College of Science and Technology

TITLE: DESIGN AND COST ANALYSIS OF AN OFF GRID SOLAR GRAIN MILL

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Declaration

I, the undersigned, declare that this dissertation is my original work, and has not been presented for a degree in University of Rwanda or any other universities. All sources of materials that will be used for the thesis work will have been fully acknowledged.

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Signature

Date of Submission**:** ______ ______

This dissertation has been submitted for examination with my approval as a university advisor.

DR. FRANCIS MULOLANI

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Abstract

OFF grid solar photovoltaic system turns solar irradiance into electricity to be used in remote areas without connecting to the national grid. Normally in those areas, they are using diesel engines in their daily activities which have negative effect on the environment. To reduce this effect of these thermal engines, this project designs a solar system that will replace those engines. An off grid solar grain mill provides the grain mill services to those people in remote areas far from national grid. The system under design uses the solar home system components such as PV modules, charge controller, batteries and an inverter as generation component and grain mill machine. It has the capacity of 10.8Kw where 7.5kW of them is used to run grain mill machine and the remaining is used for local community in lighting purpose. Design and simulation was done by use of MATLAB SIMULINK for solar system while for grain mill there is use of SOLID WORKS software. The research method includes site survey, data collection in different organization related to agriculture and energy sector and weather condition. As a result of the project, the system under design has been simulated via software and shown the ability to have the characteristics as the one of the national grids in running grain mill machine. The all system will provide the ways of getting services to people who don't have the access to the electricity especially whose daily life is agriculture.

Keywords: Off grid system, Rural electrification, Renewable Energy, Hybrid System, PV, carbon emission, MATLAB Simulink and SOLIDWORKS, grain mill machine

DEDICATION

I, NSHIMYUMUKIZA THEOGENE, dedicate this work:

To my parents,

To my brothers and sisters,

To my families and relatives

Especially this work is dedicated to my almighty God

ACKNOWLEDGEMENT

This work was important as future field Engineer and could not have been successfully carried out without the contribution of many peoples to whom, I extend my appreciations. Firstly, I thank my God for his abundant blessing and protection in my life.
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Our profound appreciation goes to my parents for their grateful support. I cannot forget my brothers, sisters and my families for their encouragements and players. I will never forget or ignore that we received from them.

Finally, I am also thankful to my colleagues especially my classmates for whom shared experiences and culture during class time, and all members participated either directly or indirectly to the completion of this work due to its excellent advice and guiding regarding this work during the whole time.

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List of Abbreviations

GDP Global Domestic Product

PV Photovoltaic

REG Rwanda Energy Group

MPPT Maximum Power Point Tracker

DC Direct Current

MW Mega Watt

CO2 Dioxide of Carbon

NASA National Aeronautics and Space Administration

CO carbon monoxides

LPG Liquefied Petroleum Gas

SHS solar home systems

REG Rwanda Energy Group

AC Alternating Current

LCCA Life-Cycle Cost Analysis

1. INTRODUCTION

1.0.General introduction

Due to the speed of the development of our country, the dependence of electricity for most of everyday activities are a problem that leads to high production. This dependence also demonstrates why electricity is regarded as one of the most significant sociological and economical in agriculture sector in this period.

The agricultural sector is the oldest and most widespread industry in the world [1]. In agriculture-based economies of sub-Saharan Africa particularly in Rwanda, agriculture is the main economic activity with 70% of the population engaged in this sector [2]. In Rwanda, the agriculture sector account for 33% of national GDP (Global Domestic Product). In general, Rwanda's GDP has been growing at the rate of 12.21% in 2019 [3]. Tea and coffee are the major exports while plantains, cassava, sweet potatoes, maize, rice, cassava flour, maize flour, poultry, and live animals with eastern Africa [2].

Transforming of harvest in various areas under various economic, environmental, social, and political constraints is one of the major challenges.

The latest record on agriculture production for food in the world shows that many crops have been milled to produce flour for cooking. Traditional crops such as yam, sorghum, millet and teff have been milled for centuries either with a crude mortar and pestle fashioned from a tree stump and branch or by using flat stones or rubbing stones [4]. From 18^{th} centuries, the agriculture has been advanced and the increased of plantations of different types such as maize, rice, beans, cassava, soya and other. Those harvests are for daily consumption by very big populated areas like military, schools etc and require to be transformed before being used. An example here is removing husks on the rice by hulling principle which is a process of applying friction to the grains to remove the outer part which is not consumable. This process is done traditionally by using two stone, knives or perforated plates. Rice has traditionally been hulled with mortar and pestle to remove the husk [4].

With the technology improvement where there is much wind associated with high speed, they developed the rotating system (wind mills) which is able to do the same task using wind energy and then produce the desired product. This is also failed due to the intermittent of wind and not also to be found in all location on the earth.

With the invention of rotating machine in mid-nineteenth, the development of the high-speed rotating grain mill using electricity or fuel engine has become the best solution in industrial processing especially small scare industrial processing for problem of intermittent of wind and the use of mortar and pestle which were used before.

The production of electricity in Rwanda concerns of hydropower plants, solar system, thermal power plant using fuel, coal, methane gas etc [1][5].

Due to the low production of electricity compare to the demand, there are some areas which are not able to have electricity. To do their day to day activities there is the use of diesel engines especially in remote area. When burning fuel oil in an engine, it produces some amount of power but also a big quantity of smoke with high temperature is ejected in atmosphere as a result of combustion. The heat sent in atmosphere causes the climate change, global warming, and reduction of rain and destruction of ozone.

This research is going to be based on how to replace internal combustion engines especially fuel engines used in agro-processing business by solar powered system for reduction of emission in atmosphere. The electricity generation of the country will be increased through this process and therefore, there is increasing of energy access and reduction of fuel oil to be used in transformation of different agricultural products toward development of the country and environment protection.

1.1. Background

In Rwanda, electricity availability and consumption are a critical input for agriculture, economic, social and political development of a country [1]. Energy is a service and a key input into economic development and household activity. Electricity is an essential driver of modern technology and socio-economic development. Use of electricity is required for both low consumption devices such as lights and mobile phones and large users such small and large scare industrial processing activities. Since those activities require electricity, there is a power shortage.

The scarcity of electricity in comparison to the demand leads to the supply of electricity in the priority areas including residential, industrial, etc. Other villages located in remote areas fall from national grid especially of agriculture based are the most people with the challenges in electricity access.

The transformation of their agricultural products and irrigation of plantation are also problems which lead to the use of thermal engines using diesel or gasoline which helps them to do their day to day activities. This project is going to eliminate thermal engines used in small scare industrial agro processing of agricultural products of people located far from national grid and also walking distance for finding services.

1.2. Statement of the Problem

In Rwanda there is the shortage of electrical energy, as in many developing countries, the demand of energy is superior to the production. Currently, the energy access is 52.8% corresponding to 224.6MW as total electrical generation and targeting to shift to 100% corresponding to 556MW by 2024 [1]. As the production of electrical energy is insufficient, to supply the power for all population and industries is more difficult. Because Rwanda is still suffering from energy shortage, for overcoming those problems thermal engines using diesel, gasoline etc are used in rural areas for agricultural activities such as irrigation, small scare industrial processing of harvest to consumable product.

The oldest transformation technique uses mortar and pestle to produce the flour from grains with the action of force from human being. Nowadays with technology, there is the use of rotating machines which uses electricity or fuel to produce mechanical force that replaces the human being.

By analyzing the status on energy access in Rwanda, it shows that big population does have electricity in their home. Therefore, there is the use of internal combustion engines which use diesel or gasoline in flour production and irrigation of some areas.

When burning coal, fuels like petroleum product, carbon dioxide and other gases are released in the atmosphere. These emission heat atmospheres which cause temperature rise, the sea level change, extremely storms and other problems related to the climate change.

Since these systems which use internal combustion principle have high impact on environment, they can be replaced by solar system to produce electricity which will increase the overall electricity access of the country, performing the same task in agriculture sector and this reduces these environmental impacts. It will also provide harvest transformation services to customers at minimum distance and cost as compared to fuel systems.

1.3. Objectives

1.3.1. Major Objective

The main objective of this project is to design and simulate 10.8kW off grid solar system that use grain mill machine and 20 surrounding families.

1.3.2. The Specific Objective

- ✓ Design and selection of solar component based on capacity of the system
- ✓ Simulation of 10.8kW solar off grid system
- ✓ Mechanical design of the grain mill machine
- ✓ Cost estimation of 10.8kW solar off grid system

1.4. Scope of the study

Due to the limitation of knowledge, time and budget, this research project investigates the performance of OFF grid Solar powered milling machines used in small scare agro processing and by use of the result gained it will show how to design solar OFF grid system, grain mill machine and the impact of the use toward environment protection.

1.5. Expected Outcomes and Significance of the Study

1.5.1. Expected Outcome of the Study

- To have an off grid solar grain mill machine of 10.8kW capacity for small scale agro-processing ready to be implemented.
- At the end of this research, it will be possible to show how to increase the energy generated in the country by 10.8kW for each constructed small scare solar system to be used in agriculture (irrigation, grain mill, etc)

1.5.2. Significance of the Study

- As the result expected to this research, is possible to show how people who will be surrounding the project are going to benefit the services near their home place if implemented.
- The energy access will be increased by this project since families using this system are accessing the electricity for their home directly.
- To show the impact of internal combustion to environmental impact and the ways to mitigate them.
- To show economic impact of solar off grid system for the purpose the elimination of the use fuel used in agro-processing business.

1.6. Thesis Outline

Chapter 2 reviews the off grid solar systems design and their different application toward environment protection and increase in energy access for rural areas, design of grain mill machines and their various types and carbon emission in atmosphere.

Chapter 3 deals with methodology used in the research including data collection from different location and institution and method that will be used in data analysis. Here MATLAB SIMULINK and SOLID WORKS are the software tools to be used in the design and simulation.

Chapter 4 discusses design of an off grid solar grain mill components. This include electrical to mechanical parts. Electrical side is based on sizing of component of solar system and mechanical side is based on design of grain mill machine in solid work software. Chapter 5 discusses simulation of component in MATLAB SIMULINNK and their results obtained Chapter 6 then present the cost analysis of the project.

Chapter 7 conclusion and recommendation

1.7. Research Limitations

This these had the following limitations

- ✓ Budget to be used in the implementation of prototype
- ✓ Luck of information from some organizations (Some participants related to the study of the project may refused to speak against their organization)

2. REVIEW ON SOLAR OFF GRID MILLING SYSTEM

Shortage of energy sources and pollution of environment in the world are becoming increasingly serious. Shifting from thermal power plant to renewable energy source is one of the solutions of the problem. Therefore, solar PV power generation, as a kind of clean energy has brought to the attention of the countries all over the world for environment protection.

Many researches have been done on solar energy generation and their different application. This Chapter, is going to discuss on some of the research and publication that already exist toward the design of an off grid solar grain mill machine.

They are categorized in three applications which are off grid solar, grain mill machines and environment protection especially carbon emission from internal combustion engines.

2.1. Previous related research work

2.1.1. Review on Off grid solar system

Mohammed Boussetta, Rachid Elbachtiri and Maha Khanfara [6] in their research, their objective was assessing the potential of Hybrid Off grid System compared to stand-alone systems for protection of environment. To meet their objective, an economic and ecological study of all possible hybrid systems such as a combination of PV-Diesel system, Wind-Diesel system, and Diesel system was done by Homer-pro software which was based on the net present cost, the emissions and renewable fraction for a project whose life span is 25years.

At the end of their research, an ecological evaluation of these different hybrid combinations was performed and calculation of the rate of emissions in atmosphere for all off-grid systems and then compared to the rate of air pollution created by diesel engine system.

This paper has been selected due to its potential in demonstration of effect of internal combustion engines on the environment.

S. Gutiérrez (2017)[7] in his study focused on design and the implementation of an off grid solar photovoltaic system with low cost solar tracking system. A prototype has been produced whose area of the photovoltaic module is always perpendicular to solar irradiance by help of an algorithm programmed inserted in microcontroller.

As a result, this research has shown that the use of a solar tracking system for off-grid photovoltaic systems increases the energy generated by values between 12.7% and 26.1% as compared to the one without solar tracking systems. This has more importance in design of solar system which reduces the number of PVs that should be used on the project and the cost reduction.

This paper has been selected due to the value of solar tracker in increasing of the output of the solar generation system.

Ajan.A and K.Prem Kumar (2015) [5] the aim of their study was the development of a 5KW off grid solar PV system and to analyze the performance of that system under varying climatic change conditions. To achieve the objective of their study, the development of model of components on solar off grid system was been developed in MATLAB SIMULINK and simulated.

As a result of this research, SIMULINK model developed is used for performance analysis of the solar PV system under varying weather conditions. The power generation changes, energy efficiency of components and losses in the system have been quantified.

This paper has been selected due to the information that it provides related to the simulation of result of solar off grid system in MATLAB SIMULINK and as a useful tool to give sizing of components.

Wu Dengsheng, Wang Lidi, Wu Xiuhua, Meng Xiaofang, Wang Jun, Guo Dan, and Wang Hui(2016)[8] in their research whose aim was to design to show how to design solar off grid system components and emphasize on system stability, reliability and the use of these system on the purpose of environment protection.
To achieve their target, a mathematical model of formulas of sizing components have been developed and used to size components based on load. In addition to this, among the component a WIFI model has been added which helped to improve communication services with manufacture or service provider (seller).
As a result, this research has shown an application form of PV power generation system especially off-grid solar PV power generation system for the remote areas far from national grid. These include island, remote mountains, desert, prairie where it is difficult or expensive to construct kiosks, tower, resting for national grid.
This paper has been selected due to the information that it provides related to the ways of sizing of components of solar off grid system and interfacing with users.

Aryulius Jasuan, Zainuddin Nawawi and Hazairin Samaulah(2018) [9] in their research whose aim was to compare the off-grid PV systems and grid connected systems in Indonesia in line with market prices. To achieve on the way to compare the two, they developed mathematical formulas to help to calculate the components size on each case from grid to off grid system. In addition to these formulas, there is also development of mathematical formulas to calculate the carbon emission in atmosphere for environment protection purpose and unit generation cost.
As a result of this study, based on generating costs of solar power plants can be used to supply electricity in urban areas especially those with low income, agriculture based and to reduce the production of CO_2 emission in atmosphere.
This paper has been selected due to the information that it provides related to the ways of sizing of components of solar off grid system and carbon emission reduction for protection of environment.

Morteza Khatami, Hashem Mortazavi, Mostafa Rajabi Mashhadi and Mahdi Oloomi (2013) [10] in their study which aims in designing an Off-Grid PV System for a Residential Consumer**.** To achieve this objective, the data was collected related to energy demand, solar data was obtained from NASA web site and RETSCREEN software, a model of mathematical formula of component sizing was used
As a result of this study, they have been able to design solar off grid system and analyzed as compared to the existing generation system.
This paper has been selected due to the information that it provides related to the ways of data collection for solar systems and to apply them in designing of components of solar off grid system.

Adithya Rajeev and K. Shanmukha Sundar [11] in their study which aim to design off grid solar PV systems that replace the use of kerosene and diesel for home lighting in rural areas. To achieve their target a survey has been done to know the basic equipment that are used in rural areas, they described the solar home system component and mathematical model developed and sized accordingly.
Software Tool was which was used to simulate is Power Sim Software version 9.2

The result of this study shows that solar home system is able to be used in place of kerosene with minimum cost end environmental impacts.
This paper has been selected due to the information that it provides related to the ways of sizing of components of solar off grid system and interfacing with users.

Anusha Ramachandran, Sairam Mannar, and Ashok Jhunjhunwala [12] in their study whose aim was to design Inverterless Solar- DC System for Off-Grid and Near Off-Grid. This was good approach to solve the electrification crisis of off-grid and near off-grid homes by using inverterless Solar DC system.
To achieve their goals, the data collection on different villages was done and from that information a mathematical model of equation was that which allowed to size different component of solar home system.
As a result, they have been able to develop a model of solar home system which works without an inverter that convert DC to AC with high efficiency and providing electricity to all homes which are not having access to national grid at lower costs.
This paper has been selected due to the information that it provides to the comparison between the solar off grid system with and without inverter

S. S. S. Ranjit, C. F. Tan and S. K. Subramaniam (2011) in their research whose aim was implement an off-grid solar photovoltaic system for electrifications purposes to an existing bus stations at Melaka, Malaysia**.**
To achieve the target of the study, calculation has been carried out to determine the system size and Real-time HOMER software was used to capture the availability of solar radiation reading based on satellite readings.
As result from this study, the Off-Grid Solar Powered System was developed and installed in the existing bus stop. There well no completely serious problems for the developed Off-Grid Solar Powered System during the system operation hours and days[13].

C. Aarthy Vigneshwari, S. Siva Sakthi Velan, M. Venkateshwaran, M. Adam Mydeen, V. Kirubakaran and M. Tech Scholar (2016) [14]in their study whose aim is to propose the performance and economic analysis of on-grid and off-grid solar system.
To achieve their objective, a mathematical model of calculation of different economical parameters like as payback period and profit were providing for having the ways of analysis.
As a result of this research has shown that by calculation, both the systems tend to be economical over a period of time after the payback years.
Even if maintenance cost and battery cost are very high for an off-grid solar system, the payback and profits are higher also as compared to on-grid solar systems. In their calculation, they end up by proving that the off-grid system is more economical and profitable as compared to the on-grid solar systems.

2.1.2. Review on Grain mill machines

Brian Clarke and Alexandra Rottger (2006) [4] in their document whose objective is to provide information on various types of hullers and small mills available in Africa.
It gives the advises how to select milling equipment, and how to install, operate and maintain small mills depending on their types.

Bhagyashree Mahale, Prof. Sapana Korde [15] in their research with aim of identification of rice quality and evaluation of rice grains on the basis of grain size and shape using image processing techniques.
To achieve their objective, they used a camera to capture picture whose size is 640 X 380 pixels and that image is sent to desktop computer so that it is manipulated(zoomed).
NI labVIEW software is used to implement image processing algorithm for analyzing the quality of the rice from that taken image.
As the result of this research, there is classification of rice quality based on length, breadth and length-breadth.
This paper has been interesting according to the ways of classifying of grain based on their quality and this can be applied to grain to be processed on grain mill under design.

Gregory D. Williams, et al., (2007) [16] in their paper with aim of Planning, Structural, and Life Safety Considerations on the grain mill machines. In this document design procedures for flour milling facilities are provided.
An overview of official standards and procedures has been was collected together and discussed in this document.
This paper provides useful information that helps in designing of grain mill machine with standard.

Shixiong Zhang et al., (2018) [17] in their study with aim of design method for the controller of flour mill with differential pair rollers driven by dual motors.
The core concept in this research is to drive the fast roller and the slow roller of flour milling machine with respectively by two independent variable frequency motors in order to optionally adjust the rotating speeds of fast roller and slow roller and the rotating speed ratio of the roller-crushing flour mill within the allowable process range, thus realizing excellent flour milling effect.

To achieve this, model of the machine has been developed and simulated in MATLAB Simulink and the result has been present with the development of manufacturing process and control technology of modern flour milling and hulling.
This document is used because they proposed a method of design of flour mill.

2.1.3. Review on diesel engine Carbon emission

Assistant Prof. Hassan abdul-whab Anjel et al., [19] in their research whose aim was to evaluate the quality of local fuel on exhaust emissions on diesel engines and also this study also focuses on investigating of the effect of cetane number of different type of fuel from different location and ethanol blended 8% on the emission characteristics in a single cylinder direct injection diesel engine under variable load and speed.
To achieve their goal, experimental studies were done in the internal combustion engine laboratory in Baghdad Technology Institute, department of machines and equipment.

As a result of this research, the % of emission from different areas were identified and the negative impact to the environment have been discussed based on the location and all of them are in the range of causing global warming.
This paper provides useful information that helps in understanding carbon emission in atmosphere from the internal combustion engine especially diesel engines.

D. Ganesh and G. Gowrishankar [20] where they had the aim of studying the effect of Nanofuel additives such as Magnalium (Al-Mg) and cobalt oxide (CO_3O_4) on the performance and emission characteristics of Jatropha biodiesel (B100) in single cylinder, air cooled, direct injection diesel engine.
To achieve on their objective, the nano particles were prepared by both chemical reaction and physical method, Cobalt oxide nano particle was prepared by Sol-Gel method which is chemical reaction method also and Magnalium which is physical method was prepared by Ball Mill process.
The prepared nano particles were added to the biodiesel and dispersion stability of the solution were studied.
As the result of all of those chemical reaction, there is a reduction in HC emission by using biodiesel because of its fuel bound O2, NOx emission in atmosphere increases by using biodiesel (B100) compare to diesel and reduction in CO emission in atmosphere was observed with cobalt oxide and magnalium Nano-fuel additive.
This paper provides useful information and advices that helps in understanding fuel to be used in diesel engines that can give at least minimum impact on environment.

Chalita Kaewbuddee et al., [21]with the aim of studying of Diesel engine performance and emissions using fuel blends by pyrolysis of waste plastic oil compared with waste plastic oil mixed with n-butanol.
To achieve on their objective, physical properties of fuel and its mixture on diesel engine which mounted on a gas exhaust detector have been tested.
The detector was used to test Nitrogen oxides (NOx) and carbon monoxides (CO) that was going in atmosphere. The engine fuel consumption was also examined by adjusting speed of the engine.
As a result, from this study in each test among all test done, emissions of exhaust gases in atmosphere such as NOx and CO were recorded and analyzed. The carbon monoxide emission increased with the ratio of the butanol-waste plastic oil blends, with this increase being higher the percentage of butanol in the blend which is too bad to the environment.

This paper also has been selected based on the experimental work done there related to carbon emission in atmosphere.

In general Due to the effect of internal combustion engines on environment, carbon has to be reduced to the minimum possible value by using different techniques like Shifting from thermal power plants (Diesel, gasoline, peat, methane etc) to renewable energy resources (hydro, solar, geothermal, wind,…) for electricity generation, replacement of firewood by LPG and biogas for cooking, shifting from fuel powered vehicles to electrical vehicles and replacement of small-scale diesel engines by solar power systems.

2.2. Gap identification

Today, many renewable sources such as solar, wind, and tidal is being exploited for the energy generation. Solar is a clean and infinite source of energy that can be used for several applications. Generally, solar PV systems can be an off-grid solar PV power generation system, on-grid solar PV power generation system or the hybrid generation system.

Due to the effect of PV power generation on national grid such as the power quality problems, the islanding problem, the problems on reliability and stability and the matters of grid benefit, off-grid solar PV power generation system can utilize solar energy effectively with its high flexibility, in order to absorb distributed load [18].

It is very good to use the off-grid solar PV power generation system in some regions far away from the power grid: island, remote mountains, desert, prairie and so on; also, in the place that is difficult or expensive for construction of transmission lines like kiosks, tower, resting places and indicator lights on the motorway. Many of these regions use solar home systems (SHS) for their daily lighting, charging mobile phone and other very small appliances. Other application with high consumption like grain mills for floor production, they usually use thermal engines mainly diesel engines which are also complicate in fuel delivery, thus causing increases of its prices and significant cost of power generation. One of the solutions is to use renewable natural power resources for energy supply, in particular solar energy. It allows the reduction of diesel fuel consumption, budget subsidies for price leveling for consumers and reduction of environmental impacts [6].

Generally, people living in remote areas work 100kms from their home to the place where they can get services and carrying their harvest for floor production is very difficult due to transportation facilities.

This research is based on design of an off-grid system which is providing electricity to be used by a grain mills for small scale industrial processing business for providing services to people located in remote areas fall from national grid.

3. RESEARCH METHODOLOGY AND MATERIALS

3.1. Introduction

In the project design and cost analysis of OFF grid solar grain mill system, there is requirement of many information related to agriculture sector in a given area where it will be used, time the production is too much at high level, weather condition for having the sustainable system which can give services to customers, cost of production of the unit kilogram of flour, cost of electricity in utilities etc. for developing the best material which will be strong on the market.

This chapter is going to describe the method and materials used in the research, research approach, the method which is used in data collection from different institution and people, the selection of sampling areas and community based on agriculture and energy sectors, the research process, data analysis based on electricity cost to flour production toward payback period, the ethical considerations and the research limitations of the project. All of these stages are achieved by use of Documentation from library, Documentation from lecturer's notes, internet documentation, site visit survey, and use of software (MATLAB SIMULINK and SOLID WORKS) and advices from our supervisor.

3.2. Research strategy

The research on off grid system in Rwanda are not new but not more applied on milling system which are more consumers of electricity in villages. Rather, numerous pieces of previous academic research on electricity generation from solar in promoting renewable energy resource and increasing energy access in rural areas, not only for Rwanda but also in East Africa and all over the world for reduction of flue gases ejected in atmosphere due to internal combustion of fuel oil in rural areas where there is no electricity.

As such, the proposed research takes the form of a new research but on an existing research subject of reduction of diesel engines toward protection of environment.

3.3. Research method

This is done in two different techniques which are qualitative and quantitative techniques

In order to enrich the objectives of this these, a qualitative research was done. This include interviews for asking people from rural area the distance that they walking for getting the flour for home consumption and to compare the flour produced using the fuels engines and the one produced using electricity for benefiting to the new project that can be implemented near them.
On quantitative techniques, there is recording of the weight that the customers bring to the current grain each and every day for knowing how much is the production needs to be processed per day or per week in a period of three months for knowing the capacity of the machine needed and money obtained for determining the payback period of the project.
In addition to this, there is recoding the walking time in hours and distance in kilometer so that at the end of this project it will be possible to know the people who are suffering due to missing of nearest service provider.

This is done on the existing two grain mills located in two different positions for having a good comparison of data to be used in design in a period of two months.

3.4. Data collection method and tools

3.4.1. Face to face Interviews

In this part of data collection, there is interview to the owner of the grain mills related to the services that they provide, and to their customers to know the services that they receive.
For getting enough information to be used in this research, depth interviews are used. It has the aim of identifying rural people emotions, feelings, and opinions regarding a production of flour in the nearest place using solar powered system than diesel engines.

The main advantage of these interviews is to involve the people who are benefiting the use grain mill machine since they are the main customers. This interview offers of getting correct information related to the crops production according to each season, availability of some type plant like cassava which is available one time in the year and others which are available for every season.

All of this information from the customers will be summarized in the following figure which helps in data analysis and estimation of payback period of the designed project.

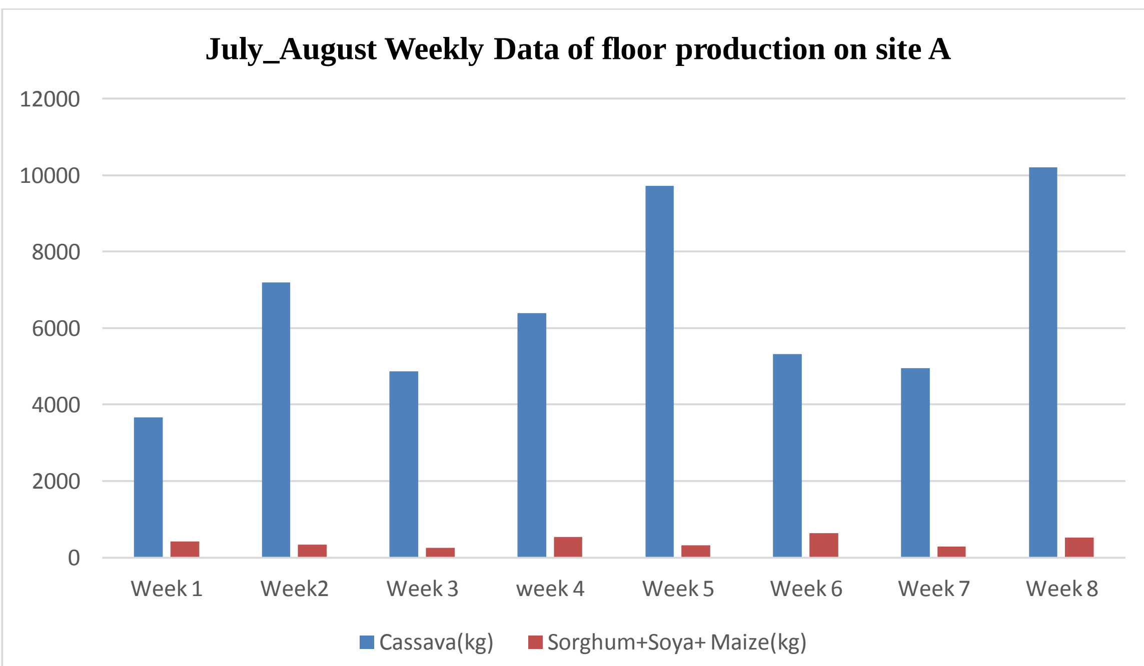

Figure 3-1: Flour Production on site A

From the above graphs, the average floor production per day is 850kg per day

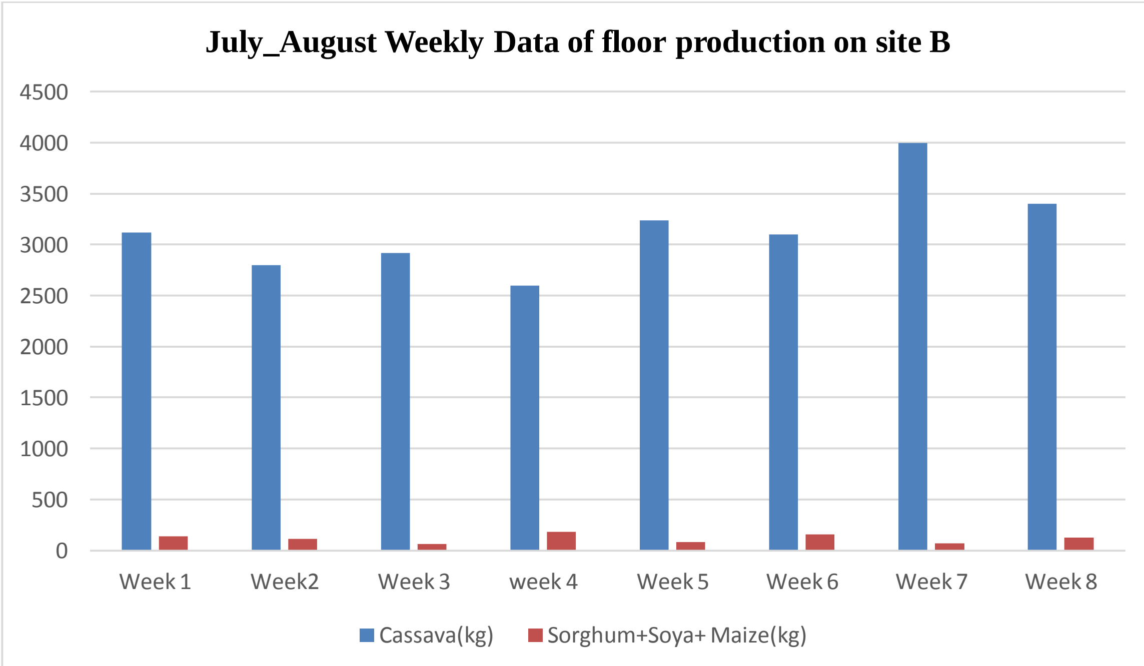

Figure 3-2: Flour production on site B

From the above data, the average floor production on this site is 420kg per day.
Combining the two sites the average production per day becomes 650kg per day but this value can go up or down for some time.

3.4.2. Data collection from organizations

Apart of the interviews, there is also data collection related to weather condition and climatic changes which will be used in design of the sustainable system.
Those data include precipitation, temperature, wind speed and direction, irradiance, peak sun hours in each district. These are more useful in design of solar system because depending on the region the same machine will not have the same performance. This is obtained from Rwanda Meteorology agency.

In addition to this, there is also to know the crop production in Rwanda and specification of each depending on the region. An example here is that in Eastern province of Rwanda, the production of maize is more advanced that other regions. So, the design of the machine which will be used in that region has to be done carefully and with precision and with powerful storage system due to many working hours per day. This is obtained from Ministry of Agriculture and Animal Resources and from survey to the existing gain mills.

Lastly, there is also the need to know the electricity cost and the focus areas where there is no electricity. This is based on the fact that the energy access in Rwanda is 52% and the remaining part of about 48% is in black out. To know this part without electricity requires data from Energy Utility Corporation limited (EUCL)

3.4.2.1. Areas of focus

As of September 2020, the cumulative connectivity rate is 56.7% of Rwandan households in which 41.3% are connected to the national grid and 15.4% accessing off-grid systems (mainly solar home system)[22].

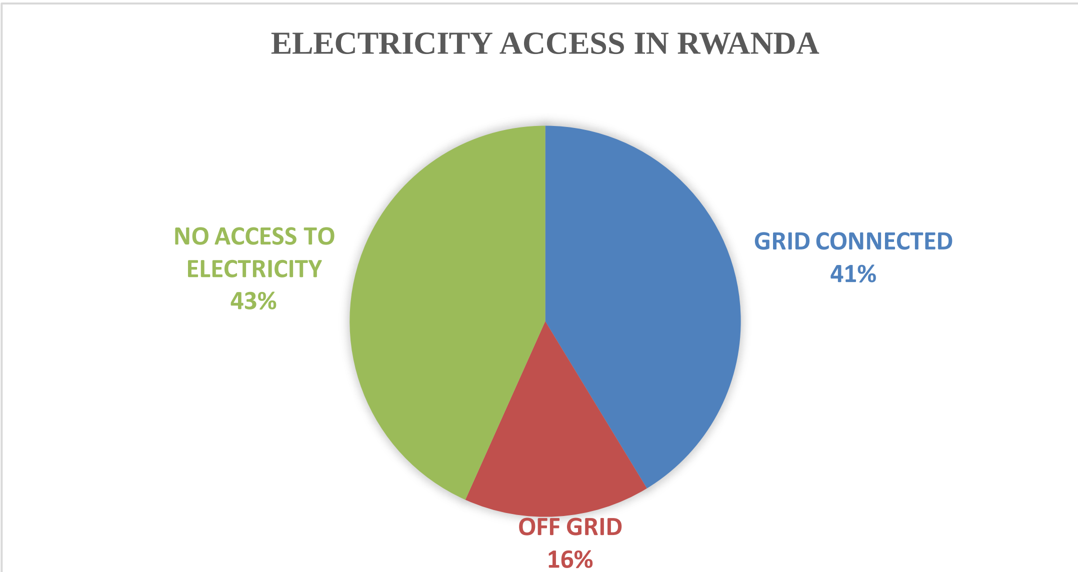

Figure 3-3: Electricity access in Rwanda

Most of people with challenge in energy access are located in villages especially with agriculture based and to have electricity requires high cost due to long transmission lines and in their low income.

The current access targets stipulate a 100% household's access to electricity by the year 2024 while productive users will be all connected before the end of the year 2022. To achieve this target, REG intends to increase the number of new connections by 500,000 every year, including 200,000 on-grids and 300,000 off-grids[22].

To get well the areas of focus there is requirement of knowing which region is having electricity and which region is not having electricity. To get the simple answer we can bas on the district energy access

The district-based agriculture, having lower energy access and strong solar irradiance are to be considered in this project. To know them we are base on their location (East, Kigali city, West and North province) which also influence the amount of energy that can be produced there.

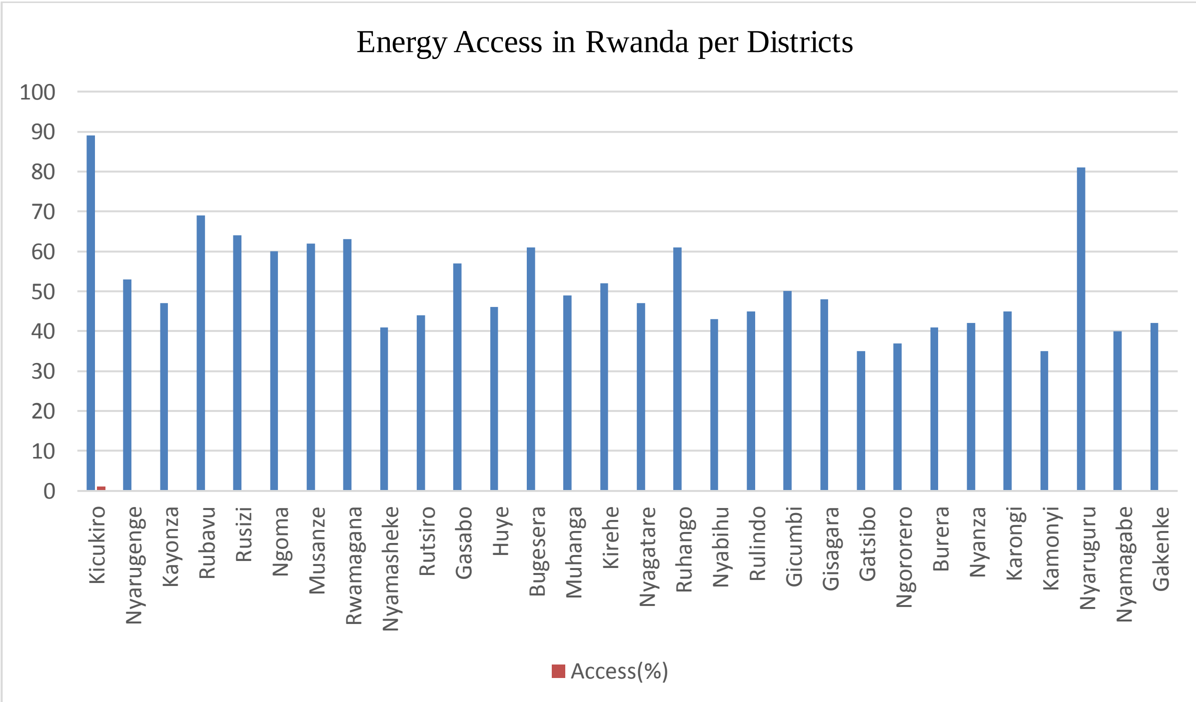

Figure 3-4: Electricity access in different districts

3.4.2.2. Cost of electricity in Rwanda

The main aim of this part of cost of electricity is to know how much it is sold so that the local community is able to pay the same amount and to allow use the calculation of payback period from income generated in the project under the study.
The electricity cost in Rwanda is based on how much the consumption per year. This consumption allows having categories that are used in payment of electricity.

Table 3-1: Tariffs for Non-Industrial Customers Categories [22]

Category	**Consumption (Kwh) Block/Month**	**Frw/Kwh (Vat Exclusive)**
Residential	[0-15]	89
	[>15 – 50]	212
	>50	249
Non-Residential	[0-100]	227
	>100	255
Telecom Towers	All	201
Water Treatment plants and Water pumping stations	All	126
Hotels	All	157
Health Facilities	All	186
Broadcasters	All	192
Commercial Data Centres	All	179

- **Tariffs for Industrial Customers Categories**

Industrial customers are those registered as industries with Rwanda Development Board (RDB). Industrial customers are categorized based on their level of consumption defined as small, medium and large [22]

Table 3-2: Categories of consumers [22]

Industry Category	Annual Consumption (Kwh/Year)
Small	≤ 22,000
Medium	> 22,000 - 660,000
Large	> 660,000

Table 3-3: Industrial Tariff per Category [22]

Category	Energy charge (FRW/kWh)	Maximum Demand Charge (Frw/Kva/Month)			Customer Service Charge (Frw/Month)
		Peak (06:00pm-10:59pm	Shoulder (08:00am-05:59pm)	Off-Peak (11:00pm-07:59am)	
Small	134	11,017	4,008	1,691	10,000
Medium	103	10,514	3,588	1,292	10,000
Large	94	7,184	2,004	886	10,000

- **Flat Rates for Industrial Customers without Smart Meters**

Industrial customers without smart meters shall be charged at flat rates until the smart meters are installed in their facilities in order to apply the Time of Use tariff described in section in table 3 above [22].

Table 3-4: The flat rates [22]

Industry Category	Flat Rate (Frw/Kwh, Vat & Regulatory Fee Exclusive)
Small	151
Medium	123
Large	106

Based on the energy access in Rwanda, agriculture sector and weather conditions the best place for the project is in Eastern province of the country.
Cost of electricity in Rwanda, quantity of grains (harvest) which needs to be transformed and weather condition are important it the design of the system to be designed

3.4.3. Instruments or Equipment (tools)

To achieve the main objective of the project, there is the requirement of knowledge of the capacity of the machine under design and this correspond to the weight of grain coming for servicing. The weight is recorded to two different positions by use of spring balance.
On other hand, there is the need of the solar radiation capacity to know how much can be generated because the output of solar system is based on irradiance input. This is measured by Luxmeter.

3.4.3.1. Spring balance

The tools which are required in this project are spring balance for recording weighting each sack of flour after milling for knowing how much to be paid by customer coming to the grain mill. Where there is this machine, they usually have them. The value obtained to the balance must be recorded in a notebook to know the rate of production of the machine which will help in cost analysis and payback period calculation.

Figure 3-5: Spring balance

3.4.3.2. Lux meter

A luxmeter or light meter is used to measure the illuminance radiation. It is interested to know the irradiance in W/m^2 available in a given area where there is a plan to construct a solar power plant.

Figure 3-6: Lux meter

This instrument was used to record the irradiance of solar in two different areas for getting good comparison between values obtained and then calculating the average value that is used in the design of solar off grid grain mill.

Table 3-5: Average solar irradiance

Time and corresponding irradiance			
Morning hours	Irradiance (W/m^2)	Afternoon hours	Irradiance (W/m^2)
6h00	105	12h30	765
6h30	170	13h00	834
7h00	360	13h30	732
7h30	610	14h00	702
8h00	670	14h30	570
8h30	770	15h00	635
9h00	740	15h30	420
9h30	796	16h00	405
10h00	815	16h30	214
10h30	830	17h00	128
11h00	824	17h30	21
11h30	750	18h00	5
12h00	780	18h30	0

All of this information has been taken in one week from Monday to Sunday after each 30min during the day and compiled by calculating the average. It shows that the irradiance is quite good between 7h30 and 16h00.

3.4.4. Simulation through Software

To obtain the expected results within the framework of this work, the following software are adapted to execute the project.

- MATLAB SIMULINK used to simulate the electrical side of the system under design of the project. This includes all part of the solar system from generation to load where all required parameters are inserted to produce the required output. In addition to this it is also used in this project in cost analysis of the system toward payback period.
  The available version used in this project is 2020 and contain almost all feature required in design of an off-grid grain mill machine.
- SOLID WORKS (2019) is used to draw, size, combine and simulate mechanical side of the grain mill machine itself for production floor. The software is helping to show the flow of the grains to be milled from the inlet to the outlet by the use of induction motor as prime mover.

4. DESIGN OF AN OFF GRID SOLAR GRAIN MILL MACHINE

Design of an off grid solar system is normally based on the load which is going to be used on that system and the time it will be used. The loads that are commonly used in those areas fall from national grid generally are lighting bulbs, televisions, few irons and some grain mills which require huge electricity.
This part is based on design of an off-grid system which is providing electricity to be used by a grain mills for small scare industrial processing business for providing services to people located in remote areas fall from national grid.
It is going to describe all solar off grid components and the loads which are grain mill machine and surrounding community. The grain mill is designed using SOLIDWORKS software to get its different parts.

4.1.Load assessment

In this design the system will use the induction motor of the grain mill machine and surrounding families as the result from survey.

4.1.1. Induction motor selection

The analyses of the harvest available on the field has given 650kg and available on the average time of 5hour per day. This means that the required machine must be able to process 150kg per hour or 2.5kg per min. This depends on the type of the grain or product to be transformed and on the type of screening used in the machine.

We know that the torque developed by an induction motor is given by $Tsh = 9.555 * \frac{Pout}{N}$

Where the **Tsh** is the shaft torque and **Pout** is the power developed by the motor.

Resistive Torque which is the load driven is also depending on the mass that that the load has and on the displacement.

$T\_resistive = F * r$ with $F = m * g$ where **F** is the Force, **r** is the radius of hammer, m is mass of driven load.
Here the mass of resistive (load) is the one of grain falling inside and the mass of hammer
$m = m\_grains + m\_hammers$
Mass of grain entering in the machine to be 2.5kg and mass of hammer to be 2.5kg with radius 200mm of so that the total mass of load is 5kg.

By substituting each value in the Resistive Torque calculation as in the formula $T\_resistive = F * r$ is obtained as 10Nm

To keep the induction motor still running, the following relation must be taken into consideration $T\_resistive < Tsh$

Let take into consideration that the $T\_resistive = Tsh$ so that it is possible to calculate the output power required.

$$Tresitive = 9.555 * \frac{Pout}{N}$$

$$Pout = \frac{T\_resistive * N}{9.555}$$

by considering the speed N to be 3000rpm, the output power becomes 3.139KW. When the motor of this rating is connected to the system, it will not run due to the resistive torque equal to the motor torque. So, to have the running system the following relation has to be obeyed $T\_resistive < Tsh$. The motor capacity must be greater to that value obtained by load torque

Predicting for future production having the machine of high reliability and strength the selected, the selected motor to be considered in this design to be of 7.5kW induction motor.

An AC induction motor of 7.5KW which is working up to 5hours per day driving a grain mill, this time was chosen base on the production of the machine which is 150kg per hour and on average crops coming to the grain mill for servicing per day which is 650kg.

4.1.2. Surrounding community load assessment

Based on the number of people located in sampled remote area where there is no electricity the basic need of electricity is for home lighting for houses and charging mobile phones. The biggest load to be considered in this design is lighting light bulbs.

Table 4-1: Local community assessment result

Family Number	Number of rooms in needed of light per family	Number of outdoor lamps per family	Total Number of lamps
5	5	2	35
6	7	2	54
5	3	2	25
4	4	2	6
Total number of families =20	Total number of lamps= 120		

$$Average\ number\ of\ lamps\ per\ family = \frac{120}{20} = 6bulbs$$

Taking the average of lamps to be 6light bulbs of 20W used 6hours per day.

Some values will be assumed depending on the component under design for getting a better output performance. Among them there is efficiency of each component, Depth of Discharge (DOD) of battery to easier calculation and design.

4.2.Components of solar off grid solar grain mill system

Solar photovoltaic system is a system that turns solar radiation into electricity to be used by a given load. Off grid photovoltaic systems turn solar light into electricity working apart from nation grid [8].

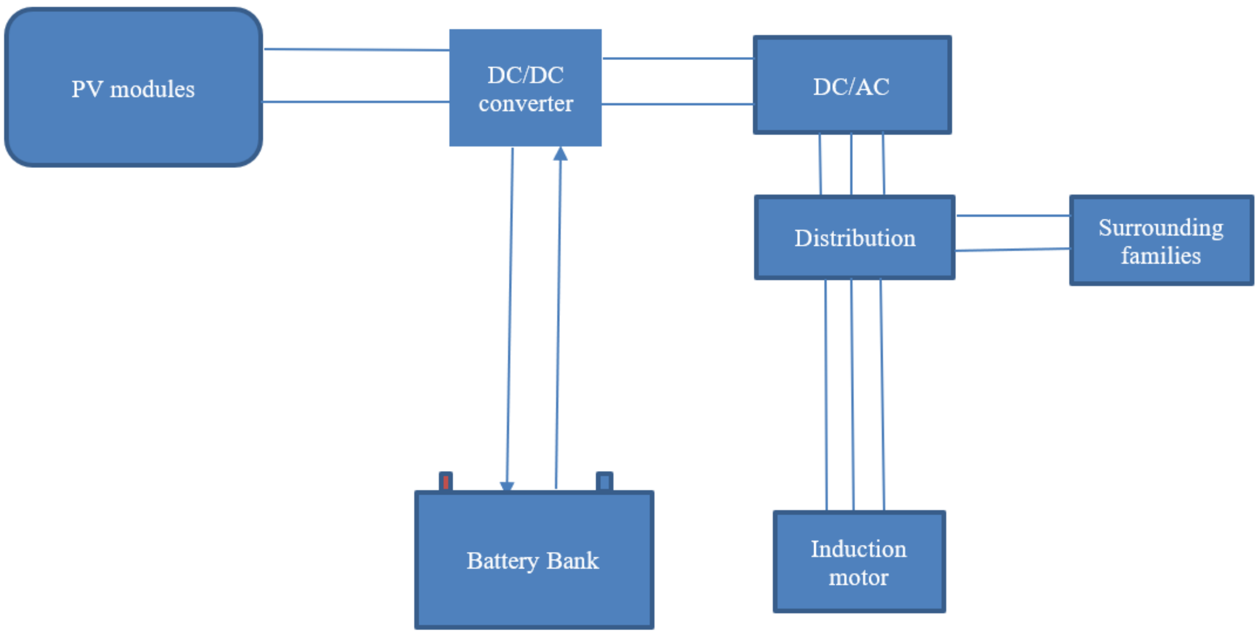

Figure 4-1: OFF grid solar grain mill system under design

The electricity produced can be used for home lighting, small scare industrial processing and surrounding families.
For the design of the off-grid solar PV power generation system, when the load demand is certain, the main principle is to make full use of solar energy, try to minimize the capacity of PV array and storage battery as possible for reduction of cost, and ensure the normal operation of the load in continuous rainy weather or cloud conditions.

4.2.1. Solar PV Module

The solar PV generator consisting of one or more solar modules converts solar radiation into electricity. The basic unit of a solar PV system is the solar cell.

The solar cells are constructed of semiconductor materials, typically silicon-based, and layered between electrodes to provide a path for electrons to flow through it. The layers are manufactured on the way to have opposing charges (positive and negative) to create the potential for an electric field. Photons in sunlight contain energy that is absorbed by the cell and stimulates electrons to dislodge from their atoms and create an electric field. The flow of electrons between the semiconductor layers is the electricity that is produced by your solar PV system to supply your home or business with renewable energy resource[23].

The solar cell can be connected in series and parallel to increase current and voltage and form a PV module. A number of solar modules connected in series and parallel is called a PV array.

4.2.1.1.PV sizing

The PV sizing start with the calculation of energy demand to know how much is required in terms of energy.

TEED (Total electrical energy demand) = $E_{\text{demand mill}} + E_{\text{demand families}}$

$$\text{TEED} = 7.5\text{kW} * 5\text{hours} + 0.020 * 6 * 20 = 38.4\text{kWh}$$

$$Total\ energy\ required\ on\ PVs\ perday = \frac{\text{Total energy energy demand}}{\text{global efficiency of the system}}$$

$$Global\ efficiency\ of\ the\ system = \eta\ battery * \eta\ inverter *\ \eta\ regulator *\ \eta\ cable$$

Assuming global efficiency of the system to be 0.85,

$$Total\ energy\ required\ on\ PVs\ perday = \frac{38.4\text{kWh}}{0.85} = 45.17kW \qquad (1)$$

In Rwanda peak Sun hours or generation factor is 4.5h,

$$Total\ required\ power = \frac{Total\ energy\ required\ on\ PVs\ perday}{\text{Peak Sun hours or panel generation factor}}$$

$$Total\ required\ power = \frac{45.17kWh}{4.5\text{h}} = 10kW$$

On the market there is different size of the PV module and by choosing any one of them the number to be used in the design also will change.

Let take the following as the sample of PV type available on the market to be used in this calculation

Figure 4-2: Data sheet of PV module

The picture was taken by the camera during the market survey to help in calculation of the number of numbers of PV modules.

As it is seen on this picture, the panel has the following characteristics:

- ✓ Peak power (Pmax) =325W
- ✓ Open circuit voltage=46.38V
- ✓ Maximum power voltage (Vmp) =37.39V
- ✓ Short circuit current (Isc) =9.17A
- ✓ Maximum power current (Imp) = 8.69A
- ✓ Maximum system voltage 1000V

By using that information from the name plate of the PV, we can calculate the number of panels that are required in production of 10kW.

$$\text{Total Number of panels} = \frac{\text{Total power to be generated}}{\text{power generated generated by single panel}}$$

$$\text{Total Number of panels} = \frac{10000\text{W}}{325\text{W}} = 31\ panels$$

For arrangement purpose and good appearance of the plant let take 32PVs instead of 31PVs
Another important parameter to be considered in the design is the maximum system voltage. On the data sheet that we are using from above, the maximum system voltage is 1000VDC which means that we are not allowed to connect all those PVs in series so that we exceed this maximum system voltage.

$$\text{Number of panels in series} = \frac{\text{Maximum system voltage}}{\text{Open circuit voltage for single panel}}$$

$$\text{Number of panels in series} = \frac{1000\text{V}}{46.38V} = 21PVs$$

To simplify the design and purpose easier in cleaning and other maintenance activities, we can connect 8PVs in series which will bring new maximum system voltage of 371.04VDC at open circuit instead of 1000VDC and of short circuit current of 9.17A since when putting PVs in series the voltage will be added up but current remain the same.

$$\text{New maximum system voltage at Open Circuit} = 8 * 46.38\text{V} = 371.04\text{Vdc}$$

This voltage is for maximum (at open circuit) the real maximum voltage is obtained at maximum power and corresponding to the maximum voltage (Vmpp) is 299.12V.

$$\text{Maximum system voltage} = \text{maximum voltage (Vmpp)} * \text{Number of PVs in series}$$
$$\text{Maximum system voltage} = 37.39\text{V} * 8 = 299.12\text{V}$$

And

$$\text{short circuit current(Isc)} = 9.17\text{A}$$

These 10PVs form a string whose power can be calculated as follows:

$$\text{Power per string} = \text{power of single panel} * \text{number of panel per string}$$
$$\text{Power per string} = 325\text{W} * 8 = 2600\text{W} = 2.6\text{kW}$$

$$\text{Total number of strings} = \frac{\text{Total power}}{\text{Power per string}}$$
$$\text{Total number of strings} = \frac{10\text{kW}}{2.6\text{kW}} = 4strings$$

These 4strings are going to be in parallel therefore their output system voltage will remain constant of 371VDC while their output short circuit current will be increase to 36.68A.

$$\text{Isc} = \text{Isc of single string} * \text{Total number strings}$$
$$\text{Isc} = 9.17\text{A} * 4 = 36.68\ \text{A}$$

General PV layout and connection

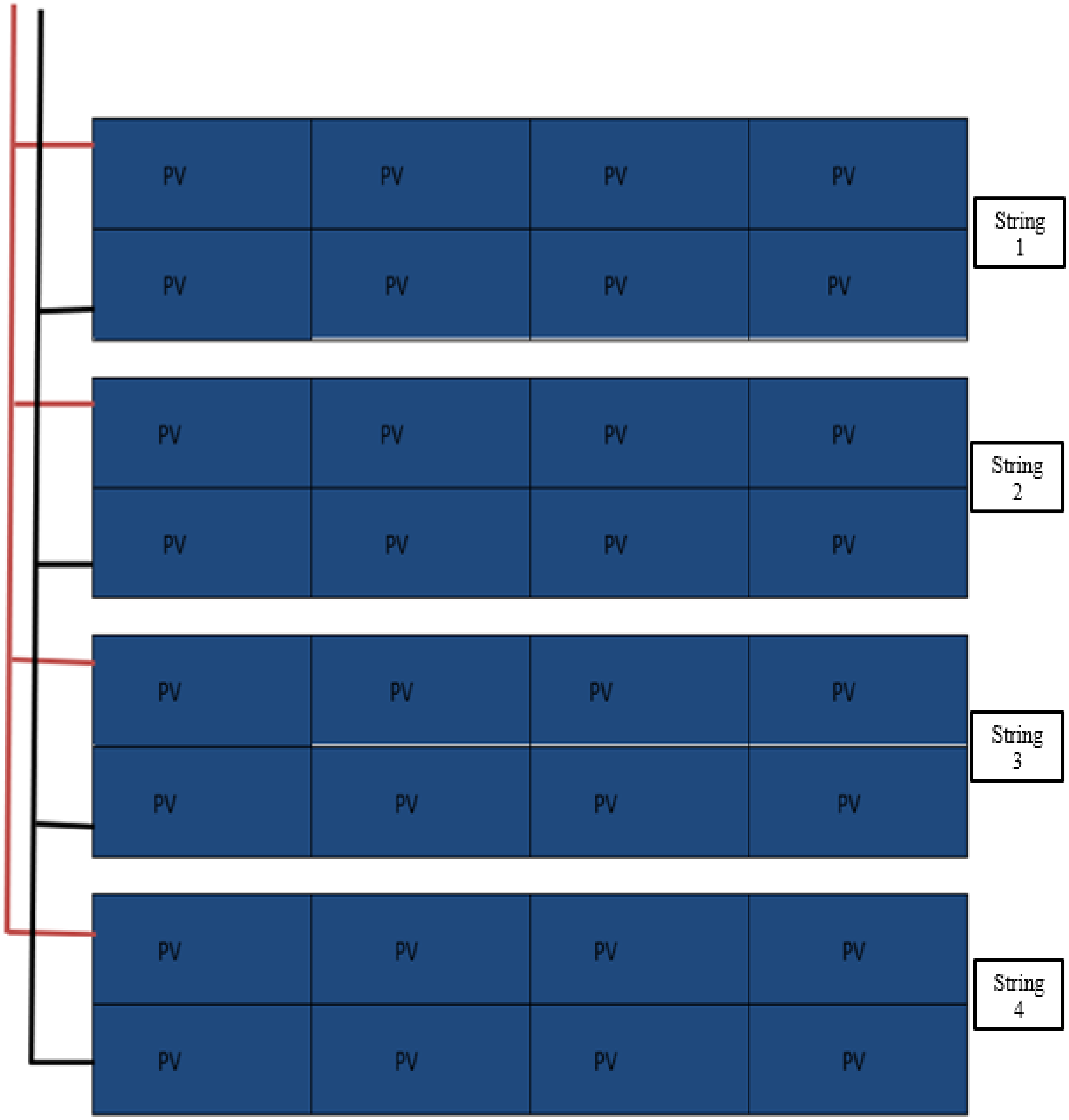

Figure 4-3: PVs layout

The above block diagram shows the arrangement of all 32solar panels grouped into 4string in parallel as calculated above and each string having 8solar panels connected in series

This arrangement will facilitate the reduction of space occupied by these PVs, easy of cleaning and maintenance due to free space between two successive strings.
The cost of the conductor is reduced due to the fact that positive and negative terminal are connected directly without any extra cable and positive and negative are in the same position on a string.
These panels would be mounted on racks, facing due south, at an angle of 30 degrees above horizontal to maximize the system for annual energy production[24]

4.2.2. Solar charge controller

In solar system, the battery remains the most delicate part of the system, and its maintenance and the quality of its control have an important influence on its life and so for the price of the final kWh generated therefore it has to be protected [25].
Charge controller is an intermediate between the PV module, storage system and the consumption point. Charge controllers are necessary in order to protect batteries from harmful over-voltage and under voltage [18]. They also protect batteries again being discharged by the PV module. It allows the connection of loads to the system and also considered as the brain of the system since when the battery is full charged it cut off power to avoid over charging and when the battery is on lower level of discharging it stop it use to avoid deep discharging.

4.2.2.1.Types of charge controller

- ✓ The series regulators which uses a switch between the generator and the battery to switch off the charge.
- ✓ The shunt regulators which short-circuit these solar generators when the charge is complete.
- ✓ MPPT charge controller, which uses a special electronic circuit enabling maximum power to be permanently drawn from the panel array.

A discharge regulator is generally added to all three types of circuit to prevent deep discharge of the battery (DOD) [23].

4.2.2.2.Criteria for selection of charge controller

- ✓ Maximum module current rating (10A, 15 A, 30A, etc.)
- ✓ Maximum load current rating
- ✓ Voltage (12, 24, 48V etc)
- ✓ PWM (pulse width Modulation), MPPT (Maximum power point tracking system) or shunt
- ✓ Self-consumption
- ✓ Voltage drops
- ✓ Physical characteristic of charge regulator

4.2.2.3.Solar charge controller Sizing

Charge controller should be able to support short circuit current (I_{SC}) of the module and maximum battery current to load current (IL max). Where the load current can be calculated by using following equation,

$$ILmax = \frac{Ptotal}{Vbattery}$$

The selection of the solar charge controller will depend on the output parameter especially current, voltage and power that are coming from the string designed in the project.
As calculated above, the charger controller input will be having Voltage of 299.12V and Current of 33.43A and the output related to the input of the battery.

$$\text{ILmax} = \frac{10\text{kW}}{299.12\text{V}} = 33.43\text{A}$$

According to standard practice, sizing of solar charge controller is to take short circuit current (Isc) of the PV array multiplied by 1.3

$$\text{Solar charge controller current rating } = \text{ Total short circuit current of PV array} * 1.3$$

In this case, the short circuit current (I_{SC}) = 9.17A*4=36.68A
Then, the Solar charge controller rating = 36.68A *1.3=47.684A
The charge controller to be used in this system must allow the flow of current of 47.684A

4.2.3. Battery

Solar energy is one of source of energy which is environment friendly, but is intermittent to mean that it is not always available all the time [18]. Generation from solar PV is possible during the day but absent at night and in cloud period while the appliances connected to it need to be used at any time depending on the user. To solve this problem is to think about storage system that can store energy which will be used in the absence of sun radiation. Battery stores electricity for use at night or during cloudy periods.
Battery converts electrical energy to chemical energy during charge and chemical energy back to electrical energy during discharge.
In such systems, energy storage represents around 20–30% of the initial investment, but over a period of 20 years of exploitation of the system, this cost can reach 70% of the total. It is, therefore, important to try to reduce the price by increasing the life expectancy of the storage elements, which is always less than that of the panels. Batteries, therefore, have to be replaced several times during the life of the system (every 2, 5 or 10 years depending on the type) [23].

4.2.3.1.Technical specification of battery

All of those parameters must be considered when choosing the battery to be used in any application of solar system for having a reliable and stronger power supply.

- ✓ Capacity: the nominal amount of energy a battery can store ampere-hours (Ah).
- ✓ Charge and Discharge: Current added or removed from a battery.

- ✓ Cycle: The charging and subsequent discharging period
- ✓ Rated Cycle Life: Number of cycles before a battery can only hold 80% of its original rated capacity
- ✓ State of Charge (SOC): the energy level for a battery at any point of time.
- ✓ Depth of Discharge (DOD): discharge level that a battery reaches after discharge
- ✓ Specific gravity of a material is its density divided by the density of water and is measured with a hydrometer.
- ✓ Self-Discharge: Tendency for batteries to lose charge when left to stand for a long time without being charged
- ✓ Nominal Voltage (Volts) [V]: is the reported or reference voltage of the battery, which also sometimes referred as 'normal' voltage of the battery.
- ✓ Open-circuit voltage (Volt) [V]: The voltage between the battery terminals with no load applied. The open-circuit voltage depends on the battery state of charge of battery. It increases with the state of charge.
- ✓ Internal Resistance (Ohm) [Ω]: The resistance within the battery. It is dependent on the state of charge battery. As internal resistance increases, the battery efficiency decreases due to internal heat generated and thermal stability is reduced.

4.2.3.2.Types of batteries

- ✓ The batteries used in stand-alone systems are generally lead-acid (Pb) battery. Nickel cadmium batteries (NiCd) are rarely used due to their high cost and they contain cadmium product which is toxic. There are also nickel-metal-hydride batteries (NiMH), which are more attractive but ranging in small scare storage system (<2 Ah). There are other types of battery like lithium batteries (Li-ion, for example) which are compact, but very expensive.
- ✓ With the development of electrical vehicles, there is improvement of existing and invention of other storage system compressed air as energy storage the long-expected life and the absence of chemical components to be recycled [26].

4.2.3.3.Battery sizing

Due to the difference between the variation of load power and solar power generation at any given time, the battery storage system is required to supply or absorb this variation. In system design, the battery along with the inverter system, placed between the rooftop PV panels and the load[9].
To determine the size and number of batteries it is more important to know the Energy require per day (E_{day}), Number of day (n_d) that the battery can save power also called days of autonomy, Rating of the battery to be used expressed in Ah (I_h), Nominal voltage of the battery (V_{bat}) and depth of discharge (DOD) of the battery system.
In this design the, lead-acid type (Pb) is selected due to its characteristic performance, availability on market and its low cost.

$$\text{The number of batteries (Nbat)} = \frac{\text{Eday} * \text{nd}}{\text{Vbat} * \text{Ih} * \text{DOD}}$$

By using lead-acid type (Pb) of the following characteristics:
Battery capacity of 200Ah

Nominal voltage of 24V
Depth of discharge (DOD) of 0.6
Day of autonomy of the system to be 2days
Also, in this design is always based on the load which is available on this system. Now in our case the load is a grain mill machine of 10KW and the services that it gives is 5hours during for 7days.
Therefore, the Energy consumed per day will be given as follows

$$\text{Energy per day} = \text{power consumption of load } * \text{time it works per day}$$

As calculated in above in equation (1), E day $= 45.17kWh$

$$\text{Nbat} = \frac{45170Wh * 2}{24\text{V} * 200\text{Ah} * 0.6} = 32\ batteries$$

Calculation of number of batteries to be in series
The output from PV string voltage is 373.9VDC as calculated in previous and this must be the input to the batteries, therefore

$$\text{Nbat in series} = \frac{373.9\text{ V}}{24\text{V per each battery}} = 16 batteries$$

This mean that the 16batteries will be in series on one side of the battery bank and therefore the system will have 2lignes in parallel each having 32batteries.

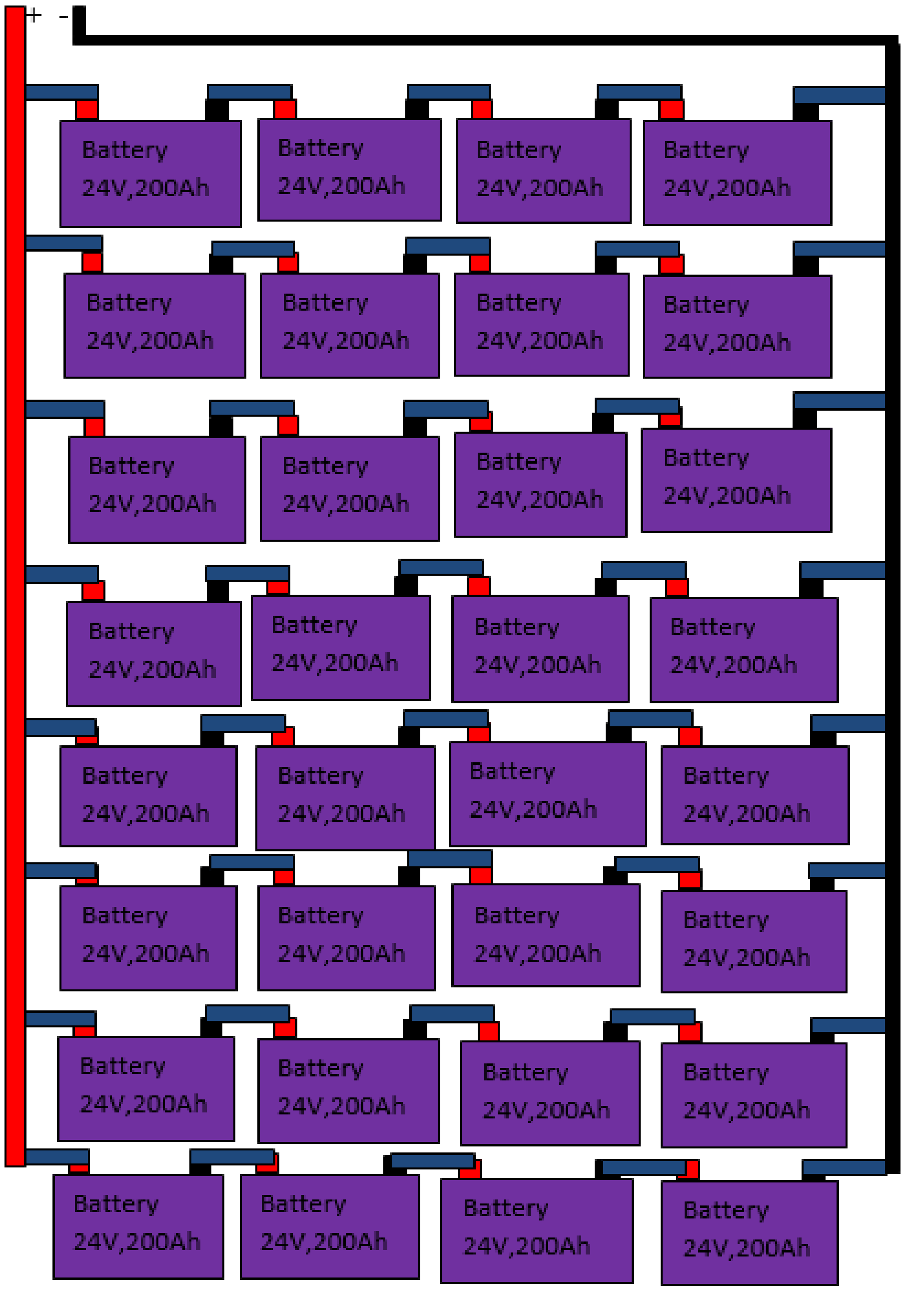

Figure 4-4: Battery bank

The figure 4.4. Presented in the previous shows the set of 32batteries connected together to form the battery bank as storage system. The 4 batteries are connected together in series for limiting voltage and current.

$$V\_batettery\_bank = Vbat * Nbat$$

$$V\_batettery\_bank = 24V * 4 = 96V$$

By connecting them in series the voltage increases and the current remain constant on one string of battery bank. So, connecting them in parallel will change the current while the voltage remains constant

$$I\_batettery\_bank = Ibat * Nbat$$

4.2.4. Inverter

Also called Power Conditioning unit is an electronic device that converts DC voltage into AC voltage of required magnitude and frequency to supply equipment (household appliances, office equipment, tools etc) which are often not available as DC appliances [27].
In solar PV applications inverters are used to power the equipment that operates from AC power source. The DC to AC conversion is required as the solar PV system generates and stores energy in the form of DC and some material are not able to work on this form of power. The inverters are sometime called DC-AC converters [24].

4.2.4.1.Characteristics of inverter

- ✓ **Rated Output Power:** it indicates the continuous power that an inverter can deliver in normal operating condition. Its unit is VA because the inverter can also be used to power loads with reactance like motor.
- ✓ **Nominal output voltage:** is the magnitude of output voltage (RMS value) that the inverter produces steadily. It is known as 220V ±10% for single phase inverter and 400V ±10% for three phase inverters.
- ✓ **Nominal Frequency:** It indicates the frequency of the output voltage or current waveform and expressed in Hz. It values in African country is 50HZ ±2% as tolerance values.
- ✓ **Efficiency:** Efficiency of an inverter is an indication of the losses of energy occurred during the conversion from DC to AC**.**
- ✓ **Maximum Quiescent Current**: is the current drawn by the inverter from the DC source in idle (no load) condition.
- ✓ **Surge Capability:** It is the capability of the inverter to deliver the power beyond its nominal power for a very short period of time. An example here is on the starting current of the induction motor.
- ✓ **Total Harmonic Distortion (THD):** expressed in percent, is the ratio of power contained in all other frequency components to the power contained in the fundamental frequency only. The THD is the measure of similarity between the real waveform and the ideal sinusoidal waveform. The THD of ideal sinusoidal waveform is essentially zero [24].

4.2.4.2.Types of Inverters

The inverter can be classified based on Output Power Rating, Output Waveform, number of phases and working condition.

- ✓ Based on output power rating, inverters can be in low power (up to 500 VA), medium power (up to 5000 VA) or high power (above 5000 VA) inverter.

- ✓ Based on Output Waveform, the inverters are sub divided into sinusoidal, quasi-sinusoidal and square wave types.
- ✓ Based on number of phases, the inverter can be single or three phase type
- ✓ Based on working condition, the inverter can be continuous duty or back-up type
- ✓

4.2.4.3.Inverter sizing

The inverter is capacity is determined by the peak load demand connected to it. Peak load demand is calculated using the relationship between the connected load and the diversity factor (DF) of the load at where the diversity factor is the ratio between maximum demand and the total connected load [26].

$$P_{inv} = \sum_{i}^{n} \frac{P_i * n_i}{DF}$$

Where Pi is the power consumption of any device of type i connected to the PV system and ni number of devices of type i.

$$\text{Total power} = 7.5\text{kW} + 0.020 * 6 * 20 = 9.9\text{kW}$$

The inverter should be 25-30% bigger than total Watts of appliances so that it is able to supply them and support the starting current. From this statement 30% of 9.9kW is 2.97kW and then the power capacity of this inverter is 12.87kW.

Most of the time the capacity of inverter is expressed in kVA

$$S = \frac{P}{\cos\varphi} \text{ By considering } \cos\varphi \text{ being 0.95}$$

By applying the above formulae, the capacity of inverter to be used in this project will be of 13.54kVA which can be approximated to 14kVA

The selected inverter a three phase, sinusoidal waveform of 14kVA based on the required power of the plant and the on the working conductions to support the load.

4.2.5. Cable Sizing

The size of cables is sized based on the place where they are going to be use. The place can be between PVs and charge controller, charge controller and battery, charge controller and inverter, and between inverter and load.

4.2.5.1.Wire between PVs and charge controller

The wire joining solar module and the charge controller must be as short as possible and resistant to solar radiation and water as well as ultra violet (UV) ray in sun light.
The inner diameter of the conductor depends on voltage drop between PVs and charge controller. The thickness of the conductor indicates how much energy in terms of heat can be dropped between the solar module and charge controller.
The size of the wire required is calculated by using the Standard Wire Gauge (SWG) formula as following [18].

$$S = \frac{0.3 * L * I_{PV}}{\Delta V}$$

S is cross section area (mm^2), L(m) length of the conductor between PVs and charge controller, I_{PV} is the current flowing from PV to charge controller (Ampere), ΔV indicates the voltage drop or voltage loss across the wire and its maximum allowed value in percentage is 5%.

$$S = \frac{\pi d^2}{4} \text{ or } d = \sqrt{\frac{4S}{\pi}}$$

Where,
S = Cross sectional area of wire (mm2)
d= Diameter of wire (mm)
Considering L = 5m, IM= 75A and ΔV= 5% and based on the above formula the cross-section area of the conductor is 11.3mm^2 or 3.8mm of diameter. If one wire is used but to simplify the wire system it is possible to combine the small cross sections to have the same value or to use small cross section and combiner to have the same situation.

4.2.5.2.Wire between charge controller and battery

The size of conductor between charge controller and battery is also calculated by using previous equations but considering the value of ΔV to be taken as 1%. No need to use UV protected wire because it is located inside the house and also supporting the large current when discharging by supplying the load. During the charging, the current flowing through this wire is the same as current from PVs (I_{PV}) and during discharging process the current in this wire is equal to load current connected to it. The value of current taken for calculating the cross-sectional area should be the higher value of both current which is exactly load current so that it will be able to supply the load when it is discharging.

$$S = \frac{0.3 * L * I_{L\max}}{\Delta V}$$

Load current $I_{L\max}$ in our case is 15A and ΔV is 1% and with length L of 1m then S=0.75$mm^2$and d=0.98mm.This wire is the same as the one between charge controller and inverter because it has been calculated based on load current.

4.2.5.3.Wire Between inverter and load

In this part of the system, ΔV is less than 5% and by using previous equation of cross section area for calculating the size of the wire between inverter and loads.

$$S = \frac{0.3 * L * I_{L\max}}{\Delta V}$$

In our case $I_{L\max}$ is 15A and ΔV is 2% and with length L of 4m then S=4$mm^2$and d=2.2mm.

4.2.6. Induction motor

Induction motor is a rotating electrical machine consumes AC voltage source to produce mechanical power. It is also known as asynchronous motor, because it never operates at synchronous speed. It is widely used industries and domestic applications due to its simple construction and better operating characteristics with compare to a dc motor.
The best type of induction motor on grain mill machine is a squirrel cage induction motor having specific characteristics based on the application.

Figure 4-5: Motor characteristics

Power	Voltage(V)	Frequency (Hz)	Speed (RPM)	Current(A)	Connection
10hP/7.5KW	400	50	2800	15.7/9.1	Delta/star

This motor is able to work as a fan having 2800rpm, so it is able to create the pressure that can allow the flour produced to pass through screening system. If the speed is too small the mechanism of separation is not possible.

4.3.Grain mill machine

Many people cannot afford paying for commercial grain-milling services and they grind by hand using traditional techniques due to very long distance from where they are located, cost of electricity which increase day to day, increase of diesel and fuel in general which increase the cost per unit kilogram of harvest to be pounded. It is often a social activity, carried out predominantly by women [4].

Figure 4-6: Pounding by with mortar and pestle Figure 4-7: Pounding by grain mill driven by motor

4.3.1. Milling Mechanism

Grains subjected to any force respond in three stages which are elastic deformation, plastic deformation, and breakage or fracture. All of them are successive and preparative one to another.
Elastic deformation means that the grain deforms under force but returns to its original shape when the force is removed and this due to the humidity which is inside that grain which cause not to break directly.

As the force is increased on a grain to be milled, plastic or permanent deformation takes place on it, even when the force is removed. The grain appears to be flattened or distorted in some way but is still in separate, identifiable units. The grain eventually fractures when forces are increased further [4].
Based on the questionnaire that has been filled by different customers of the grain mill, sometime the flour contains the iron fillings. The machine under design is of stainless still sheets to reduce the impact on human being and to improve the quality of services provided.
In addition to this on the quality of the four productions, the flour produced by the use of fuel is always having bad smell.

4.3.2. Mechanic design of hammer grain mill machine

4.3.2.1.Hopper

The design of hopper must be well done to ensure the flow of grain in the machine and proper selection of metal sheet for having high mechanical strength and avoiding unnecessary the sound when the machine is running. In general, the metal sheet chosen here to be used on this hopper is of 6mm of thickness of stainless type for avoiding lusting which can cause diseases to human being.
The dimension of each side is based on the quantity that the machine is able to produce per hour and on dimension of the grain to be milled. Big product like cassava require big hopper due to their size before being milled.
The following shows the hopper of the machine producing 150kg per hour as an average. The dimension of each side is shown on and expressed in mm

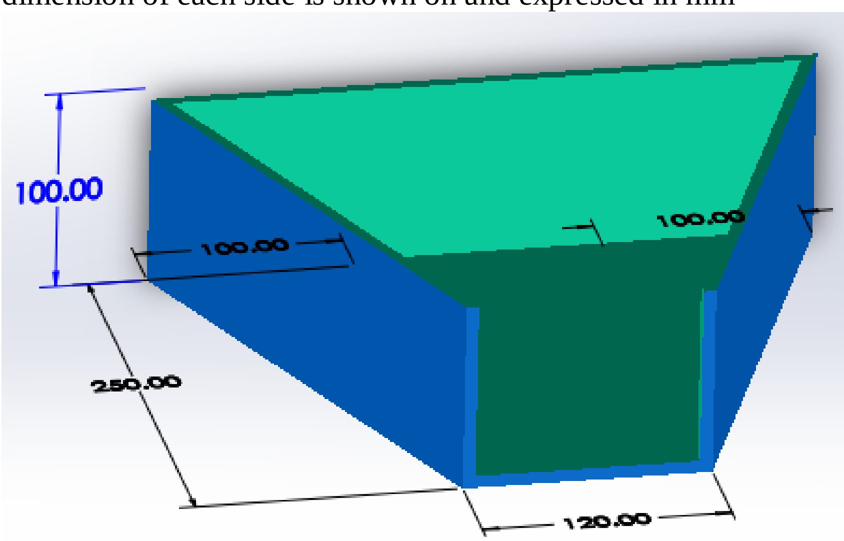

Figure 4-8: Hopper

4.3.2.2.Hopper and cover mate together

The hopper has been described in Figure 4-9 and combined with the cover which is movable on the machine. It has the same diameter 500mm as the arc of the ceiling of the machine and same thickness of 6mm as the metal sheet used in this design.

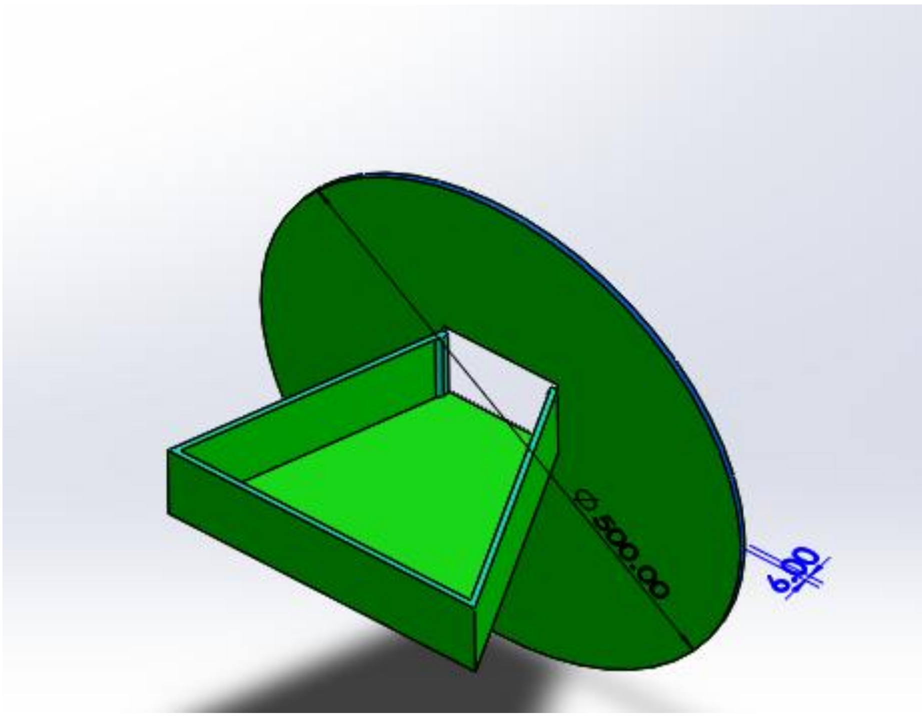

Figure 4-9: Hopper and cover mate together

This one again should have to be moved at any time when they are doing maintenance inside the machine. The white hole in the center describe the input of the grains in the machine and it has to be limited so that the grains are no to be too much inside the machine and causes overload of the motor.

4.3.2.3.Internal structure

This internal structure has to be taken into consideration when size due to its function and direct contact with the consumable product (flour) for avoiding having to be mixed with iron fillings which are dangerous to human being. It must have high mechanical strength to resist to rotation of hammers inside. The best metal sheet is stainless still metal sheet for avoiding rust inside. Its thickness here is of 6mm also and also having the brake bars on its sealing to so that hammer flow the grain on them and become a power which passes in screening system. The screening support is of the two arc metals located inside the housing in black color. They are of small thickness (3mm)
The dimensions of each side are shown on the diagram under design and expressed in mm. The form allows easy collection of flours after milling and reduction of it in the house in form of dust which causes loses to customers.

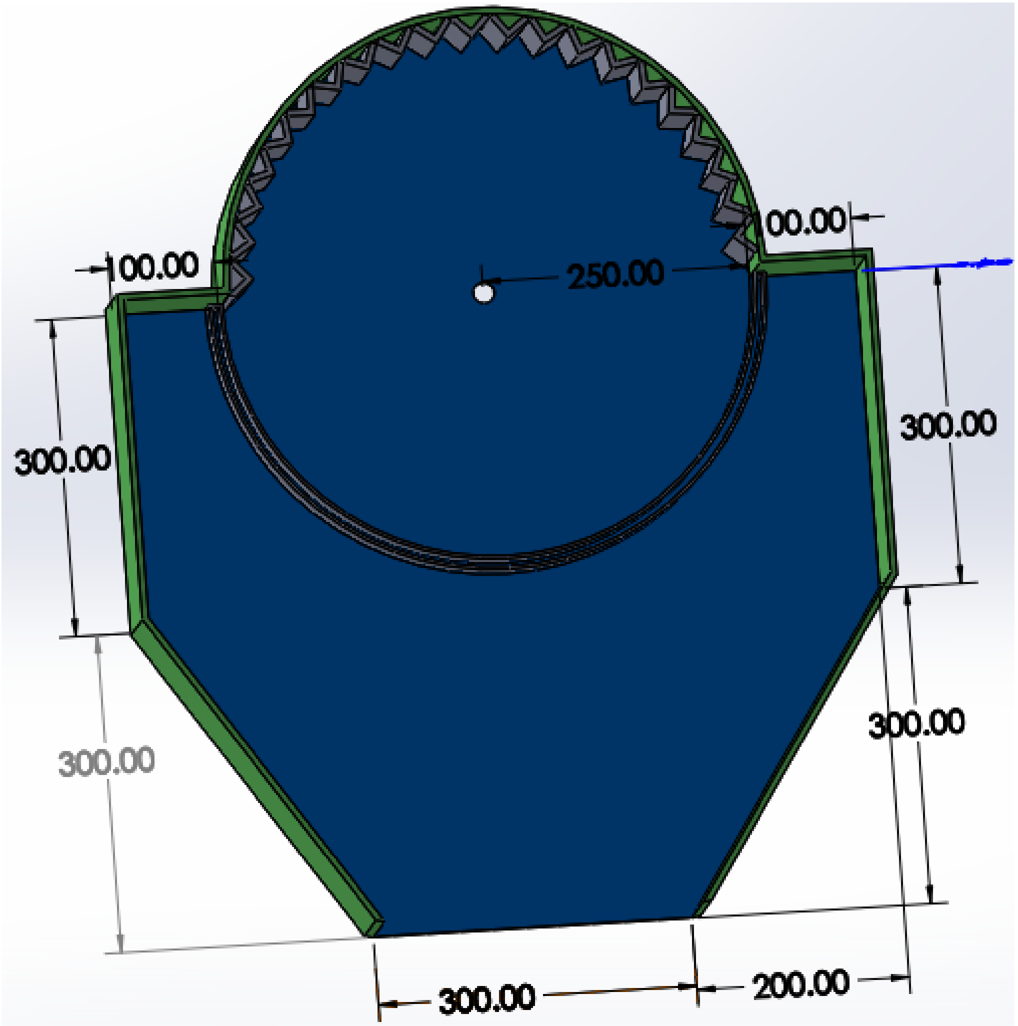

Figure 4-10: Internal structure

The inside double arc in black color is the screening support that are used to separate the floor milled with residues. This must have high mechanic strength to be able to hand the mass of floor falling on it at every time the machine is working.

The taken dimension in design was 30mm wide to limit the holes of the screen that can be coved when it is this arc. It each metal arc is also having 3mm thickness and diameter of 500mm as the sealing of the machine for having a complete circle. Between the two arcs there is Air gap of 3mm and corresponding to the one of screening system.

4.3.2.4.Screen structure

The screen is the metal sheet of stainless type whose thickness is about 1mm and of length equal to the half of the circle of the machine. It is filled in the opposite side of the ceiling whose diameter is 500mm.

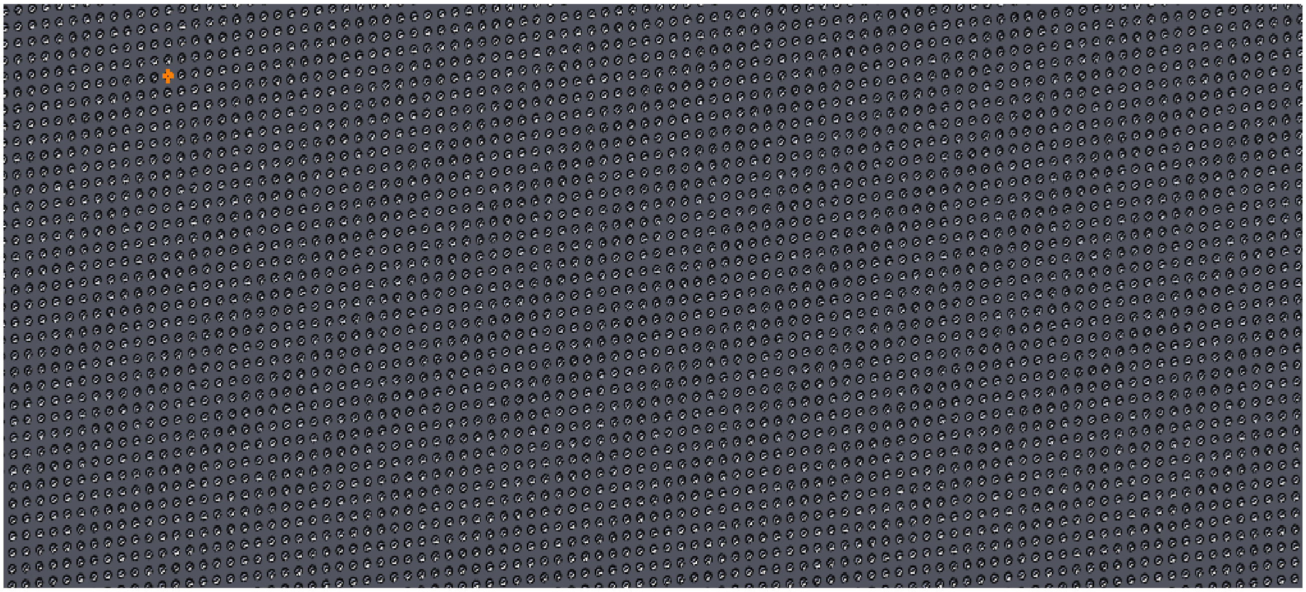

Figure 4-11: Screening system

The length of this screen can be calculated using mathematical formula

$$L = \frac{Circ}{2} = D * \frac{\pi}{2}$$

Where **L** is the length of the screen, **Circ** is the circumference of the ceiling **D** diameter of the ceiling equal to 500mm. By applying the above formula, L is 785mm and width of the same value as the one of the machines which is 100mm as shown on Figure 4-13.
In addition to this it contains a set of holes arranged on order where each is of 0.6mm diameter and between the two successive there is 2mm

The mass that it can support can be calculated and identified based on what can be produced during a day.
As stated at the beginning of this chapter in part of load assessment, the daily production of floor is 650Kg per day and the machine is working 5hour a day

$$mass = \frac{mass\_available\_Per\_day}{number\_of\_hour\_per\_day},$$

This a non-stop working conduction and it can go beyond these values depending on what customers are bringing for servicing. By using the above formulae, the mass that it is able to produce is 130kg per hour or 10kg per 5min which can increase or decrease depending on the quantity moisture in grains and on the type of grains to be milled (an example here is that cassava takes a short time than maize).

4.3.2.5.Hopper, cover and internal structure mate together

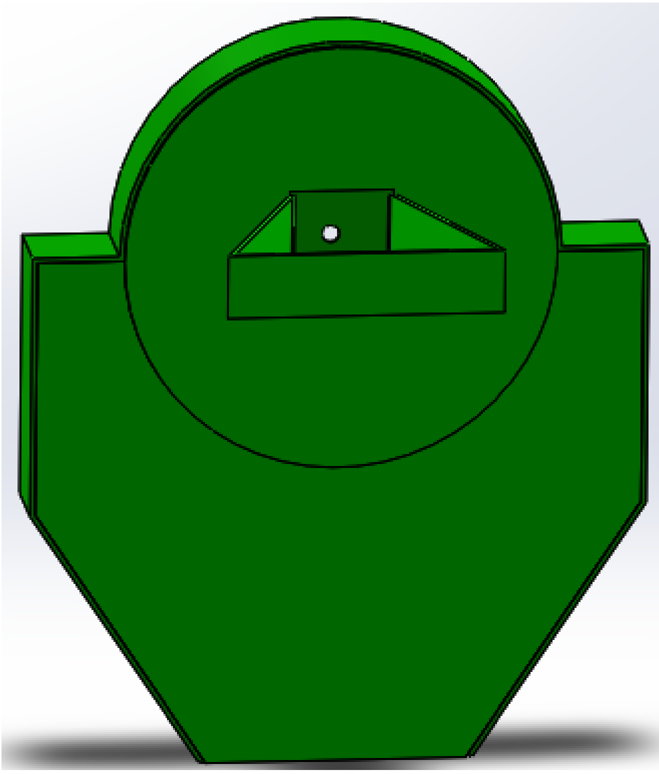

Figure 4-12: External structure of the grain mill machine

The picture previous figure shows the outside housing of the grain mill where the floor is processed. On the outer part there is hopper where all grains are deposed for putting small quantity for avoiding overloading the machine. In this structure all the dimensions are shown Figure 4-15 and Figure 4-16 because they are combination of the two.

The hole seen in the center of this picture is where the shaft of prime mover (induction motor) passes to drive the hammer that mill the grain when they inter in the machine

4.3.2.6.Support structure

The support structure is also important and can vary based on the type of grain mill and the metals that can be used depends on their availability. An example is the use of circular metal tubes, U-form, V-form etc. The used metal structure is of plate form of 20mm thickness to support the machine and of 1m length so that it is possible to be accessed by the user in an easy way.

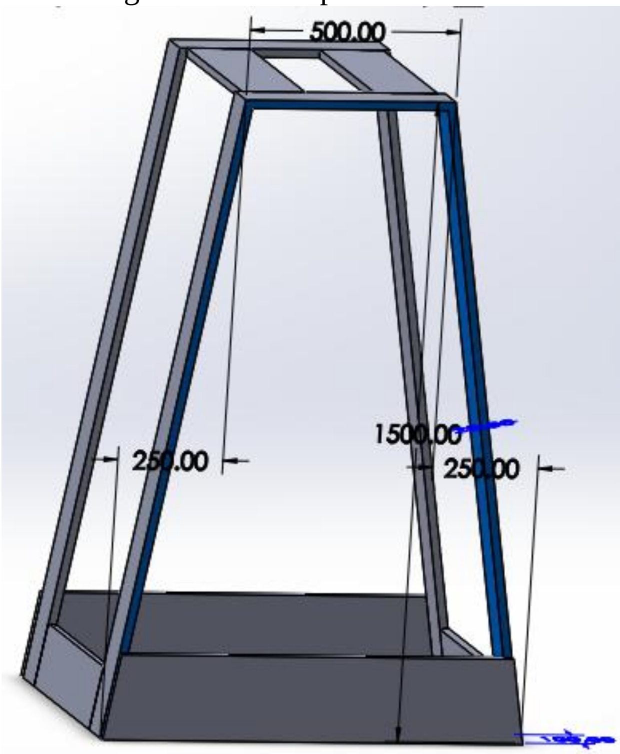

Figure 4-13: Vertical dimensions

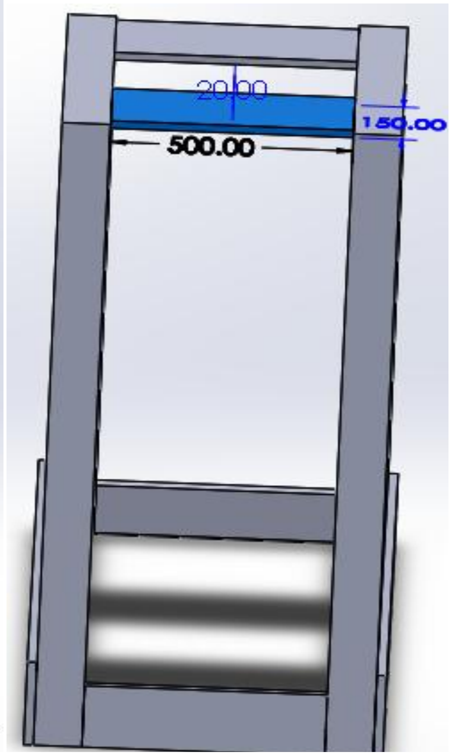

Figure 4-14: Horizontal dimension

The unpainted support structures shown in Figure 4-19 and in Figure 4-20 indicate the size of components and based on the way it is built here, the corresponding faces are equivalent in size. All values are in mm.

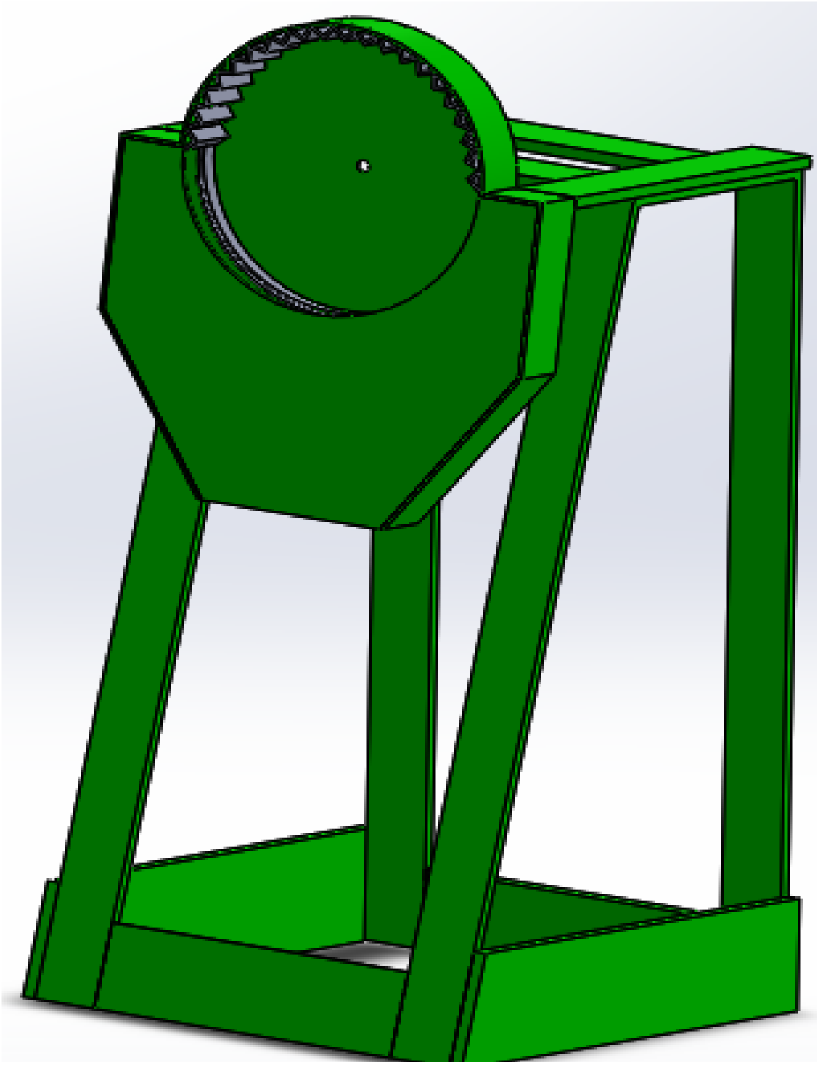
Figure 4-15: Support structure

Here on the support structure, the 4pieces of metal forms the standing table and must have inclination of a given angle for having the stability of the table when the machine is under action.
The inclination angle in this design has been considered as 20degrees in comparison to vertical axis and this is done in two directions only which are inclination going in front and in back sides while right and left remain in their normal position of inclination of 0degree.

On the top of this table there is position reserved for prime mover (induction motor). This place must have very high mechanical strength to support the induction motor weight which is somehow very high of around hundreds kg depending on the capacity of the motor.

In this design the motor working with the machine is of 7.5kW and depending on the manufacture and on quality they are between 75kg and 200kg but selected is of 75kg which is not too high as compared to others.

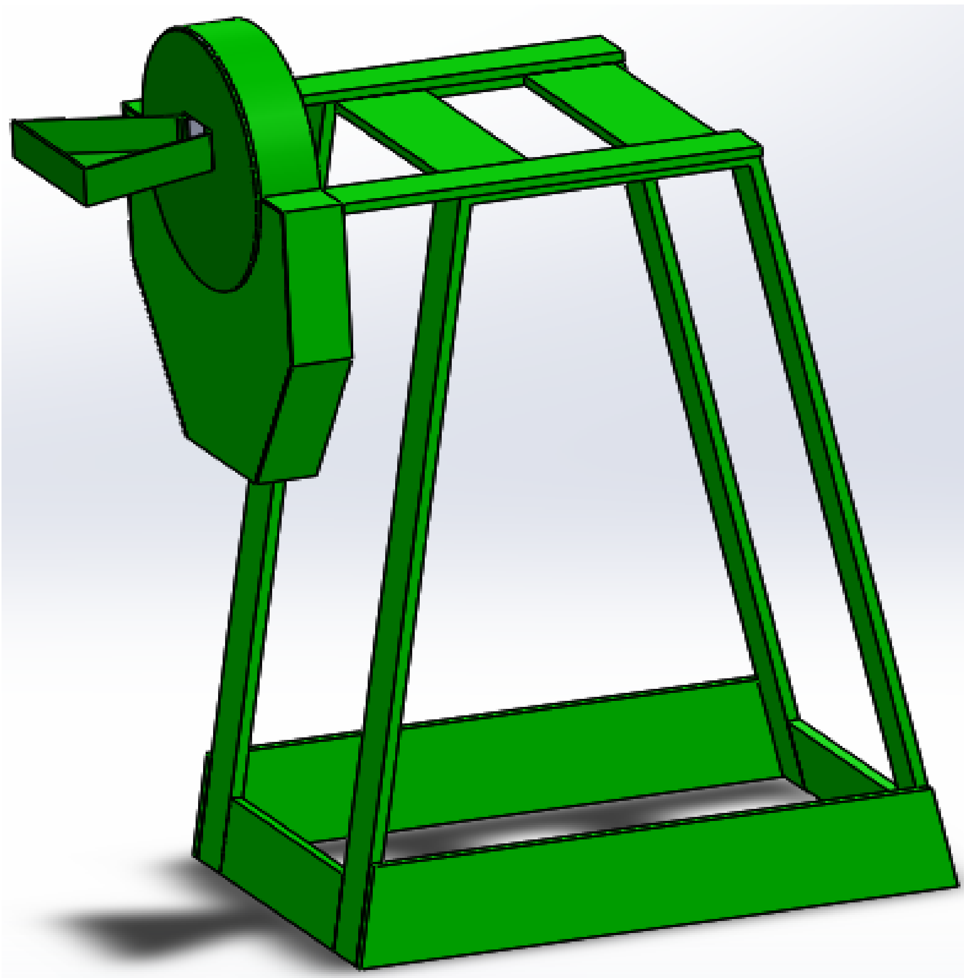

Figure 4-16: Motor position

The all required dimension of the component were shown in the previous figures.

After fixing the motor to the grain mill, the following picture is produced to dhow the position of the induction motor on the table.

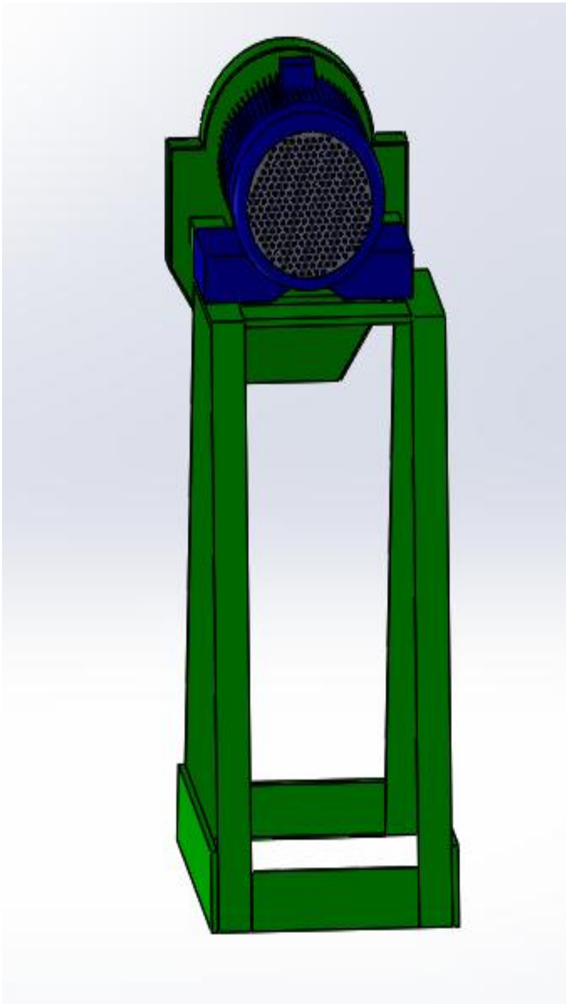

Figure 4-17: After Fixing a Motor position in its position

Direct connection of the hammer to an induction motor is possible when the motor speed is higher enough to work as a fan. Here the motor is of 2poles induction motor which produce around 2800rpm and this is possible to generate wind pressure used in separation of flour with residues.

By using the same motor having speed of 1460rpm, the machine is not possible to separate flour with the residue due to low wind pressure. In this case the possible ways to hand the problem is to use pulleys of different sizes that multiply speed from this value to the required values.
The all required dimension of the component were shown in the previous figures.

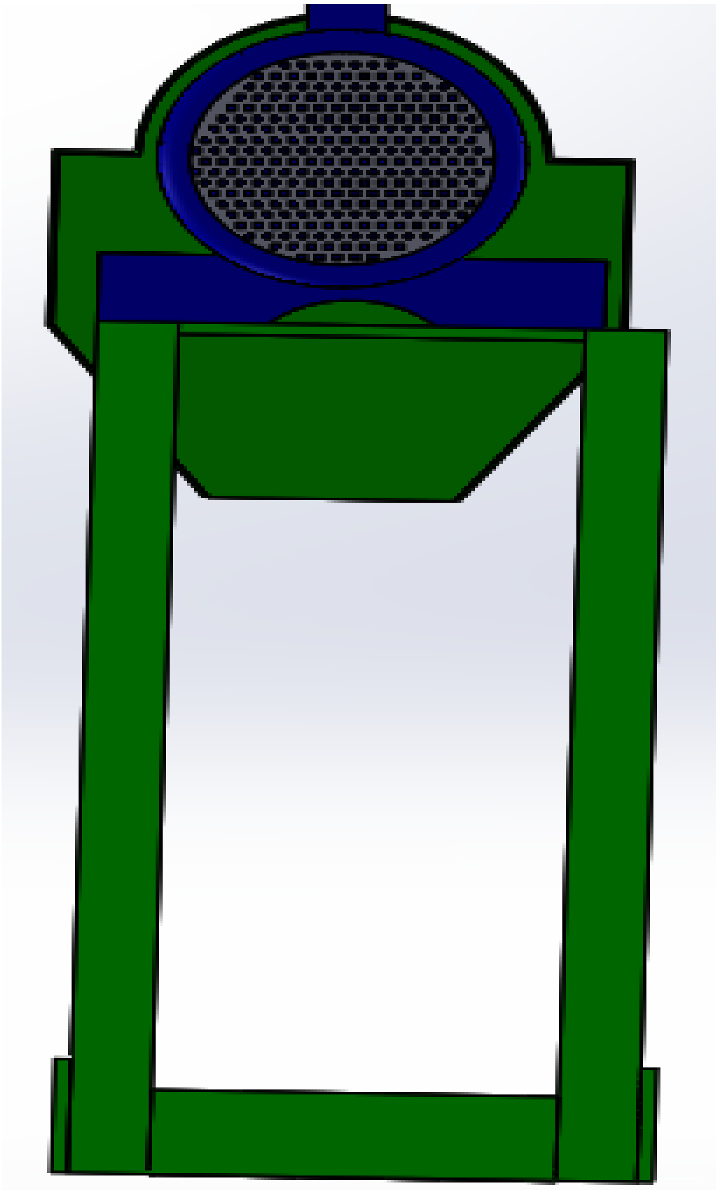

Figure 4-18: The back side of the machine

The back side of the machine shows clearly the position of the induction machine to allow cooling of the machine with air which is not full of dust from the floor.

The mass of the hammers connected to this motor is between 2kg and 3kg to avoid this overload and to reduce their effect on bearing.

The position of the prime mover allows the reduction of cost of the machine by removing the pulley, bearing blocks, belts and separate motor support structures. The machine has to be used carefully to avoid the overloading which can cause the motor to be damaged due to direct interconnection of it with load.

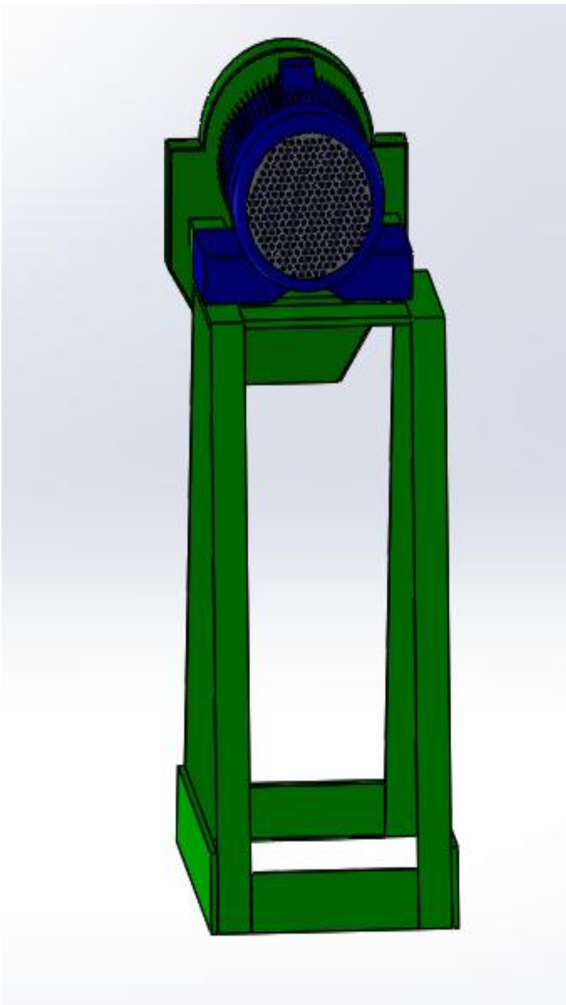

Figure 4-19: Complete machine

The mass of the hammers connected to this motor is 3kg as stated in the starting of the design. This is to avoid overload and to reduce their effect on bearing when the motor is running.

Complete figure of grain mill showing all part combined together

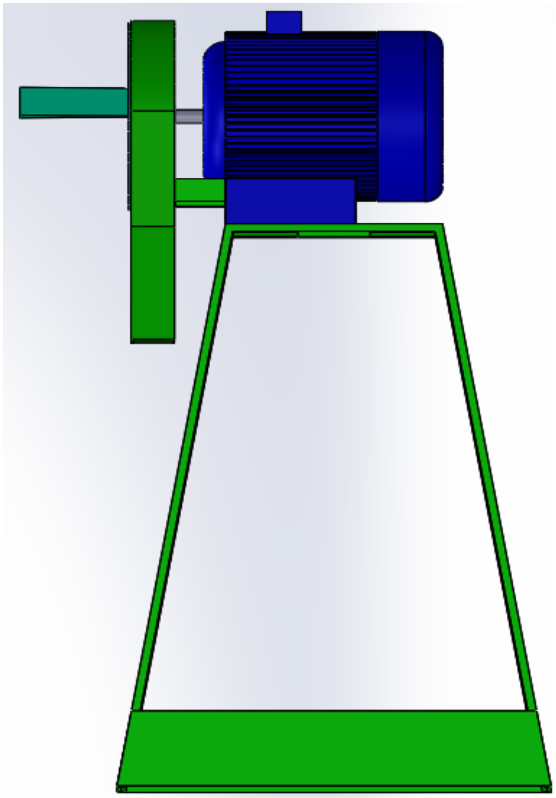

Figure 4-20: Side View

This is taken by using right view so that all part can be seen clearly
The above figure shows the complete diagram of the machine after mating all components together and disposing the induction motor on it position.

5. SIMULATION OF COMPONENTS IN MATLAB SIMULINK

After calculating all the values of current, power and voltage of each component using mathematical formulae, these values become the input to each component of solar system.
The following block diagram shows the electrical side developed in MATLAB SIMULINK and then the result on each component represented aside. Due to the length of the block diagram, the elements of each component have been compressed together to create a subsystem.

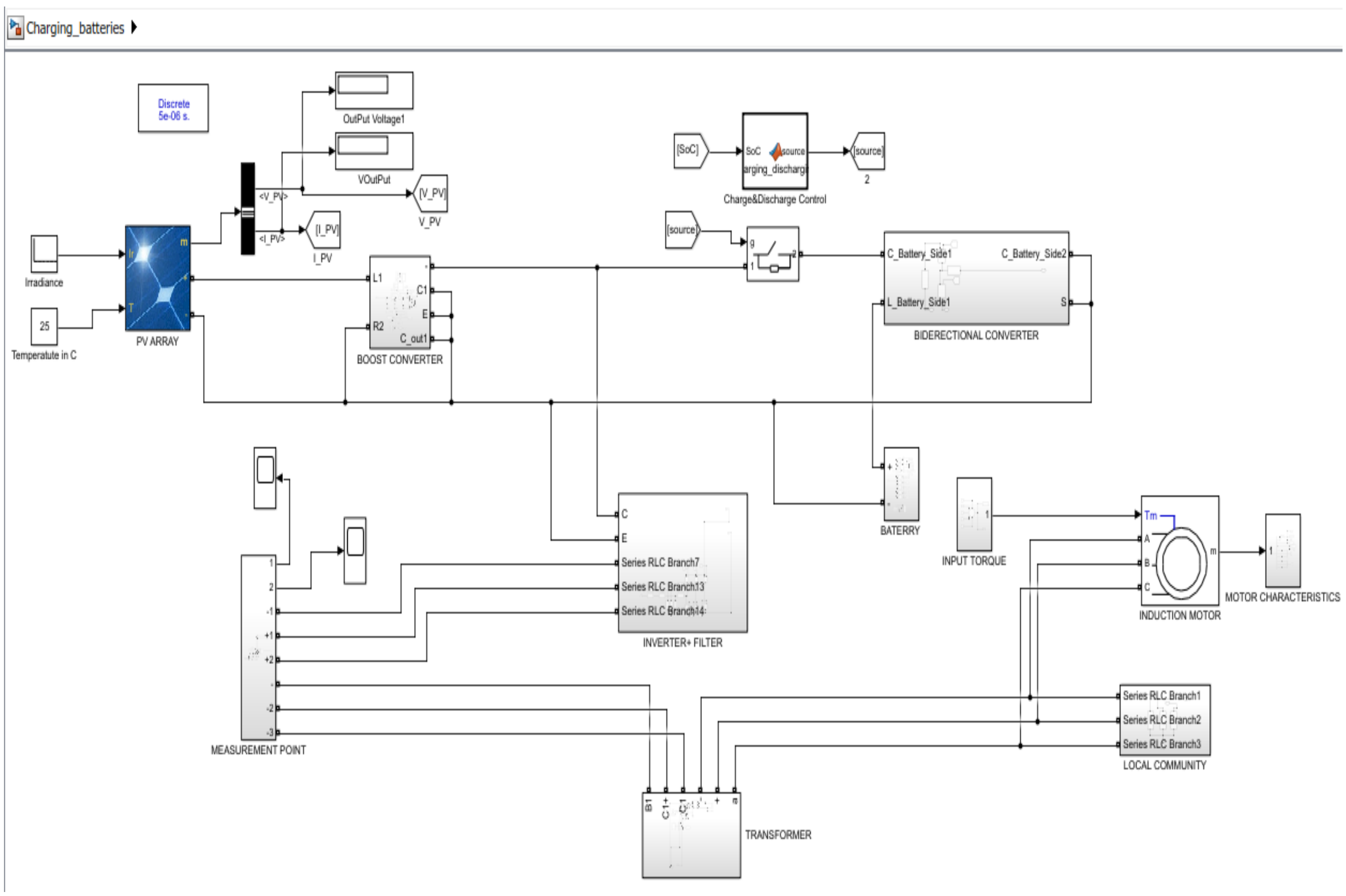

Figure 5-1: Simulation of Components

By simulating, the information related to each side where extracted, presented and analyzed.

5.1.PV side

After inputting the number of modules in series calculated above and the number of strings in parallel to the module block in MATLAB SIMULINK then plot the IV curve of the system designed under different irradiance values.
By arranging 8PVs of 335W each in series to form a string and combining 4strings in parallel and plotting the IV curve of the output of the system, the output will vary depending on the input irradiance.

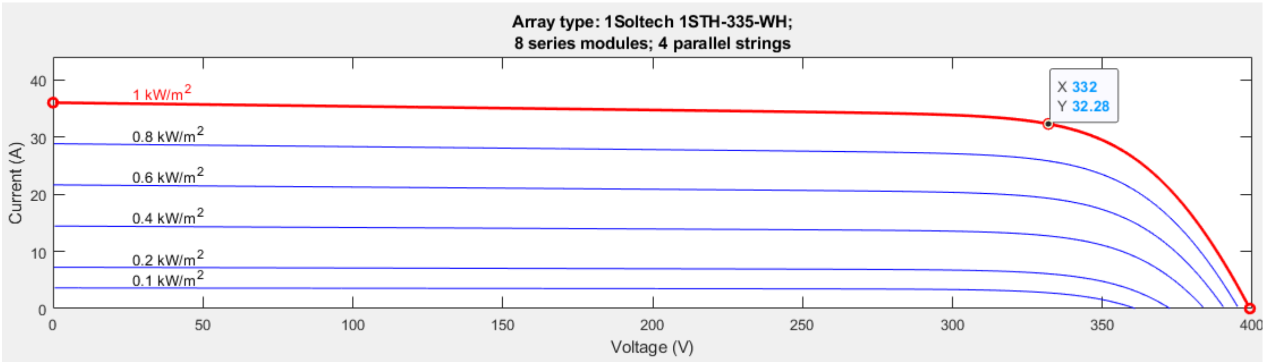

Figure 5-2: IV Curve with different irradiances

As the input irradiance decrease, the output current also decrease and this affect the output power of the all system. This has the meaning by comparing the output power of solar PV in different time during the day. Before noon the output power on PVs is high than the afternoon power generation due to high intensity of sunshine.

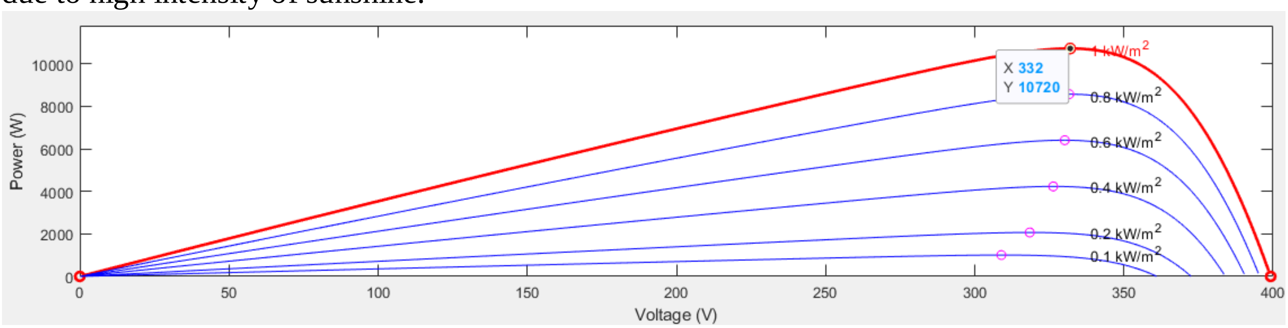

Figure 5-3: PV curve with different irradiances

Here the voltage is presented on x axis while current is on Y axis and the corresponding value of power p is calculated as $P = V * I$

This shows that the output maximum output current Imax=32.28A and maximum voltage Vmax=332V

The maximum power output Pmax= 10720W this at corresponding to 1000W/m^2 which is not possible in real life.

Table 5-1: Result from PV

Irradiance (kW/m^2)	Current(A)	Voltage(V)	Power(kW)
1	32.28	332	10.720
0.8	25	331.17	8.569
0.6	19.5	330.2	6.404
0.4	12.97	326.3	4.231
0.2	6.491	318.4	2.067
0.1	3.249	308.9	1.004

The output power of the designed system reduces with a reduction of the irradiance.

PV output Input signals

By running the system in MALTAB SIMULINK the output voltage of output from the PV is ranging between 0 and 330V depending on the value of the input irradiance.

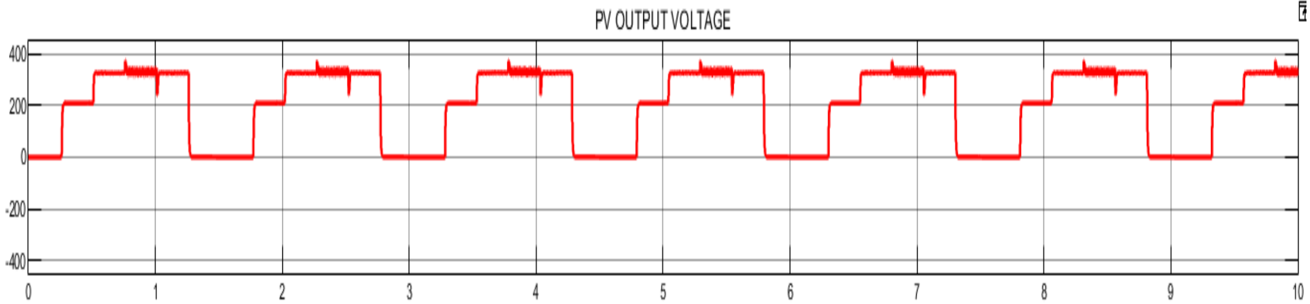

Figure 5-4: Resulting output on PVs and Boost converter

Since the system is working by the use of perturb and observe to attract the maximum power point it just records the point of maximum output power.
The output is changing depending on the input irradiance. When the irradiance goes to zero, the output voltage also goes to zero and there is no power generated in that case on PVs

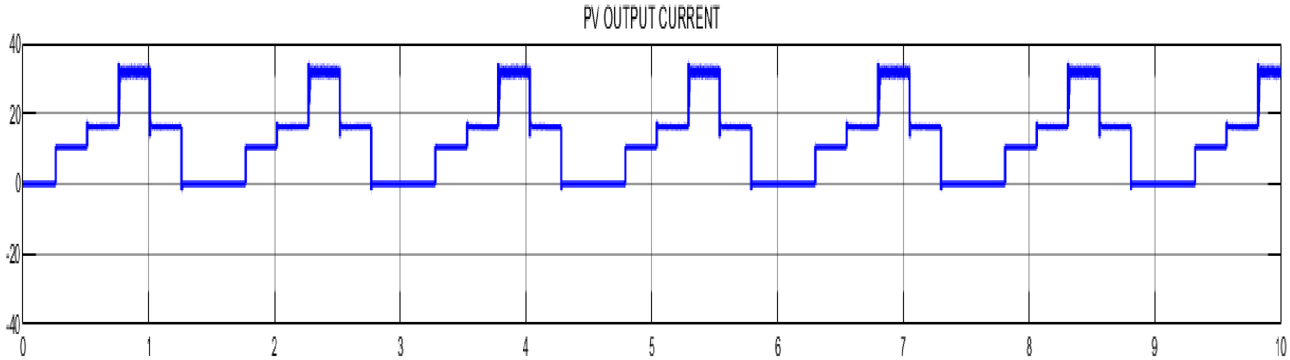

Figure 5-5: PV Output Current

On other hand, the output current of the PV is in the range between 0 and 35A depending on the input irradiance

5.2.Boost converter with MPPT system

Boost converter is a DC-DC converter used to change the voltage level of a DC source from one to another [28].

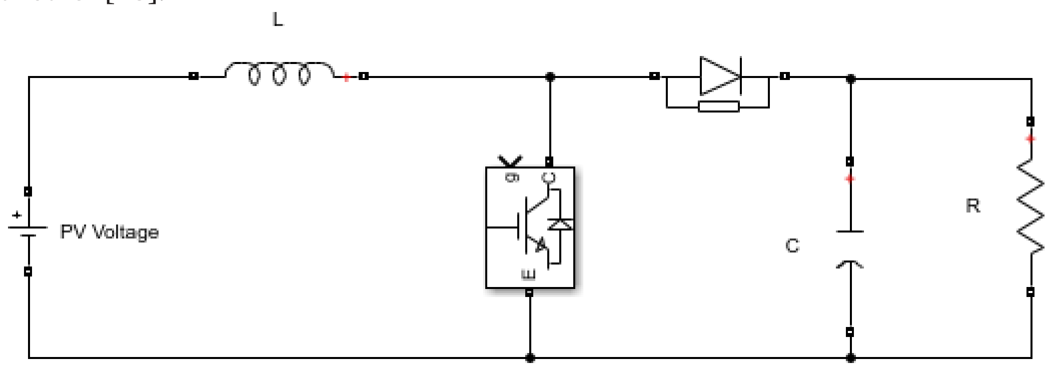

Figure 5-6: Boost converter

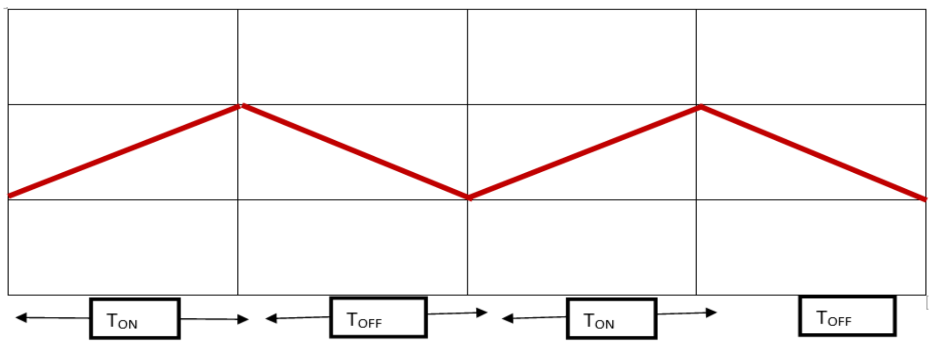

Figure 5-7: Switching period of Switch

Consider **D** to be duty ratio and **T** the period for this switch to be on and off (to complete the cycle) It is possible to calculate the output voltage and current knowing the input as follows

$V_S = (1-D)V_0$ or $V_0 = \frac{V_S}{(1-D)}$ and corresponding current of $I_L = \frac{I_0}{(1-D)}$ or $I_0 = (1-D)\,I_L$

Where

V_S an I_L are the Voltage and Current sent by PVs,

V_0 and I_0 is the voltage output to boost converter and it is also the input voltage to the battery.

The voltage of the battery side must be less that the voltage output on the boost side to create the storage of some charges.

$I_L = \frac{I_0}{(1-D)}$ or

Where

V_S and I_L are the Voltage and Current sent by PVs,

V_0 and I_0 is the voltage output to boost converter and it is also the input voltage to the battery.

These values are known because they are from PV side and can help us to calculate the duty cycle by fixing the period.

Duty cycle is calculated as $D = 1 - \frac{V_S}{V_0}$ or $D = \frac{I_0}{I_L} - 1$

The value of Duty cycle is always between 0 and 1, $0 \le D \le 1$

The other important values which are required are Critical inductor and Critical capacitor

Let first start by Critical inductor (L_C) by the use of equation $L_C = \frac{(1-D)^2 D * R}{2f}$

Secondly go to Critical capacitor (C_C) by the use of equation $C_C = \frac{D}{2f * R}$

As calculated above, $D = 1 - \frac{240}{600} = 0.6$

$$L_C = \frac{(1-0.6)^2 0.6 * 100}{2 * 6 * 10^6} = 8e^{-8}$$

$$C_C = \frac{0.6}{2 * 6 * 10^6 * 100} = 5e^{-10}$$

Resulting output can be obtained by setting value into MATLAB SIMULINK for simulating the converter.

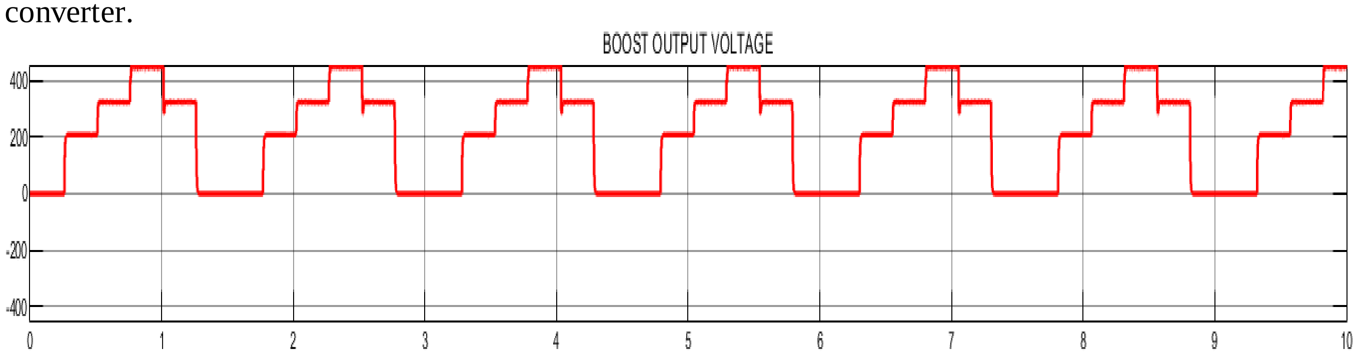

Figure 5-8: Voltage Output after boosting

By increasing voltage from low value to high value the output voltage is able to charge the battery and increase in the state of charge.

The output after boosting is very large as compared to the input of the PVs

The voltage has been increased here in the range of 0 to 330V of PV level and became in the range of 0 450V depending on the input irradiance after boosting and this has the effect on the process of charging of the battery.

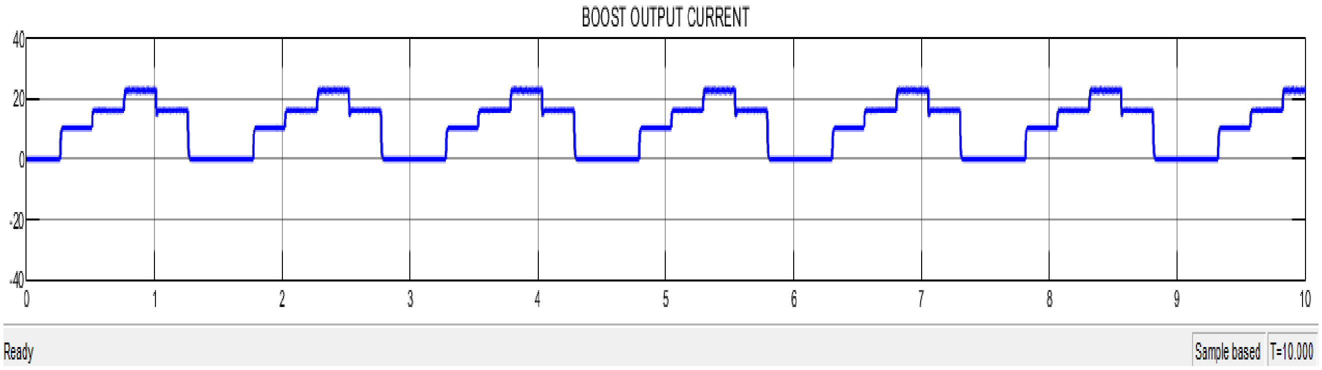

Figure 5-9: Output Current after boosting

An increase in voltage causes the decrease in current to keep the output power constant. Here the output current from PV was between 0 and 35A which has decreased to the range between 0 and 25A depending on the irradiance input.

5.3.Battery side

On other hand there is need of storing the electrical energy from the boost converter and it is not done randomly. The need of internal arrangement of them and production of same voltage as the one produced by boost and for purpose of increasing state of charge.
A set of batteries has been presented as follows

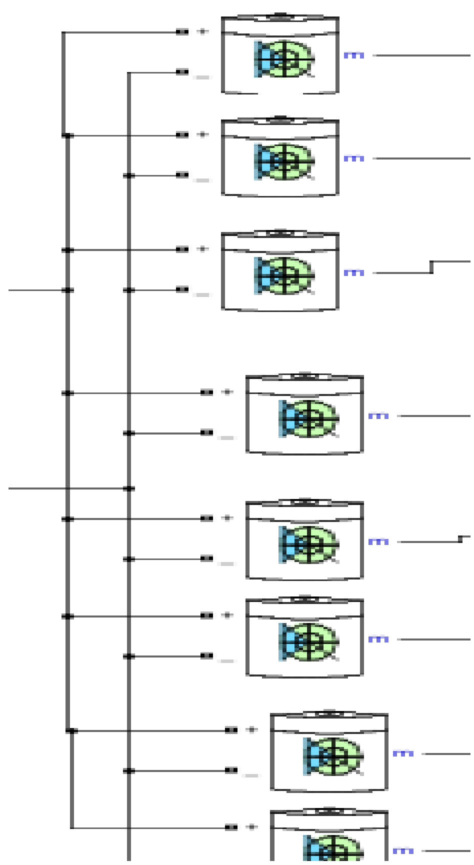
Figure 5-10: Battery layout in MATLAB SIMULINK

Each block diagram of battery is a set of 4batteries connected in series each having 200Ah 24V.It mean that each block having 800Ah and voltage of 96V. the state of charge has been set to 45% to limit the battery to go the lower level and they have to be charged whenever they are not full charged. If they are full charged, the system cut of power going to the battery of avoiding the overcharging which reduces their life span.

By running the program, the state of charge which was initial to 45% starts to increase as follows increase slowly until it reaches the maximum state of charge.

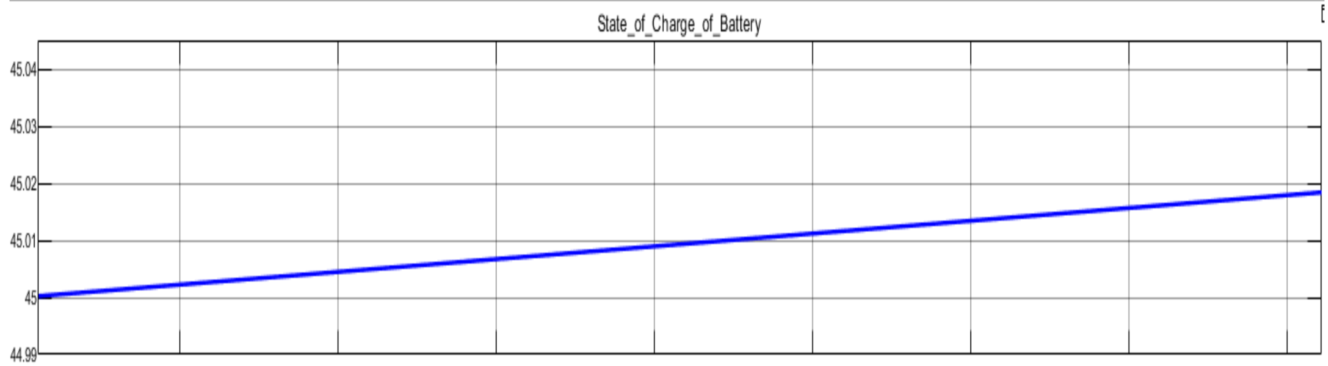

Figure 5-11: State of charge

As the state of charge increases the energy is being stored in battery and it takes some time to increase from the initial state of charge to the final state of charge which is at 100%.

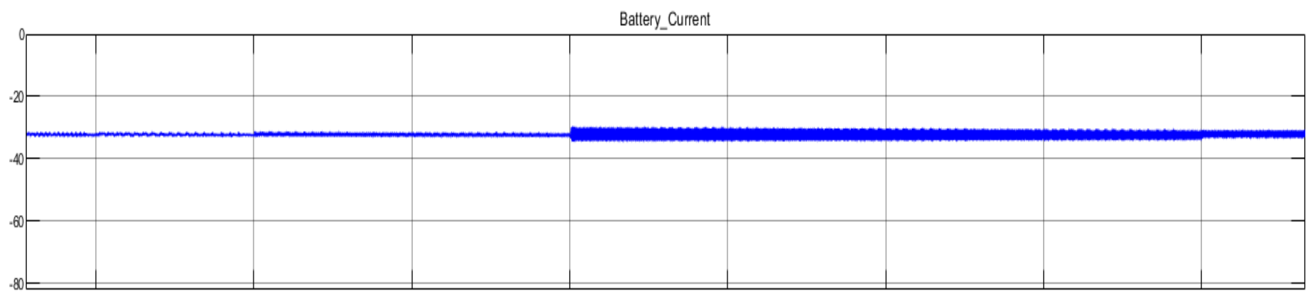

Figure 5-12: Battery current

When simulating, the battery voltage and current will change by given value depending on whether charging or discharging. It is charging when the input irradiance is somehow high and discharging when it is low while the load is connected to it.

Like the graph in figure 5.12 shows the discharging process of the battery at night for supply the or in ground period when there is no sun shine. It has been obtained by setting the input irradiance to 0 and running the system. In this case, the output power from PVs became 0 while the load demand is available. The battery bank reacts by supplying the stored energy to the surrounding families and grain mill machine.

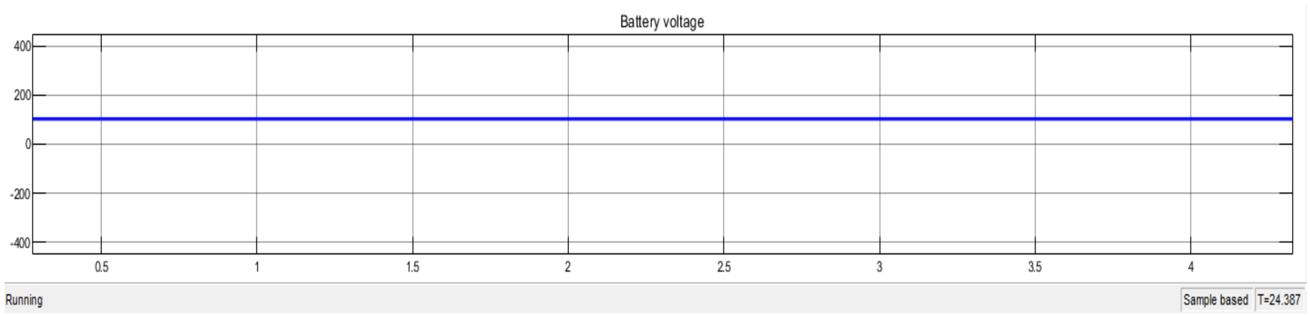

Figure 5-13: Battery voltage

Whenever the battery is under charging it related voltage will be increased by some amount so that the charges will be stored in the battery. The battery is on around 110V when it is charging

5.4.Inverter

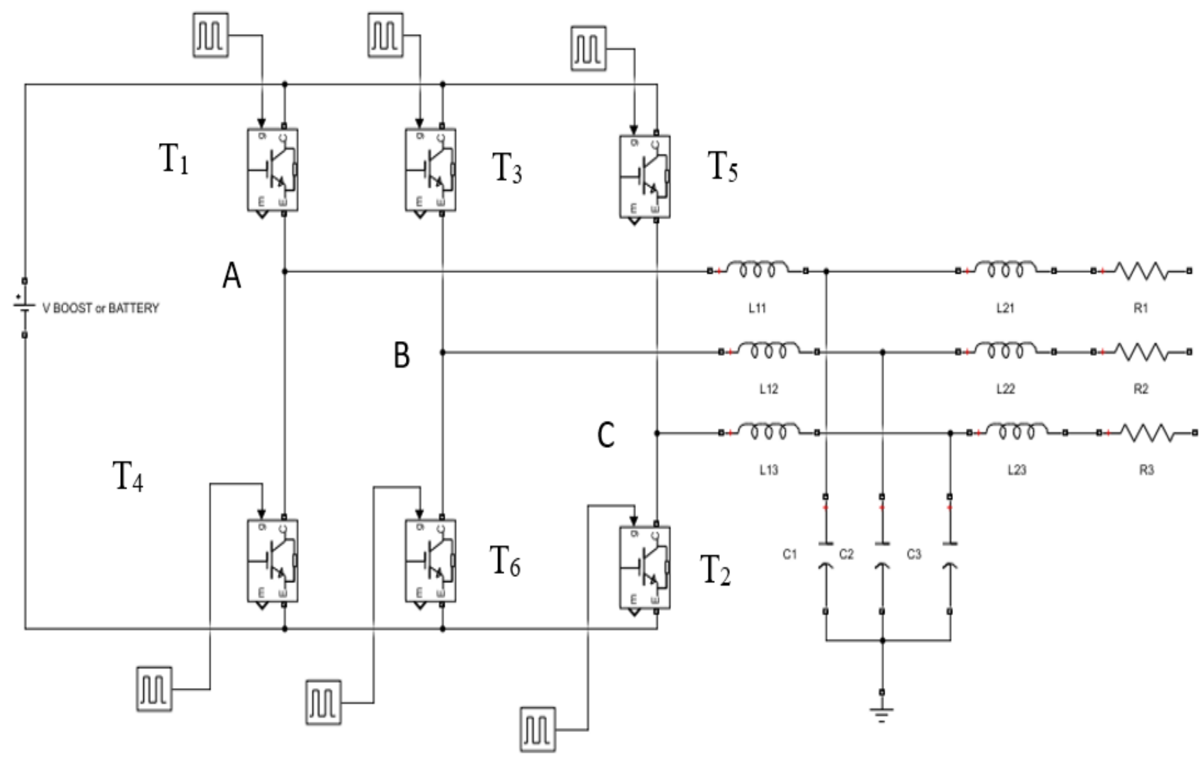

Figure 5-14: Inverter in MATLAB SIMULINK

Each IGBT (insulated-gate bipolar transistor) conductor for 120^0 and become off. In this case at every interval, the 2 IGBTs will conduct while the remaining is in OFF state.

For getting the signal with low harmonic, there is the use of LCL filter. The waveform obtained by running the inverter without LCL filter is sinusoidal waveform whose amplitude is 40V with ripples that needed to be reduced for having the output waveform of high quality.

The value of $L_{11}=L_{12}=L_{13}$ =0.08H while $L_{21}=L_{22}=L_{23}$=0.06 and the capacitor in parallel with them is $C_{11}=C_{12}=C_{13}= 5*10^{-6}$ C

Inverter output before connecting transformer
The inverter output voltage is not able to run the machine due to its lower value as compared to the motor rating.
The motor rating is of 400V as the voltage while the output voltage of the inverter is in between -40V and 40V

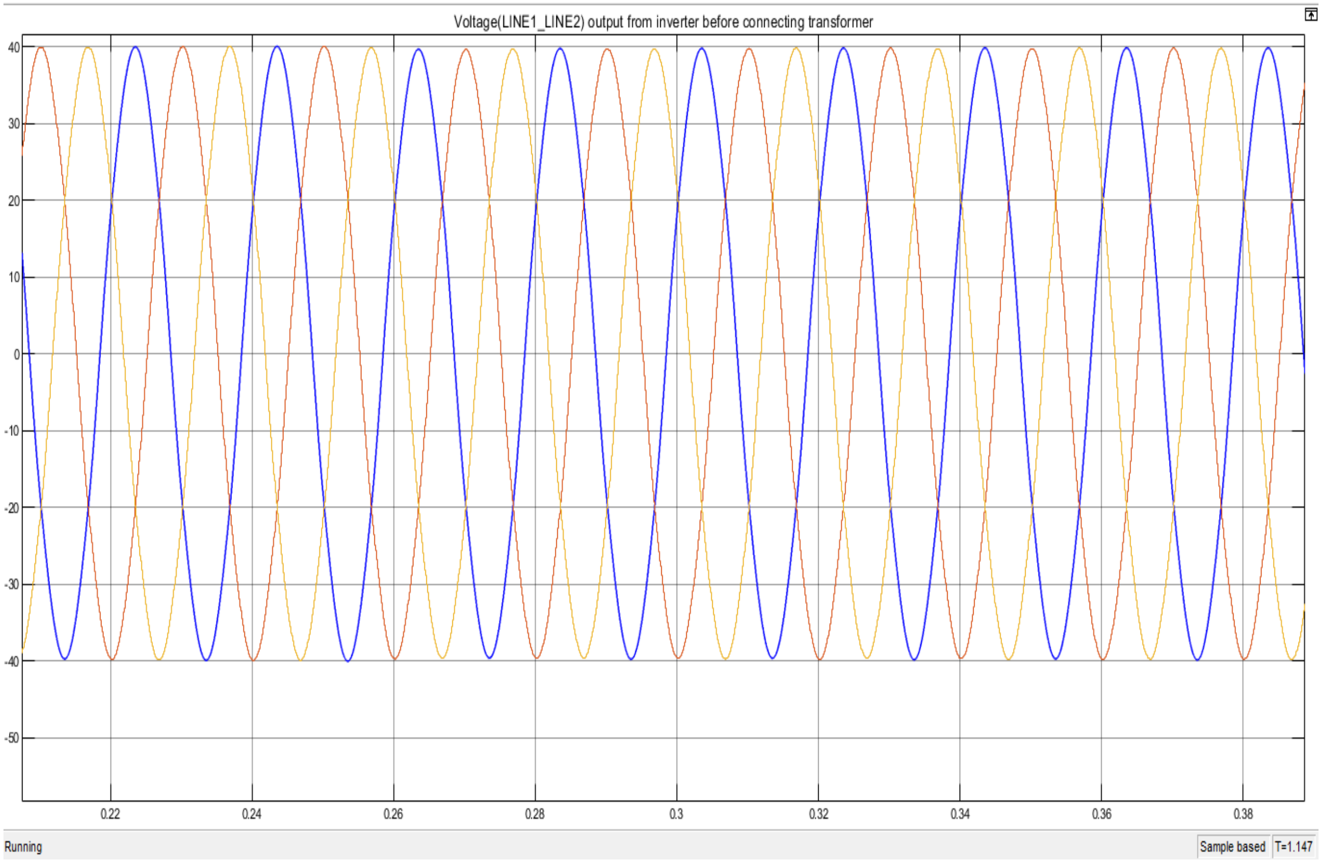

Figure 5-15: Inverter output before connecting transformer

This level of voltage needs to be stepped up to have the standard rating that is possible to be used by the induction motor and the local community. The only way to change to the high value is to step it by using a step-up transformer which increase the level up to 400V.

Inverter output after connecting transformer

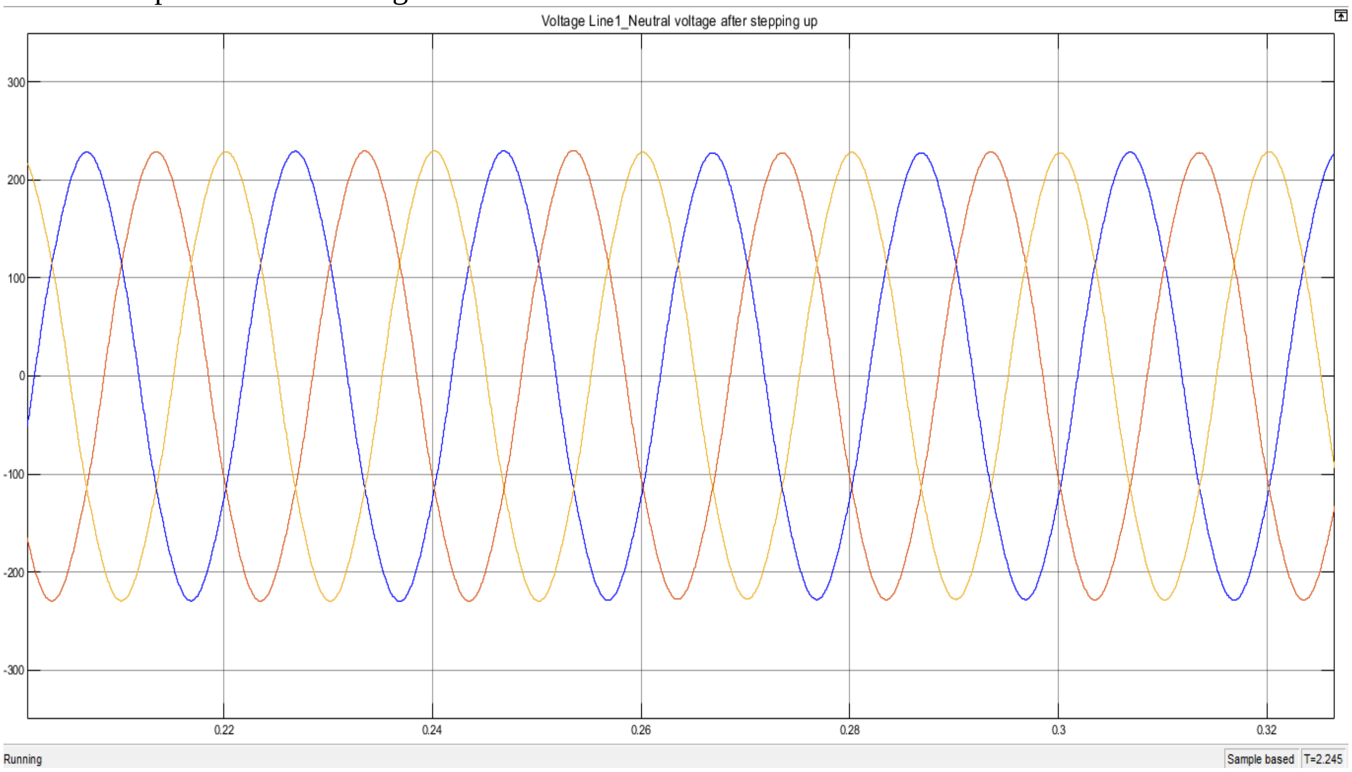

Figure 5-16: inverter output after connecting transformer

The presented voltage is the line neutral voltage and it of 230V and by measuring the voltage between the two phases, the value obtained is of 400V as the one of national grid

5.5.Induction motor parameter

The induction motor used in this project is three phase motor of 7.5kW,400V, 2860rpm other remaining parameter like current and torque are being calculated and inserter to the block in MATLAB SIMULINK.

$$Ns = \frac{120f}{p}$$ Where f is frequency and it is 50Hz and p is number of poles

Ns=3000rpm this is never attained on induction motor practically. So, it varies between that value and 2700rpm depending on the load (torque) connected to it.

Torque is calculated by using as

5.5.1. Induction motor starter

The equivalent circuit of a three-phase induction motor is similar to that of a transformer with secondary winding short circuited. At starting, the speed is zero and slip is one, hence the emf induced in rotor circuit is high at starting. Therefore, if a three-phase induction motor is started with full rated voltage applied to the stator, it will draw very high starting current for some time.

An induction motor, when directly started with full rated voltage, draws 4 to 7 times of their full load current, the actual value depending upon the size and quality of the motor [30]. This high starting current is harmful for the motor itself as well as other loads connected to the same supply system and power supply itself, because this high starting current will cause large voltage drop in the line momentarily.
Hence, only small induction motor shall be directly started with full supply voltage. For large induction motors, some starting methods like star delta starting, auto transformer starting or stator resistance starting has to be used to reduce starting current. In case of the induction motor working with the inverter, the inverter itself is used as a soft starter to reduce this starting current.

5.5.2. Motor torque

When starting in star the power developed is reduced as follow

$Pstar = \frac{Pmot}{3}$ where Pstar is power in star starting and Pmot is the same as Pout of the motor
In the above conditions starting torque is given the starting torque also will be reduced as the power reduces.

$$T = 9.555 * \frac{7.5 * 10^3}{2800} = 25.59 Nm$$

The machine can be started by changing the frequency as the power supply is from the inverter and it has that ability to start the machine as soft starter.
On the machine which is supplied by human being, the torque is not constant. It is always changing depending on what they are feeding and, on the place where they are getting them.
In this case we are let take 5 different.

Table 5-2: Input torque

Time	5sec	10sec	15sec	20sec	25sec
Torque	25.59Nm	12.79Nm	6.39Nm	12	9

To have the result on the machine, there is requirement of the load and in this case, it is the grains supplied inside. The load here is in terms of torque (Nm) that the motor is required to develop so that it is possible to transform grain into power (flour).
The torque in the table 4.2 is the input as the load of the machine to show its characteristic when it is running at no load and when it is having the grains inside

Load Torque characteristic

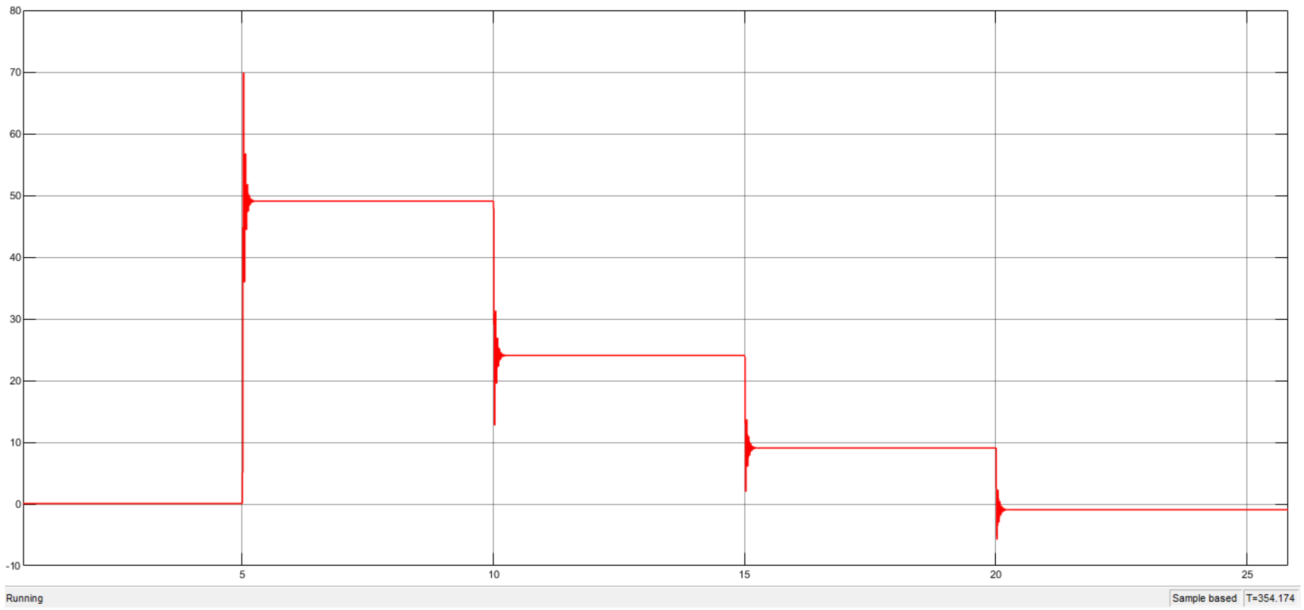

Figure 5-17: Load Torque characteristic

The above graph is exactly the presentation table 4.2 of the load that has been inserted in the machine. At starting the machine have no load and after 5sec the grain were allowed to inter inside. After 10secs, the grain has been reduced to a given value and again after 15 secs reduced to a low value because they were about to finish in the hopper.
At 20sec the hopper is almost empty and the machine has to be stopped to avoid the consumption of electricity for nothing.

To understand the work the motor is doing here, let have a look on the speed characteristic when the load is changing inside grain mill machine.

Speed characteristics

By running the system and recording the spend with respective time, the following speed characteristics is obtained

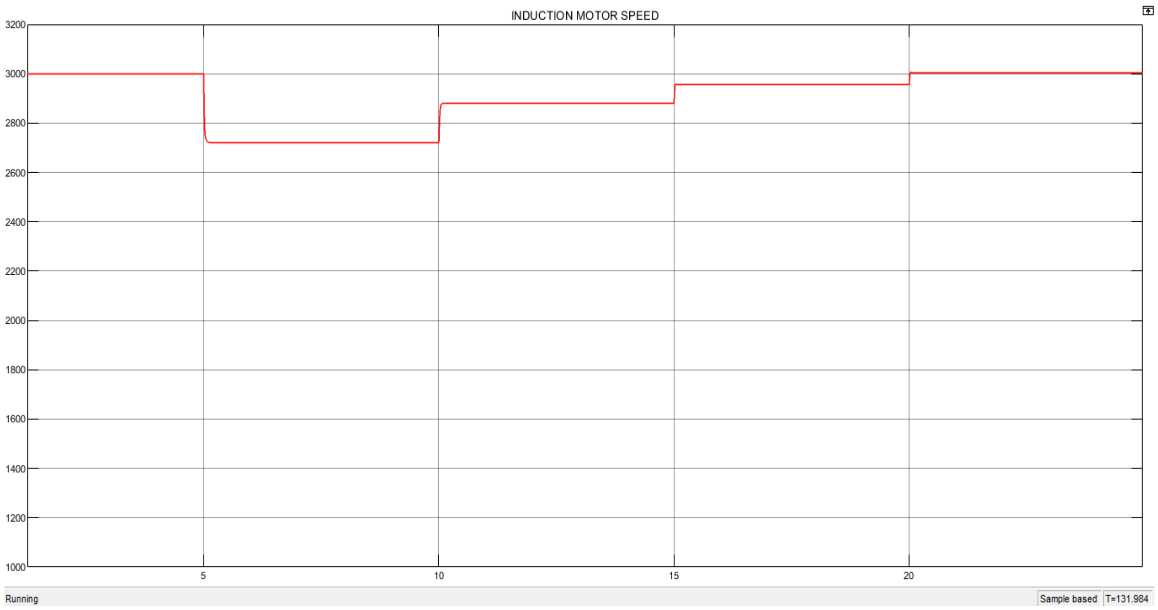

Figure 5-18: Speed Curve

By changing the load (torque) speed will be affected directly
At no load (when there is nothing inside the machine), the machine is running at maximum speed near which is around 3000rpm.
Between 5seconds and 10 seconds the grain was allowed to inter inside for transformation in this case the, the speed was decreases because of the opposition of force of the machine with the mass of the grains where the last value becomes around 2700rpm. By reducing again, the quantity of the grain entering in the machine the speed is affected again between 15 and 20sec where the speed has increased near 2900rpm.
The speed of the machine is affected by the quantity of the grain entering in the machine therefore it is very important to control the input of the machine in the hopper to avoid the overloading of the machine.

6. SOCIAL, ECONOMIC, TECHNICAL FEASIBILITY STUDY

Solar energy is free and can be extracted to electrical energy in wide range of capacity from small scale to large scare depending on the needs. Even if it is free, its extraction is not free due to required material for conversion. For medium and large scales, a high initial capital investment is required[31]. Before putting investment resources into any new project, technical and economic/financial study has to be done to see if it is feasible for investment and to avoid any losses that can occur.

This is nothing but the techno-economic /financial evaluation or assessment of the project before actually going into action. Such study is necessary to minimize the risk of investment and maximize the benefit from the scarce investment resources [32].
A solar system project needs sufficient amount of investment and is expensive. Such project involves risk because most of the cost needed must be used at the starting of the project. It is by natural that the supporter (investors) of the project needs to be convinced that the project is technically and economically /financially feasible and the investment will not be lost.

This part is going to help us to evaluate the projects design of an off grid solar grain mill machine on technical, economic and financial with the objective of giving different alternatives wherever they are possible with purpose of avoiding any loss.

In this case, the plant factor and unit energy cost are the two basic and important indicator which gives more information because they can be quickly calculated at each stage of planning a project (the pre-feasibility stage) to predict financial viability [32]. They help to do initial comparisons between new generation of energy source and alternative energy or power sources.

Apart of plant factor and unit energy cost there is also net present value (NPV), internal rate of return (IRR) and payback period. The calculation of simple and discounted payback periods of solar home system project investment also gives the idea on how many years the investment will be gained back.

6.1.Technical Feasibility Study

Technical viability comes first in feasibility study due to its importance in demonstration of how electricity can be generated by using solar panels and the influence of weather condition on the output power which is generated by the system.
The output of solar panels is highly by solar irradiance available in the given area, temperature, precipitation, air humidity, wind speed and direction. All of them they have to be considered in choosing the place for construction of solar generation systems.
In design of an off grid solar grain mill machine projects, technical viability is highly influenced
by availability sufficient sunshine. The location of proposed project has high sunshine. It is located in eastern province of the country where the peak sun hours are very high in comparison to other location in Rwanda. Other location is having lower sunshine especially in Northern Province which is coved by fog in almost the part of the part of year.

Based on the data from meteorological agency and taken on two different districts related to solar irradiance, the place is more powerful with enough sunshine possible of giving the electrical energy that can run grain mill machine.

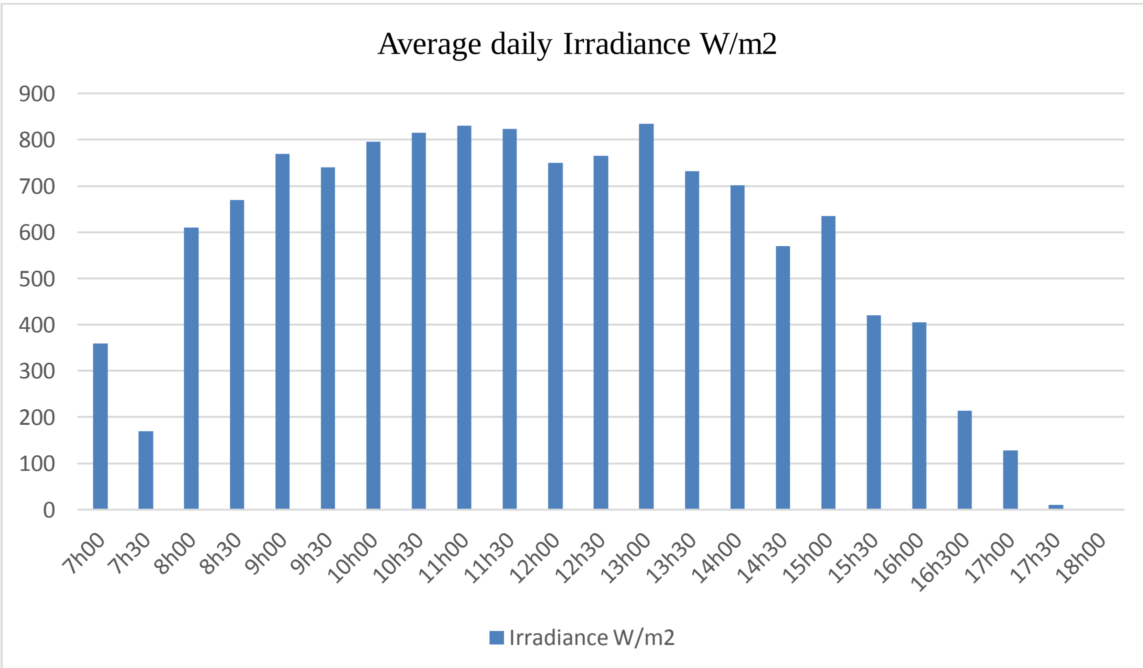

Figure 6-1: Average daily irradiance

Based on the characteristic of PVs available on the market the project which can be implemented in the region of having the irradiance as the one shown in the table will have a good output.

6.2.Energy Demand study

For determining the capacity of solar home system project, the estimation of energy demand has to be taken into consideration. In grain mill machine which are used for commercial purpose, the machine which can try to have efficiency in terms of production and supporting the overload must have the induction of at least 7.5Kw and able to produce an average of 300kg of floor per 1hour. In addition to this, there is also to supply a surrounding community for home consumption especially lighting. It is about 20families each of 6light bulbs of 20W used 6hours corresponding to 2400W or 2.4kW.

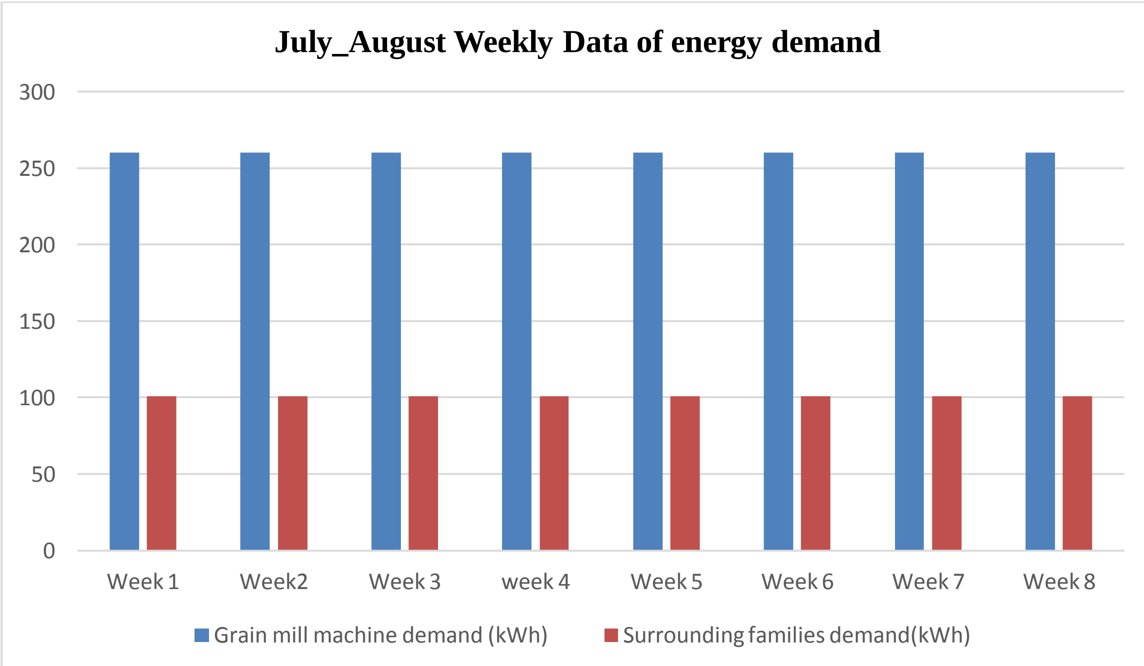

Figure 6-2: Power demand

6.3.Financial Analysis

This part of the project is going to help us to analyze the status of the project financially and the end-use services beneficiaries.

Different financial aspects of the project are to taken into account for exploring financial viability. Among them there is cost of project, projection of income and expenditure, financial feasibility analysis.

The cost of solar panel which is among the main component of solar energy system has been decreased with the time and lead to high production of solar energy all over the word. The following graph shows how the cost of module has been decrease and then affected the global generation by increasing in a short period.

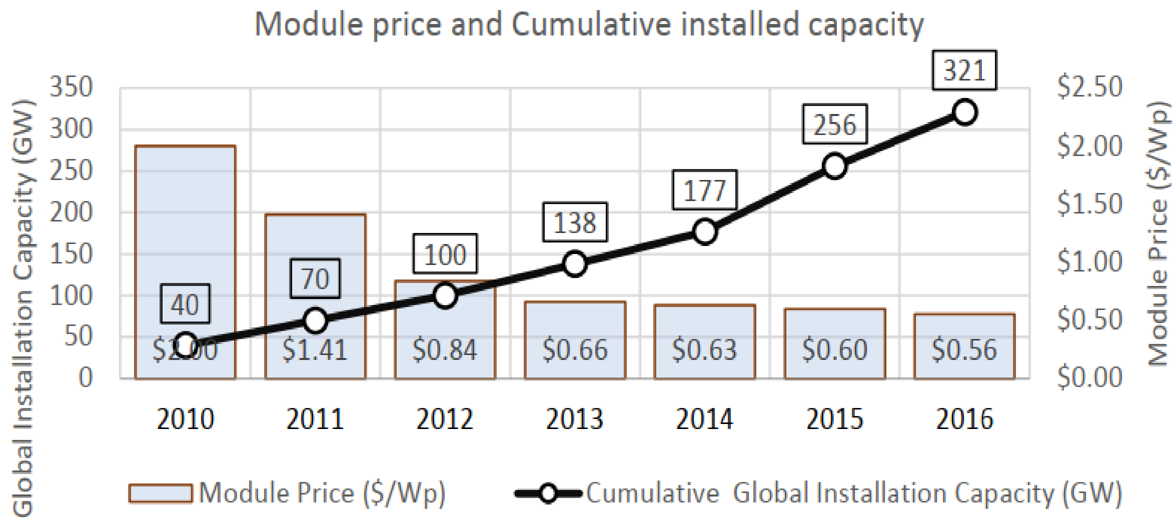

Figure 6-3: Module price and installed capacity

Currently, the module price depends on the type of cells which are used to make it but it is in the range between 0.2US$/Wp and 0.6US$/Wp depending on the type and manufacture.

6.3.1. Project Costing

The total cost of the project includes all cost of material and installation cost. To obtain this the market survey is done to get the cost of PVs, inverter, cables, charge controller, and support structure. In addition to this there is also transport, man power until the project is able to run.
The cost of all those items was obtained on online market including shipping and also compared to Rwanda market.
The label market of Rwanda also has influence in estimation of cost of the man power and the required number of days that the system can be installed. If there is gap on cost estimation by becoming lower that it was planned, the contingencies compensate to the system.

6.3.2. Material required or proposed project and corresponding cost

Figure 6-4: Bills of quantity

Material	quantity	Unit cost US $	Total cost US $
PV	35	150	5250
Charge controller	1	800	800
inverter			1000
Batteries	35	300	10500
Cables+ connectors	100m DC, 100m AC underground, Connectors 150	1.5, 5 0.2	150 500 30
Hardware (mounting structure)		400	400
Protection (lightning, overload, etc)			200
Induction Motor	1	600	600
Strain less Metal shits	2200*1800*6 mm	250	250
Welding electrodes	5	10	50
Cutting Disks	10	3	30
Bolts and nuts	500	0.2	100
Mill support structures			400
Man power	5*10days	50	2,500
contingencies			1,260
Total			**24,020**

The total cost of the project design of an off grid solar grain mill is 24,020US$ so that it can be able to run the machine and also to supply electricity to 20surrounding families for home lighting.

6.3.3. Projection of Income and Expenditure

After running the system, it starts produce some amount of money to pay worker who are under the survey operation, buying screen whenever they are needed and other maintenance related activities as they can be required. The income generated is based on the agricultural product which is there for servicing (to be milled). The survey done on two different sites, show that on average site A had 600kg per day and on site be has an average of 650kg. In addition, there power consumption for home lighting of 20surrounding families of 2.4kWh per day.
Consider the cost of production of kg of floor to be 50Rwf and unit cost of electricity to the surrounding community to be 85Rwf per kWh.

$$\Pr ojection\_Income\_Daily = Daily\_income_{mill} + Daily\_income_{community}$$

The projection income includes taxes and manpower on the grain mill. So, it contains the expenditure.

$Expenditure = Expenses_{Worker} + Tax + Contengencies$, this is done monthly.

$$Daily\_Projection\_Income = \frac{650kg}{day} * 50 + \frac{2.4kWh}{day} * 90 = 32,716Rwf$$

$$Monthly\_Projection\_Income = 32,716Rwf * 30days = 975,216Rwf$$

Let Taxes be 50,000Rwf and Manpower be 40,000Rwf per month

$$Expenditure = 50,000 + 40,000 + 100,000 = 190,000Rwf$$

$$Monthly\_Income = 975,216Rwf - 190,000Rwf = 785,216Rwf$$

The total monthly income of the project is 785,200Rwf corresponding to 810US$ and 9,720US$ per year.

Here it is possible to calculate the payback period of the project when knowing the investment of the project whenever implemented.
From the table of proposed materials of project and corresponding cost, the total cost of the project is 24,020US$ and the annual projection income is 9,720US$, the payback of the project is

$$Payback = \frac{Total\ investment}{Annual\ income}$$

$Payback = \frac{24,020US\$}{9,720US\$,} = 2.5years$, this is possible whenever no money is spent on any other except taxes, manpower and process contingencies.

6.3.4. Life-Cycle Cost Analysis (LCCA)

In analyzing the cost of the project to see its economic viability, different technics are adopted and among them there is payback period to see when it will return back the investment. This is not enough to say that the project is financially feasible because it can give a short time to get back money used but also the materials used in the project expire in short time than this period.

An example here is solar system project having storage system. In solar home system the battery has life cycle of around five years, PVs have 25 years so after each 5 year the batteries have to be replaced. In this case the payback period of this project must be less than 5 years, so that it is possible to pay the total investment of the project and to have in hand the money to be used in replacement of them in this period.

Life cycle cost analysis is the best way for economic comparison between solar system and other electrical generation. It depends on three different phases which are construction, operational and decommissioning phase.

Construction cost of the system include cost of materials and workers of the project until it star operating to produce floor for home consumption and it is known as the initial cost of the project.

Operation cost here include the cost on wages and maintenance since there are some material which can need to be replaced when they are damaged or old here an example is screens which require to be replaced at least every one month.

6.3.5. Life Cycle Costing (LCC) for Solar PV system

Life cycle cost analysis of solar grain mill system is divided into five different categories which are development/planning (C_{dev}) Solar PV (C_{PV}) electrical components (C_{el}) mounting structure and civil works (C_{Civ}) and operation and maintenance cost ($\mathbf{C_{O\&M}}$).

$$LCC = C_{dev} + C_{PV} + C_{el} + C_{Civ} + C_{O\&M}$$

The cost of all required material and their quantity are given in the table Material required given above but it doesn't include maintenance and operation cost because it is the table of required so that the plant start at the first time.
They are summarized in the following graphs where high cost is storage system occupy 39% while Solar PV is 33%, electrical component has 12%, Mounting and civil works 11% and Operation and maintenance of 5%.

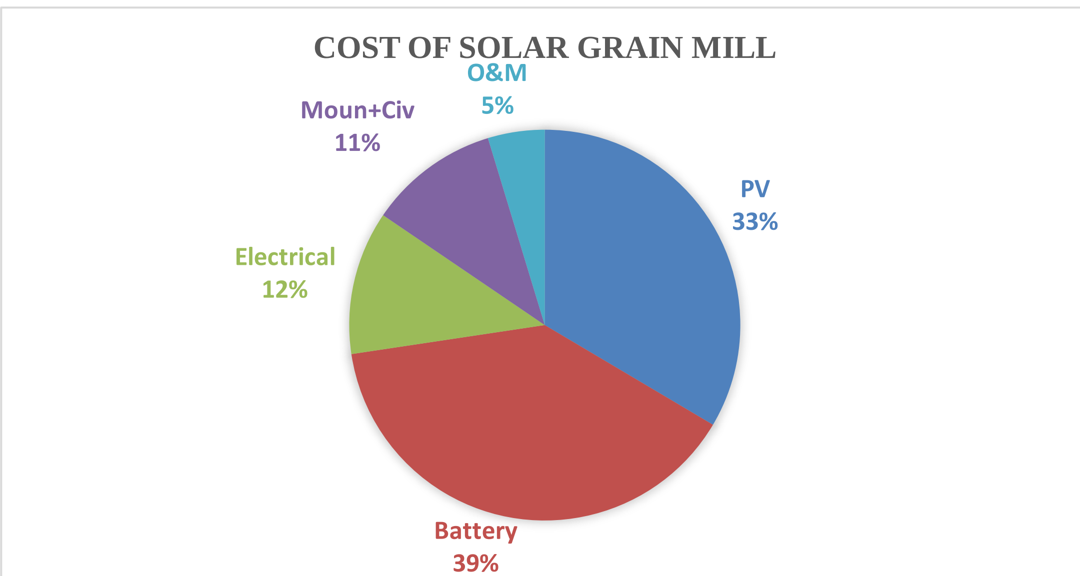

Figure 6-5: Cost of grain mill

Based on the cost of the project and on hoe is generated or spent, the flow chat explains very well the amount which is going on each component. Some of them are bought one while others need replacement after a period. Among them there is batteries which are even taking a big part of the project but because of short payback period, the project is able to use on the money generated in the business to replace them when they are old.

Whenever it is impossible to use the battery, the system can still work but providing the services to customer during day time when sun radiation is available and stop working at night.

7. CONCLUSION AND RECOMMENDATIONS

7.1.CONCLUSION

This work was the proof of concept effort to study the design of an off grid solar grain mill machine associated with home lighting system of 20 surrounding families. This effort resulted in the intelligent distributed production of electrical energy from solar radiation, thereby raising overall power generated in a country and reduction of fossil fuel consumption toward protection of environment.

The system components designed included civil work components which comprised of the support construction of PV panels, and the electromechanical equipment such as PVs, charger controller, energy storage and grain mill machine.

This project is designed to generate 10.48kW for which 7.5kW is to be used for grain mill machine to provide services in remote areas fall from national grid and the remaining for home righting of surrounding community.

This off grid solar power plant has been analyzed based on different parameters including technical, economic feasibility study and plant life cycle. The result has shown that the project is technically feasible based on the irradiance available and as compared to the PV modules characteristics. It is economically feasible based on its payback period which is 2.5years and with life cycle of battery of from 4 to 5years.

Although, this system will reduce the use of fuel which is used to agriculture activities like small scare agro-processing and irrigation by the use of diesel engines. These small internal combustion engines have to impact on the environment and they can be replaced by solar powered systems for environment protection purpose and operating cost reduction.

Whenever it is impossible to use the battery due to different reasons like high cost of the project, the system can still work but providing the services of grain mill to customer during day time when sun radiation is available and stop working at night.

Development of many solar off grid power plants can reduce the electricity shortage and make scale savings if carefully planned.

7.2.FURTHER WORK FOR IMPROVEMENT

Rwanda is a developing country so that to reach the vision 2024, it needs to increase electrical energy.

The Strategic Plan of the country is to reach on 563 MW of electricity generation 2024. T will be achieved by construction of many different generation system as generation mix of hydro, methane, geothermal, peat to power and solar.

Due to the power shortage in our country that causes the use of thermal power plant particularly internal combustion engines, I recommend:

- To replace internal combustion engines by solar power systems.
- Leader in charge of energy sector think about renewable energy resources especially solar.

- Engineers and researchers to make a study on all big thermal power plants found in the country on their environmental impacts.
- Engineers to do more research on all small scare internal combustion engines found in the country.
- The Rwandan government to encourage private investor to construct many off grid solar power plants for increasing the energy access and reduction of thermal power plants causes global warming.
- Upcoming students to conduct their project in case of implementation of off grid solar grain mill.

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APPENDIX A

Sample questions that were included in the prepared questionnaire

1. What do you know on the grain mill machine?
2. Where are you coming from?
3. How fall from this place to your home? (estimate the time used from here to your home)
4. How much kilogram did you bring?
5. When did you rich here?
6. How long is it going to take you to get service?
7. How much are you did you pay for the service?
8. How is the service that here?
9. Are you using the flour from here for home consumption or business?
10. When are you planning to be back for the same service?
11. How is the crops production in your village? (example maize or cassava)
12. What is the dominant harvest in your area? Cassava, maize, soya, sorghum, rice etc what?
13. Is there any interest on having mill machine near your home?
14. Is there any difference between flour produced by the machine driven by diesel and electricity?
15. Do you have electricity at your home or near?
16. If the previous is yes and you know to differentiate single phase with three phases. Is your distribution lines single phase or three phases?