PAU
Nurturing Quality, Exemplifying Excellence
Pan African University
Institute of Water
and Energy Sciences

PAN-AFRICAN UNIVERSITY
INSTITUTE FOR WATER AND ENERGY SCIENCES
(including CLIMATE CHANGE)

Master Dissertation

Submitted in partial fulfillment of the requirements for the Master degree in

[Energy Engineering]

Presented by

Shallirosena Paschal MBWETTE

OPTIMAL DESIGN OF A PV SYSTEM FOR THE MODEL JUA HOUSE: A TYPICAL GREEN AFRICAN HOUSE

Defended on 30/09/2019 Before the Following Committee:

Chair	Nabila LABRAOUI	Dr.	University of Tlemcen
Supervisor	Yao K. AZOUMAH	Prof.	KYA-Energy Group
Co Supervisor	Alain TOSSA	Dr.	KYA-Energy Group
External Examiner	Sofiane AMARA	Prof.	University of Tlemcen
Internal Examiner	Zineb BEDRANE	Prof.	University of Tlemcen

OPTIMAL DESIGN OF A PV SYSTEM FOR THE MODEL JUA HOUSE: A TYPICAL GREEN AFRICAN HOUSE

A Thesis

Submitted to Pan African University in partial fulfillment of the requirements for the degree of Master of Science.

By

Shallirosena P. Mbwette

BSC. Electrical Engineering

Advisors:

Prof. Yao K. Azoumah (Supervisor)

Dr. Alain TOSSA

Date and Location:

31st September 2019

Tlemcen, Algeria

Approval Page

Submitted by

Shallirosena P. Mbwette	Rushalli	1/09/2019
Name of Student	Signature	Date

Approved by Examining Board

Name of Examiner	Signature	Date

Thesis/ Dissertation Advisors

Prof Yao AZOUMAH		02/09/2019
Name of Advisor	Signature	Date
Name of Co-Advisor	Signature	Date

Institute Dean

Name of Dean	Signature	Date

Pan African University

Name of Rector	Signature	Date

Dedication

This thesis is dedicated to the Jua Jamii project and team. I am grateful for the challenges and lessons learned. This is just the beginning, greater is coming.

Statement of the Author

By my signature below, I, hereby declare that the work presented herein is original work done by me and has not been published or submitted elsewhere for the requirement of a degree Programme. I submit this document in partial fulfillment of the requirement for a degree from Pan African University. This document is available from the PAU Library to borrowers under the rules of the library.

I have followed all ethical principles of scholarship in the preparation, data collection & analysis, and completion of this thesis. I have given all scholarly matter recognition through accurate citations and references. I affirm that I have cited and referenced all sources used in this document. I have made every effort to avoid plagiarism.

Scholars may use brief quotations from this thesis without special permission if they make an accurate and complete acknowledgment of the source. The dean of the academic unit may grant permission for extended quotations or reproduction of this document. In all other instances, however, the author must grant permission.

Name: Shallirosena P. Mbwette Signature:

Date: 31st September 2019

Academic Unit: Energy Engineering

PAU Institute: PAUWES

Biographical Sketch

Name: Shallirosena Paschal Mbwette

Nationality: Tanzanian

Education:

May 2015 Texas Board of Professional Engineers (TBPE), San Antonio, USA
Engineer in Training Certification

2011 – 2015 Trinity University, San Antonio, USA
Bachelor in Engineering Science: Electrical Engineering & Electronics and 3.0

2009 – 2011 Haven of Peace Academy (HOPAC), Dar-es-Salaam, Tanzania

A level: Physics, Chemistry and Mathematics.

Work/Volunteer experience

Work Experience

1. MSc, Energy Engineering intern – KYA Energy Group, Togo
2. MSc. Energy Engineering intern – The Sustainability Institute, South Africa
3. Project Coordinator for internal & external Off-Grid Solar projects implementation – Rex Energy Ltd, Tanzania
4. Assistant Project Coordinator for TZ to UG Pipeline Desktop Study & Strategic Environmental and Social Impact Assessment – Env Consult (T) Ltd, Tanzania
5. Project Coordinator Consultant – eMaktaba Project Deployment, Tanzania
6. Engineering Intern for Youth Exploring Science (YES) - Saint Louis Science Center in Missouri, USA

Volunteer:

1. Ambassador - Venture Cafe St. Louis
2. Bridge Coach - Youth Learning Center: Two Degrees
3. Practice Field Attendant – FIRST Robotics
4. Volunteer – National Society of Black Engineers (NSBE)

See most recent CV in appendix

Acknowledgements

This thesis would not have been possible without the financial support of the Pan African University research grant through the African Union Commission.

A special debt goes out firstly to, my supervisor Prof. Yao Azoumah, the Managing Director at KYA-Energy Group who agreed to my stay as an intern and provided me with the necessary tools and supervision during my internship and throughout the thesis period. Secondly to Dr. Alain Tossa, the Technical Director at KYA-Energy Group, for his technical directives and guidance. My objectives would not have been met without their knowledge and stern attitude towards working hard.

I would also like to acknowledge the staff and interns at KYA-Energy Group. I am gratefully for their valuable comments and advice on this thesis.

Finally, I must express gratitude to my family and friends for their support and encouragement throughout this intensive period.

Abbreviations and Acronyms

AC	Alternating Current
AGM	Absorbed in Microporous Material
CdTe	Cadmium Telluride
CIS/CIGS	Copper Indium Gallium Selenide (CIS/CIGS).
CV	Capitalized Value
CPB	Conventional Payback (CPB)
BIPVT	Building Integrated Solar Active Systems: Photovoltaic system
DOD	Depth of Discharge
DC	Direct Current
DGPV	Distributed Generation Photovoltaic system
DPI	Discounted Profit-to-Investment ratio
DPB	Discounted Payback (DPB)
ELF	Equivalent Loss Factor
GHG	Green House Gas
GHI	Global Horizontal Irradiance
HIT	Heterojunction Solar Modules
IPCC	Intergovernmental Panel on Climate Change
KEG	KYA- Energy Group
MPPT	Maximum Power Point Tracker
LA	Level of Autonomy
LCC	Life Cycle Cost
LCOE	Levelised Cost of Electricity
LD	Load Demand
LLP	Loss of Load Probability
LOLE	Loss of load expected
LPSP	Loss of pressure drop probability/Loss of power supply probability
NFV	Net Future value

NAV	Net Annualized Value / Equivalent Annuity
NiCd	Nickel Cadmium
NiMH	Nickel Hydride Metallic
Net ZEB	Net Zero Energy Building
NFV	Net Future Value
NPV	Net Present Value
PV	Photovoltaic
SOC	State of charge
TEL	Total Energy Loss
VRLA	English Valve Regulated Lead Acid Battery

Table of Contents

List of Tables

List of Figures

Abstract

In the wake of the current global energy crisis, the African continent is lagging behind with tremendous challenges in energy security and energy efficient buildings. The continent needs a wakeup call and a shift to a new paradigm of smart energy use (Solar Decathlon, 2017).

Renewable energy powered and self-sustainable buildings should be part of Africa’s new construction. In the scope of the Solar Decathlon Africa, a model of such green and self-sustainable building is under construction by PAUWES students, Team Jua Jamii. This study presents an intuitive and numerical methodology to perform the sizing and optimization of the model Jua House PV system. The purpose is to find a suitable configuration, among a set of system components and technologies, and solar decathlon rules, that meets the load requirement at the lowest cost. A 27.615 kWh/day PV load of the Jua House was split between day time load of 9.460 kWh/day off grid assembly and night time load of 18.178 kWh/day grid tied assembly. The system was sized based on the KEG-Method mathematical model and then programmed on MATLAB Simulink environment to simulate the behavior, and numerically find an optimal combination of PV array and battery in terms of the techno economic parameters: LLP, TEL, SOCmin and LCOE. The results for off grid assembly (day time load) optimization showed that the optimum configuration obtained using 17 of 270 Watt Almaden Poly SAP60T PV module, 4 of 220Ah 12V Victron Energy Gel battery, and one Infinisolar V-5K-48 Inverter technology provided for the desired system reliability (LLP = 0), with the lowest LCOE of 0.727 $/kWh (413.4179 FCFA/kWh) and a SOCmin of 37.2%. The results for grid tied assembly (night time load) optimization showed that the optimum configuration obtained using 21 of 250 Watts Panasonic HIT PV module, and one Infinisolar V-5K-48 Inverter technology provided for the desirable system reliability (LLP = 0), with the lowest LCOE of 0.0802$/kWh and energy to the grid of 5296kWh. Consequently, the entire system contains 9.840 kW PV Capacity, an emergency storage of 880Ah at 12V, and a 10kW inverter capacity. All at a total cost of $21406.5, which is $11541.7 lower than the non-optimized system. System optimization has reduced the total cost of the Jua House PV system by 35% and insured the desired system reliability, LLP of 0.

Keywords: PV Optimization, techno economic parameters, green energy, system reliability

Shallirosena P. Mbwette

1. INTRODUCTION

1.1. Background

According to the Intergovernmental Panel on Climate Change (IPCC), global warming is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and oceans have warmed, the volume of snow and ice have diminished, and the sea level has risen. In 2010, the global indirect anthropogenic GHG emissions were about 25.6% of total GHG emissions. Those emissions are related to electricity and heat production, and thus indirectly to electrical appliances utilization. Furthermore, in low and middle-income countries, residential energy consumption is high and intensity has been increasing. With this increasing emission of greenhouse gases, along with the depletion of fossil base energy resources and the rise in the recent global population, energy efficiency is taking a leading role in recent debates on residential building technology. Although the energy consumption of buildings varies according to factors such as social differences, climate, geographical location, and cultural habits, it is estimated that around 40% of the annual energy consumed in the world is used in the buildings today. Based on all these reports, over the last century, increasing effort has been put into the development of energy efficient design (HARPUTLUGİL, 2017).

One of the most prominent developments of the 19th century was the Industrial Revolution, space craft requirements, electric energy grid and mass production. Prior to the 20th century the main concepts in energy efficiency in buildings were designed with climate and passive design systems. In this context, energy efficiency and comfort could be provided based on criteria such as location, orientation, shape of the building, shading according to other buildings and landscape, building envelope, heat conservation, moisture movement, and cooling based on natural ventilation. The systems used were a reflection or development of past experiences (HARPUTLUGİL, 2017).

Starting in the early 2000’s came the concept of Net-ZEB, net zero energy buildings. In 2008 the international energy agency launched the project “Towards Net Zero Solar Energy Buildings” to develop a common international understanding and consensus of the term Net-ZEB. (François Garde, 2014). In simple terms, a Net ZEB is a low energy consuming building through the use of renewables on site. In order to achieve Net-ZEB, two goals have to be achieved: First off, the reduction of building energy demand through passive solutions and energy efficient systems. Secondly, the generation of energy by renewables.

Nevertheless, Energy efficiency in Africa is still generally low, both at the industrial, transport and domestic level. However as higher energy efficiency is usually linked with higher productivity and production technologies are usually linked with energy, hence energy efficiency points towards lower cost incurred. With this more efficient based energy projects are being pursued in Africa (UNIDO) such as the Team Jua Jamii project.

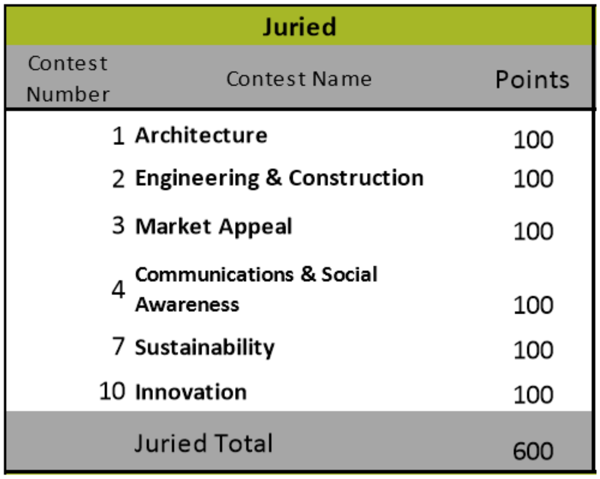
This study focused on energy efficiency through the generation of energy through renewables for the model Jua House: A typical green African house.

1.2. Problem Statement and Motivation

On the other hand, even with all these improvements and in the wake of global energy crisis, the African continent is still lagging behind with tremendous challenges in energy security and energy efficient buildings. The continent needs a shift to a new paradigm of smart energy use (Solar Decathlon, 2017). In the scope of the Solar Decathlon Africa, a model of such green and self-sustainable is under construction by PAUWES students, Team Jua Jamii.

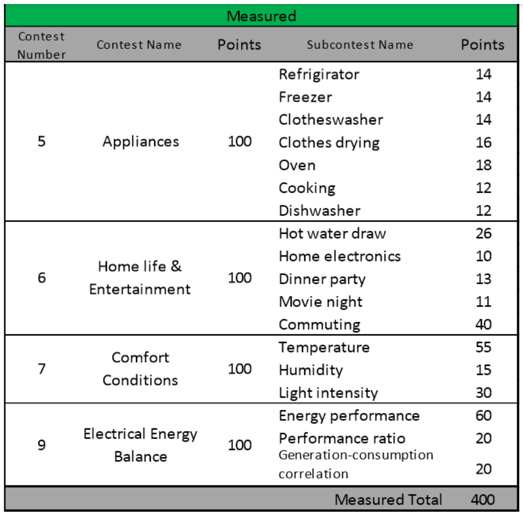
The international Solar Decathlon competition also known as Solar Energy Olympics, is sponsored by the U. S. Department of Energy, for colleges and universities globally, to participate in building with solar power technology. The purpose of solar decathlon is to accelerate the teaching, research integration and exchange of solar energy industry to promote the innovation and development of the wide range of application for solar technology. (Li, 2015) December 2017, marked the first solar decathlon Africa, opening integration and exchange of the African solar market and local know how within African institutes/industries and the global landscape.

The Solar Decathlon Africa will judge the performance of the model greenhouse based on the following contest.



Juried		
Contest Number	Contest Name	Points
1	Architecture	100
2	Engineering & Construction	100
3	Market Appeal	100
4	Communications & Social Awareness	100
7	Sustainability	100
10	Innovation	100
	Juried Total	600

Figure 1 Juried Contest, source: (SDA, 2019)



Measured				
Contest Number	Contest Name	Points	Subcontest Name	Points
5	Appliances	100	Refrigirator	14
			Freezer	14
			Clotheswasher	14
			Clothes drying	16
			Oven	18
			Cooking	12
			Dishwasher	12
6	Home life & Entertainment	100	Hot water draw	26
			Home electronics	10
			Dinner party	13
			Movie night	11
			Commuting	40
7	Comfort Conditions	100	Temperature	55
			Humidity	15
			Light intensity	30
9	Electrical Energy Balance	100	Energy performance	60
			Performance ratio	20
			Generation-consumption correlation	20
			Measured Total	400

Figure 2 Measured and sub Contest, source: (SDA, 2019)

1.3. Objective

The objective of this study in relation to the solar decathlon is to design an optimized PV system for the Model Jua House, in respective of the Engineering & Construction, Appliances and Electrical Energy Balance contest requirements.

1.4. Research Questions and Working Hypothesis

I. Can a building or residential energy demand be reduced through the use of efficient technologies?

II. Does optimization reduce the overall cost and increase reliability of a PV system?

Working Hypothesis: An optimized PV system for innovative energy efficient and self-sufficient smart African house will reduce load consumption, minimize overall cost and improve system reliability.

1.5. Previous works

Recently, different works related to PV system sizing and optimization have been implemented to find the best and optimal design. Tamer et all, proposed the optimal sizing of standalone photovoltaic (PV) system based on the optimal sizing of PV array and battery storage. A range of PV array area were selected considering LLP, PV array energy output, and load demand. A MATLAB fitting tool is used to fit the resultant sizing curves in order to derive general formulas for optimal sizing of PV array and battery. (Tamer et all, 2011,). Li, proposed a generic algorithm that uses time series to optimize the size of PV and the battery system by adjusting the battery charge and discharge cycles using available solar resources and time of use tariff structure. Like this study, houses without preexisting solar systems are considered.(Li, 2019). Khaled Bataineh, developed a computer program to simulate the PV system behavior and to numerically find an optimal combination of PV array and battery bank for the design of stand-alone photovoltaic systems in terms of reliability and costs. Moreover, economic parameters were assessed using the program by calculating the life cycle cost and annualized unit electrical cost. (Khaled Bataineh, 2012). Elsheikh Ibrahim, developed a system based on a clear sky model for global solar prediction in Sudan. Jordan and Liu model for solar energy incident on a tilt surface was utilized for PV panel tilt angle optimization. The stored energy in a storage battery was defined as equal to the difference between the load power and PV array generated power(Elsheikh Ibrahim, 1995).

Moreover, from literature review, it is apparent, that even with the strides in the field, more needs to be done for seamless incorporation of renewable energy innovations, as they become cost effective. Furthermore, very little research and implementation of energy efficient and self-sufficient building is done in Africa. Therefore, the current study will create and contribute to the development of green and energy self-sustainable building in Africa.

1.6. Significance of Study

This study looks at how to improve the sizing of the previously sized photovoltaic system of the Jua house as a whole rather than on component level only. The appliances are carefully studied and chosen and then the PV module, battery and inverters are studied with a focus on their operation within a system. This facilitates the effective selection of a system that is in conformity with the solar decathlon competition rules, and economically and technically sound.

1.7. Thesis Organization

The paper is organized as follows. Section 2, illustrates the study of PV systems and its components. In section 3, characteristic of the study, including the steps taken, components selected, equipment sizing, calculations needed, as well as the MATLAB program created will be presented. In section 4, the results from the methodology, section 3, will be presented and discussed. Finally, section 5 will provide the conclusion and recommendations.

2. GENERALITIES IN PV

2.1. Introduction

This study will focus on energy efficiency through the generation of energy through renewables.

A photovoltaic system (PV) is a set of interconnected components, which are tailored depending on the needs of the location of the system installation. Each location has different environmental aspects. These aspects affect the type of system, chosen components and level of performance. According to Balfour in the book, Introduction to photovoltaic system design, PV systems include the followings (Balfour, 2011):

1. The solar resource: sun
2. Photovoltaic Modules
3. Battery
4. Inverter
5. Charge controller
6. Electrical load
7. Wiring
8. Surge protectors

2.2. Photovoltaic Classification

Today, there are many ways of implementing PV systems in residential buildings power systems. Nowadays, photovoltaic systems are highly customizable. Some systems are needed only during daylight hours. Others, called standalone systems, use an energy storage device to store solar energy for use at night or on cloudy days. There are grid-tied systems that can use batteries for backup during outages. There are also grid-tied systems that do not use batteries at all. However, when the grid goes down, the system shuts off until the grid voltage returns. The ability to design each system installation, based on site needs, helps minimize equipment costs. Custom PV systems also guarantee that users' energy needs will be met effectively (Pearsall, 2016, p. 9).

The following is a list of the major options:

- Stand-alone PV system,
- Grid-tied PV system,
- Hybrid PV system.

2.2.1. Stand Alone PV Systems

Stand-alone PV systems can be defined as systems that are not connected to the public grid. The system comprises of PV modules with or without batteries for energy storage depending on the application. Charger controller is utilized in the presence of a battery to regulate and control the battery state of charge. It controls the charging and discharging of the battery bank, by allowing a complete charging while removing any risk of overcharging by interrupting the power supply if state of discharge/charge is less or above threshold of protection. A standalone PV system must have enough electricity to cover the needs of its applications, and some storage for use during periods of unpredictability and fluctuations for systems with constant supply. They can be divided as follows: with direct current (DC) load, with alternating current (AC) load or both.

2.2.2. Grid Connected PV Systems

Grid connected PV systems can be defined as systems that are connected to the grid by the use of inverters. The system comprises of building integrated Photovoltaic systems, (BiPV) and distribution generation Photovoltaic systems, (DGPV) systems. BiPV systems usually supply energy to a specific load and the excess to the grid. On the other hand, the GDPV systems supply their entire production to the grid without supplying to any local load. (Eltawil & Zhao, 2010).

The sizing of BiPV system depends on the specific load and grid demand, while the sizing of DGPV depends on the grid demand, amount of power to be supplied to the grid. Nevertheless, in most of the research, the primary sizing focus is on PV array size, tilt angle, orientation and inverter size. As a matter of fact, the inverter’s rated power must be matched with the PV array power through the inverter power ration factor, to achieve maximum PV array output.

2.2.3. Hybrid PV Systems

Hybrid PV systems can be defined as systems that comprise of PV arrays and two or more energy resources. This helps to alleviate site logistic barriers and system equipment costs limitations incurred when PV arrays are the only energy source. The most common hybrid systems include diesel generators; though, wind turbine systems are increasing in popularity, as well as small or micro hydro systems. Moreover, it is possible to combine all these sources into one system, for constant high quality supply.

2.2.4. Conclusion

For this study focus will be on Grid connected BiPV systems that supplies the daily load requirement and inject the excess energy to the grid and emergency battery, to be later retrieved for use during the absence of solar. This system will come with a stand-alone PV system assembly option/design, with DC and AC loads, and smart grid interaction design. The smart grid interaction allows for net metering; for excess energy to be fed to the competition grid and consumption from the competition grid if offset by an equal or greater amount of energy produced. The system will come incorporated with an emergency management storage system not exceeding 5kWh, as per solar decathlon competition requirements.

2.3. Photovoltaic System components

The primary components in a grid connected or stand-alone PV system are: PV Modules, regulator, batteries, and the inverter.

The following section will briefly introduce these components and outline the conventionally used PV components.

2.3.1. Solar Photovoltaic Modules

Solar cells are very small, less than a square inch in size or up to six or eight inches' cells cut from a boule or ingot. Voltages and amperage depend on technology type, size, and application design. A set of solar cells forms a solar module or panel. Modules come in different sizes, voltages, amperages, and DC wattages(Balfour, 2011).

There are three main generation of solar modules technology:

2.3.1.1. First generation: silicon wafer technology

a. Monocrystalline & Polycrystalline silicon

This generation is one of the most commonly used today, with silicon as its base material.

Monocrystalline silicon has an orderly atomic structure. This makes the material predictable with an efficiency rate of less than 15 percent to over 21 percent. It is also easier to use. The downside of is that it is expensive to make. The manufacturing process is slow and precise to create a predetermined and orderly cell structure. On the other hand, polycrystalline silicon has a less orderly cell structure. It is less expensive to make than crystalline silicon. Carrier flows are blocked in multi-crystalline silicon. This reduces cell performance and allows higher energy levels in the forbidden gap. Multi-crystalline silicon cells have an efficiency rate of 13 to 16 percent.

2.3.1.2. Second generation: thin films technology

Second-generation solar cells are usually termed, thin-film solar cells, the substrate used for thin-film cells is commonly glass. Thin film solar cells' substrate can take any shape or size, and is coated with a semiconductor. Only same-size cells can be strung together, so the most common shape is rectangular. Their cells are monolithically connected during the layering and coating processes. This differs from the soldering technique used for crystalline cells. You do not refer to thin-film solar cells as cells and modules. They are referred to as raw modules.

There are generally three types of solar cells that are considered in this category:

- Amorphous silicon, the most prevalent
2. Cadmium telluride (CdTe), and copper indium gallium selenide (CIS/CIGS).
3. Third generation: high efficiency concentrator solar cells

2.3.1.3. Intermediate Generation

In 1990, the scientist at SANYO introduce a Hybrid HIT cell, as an improvement to the classic monocrystalline cell. This heterojunction with intrinsic thin layer consist of monocrystalline wafer coated with thin amorphous silicon. The result proved for a more efficient solar cell, in terms of indirect light absorption and working at higher temperatures. Recently, HIT is one of the fastest growing technology in the market with proven higher efficiencies. In March 2016, Panasonic set the record for efficiency of a solar module in commercial size with a panel of 275W (aperture area of 1.1562 m^2) (Panasonic, n.d.).

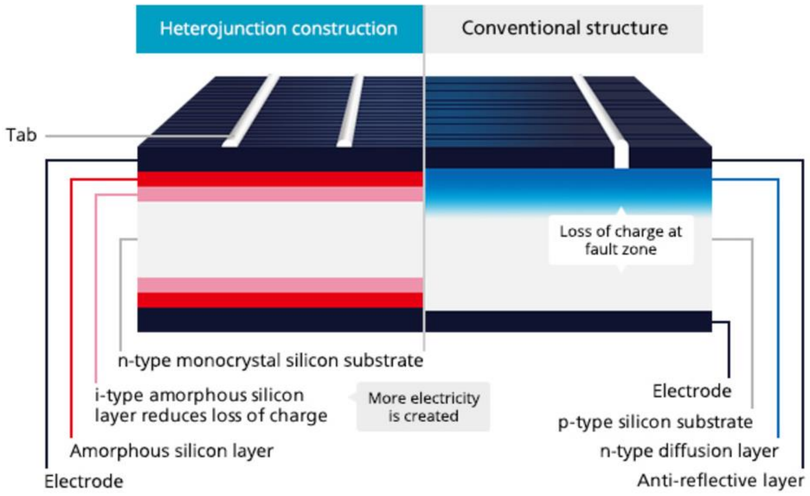


Figure 3 Heterojunction Vs Convention first generation module technology Source: Panasonic Global.

2.3.1.4. Third generation

Third generation approaches to photovoltaics (PVs) aim is to achieve more efficient, useful and less expensive solar technology, by still using thin-film, second-generation deposition methods. Currently, most of the works of the third generation PV technology lies in the laboratory. This new generation is being made by a variety of materials besides silicon. The purpose of this generation's works is to make solar more efficient, useful and less expensive.

Below are examples of the types being developed in this category:

a. Organic solar cells
b. Dye sensitized solar cells
c. Nanostructures solar cells
    i. Perovskites
d. Multijunction, multi-multiplejunctions solar cells

2.3.1.5. Efficiency and Cost Relationship

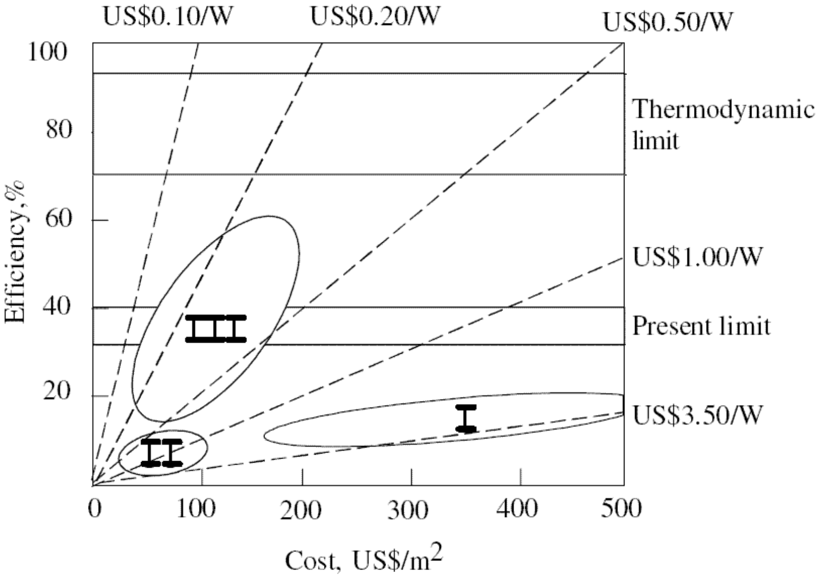


Figure 4 Efficiency/Cost relationship Of the Three PV Generations(Conibeer, 2007, fig. 1)

For most applications, silicon based PV solution is usually the best option, as these technologies provides the right balance of efficiency and price as seen on the figure 5 above.

Recently, with the introduction of HIT module's, according to, The National Renewable Energy Laboratory, NREL, as seen in Figure 5 below, Hybrid Heterojunction are taking the front center as their efficiency surpasses the other generation. Currently, University of New South Wales, UNSW HIT module is the highest and most efficient technology holding the world record.

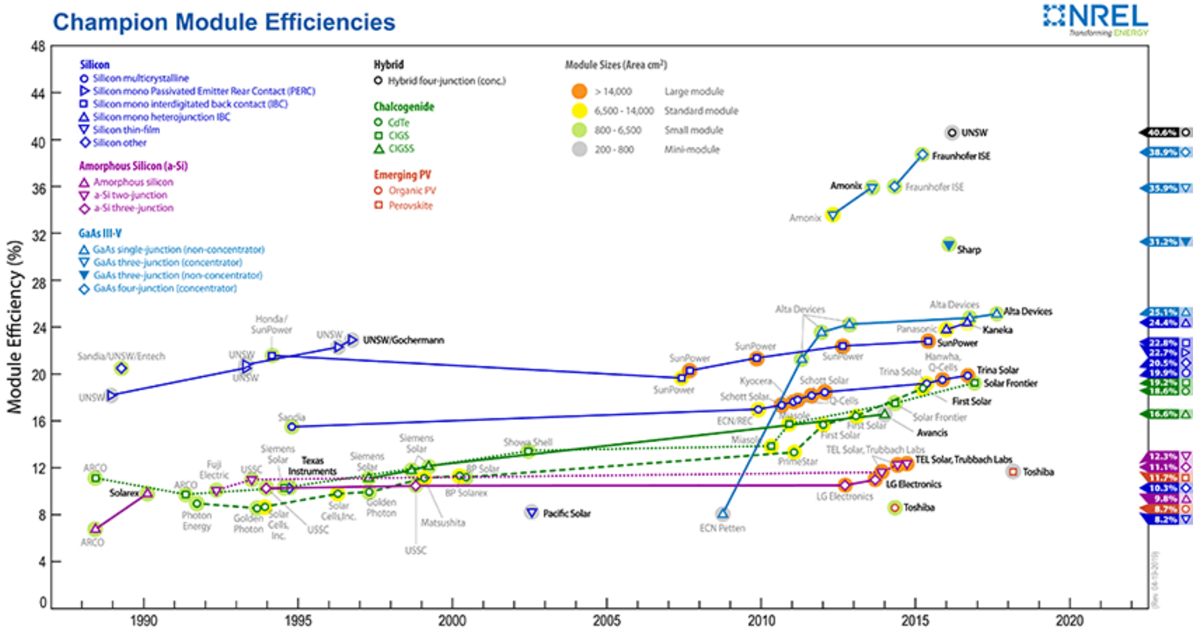


Figure 5 Nrels' chart for module efficiency- "This plot is courtesy of the National Renewable Energy Laboratory, Golden, CO”

2.3.1.6. PV Module Technology Selection

In this study, the following are the criterions for choosing the PV technology: ease of availability, time test technology and efficiency.

Table 1 PV Module Technology Selection

Generation	Ease of Availability	Time tested Technology	Efficiency
First	✓	✓	✓
Intermediate	✓	✓	✓
Second		✓	
Third			✓

Therefore, the chosen PV module technology for this study were:

1. First Generation: Polycrystalline &Monocrystalline
2. Intermediate Generation: HIT

Due to criteria for choosing the PV type, the third generation modules will not be included, as they do not fit the criteria. The system will be sized using above selected technologies and an optimal design will be chosen depending on the defined optimization criteria of entire PV system.

2.3.2. Inverter

The fundamental part of a PV system is inverter. Generally, they are the principal cause of breakdown of large scale PV systems (Dogga & Pathak, 2019). An inverter is a device that is used to convert direct current, DC into usable appliance and grid-suitable alternating current, AC.

For this study the following are the main categories of PV inverter studied:

I. Standard String Inverter
II. Micro Inverter
III. Battery Inverter
IV. Hybrid Inverter
V. Grid-tied Inverter
VI. Off-Grid Inverter.

Table 2 Inverter technology comparison

Inverter	Pros	Cons
Hybrid	• More seamless, cost-effective and all in one solution • Flexibility to install a solar battery at a later date, if necessary • Intelligent and programmable	• Less efficient as they perform two integral function, • Less design flexibility
Grid-Tied	• Time-tested technology • Countless product options available	• Dependent on the state's rule on grid tied connections
Off-Grid	• Energy independence • built-in AC charger option, that not only allows you to connect a backup generator, but also charge a battery	• Deciding to go off grid is a costly procedure with future implications • Invest in a diesel generator which can be extremely costly,

2.3.2.1. Inverter Technology Selection

In this study, the configuration of the PV system is already defined by the competition requirements, as a standalone PV system with grid compatibility, a hybrid inverter will be used to design the optimum PV configuration.

2.3.3. Regulator or Controller

The role of a controller is to control the battery state of charge. It controls the charging and discharging of the battery bank, by allowing a complete charging while removing any risk of overcharging by interrupting the power supply if state of discharge/charge is less or above threshold of protection. Nowadays, the controller comes built in with the inverter. It can be found in battery based, off grid and hybrid inverter.

2.3.4. Energy Storage - Battery

The battery is an example of a common electrochemical energy storage. Electrochemical storage systems are the most commonly used today(Jossen, Garche, & Sauer, 2004). They convert electrical energy into storable chemical energy by use of an electrical-chemical converter. In case of need, the stored chemical energy is converted into electrical energy by the chemical-electrical converter. The converters are electrochemical cells. The power is determined by the electrochemical cells and the capacity by the storage unit (Jossen et al., 2004).

2.3.4.1. Main Characteristics of batteries

The following are the main characteristic of batteries:

a. Capacity - The capacity of a battery in amp hour (Ah) is defined as the product of the intensity in Ampere (A) of the current it delivers and the duration in hours (h) during which the intensity is debited.
b. Cutoff voltage - This is the minimum voltage allowed. It is this voltage that usually defines the "empty" state of the battery (MIT Electric Vehicle, 2008).
c. Nominal capacity - This is the total number of ampere hours (Ah) available when the battery is discharged with a certain discharge current (specified as a C / time rate, the time in hours) of the state of charge at 100% at the breaking voltage (MIT Electric Vehicle, 2008).
d. State of Charge (SOC) - It shows the real-time capacity of the battery as a percentage of its rated capacity.
e. Rated voltage - This is the signal or reference voltage of the battery, sometimes also considered as the "normal" battery voltage (MIT Electric Vehicle, 2008).
f. The depth of discharge (DOD) - This is the percentage of energy delivered by a battery in relation to its rated capacity. An over 80% discharge of DOD is called a deep discharge (MIT Electric Vehicle, 2008).
g. Cycle holding - Cycle resistance is the number of cycles that the battery can sustain before it deteriorates.

a. Energy efficiency - The energy efficiency of a battery is the amount of energy that can be used as a percentage of the amount of energy needed to store it (MIT Electric Vehicle, 2008).
b. Self-discharge - Self-discharge is the loss of the capacity of the battery at rest.

2.3.4.2. Categories of Solar PV Batteries

In photovoltaic, common commercially accessible electrochemical batteries systems can be divided to the following basic groups:

I. Standard batteries (lead acid, Ni-Cd),
II. Modern batteries (Ni-MH, Li–ion, Li-pol),
III. Special batteries (Ag-Zn, Ni-H2),
IV. Flow batteries (Br2-Zn, vanadium redox) and
V. High temperature batteries (Na-S,)

2.3.4.3. Commonly used Batteries in PV

Table 3 PV system commonly used battery technology

Battery Type	**Characteristics**
Lead Acid	• Most commonly used in PV installations and Low cost. • Reliable. Over 140 years of development. • Typical cycle life is 300 to 500 cycles. • 50 – 95% discharge/charge efficiency • Heavy and bulky, danger of overheating during charging
Ni-MD	• Typical cycle life is 3000 cycles. • Can be deep cycled. (80% to 100% DOD) • 66 – 92% discharge/charge efficiency • Environmentally friendly (No Cadmium, Mercury or Lead) • Much safer than Lithium based cells due to the use of more benign active chemicals
Lithium Ion	• Fastest growing battery type in the consumer • Long cycle life. 1000 to 3000 deep cycles. • 80 – 90% discharge/charge efficiency • Stability of the chemicals has been a concern in the past as lithium is more chemically reactive

2.3.4.4. Selected Battery Technology

In this study, the following are the criterions for choosing the battery technology: ease of availability, time test technology and efficiency.

Table 4 PV Module Technology Selection

Generation			
	Ease of Availability	Time tested Technology	Efficiency
Lead AGM	✓	✓	✓
Lead GEL	✓	✓	✓
Lithium Ion	✓	✓	✓
Ni-MD			✓

Therefore, the chosen battery technology for this study were lead acid and lithium ion.

2.4. Photovoltaic system sizing techniques

2.4.1. Introduction

The sizing of a PV system must be designed to meet the load requirement. There are two main paradigms for optimal designing and sizing of photovoltaic systems. First, the system can be designed such that the generated power and the loads, that is, the consumed power, match. A second way to design a photovoltaic system is to base the design on economics. (Reaz Reisi & Alidousti, 2019). Many sizing methods for PV system can be found in the literature. According to (Tamer Khatib A. M., 2013), the methodology of sizing can be the same for standalone, hybrid and grid connected PV systems depending on the nature of the system. Below are the four major PV system sizing techniques:

A. The intuitive,
B. Numerical (simulation based) and,
C. Analytical methods,
D. Other methods:
    - Artificial Intelligence
    - Hybrid

2.4.2. The Intuitive

The intuitive method is defined by Sidrach-de-Cardona & López, 1998, as a basic calculation based on experience, of the size of the system done without establishing any connection between the different subcomponents, nor the intermittence nature of solar radiation. This method is sometimes based on the lowest monthly average of solar energy (worst month method) or the average annual or monthly solar energy. With this, this method may lead to over/under sizing of the PV system and may result to unreliable and cost intensive system. Moreover, as seen from (Tamer Khatib A. M., 2013) literature review that the security of such systems is not very well defined.

2.4.3. Numerical (Simulation based)

According to Tamer et all, 2013 a system simulation is used for this technique. In this, the energy balance of the system and the battery state of charge is calculated, for each day or hour considered. Furthermore, this method can be subdivided into deterministic and stochastic methods. The former, uses daily averaged solar data and load requirement whereas the latter, takes into account the fluctuations of solar radiation and the load requirement by simulating hourly data. This method relates the available solar radiation, load requirement and energy of the battery bank, to size PV solar systems. Compared to the first intuitive method, the numerical method is more accurate and reliable. System reliability is defined as the load percentage satisfied by the photovoltaic system for long periods of time. This method allows for better optimization of the energy in a cost effective manner (Tamer Khatib A. M., 2013).

2.4.4. Analytical methods

For this technique, equations are used to determine the size of the PV system as a function of reliability. With this method it is very easy to calculate the size of the PV system, but the difficulty comes to determining the equation coefficients, which are location dependent. The Analytical methods are usually based on the probability of pressure drop (LPSP), defined as the ratio between the estimated energy deficit and the energy demand on the total operating time of the installation. Sizing methods of this type are frequently used in applications where high reliability is required.

2.4.5. Other method

The remaining techniques are the artificial intelligence and hybrid technique.

The artificial intelligence technique is becoming useful as alternate approaches to conventional techniques or as components of integrated systems. AI techniques have the following benefits: can learn from examples; are fault tolerant; are able to deal with non-linear fluctuation of energy resources; and once taught can perform prediction and generalization at high speed. (Mellit, Kalogirou, Hontoria, & Shaari, 2009) Sometimes, the AI technique is employed to simplify the analytical method, as shown in a part of the reviewed researches in Tamer Khatib, 2013 research work. “Additionally, AI-based sizing techniques of PV systems provide good optimization, especially in isolated areas, where the weather data are not always available” (Mellit et al., 2009). Hybrid technique combines the limitations of all the previously mentioned techniques and combines two or more techniques for an effectively optimized system.

2.4.6. Conclusion

In conclusion, the above techniques, according to Tamer et all, 2013 review findings, a PV system’s size and performance is subject to the metrological variables. And in literature, more than 63% of the works done implemented numerical method, with about 17% and 20%, employing the intuitive and the analytical, respectively. This is because of the accuracy of the numerical method as compared to the intuitive method and the simplicity of the numerical method as compared to the analytical method. While the artificial techniques have only been recently used. (Tamer Khatib A. M., 2013).

In this study a mix of both intuitive and numerical will be employed to optimal size the PV system for the Jua House.

2.5. Optimization in PV systems

From Merriam Webster dictionary, “optimization is an act, process, or methodology of making something (such as a design, system, or decision) as fully perfect, functional, or effective as possible. “ In (Khatib, Mohamed, & Sopian, 2013), the authors quotes optimization of a PV system, “as the process of determining the cheapest combination of PV array and battery that will meet the load requirement with an acceptable level of security over the expected life time.”

According Tamer et all, 2012 the size and performance of PV systems are very much dependent on the metrological variables; irradiation, ambient temperature etc. In order to optimize, one needs accurate models. From literature, there are two types of PV system models: energy flow models and current-based models. Energy flow models are utilized for PV system sizing, while current-based models are for demonstrating system control strategies. (Tamer Khatib A. M., 2012). This study will utilize an energy flow model for the sizing of the Jua House PV system. Recently, different works related to PV system sizing and optimization have been implemented to find the best and optimal design. Tamer et all, proposed the optimal sizing of standalone photovoltaic (PV) system based on the optimal sizing of PV array and battery storage. A range of PV array area were selected considering LLP, PV array energy output, and load demand. A MATLAB fitting tool is used to fit the resultant sizing curves in order to derive general formulas for optimal sizing of PV array and battery. (Tamer et all, 2011,). Li, proposed a generic algorithm that uses time series to optimize the size of PV and the battery system by adjusting the battery charge and discharge cycles using available solar resources and time of use tariff structure. Like this study houses without preexisting solar systems are considered.(Li, 2019). Khaled Bataineh, developed a computer program to simulate the PV system behavior and to numerically find an optimal combination of PV array and battery bank for the design of stand-alone photovoltaic systems in terms of reliability and costs. Moreover, economic parameters were assessed using the program by calculating the life cycle cost and annualized unit electrical cost. (Khaled Bataineh, 2012). Elsheikh Ibrahim, developed a system based on a clear sky model for global solar prediction in Sudan. Jordan and Liu model for solar energy incident on a tilt surface was utilized for PV module tilt angle optimization. The stored energy in a storage battery was defined as equal to the difference between the load power and PV array generated power(Elsheikh Ibrahim, 1995).

Moreover, economic parameters have been implemented into optimization algorithms to find the best and optimal design. Kim et al, developed a multi-criteria decision support system of the PV and STE systems using the multi-objective optimization algorithm (Kim et al., 2019). Environmental and economic parameters were assessed from the life cycle perspective and present worth method: net present value/saving to investment cost were considered as economic criteria's. Integrated multi-objective optimization (iMOO) with a genetic algorithm is used. Similarly, according to Aussel et al, a study done by, Ruiz et al. proposed a multi-objective optimization method for auxiliary service design in a coal driven power plant. Economic investment and the net present value were considered as economic criteria, together with the energy saving criterion. The problem is solved using evolutionary multi-objective optimization. (Aussel, Neveu, Tsuanyo, & Azoumah, 2018).

As it pertains to economic criteria's, Aussel et al, 2018, study determined that most studies use payback period, with a few indicating if it is simple or discounted payback period. Moreover, Net Present Value is extensively used, in particular when optimization is concerned. LCOE is commonly chosen for energy production processes and very few evaluate the internal rate of return, though commonly asked for funding purposes.

2.6. Optimization Criteria

Commonly, optimal design of a power generation system involves taking into account the technical constraints, and economic criteria's. This is because to select an optimum PV combination to meet sizing constraint, it is necessary to evaluate power reliability, system technology and economic benefits analysis for the recommended system. The following were criterion observed for this study.

2.6.1. Technical Parameters

With the widespread adoption of renewable energy resources and technologies, comes an increase in energy demands. It is well known that some of these renewable energy technologies have a fluctuating nature, including solar, it is important to design a system that meets such fluctuations.

Below are the most prevalent criteria's used to analyze the technology of a PV system. Further description can be found in Appendix C.

I. Loss of power supply probability, LPSP
II. Loss of load probability, LLP
III. Loss of load expected, LOLE
IV. Equivalent loss factor, ELF
V. Total energy loss, TEL
VI. Level of Autonomy, LA
VII. State of charge of a storage battery, SOC

2.6.2. Selected Technical criteria

As LPSP, LLP, LA and LOLE lead to the same decision, LLP was utilized in this study to represent the same decision.

Therefore, the following were the selected technical criteria for analysis and system optimization:

I. Loss of load probability (LLP)
II. Total energy loss (TEL)
III. State of charge of a storage battery (SOC)

2.6.3. Economic Parameters

According to Aussel et al, In a project or study, there are mainly three activities to be considered(Aussel et al., 2018, pp. 494–499):

- Investment activity – cash flow is defined as the difference between the inflows (subsidies, grants, etc.) and the capital expenditures (CAPEX)
- Operational activity – cash flow is defined as the difference between incomes and the expenses linked to the operation of the system/project (OPEX).
- Finance activity - the cash flow includes the debt reimbursement and the dividend

In engineering projects such as energy projects, the investment and operational activities are the main activities considered (Aussel et al., 2018, pp. 494–499).

Economic criteria are generally classified into four large families. The following table lists out the classifications:

Table 5 Economic parameters for PV system sizing

Classification	**Further description**	**Main Criteria's**
Net present value method	Discount rate	Net present value (NPV), Net future value (NFV), Net annual value(NAV), Capitalized value (CV), lifecycle cost (LCC)
Rate of return method	Rate of return	Internal and External Rate of return,
Economic ration method	Benefit in relation to investment	Profit/Investment DPI, Cost/Benefit, Levelised Cost of Electricity (LCOE)
The payback method	Minimal time to recover initial investment	Conventional (CPB) and Discounted payback period (DPB)

Further study on the main economic criteria's can be found in Appendix C.

Inflation rate - the rate at which prices increase over time, resulting in a fall in the purchasing value of money.

Discount rate - Refers to the interest rate used in discounted cash flow (DCF) analysis to determine the present value of future cash flows. It expresses the time value of money and can make the difference between whether an investment project is financially viable or not.

The project is desirable and accepted if project, lifetime ≥ DPB, and otherwise rejected.

2.6.4. Selected Economic criteria

Following the above list of criteria's some of the economic criteria are considered of economically equivalence and thus marked redundant. According to Aussel et la, the economic equivalence for optimal design, is such that criteria 1 and criteria 2 are equivalent if, for any project, the optimal solutions of problem with criteria 1 are the same as the optimal solutions with criteria 2. (Aussel et al., 2018). For this study, optimal design equivalence 6, which states, "the following economic criteria are of -equivalent on the class of projects such that the initial investment and the salvage value does not depend on the physical value of the optimal solution," applies. Therefore, NPV is equivalent to NFV, NAV, CV, DPI, PI, LSR, CBC. Hence, only one can be used to represent the decision of all. As the study is the optimization of a PV system for a competition, Solar Decathlon Africa, that has already been invested in and therefore no decision of doing otherwise. There was no income generation or strategies for income generation for the Jua House Case study and thus this criterion was not relevant for this study. Consequently, all equivalent criteria's not relevant. Moreover, this same decision stood for IRR, ERR, CBP, and DPB. Hence, the following were the selected economic criteria for analysis and system optimization:

I. Levelised Cost of Electricity, LCOE

II. Life Cycle Cost (LCC)

2.6.5. Optimization criteria equations

The following are the guiding equations used for the selected criteria's:

2.6.5.1. Technical Criteria Equations

1. To find the Loss of Load Probability, LLP the following equations are utilized,

$$LLP = \frac{\sum_t^T DE(t)}{\sum_t^T Pload(t) * \Delta t} \tag{1}$$

$$E_{net} = \sum_{1}^{366} E_{Pv} - E_D \tag{2}$$

Condition 1: $If\ E_{pv} > E_D then\ EE,$

Condition 2: $If\ E\_pv\ <\ E_D\ the\ ED$

Where for the first equation DE(t) is the deficit energy at a specific time period, Pload(t) is the load demand at the same time period, Δt is the time period for both terms.

For the second equation E_{net} is energy difference between E_{Pv}, energy produced by the PV and E_D is the total daily energy requirement. For which condition 1 is satisfied when there is extra energy generated, EE. And condition 2 is satisfied when there is an energy deficit, ED.

The recommended values of LLP for various applications are shown in the Table below

Table 6 Recommended values of LLP in Aussel et al., 2018

Application	**Recommend LLP**
Domestic	
Illumination	10^{-2}
Appliance	10^{-1}
Telecommunication	10^{-4}

According to above table, the best LLP value for domestic use is roughly between 10^{-2} and 10^{-1}. For this study the ideal optimum values will be between those 2 values.

2. To find the Total Energy Loss, (TEL) the following equation is utilized:

$$TEL = \sum_{t=1}^{T} \begin{matrix} \left(EE - E_D(t)\right) \ if \ E_D(t) < EE \\ 0 \end{matrix} \tag{3}$$

$$0 < TEL \ \leq THR \tag{4}$$

Where EE is extra energy generated, E_D is the total daily energy requirement, and THR = a is the specified threshold over the time t. Extra energy generated is sent to the grid

3. To find the battery, SOC, the following equation is utilized:

$$SOC\ (t+1) = SOC\ (t)\sigma + I_{bat}(t)\Delta t\eta\left(I_{bat}(t)\right) \tag{5}$$

Where σ is the self-discharge battery rate, Ibat(t) is the battery current which may be charging/ discharging current, Δt is the sampling time period, and η is the battery charging efficiency

2.6.5.2. Economic Criteria Equations

1. The following is a simple equation for finding the annualized life cycle cost of the system, ALCC

$$ALCC = (Ccap, a + Co\&M, a + Crep, a - Cs, a) \tag{6}$$

Where ALCC is the annualized life cycle cost, Ccap,a is the annualized capital cost, Co&M,a is annualized operation and maintenance cost, Crep,a is the annualized replacement cost, and Cs,a is annualized salvage cost.

2. The Levelised cost of electricity, LCOE, is obtained by the following equation:

$$LCOE = \left(\frac{ALCC}{LCE} = \frac{ALCC}{AEP}\right) \tag{8}$$

$$LCE = \left(\frac{AEP * (1-df)n}{\left((1-r)n\right)}\right) \tag{9}$$

$$AEP = E_D * N_{clear} \tag{10}$$

Where AEP is the expected annual energy produced, kWh, ED = the daily energy demand, kWh, N_clear is the number of clear days in a year as per location = 300, ALCC is the Annualized total life cycle cost, and AEP is the expected annual energy produced.

For the second equation the LCE is the Levelised cost of energy, n is the estimated life of the project, r represents the interest rate, and df = degraded output power yield factor will be degraded with a factor

2.7. Operating Protocol

For this study, optimization of a photovoltaic system design, is defined as optimal selection of system components size with respect to:

I. Meeting the energy demand and for grid tied, ensuring net positive or zero system,
II. Conforming to the rules of the solar decathlon Africa competition,
III. Utilization of efficient technologies,
IV. Selected techno economic parameters.

3. METHODOLOGY

The methodology aimed at finding the optimum configuration, among a set of system components and technologies, and solar decathlon rules, that meets the load requirement at the lowest cost. In this section, an intuitive and numerical method was developed for optimum sizing of the PV/Inverter/battery combination for the off grid assembly and PV/Inverter combination for the grid tied assembly of the Jua house PV system. The steps taken, components selected, equipment sizing, calculations needed, as well as the MATLAB program created will be presented.

3.1. Characteristics of the study

3.1.1. Solar Decathlon Guidelines

3.1.1.1. Rules

The relevant rules and guidelines of the solar decathlon for the PV system designs are as follows:

Rule 4: Site Operations

4-5. Electrical construction power and lighting at competition site

- Electrical power will be available on each team's lot in a specific construction box, and the provided power will be limited and monitored. Additional details on the construction site box will be provided on the project group.
- The Solar Decathlon AFRICA organization will provide access to the village grid with an electric service of AC 50 Hz, 220 V (phase-neutral), 380 V (phase-phase). All teams must design their houses with the necessary equipment to connect to the village grid.

4-8. Electric Vehicles

- Teams are expected to provide an electric vehicle within their solar envelopes during contest week.

Rule 8: Energy

8-2. PV System Size Limitation

- Photovoltaic installation size is limited to a maximum 10 kW rated DC capacity.

8-4. Energy Sources

- All other energy sources, such as AC grid energy, consumed in the operation of the house must be offset by an equal or greater amount of energy produced, or "regenerated," by the house.

- Fireplaces, fire pits, candles, and other devices using non-solar fuels are not permitted in the designs. Exception: The use of batteries is permitted by Rule 8-5.

8-5. Batteries

- The use of batteries as part of the competition prototype design is permitted. The batteries must begin the competition fully-charged and end up fully-charged.
- The maximum battery storage capacity is 5 kWh.

8-7. Village Grid

The organizers shall provide the village with an electric power grid that provides AC power to and accepts AC power from the houses.

- The organizers shall provide the necessary service conductors and connect the conductors at the utility interconnection point.
- All houses shall operate with an AC service of 50 Hz, 220/380V split-phase with neutral.

8-8. Net Metering Rules

When the competition starts, each team's bidirectional meter resets to zero.

3.1.1.2. Contests

The relevant guidelines of the solar decathlon for the PV system in respective of the Engineering & Construction, Appliances and Electrical Energy Balance state that:

Contest 2: Engineering & Construction

a. Electrical System Design and installation: design and dimensioning of the related system, as well as the evaluation of its suitability considering the house's needs. The energy efficiency approach is positively evaluated.

b. Photovoltaic (PV) System Design and installation: The jury will evaluate the functionality, technical design, implementation, and reliability of the PV system considering the following items:
I. Analysis of the Electrical Production Simulation: A detailed report about the electrical energy production of the household will be prepared based on the climate conditions of both Benguerir and site target of competition prototype house.
ii. Technical documentation of the photovoltaic installation: Quality of the solar photovoltaic system and renewables-related technologies will be assessed.

c. Building Integrated Solar Active Systems (BIPV "Photovoltaic", BIPVT "Photovoltaic and Thermal"): The Solar Active Systems' installation will be evaluated relative to its integration in the house. It will be considered that the "building integration" exists when the modules are elements of the house's composition, fulfilling dual functions at a time: produce electricity and be a component of the finished house.

Contest 5: Appliances

The objective is to evaluate the functionality and the efficiency of the selected appliances, in order to test the performance of the house while complying with the demanding standards of present day society in term of Appliances' use. Scoring will value results rather than means and it will be assessed on data collected by the organization's monitoring system during the contest week. The following table highlights the main evaluation criteria for the house appliances:

Table 7 Appliances Evaluation Criteria

Refrigerator	**1.0 C≤ Temperature ≤ 4.5 C**
Freezer	-30°C ≤ Temperature ≤ -15°C
Clothes Washer	One complete wash cycle
Clothes Drying	% of the original weight < 100
Oven	Oven Temperature ≥ 220°C
Light Intensity	Lighting Level ≥ 300 lux
Energy Performance	Net Electrical Energy ≥ 0 kwh

Contest 9: Electrical Energy Balance

The objective is to evaluate the houses' self-sufficient electricity provided by active solar technology.

Sub-contest: Energy Performance

All available points are earned at the conclusion of the specified Energy performance period for a net Electrical Energy Balance of at least 0 kWh. A positive net Electrical Energy Balance indicates net production; a negative net Electrical Energy Balance indicates net consumption.

3.1.1.3. Conclusion

Consequently, from above rules and contest requirements the PV system should function as a standalone system with storage requirements to effectively supply to the load. The storage requirement for the system under this study will be sent to the battery for management of fluctuations during the day not more than 5kWh, and sent to the grid for production during the absence of solar energy.

3.1.2. Project Location Details

The Jua house will be located at the Solar Decathlon Africa competition site in Morocco, Ben Geurri. Benguerir is located at 32.23°, -7.95°.

The location has the shortest daylight in December, and the longest in June. Typical Meteorological Year (TMY) Data show that BenGuerir has the lowest irradiance (GHI) in December, peaking at around 650 W/m^2, and the highest in June, peaking at around 1100W/m^2. The peak sun height for December and June are 35° and 80° respectively. GHI in September peaks at around 950 W/m^2. The peak sun height for September is around 60°.

3.1.3. Software's chosen

The analysis of the techno economic criteria required software tools for the design, analysis, optimization, and economic viability of the systems. The research work was carried out by optimizing the Jua House PV system using MATLAB and Simulink environment. Furthermore, KYA-Sol Design was used to achieve the intuitive sizing of the off grid assembly.

3.1.4. Load Assessment and Profile

In order to properly address the load assessment, the previously proposed load consumption of the Jua House was retrieved, careful examined and updated.

This was done following the steps below:

1. System clarification from departments of the Jua House (i.e., water, mechanical and architecture),
2. Conforming to the SDA appliance requirements,
3. Selection of energy star appliances. (Consortium for Energy Efficiency. "National Awareness of Energy Star for 2016" (PDF)., 2016),
4. Appliance Hour allocation estimated from experience and chosen manufactures specification,
5. Applying the KEG method of splitting day and night loads,
6. Applying a 10% safety factor to the load, to ensure system design security for the system equipment.

3.2. System Sizing

As per the solar decathlon rules seen previously, the PV system should function as a standalone system with storage requirement to effectively supply to the load. The storage requirement for the system under this study will be sent to the battery for management of fluctuations during the day, not more than 5kWh, and sent to the grid for production during the night.

The design starts by splitting the Jua house load into daytime load and night time load. The day time load was sized as an off grid assembly and the night time load was sized as a separate grid tied assembly.

3.2.1. Grid Tied Assembly

For the Grid tied system, an excel based energy flow model based on the KEG mathematical model was developed to size and preliminary optimally choose the best performing inverter. The purpose of the grid tied system is to supply the night time load of the Jua house to the grid during the day.

The following were the steps taken for intuitive system sizing. Further detail on the guiding equation for each step can be found in Appendix E.

1. Input/Set location coordinates
2. Input Selected PV component specification
3. Input load demand
4. Input meteorological Data
5. Storage Capacity
6. Solar field Capacity
7. Grid Tied Inverter Capacity, MPPT
8. Cables and Fuses Dimensions

3.2.2. Off Grid Assembly

The off grid system was sized using the KEG Method mathematical model. The system was preliminary sized and simulated with one set of system components on KYA-Sol Design to conform with the chosen KEG Method Model. Then a program was developed on MATLAB to size the system using the KEG Method model with the same parameters as KYA-Sol Design, the output values were then compared between the MATLAB program and KYA-Sol Design.

3.2.2.1. Sizing Methodology: The KEG Method

The KEG sizing method was developed within the R & D unit of KYA-Energy Group. It results from an in-depth study of the current dimensioning methods of which it fills the gaps.

The KEG method involves 2 parts:

a. Intuitive
b. Numerical

Intuitive

This method is iterative and based on five steps, which are as follows:

1. Assessment of energy needs daily
2. Input preselected PV component technology
3. Dimensioning the Hybrid Inverter
4. Dimensioning and configuration of the PV field
5. Dimensioning and configuration of the battery bank
6. Dimensioning the cables and elements protection

Numerical

This method involves optimizing the storage coefficients of the KYA-Sol Design, namely; the daytime storage coefficient for smoothing production during the day and the storage coefficient of production for night use. Furthermore, three techno-economic criteria were considered for this optimization: LCOE, LLP and SOCmin. The optimization was done through the use of a dynamic simulator, called KEGSIM_PV, created in the Simulink environment from MATLAB R2018a to simulate the real-life behavior of PV systems autonomous. This simulator has then since been embedded in the KYA-Sol Design software package for dimensioning PV systems. The numeric analysis behind the simulator is based off Toufik Madani Layadi et al. [14], model based on the algorithm "Rainflow" which takes into account the depth of discharge (DOD) and the temperature internal batteries. Which had previously been applied to a hybrid solar photovoltaic system and now to autonomous.

3.2.2.2. Off Grid MATLAB Program sizing

A program was developed following the KEG sizing method to size the off grid system and compare the results with the ones calculated using KYA-SOL Design. The following are parameters used in the program:

Program Inputs:

I. Load Profile

II. Sizing Parameters

The following are the parameters inputs for the MATLAB sizing program

Table 8 Off Grid System Sizing Parameters

Average daily irradiation in kWh / day
Ratio of performance
Charge controller's efficiency
Inverter efficiency
Battery efficiency
DOD max battery
Battery system voltage
Battery nominal capacity Ah
Inverter type (1 for MPPT and 0 for PWM)
PV module Unit power Wc
PV module MPP Volts
PV module MPP Current
PV module nominal Volts
PV module Voc
PV Module Isc
PV Module Temp Coefficient, Pmax
PV Module NOCT
Beginning of the daytime usage range
End of the daytime usage range
Night coefficient
Daytime coefficient
Inverter Size, Pinv
Inverter MPP I
Inverter MPP V

III. Battery Depth of Discharge and the corresponding cycles

Program Outputs

I. PV module configuration

II. Battery configuration

III. Inverter size

3.2.2.3. MATLAB Program Vs KYASOL-DESIGN

The off grid MATLAB program outputs were then compared with the KYA-SOL Design. Once the output results were the same, the 10% safety factor was added then was sized and optimized.

3.2. System Optimization

3.2.1. Grid Tied Assembly

Once the intuitive results are retrieved and analyzed. The grid tied system was further sized on MATLAB with a combination of PV components from the selected technologies. A dynamic simulator called KEGSIM_GRIDSDA created in the Simulink environment from MATLAB R2018a. This simulator was used to simulate the systems hourly behavior and numerically find an optimal PV sizing in respect to LLP, LCOE and energy balance to the grid.

For this assembly, only the combination of PV module is varied for the optimization. One type of hybrid inverter is used for the sizing and optimization, so as to remain consistent with the inverter in the off grid assembly.

Program Inputs:

a) Load Profile

b) Grid tied Sizing Parameters

The following are the parameters inputs for the grid tied MATLAB optimization program

Table 9 Grid tied assembly program input parameters

Average daily irradiation in kWh / day
Ratio of performance
Charge controller's efficiency
Inverter efficiency
Inverter type (1 for MPPT and 0 for PWM)
Beginning of the daytime usage range
End of the daytime usage range
Night coefficient
Daytime coefficient
Power factor
AC voltage min
AC max voltage
AC min frequency
AC max frequency

c) Module Information

Table 10 Grid Tied program module specifications

Name	**Module Ref**	**Module power**	**Mpp Voltage**	**Mpp Current**	**Nominal operating Voltage**	**Open Circuit Voltage**	**Short circuit current**
Symbol	**Ref_mod**	**Pc**	**Vmp**	**Imp**	**Vnom**	**Voc**	**Isc**

Temp coefficient of Pmax	**Night operating conditions**	**Surface area**	**Module Price**	**Lifetime**	**Temp Coefficient of_Voc**
Kt	**Noct**	**Smod**	Pr_mod,usd	**D_mod**	**Coef_temp_Voc**

For optimal sizing the higher the PV component sets were the better. As this resulted to a more accurate and optimal design

d) Inverter Information

Table 11 Grid tied program Inverter specifications

Name	**Efficiency**	**Depth of Discharge**	**Nominal Operation Voltage**	**Nominal Capacity, Ah**	**Price**	**Lifetime**
Symbol	rend	DOD	Vnom	Cnom	Pr_bat	D_bat

Program Outputs

I. PV module configuration
II. Inverter size
III. Techno-economic parameters

3.2.1. Off Grid Assembly

Once the intuitive results are retrieved and analyzed. The off grid system was further sized on MATLAB with a combination of PV components from the selected technologies A dynamic simulator, called KEGSIM_PV, created in the Simulink environment from MATLAB R2018a, is used to simulate the behavior and numerically find an optimal combination of PV array and battery. The program calculates the LLP, TEL, SOCmins and LCOE. This method determines the optimum configuration that meets the load demand with the minimum cost and high reliability.

For this assembly, only the combination of PV module and battery is varied for the off grid system optimization. One type of hybrid inverter is used for the sizing and optimization, so as to remain consistent with the inverter in the grid tied assembly.

Program Inputs:

a) Load Profile
b) Off Grid Sizing Parameters

The following are the parameters inputs for the off grid MATLAB optimization program

Table 12 Off Grid assembly program input parameters

Average Day Irradiation in kWh
Ratio of performance
Charge controller's efficiency
Inverter efficiency
Battery efficiency
Inverter Type 1 for and 0 for PWM MPPT
Beginning of the daytime usage range
End of the daytime usage range
Night coefficient
Daytime coefficient
Inverter Size, Pinv
Inverter MPP Current, I
Inverter MPP Voltage, V
Inverter Cost

c) Module Information

Table 13 Off Grid MATLAB program module specifications

Name	**Module Power**	**Mpp Voltage**	**Mpp Current**	**Nominal operating Voltage**	**Open Circuit Voltage**	**Short circuit current**
Symbol	Pc	Vmp	Imp	Vnom	Voc	Isc

Temp coefficient of Pmax	**Night operating conditions**	**Surface area**	**Price**	**Life time**
Kt	Noct	Smod	Pr_mod	D_mod

For optimal sizing the higher the PV component sets were the better. As this resulted to a more accurate and optimal design.

d) Battery Information

Table 14 Off Grid MATLAB program battery specifications

Name	**Efficiency**	**Depth of Discharge**	**Nominal Operation Voltage**	**Nominal Capacity, Ah**	**Price**	**Lifetime**
Symbol	rend	DOD	Vnom	Cnom	Pr_bat	D_bat

For optimal sizing the higher the battery component sets were the better. As this resulted to a more accurate and optimal design

Program Outputs:

I. PV module configuration
II. Battery Size
III. Techno-economic parameters

3.2. System Cost

The following section will evaluate the total cost of the whole designed greenhouse PV system from the energy viewpoint.

3.2.1. Cost of Off Grid Assembly

The cost of the off grid system, $C_{TIC_{OFF}}$ is given by the following equations:

$$Total\ System\ Investment\ Cost = C_{TIC_{OFF}} = Ccap\ + C_{wo} \tag{11}$$

$$Ccap_{Off} = Cpv + Cinv + Cbat \tag{12}$$

$$C_{wo} = 0.26(Cpv + Cinv + Cbat) \tag{13}$$

Where $C_{TIC_{OFF}}$ is the total system investment cost for off grid system, Cpv is the total price of the PV modules, Cinv is the total price for the inverter, Cbat is the total price for the batteries, and C_{wo} is the wiring and accessories cost for the system.

3.2.2. Cost of Grid Tied Assembly

The cost of the grid tied system, $C_{TIC_{GRID}}$ is given by the following equations:

$$Total\ System\ Investment\ Cost = C_{TIC_{GRID}} = Ccap + C_{Wg} \tag{14}$$

$$Ccap_{grid} = Cpv + Cinv \tag{15}$$

$$C_{wg} = 0.26(Cpv + Cinv) \tag{16}$$

Where $C_{TIC_{OFF}}$ is the total system investment cost for off grid system, Cpv is the total price of the PV modules, Cinv is the total price for the inverter, and C_{wg} is the wiring and accessories cost for the system. There is no cost of a battery as this system does not have one.

3.2.3. Total Cost of System

The total cost of both systems is then given by the following equation

$$C_{TOT(off+grid)} = C_{TIC_{OFF}} + C_{TIC_{GRID}} \tag{17}$$

4.0. RESULTS AND DISCUSSION

4.1. Load Assessment and Profile

4.1.1. Previous Load Assessment

The following is a table of the previous load assessment done before the commencement of this study:

Table 15 Previous load assessment retrieved from Jua Jamii Electrical Department

Load Description	Qty	Power rating	Daily Usage	Energy Consumption	Energy Consumption
(Appliances/Sys Equipment)	***(No.)***	***(Watts)***	***(Hours)***	***Total Daily (Wh)***	***Total Annually (Wh)***
Fridge /Freezer	1	200	15.8	3160	1153400
Clothes Washing Machine/Dryer	1	1000	0.25	250	91250
Dishwasher	1	1050	0.5	525	191625
Cooker/Stove/Oven	1	2400	2	4800	1752000
LED bulbs	15	10	7.66667	1150.0005	419750.1825
Domestic Electric Car Charger Socket	1	3300	2.5	8250	3011250
HVAC System Pump	1	5000	4	20000	7300000
Water pump (House)	1	50	0.5	25	9125
Water Pump (Waste Water)	1	200	1	200	73000
Water Pump (Aquaponics)	1	22	24	528	192720
Air Pump (Aquaponics)	1	10	24	240	87600
Phones	7	6	4	168	61320
Computers (Laptop)	5	70	4	1400	511000
TV	1	70	4	280	102200
Total Load Points	38	13388	94.21667		
Total Energy Req. (Wh)				**Daily**	**Yearly**
				40976.0005	14956240.18

4.1.2. Previous Load Profile

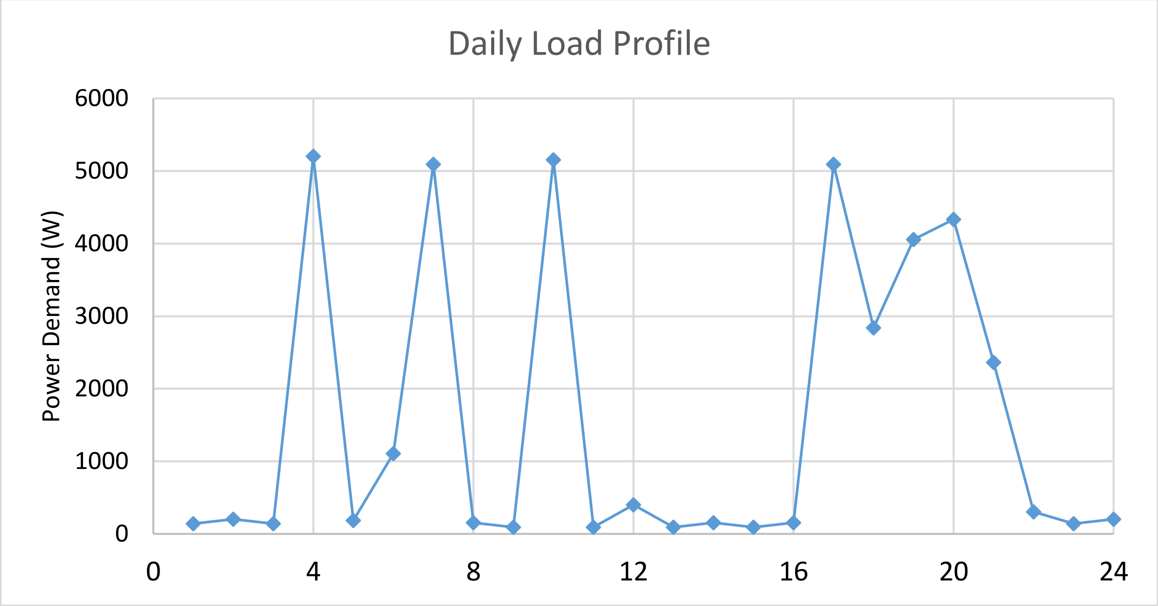


Figure 6 Generated load profile from the initial load assessment

The following load profile was constructed using the loads from the previous load assessment provided in section 4.1.1. The peak power demand is around 5100 W and happens daily at 4:00AM, 7:00AM, 11:00AM and 5:00PM. And another peak slightly lower but worth the mention occurring at 4334 W at 8:00PM. The daily energy demand was 40.9kWh.

4.1.3. Updated Load Assessment and Load Profile

Table 16 The current load assessment for the Jua House load

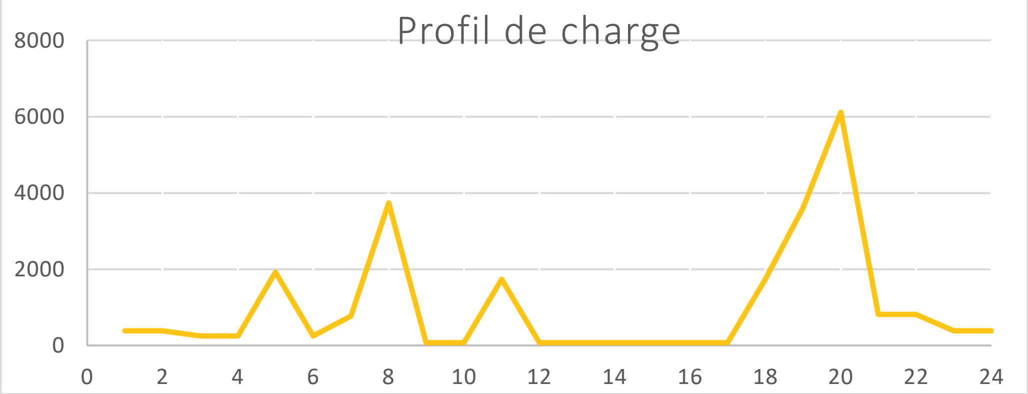


Figure 7 The current load profile for the entire Jua House load

The daily load profile was constructed using the completion rules (for appliances) and house systems equipment. The peak power demand is around 6114 W and happens at 8:00PM. There are other lower peaks at 8:00 am at 3738 W. The daily energy demand is 25.1 kWh, and 27.6kWh with a 10 % safety factor. Unlike the previous load profile seen in section 4.1.2. these profile has no surge of peaks.

4.2. System Sizing

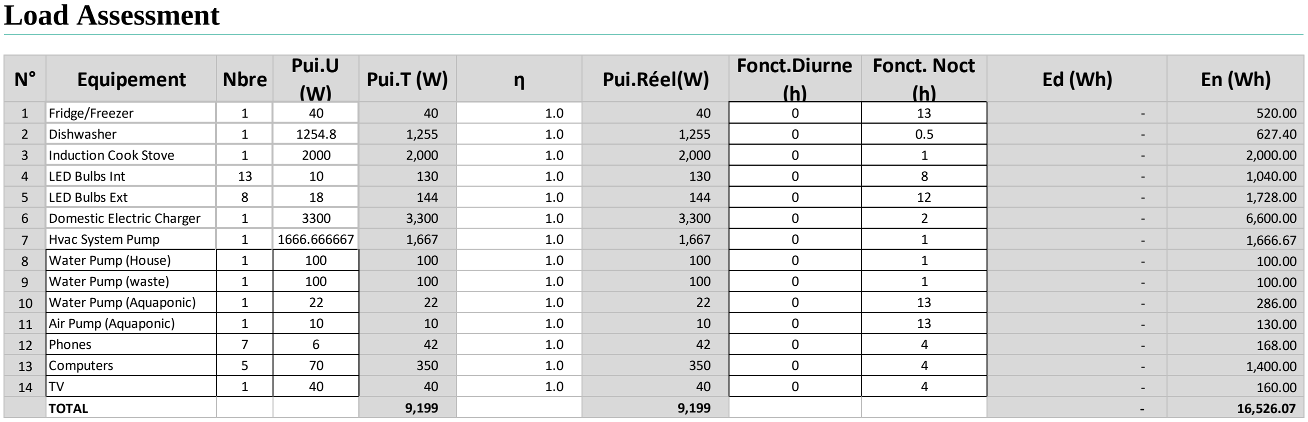
4.2.1. Updated System Design

A 27.615 kWh PV load with a 10 % safety factor for the Jua House was split between day time load of 9460 Wh and night time load of 18,178.7 Wh system, by sizing two different configurations. The day time load was sized as an off grid system and the night time load was sized as a separate grid tied system.

4.2.2. Grid Tied Assembly

In order to take into account, the night time load a grid tied system was sized. The following were the steps followed.

4.2.2.1. Grid Tied Load Assessment and profile



Load Assessment

N°	Equipement	Nbre	Pui.U (W)	Pui.T (W)	η	Pui.Réel(W)	Fonct.Diurne (h)	Fonct. Noct (h)	Ed (Wh)	En (Wh)
1	Fridge/Freezer	1	40	40	1.0	40	0	13	-	520.00
2	Dishwasher	1	1254.8	1,255	1.0	1,255	0	0.5	-	627.40
3	Induction Cook Stove	1	2000	2,000	1.0	2,000	0	1	-	2,000.00
4	LED Bulbs Int	13	10	130	1.0	130	0	8	-	1,040.00
5	LED Bulbs Ext	8	18	144	1.0	144	0	12	-	1,728.00
6	Domestic Electric Charger	1	3300	3,300	1.0	3,300	0	2	-	6,600.00
7	Hvac System Pump	1	1666.666667	1,667	1.0	1,667	0	1	-	1,666.67
8	Water Pump (House)	1	100	100	1.0	100	0	1	-	100.00
9	Water Pump (waste)	1	100	100	1.0	100	0	1	-	100.00
10	Water Pump (Aquaponic)	1	22	22	1.0	22	0	13	-	286.00
11	Air Pump (Aquaponic)	1	10	10	1.0	10	0	13	-	130.00
12	Phones	7	6	42	1.0	42	0	4	-	168.00
13	Computers	5	70	350	1.0	350	0	4	-	1,400.00
14	TV	1	40	40	1.0	40	0	4	-	160.00
	TOTAL			**9,199**		**9,199**			**-**	**16,526.07**

Figure 8 Load assessment for night time storage using KYA-SOL Design. ***Retrieved from Kya-Sol Design****.*

The following assessment was developed on KYA-SOL Design

Load Profile

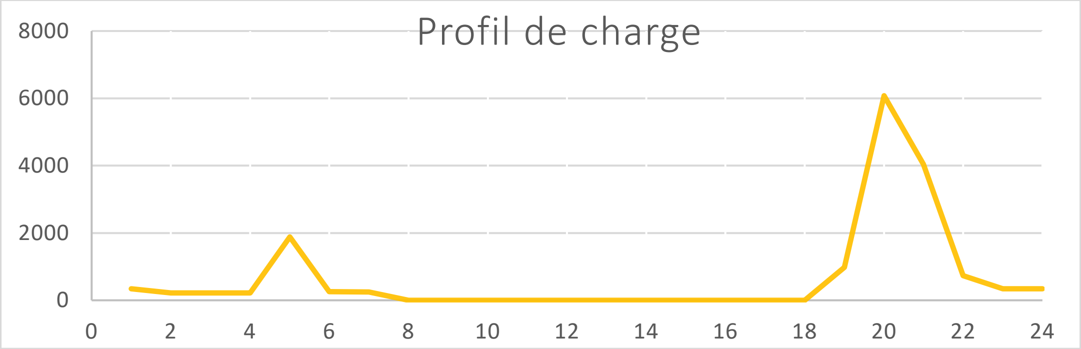


Figure 9 KYA Sol Generated Grid Tied Load Profile

The peak power demand is around 6078 W and happens at 8:00PM. And another very smaller peak worth the mention occurring at 5:00AM at 1883 W. The daily energy demand is 16.5kWh, 18.2kWh with a 10 % safety factor.

4.2.2.2. Selected PV components

Table 17 Selected PV Module for Grid Tied Sizing

Module Information

N°	Ref_mod	P,W	Vmp,	Imp	Vnom	Voc	Isc
1	Panas_HIT_VBHN250SJ25	250	44.3	5.65	24	53.2	6.03
N°	Ref_mod	Noct	Smod	Pr_mod	D_mod	Coef_temp_Voc	Kt
1	Panas_HIT_VBHN250SJ25	44	1.26	159040	25	-0.24	-0.258

Table 18 Selected Inverters for Grid Tied Sizing

Inverter Datasheet Information

Inverter reference	Rated power	Rated voltage	Maximum PV field power	VMPPmin	VMPPmax	Imax	Price_inv	Dond (in year)
Infinisolar V-5K-48	5,000	48	6000	60	115	40	814903.92	10

4.2.2.3. System sizing results

Table 19 Grid tied assembly intuitive sizing results from the excel based model

Results	
Item	**Capacity**
Load, Wh	18,178.67
Irradiation, kWh/m^2/day	5.644693164
Hybrid Inverter Capacity, W	5,000.00
Solar field capacity, W initial	5111.886062
VmaxMppInv/VMPPmodule	2.60
VminMppInv/VMPPmodule	1.35
Solar field capacity, W final	5500
PV Configuration	2*5 2*6
Fuse Link Voltage, V	122.36
Fuse Link Current, A	9.045
PV Cable/Inverter Dimension, mm^2	14.9/11.53

Infinisolar Inverter Capacity	

Grid Tied Inverter Capacity				
	Symbol	Value	Equation	Capacity
Inverter Power Factor	PF	>0.99	Ppv/Pinv	1.10
Inverter Power	Pinv	5,000.00		
Ppv field	Ppv	5,500.00		
Max Recommend PV power, W	Ppv Max	6,000.00		>0.99
Inverter Check	Ppv < PpvMax	PV is Okay		
Capacity (W)				**1.10**

Table 20 Grid tied intuitive sizing system description

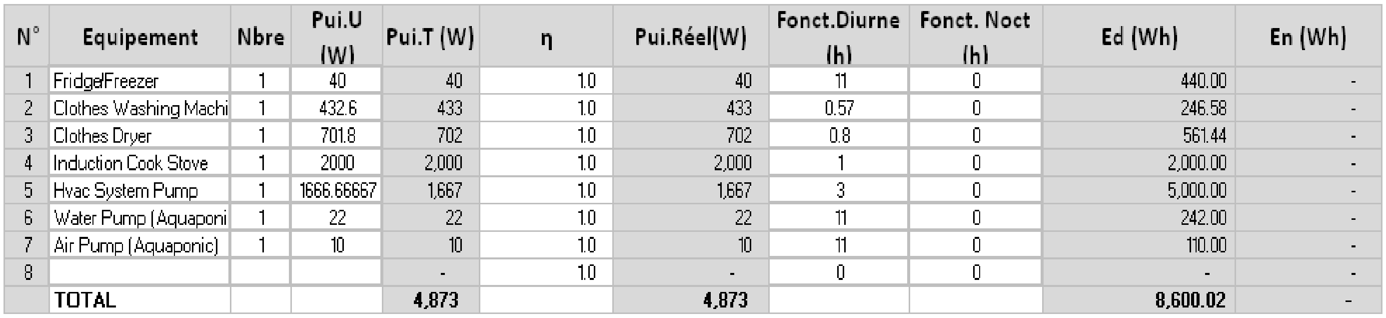
Item	Description	Quantity
Infinisolar V-5K-48	5 Kw	1
slim VBHN250SJ25 Panasonic 250Wc	250 WC	22
Selected Fuse Link	Bussmann PV-10A10F selected, 10 x 38mm	
PV/Battery/Inverter Cable		16mm^2, 61A/2.5mm^2, 21 A

4.2.3. Off Grid System

4.2.3.1. KYA-Sol Design

In order to take into account, the day time load an off grid tied assembly was sized. This system was sized using KYA-SOL Design and a profile was generated as below.

4.2.3.1.1. Load Assessment



N°	Equipement	Nbre	Pui.U (W)	Pui.T (W)	η	Pui.Réel(W)	Fonct.Diurne (h)	Fonct. Noct (h)	Ed (Wh)	En (Wh)
1	Fridge/Freezer	1	40	40	1.0	40	11	0	440.00	-
2	Clothes Washing Machi	1	432.6	433	1.0	433	0.57	0	246.58	-
3	Clothes Dryer	1	701.8	702	1.0	702	0.8	0	561.44	-
4	Induction Cook Stove	1	2000	2,000	1.0	2,000	1	0	2,000.00	-
5	Hvac System Pump	1	1666.66667	1,667	1.0	1,667	3	0	5,000.00	-
6	Water Pump (Aquaponi	1	22	22	1.0	22	11	0	242.00	-
7	Air Pump (Aquaponic)	1	10	10	1.0	10	11	0	110.00	-
8				-	1.0	-	0	0	-	-
	TOTAL			**4,873**		**4,873**			**8,600.02**	-

Figure 10 Load assessment for day time storage using KYA-Sol Design. Retrieved from Kya-Sol Design

4.2.3.1.2. Off Grid Load Profile

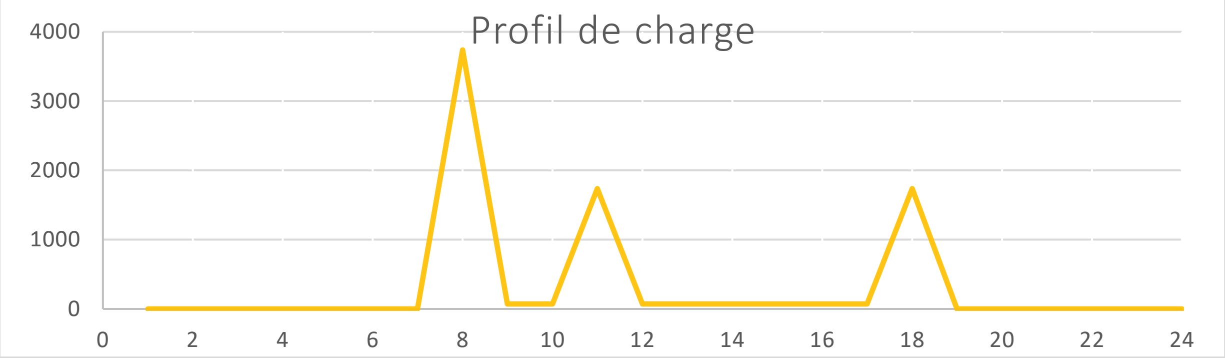


Figure 11 KYA Sol Off Grid Assembly Generated Load Profile

The peak power demand is around 3738 W and happens at 8:00AM. There are two other smaller peaks worth the mention occurring at 11:00 am and 6:00 pm at 1738 W. The daily energy demand is 8.6kWh.

4.2.3.1.3. Selected PV components

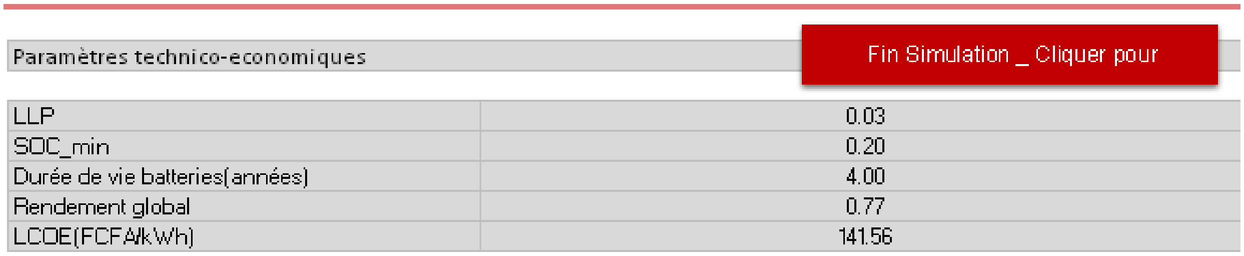
The PV and Inverter technology are the same as for the Grid tied intuitive sizing. The following is the selected battery technology for the off grid sizing.

Table 21 Selected Battery technology for Off grid sizing

Ref_bat	Efficiency	DOD	Vnom	Cnom	Pr_bat	D_bat
PHI1.3_BATTERY TM	0.98	0.8	12.8	105	877560	15

4.2.3.1.4. System simulations results

Table 22 KYA-SOL Design simulation Results. Retrieved from KYA-Sol Design



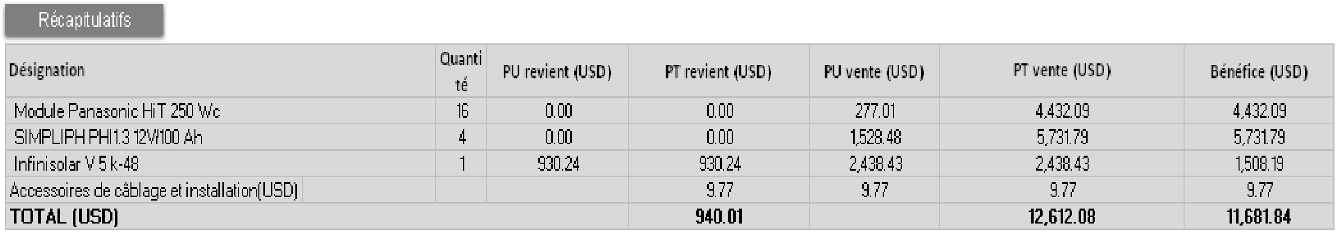
Paramètres technico-economiques	
LLP	0.03
SOC_min	0.20
Durée de vie batteries(années)	4.00
Rendement global	0.77
LCOE(FCFA/kWh)	141.56

From the above results the following is deduced:

- Only 3 percent of the load was not met by the system. This is a 2% difference from the recommend value. According to literature, the recommended LLP for domestic is 0.01(Kalogirou, 2007)
- 20 percent maximum discharge state achieved by the battery bank,
- 4-year life time for the batteries and,
- Global effective efficiency of 0.77,
- An LCOE of 0.248 USD/kWh, which is 50% more than the current price of electricity in Morocco, which is 0.11Usd/kWh. Although the calculated is higher compared to the current unit cost of electricity, it is predicted that this price will drop significantly in the future due to decrease in the initial cost of the PV modules. Moreover, if the future unit cost of electricity in Morocco increases due to the rapid increase in the conventional fuel prices, therefore PV energy generation will be promising in the future house electrification due to its expected future lower unit electricity cost, efficiency increase, and clean energy generation compared to the conventional utility grid.

4.2.3.1.5. System size and cost

Table 23 KYA-SOL Design Sizing Results



Désignation	Quantité	PU revient (USD)	PT revient (USD)	PU vente (USD)	PT vente (USD)	Bénéfice (USD)
Module Panasonic HiT 250 Wc	16	0.00	0.00	277.01	4,432.09	4,432.09
SIMPLIPH PHI1.3 12V/100 Ah	4	0.00	0.00	1,528.48	5,731.79	5,731.79
Infinisolar V 5 k-48	1	930.24	930.24	2,438.43	2,438.43	1,508.19
Accessoires de câblage et installation(USD)			9.77	9.77	9.77	9.77
TOTAL (USD)			**940.01**		**12,612.08**	**11,681.84**

4.2.3.2. Off Grid System MATLAB Output

4.2.3.2.1. Input Parameters

The following is list of the off grid assembly MATLAB program inputs

1. The off grid assembly profile of the daily energy demand of 8.2 kWh
2. The Battery parameters as seen below:

Battery parameters
Battery efficiency
DOD max battery
Battery system voltage
Battery nominal capacity Ah

Battery parameters	
DOD	N_cycles
0.2	15000
0.8	10000
0.9	5000
1	3500

3. The sizing parameters as seen below:

Sizing parameters	
Hour	Average daily irradiation in kWh / day
0	Ratio of performance
1	Charge controller's efficiency
2	Inverter efficiency
7	Inverter type (1 for MPPT and 0 for PWM)
8	PV module Unit power Wc
9	PV module MPP Volts
10	PV module Mpp Current
11	PV module nominal volts
12	PV module Voc
13	PV Module Isc
14	PV Module Temp Coefficient, Pmax
15	PV Module NOCT
16	Beginning of the daytime usage range
17	End of the daytime usage range
18	Night coefficient
19	Daytime coefficient

4.2.3.2.2. Off Grid Sizing Program in Appendix A

The developed program can be found in Appendix D, off grid system sizing program.

Results

The following results were obtained after running the off grid sizing program in Appendix D

Item	Value
Total number of Modules	16
Number of Batteries in series	4
Number of Batteries in parallel	1

MATLAB Vs KYA-SOL Design Comparison

Item	MATLAB	KYA-SOL DESIGN
Total number of Modules	16	16
Number of Batteries in series	4	4
Number of Batteries in parallel	1	1
Inverter Size	5000	5000

As the following results were similar proceeded with the optimization

MATLAB Off Grid Sizing Results with 10% safety factor

Before optimization the system was sized adding a 10 % safety factor. The following were the results from MATLAB program off grid sizing with 10 safety Factor:

Item	With 10 Safety Factor
Total number of Modules	17
Number of Batteries in series	4
Number of Batteries in parallel	2

The following is the load profile for the off grid system with the 10 % safety factor.

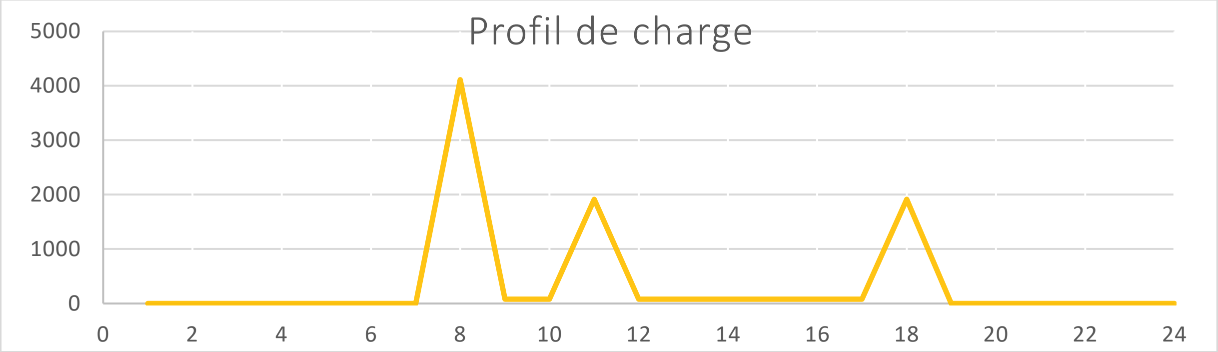


Figure 12 Off Grid Load Profile with 10% Safety Factor

The peak power demand is around 4112 W and happens at 8:00AM. There are two other smaller peaks worth the mention occurring at 11:00 am and 6:00 pm at 1912 W. The daily energy demand is 9.46kWh. The following profile is not very different from the initially generated in section 4.2.2.1.2, it deviates by 10% and will be used in the optimization.

4.3. System Optimization

4.3.1. Off Grid Assembly

4.3.1.1. Optimization program Parameters

The following are the parameters used for optimization of the off grid PV system, along with the off grid load profile, as seen earlier.

Table 24 Off grid sizing parameters

Sizing parameters	
Average daily irradiation in kWh / day	5.35
Ratio of performance	0.7
Charge controller's efficiency	0.93
Inverter efficiency	0.9
Inverter type (1 for MPPT and 0 for PWM)	1
beginning of the daytime usage range	8
End of the daytime usage range	18
night coefficient	0
daytime coefficient	0.4

Table 25 Selected Modules from Manufactures for off grid system

Module Information

N°	Ref_mod	Pc	Vmp	Imp	Vnom	Voc	Isc	Kt	Noct	Smod	Pr_mod	D_mod
1	Panas_HIT_VBHN250SJ25	250	44.3	5.65	24	53.2	6.03	-0.258	44	1.26	159040	25
2	SANYO_HIT_H250E01	250	34.9	7.18	24	43.1	7.74	-0.3	46	1.54721	159040	25
3	LG_Mon_LG300N1K-G4	300	32.5	9.26	24	39.7	9.7	-0.38	45	1.64	176080	25
4	Mon_RNG-300D	300	32.25	9.33	24	39.82	9.78	-0.47	47	1.64505	174370.3	25
5	Almaden_Poly_SEAP60T-270	270	31.51	8.57	24	38.51	9.04	-0.399	45	1.645	0	25

Table 26 Selected Batteries from Manufacturers for off grid system

Batteries

Ref_bat	**Efficiency**	**DOD**	**Vnom**	**Cnom**	**Pr_bat**	**D_bat**
PHI1.3_BATTERY TM	0.98	0.8	12.8	105	877560	15
VIC_LFPSmart_12,8/300	0.92	0.7	12.8	300	1704000	5
VIC_AGM_BAT412201084	0.8	0.5	12	220	316501	2
VIC_GEL_BAT412201104	0.8	0.5	12	220	325163	3
RNG-BATT-AGM12-200	0.8	0.5	12	200	227194.3	2
RNG-BATT-GEL12-200	0.8	0.5	12	200	255594.3	3

The same inverter as for the intuitive sizing for the off grid system, seen in section 4.2.2.1.3 is used for the optimization.

4.3.1.2. Optimization Program in Appendix A

The developed program can be found in Appendix A, off grid optimization program.

4.3.1.3. Model Results

Table 27 Optimization off grid model results

N°	Ref_mod	Ref_bat	nb_Mod	nb_Bat	LLP	SOC_min	TEL	LCOE(CF/kWh)
1	Panas_HIT_VBHN250SJ25	PHI1.3_BATTERY TM	17	8	0	0.397246	6248.167	588.0684
2	Panas_HIT_VBHN250SJ25	VIC_LFPSmart_12,8/300	18	4	0	0.320819	6752.875	848.0078
3	Panas_HIT_VBHN250SJ25	VIC_AGM_BAT412201084	19	4	0	0.372469	7078.68	538.77
4	Panas_HIT_VBHN250SJ25	VIC_GEL_BAT412201104	19	4	0	0.372469	7078.68	480.3929
5	Panas_HIT_VBHN250SJ25	RNG-BATT-AGM12-200	19	8	0	0.436235	7056.131	633.6022
6	Panas_HIT_VBHN250SJ25	RNG-BATT-GEL12-200	19	8	0	0.436235	7056.131	571.5263
7	SANYO_HIT_H250E01	PHI1.3_BATTERY TM	17	8	0	0.397246	6248.167	632.4368
8	SANYO_HIT_H250E01	VIC_LFPSmart_12,8/300	18	4	0	0.320819	6752.875	894.9861
9	SANYO_HIT_H250E01	VIC_AGM_BAT412201084	19	4	0	0.372469	7078.68	588.3583
10	SANYO_HIT_H250E01	VIC_GEL_BAT412201104	19	4	0	0.372469	7078.68	529.9812
11	SANYO_HIT_H250E01	RNG-BATT-AGM12-200	19	8	0	0.436235	7056.131	683.1904
12	SANYO_HIT_H250E01	RNG-BATT-GEL12-200	19	8	0	0.436235	7056.131	621.1146
13	LG_Mon_LG300N1K-G4	PHI1.3_BATTERY TM	15	8	0	0.397611	6862.128	614.8243
14	LG_Mon_LG300N1K-G4	VIC_LFPSmart_12,8/300	15	4	0	0.320819	6752.875	857.8639
15	LG_Mon_LG300N1K-G4	VIC_AGM_BAT412201084	16	4	0	0.37256	7203.437	552.6631
16	LG_Mon_LG300N1K-G4	VIC_GEL_BAT412201104	16	4	0	0.37256	7203.437	494.2861
17	LG_Mon_LG300N1K-G4	RNG-BATT-AGM12-200	16	8	0	0.43628	7180.888	647.4953
18	LG_Mon_LG300N1K-G4	RNG-BATT-GEL12-200	16	8	0	0.43628	7180.888	585.4195
19	Mon_RNG-300D	PHI1.3_BATTERY TM	15	8	0	0.397611	6862.128	614.6338
20	Mon_RNG-300D	VIC_LFPSmart_12,8/300	15	4	0	0.320819	6752.875	857.6734
21	Mon_RNG-300D	VIC_AGM_BAT412201084	16	4	0	0.37256	7203.437	552.46
22	Mon_RNG-300D	VIC_GEL_BAT412201104	16	4	0	0.37256	7203.437	494.0829
23	Mon_RNG-300D	RNG-BATT-AGM12-200	16	8	0	0.43628	7180.888	647.2922
24	Mon_RNG-300D	RNG-BATT-GEL12-200	16	8	0	0.43628	7180.888	585.2163
25	Almaden_Poly_SEAP60T-270	PHI1.3_BATTERY TM	16	8	0	0.397348	6420.081	539.9446
26	Almaden_Poly_SEAP60T-270	VIC_LFPSmart_12,8/300	16	4	0	0.32036	6308.632	782.9842
27	Almaden_Poly_SEAP60T-270	VIC_AGM_BAT412201084	17	4	0	0.372178	6679.335	471.7949
28	Almaden_Poly_SEAP60T-270	VIC_GEL_BAT412201104	17	4	0	0.372178	6679.335	413.4179
29	Almaden_Poly_SEAP60T-270	RNG-BATT-AGM12-200	17	8	0	0.436089	6656.786	566.6271
30	Almaden_Poly_SEAP60T-270	RNG-BATT-GEL12-200	17	8	0	0.436089	6656.786	504.5513

The following shows that the optimum configuration is obtained using 17 of 270 Watt Almaden Poly SAP60T PV module, 4 of 220Ah Victron Energy Gel battery, and 1 Infinisolar V-5K-48 Inverter technology. These configurations and technology provided for the desired system reliability (LLP = 0), with the lowest LCOE of 0.727 $/kWh (413.4179 FCFA/kWh) and a SOCmin of 37.2%.

4.3.2. Grid Tied Assembly

4.3.2.1. Optimization program Parameters

The following are the parameters used for optimization of the grid tied PV system, along with the grid tied load profile, as seen earlier.

Table 28 Grid tied sizing inputs

Sizing parameters

Average daily irradiation in kWh / day	5.35
Ratio of performance	0.7
Charge controller's efficiency	0.97
Inverter efficiency	0.97
Inverter type (1 for MPPT and 0 for PWM)	1
beginning of the daytime usage range	8
End of the daytime usage range	18
night coefficient	0
daytime coefficient	0.4
Power factor	0.9
AC voltage min	180
AC max voltage	280
AC min frequency	45
AC max frequency	55

Table 29 Selected Modules from Manufactures for grid tied system

Module Information

Ref_mod	Pc	Vmp	Imp	Vnom	Voc	Isc	Kt	Noct	Smod	Pr_mod	D_mod	Coef_temp_Voc
Panas_HIT_VBHN250SJ25	250	44.3	5.65	24	53.2	6.03	-0.258	44	1.26	159040	25	-0.24
SANYO_HIT_H250E01	250	34.9	7.18	24	43.1	7.74	-0.3	46	1.54721	159040	25	-0.108
LG_Mon_LG300N1K-G4	300	32.5	9.26	24	39.7	9.7	-0.37	45	1.64	185713.3	25	-0.27
Mon_RNG-300D	300	32.25	9.33	24	39.82	9.78	-0.47	47	1.64505	174370.3	25	-0.33
Almaden_Poly_SEAP60T-270	270	31.51	8.57	24	38.51	9.04	-0.399	45	1.64545	198800	25	-0.307

The same inverter as for the intuitive sizing for the grid tied system, seen in section 4.2.1.2 is used for the optimization.

4.3.2.2. Optimization Program in Appendix B

The developed program can be found in Appendix E, grid tied optimization program.

4.3.2.3. Model Results

Table 30 Optimization grid tied model results

N°	Ref Module	Nb of PV module	LPP	LCOE (devise/kWh)	Energy to the grid (kWh)	Energy from grid inverter (kWh)
1	Panas_HIT_VBHN250SJ25	21	0.000	47	5,296	11792.12291
2	SANYO_HIT_H250E01	21	0.000	49	5,096	11591.96942
3	LG_Mon_LG300N1K-G4	17	0.000	49	4,592	11088.08191
4	Mon_RNG-300D	17	0.000	48	4,177	10672.96131
5	Almaden_Poly_SEAP60T-270	19	0.000	55	4,570	11065.95759

The following shows that the optimum configuration is obtained using 21 of 250 Watts Panasonic HIT PV modules, and 1 Infinisolar V-5K-48 Inverter technology. These configurations and technology provided for the desirable system reliability (LLP = 0), with the lowest LCOE of 47FCFA/kWh (0.0802$/kWh) and energy to the grid of 5296kWh. Moreover, as the energy to the grid is positive, the PV field alone is able to feed the loads, and thus energy from the grid is less than energy from the inverter.

4.4. System Cost

System cost is given from the results of the tables below guided by equations 11 – 17.

4.4.1. Previous System Cost

The following is the previously sized Jua House PV system cost:

Table 31 Previous Jua House PV System Cost

Total Cost			
Item	**Unit cost**	**Quantity**	**Total cost**
Fronius Primo 8.2-1	$1,720	1	$1,720
10kVA Victron Quattro Inverter	$4,100	1	$4,100
slim Panasonic 250W	$280.00	32	$8,960
PHI1.3_BATTERY TM	$1545	4	$6,180
Wiring and accessories		lump sum (0.26 of Main comp)	$5449.6
Total Cost			**$30,607.04**

The previous system sizing was achieved with 22 of 250W Panasonic HIT modules, 4 of 100Ah 12V Simpliph Phil 1.3 Battery, a Fronius primo and Victron Quattro inverter. All this was at a cost of $30,607.04 for the daily energy demand of 40.9kWh (as seen in section 4.1.1).

4.4.2. Updated System Cost

4.4.2.1. Intuitive Sizing System Cost

The total cost of both intuitive systems assemblies is given below:

Table 32 off grid Intuitive sizing assembly Cost

Total Cost			
Item	**Unit cost**	**Quantity**	**Total cost**
Infinisolar V-5K-48	$1,434.69	1	$1,434.69
slim Panasonic 250W	$280.00	17	$4,760.00
PHI1.3_BATTERY TM	$1545	8	$6180
Wiring and accessories		lump sum (0.26 of Main comp)	$4824.2
Total Cost			**$23,378.9**

The intuitive off grid assembly sizing is achieved with 17 of 250W Panasonic HIT modules, 8 of 100Ah,12V Simpliph Phil 1.3 Battery and an Infinisolar inverter. All at a cost of $23,378.9 for the daily energy demand of 9.46kWh (10 % safety factor included).

Table 33 Grid tied Intuitive sizing assembly cost

Total Cost			
Item	**Unit cost**	**Quantity**	**Total cost**
Infinisolar V-5K-48	$1,434.69	1	$1,434.69
slim Panasonic 250W	$280.00	22	$6,160.00
Wiring and accessories		lump sum (0.26 of Main comp)	$1,974.62
Total Cost			**$9,569.31**

The intuitive grid tied assembly sizing is achieved with 22 of Panasonic HIT modules and an Infinisolar inverter. All at a cost of $9,569.31 for the daily energy demand of 18.2kWh (10 % safety factor included).

Table 34 Total cost of the intuitively sized system

$C_{TIC_{OFF}}$(USD)	$C_{TIC_{GRID}}$(USD)	$C_{TOT(off+grid)}$(USD)
23,378.9	**$9,569.3**	32,948.2

Total cost of the Jua House PV system from the intuitive system sizing is $32,948.2.

4.4.2.2. Optimized System Cost

The total cost of both optimal system assemblies is given below:

Table 35 Optimized Off Grid assembly Cost

Item	Price	Quantity	Total Cost
Infinisolar V-5K-48	1,434.69	1	1434.69
Almaden Poly 270W	350	17	5950
VIC_GEL_BAT412201104	572.47	4	2289.88
Wiring and accessories			2515.388
Total Cost			**$12189.96**

The intuitive off grid assembly sizing is achieved with17 of 270 Watt Almaden Poly SAP60T PV modules, 4 of 220Ah 12V Victron Energy Gel battery, and one Infinisolar V-5K-48. All at a cost of $12189.96 for the daily energy demand of 9.46kWh (10 % safety factor included).

Table 36 Optimized Grid Tied assembly Cost

Item	Price	Quantity	Total Cost
Infinisolar V-5K-48	1,434.69	1	1434.69
slim Panasonic 250W	280	21	5880.00
Wiring and accessories			1901.8
Total Cost			**9216.5**

The intuitive grid tied assembly sizing is achieved with 21 of Panasonic HIT modules and an Infinisolar inverter. All at a cost of $9,569.31 for the daily energy demand of 18.2kWh (10 % safety factor included).

Table 37 Total cost of optimized system

$C_{TIC_{OFF}}$(USD)	$C_{TIC_{GRID}}$(USD)	$C_{TOT(off+grid)}$(USD)
12189.96	9216.509	21,406.5

The total cost for the optimized Jua House PV system throughout its life cycle is $21,406.5. In comparison to section 4.2.3, where the total cost of the Jua House PV system from the intuitive system sizing was $32,948.2, the price of the optimized is lower by $11541.7. Consequently, optimization has reduced the cost by 35%.

4.4.3. Conclusion

It is apparent from the above cost calculations, that the total cost of the optimized system is lower than both, the previously designed and intuitive system design. The total cost difference with the previously designed system is $30,607.04 - $21,406.5 = $9,200.54, that is a 30% difference. The total cost difference with the intuitive system design is $32,948.2 - $21,406.5 = $11541.7, that is a 35% difference. Consequently, optimization has reduced the cost by 30 - 35%.

5.0. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

5.1. Summary and Conclusion

The energy sector is undergoing remarkable changes and expansions in the world. Nevertheless, even with the strides in the field, the African continent is still behind with tremendous challenges in energy security and energy efficient buildings. In the scope of the Solar Decathlon Africa, a model green and self-sustainable building called the Jua House is under construction by PAUWES students, Team Jua Jamii.

This study aimed at designing an optimum and efficient PV system for the model Jua house. As the previously designed system was not optimally designed and did not provide for the desirable system reliability and cost. It can be concluded that technical and economic criteria are important factors to consider when designing a PV system. This is due to the fact that to select an optimum PV combination to meet sizing constraint, it is necessary to evaluate power reliability, system technology and economic benefits. The results showed that the optimized PV system reduced the daily load consumption, minimized overall cost and improved system reliability. Moreover, the components and technology selection are very crucial in cost reduction and energy production.

A 27.615 kWh/day PV load for the Jua House was split between day time load of 9.460 kWh/day and night time load of 18.178 kWh/day. The day time load was sized as an off grid system and the night time load was sized as a grid tied system. Each assembly was initially sized intuitively based on the KEG mathematical model and then further sized on MATLAB with a combination of PV components from the selected technologies. Two dynamic simulator were then created in the Simulink environment from MATLAB R2018a. These simulators were used to simulate the systems hourly behavior and numerically find an optimal PV sizing in respect to the techno economic optimization criteria: LLP, LCOE and energy balance for the grid tied assembly. These techno economic criteria were determined from literature review.

The results for off grid assembly optimization showed that the optimum configuration obtained using 17 of 270 Watt Almaden Poly SAP60T PV modules, 4 of 220Ah 12V Victron Energy Gel battery, and one Infinisolar V-5K-48 Inverter technology provided for the desired system reliability (LLP = 0), with the lowest of LCOE of 0.727 $/ and a SOCmin of 37.2%. The results for grid tied assembly optimization showed that the optimum configuration obtained using 21 of 250 Watts Panasonic HIT PV module, and one Infinisolar V-5K-48 Inverter technology provided for the desirable system reliability (LLP = 0) with the lowest LCOE of 0.0802$/kWh and energy to the grid of 5296kWh. For both systems assemblies, the components and technology selection were crucial in cost reduction and energy production.

In total the optimized system contains 9.840 kW PV Capacity from: 17 of 270 Watt Almaden Poly SAP60T PV modules and 21 of 250 Watt Panasonic HIT. An emergency storage capacity of 880Ah from 4 of 220Ah 12V Victron Energy Gel battery. And 10kW inverter capacity from two InfinisolarV-5K-48 inverters. All at total cost of $21406.5, which is $11541.7 lower than the intuitive design system cost. Consequently, system optimization has reduced the total cost of the Jua House PV system by 35% and insured the desired system reliability, LLP of 0.

Figure 13 The model green and self-sustainable Jua House

5.2. Recommendation

With the widespread adoption of renewable energy resources and technologies, the increase in energy demand and the shift to sustainability. Renewable energy powered and energy self-sustainable buildings should be part of Africa’s new construction.

At the regional level, there are enough resources available to meet the future energy demand. However, they are unevenly distributed and many of the countries in the sub-Saharan African region will, for the foreseeable future, depend on imported oil—a major contributor to the balance of payments problem experienced by most sub-Saharan African countries. In most countries in the region, the present pattern of energy utilization is sub-optimal and industrial energy use, in particular, is very inefficient. These inefficiencies constitute a large drain on many of the economies in the region (UNIDO). Hence, a lot more work and research needs to be done for the seamless incorporation of energy efficiency measures and renewable energy innovations.

The finding of this research define an optimal sizing methodology for a model African green house, for the solar decathlon Africa. It is important for the optimal design of a power generation system, to consider the technical and economic parameters and constraints. Furthermore, this study fills the void of lack of sufficient research in the field of energy efficiency and self-sufficient buildings in Africa. Subsequently, help propel actions on reaching sustainable energy for all Africans.

5.2.1. Suggestions for Future Research

In future research, the accuracy of the research can be increased by the following:

- In depth study of the different PV components technology and development of a mathematical model for technology selection.
- Performing optimization with more PV components combinations. As seen on the study the more the number of PV component sets were, the more accurate and optimal design.
- More time spent on literature review and methodology
- In depth cost analysis of the PV system on financial analysis software such as Ret Screen, to properly asses the feasibility and cost effective benefits of the system.
- In depth environmental analysis on a life cycle basis to be added to the methodology

Bibliography

Aussel, D., Neveu, P., Tsuanyo, D., & Azoumah, Y. (2018). On the equivalence and comparison of economic criteria for energy projects: Application on PV/diesel hybrid system optimal design. *Energy Conversion and Management*, *163*, 493–506. https://doi.org/10.1016/j.enconman.2017.12.050

Balfour, J. R. (2011). *Introduction to Photovoltaic System Design*. Retrieved from https://books.google.tg/books?id=ct5bAwAAQBAJ

Bhatia, S. C. (2014). 1 - Energy resources and their utilization. In S. C. Bhatia (Ed.), *Advanced Renewable Energy Systems* (pp. 1–31). https://doi.org/10.1016/B978-1-78242-269-3.50001-2

Conibeer, G. (2007). Third-generation photovoltaics. *Materials Today*, *10*(11), 42–50. https://doi.org/10.1016/S1369-7021(07)70278-X

Dogga, R., & Pathak, M. K. (2019). Recent trends in solar PV inverter topologies. *Solar Energy*, *183*, 57–73. https://doi.org/10.1016/j.solener.2019.02.065

Elsheikh Ibrahim, O. E. (1995). Sizing stand-alone photovoltaic systems for various locations in Sudan. *Fifth Arab International Solar Energy Conference*, *52*(2), 133–140. https://doi.org/10.1016/0306-2619(95)00031-M

Eltawil, M. A., & Zhao, Z. (2010). Grid-connected photovoltaic power systems: Technical and potential problems—A review. *Renewable and Sustainable Energy Reviews*, *14*(1), 112–129. https://doi.org/10.1016/j.rser.2009.07.015

Hadj Arab, A., Ait Driss, B., Amimeur, R., & Lorenzo, E. (1995). Photovoltaic systems sizing for Algeria. *Solar Energy*, *54*(2), 99–104. https://doi.org/10.1016/0038-092X(94)00091-Q

Jossen, A., Garche, J., & Sauer, D. U. (2004). Operation conditions of batteries in PV applications. *Solar Energy*, *76*(6), 759–769. https://doi.org/10.1016/j.solener.2003.12.013

Kalogirou, S. (2007). *Artificial Intelligence in Energy and Renewable Energy Systems*. Retrieved from https://books.google.tg/books?id=PpynLn1aXw4C

Khatib, T., Mohamed, A., & Sopian, K. (2013). A review of photovoltaic systems size optimization techniques. *Renewable and Sustainable Energy Reviews*, *22*, 454–465. https://doi.org/10.1016/j.rser.2013.02.023

Kim, J., Hong, T., Jeong, J., Koo, C., Jeong, K., & Lee, M. (2019). Multi-criteria decision support system of the photovoltaic and solar thermal energy systems using the multi-objective optimization algorithm. *Science of The Total Environment*, *659*, 1100–1114. https://doi.org/10.1016/j.scitotenv.2018.12.387

Li, J. (2019). Optimal sizing of grid-connected photovoltaic battery systems for residential houses in Australia. *Renewable Energy*, *136*, 1245–1254. https://doi.org/10.1016/j.renene.2018.09.099

Mellit, A., Kalogirou, S. A., Hontoria, L., & Shaari, S. (2009). Artificial intelligence techniques for sizing photovoltaic systems: A review. *Renewable and Sustainable Energy Reviews*, *13*(2), 406–419. https://doi.org/10.1016/j.rser.2008.01.006

Pearsall, N. (2016). *The Performance of Photovoltaic (PV) Systems: Modelling, Measurement and Assessment*. Retrieved from https://books.google.tg/books?id=ON_lBwAAQBAJ

Reaz Reisi, A., & Alidousti, A. (2019). *Optimal Designing Grid-Connected PV Systems*. https://doi.org/10.5772/intechopen.79685

Sidrach-de-Cardona, M., & López, L. M. (1998). A simple model for sizing standalone photovoltaic systems. *Solar Energy Materials and Solar Cells*, *55*(3), 199–214. https://doi.org/10.1016/S0927-0248(98)00093-2

Sparrow, E. M., Abraham, J. P., Gorman, J. M., & Cho, Y. I. (2013). *Advances in Heat Transfer*. Retrieved from https://books.google.tg/books?id=7QluAAAAQBAJ

Spiers, D. (2012). Chapter IIB-2 - Batteries in PV Systems. In A. McEvoy, T. Markvart, & L. Castañer (Eds.), *Practical Handbook of Photovoltaics (Second Edition)* (pp. 721–776). https://doi.org/10.1016/B978-0-12-385934-1.00022-2

A. Ristow et al, M. B. (2008). Development of a Methodology for Improving Photovoltaic Inverter Reliability. *IEEE Trans. on Ind. Elecs, vol. 55*, pp. 2581-2592.

A. Schnewly, R. G. (n.d.). “Properties and applications of supercapacitors - From the state-of-the-art to future trends”,. *PCIM2000 Power Quality*.

A. Scognamiglio, H. R. (2013). Photovoltaics and Nearly Zero Energy Buildings: A New Opportunity and Challenge for Architecture. *27th European Photovoltaic Solar Energy Conference and Exhibition*, (pp. 3848 - 3858).

AG, S. S. (n.d.). *CO2 Factor:Factor for calculating the amount of CO2 avoided in power generation.* SMA.

Alexander Zerrahna, W.-P. S. (2018). On the economics of electrical storage for variable renewable energy sources . *European Economic Review 108* , 259–279.

Amit Kumar Rohita, K. P. (2017). An overview of energy storage and its importance in Indian renewable energy sector. *Journal of Energy Storage 13*, 10–23.

(2016). *Consortium for Energy Efficiency. "National Awareness of Energy Star for 2016" (PDF).*

Constantin Ionescu, T. B.-E. (2015). The historical evolution of the energy efficient buildings. *Renewable and Sustainable Energy Reviews*, pp. 243-253.

François Garde, A. L. (2014). Design of Net Zero Energy Buildings: Feedback from International Projects. *Energy Procedia, Elsevier*, pp. 995-998.

HARPUTLUGİL, T. (2017). ENERGY EFFICIENT BUILDING DESIGN DEVELOPMENT: A RETROSPECTIVE APPROACH. *International Symposium on Energy Efficiency in Buildings*, 296-303.

Khaled Bataineh, D. D. (2012). Optimal Configuration for Design of Stand-Alone PV System. *Smart Grid and Renewable Energy*, 139 - 147.

Lakshmi Prakasha*, S. K. (2015). Self-sufficient Smart Prosumers of Tomorrow. *Procedia Technology 21*, 338 – 344.

Lamberto Tronchin, M. M. (2018). Energy efficiency, demand side management and energy storage technologies – A critical analysis of possible paths of integration in the built environment,. *Renewable and Sustainable Energy Reviews*, 341-353.

Li, Y. L. (2015, March). Interpreting Solar House-Using International Solar Decathlon Works as Example. *Advanced Materials Research*, pp. 567-572.

Mekhilef, A. S. (2019, January). Energy Management and Optimization of a PV/Diesel/Battery Hybrid Energy System Using a Combined Dispatch Strategy. *Sustainability, MDPI, Open Access Journal,*, pp. 1-26.

MIT Electric Vehicle, T. (2008). A Guide to Understanding Battery Specifications. 3.

P. Manimekalai, R. H. (2013). An Overview of Batteries for Photovoltaic (PV) Systems. *Int. J. Comput. Appl*, pp. 28-32.

Panasonic. (n.d.). *Unique Technology* . Retrieved from Panasonic : https://eu-solar.panasonic.net/en/hit-heterojunction-sanyo-panasonic.htm

SDA, S. D. (2019). *RULES.* Solar Decathlon .

Solar Decathlon, A. (2017). *Request for Proposal.* IRESEN.

Tamer Khatib, A. M. (2012). A New Approach for Optimal SIzing of Standalone Photovoltaic Systems. *International Journal of Photoenergy*, p. 7.

Tamer Khatib, A. M. (2013). A review of photovoltaic systems size optimization techniques. *Renewable and Sustainable Energy Reviews 22*, 454–465.

Tarroja B, C. F. (2018). Translating climate change and heating system electrification impacts on building energy use to future greenhouse gas emissions and electric grid capacity requirement in california. *Appl Energy* , 522-34.

UNIDO, U. N. (n.d.). Sustainable Energy Regulation and Policymaking for. In S. T. K. Syngellakis, *Introduction and User Manual* .

Yong Lia, J. Y. (2017). Efficient storage mechanisms and heterogeneous structures for building better next-generation lithium rechargeable batteries. *Renewable and Sustainable Energy Reviews*, 1503–1512.

Yuqing Yang, S. B. (109-125). Battery energy storage system size determination in renewable energy systems: A review. *Renewable and Sustainable Energy Reviews*, 2018.

Appendix

A: Photovoltaic modules Generation Comparison

Table 38 In Appendix: Advantages and Disadvantages of the PV Generations

Generation	Advantages	Disadvantages
First	• High Efficiency (14-22%) • Established technology (The leader) • Stable	• Expensive production • Low absorption coefficient • Large amount of highly purified feedstock
Intermediate	• High Efficiency • Functions at High temperatures • Reduction in loss of charge at cell boundaries	• Expensive production • Transversal current flow leading to voltage drops at the heterojunctions with significant band edge discontinuity
Second	• High absorption (don't need a lot of material) • Established technology • Ease of integration into buildings • Excellent ecological balance sheet • Cheaper than the glass, metal, or plastic you deposit it on	• Only moderate stabilized efficiency 7-10% • Instability- It degrades when light hits it

Third	- Low current, high voltage devices therefore less I^2R loses	- Stability of devices - Not commercial available - Laboratory based

B: Further inverter comparison

Table 39 In Appendix: Inverter Types Advantages and Disadvantages

Inverter	Pros	Cons
Standard String	- Time-tested technology - Countless product options available	- Do allow for battery integration - Need a charger controller, battery based inverter and an additional energy management system to increase your system's efficiency
Micro	- Better PV performance as every modules output is collected individually,	- Expensive production
Battery	- Modular nature lends to greater system design flexibility - Long history of use in off-grid and stand-alone power systems - Sturdy and durable - Can be relatively easily retrofitted onto existing solar PV systems for	- Dependent on your state's network retrofitting rules - Retrofitting a battery inverter will usually cost more than installing a hybrid inverter when initially purchasing your system

	addition of battery storage	
Hybrid	- More seamless and cost-effective solution - Design flexibility - All-in-one inverter solution. - Frequently intelligent and programmable for maximizing overall system efficiency and savings	- Less efficient as they perform two integral function - Less design flexibility than modular solutions which use separate PV and battery inverters
Grid-Tied	- Time-tested technology - Countless product options available	- Dependent on the state's rule on grid tied connections
Off-Grid	- An off-grid inverter system means your home is no longer susceptible to power outages caused by the grid, giving your home greater energy independence - Some come with a built-in AC charger option, that not only allows you to connect a backup generator, but also charge a battery	- Deciding to go off grid is a costly procedure and will often require total disconnection from the grid. This can be hard to undo, so you'll need to consider the future implications (re-sale value of your home, future energy needs, etc.). - You may also need to invest in a diesel generator which can be extremely costly, and become much more conscious of your

		energy usage to avoid your system tripping from an overload

C: Miscellaneous

1. Optimization Technical Criterias

Below is a further study of the most prevalent criteria's used to analyze the technology of a PV system.

Loss of power supply probability, LPSP

The Loss of power supply probability (LPSP) is defined as the percentage of power supply that it is not able to satisfy the load demand. It indicates the reliability of power supply to load. LPSP is given by the ratio of summation of all loss power supply, LPS (t) at a specific time period (t) over the summation of load demand, LD(t) at the same time period (t). Meanwhile, if LPSP is equal to 0, it means that the load demand is totally satisfied at a specific time period (t). On the other hand, if LPSP is not equal 0, it means that the load demand is not totally satisfied

Loss of load probability, LLP

The Loss of load probability (LLP) indicates how often a system is not being able to satisfy the load demand or the mean load percentage not met by the system. It is defined as the ratio of total energy deficit to the total load demand during a specific time period.

Loss of load expected, LOLE

The Loss of load expected (LOLE) or also known as expected energy not supplied is defined as the amount of energy not provided to load demand when the load demand exceeds the energy generation from the system due to generating capacity deficiency, shortage in energy supplies and/or sudden increase in load demand.

Equivalent loss factor, ELF

The Equivalent loss factor (ELF) term contains the needed information about load outages for both number and magnitude of them which is defined as the ratio of effective time period in hours of load outage to the total operation time in hours.

Total energy loss, TEL

The Total energy loss (TEL) indicates the energy loss due to the extra power generated from a standalone energy system. TEL should be minimized by imposing the regulation in which power generation should not exceed the desired threshold at an analyzed time period T, which is assumed to be 8760 h.

Level of Autonomy, LA

The Level of autonomy (LA) is the time ratio which expressed the percentage of load covered based on the operational time of the system. LA can be presented as one minus the result of number of hours of load not met by the system to the system's operational time.

State of charge (SOC) of a storage battery

The State of charge (SOC) of a storage battery indicates the amount of energy that can be stored in a system for the purpose of selecting a suitable battery capacity for a given system.

1.1.Selected Technical criteria

As LPSP, LLP, LA and LOLE lead to the same decision, LLP will be used utilized in this study to represent the same decision. This leaves **LLP, TEL and SOC**, which will be investigated in this study for the Jua House PV system case study.

2. Optimization Economic Criterias

Below is a further study of the economic criteria families

A. Net Present value method

The main criteria for the net present value method include (Aussel et al., 2018)

- Net present value (NPV)

The Net Present Value (NPV) sums the annual cash flows returned to the equivalent value at the beginning date of the project. The project is desirable if NPV ≥ 0.

As there is no income generated or strategies for income generation on this study this criterion is not relevant for this study. As the study is the optimization of a PV system for a competition, Solar Decathlon Africa, that has already been invested in and there is no decision of doing otherwise, not investing.

- Net Future value (NFV)

The NFV sums the annual cash flow and measures their worth at the end of the project or in a future date, at certain interest rate and rate of return. The project is desirable if NFV ≥ 0.

As there is no income generated or strategies for income generation on this study this criterion is not relevant for this study. The same decision as choosing not to use NPV stands.

- Net Annualized Value (NAV)/ Equivalent Annuity

The NAV sums the annual cash flows during the project lifetime and provides an annual equivalence value, unlike NPV and NFV. The project is desirable if NFV ≥ 0.

As there is no income generated or strategies for income generation on this study this criterion is not relevant for this study.

- Capitalized value (CV)

This method caters to project with a long lifespan, longer than their planned lifetime, therefore not applicable for this study. In this the annual equivalent cash flow of the project is evaluated on an infinite period of time. The project is desirable if CV ≥ 0.

- Life Cycle Cost (LCC)

The LCC represents the total amount of costs that are involved during the lifetime of a project. This criterion does not include the incomes generated but rather helps obtain an optimal design of a project and therefore more relevant for this study.

B. Rate of return method

The main criteria for the rate of return method include (Aussel et al., 2018)

- Internal rate of return

The Internal Rate of Return IRR of a project P is the real discount rate at which the net present value of the project is zero. As there is no income generated or strategies for income generation on this study this criterion is not relevant for this study. The same decision as choosing not to use NPV stands.

- External rate of Return

The External rate of return designed to avoid the computational issues of IRR by defining the positive cash flows separate from the negative cash flows. As there is no income generated or strategies for income generation on this study this criterion is not relevant for this study. The same decision as choosing not to use NPV stands.

C. Economic Ratio Method

The main criteria for the economic ratios method include (Aussel et al., 2018)

- Discounted Profit-to-Investment ratio (DPI)

The discounted profit to investment ratio, is the ratio between the net present value of a project and the associated initial investment. The project is desirable and accepted if DPI ≥ 1, as the initial investment will be at least recovered at the end of project.

- Benefit/cost ratios

The “conventional B/C ratio” (CBC); the “Lorie-salvage B/C ratio” (LSR) and the “Profitability Index” (PI) are the commonly used and known ratios.

The project is desirable and accepted if CBC, LSR and PI ≥ 1, and otherwise rejected.

- Levelised Cost of Energy (LCOE)

The Levelised cost of energy is implicit for energy projects, and is one of the most used parameters in energy projects. It is defined as the discounted average cost of electricity energy produced by the system. It is obtained by dividing the total life cycle cost of the project by the total energy generated by the system over the life. It is a constant value expressed in currency / kWh or in currency / MWh

Moreover, LCOE can be seen as the minimal selling tariff of energy to break even, therefore as it relates to this study, it can provide a comparison of energy from the Jua house PV system and energy from the grid at solar decathlon competition location. For this study this criterion is helpful for optimal design of the system as it pertains to ensuring a more cost effective and energy efficient design.

D. Payback method

The main criteria for the payback method include (Aussel et al., 2018)

- Conventional payback (CPB)

The conventional payback assesses the payback time of the project based on nominal discount rate only, with no consideration on the inflation rate.

The project is desirable and accepted if project, lifetime ≥ CPB, and otherwise rejected.

- Discounted Payback (DPB)

The Discounted Payback assesses the payback time of the project based on real discount rate, which takes into account the inflation rate

The project is desirable and accepted if project, lifetime ≥ DPB, and otherwise rejected.

3. Selected Energy Star Appliances

Appliance	Selected Technology & Specifications
Fridge and Freezer	a. 9.89 Cu.Ft Insignia NS-RTM10WH7 b. Annual energy consumption of 296 kWh/yr.
Clothes Washing Machine	a. 2.2 Cu. Ft Samsung Front Load Washer with VRT (WW22K6800AW/A2) b. Annual energy consumption of 90kWh/yr. c. 295 loads per year – 0.8loads per day [1] d. 4 hours per week [2]
Clothes Dryer	a. 4.4 Cu. Ft, Samsung DV22N680*H*/DV22K6800EW b. Annual energy consumption of 146kWh/yr. c. 283 cycle/year – 0.77 cycle/day – 5.39 cycle/week [3] d. One cycle is roughly 1 hour – 5.39 hours/week e. O.77 hours/day
Dishwasher	a. Beko, DIS25840 b. Annual energy consumption of 229kWh/yr. c. 8 Place setting d. One load per day [2] e. 30 minutes a day
Induction cook stove range	a. Frigidaire FGIF3061NF, 1800 W b. 2300 W at 0.25 hours daily [2] c. 1 hour (Morning and afternoon), 1 hour at night
TV	a. VIZIO - D32f-F1, 31.5Inches b. 1080 resolution c. Annual energy consumption of 56.2 d. Power of 27.92 e. 4 hours a day
Phone	a. Teams and Jury's Device b. Power c. 6 Watts
Computer	a. Team's Device b. 70 Watts
Electric Car Charger	a. NEMA 14-50R 240-volt outlet b. Level 2 c. 20 – 25 miles/hr. d. 6.6kw for 2 – 4 hrs. of dwell time e. Only used 3.3kW for 1 – 2hrs of dwell time to satisfy the 65 minutes of driving

4. Solar Decathlon Africa Contest and Associated points

Table 40 In Appendix: Jury Contest and Points

Juried		
Contest Number	**Contest Name**	**Points**
1	Architecture	100
2	Engineering & Construction	100
3	Market Appeal	100
4	Communications & Social Awareness	100
7	Sustainability	100
10	Innovation	100
Juried Total		**600**

D: Off Grid System

1. KYASOL DESIGN Workspace: Parameters and Component selection

Part de la consommation prise en charge 100%

Paramètres

Pays	Marocco
Localité	Benguerir
Irradiation (kWh/m²/j)	5.35
Facteur de simultanéité	0.7
Couple (αd,αn)	(0.4 ; 1.0)
Nombre de sous-systèmes	1
Ratio de performance du système	0.7
DOD batteries	0.8
Angle d'inclinaison module PV (°)	0

Modules PV

Reference	Stock
Module Panasonic HiT 250 Wc	32

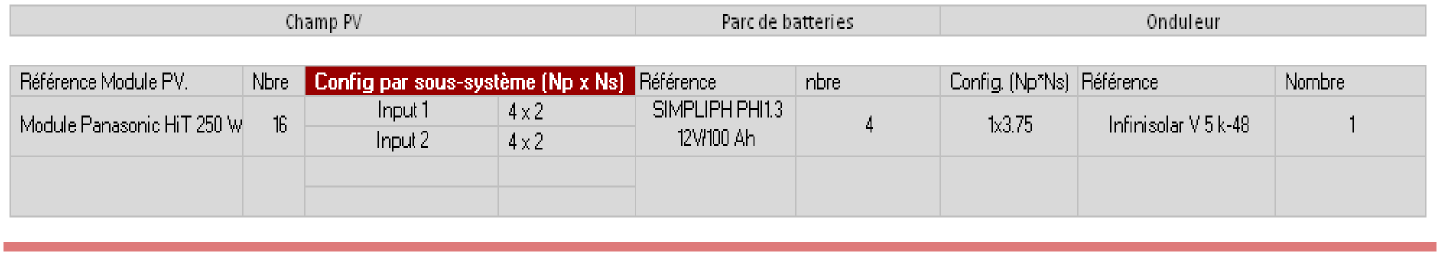
Batteries

Reference	Stock
SIMPLIPH PHI1.3 12V/100 Ah	-

Onduleurs

Référence	**Stock**	Choix
Infinisolar V 5 k-48	-	MPPT
Pas d'onduleur PWM		

Figure 14 In Appendix: KYASOL Workspace - Parameters and Component Selection



Champ PV				Parc de batteries			Onduleur	
Référence Module PV.	Nbre	Config par sous-système (Np x Ns)		Référence	nbre	Config. (Np*Ns)	Référence	Nombre
Module Panasonic HiT 250 W	16	Input 1	4 x 2	SIMPLIPH PHI1.3 12V/100 Ah	4	1x3.75	Infinisolar V 5 k-48	1
		Input 2	4 x 2					

Figure 15 In Appendix: KYA SOL Dimensioning Space

E: Grid Tied System

I. Grid Tied Sizing Methodology Detailed

1. **Input/Set location coordinates**

   Set Latitude

   Set Longitude

2. **Input Selected PV component specification**

   The following table information are the parameters and specification needed to be retrieved from the components manufacturers/datasheet for grid tied sizing

3. **Input Load demand**

   The average of the daily load is expressed by the following equations as

$$E_D = \sum_{i=1}^{15} Pi * Tdi \tag{11}$$

$$P_T = \sum_{i=1}^{15} P_i \tag{12}$$

   Where E_D is the total daily energy requirement, P_T is the total power from load/daily requirement and Pi is the power consumption for each equipment or appliance and Tdi is the time of use of each equipment or appliance in the house.

4. **Input meteorological Data**

   To find the average daily global irradiance the following equation is utilized,

$$E_s = AVG\left(\sum_{i=1}^{12} (E_{ghIM}/N_m\right) i \tag{13}$$

   Where E_s is the average daily global irradiance, $E_{ghIM}$is the monthly global horizontal irradiance (@weather data according to lat & lod) and $N_m$is number of days per month

5. **Storage Capacity**

Since the function of the system is to produce the night time energy during the day, the storage is assumed to be the grid and therefore, all energy produced is directly sent to the grid as expressed below,

$$S_T = E_D \tag{14}$$

where S_T is the total storage capacity and E_D is the total daily energy requirement.

6. Solar Field Capacity

Solar field capacity is expressed by the following equations:

$$E_j = E_D = S_T \tag{15}$$

$$E_{pv} = \left(\frac{1}{\eta_i * PR * E_s}\right) * (E_d) \tag{16}$$

$$Nmodule_{tot} = \frac{Epv}{Pmodule} \tag{17}$$

Where E_j is the useful energy to be generated and E_{pv} is the solar field capacity that depends on η_i the inverter efficiency, PR the systems' performance ratio, E_s the previously calculated average daily global irradiance, and E_D the total daily energy requirement. Finally the calculated E_{pv} is used to determine the preliminary number of modules prior to taking into account the inverter's rate power.

7. Inverter Capacity, MPPT

Before selection of the inverter and finalizing the configuration of the modules, the following conditions need to be met

I. Mpp Current Range is within the expression below:

$$\frac{I_{minMppInv}}{I_{MppModule}} < Np < \frac{I_{maxMppInv}}{I_{MppModule}} \tag{18}$$

Where $I_{minMppInv}$ is minimum inverter mpp current, $I_{MppModule}$ is the modules maximum mpp current, and $I_{maxMppInv}$ is maximum inverter mpp current.

II. Mpp Voltage Range is within the expression below:

$$\frac{V_{minMppInv}}{V_{MppModule}} < Ns < \frac{V_{maxMppInv}}{V_{MppModule}} \tag{19}$$

Where $V_{minMppInv}$ is minimum inverter mpp voltage, $V_{MppModule}$ is the modules maximum mpp voltage, and $V_{maxMppInv}$ is maximum inverter mpp voltage.

III. Inverter maximum recommend power of PV

In order to select the right inverter, need to ensure the power of the PV is within the range of inverter datasheet PV maximum recommend power.

IV. Inverter power ratio

Finally, the inverter's rated power must be matched with the PV array power through the inverter power ration factor, to achieve maximum PV array output. The inverter's rate power equation is expressed as follows:

$$R_s = \frac{P_{pvR}}{P_{iR}} \tag{20}$$

Where R_s is the ratio between the rated power of the PV array and the rated power of the inverter. And P_{pv} is the PV rated power and P_iR is the inverter's rated power.

9. Cables and Fuses Dimensions

Fuse dimensions

To properly dimension the fuses voltage, FL_V and current FL_I, the follow equations are utilized:

$$FL_V = 1.15 * Voc * Ns \tag{21}$$

$$FL_I = 1.5 * Isc \tag{22}$$

$$FL_I \leq I_{MaxOCPR} \tag{23}$$

Where Voc is the module open circuit voltage, Ns is the number of modules in series, Isc is the module short circuit current and $I_MaxOCPR$is the module maximum overcurrent protection rating.

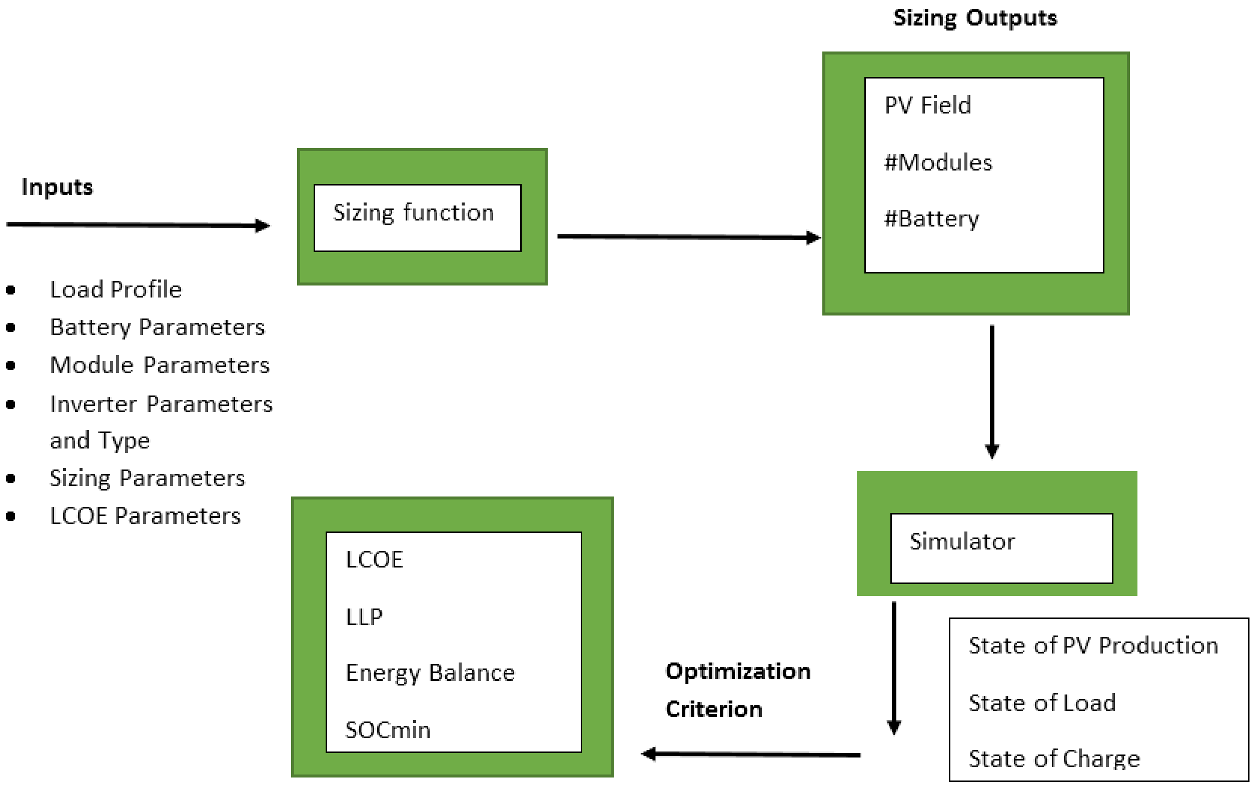
Cable Dimensions

The cable size, S can be approximated with the following equation:

$$S = \frac{(\rho * b * L * I)}{U * VI} \tag{24}$$

Where ρ is the electrical resistivity of material, L is the length of the cable, I is the current of the source (PV or battery), VI is the acceptable wire voltage drop percent, U is the voltage of the component, and b is 2 for $U = 230/220V$.

F: Matlab Sizing and Optimization Organigram

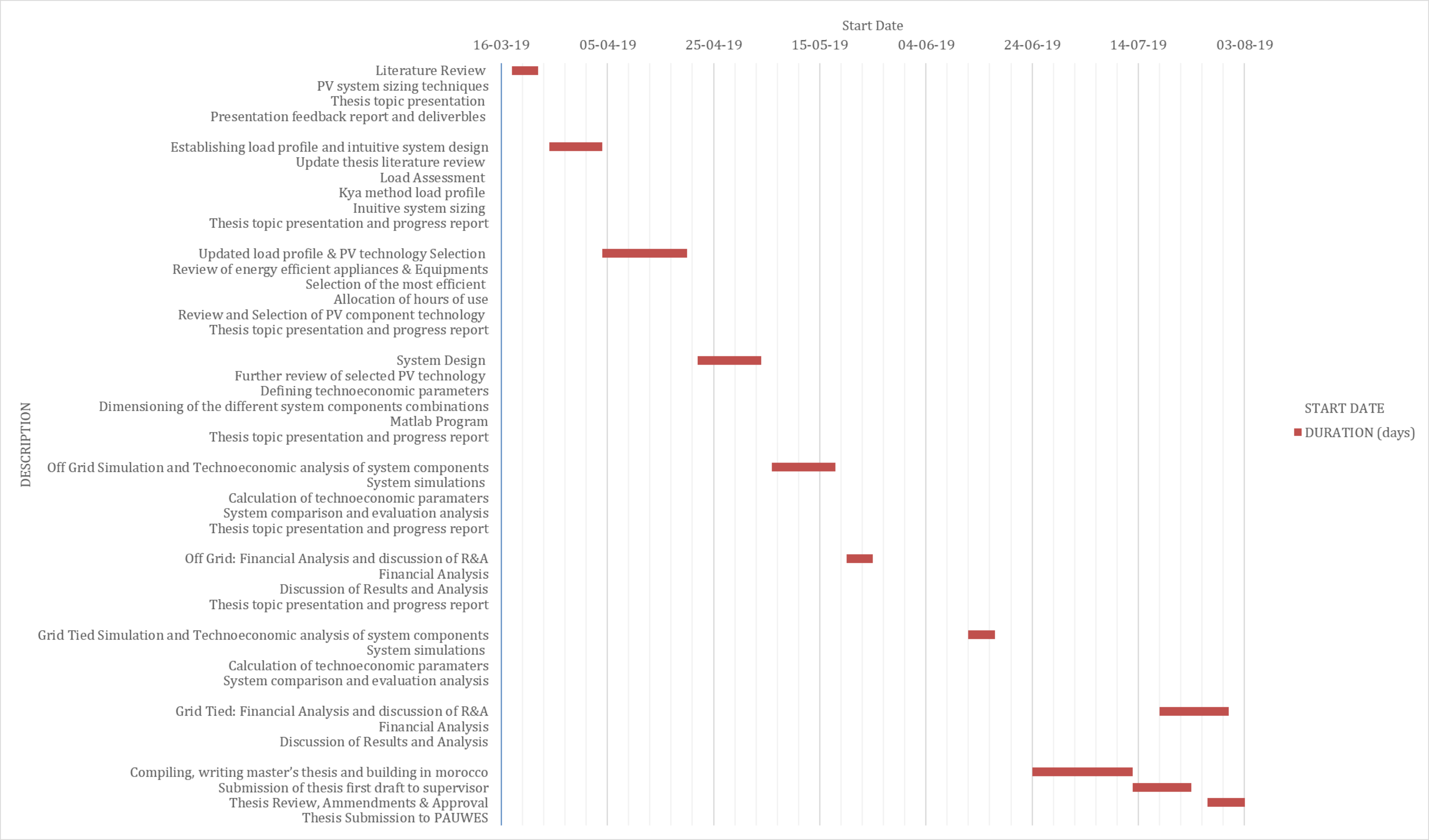


G: Master Thesis Budget

S/NO.	Item	Unit Price,$	Quantity	Amount, $	Link to research activity
A.	**Material and Supplies**				
1	System design software's license	$300.00	$1.00	$300.00	PV System design and optimization
2	Internet Services	$100.00	$2.00	$200.00	Online Research - Data collection
3	Online scientific journals/books	$50.00	$2.00	$100.00	Load consumption pattern, energy efficiency, PV optimization
B.	**Equipment**				
C.	**Travel + Visa costs**				
1	Flight from Tlemcen, Algeria to Lomé, Togo	$1,150.00	$1.00	$1,150.00	Thesis Research - data collection, methodology and system design
2	Visa to Togo	$50.00	$1.00	$50.00	

2	Flight from Tlemcen, Algeria to Ben Geurri, Morocco	$500.00	$1.00	$500.00	Thesis Internship - prototype building, implementation, site testing and site data collection
3	Field Transport Casablanca to Bengeurir	$200.00	$1.00	$200.00	Thesis Internship - prototype building, implementation, site testing and site data collection
4	Visa to morocco	$100.00	$1.00	$100.00	
5	Travel Insurance	$100.00	$1.00	$100.00	Research/Internship
D	**Special Activities**				
1	Administration fee	$100.00	$1.00	$100.00	
2	Report preparation	$100.00	$1.00	$100.00	Thesis publication/submission
3	Publication	$100.00	$1.00	$100.00	Thesis publication

H: Master Thesis Timeline



I: Curriculum Vitae

Shallirosena P. Mbwette

Pole Chetoune, Tlemcen 13000, Algeria
Home Address: P. O. BOX 31318, Dar-es-Salaam, Tanzania
+213540034579 | smbwette4@gmail.com |www.linkedin.com/mwlite/me

PERSONAL PROFILE

Innovative and confident energy engineering student from Tanzania, currently pursuing a Master's at the Pan African University Institute for Water and Energy Sciences (PAUWES). I have acquired a Bachelor's in engineering science with a concentration in electrical engineering and a minor in mathematics. Verified as an Engineer in Training (E.I.T) by the Texas Board of Professional Engineers, I am actively looking for opportunities within the Engineering discipline.

EDUCATION

2017 – today Pan African University institute of Water and Energy Sciences (PAUWES), Tlemcen, Algeria

Masters of Science in Energy Engineering.

Relevant Modules: Renewable Energy Technologies, Energy for Sustainable Development, Energy Economics, Finance & Management, Energy Conversion & Technologies, Thermal Science and Engineering Applications

2011 – 2015 Trinity University, San Antonio, USA

Bachelor in Engineering Science: Electrical Engineering & Electronics and 3.0

Relevant Modules: Calculus (I-III), Heat Transfer, Thermodynamics, Engineering Materials, Electric Circuits, Electronics, Control Systems, Mechatronics, Digital Logics, Engineering Design (I – VII)

Projects: CSI BORG Project (2014-15), Arduino Light Control Project (2013), Solar Car Project (2012)

2009 – 2011 Haven of Peace Academy (HOPAC), Dar-es-Salaam, Tanzania

A level: Physics, Chemistry and Mathematics.

WORK EXPERIENCE

March 2019–Ongoing KYA ENERGY GROUP, Lomé, Togo

MSc Energy Engineering Research

- Optimal design of innovative energy efficient and self-sufficient smart African solar house PV system

July 2018–September 2018 The Sustainability Institute, Stellenbosch, South Africa

MSc Energy Engineering Intern

- Mapping the sustainability institute's water, waste and energy systems using Auto CAD
- Creating a technical manual and report for the water, waste and energy systems
- Providing recommendations and solutions for effective use of the systems

August 2016–September 2017 Rex Energy, Dar-es-Salaam, Tanzania

Project Coordinator

- Coordination of the implementation of internal & external Off-Grid Solar projects.
- Supported, set and communicated project procedures and performance targets to project staff.
- Communicated and consulted with clients and project stakeholders.

April 2016 – December 2016 ENV CONSULT (T) LTD, Dar-es_Salaam, Tanzania

Assistant Project Coordinator

- Coordination of the development of the Tanzania to Uganda Pipeline Project's Desktop Study (DTS).
- Coordination of the development of a Strategic Environmental & Social Impact Assessment (SESIA) for the upstream Oil & Natural Gas Sub sector in Tanzania and regular exchange with the local government.

April 2016 – April 2017 eMaktaba Deployment Project, Dar-es-Salaam, Tanzania

Freelancer Project Coordinator

- Coordinated the implementation of an electronic library material management system for Tumaini University of Dar-es-Salaam.
- Trained and consulted with the Tumaini University team.
- Provided solutions to arising problems and requested information as per contract.

January 2016 – May 2016 WyzAnt Tutoring Company, Missouri, USA

Math and Engineering Tutor

- Coordinated multiple schedules in order to provide optimum service to all students.
- Conducted comprehensive test review sessions and prepared lesson plans.

September 2015 – December 2015 Youth Exploring Science (YES), Missouri, USA

Engineering Intern

- Developed, prepared, and presented various informal science learning activities to a cohort of teens in the Youth Exploring Science (YES) program utilizing Engineering research.
- Researched and developed a female and male cosmetic product line.

VOLUNTEERING

February 2016 – today First Robotics Competition, Missouri, USA

Field Supervisor

- Supervised field construction in collaboration with the FIRST Technical Advisor.
- Facilitated adherence to match timing.

- Monitored placement of robots within student groups.

November 2015 – today Venture Café Saint Louis, USA

Ambassador

- Engaged guests and newcomers to help them orient themselves.
- Helped troubleshoot kiosk and nametag printer issues.
- Helped with setup for the weekly gatherings.
- Networking with other ambassadors online

ORGANISATIONS, CLUBS & SOCIETIES

April/2018– today Solar Decathlon Africa: Electrical Engineer/Measured contest officer

- Co-founder of Team Jua jamii; one of the 20 decathletes of the solar decathlon Africa competition
- Designing the PV system and electrical system of the house

January/2018– today Community of Practice (CoP): Team Leader

- Leading the Technical Support and Evaluation Team for CoP platform at PAUWES

January/2016 – today National Society of Black Engineers (NSBE): International Member

- Engaging on NSBE platforms with other members
- Attended NSBE Youth Conference/Competition in Saint Louis
- Received mentoring by a Technical Profession

September 2015 – today Coder Girl Saint Louis: Coder

- Learned the basics of Java Language coding.
- Receiving coding language material.
- Active networking with other coders.

December/2015 – today Society of Women Engineers (SWE): Member

- Networking with other SWE members.
- Attended SWE conference in Austin.

August/2011 – August/2015 Institute of Electrical and Electronics Engineers: Collegiate Member

- Active communication with and support to other members via the IEEE platform.

QUALIFICATIONS, AWARDS AND PUBLICATIONS

- June 2018 Presenting at the RES2PRAC forum at PAUWES
- September 2017 Monthly Scholarship for Master's degree at PAUWES, Tlemcen (living expenses, tuition, full-board)
- April 2016 British Council Tanzania: Interview skills
- May 2015 Engineer in Training by Texas Board of Professional Engineers
- August 2011 National Merit Scholarship, Trinity University, USA

LANGUAGES

- Swahili: Mother Tongue
- English: Fluent
- French: Beginner
- Spanish: Beginner

TECHNICAL AND OTHER SKILLS

PV Design, Homer, RET Screen, Digital and Analog Circuit Design, Electrical Simulations, MATLAB, LabVIEW, Pro Engineer, AUTOCAD, Multisim, EES (Engineering Equation Solver), Excel, Bill of Materials, Scala, Assembly language (basic), Minitab, Logic Works, Maple, Google Sketch up, Adobe Premier Pro, Communication, Troubleshooting.

Energy expert, Planning and Prioritizing, Presentation Skills, Project Management, Time Management, Active Listening, Problem Solving, Critical thinking.

REFERENCES

Available upon request.