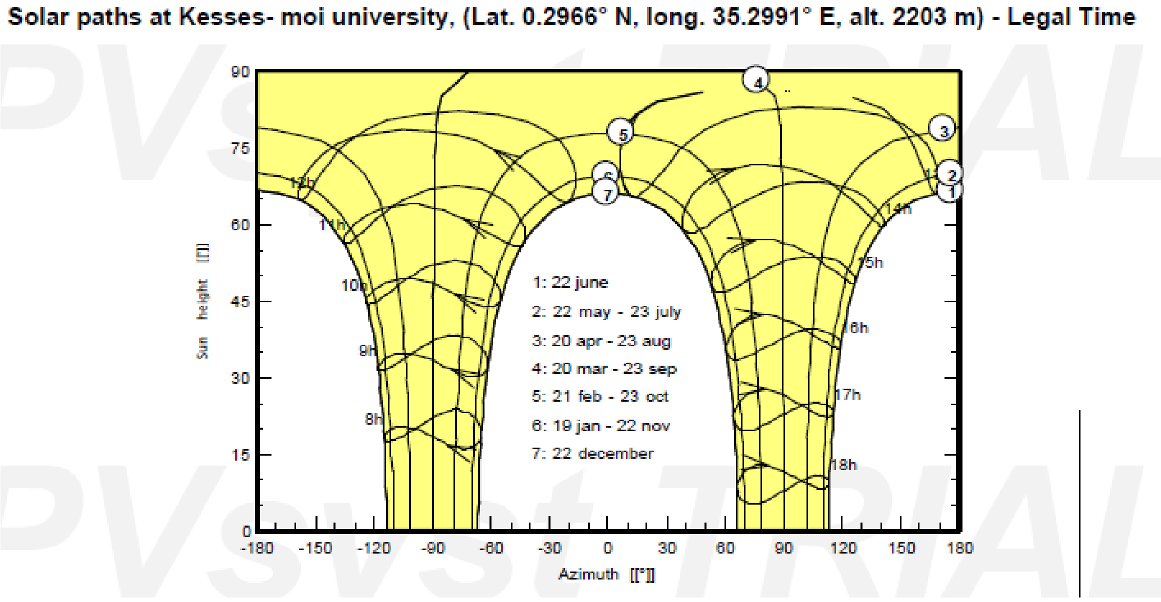


Figure 4.1: Solar path at Kesses -Moi University

4.3 Average Sun hours

The sun-hour varies throughout the year. For Grid connected system with no net metering and with high FiT values, average monthly sun-hours are used in sizing unlike in off-grid system where the lowest monthly average value is used.

Table 4.1: Moi administration block irradiation table

	Jan	Feb	Mar.	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Year
Hor. Global	6.29	6.39	6.18	5.55	5.2	5	4.4	4.54	5.77	5.75	5.54	6.2	5.564
Amb. Temperature	17.5	18.5	18.5	17.8	17	16	16	15.8	16.4	17.3	17.1	17	17.17
Wind Velocity	4	4.1	3.9	3.3	2.8	2.6	2.5	2.5	2.8	3.5	3.9	3.9	3.317

Worth noting is that wind velocity is directly proportional with Global irradiation as shown in Figure 4.2.

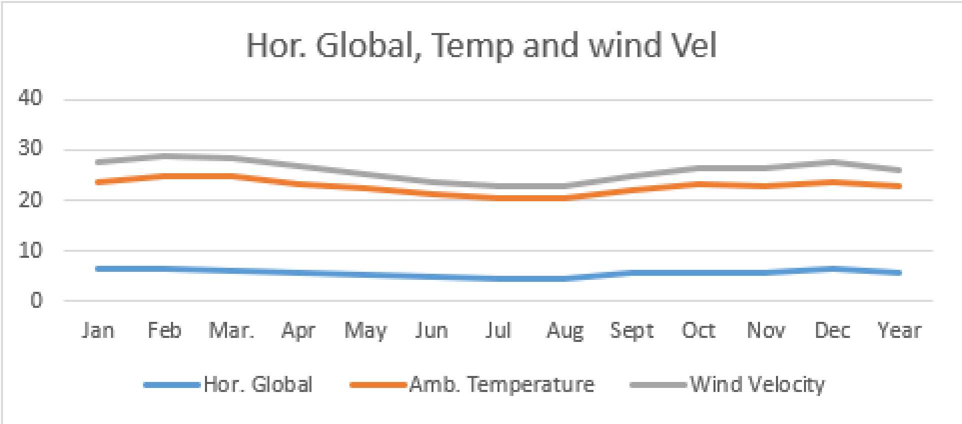


Figure 4.1: Global irradiance, temperature and wind velocity curves

4.4 Administration Block Roof Analysis

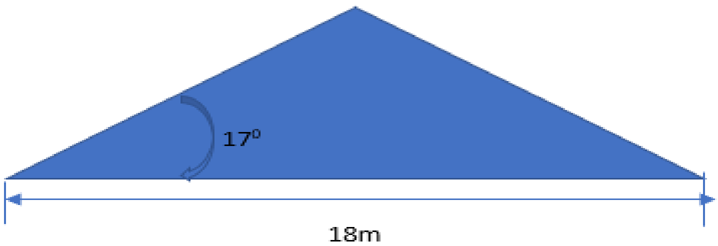


Figure 4.1: Roof Analysis Administration block

The main width was found to be 18m while the roof forming slopes of was 17^0 from the opposite walls, resulting to two faces of the roof; one facing south at an azimuth of $21^0$and the other facing North with an azimuth angle of 159^0 (Hypotenuse) as captured by Google campus (Figure 3.6). Width of the roof =W roof = 9/cosine 17°= 9.41m

Figure 4.2: Administration Block Moi University

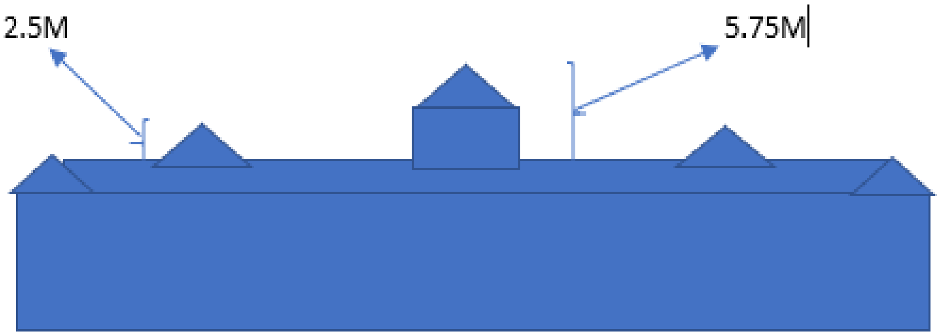


Figure 4.3: Front view of Administration Block

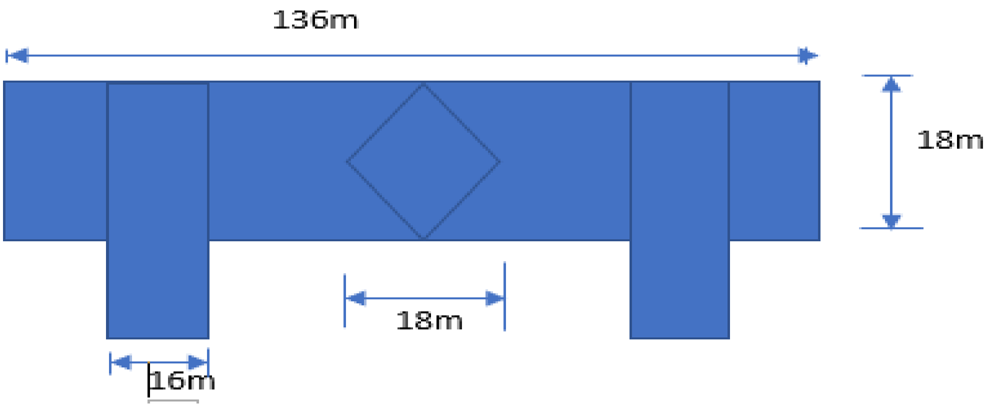


Figure 4.4: Aerial view of Administration Block

The available longitudinal length of the North/South facing roof to lay the panels without considering the shading effects of the protruding sections of roof was

$$= 136M - (18 + 2\,X\,16) = 86m$$

Total area on either side of the roof (North/South) was

$$A = 86\ x\ 9.41 = 809.26m^2$$

4.5 Sizing the Solar Plant

Taking high-rate meter reading as captured in monthly electric bill of 1^{st} July– 2^{nd} August, 2018 (Table 4.2) - previous meter reading of July 2018 bill and also previous meter reading in 1^{st} July- 2^{nd} August 2019 (Table 4.3) gave a twelve months actual consumption.

Table 4.1: KPLC Bill 02/07/2018-01/08/2018

Meter No.	**Previous reading**	**Current reading**	**Reading Type**	**Consumption**	**Consumption type**
040016113631	0	96	Real	96	Demand KVA
040016113631	0	94	Real	94	Demand KW
040016113631	***563873***	582889	Real	**19016**	High rate
040016113631	368516	378147	Real	9631	Low rate

Table 4.2: KPLC Bill 02/07/2019-01/08/2019

Meter No.	**Previous reading**	**Current reading**	**Reading Type**	**Consumption**	**Consumption type**
040016113631	0	99	Real	99	Demand kVA
040016113631	0	97	Real	97	Demand kW
040016113631	***800803***	823052	Real	**22249**	High rate
040016113631	506052	519062	Real	13010	Low rate

Actual consumption was

$$800803 - 563873 = 236930\ kWh/year$$

$$236930/12 = 19744.17 kWh/month$$

$$19744.17/30 = 658.14 kWh/day$$

$$658.14/5.6 = 117.53 kW$$

4.6 Electrical Load Mapping

Electrical power rating of the equipment, was presented as in Table 4.4.

Table 4.1: Mapped Appliance Table

Item Description	Qty	Wattage	Total watts	Time of Usage (Hrs)	Watt-Hrs
Switches	1	480	480	2	960
Shredder	1	240	240	2	480
Scanner	11	15	165	2	330
Printers	1	696	696	2	1392
Coil	1	2400	2400	1	2400
Conditioning fan	1	134.4	134.4	2	268.8
Cooker	5	1200	6000	2	12000
Decoder	2	10	20	8	160
Desktop	218	200	43600	8	348800
Dvd player	1	8	8	8	64
Electric coil	3	1200	3600	2	7200
Kettle	12	2200	26400	2	52800
Fan	3	134.4	403.2	2	806.4
Fax machine	3	19.2	57.6	5	288
Fridge	4	100	400	15	6000
Internet switch	5	66	330	24	7920
Laptop	37	50	1850	6	11100
Microwave	9	1200	10800	2	21600
Photocopier	15	1224	18360	2	36720
Printers	106	480	50880	2	101760
Projector	2	312	624	2	1248
Tv	2	94	188	8	1504
Ups	20	528	10560	8	84480
Dispenser	7	550	3850	6	23100
Water heater	3	220	660	1	660
Grand Total			**182706.2**		**724041**

Table 4.2: Mapped lighting points table

Item	Item Load	Qty	Total watts	Total use hrs per day	Total Watt Hours
2 FT Tube lights	18	97	1,746	8	13,968
4 FT Tube lights	36	1,353	48,708	8	389,664
5 FT Tube lights	58	19	1,102	8	8,816
CFL LIGHTS	10	13	130	8	1,040
Total			**55,230**		**413,488**

From the physical mapping of electrical equipment and their consumption. The sum watt-hours of a day are divided by average daily sun-hours

Daily consumption = Appliances + lighting

$$724041.2 + 413488.0 = 1137529.2\, Wh/day$$

Then, the system size will be

$$1137529.2/5.6 = 203.13kW$$

The value of 203.13 kW was ignored since it was far from the accurate. The reason was that during audit, the operation time of lights and appliances are purely guessed work. Some equipment may have ceased being used and yet to be faced out as seen in Figure 4.7.

Figure 4.1: Unused equipment stilled hooked to power

This method is only good for small housed hold system where exaggeration will not impact so much on the cost of the system (Hawkins, 2010).

For the case of this study, the mapping data obtained was used to size battery bank for critical loads - 66240Wh. Its accuracy was found to be high since the end user usually dictate backup time depending their experiences on duration of discomfort caused by outage.

From the KPLC bill the highest peak power was 99Kw. It was found that, the economical and sustainable size system for administration block was 100kW. This is because the peak load of administration block is 99kVa which is definitely during the day when most activities is on. Also, analysis of KPLC bill resulted to 117kWh per day and that net metering bill is not enacted, the system being small compared to set threshold FiT value of 500KWp and export of excess power meant extra bill to the university.

4.7 Critical Load Battery Backup

From the physical mapped load list, this research picked crucial loads that was in the offices taking into consideration of existing 235 offices in administration block. These were internet server and network switches, a desktop and two 4ft tube florescent tubes in a third the number of offices in administration block.

Table 4.1: Critical load table

Item	Item Load	Qty	Total watts	Total use hrs per day	Total Watt Hours
Desktop	120	75	9,000	4	36,000
4 FT Tube lights	36	150	5,400	2	10,800
switches	66	5	330	24	7,920
Server	480	1	480	24	11,520
Total			**15,210**		**66,240**

Size of Battery bank at nominal DC voltage of 48V and 65% depth of discharge

$$\frac{66240 \text{ Wh}}{48 \times 0.65} = 2{,}123 \text{ Ah}$$

Battery base inverter of 15KVA at 48V was enough to serve critical load service board. This research used 4V Trojan 2145Ah batteries. For a 48V nominal voltage system, it took 12 Trojan batteries all connected in series.

On off-grid system of such size of critical load as indicated by Table 4.6, 65% Depth of discharge would have at least seven years lifespan with 2600 life cycle for daily battery use- Figure 4.8. But, for this case where batteries are used as backup, 2600 life cycle represent quite long-life span given that cycles are utilized only when utility grid is down.

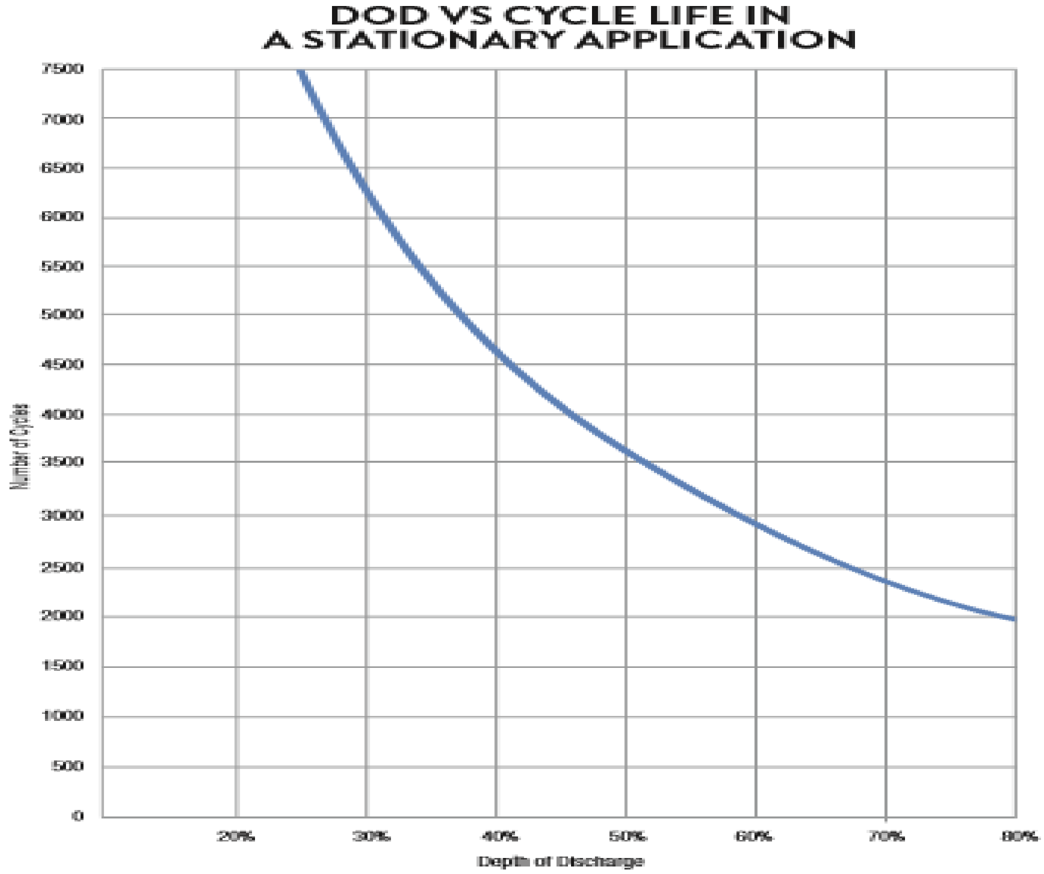


Figure 4.1: DOD vs Cycle Life Curve Graph

Table 4.2: Cost of Incorporating Battery Back up

ITEM DISCRIPTION	**QTY**	**Unit price**	**DISC**	**VAT**	**EXPECTED PRICE**
4V 2145 AH Trojan BATTERY	12	167,500.00	15%	0%	1,708,500.00
6KVA INV/CHG	3	227,000.00	15%	0%	578,850.00
AVS & change over	2	14,500.00	0%	16%	33,640.00
Installation Materials	1	32,200.00	0%	16%	37,352.00
Labour	1	34,700.00	0%	16%	40,252.00
GRAND TOTAL VAT					**2,398,594.00**

Table 4.7 is the current market price of doing battery backup systems of 12 pieces of 4V 2145Ah batteries

4.8 Plant Layout

The total rating of the system was100KW taking 360 pieces of Jinko panels model JKMS295M-60V Maxim shall cover a total rooftop area of 589 m^2. With administration block's longitudinal length of 135m, larger roof surfaces facing north and south was used for simulation. The plant uses a total of 360 solar panels and 4 three phase inverters with rating of 25 KW - model Tri power 25000TL-JP-30 as in Figure 4.9. These inverters were used for DC to AC conversion and the output was fed to the 11 KV grid.

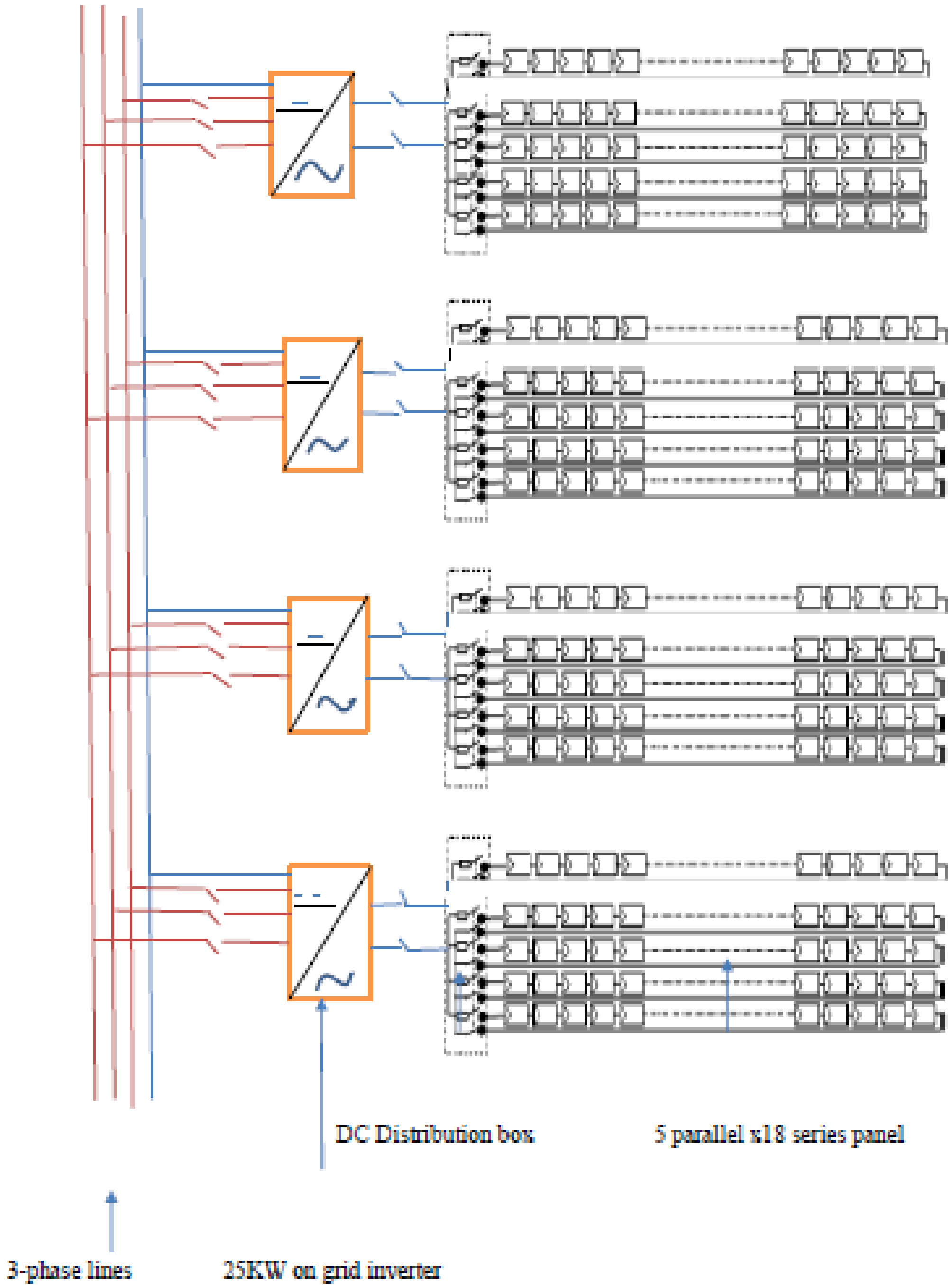


Figure 4.1: Plant layout

The array dimensions and space required was computed as follows:

$$\text{Length} = 0.996 \times 18 = 17.928 \text{ m}$$

$$Width = 1.657 * 5 = 8.285m$$

The inverter manufacturers specification that should not be exceeded by pant parameters is shown in table 4.8.

Table 4.1: Inverter Dc Input parameters verses designed system parameters

Inverter dc input Parameter	Layout/Array parameters
Mpp voltage Range/Rated input Voltage: **390V** to **800V/600V**	No. of panels in series X V_{oc} 18 x 39.70 = **714.60V**
Maximum input current: **33A**	No. of strings in an array Y I_{sc} 5 x 9.61 = **48.05A**
No. of independent MPPT inputs	**2**
Min input Voltage/Start input Voltage: **150V/188V**	**150V/188V**

4.9 PVSYST System Simulation

This research looked into the tilt and orientation of the two main longitudinal faces of the roof – south and north. It simulated energy production from each independently and further investigated the possibility of energy enhancement. Results and Analysis

PVsyst allows the user to import the metrological data from various sources and analyze grid connected solar systems depending on the specifications of the system and characteristics of its components such as PV module, inverters and others components. The experimented tilt angles at existing roof orientations helped to point out the existing relationship between the latitude of a location and the optimal tilt angle to harness the sun energy.

Table 4.1: Experiment results table

Tilt angle°	1st Current reading	2nd Current reading	3rd Current reading	1st Voltage reading	2nd Voltage reading	3rd Voltage reading	AVERAGE POWER
5	0.452	0.442	0.436	20.178	20.071	20.037	8.909
15	0.596	0.575	0.593	20.525	20.359	20.552	12.042
25	0.460	0.450	0.456	20.345	20.112	20.248	9.214
35	0.447	0.446	0.448	20.085	19.870	19.933	8.923

Plotting these values in Table 4.9 against tilt angles resulted to curve as seen in Figure 4.10.

Figure 4.1: Average power vs Angle curve

The results obtained from simulations of varying scenarios are given in Figure 4.11 to figure 4.18.

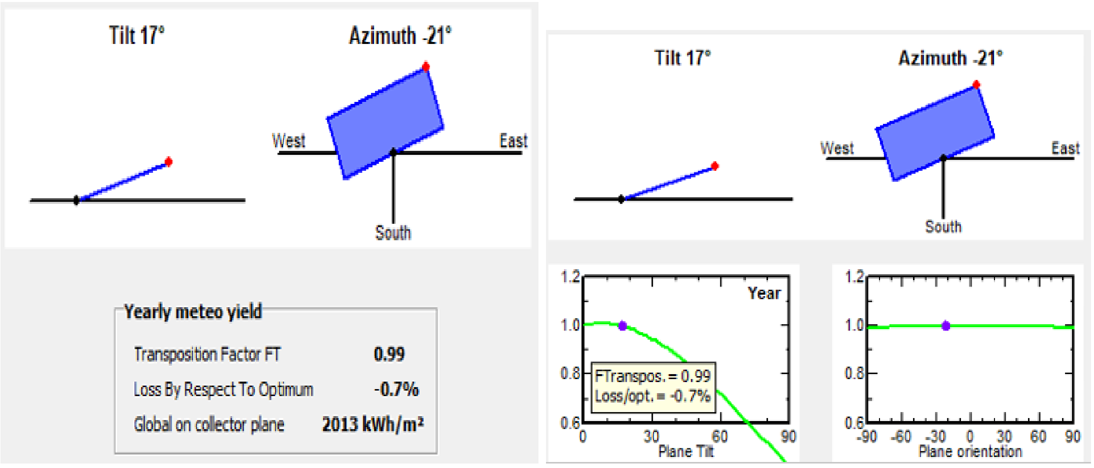


Figure 4.2: Diagram of the south facing roof surfaces

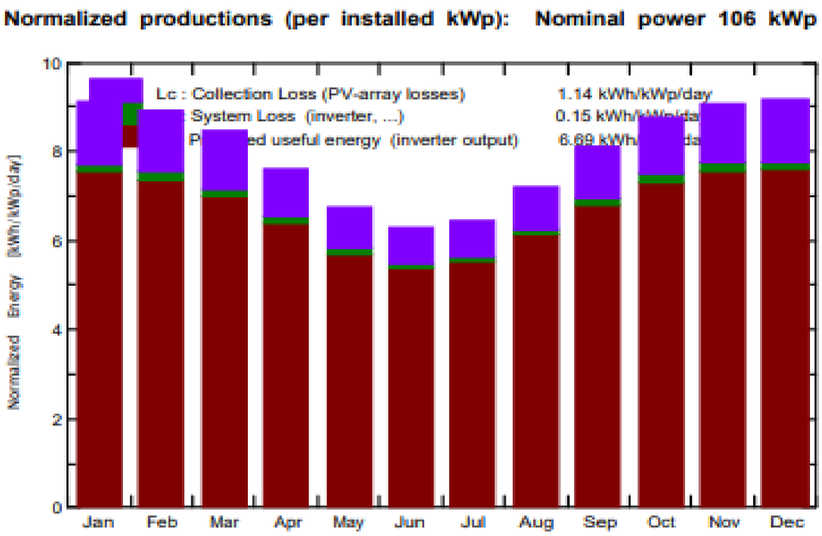


Figure 4.3: Normalized production Bar graph

For orientation tilt 17, azimuth -21 in figure 4.11, transposition factor is 0.99 and loss with respect to the optimum is -0.7. This mean ratio of incident to horizontal is close to one but there are minimal losses incurred in harnessing the sun on the panel due to its orientation. The system’s production is at 259.2 mWh annually.

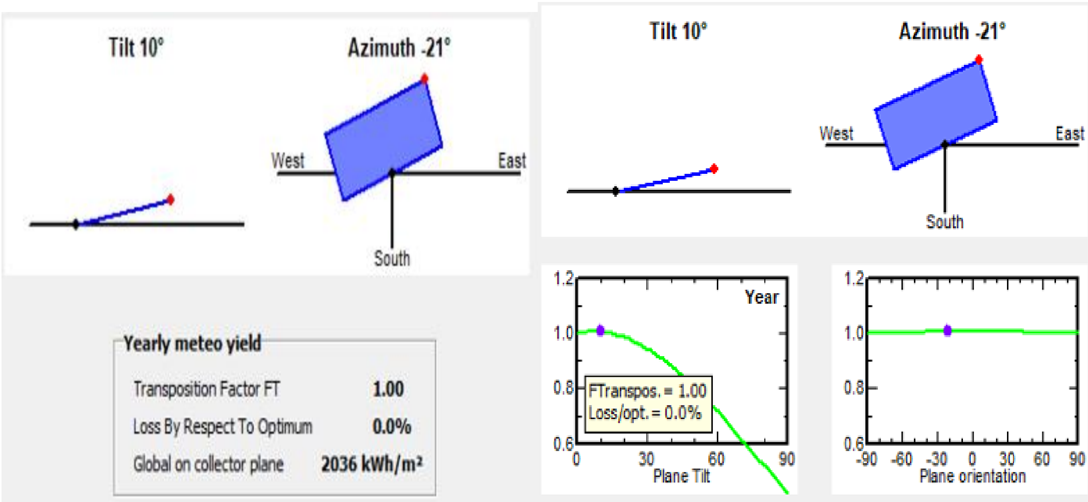


Figure 4.4: Optimized tilt of the south facing roof

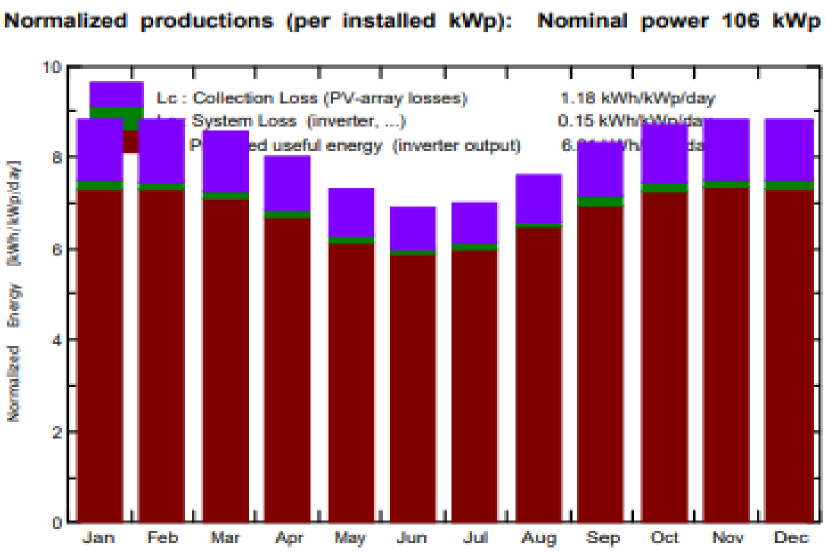


Figure 4.5: Normalized productions bar graph

For orientation tilt 10^0, azimuth -21^0 in figure 4.13, transposition factor is 1 and loss with respect to the optimum is 0.0%. This mean ratio of incident to horizontal is one and zero gain/losses incurred in harnessing the sun on the panel due to its orientation. The system's production of 263.9 mWh annually.

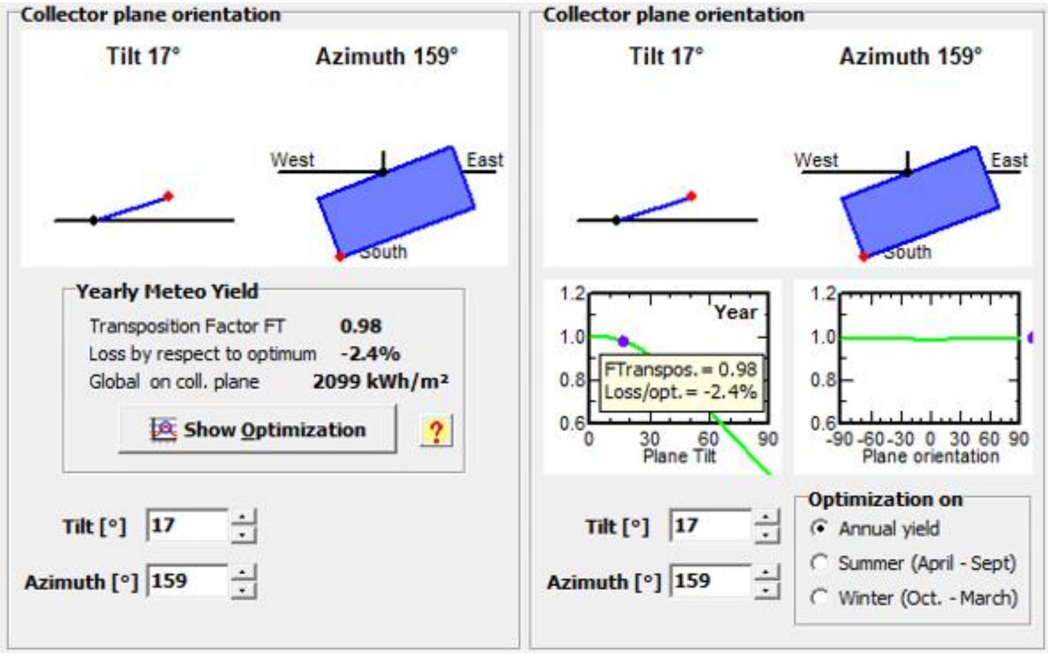


Figure 4.6: The North facing roof surfaces

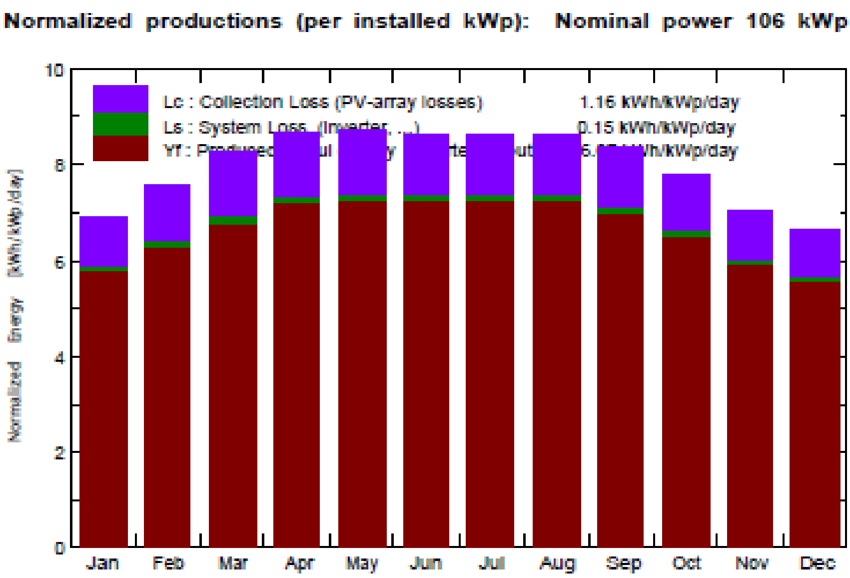


Figure 4.7: Normalized production Bar graph 3

For orientation tilt 17^0, azimuth 159^0 in figure 4.15, transposition factor is 0.98 and -2.4% loss with respect to the optimum. This mean ratio of incident to horizontal is less than one and significant losses incurred in harnessing the sun on the panel due to its orientation. The system's production of 258.6 mWh annually.

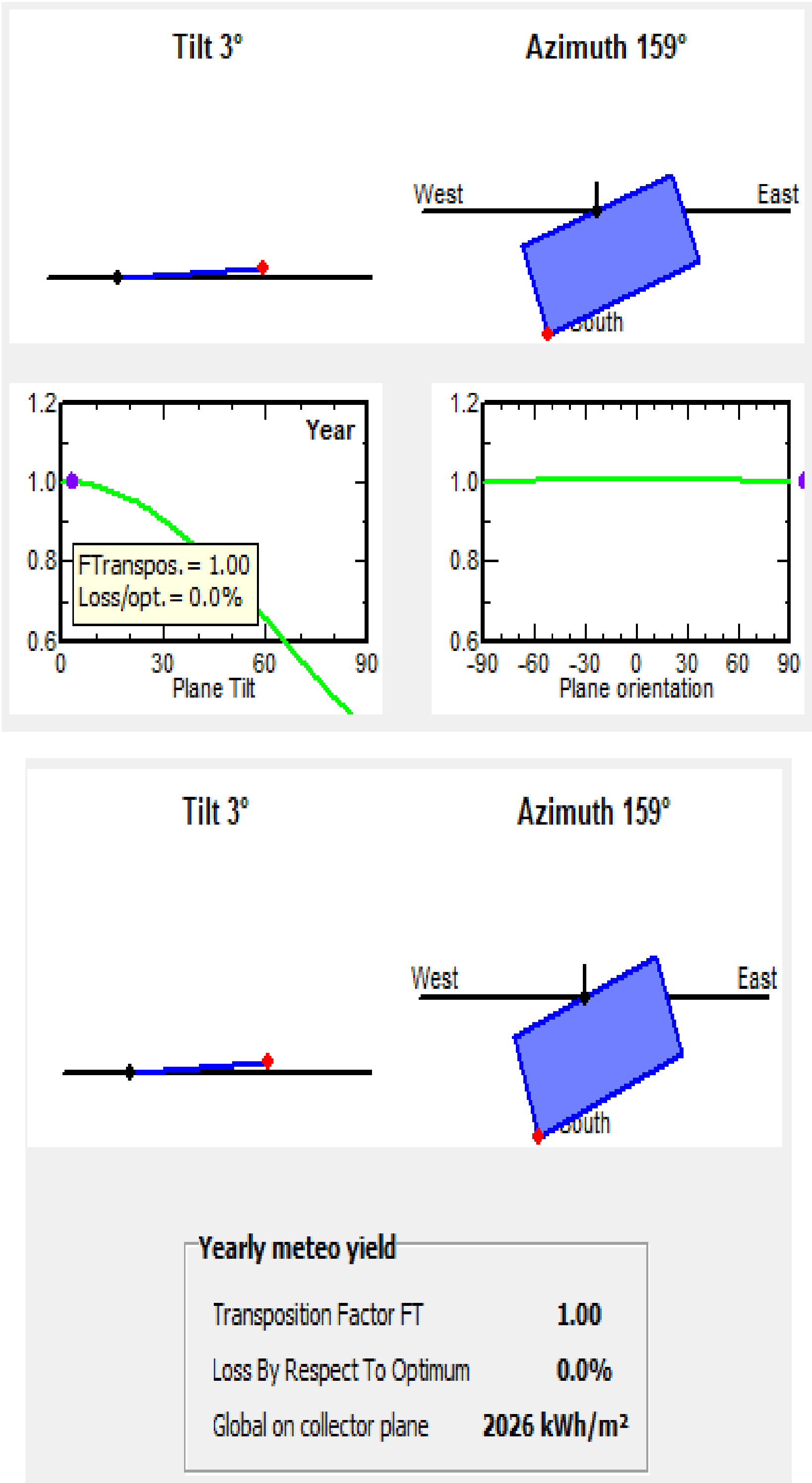


Figure 4.8: Optimized tilt of the south facing roof

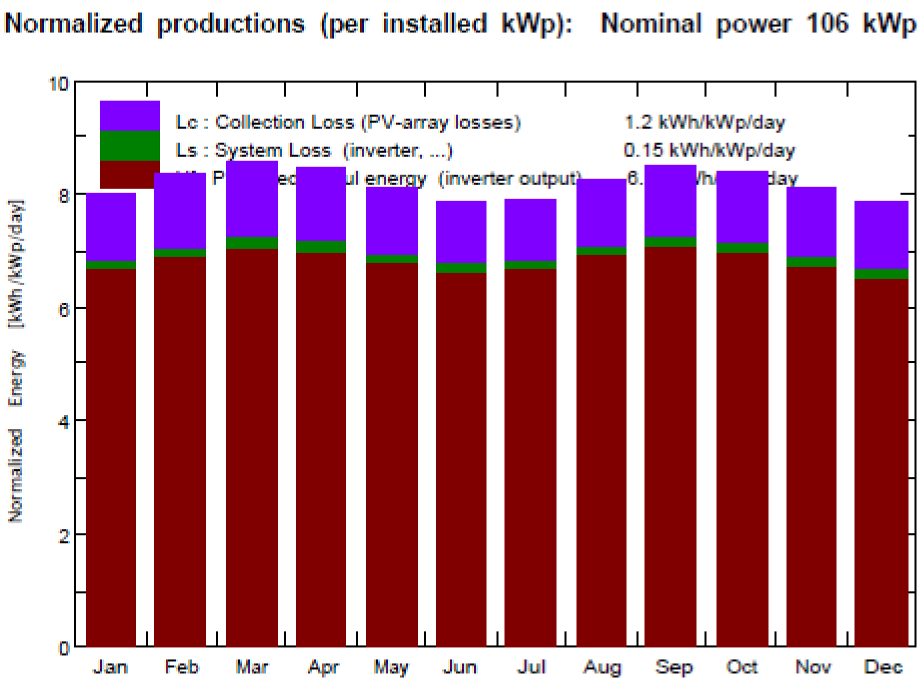


Figure 4.9: Normalized Production Bar graph 4

For orientation tilt 3^0, azimuth 159^0 in figure 4.17, transposition factor is 1 and 0.0% loss with respect to the optimum. This mean ratio of incident to horizontal is one and no losses incurred in harnessing the sun on the panel due to its orientation. The system's production is 265.2 mWh annually.

Table 4.2: Summary table of various simulation

Tilt°	Azimuth°	Glob on Coll	System Prod mWh/yr	Specific Prod kWh/kWp/yr	Performance Ratio	Normalized Prod kWh/kWp/day	pv loss kWh/kWp /day
3	159	2026	265.2	2497	0.835	6.84	1.20
10	-21	2036	263.9	2484	0.837	6.81	1.18
17	-21	2013	259.2	2441	0.838	6.69	1.14
17	159	2099	258.6	2435	0.834	6.67	1.16

On analysis of the values in Table 4.10 it is certain that the normalized energy from the optimized 3-degree tilt angle (6.84 kWh / kWp / day) is more than the rest which get lower to the lowest 6.67 of 17-degree tilt angle. PV- array losses is also higher for this tilt angle just as yearly system production and specific production.

Therefore, the suitable orientation for solar energy harnessing at Moi university administration was obtained as Tilt angle of 3° and Azimuth angle of 159°.

Table 4.3: Simulation data of 100KW plant with tilt 3° and azimuth 159°

	GLOBLE HORIZONTAL kWh/m^2	**GLOBLE INCIDENCE kWh/ m^2**	**E-GRID MWH**	**PRODUCTION RATIO**
JAN	254.5	248.2	21.96	0.833
FEB	237.6	234.0	20.52	0.826
MAR	266.6	266.0	23.26	0.823
APR	250.9	253.8	22.36	0.830
MAY	245.4	251.1	22.33	0.838
JUN	228.9	235.4	21.18	0.847
JUL	239.3	245.4	22.09	0.847
AUG	251.6	255.6	22.86	0.842
SEP	254.1	254.9	22.57	0.834
OCT	263.7	260.8	22.99	0.830
NOV	248.2	242.5	21.50	0.835
DEC	250.5	243.3	21.59	0.836
TOTALS	**2991.3**	**2991**	**265.21**	**0.835**

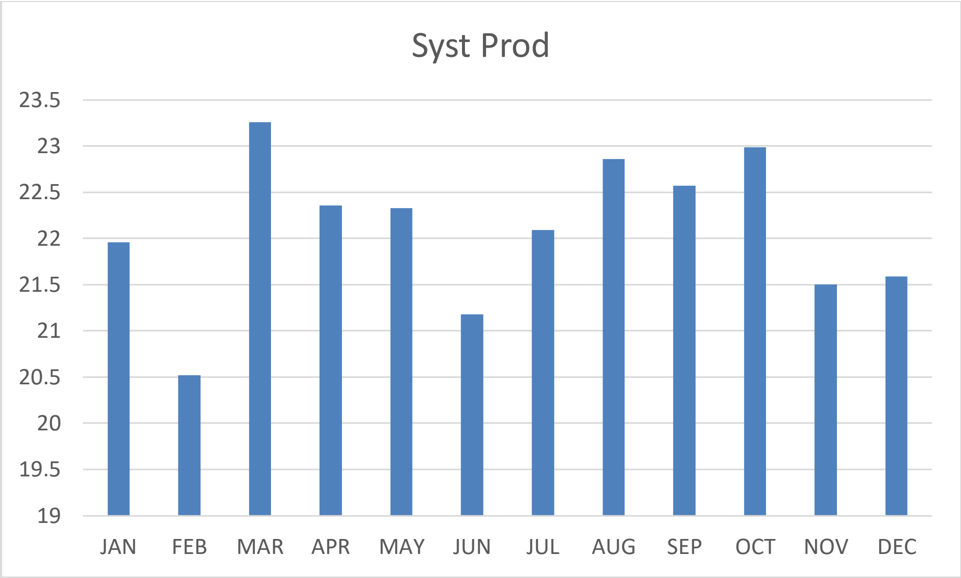


Figure 4.10: Yearly production bar graph

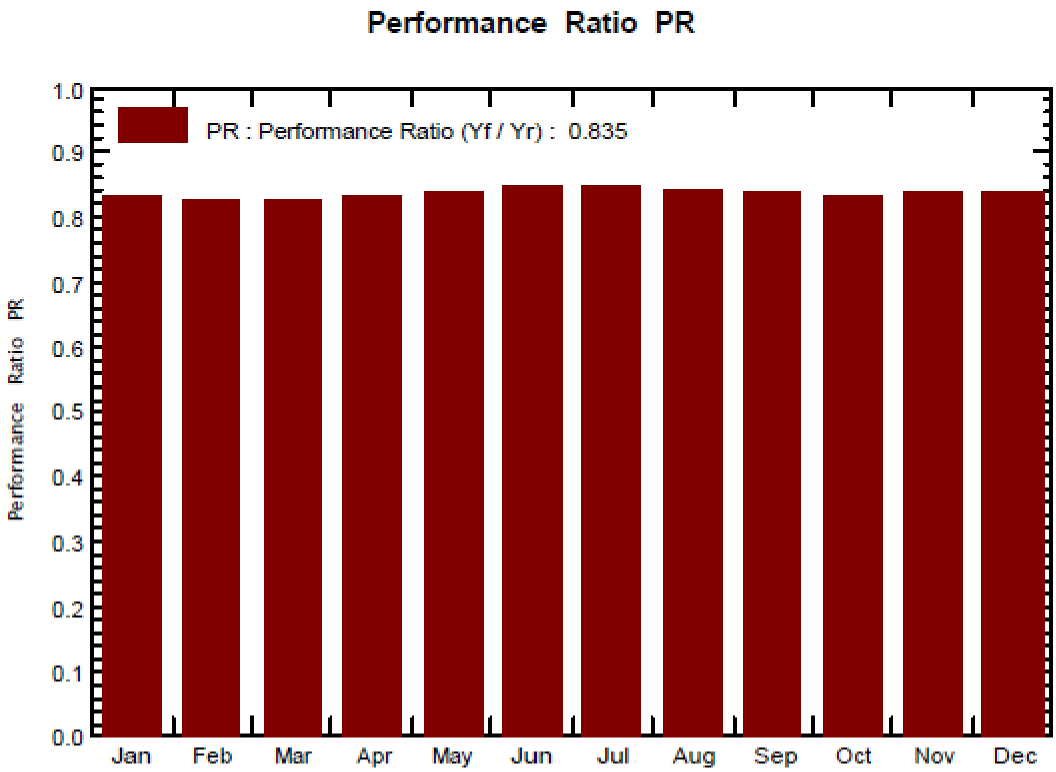


Figure 4.11: Performance Ratio PR Bar Graph

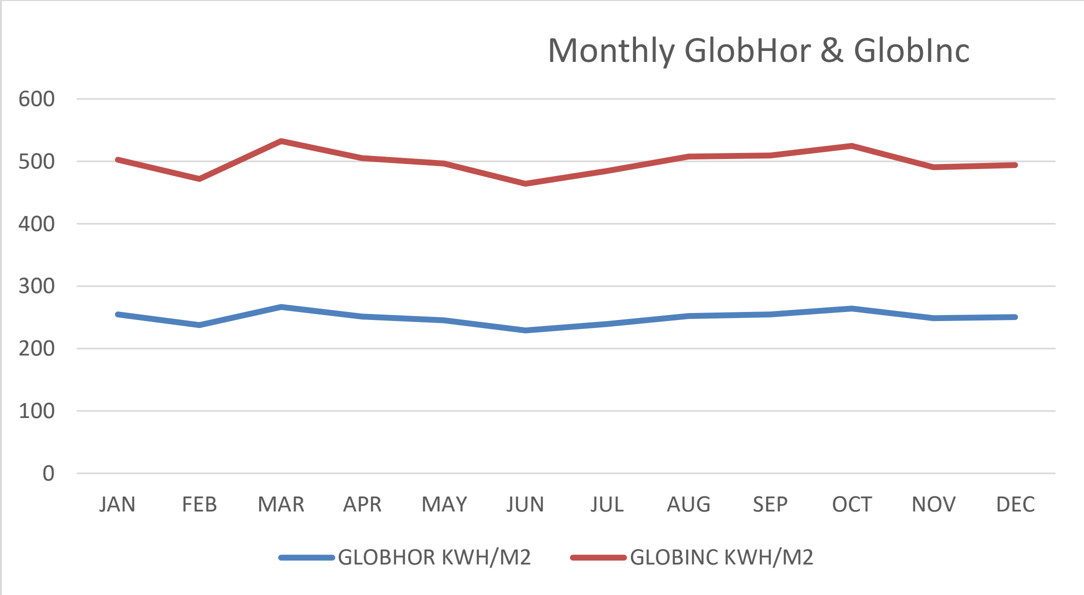


Figure 4.12: Monthly Global Ho &Glob Inc kWh/m^2

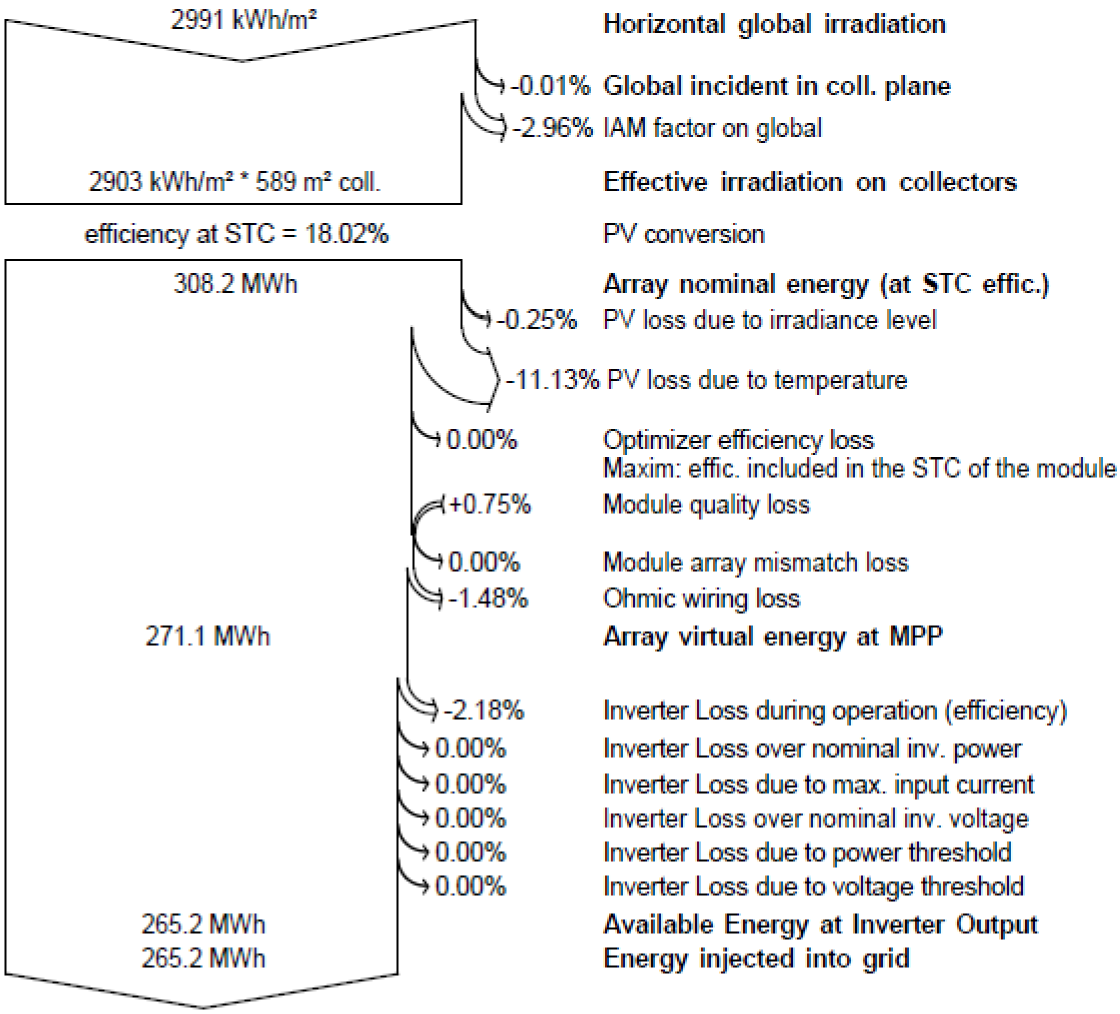


Figure 4.13: Loss Diagram

From the loss in Figure 4.23 the effective irradiation on the collector plane was $2903kWh/m^2$ and the global horizontal irradiance was $2991kWh/m^2$. The solar radiation incident on the solar panels will convert into electrical energy. On PV conversion, the nominal array energy was 308 mWh, while the PV array efficiency was found to be 18.02% at standard test condition (STC) (Figure 4.23). Array virtual energy obtained was 271.1 mWh. After the inverter losses the available energy obtained at the inverter output was 265.2 mWh. The importance of doing simulation is to have optimal orientation where the modules are well exposed to the sun and rays are harness with minimal losses so as to obtain more solar energy conversion to electrical energy.

4.10 Cost of the System without Batteries

Taking the current prevailing market prices, the total system cost without batteries was as in the table 4.12. The total cost formed the basis of economic analysis. The costing assumed there is a dedicated room within administration bock to house the inverters and other balance of system- without batteries.

Table 4.1: Prices based on Chloride Exide – major solar distributor in Kenya

ITEM DESCRIPTION	QTY	Unit price (Kshs.)	VAT	PRICE EXCL VAT(Kshs.)	VAT	PRICE INCL VAT (Kshs.)
SOLAR MODULE C-SI 295 W	360	16,994.20	0%	6,117,910.24	0.00	6,117,910.24
25kW GRID-TIE INVERTER	4	470,159.76	0%	1,880,639.02	0.00	1,880,639.02
AC DISTRIBUTION BOX	1	89,204.55	16%	89,204.55	14,272.73	103,477.27
COMMUNICATION EQUIPMENT	1	73,568.18	16%	73,568.18	11,770.91	85,339.09
DC CABLE (4 mm^2)	540	127.50	16%	68,850.00	11,016.00	79,866.00
AC CABLE (10 mm^2)	270	293.25	16%	79,177.50	12,668.40	91,845.90
PANEL MOUNT - ROOF MOUNT	1	997,159.09	16%	997,159.09	159,545.45	1,156,704.55
REVERSE CURRENT PROTECTION	1	850,777.78	16%	850,777.78	136,124.44	986,902.22
ELECTRICAL INTEGRATION GEAR	1	560,713.79	16%	560,713.79	89,714.21	650,428.00
INSTALLATION LABOUR	1	713,438.63	16%	713,438.63	114,150.18	827,588.81
	GRAND TOTAL			**11,431,438.78**	**549,262.32**	**11,980,701.10**

4.11 Cost of Electricity

According to Moi university electric bill for the month of July, 2019; the total monthly cost was Ksh. 755 960.09. This was after a consumption of total units of 35259Kwh in both high and low rating. The main part of the bill that solar system will substitute was the high rating of the bill, A unit kwh cost was obtained as shown in Table 4.13:

Table 4.1: KPLC Cost of electricity

Energy							
	High-rate cons			22249KWh X 2			266,988.00
	low-rate cons			11399kwh x 12			136,788.00
	low-rate cons			1611kwh x 6			9,666.00
	max Demand KVA			99kva x 6			79,200.00
	Fuel Energy Cost			35259kwh x 3.67			129,400.53
Total Energy							622,042.53
	Levies and adjustments						
	Forex exchange			35259kwh x 0.0452			1,593.71
	Inflation			35259kwh x 0.25			8,814.75
	ERC LEVY			35259kwh x 0.03			1,057.77
	REP Levy			413442 x 5			20,672.10
	Warma Levy			35259kwh x 0.0169			595.88
Total levies and Adjustments							32,734.21
	Rounding Adjustment						0.10
	VAT						101,192.16
Total monthly bill							**755,969.00**

KWh Price = 1(12+3.67+0.0452+0.25+0.03+0.0169+.16) Kenya shillings

= Ksh. 16.17/kwh

Therefore, using this rate, the yearly saving obtained from the simulated yearly system production before introducing batteries to enhance self-consumption was as shown in the table 4.14.

Table 4.2: System Production

Month	Syst Prod MWh	Unit Cost	Saving (Kshs)
Jan	21.96	16.17	355,093.20
Feb	20.52	16.17	331,808.40
Mar	23.26	16.17	376,114.20
Apr	22.36	16.17	361,561.20
May	22.33	16.17	361,076.10
Jun	21.18	16.17	342,480.60
Jul	22.09	16.17	357,195.30
Aug	22.86	16.17	369,646.20
Sep	22.57	16.17	364,956.90
Oct	22.99	16.17	371,748.30
Nov	21.5	16.17	347,655.00
Dec	21.59	16.17	349,110.30
Totals	**265.21**	**16.17**	**4,288,445.70**

The total cost of the system after incorporating battery backup was obtained as **Kshs. 14,379,295.10.** The break-even point was

11980701.10 + 2398595.00 = 14379295.10 shillings

14379295.10/4288445.70 **= 3.35 years**

4.12 Return On Investment (RoI) of the system without batteries

ROI= **11,980,701.10/ 4288445.70**

= 2.793 roughly 3 Years

This calculation assumes the university has already existing estates and maintenance team capable of doing maintenance without any extra cost. The reduction in ROI time compared to the case with batteries is small because the battery backup load is just Critical loads that need to run during outage times.

Supposed the whole administration load were backed up by batteries, the cost of the system would be significantly large to give economic justification. Therefore, backing up of only critical loads improve reliability of grid connected system as well as controlling system cost to economic viability region.

4.13 Sensitivity Analysis

The study further studied the relation of array orientation to system production and return on investment time as shown in table 4.15

Table 4.1: Sensitivity of ROL to array orientation

Tilt (°)	**Azimuth°**	**System Prod mWh/yr**	**System production market Price (Ksh)**	**Scenario's ROL- With batteries(Yrs)**
3	159	265.2	4,288,284	3.353
10	-21	263.9	4,267,263	3.370
17	-21	259.2	4,191,264	3.431
17	159	258.6	4,181,562	3.439

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This study has ascertained adequate solar resource in Moi University. If harnessed with well-designed systems, they will meet the demand of intended facility, hence; reduce dependence on the grid electricity. The ROI difference is small between systems with and without batteries. This favors battery incorporation and the fact that batteries will last longer when used as backup than when used on daily basis as in off-grid scenario.

Moi university administration block being operational for 8 hours and mainly on daytime duration of the day, have the potential of leveraging on this adequate solar resource. This will minimize its reliance on fault prone grid and exploitation of nonrenewable resources such as fossils fuels.

With grid connected PV system, batteries are not mandatory. They only serve as backup for major critical load during outage. This means a considerable small battery bank whose cost is significantly small compared to backing up whole building loads. Moreover, in this case batteries are only used in the event of power outage. Therefore, the useful lifecycles of batteries are reserved for outage period- the batteries last longer than in the case of off grid system.

The four scenarios of simulation yielded different values with highest being 265.2Mw while the lowest at 258.6 Mw per year, with a range of 6.6 MW in a year for a 100kw system. This shows that with proper installation at optimal site parameter, one can enhance production with a significant value than can positively impact on economic feasibility of the system as well as shortening the breakeven duration.

Current technologies have enhanced production of solar system. The likes of centralized inverter with a number of MPPT capabilities have allowed utilization of space that even get shaded in part some part of the day. Some OEM recognizes developing countries without Net metering and have developed functionalities in inverter that limits export of power to grid or gadget (limiter) that facilitate grid connected inverters with normal one directional meter.

5.2 Recommendation

This study recommends a grid connected solar system not just for administration block but to whole university to leverage on adequate solar resource in order save on electric bills, for university to serve as a forerunner in encouraging adoption of solar energy and attract a clique of solar professions.

Thoroughly analysis of site and optimal parameters is paramount for decision making otherwise wrong decision would be made if inadequate research is done on a site as well has impacting on the grid substitute value as well as pay-back period of the system.

The cost addition on grid connected system due to precaution being put in place to avoid export of power to the grid in term of power limiter can be done away if the net metering bill is enacted. Also, the threshold capability for FiT should be lowered to increase target market as well as participation.

REFERENCES

AHK, (2013). Target Market Study Kenya Solar PV & Wind Power, Delegation of German Industry and Commerce in Kenya.

Alternative Energy Tutorials, Home of Alternative and Renewable Energy Tutorials. www.alternative- energy- tutorials.com/energy-Articles/solar-cell-i-v-characteristic.html

Eberhard A & K Gratwick (2010) IPPs in Sub-Saharan Africa: *Determinants of Success*. *MIR Working Paper*, Energyinformative.org/grid-tied-0ff-grid-andhybrid-solar-systems

ERB (Electricity Regulatory Board) (2005) *Retail Electricity Tariffs Review Policy*.

ERC (Energy Regulatory Commission) (2008). *Kenya Electricity Grid Code*.

Government of Kenya (2004) session Paper No. *4* of 2004 on Energy. *Nairobi. Government of* Kenya (2007). https://www.elsevier.com/books/distributed-energy-resources-in-microgrids/chauhan/978-0-12-817774-7

http://re.jrc.ec.europa.eu/esti/ http://www.erc.go.ke/retail-tariff.pdf.

https://energypedia.info/wiki/Publication_-_Renewables_2020_Global_Status_Report

https://greenminigrid.afdb.org/gvep-international-presentation-financing-mini-grids-east-africa-2014

https://www.esmap.org/node/57633

https://www.pv-magazine.com/2020/12/29/solarcentury-to-install-11-2-mw-of-solar-8-5-mw-battery-at-mozambique-mine/

https://www.researchgate.net/scientific-contributions/Hatem-H-Zeineldin-2113245701

https://www.tesla.com/solarpanels

IMF (International Monetary Fund) (2010) Kenya: *Staff Report for the 2009 Article IV* Consultation. Washington DC: IMF.

Jayanna Kanchikere, K. Kalyan kumar, "Proposal for 1 kW Roof-Top Solar PV Plant", International Research Journal of Engineering and Technology (IRJET), Vol. 4, Issue 7, July2017

Kefa V.O Rabah, Integrated *Solar Energy Systems for Rural Electrification in*

Kenya Vision 2030, from http://safaricom.co.ke/foundation/file admin/template/main/ downloads

Kenya_VISION_*2030*-final_report-October_2007.pdf.

Manu Kumar D. M., Ganesha T., Mallikarjunayya C. Math, "Performance and Evolution of Grid Connected to 5MW Solar Photovoltaic Plant in shivanasamudra", International Journal of Research in Advent Technology, Vol. 3, No. 1, June 2015

Mark Hankins: *"Solar Energy systems for Africa"* November 2010

NREL, "PVWatts Calculator," [Online]. Available: https://pvwatts.nrel.gov/pvwatts.php. [Accessed 2 February 2019]

Ondraczek, J., 2014. Are we there yet? Improving solar PV economics and power planning in developing countries: The case of kenya. Renewable and Sustainable Energy Reviews, 30, pp.604–615. Available at: http://dx.doi.org/10.1016/j.rser.2013.10.010.

SE4All, 2016. Sustainable Energy for All (SE4All). Kenya's Investment Prospectus. , pp.1–63.

SolarCentury, Williamson Tea 1MWp solar farm, Available at: http://www.solarcentury.com/za/wpcontent/uploads/sites/6/2014/05/Williamson-Tea-Changoi-CS-web.pdf.

www.globallegalinsights.com/practical-areas/energy-laws-and-regulations/kenya

www.irena.org

APPENDICES

Appendix I: July 2018 Electric Bill

Invoice Number: 201808DC0014983051
Supply Location: ADMINISTRATION BUILDING

CONSUMPTION DATA

Meter Number	Previous Reading	Current Reading	Reading Type	Cons.	Cons. Type
040016113631	0	96	Real	96	Demand KVA
040016113631	0	94	Real	94	Demand KW
040016113631	563873	582889	Real	19016	High Rate
040016113631	368516	378147	Real	9631	Low Rate

Consumption Period: 02/07/2018-01/08/2018
Method of Charge: C1-3 Commercial-Industrial Method CI1 - High/low rate

Appendix II: August, 2019 Electric Bill

Meter Number	Previous Reading	Current Reading	Reading Type	Cons.	Cons. Type
040016113631	0	99	Real	99	Demand KVA
040016113631	0	97	Real	97	Demand KW
040016113631	800803	823052	Real	22249	High Rate
040016113631	506052	519062	Real	13010	Low Rate

Consumption Period: 02/07/2019-01/08/2019
Method of Charge: C1-3 Commercial-Industrial Method CI1 -

CONSUMPTION TREND

Billing Concepts		Amount (Ksh)
Bill-201908BC0014150256		
Energy		
HighRateConsumption	22249kWh x 12	266,988.00
LowRateConsumption	11399kWh x 12	136,788.00
LowRateConsumption	1611kWh x 6	9,666.00
MaximumDemandKVA	99kVA x 800	79,200.00
Fuel Energy Cost	35259kWh x 3.67	129,400.53
Total Energy		622,042.53
Levies and Adjustments		
Forex Exchange Adj. (FERFA)	35259kWh x 0.0452	1,593.71
Inflation Adj. (INFA)	35259kWh x 0.25	8,814.75
ERC Levy	35259kWh x 0.03	1,057.77
REP Levy	413442 x 5	20,672.10
Warma Levy	35259kWh x 0.0169	595.88
Total Levies and Adjustments		32,734.21
Rounding Adjustment		0.10
V.A.T.	632450.99 x 0.16	101,192.16
Total Monthly Bill		755,969.00

Appendix III: Array Setup

PV Arrays Characteristics (4 kinds of array defined)				
PV module Si-mono	Model	**JKMS295M-60V Maxim**		
Original PVsyst database	Manufacturer	Jinkosolar		
Maxim integrated optimizers	Model	**MAX20800**	Unit Nom. Power	3 x 107 W
Sub-array "Sub-array #1"	In series	18 modules	In parallel	5 strings
Total number of PV modules	Nb. modules	90	Unit Nom. Power	295 Wp
Array global power	Nominal (STC)	**26.55 kWp**	At operating cond.	23.94 kWp (50°C)
Array operating characteristics (50°C)	U mpp	526 V	I mpp	46 A
Sub-array "Sub-array #2"	In series	18 modules	In parallel	5 strings
Total number of PV modules	Nb. modules	90	Unit Nom. Power	295 Wp
Array global power	Nominal (STC)	**26.55 kWp**	At operating cond.	23.94 kWp (50°C)
Array operating characteristics (50°C)	U mpp	526 V	I mpp	46 A
Sub-array "Sub-array #3"	In series	18 modules	In parallel	5 strings
Total number of PV modules	Nb. modules	90	Unit Nom. Power	295 Wp
Array global power	Nominal (STC)	**26.55 kWp**	At operating cond.	23.94 kWp (50°C)
Array operating characteristics (50°C)	U mpp	526 V	I mpp	46 A
Sub-array "Sub-array #4"	In series	18 modules	In parallel	5 strings
Total number of PV modules	Nb. modules	90	Unit Nom. Power	295 Wp
Array global power	Nominal (STC)	**26.55 kWp**	At operating cond.	23.94 kWp (50°C)
Array operating characteristics (50°C)	U mpp	526 V	I mpp	46 A
Total Arrays global power	Nominal (STC)	**106 kWp**	Total	360 modules
	Module area	589 m²	Cell area	513 m²

Appendix IV: PVGIS Curves of Admin GIS Location at 0^0, 3^0 & Optimum Tilt.