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''PV_SYSTEM GRID CONNECTED MANAGEMENT USING AUTOMATIC CHANGEOVER SWITCH''

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Declaration

I, the undersigned, declare that this Project proposal 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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This thesis proposal has been submitted for examination with my approval as a university advisor.

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ABSTRACT

Integrated renewable energy systems, which use different energy sources such as solar energy, hydro-energy and wind to satisfy various energy needs, are well suited for intertropical countries. Solar energy provides free energy solutions for many countries near the equator, including Rwanda. Even if solar energy technology keeps on its advancement, hydropower remains the principal power source in Rwanda even though it is expensive. Some households, schools, and health centers are getting solar energy systems from donations; others bought them due to the arrival of the national grid. Those systems are not used efficiently, they use them when there is a national grid cutoff. The intermittency of solar energy makes users shift from solar energy to the national grid. REG (Rwanda energy group) has set an energy strategic plan since 2015 for achieving a minimum of 512 MW of energy production in 2024/2025 to meet the total energy demand. They wanted to feed electrical energy 52% grid-connected and 48% for off-grid. The off-grid systems are often to be solar energy systems. Many African countries have an issue of overload on their national transmission line due to high population numbers. These days Rwanda is expanding transmission lines, but also it is not sustainable. Main research showed that the solution to the energy demand of any country is distributed generation (DGs). This study was focused on renewable energy integration, where solar energy systems will be connected to the national grid at the consumer level to reduce the heavy load on the national grid and to save money because DGs make energy cheap. The system name is PV system grid connected; solar energy uses the national grid as a backup. This system uses an advanced power electronic device called an automatic changeover switch. The system works automatically, when solar energy is weak, the device switches to the national grid automatically and even television continues to display. This study focused on the management of energy produced from solar energy in different households, schools and health centers also connected to the national grid. These energy users do not use solar, energy efficiency due to the solar intermittent. The case study was an electrical shop located in Gitega sector, Kigali city, where even Covid-19 measures could not interrupt the study. A solar energy system of 273 W was built and connected to the national grid that the shop uses. They use 273 W (Pmax) in fourteen hours (14 h). The total daily energy consumption is 3.822 kWh. The results showed that 97.5% of the energy from the national grid was saved.

Key words: PV system, national grid**,** automatic changeover switch, off-grid PV system, solar home system,

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List of abbreviations

REG: Rwanda Energy Group

REI: Renewable energy Integration

PV: Photovoltaic

IEA PVPS: International Energy agency Photovoltaic Power System Programme

DGs: Distributed Generations

ACE-ESD: African Centre of Excellence in Energy and Sustainable Development

RES: Renewable Energy System

IEEE: Institute of Electrical and Electronics Engineers

PCC: Point of Common Coupling

d-q: Direct Quadrature

STACOM: Static Synchronous Compensator

D-STACOM: Distribution Static Synchronous Compensator

UPS: Uninterruptible Power Supply

DVR: Digital Video Recorder

ATS: Automatic Transfer Switch

ACS: Automatic Changeover Switch

ESMAP: Energy Sector Management Assistance Program

RER: Renewable Energy Resources

DC: Direct Current

AC: Alternating Current

MI: Modulation Index

EMI: Electromagnetic Interface

EHRHART: German Nickname (a supplier company)

Vmax : Maximum Voltage

Imax : Maximum Current

Pav: Average Power

NO: Normal Open

NC: Normal Closed

PWM: Pulse Width Modulation

AT: Access Time

UART: Universal Asynchronous Receiver-Transmitter

ICSP: In-Circuit Serial Programming

EEPROM: Electronically Erasable Programmable Read-Only Memory

SD: Secure Digital

LCD: Liquid Crystal Digital Display

RTC: Real Time Clock

IC: Integrated Chip

Chapter 1: INTRODUCTION

1.1 Background

Due to the cost reduction of solar energy technology and the maturation of photovoltaic technology, solar energy technology has become the most renewable energy technology that is growing very fast in the World. This Technology is being implemented by governments for carrying out different energy policies of boosting Energy diffusion[1]. In 2015 the level of photovoltaic was not more than 1.3% of the electricity generated in the World, and it is expected that this level will continuously increase. It is expected to reach 13% in 2040 from the new set in the Paris Agreement[2]. Solar power plants are very suitable to be installed at the distribution level of buildings, residential houses, and industrial facilitation. This power technology plays a big role in renewable energy integration (REI). Solar energy technology systems are single-phase or three-phase at the distribution level[3]. The photovoltaic system is either tied in series or either in parallel and integrated on the grid through a central photovoltaic inverter. It is also called a hybrid system[4].

The reduction of the cost of photovoltaic (PV) solar modules is driving the deployment of PV systems worldwide to reach a total greater than 75 GW peak power of PV installed in 2016 in the international energy agency PV power system program (IEA PVPS) countries[5]. But some countries are still having problems related to lack of energy access and challenges of grids characterized by frequent blackouts and power outage day to day. Many energy literatures said that above 600 million people do not have access, to electricity in sub-Saharan Africa. Rwanda is among the countries that also are facing a lack of energy accessible to citizens. As Rwanda has been selected to be the case study of the renewable energy project, it was an opportunity for getting donations from donor agencies that have been key players in financing energy projects in Africa. Rwandan institutions like schools and hospitals received solar panels for lighting before the arrival of grid electrifying [7]. And then after these solar energy systems are used only when there is an electrical outage! It is seen that solar energy itself is not reliable. That’s why institutions most of the time use energy from the Grid. This project has the solution; to use an Automatic change over switch that will make the two systems work together. The combined system will use the grid as a backup to strengthen the solar energy system. Currently, Rwanda has 221MW of installed electricity generation, 51% is electricity access where 37% is the national grid and 14% is mainly solar [8]. The national power network presents high percentage losses, sometimes going beyond 30.0%. Rwanda has some small and old electrical grid infrastructures, and also has a rapidly increasing population, and widening supply-demand. With such an imbalance of the population's energy demand and available capacity, the government of Rwanda aims to achieve 512 MW installed power generation capacity in 2023/2024[8][9]. Therefore, the use of electrical energy efficiency is one of the keys to fixing optimally the issue of electrical energy in Rwanda. It is in this line that the project is studying the possibility of integrating solar energy with the Grid, where the Grid will work as a backup. The combination of different energy sources improves system reliability and decreases Energy costs. Moreover, HES contributes to the reduction of energy storage requirements as compared to systems consisting of a single resource. The outcome of this project is to optimize the advantages of integrating solar energy with the grid at the consumer level.

1.2 Statement of the problem

Access to electricity plays a big role in accelerating economic development by improving health and life standards. Solar Energy constitutes a tremendous resource of energy; however, people still suffer from the lack of energy. Rwanda's government is investing significant investment in electrical energy production to improve electricity access where a strategic plan since 2015 has set to produce a minimum of 512 MW in 2024/2025 where about 52% will be connected to the national grid; 48% further from the transmutation line will use off-grid (They proposed off-grid PV systems) and they have plans to connect 100% by 2050[10]. Many institutions and some households in Rwanda have Solar PV systems, and they use more electrical energy from the national grid. They use a PV system when grid energy is not there (cut off). Users say that solar energy has some challenges. It is unpredictable and not available all day long, and the amount of energy generated by the sun depends on Weather conditions and the location of the user. Many researches on electrical energy production and power quality showed that distributed generation DGs is a strong way to reach sustainable electrical energy[9][11]. The combination of different energy resources in the form of energy integration is needed instead of using traditional connections to the national grid. To use a new technology where PV systems off-grid becomes connected to the national grid at the consumer level by using advanced power electronics. This technology can serve as an economical and reliable solution for consumers and reduce overload on the national grid.

In recognition of the above-proposed solution, this project responds to these challenges by providing a solution to institutions and households. New technology will be used to connect PV systems to the national grid by using an **Automatic changeover switch** at a consumer level**.** This technology is not popular in our country, but it is used in different countries and helped them to solve energy issues. The dominant power source will be the Solar PV system, and the Grid will be therefore the secondary.

1.3 Objectives

1.3.1 Major objectives

The main objective of this thesis is to show how photovoltaic (PV) systems found in different schools, health centers and households that have been bought or got from donors before the arrival of electricity from the main grid can be used to contribute efficiently to the energy conception to reduce the energy tariff to the users here in Rwanda. Since the energy from the grid is expensive compared to the energy from solar due to the high cost of initial investment, high cost of transmission lines per Km and operational cost, a hybrid system technology such as PV_system Grid connected is proposed in terms of cost reduction and efficiency. In addition, Rwanda climatic conditions are favorable for solar irradiance, and many areas of the country receive abundant amounts of sunshine in all months of the year. Since many schools, hospitals and some households have both solar energy systems with battery backups and grid, the PV_system Grid connected using an automatic changeover switch will contribute to the sustainable and economic energy system

The following specific objectives should be accomplished to achieve the desired goal:

- Design a solar energy system here around ACE-ESD so that Covid-19 measures could not interrupt the project.
- Analysis of solar irradiation in the Gitega sector during the period of data recording by using Rwanda Meteorology data.
- Evaluate the performance of the solar energy system using a smart charge controller.
- Design an automatic changeover switch using Proteus.
- To implement an automatic changeover switch that will be used to connect the solar system and grid.
- To install a memory card in the automatic changeover switch so that we will be sure that the data we will get are accurate and true.

- To build an affordable energy system that prioritizes solar PV systems and uses Grid energy as a backup.
- Evaluation of electrical energy will be saved after connecting two energy systems by using an automatic changeover switch.

1.3.2 Scope of the study

This project will work on the design of PV systems, integration of PV systems on the grid and compare the new system with the recent one by looking at the management of energy from the systems and energy tariff.

1.4 Expected outcomes and significant of the study

1.4.1 Expected outcome of the study

I. Reduction of electricity tariff to the users, the solar peak hours here in Rwanda is 5hrs, the solar energy density is 4 kWh/m^2 at the North of Musanze city, it is 5.4 kWh/m^2 in the South of Kigali city, Southern and Eastern province. This information shows that Rwanda is among the countries that may benefit from solar energy to use cheap and clean energy from the Sun.

II. The second result will be the power saved to the grid, which will be used for other purposes. Our days Rwanda energy groups use diesel engines to supply industries during peak load periods. It costs a lot and is a pollutant. The use of this technology is one of the solutions to that issue.

III. With this power generation at the distribution level, a new project like environmental protection will be raised where the use of an electric cook stove may replace the traditional methods of cooking.

IV. There will be many benefits from this project:

The improvement of energy efficiency at the consumer level.

- Creation of new jobs in the country. People will invest in this technology; electrical technicians will get jobs and different deals with businesses.
- The increase of users of renewable energy.

- Increase in the energy profitability of the households and institutions concerned. Due to energy tariffs people are afraid to use some big loads like washing machines. This technology will bring freedom in energy use.

1.4.2 Significant of the study

The study on PV system Grid connected management is a way of efficiently using the PV systems found in many schools, health centers and households. This study will help to enhance the use of renewable energy sources. The project's goal is designed to help the country solve the issues of electrical energy and help people to use very cheap and quality energy. Investors will get opportunities and energy researchers will use data from here for different purposes.

Chapter 2: LITERATURE REVIEW

The presence of global climate change and the contamination of generating systems have promoted the use of renewable energy sources to be the most used, solar energy and wind energy [3], [6]. The issue with those systems is that their energy sources (sun, wind) are intermittent sources. So, the generation of power also becomes intermittent, too. This fact generates instability, unreliability and power quality problems when they are integrated into the main electric grid[7]. The integration of renewable energy sources by using advanced power electronic devices has been chosen as the best solution[8]. Hybrid renewable sources are a promising solution where the distribution network expansion is not feasible or not economical. Integrating renewable energy sources provides energy security, substantial cost savings and a reduction in greenhouse gas emissions, enabling nations to meet emission targets [15].

In this project, we will work on a hybrid system made with a PV system grid, connected by using an automatic changeover switch at the consumer level.

2.1 Problem review

Renewable energy is nowadays a key contributor to the development of our modern society, but its integration with the traditional power grid poses technical challenges. The most significant technical challenges are power quality which concerns firstly voltage and frequency fluctuation caused by the non-controllable variety of renewable energy systems, secondly to harmonics which are introduced by the power electronic devices used during power electrical generation [16][17], [18].

2.1.1 Power quality

Renewable energy sources (RES) more precisely solar and wind are the future alternative energy needs due to their immense presence in nature. They are used to being considered the principal source of renewable energy for future electrical generation. But their integration into the main grid presents different technical issues such as voltage regulation, flicker, harmonic distortion [19] etc.

These challenges provide different economic challenges like high electricity tariffs and less electrical performance due to the low efficiency of the energy system. One among voltage issues is voltage sags and swells where short-duration phenomena in the power system happened where the root-mean-square (RMS) voltage magnitude decreases between 10% and 90% of the nominal RMS voltage at the power frequency for a period of 0.5 cycles to one minute as shown in fig1[20].

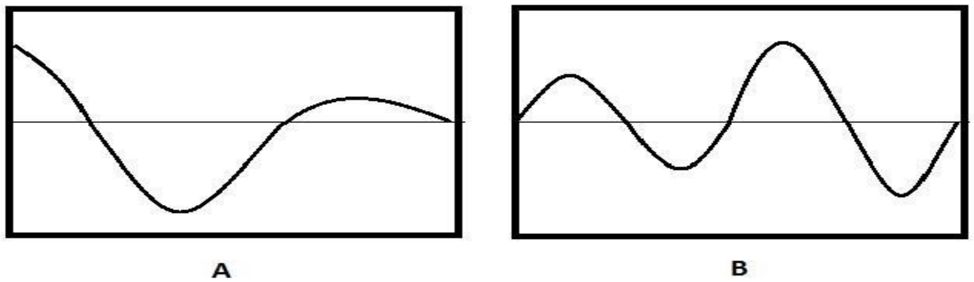


Figure 2. 1A: Voltage sag, B: voltage swell

Different control techniques are used to maintain the power quality of the system at the standard. IEC and IEEE set different measures that help in power quality protection during renewable energy integration.

2.1.2 Effect of power electronics in power system

Our traditional power network is designed with a centrally controlled power system. For the grid to adopt distributed energy generation, power electronic devices are needed. The adoption of distributed generation to the grid increases the energy efficiency of the system, even though some attention is required [15]. The introduction of power electronic devices needs more skills so that the power quality is maintained. Power electronic devices make little changes to the nature of renewable energy sources while they are allowing it at PCC (point of common coupling). Here, engineers have to be careful when they decide on the device to be used. For example, the VSM-based controller has a much smaller frequency range of negative impedance than the d-q frame controller as it is shown in the fig2

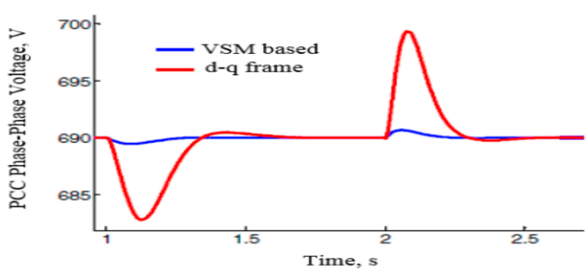


Figure 2. 2: Comparison of PCC voltage regulation performance between a VSM based STATCOM

controller and a conventional cascaded d-q frame STAT COM controller when the power fluctuated by o.25pu [21].

Many researchers that have been working on different power quality challenges and solutions due to renewable energy integration have been reported. Reports show that smart grid attracts more attention from academics and industries [16]. This research consists of an approach to improve power quality.

2.2 Power converter review

The purposes of renewable energy integration are to reduce the overload of the main grid, to resolve the issues of power quality and electrical tariff. Power converters play a critical role. A comprehensive study of power quality in electrical systems, including renewable energy systems was done by different researchers. They have found that the use of advanced power electronic converters and switches is the potential choice[9]. Some examples of advanced power electronic devices are D-STATCOM, UPQC, UPS, DVR, ATS[10] etc. for our case, we need to improve the distribution generation system in Rwanda using ACS (Automatic changeover switch). It is an advanced power electronic device that works automatically to allow one source of energy and stop others. It is a new technology here in Rwanda, it will provide different electrical solutions to the consumer level as well as to the main grid.

2.3 **Research gap**

The exponential growth of power demand due to the demographic growth, has emerged a mass penetration of distributed generation (DG) using renewable energy sources in the power distribution systems[11]. The possibility of meeting energy forecast requirements is only to use renewable energy integration (REI). The future energy needed is given by the following equation [12].

$$E_n = E_0(1 + \frac{R}{100}) \quad \text{.......} \quad (1)$$

Where, E_n: is the future energy in n years

$E_{o:}$ is the present energy

R: is the demographic growth rate

Electricity from different solar energy technologies had been deployed in Rwanda since 1980's mainly through support from donors and NGOs (Non-Governmental Organizations) and a study conducted by ESMAP (Energy Sector Management Assistance Program)/World Bank project in 1991 provided an assessment of the market at that time. Between 2009 and 2012 a big project of installing PV systems in 300 schools and health centers that are far from 5km from the grid line manifested[13].

Many books and papers were written on the electrical systems made by more than one source and their working principles. The integration of PV systems to Grid systems is one type of renewable energy integration that is cheap and available strongly in all regions of inter- tropics[14]. The weakness of solar energy is the changing of its output due to the irradiation change. The nature of solar energy results in the power output of photovoltaic systems. During the day, sun is available most of the time and swipes at evening. In recent years many countries have been promoting this type of distributed generation mostly in residential areas for the generation up to 5kW. The purpose of integrating PV system to electrical grid was to make the system stable, reliable and economic[15].

Renewable energy resources (RER) have become a support to improve the quality of electrical power sources due to global warming and environmental conditions. The use of power electronic devices plays a big role in distributed generation and in the interconnection between renewable energy sources and the electrical grid network[16].

The main purpose of this research is to design a system in which the users would be able to power their residence with the combined energy systems using solar PV system and Grid power. The power from solar will be the most dominant source of power, in order to reduce the cost of electricity and load to the grid. Even though we want to make the most solar energy, this energy is unpredictable and not available all day long, and the amount of energy generated by the sun depend on weather condition and the location of the user, due to those factors, to ensure uninterrupted energy usage at residential level, the use of an automatic changeover switch will help the interchangeability between power from solar and grid. Let's say once energy from solar becomes down, the system will switch itself to grid power by using an automatic changeover switch.

2.4. Problem formation

The general output current of PV cell is given by the following equation

$$I = I_{ph} - I_0 \left[exp\ exp\ \left(\frac{q(V+IR_S)}{AKT}\right) - 1\right] - \frac{V+IR_S}{R_{sh}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where I_{ph} is the photo – current; I_o is the reverse saturation current of the diode; q is the electron charge, $1.602x10^{-19}$C; K is Boltzmann's constant, $1.38x10^{-23}$J/k; A is the diode ideality factor; R_s is the series resistance; R_{sh} is the shunt resistance; V is the output voltage. After generation of the current, the DC/AC converter converts it into AC current in order to be used by AC load. We need to convert it because many loads use AC, and grid source is AC source[17].

The design of the output part of the PV System, which is the inverter for the alternative current PV (AC PV) system, allows the PV system to accept AC backup source or to work as AC backup. The control techniques of inverters (to fix switching frequency and a variable duty cycle approach to produce sinusoidal output voltage with minimum harmonic distortion) play a big role. The output rms voltage of the inverter is depending on the modulation index (MI) of the reference sine - wave form.

$$MI = \frac{Amplitude\ \ of\ Reference\ Sine\ Wave\ form}{Amplitude\ of\ Carrier\ Waveform} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

To achieve the required turn on delay time, the gate resistance value has to be discussed. Also, to have a faster turn off, a diode has to be used. The higher resistance has to be introduced between the terminals gate and source of the switches to avoid the reverse recovery current damaging the switch. Due to the power loss during conversion, thermal resistance (R) is obtained by:

$$R = \frac{Tmax - Tambiant}{Ploss - \frac{Mosfet}{4}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Filters and snubbers are used to obtain a smooth sinusoidal waveform to improve the performance of the switching circuits and contribute to higher reliability, higher efficiency, lower electromagnetic interference (EMI)[18]. Solar energy requires storage to effectively complement the intermittency found to most renewable energy sources. The storage helps the PV system to maintain the power quality and reliability. The active rectifier control system should provide a fast and reliable closed loop controller for active or reactive power. This loop basically determines the amplitude of the current component aligned with the grid voltage. The reactive power control loop determines the quadrature current component; 90^0 phases shifted from the grid voltage[19].

The active power P and reactive power Q of the system will be given by the following equations

$$P = V_{rms} \times I_{rms} \times cos\theta \ldots\ldots (5)$$

$$Q = V_{rms} \times I_{rms} \times sin\theta \ldots\ldots (6)$$

The energy of the system is given by

$$E = P \times T \ldots\ldots (7)$$

Where E: energy, P: electrical power in the system, T: time taken by the system to do a work.

For this study, the PV Grid power system does not have instantaneous power because the Automatic changeover switch works as a switch.

2.5 The use of changeover switches

To integrate one source of energy to another requires a power electronic or electrical switch like changeover switch or another changing material to change either manually or automatically from one source to another. Many hybrid systems found in Rwanda are grid with another backup; mostly generators.

2.5.1 System using manual changeover switch

Manual switches are devices many times made in mechanical relays and contactors. When you are turning ON or OFF you hear some noise. Manual changeover switches act as a middleman between your generator and your other energy system. When using a generator backup, safety is always the priority. During the cutoff a person used to turn on the switch to allow another available source of energy to work. The manual switches are affordable compared to automatic changeover switches. Their weaknesses are:

- Unreliability of the system.
- Power loss during ON and OFF.
- Noise while switching ON and OFF
- Long time during switching to the backup

One example of the place where they use manual switching system is in (UR) University of Rwanda. The university of Rwanda (UR) uses generators for the purpose of backup during national grid cutoff. The university of Rwanda installed in all campuses 37 internal combustion diesel engines generators (ICDEGs)[20]. During cutoff one UR electrical technician uses to go to put generator online manually. This type of backup raises time of cutoff, unreliability of the system and high-power loss during ON and OFF. One among many bad effects is interruption of academic activities.

2.5.2 System using automatic changeover switch

The instability of power supply makes people use backup to utility. All modern hybrid energy systems use Automatic changeover switches. Many automatic changeover switches (ACS) found on the Rwanda market are also made in mechanical contractors and relays. They have noise when they are switching from one source to another like manual switches. Generators that many people use are automatic but automation cannot be smooth, some seconds needed for a generator to run[21][22]. In hospitals, they add UPSs in the energy system for critical machines to make the energy system more reliable.

EHRHART energy (wholesaler of fuel and generator) says that the generator uses a few seconds to run and some time to stabilize the voltage before the system is switching from the grid to the generator. The minimum feeding time for good generators that connect automatically is between 10 and 20s.

Automatic changeover switches (ACS) used here in Rwanda have low switching frequency. They switch automatically to other sources of energy but some materials like television get off while switching to another source of energy.

2.5.3 Proposed method

a. Background

Between 2009 and 2012 a big project of installing PV systems in 300 schools and health centers that are far from the line of the main grid have manifested. That project was sponsored by the World Bank. After a few years, the Rwanda energy group (REG) continued to distribute electricity all over the country mainly in public places like schools and health centers. After the arrival of electricity from the national grid, solar energy users have mainly used energy from the national grid; others sold their PVs and shifted to the national grid. Due to the intermittency of solar energy as other renewable energies, solar energy users prefer to use energy from the grid rather than solar energy whereas it is cheap compared to grid energy.

48% of Rwandans do not have access to electricity due to insufficiency of electrical generation here in Rwanda but we have energy in different schools and health centers used only when there is a cutoff! The solution is the system that uses the solar system and uses the main grid when solar energy is weak.

b. Discussion

Aim of this Master's final project is to optimize energy systems found in some households, schools and health centers. There are partially used solar systems. The project is to make a system that uses both solar energy system and grid by using automation methods.

Rwanda's energy daily solar irradiance ranges between 4kWh/m^2 to 5.4kWh/m^2 where the good range for energy production is 3.5-7Wh/m^2[23]. This shows that we are lucky to benefit from solar energy. The Rwanda national electrification framework shows that energy from solar is the third after Hydropower, thermal and peat technology. The presence of more than 14,970 solar home systems are installed in different corners of the country[24]. As 12.230MW generated from different solar power plant around in Rwanda (Rwamagana Gigawatt generates8.5MW, Jali generates 0.25MW, Ndera generates 0.15MW and Nasho generates 3.3MW) also small off grid solar systems found in schools, Health centers and some households, may also contribute on Rwanda energy system by using switches at consumer level. This thesis will contribute in giving more information about such systems

c. Mapping of the method to problem

To optimize these weaknesses above, the system that uses two sources of energy which are rapidly connected and disconnected will be used. The system is called PV_Grid system.

The automatic changeover switch that will be used, has a high switching frequency so that the users will not see any change at their loads. The following figure (fig 2.3) shows the PV_Grid system with an electronic changeover switch as the central part and figure 2.4 shows the algorithm of the system.

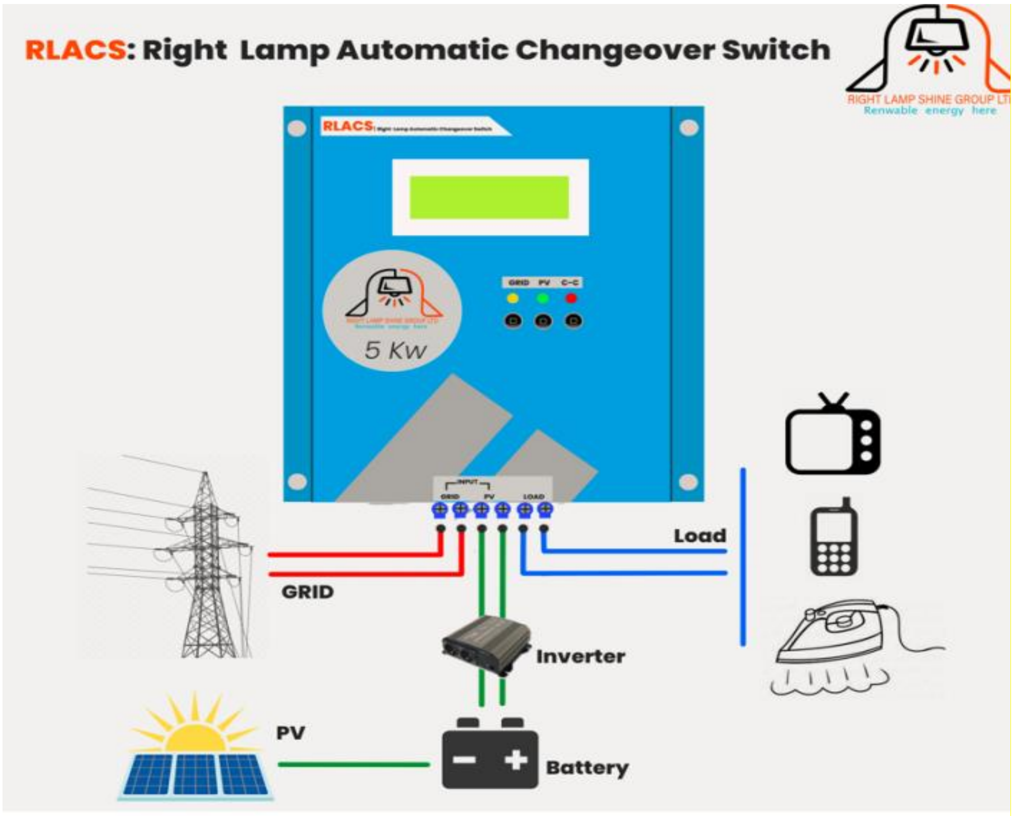


Figure 2. 3: PV system Grid connected using an automatic changeover switch drawn to show the features of the project.

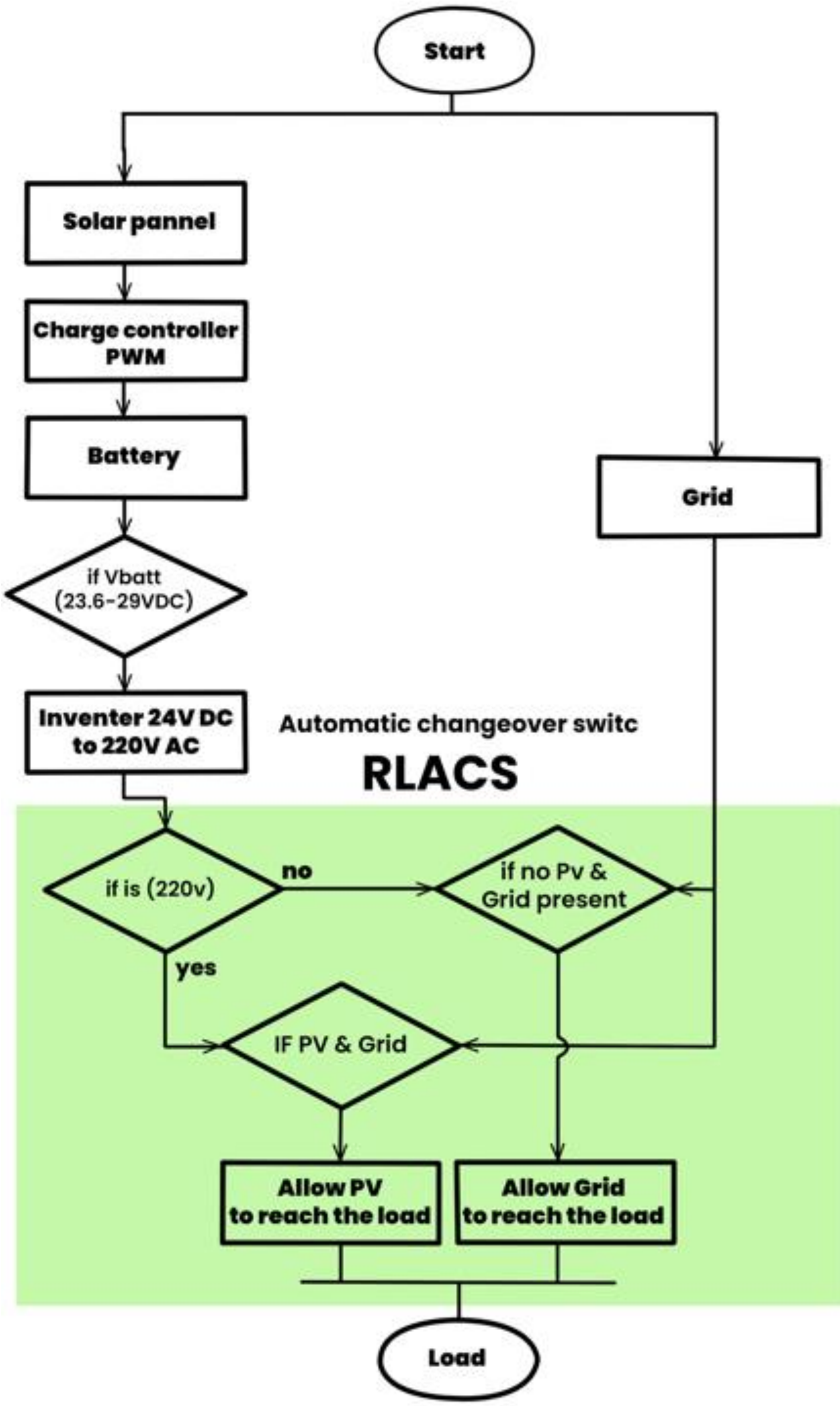


Figure 2. 4: The algorithm of PV system grid connected

1.5 Chapter conclusion

In concluding this chapter, renewable energy integration REI of distributed generation DGs is the best choice to solve the different issues of the main grid. Power electronics development has brought many facilities to achieve reliable hybrid systems. Those systems happened in two ways. One way is when DGs are connected to the main Grid, the second system is when DGs work alternatively with the grid at consumer level by using the switches. Many books and papers were written on the electrical systems made by more than one source and their working principles.

- The integration of PV system to Grid system is one type of renewable energy integration that is cheap and available strongly in all regions of inter- tropics.
- Prices are like that: grid connected-PV-battery system: 0.0645$/kWh, Diesel generator-PV-batteries: 1.38$/kWh, PV-batteries system: 0.15$/kWh, Grid only: 0.2621$/kWh[25].

Chapter 3: METHODOLOGY

3.1 Introduction

To achieve successfully the main objectives and specific objectives of this thesis project, the detailed methodology was developed. Documentation, data collection, simulation tools and experimental setup of PV system Grid connected, and the site selection.

3.2 Documentation

Through different researches like recent published papers, conference articles, renewable energy books and scientific reports have been used in literature review to get information about hybrid systems, and to know how to designs a hybrid system using power electronics devices.

3.3 Data collection

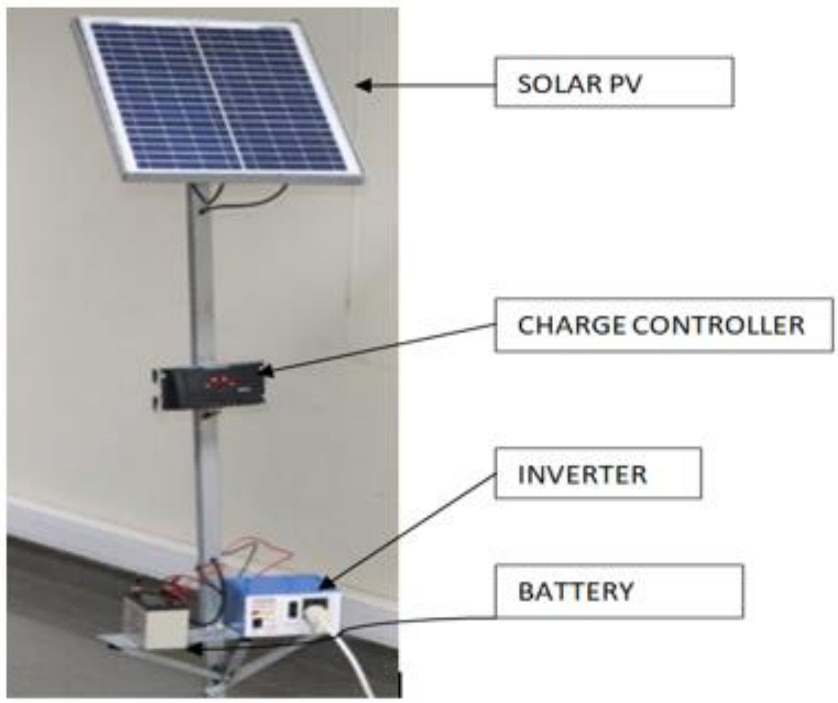
In this project several steps and procedures with data collection process were proposed to develop a good design of PV_Grid system that will help in reducing electricity cost at residential level, these include sizing of PV system based on data collected about electricity usage at selected case study.

In fact, the first step was to determine daily energy consumption, due to the fact that in Rwanda there are no specific seasons that can affect solar irradiation like winter, etc. In this project we didn't consider variation of power produced by solar PV due to season changes, average daily energy consumption was determined based on data collected through questionnaire designed with different open-ended questions.

Moreover, data from Rwanda meteorology have been used. From partnership of University of Rwanda and Rwanda meteorology, data of solar irradiation have been given to be used in analysis of solar energy production.

3.4 Experimental setup and simulation tools

To make sure that the solution to the problem stated in 1.2 will be found, the prototype has been built. The main parties of PV-Grid system are: PV system, Automatic changeover switch and national Grid. Different software and simulation tools like PV system software, proteus, excel photoshop and the google sheet were used. In the figure 3.3 are shown pictures of the prototype elements.



PV System

Automatic changeover switch (1) electromechanical, (2) digital

Figure3. 3: prototype of PV system and ACS

During the experiments, the outlet of 220v AC of the national grid has been used.

3.5 Case study

Due to Covid – 19 measures, to select a case study near the university was a good key to reach to the target. The selected case study was electrical shop found in Gitega sector in Gacyamo cell, Uwamahoro village (Biryogo), KN104, in Kigali city. The selection was based on the following ideas

a) The Covid-19 measures sometimes block movement between Kigali and provinces, districts movements and sometimes the country used to be in total lockdown. To mitigate these issues, the PV system grid connected has been installed near the university where it is possible to access it even in difficult periods.

b) The information from Rwanda Meteorology shows that Kigali has good solar radiation that can be used to generate electricity. The average solar radiation there Biryogo is 5.5kWh/m^2 see table 4.10.

c) Lastly, a good consumer of electrical energy with less complexity of circuit and materials (light load). This electrical shop that has been chosen uses more than 110.5kWh/month. They use this energy mainly for lighting

3.6 Chapter conclusion

The proposed method show that the system has the interface part which is automatic changeover switch (ACS). It will control and connect these two energy sources to gather. Due to high switching frequency of the automatic changeover switch, the system will raise the stability and efficiency of the PV system. The experiments done using a prototype showed that the system will work well. The issue of energy cutoff to the users will be reduced at a very high percentage.

Chapter 4: DESIGN OF THE PV_SYSTEM GRID CONNECTED

This chapter will show all about the system used to get data. This chapter will describe all steps involved in designing a PV_Grid system and automatic changeover switch. In determining the total energy consumption, the designed automatic changeover switch will have a saving system where energy used by the selected case study either from the PV system or grid will be saved in different files. The selected case study is an electrical shop found in Gitega sector as said in previous chapter.

4.1 Overview of Gitega sector

4.1.1 Location and population of Gitega sector

Gitega is located in Nyarugenge district, in Rwanda country[26]. Nyarugenge district has 10 sectors. The total population is 282,000 with 2,127 persons /Km^2[27]. The primary source of energy used for lighting is the national grid. 61.6% of households in Nyarugenge district use electricity for lighting. The following is the map of electricity usage in the lighting process in Rwanda.

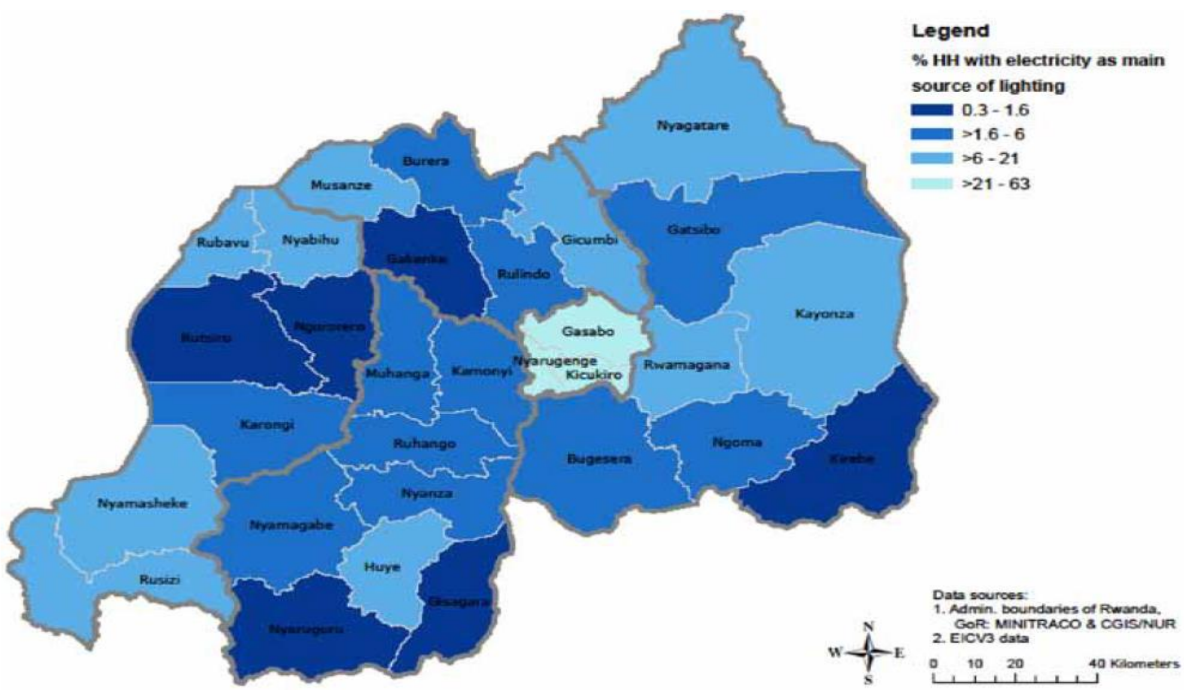


Figure 4. 1: Map presenting the percentage of households with electricity as the main source of lighting, by district[27].

Gitega is the most popular sector of Nyarugenge district, its population density is 24,482. In the Gitega sector are many small businesses that use electricity in refrigeration, lighting and so on. The undervoltage in Gitega sometimes reaches 180V[28]. The following map shows the level of population density of the Gitega sector.

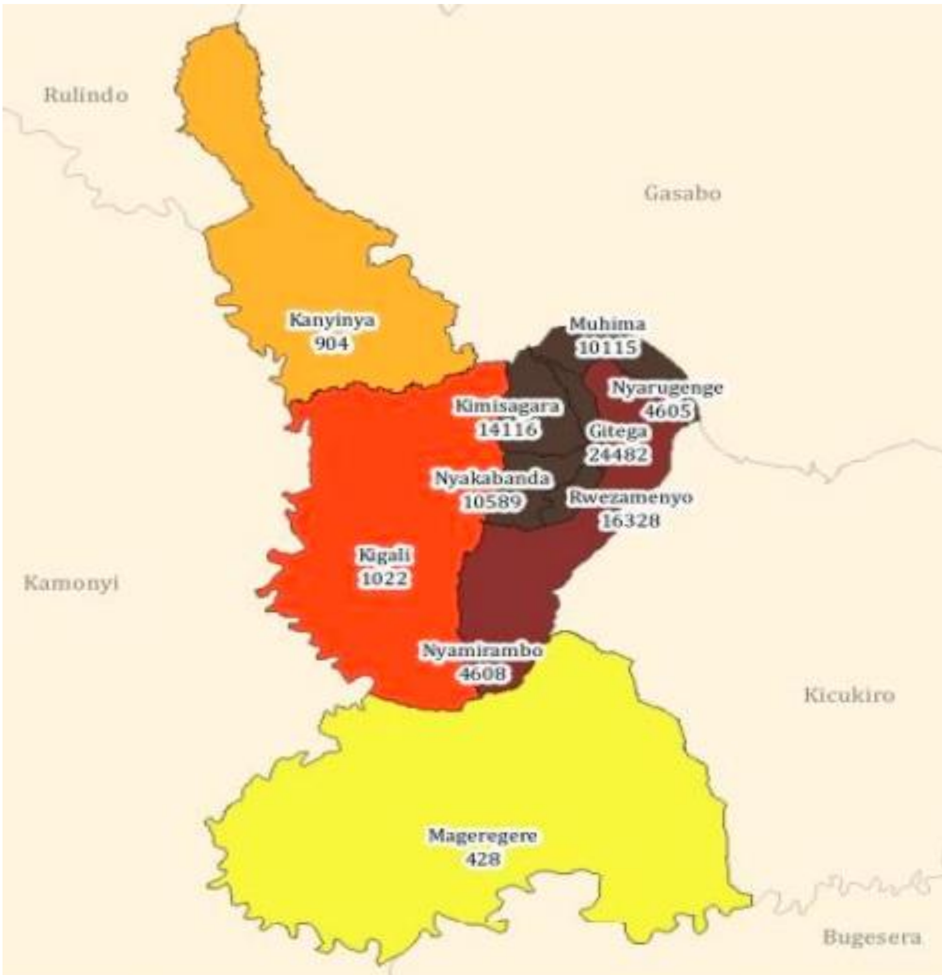


Figure 4. 2: map of population density in Nyarugenge district[29].

4.1.2 Solar irradiation overview

By using PV system software, all parameters that can affect solar energy production are highlighted (See Table 1). The highlighted parameters are global horizontal irradiation, horizontal diffuse irradiation, temperature, wind velocity linke turbidity and relative humidity.

TABLE 4. 1: Geographical site parameters of Gitega sector

Geographical site parameters, new site

Geographical Coordinates | Monthly meteo | Interactive Map

Site: **Gitega (Rwanda)**

Data source: Meteonorm 8.0 (1991-2007), Sat=100%

	Global horizontal irradiation kWh/m²/day	Horizontal diffuse irradiation kWh/m²/day	Temperature °C	Wind Velocity m/s	Linke turbidity [-]	Relative humidity %
January	5.94	2.28	21.4	1.79	4.169	76.5
February	5.80	2.18	21.8	2.00	4.219	74.4
March	5.72	2.47	21.6	1.89	3.687	76.2
April	5.54	2.28	20.8	1.90	3.073	80.8
May	5.47	1.87	21.1	2.00	3.204	78.2
June	5.30	1.98	20.9	2.40	3.589	72.0
July	5.59	1.85	20.5	2.49	4.077	69.4
August	5.43	2.30	20.9	2.39	3.998	72.0
September	5.37	2.44	20.9	2.31	3.514	74.7
October	5.39	2.48	21.4	2.10	3.283	75.0
November	5.51	2.31	20.7	1.80	3.130	79.6
December	5.59	2.07	20.9	1.69	3.543	78.1
Year	**5.55**	**2.21**	**21.1**	**2.1**	**3.624**	**75.6**

From this table, the global horizontal irradiation measured at Gitega Sector is 5.55 kwh/m^2/day and falls in the good quality range for solar radiation use that is from 3.5 to 7.8kWh/m^2/d[30].

4.2. Design of solar home system

The solar cells have special electrical properties of providing maximum voltage (Vmax) needed for driving the maximum current (Imax) through an external load. The power generated by the cell and the cell efficiency at its maximum power point is obtained by the following equations.

$$P_{max} = I_{max} \times V_{max} \quad \text{.......} \quad (8)$$

$$\eta = \frac{P_{max}}{P_{in}} \quad \text{.......} \quad (9)$$

Pmax is defined as power which a solar cell can convert from absorbed light to electricity. The input power Pin is defined as incident power from the sun. η is the efficiency of the system.

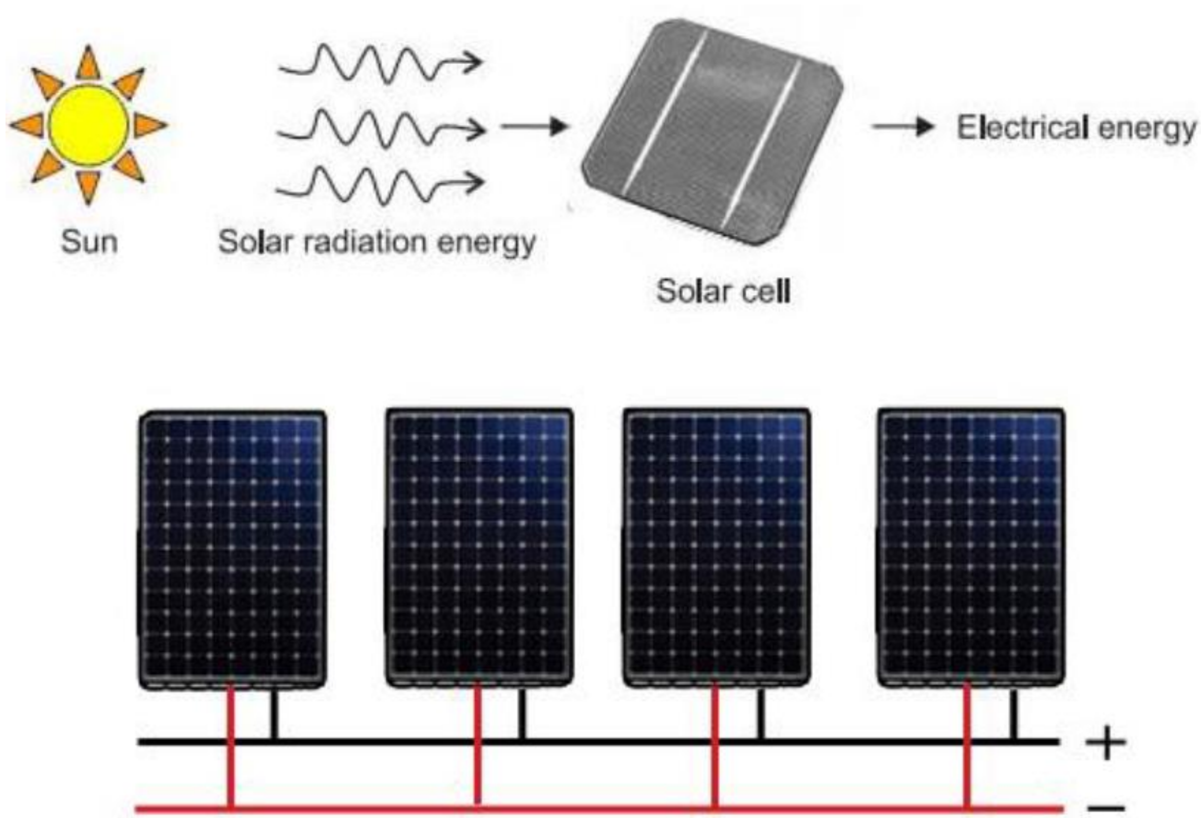


Figure 4. 3: Basic operation mechanism of the solar photovoltaic cell[31].

4.2.1 Design of solar home system by using PV system software

The system is a standalone solar home system. The user uses different types of lamps in his shop.

TABLE 4. 2: daily load evaluation

No	Equipment	N^0 of lamps	Power (W)	Total Power (W)	Hours/day	Watt Hours/day
1	Lamp 1	4	7	28	14	392
2	Lamp 2	1	10	10	14	140
3	Lamp 3	1	12	12	14	168
4	Lamp 4	1	15	15	14	210
5	Lamp 5	1	18	18	14	252
6	Lamp 6	1	25	25	14	350
7	Lamp 7	4	40	160	14	2240
TOTAL		13		268		3752

PV system software does not have places where you can input all these lamps found in table1, to make the daily load understandable to the software, the sum of lamps and average power (P_{av}) was used.

$$P_{av} = \frac{P_{total}}{N_{of\ lamps}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(10)}$$

$$P_{av} = \frac{268W}{13} = 20.61 \approx 21W$$

The input data are the number of lamps (13), their power (21W) and daily time these lamps light (14h). The illustration of design results is presented in Figures 4.4-.4.7

PVsyst V7.2.6
VC0, Simulation date:
01/10/21 17:09
with v7.2.6

Project: GITEGA PROJECT 1

Variant: New simulation variant

Project summary

Geographical Site		Situation		Project settings	
Gitega		Latitude	-1.96 °S	Albedo	0.20
Rwanda		Longitude	30.06 °E		
		Altitude	1503 m		
		Time zone	UTC+2		

Meteo data
Gitega
Meteonorm 8.0 (1991-2007), Sat=100% - Synthetic

System summary

Stand alone system — **Stand alone system with batteries**

PV Field Orientation		User's needs	
Fixed plane		Daily household consumers	
Tilt/Azimuth	15 / 0 °	Constant over the year	
		Average	3.8 kWh/Day

System information

PV Array		Battery pack	
Nb. of modules	3 units	Technology	Lead-acid, sealed, Gel
Pnom total	1020 Wp	Nb. of units	10 units
		Voltage	24 V
		Capacity	775 Ah

Results summary

Available Energy	1691 kWh/year	Specific production	1658 kWh/kWp/year	Perf. Ratio PR	68.69 %
Used Energy	1404 kWh/year			Solar Fraction SF	100.00 %

Table of contents

Figure 4. 4: Project Summary

Project: GITEGA PROJECT 1

Variant: New simulation variant

PVsyst V7.2.6
VC0, Simulation date:
01/10/21 17:09
with v7.2.6

General parameters

Stand alone system — **Stand alone system with batteries**

PV Field Orientation

Orientation		Sheds configuration	Models used	
Fixed plane		No 3D scene defined	Transposition	Perez
Tilt/Azimuth	15 / 0 °		Diffuse	Perez, Meteonorm
			Circumsolar	separate

User's needs

Daily household consumers
Constant over the year
Average 3.8 kWh/Day

PV Array Characteristics

PV module

Manufacturer	Generic
Model	RS6K-340M
(Original PVsyst database)	
Unit Nom. Power	340 Wp
Number of PV modules	3 units
Nominal (STC)	1020 Wp
Modules	3 Strings x 1 In series
At operating cond. (50°C)	
Pmpp	922 Wp
U mpp	31 V
I mpp	30 A

Battery

Manufacturer	Generic
Model	Solar Block SB 12/185A
Technology	Lead-acid, sealed, Gel
Nb. of units	5 in parallel x 2 in series
Discharging min. SOC	20.0 %
Stored energy	14.9 kWh
Battery Pack Characteristics	
Voltage	24 V
Nominal Capacity	775 Ah (C10)
Temperature	Fixed 20 °C

Controller

Universal controller	
Technology	MPPT converter
Temp coeff.	-5.0 mV/°C/Elem.
Converter	
Maxi and EURO efficiencies	97.0 / 95.0 %

Battery Management control

Threshold commands as	SOC calculation
Charging	SOC = 0.90 / 0.75
approx.	26.5 / 25.1 V
Discharging	SOC = 0.20 / 0.45
approx.	23.6 / 24.4 V

Total PV power

Nominal (STC)	1 kWp
Total	3 modules
Module area	5.1 m²
Cell area	4.9 m²

Array losses

Thermal Loss factor

Module temperature according to irradiance
Uc (const) 29.0 W/m²K
Uv (wind) 0.0 W/m²K/m/s

DC wiring losses

Global array res. 17 mΩ
Loss Fraction 1.5 % at STC

Serie Diode Loss

Voltage drop 0.7 V
Loss Fraction 2.0 % at STC

Module Quality Loss

Loss Fraction -0.8 %

Module mismatch losses

Loss Fraction 2.0 % at MPP

Strings Mismatch loss

Loss Fraction 0.1 %

IAM loss factor

Incidence effect (IAM): Fresnel smooth glass, n = 1.526

0°	30°	50°	60°	70°	75°	80°	85°	90°
1.000	0.998	0.981	0.948	0.862	0.776	0.636	0.403	0.000

01/10/21 PVsyst Evaluation mode Page 3/8

Figure 4. 5: General parameters

Project: GITEGA PROJECT 1

Variant: New simulation variant

PVsyst V7.2.6
VC0, Simulation date:
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with v7.2.6

Detailed User's needs

Daily household consumers, Constant over the year, average = 3.8 kWh/day

Annual values

	Number	Power	Use	Energy
		W	Hour/day	Wh/day
Lamps (LED or fluo)	13	21W/lamp	14.0	3822
Stand-by consumers			24.0	24
Total daily energy				3846Wh/day

Hourly distribution

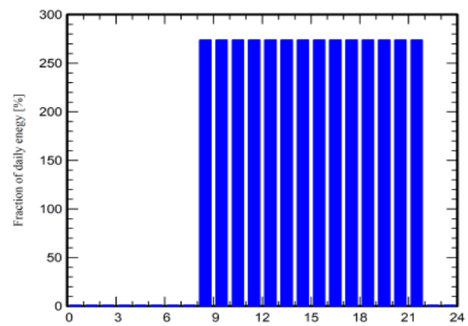


Figure 4. 6: Details user's needs

Project: GITEGA PROJECT 1

Variant: New simulation variant

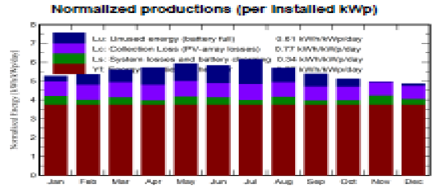
PVsyst V7.2.6
VC0, Simulation date:
01/10/21 17:09
with v7.2.6

Main results

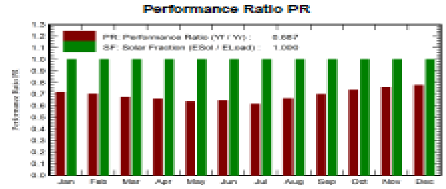
System Production

Available Energy	1691 kWh/year	Specific production	1658 kWh/kWp/year
Used Energy	1404 kWh/year	Performance Ratio PR	68.69 %
Excess (unused)	227 kWh/year	Solar Fraction SF	100.00 %
Loss of Load		**Battery aging (State of Wear)**	
Time Fraction	0.0 %	Cycles SOW	94.7 %
Missing Energy	0 kWh/year	Static SOW	90.0 %
		Battery lifetime	10.0 years

Normalized productions (per installed kWp)



Performance Ratio PR



Balances and main results

	GlobHor	GlobEff	E_Avail	EUnused	E_Miss	E_User	E_Load	SolFrac
	kWh/m²	kWh/m²	kWh	kWh	kWh	kWh	kWh	ratio
January	184.3	156.4	136.6	8.39	0.000	119.2	119.2	1.000
February	162.4	145.0	125.7	15.53	0.000	107.7	107.7	1.000
March	177.2	168.4	146.0	20.40	0.000	119.2	119.2	1.000
April	166.2	166.9	144.6	27.42	0.000	115.4	115.4	1.000
May	169.4	179.3	155.4	28.39	0.000	119.2	119.2	1.000
June	158.9	171.4	149.8	28.17	0.000	115.4	115.4	1.000
July	173.2	185.9	162.8	40.83	0.000	119.2	119.2	1.000
August	168.4	172.0	150.0	23.35	0.000	119.2	119.2	1.000
September	161.1	156.8	136.8	19.68	0.000	115.4	115.4	1.000
October	167.1	153.2	133.7	12.34	0.000	119.2	119.2	1.000
November	165.3	142.5	124.4	0.00	0.000	115.4	115.4	1.000
December	173.3	143.6	125.6	2.69	0.000	119.2	119.2	1.000
Year	2026.8	1941.3	1691.4	227.19	0.000	1403.8	1403.8	1.000

Legends

GlobHor	Global horizontal irradiation	E_User	Energy supplied to the user
GlobEff	Effective Global, corr. for IAM and shadings	E_Load	Energy need of the user (Load)
E_Avail	Available Solar Energy	SolFrac	Solar fraction (EUsed / ELoad)
EUnused	Unused energy (battery full)		
E_Miss	Missing energy		

01/10/21 PVsyst Evaluation mode Page 5/8

Figure 4. 7: Main results

4.2.2 Design of solar home system by manual calculation

The total consumption time is 14h. The total energy per day will be:

$$E = P \times t \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{(11)}$$

Where E is the energy, P is the power and t are the time loads used during lighting.

$$E = 273W \times 14h = 3822Wh$$

$$solar\ mass = \frac{E_t}{peak\ hour} = \frac{3822Wh}{5h} = 764.4W \ \ldots\ldots\ldots\ldots\ldots\ldots \textbf{(12)}$$

$$Number\ of\ PV = \frac{solar\ mass}{modul\ capacity} = \frac{764.4W}{340V} = 2.24 \approx 2\ldots\ldots\ldots\ldots \textbf{(13)}$$

$$Number\ of\ batteries = \frac{E_t}{12V \times Bc} = \frac{3822Wh}{12V \times 165Ah} = 1.930 \approx 2\ldots\ldots\ldots \textbf{(14)}$$

Where Bc is the battery capacity

$$Inverter\ sizing = total\ power \times 1.3 = 273W \times 1.3 = 354.9W\ldots\ldots \textbf{(15)}$$

The system used a 1kW inverter for future forecasting.

The charge controller for the system is 30A due to the range of variation of the current which cannot even be 10A. but it is not easy to see a charge controller of less than 30A at the market. The current is given by the following equation:

$$I = \frac{P}{V} = \frac{273}{220} = 1.240A \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{(16)}$$

Among software design and hand design, the preferred is hand design because software works on each and every loose. The PV-Grid system is designed without considering days of autonomy, no consideration of system losses because the grid supports the system when energy from solar becomes weak. Therefore, the system is expected to be cheap compared to a standalone solar system.

4.3. PV_system

The PV system used in this thesis is sized using a hand. It is a standalone system as it is seen in figure 10. The solar system will be connected to the Grid, where the grid will work as a backup. This system has three main parts which are solar energy, automatic changeover switch and grid.

4.3.1. Solar energy system

Solar energy system is made up of solar photovoltaic cells, a charge controller, inverter and batteries. Considering results from calculation, it was selected components with the following parameters:

a. **Solar photovoltaic cell (PV**)

It used two photovoltaic cells (See figure 10). Their specifications are the following:

- Maximum power (Pmax): 340W
- Peak voltage (Vmp): 38.30V
- Open circuit voltage (Voc): 46.80V
- Short circuit current (Isc): 9.38A
- Peak current: 8.88A
- Maximum system voltage: 1000V
- Maximum series fuse rating: 15A

Figure 4. 8: PV system found in Gitega

b. Charge controller

Charge controller is used principally to protect batteries from overcharging. The type of selected charge controller is PWM. For the small system, the performance of PWM is good. It has an LCD that helps to show different information between PVs and the batteries. The specifications of this charge controller are the following:

- Model: EL2430Z
- Rated voltage: 12/24V
- Rated current: 30A
- USB: 5V 2A*2

c. Inverter

Inverter is used to convert DC from the PV cells into AC. It is a pure sine wave. It has the capacity to control the battery level of discharge and stop inverting in order to protect the battery cycle. A converter has been used because the system is working alternatively with AC from the main grid. The main grid will work as backup. The specifications of inverter are:

- Input: 12-32DC V
- Output: 230/220 AC V
- Frequency: 60Hz/50Hz
- Power Max: 1kW

d. Batteries

Storage has been used to optimize solar energy. A 24V charging system has been used with two batteries. the specifications of the batteries are the following:

- Nominal charge voltage: 12V
- Battery capacity: 165Ah, c_{10} (1.80/cell at 20^0C)
- Cycle operation: 14.40V/ float operation: 13.62V
- Terminal hardware torque: 8Nm
- Part number: NGPC120180HSOMA

The Cable section used from PVs up to the batteries is (3/2.5mm^2). PV protection was installed using 32A fuse and 16A fuse to protect the inverter and all the system was protected by using schneider circuit breaker (40A) for earthing.

4.3.2 Automatic changeover switch

An automatic changeover switch plays a role of interchanging sources from the solar energy system to the main grid and so on. The main grid comes as a backup of the solar. The automatic changeover switch is an electronic switch of very high switching frequency. The automatic changeover switch used here is 5kW capacity. Automatic changeover switch has the major parts that are enumerated down here:

a. Two full bridge rectifiers (detectors)
b. Photocoupler U_1, U_2
c. Relays (switching)
d. EEPROM 256
e. LCD 20x4
f. Current measurement and Voltage measurement

The following circuit shows the parts of the Right Lamp Automatic Changeover Switch. It is designed using proteus software.

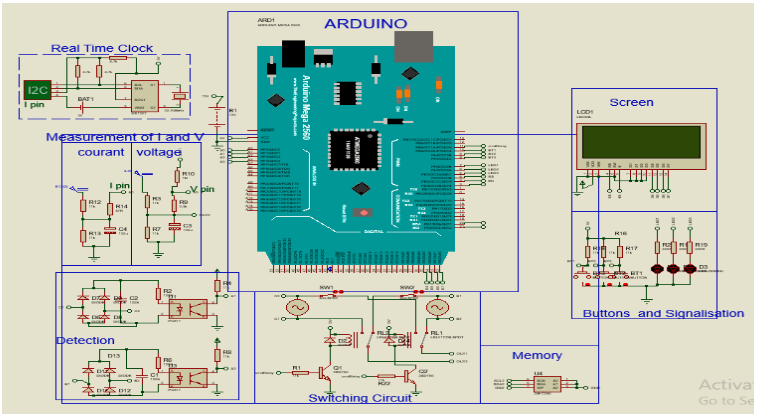


Figure 4. 9: The circuit of Right Lamp Automatic changeover switch

Function of the circuit of Right Lamp Automatic changeover switch

a. Detection

This automatic changeover switch is designed to interchange two sources of energies. One is PV source, the other is Grid source. At the entrance of each source there is a full bridge rectifier (detector). A rectifier is an electronic circuit that changes Alternating current (AC) into Direct Current (DC). A full bridge rectifier uses diodes to convert waves from AC to DC. For our case, we have four diode bridges for one full bridge rectifier. At the output of a full bridge rectifier, there is a photocoupler. A photocoupler or optocoupler or opto-isolator or optical isolator is an electronic component that transfers electrical signals between two isolated circuits by using light (photo). It prevents high voltages from affecting the system receiving the signals.

The input voltage (V_{in}) that comes from either PV system or Grid system (utility) is in the range of 185V and 230V AC. The maximum output voltage (V_{out}) is 5V DC. Microcontroller (arduino) uses 5VDC at its input. When there is input voltage on the PV gate, the microcontroller allows the PV system to feed the load and stop grid. When PV terminals do not have power, the grid feeds the load automatically. Grid works only when the PV system is not producing electrical energy.

b. Switching circuit

Electronic relays have been used so that two energy sources cannot collide. A relay is a switch that opens or switches a circuit electronically or electromechanically. A relay controls one electrical circuit by opening and closing contacts in another circuit. When a relay contact is normally open (NO) or normally closed (NC), the change from one source to another happens.

The command from arduino helps a relay to be either normally closed or normally open. If a relay is normally open (NO), the PV system supplies the load and stops the Grid. When we have normal closed (NC), Grid supplies the load, this case happens when the PV system is low.

c. Arduino

The device uses arduino mega 2560 due to its number of pins. The Arduino mega 2560 is a microcontroller board based on the AT mega 2560. It has 54 digital input or output pins where 15 can be used by PWM output, 16 analog input, 4 UARTs, 16MHz crystal oscillator, a USB connector, a power jack, an ICSP header and a reset button. From the arduino our device is able to alternate two energy sources where PV energy is priority and grid work as a backup. Also, we store energy used by the consumer separately. Energy used from PV has its file and Grid has its file. This will help in data analysis, where we will see if PV has a significant contribution on the energy use profile of the user.

d. EEPROM 256 and flash memory card

EEPROM is electronically erasable programmable read-only memory. We have used EEPROM to store data to be used in analysis of the system. This memory card has 256k Bytes of storage capacity. This EEPROM is used to store data in case of a cut off so that the device does not start at zero. This means when the system goes down from the cutoff of both side PV and Grid, EEPROM stores the last data at that time and when any energy system comes ON, the device continues to save from where it stopped.

Flash memory cards are used commonly to store photos and transferring programs and data handheld computers. It includes secure digital (SD) memory cards. For our case, we are using 2GB to store hourly energy from any source, either PV system or Grid system separately.

e. Screen (LCD 20x4)

LCD in full is Liquid Crystal Display. It is a method of displaying readings continuously, as on digital watches, portable computers, and calculators using a liquid crystal film sealed between glass plates that changes its optical properties when a voltage is applied.

20x4 LCD means that the LCD can display 20 characters per line and there are four such lines. Four our LCD, each character is displayed in 5x7 pixels. This LCD has two registers namely, command and data. For our case we need the data of voltage, current, power and energy. Four types of data. That's why we have chosen to use a 20x4 LCD.

f. Real time clock

RTC (a real time clock) is an electronic device in the form of an integrated chip (IC) available in various packaging options. The purpose of an RTC or a real-time clock is to provide precise time and date which can be used for various applications.

g. Buttons and signalization

Near the screen of our device, there are different buttons used to light or to switch the screen and to change manually from one source of energy to another. Also, there are lighting diodes that work as signs to show if it is PV that is feeding the load grid.

h. Current measurement and voltage measurement

To measure the current, there are two general categories of circuit current measurement mostly used. Resistive and magnetic. In our case, we are using both resistance and magnetic through the inductor. As the arduino cannot read the negative voltage, we have added a continuous voltage U_1. The maximum value of U_i has to be less or equal to 2.5VDC. We calculate the current using the following equation.

$$U_i = \frac{I}{n} * R \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (16)$$

Where U_i is the continuous voltage, I: is the current that is passing at the output of the device and R is the resistance we have chosen for our purpose. R= 47Ω for our case.

To measure the voltage, voltage is the difference of electrical potential between two points of an electronic circuit or electrical circuit, expressed in volts. For our device, we want to measure an AC voltage, at the output of the relays. Its value is theoretically 220V. This value is too big compared to the maximum reading of the arduino. So, the voltage divider is used and added continuously.

The equation used to calculate the voltage is:

$$U_v = V_{load} \times \frac{R2}{R1+R2} \quad (17)$$

Where U_v is the voltage that arduino will read, U_{load} is less or equal to 2.5V. R is 11kΩ for our case.

By applying eq9

$$U_v = 220V \times \frac{3.3k}{3.3k+1000k} = \pm 0.723V \quad (18)$$

$$U = 2.5V \pm U_v = 2.5V \pm 0.723V \quad (19)$$

The result from simulation of voltage measurement is presented in figure 4. 10

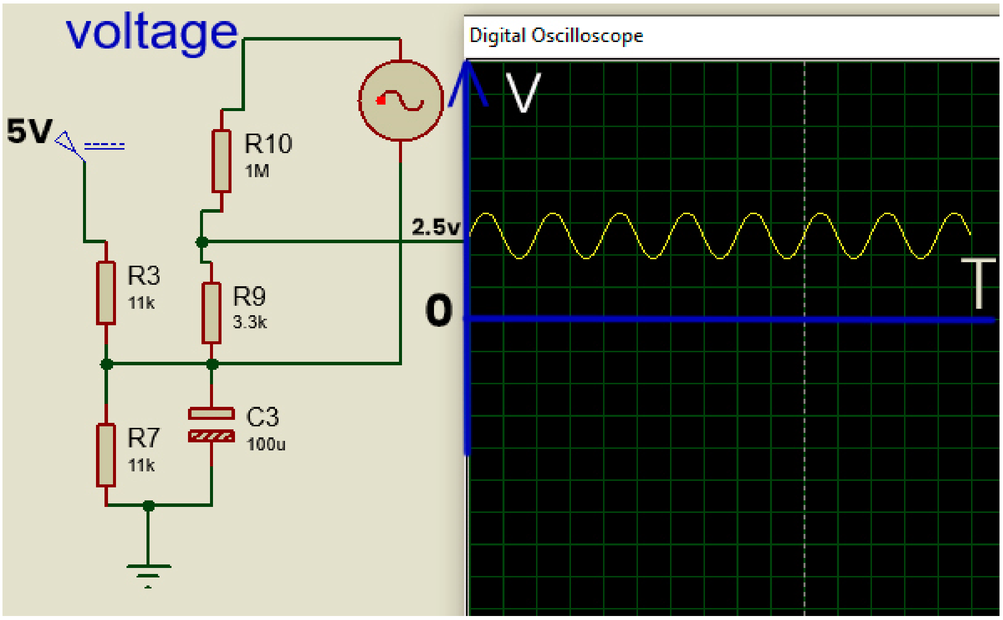


Figure 4. 10: The voltage gained by arduino in this device. Simulation using proteus

The measurement of current and voltage allows us to know the power output. From the power we can easily know the energy used in the interval of time. By using a real time clock (RTC 1307), we record energy used in each and every hour.

$$E = \sum_{n,m=1,2,..}^{\infty} = U \times I_n \times t_m \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(20)}$$

Where, E is the energy to be saved by memory card, U is the voltage at the output, I_n is the consumption current and T_m is the time the consumption takes.

The memory card saves energy consumed in every hour and the summation of all energies consumed in all time for each system is appearing on the screen of the automatic changeover switch.

The operation Principle of this device is summarized in the figure 4.11

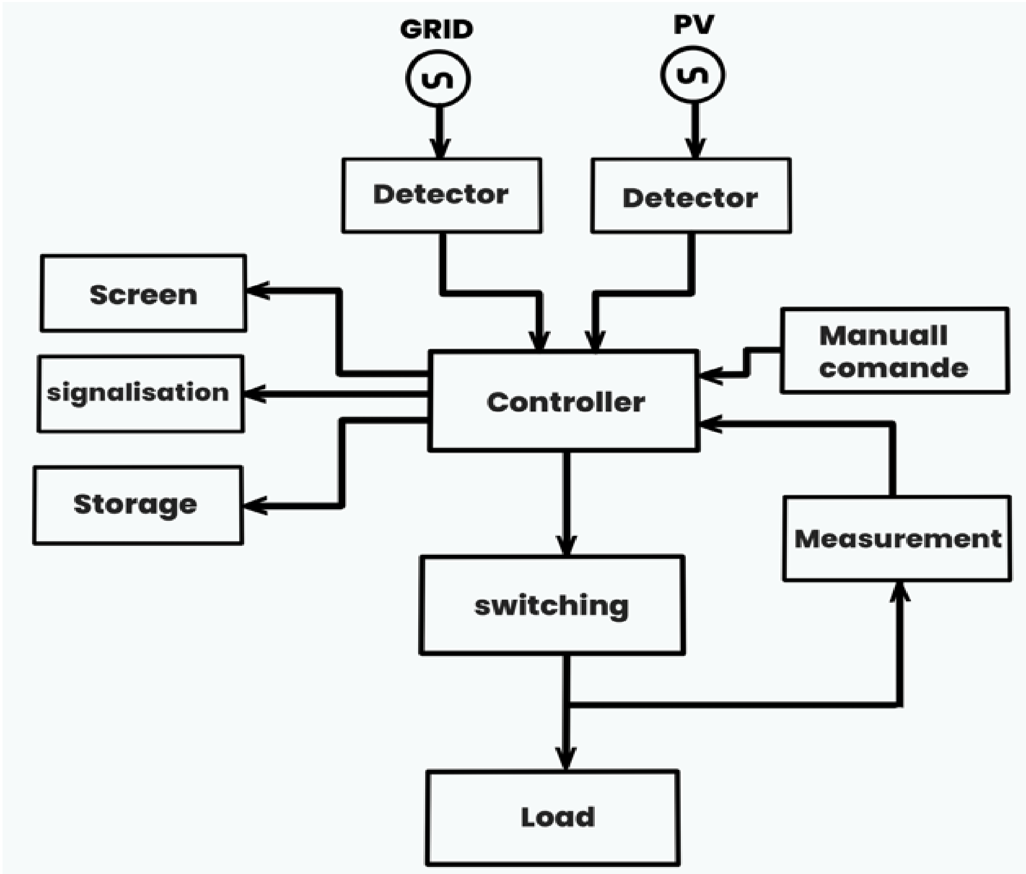


Figure 4. 11: block diagram of the device

4.3.3 Grid

Grid is the national main source of energy delivered by Rwanda energy Group (REG). It is Alternating current (AC). It is a reliable source of energy but expensive compared to solar energy. It is a good idea to prioritize cheap energy and strengthen it using strong one.

Chapter 5: RESULTS AND ANALYSIS

This chapter will be focusing on the analysis of the results obtained from the saving system of the Automatic changeover switch (ACS) and will be compared with data that have been received from the Rwanda Meteorology on solar radiation in the period of one month. From 1/09/2021 up to 30/9/2021.

The data from the ACS saving system are the energy used by the chosen sample, which is coming from two sources of energy alternatives. The National grid works as a backup PV system. The data received are very essential to this project, they will help to know the contribution of PV systems on energy, daily energy consumption, cost reduction and reliability for the users of both solar energy systems and the National grid.

5.1 Results

The results from the ACS saving system have been interpreted using Google Sheets. The data saved are energy consumed by the user selected as a sample. The solar home system used was composed of two PVs with a production capacity of 680W, two battery storage systems of 165Ah each, a nominal voltage is 12V each and a charging system of 24V. It was designed to supply 273W in 14h to the electrical shop found there in Gitega. The electrical shop uses National Grid as a backup in case of solar intermittence. They have a business selling electrical appliances, especially lamps. They have many lamps used as samples of that light in all working periods. Furthermore, they also do tests while showing the customer the power of the lamp. Due to those different activities, the consumption varies depending on the number of tests they did. The recordings are set every hour. The ACS saving system did the cumulative addition of energy consumed in every hour from either PV or National Grid. The data are divided into four tables for the purpose of visibility.

For that shop, the work starts at 8:00 and ends at 22:00, but the timetable has been changed during Covid -19, from 1/9/2021 up to 21/9/2021. The national measures were to stop working at 21:00 and from 22/9/2022 the shop used to work 14 hours as usual. The data recorded by the automatic changeover switch saving system are presented in the following tables.

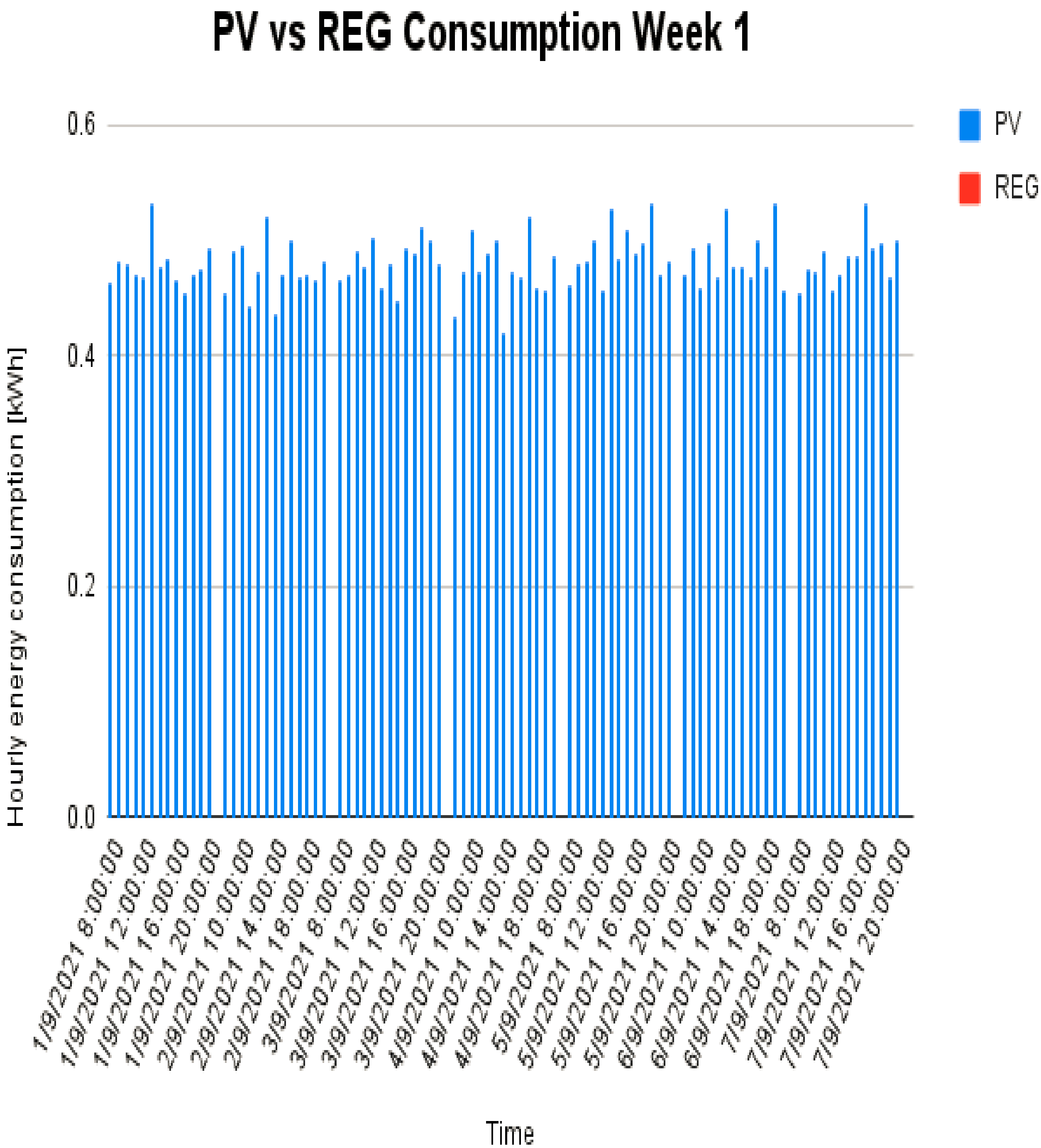


Figure 5. 1: Energy consumed in week 1

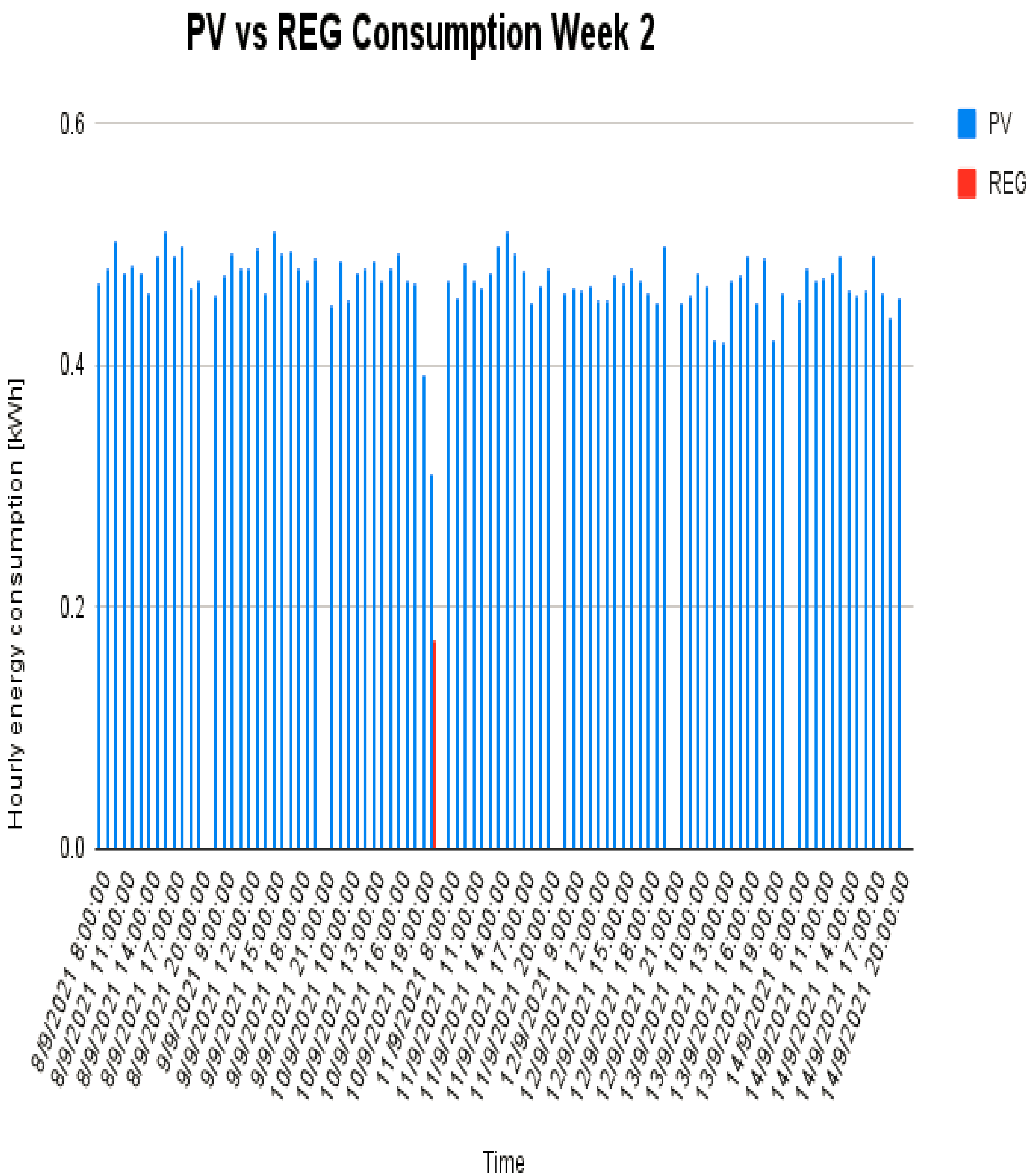


Figure 5. 2: Energy consumed in week 2

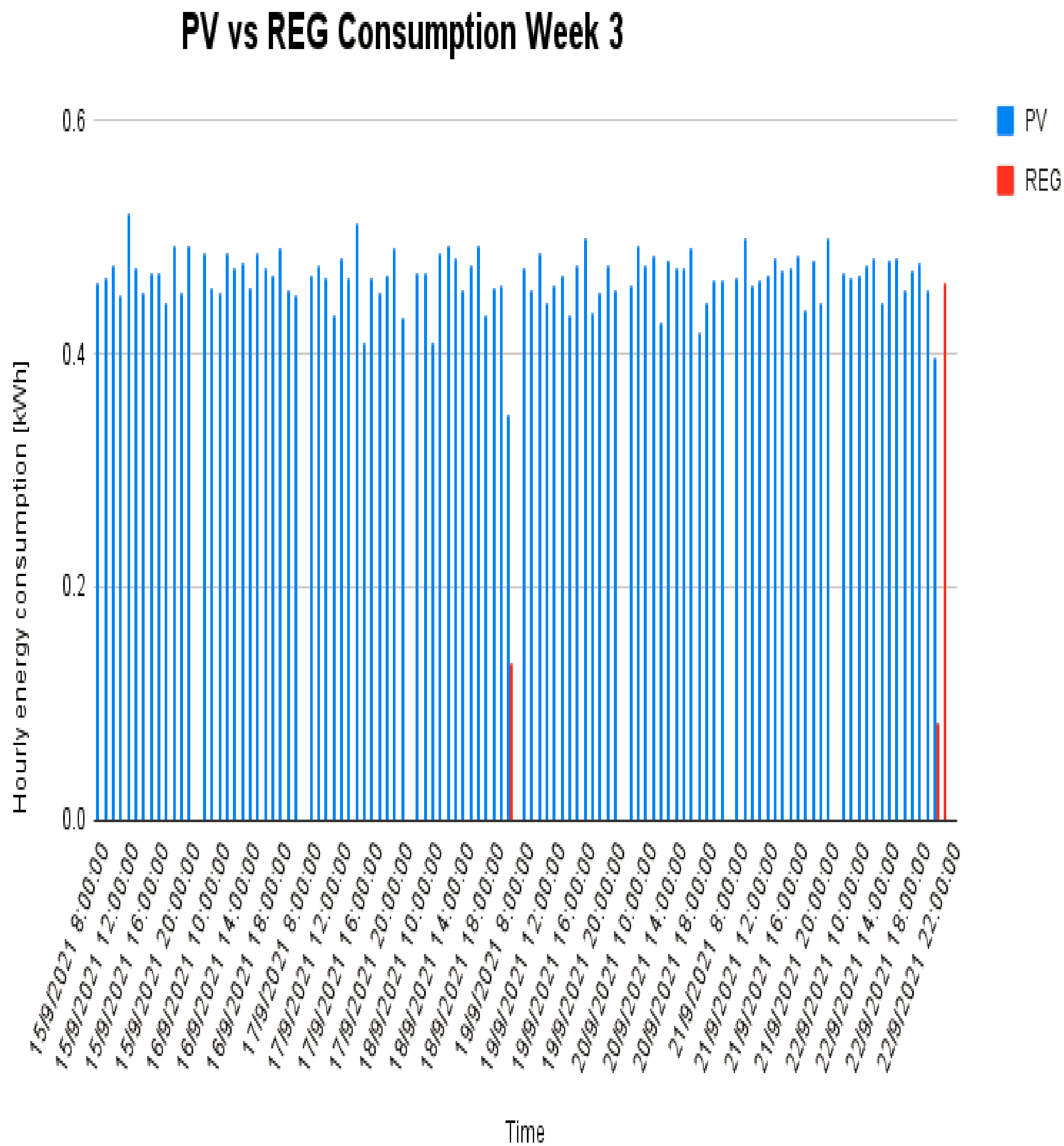


Figure 5. 3: Energy consumed in week 3

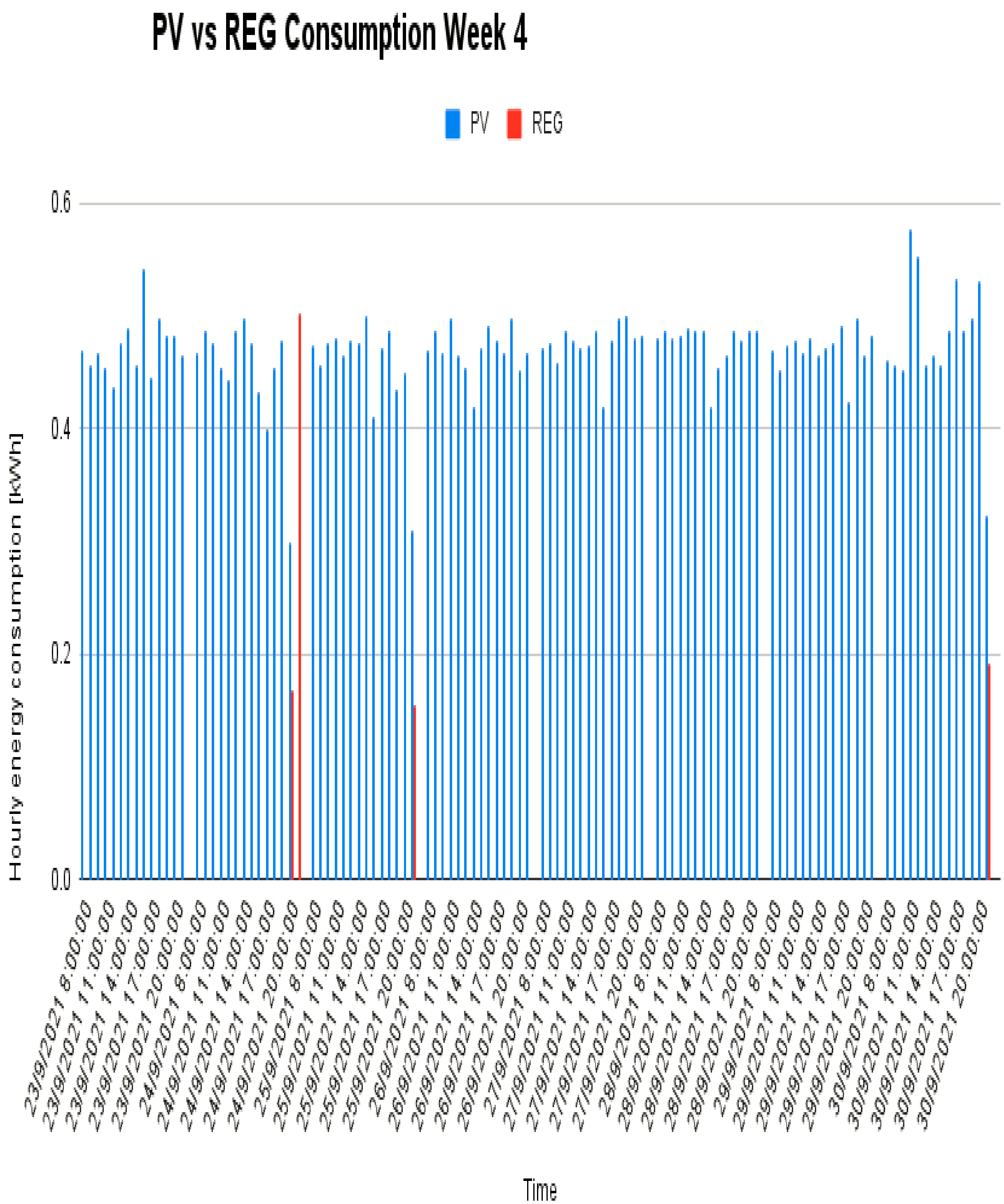


Figure 5. 4: Energy consumed in week 4

The total energy consumption from the PV system was 101.178 kWh and 2.578kWh from the National grid (REG). The details of results are in the appendices.

5.1.1 Results analysis

The introduction of a hybrid energy system that uses an Automatic changeover switch to alternate PV system and national grid as a backup, improves the power quality and reduces energy cost especially to the users already having both two energy systems said above. The contribution of PV system and National Grid was calculated like this:

$$PV_r = \frac{E_{pv}}{E_T} \times 100 \quad \text{………………………..…………… (20)}$$

PV_r is the rate of energy from PV system in %, E_{pv} is the energy from PV system and E_T is the total energy used by the electrical shop.

$$Grid_r = \frac{E_g}{E_T} \times 100 \text{…………………….………..………… (21)}$$

$Grid_r$ is the rate of energy from Grid in % and E_g is the Energy received from the National grid.

$$PV_r = \frac{101.178}{101.178 + 2.578} \times 100 = 97.51 \approx 97.5\%$$

$$Grid_r = \frac{2.578}{101.178 + 2.578} \times 100 = 2.48 \approx 2.5\%$$

These results show that households, high schools and health centers already owned solar energy systems may benefit 97.5% depending on the weather condition.

5.1.2 Validation of the Results

Firstly, let's compare the found results with another research that has been done. The study done by Nsengimana Cyprian, published on 21 November 2020 titled: “comparative analysis of reliable, feasible and low-cost photovoltaic microgrid for a residential load in Rwanda” focused on the economic power generation model, mainly solar resources to minimize the energy tariff. By using the simulation results based on the economic comparison, the analysis found that the Levelized cost of energy (LCOE) and net present cost (NPC) of hybrid energy systems made up of National Grid and solar energy systems are the cheapest energy system for intertropical regions. Moreover, the results showed that electricity produced by Grid-connected PV batteries was four times cheaper, more reliable and affordable. The results showed that the LCOE for electricity production by Grid-connected PV system batteries were $0.0645/kWh, compared to $0.2621/kWh for the current residential electricity tariff 2020 for Rwanda.

The results in this thesis showed a 97.5% gain because those who already have solar systems and use the national grid, add only an ACS to their systems. The results of this project are interpreting energy entered into the system when ACS is added. These two results showed that the Grid-connected PV system may be very cheap when the PV system is the priority and the Grid works as a backup. Here the ACS plays a major role in the purpose of reliability.

Secondly, the data from the ACS saving system have been compared with solar irradiation for Gitega. The used data were from the Rwanda meteorology agency. The result is summarized in the following table.

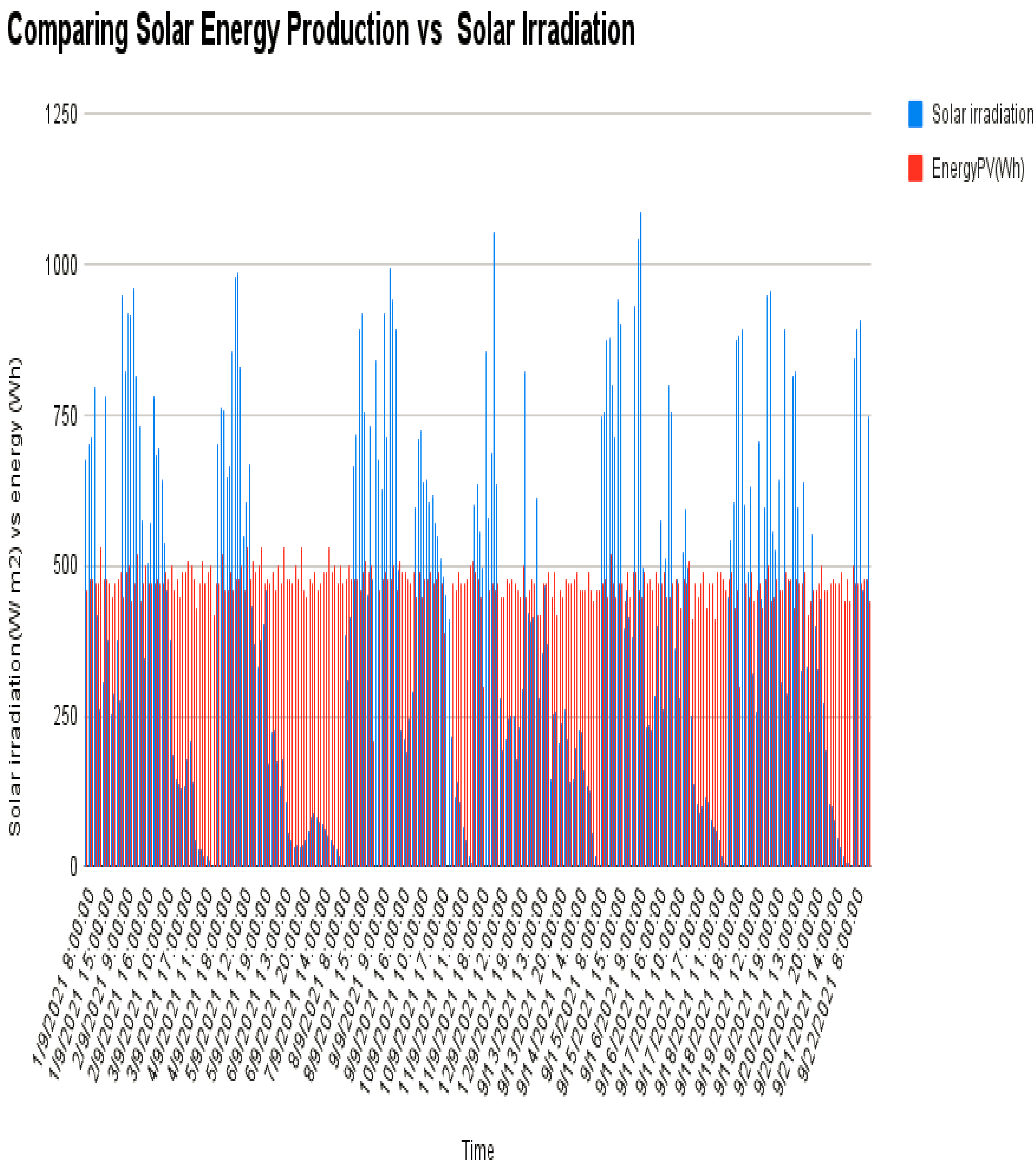


Figure 5. 5: Comparison of solar irradiation in Gitega sector with solar energy production

The study was done in September, from the 1st up to the 30th. To present the data, a Google sheet has been used. Representing how both solar irradiation and solar energy behave. Solar irradiation is presented by blue color and red color presents solar energy. The knowledge behind, when solar irradiation is high the PVs reach their maximum power. When PVs produce power, one part of the power is used by the load in the form of energy and the other part remains stored in the batteries to be used when solar radiation is not there. That's why energy seems to be constant.

5.3 Chapter conclusion

This chapter demonstrated the comparative analysis of two energy systems. The first is National Grid, the second is a PV system grid, connected by using an automatic changeover switch. According to the result and their validation of other studies related, it was possible to make a decision about which type of energy system is reliable, feasible and benefiting can be used. The results show the PV system grid connected using ACS is able to supply the load with the saving of 97.5% of energy from the National Grid.

Chapter 6: CONCLUSION AND RECOMMENDATION

6.1. Conclusion

The main purpose of this master's thesis project was to design an economic, energy system that may help people who use both the National grid and solar system unconnected to use their energy systems efficiently by connecting them using advanced power electronic devices. The outcome of this project was to reduce the electricity tariff and bring a cheap energy system to electrical users and reduce the load on the national grid. The case study was an electrical shop found near ACE-ESD in Gitega sector, where Covid-19 measures may not interrupt the study.

In fact, the method of gathering climate data and solar behavior of the Gitega sector has been a useful approach to installing a solar home system. One solar home system has been installed at an electrical shop located in Gacyamo cell at one electrical shop. The power output of that system is 273W. It is the power that meets the load of that shop.

Solar energy systems are not capable of supplying load continuously due to renewable energy's intermittent properties. These issues make many people shift from solar energy to the national grid, whereas national grid energy is expensive and has limited capacity. Hence, an automatic changeover switch (ACS) has been designed using Proteus software and implemented to be used for integrating solar energy to the national grid at the consumer level. The ACS had a saving system that saved energy used by the load. It is saved in two files, one for PV data and another for National grid data.

Finally, the automatic changeover switch helped to reach the goal of this project, where the system PV Grid-connected showed savings of 97.5% of energy from the National grid. This implies a great reduction of energy tariffs, especially for people who already have a solar home system and have access to the National grid.

6.2. Contribution to knowledge

Electrical energy is continuing to be expensive in many countries due to a large number of users. To forecast electricity became an impossible science. Different researchers suggested that the solution is to use distributed generation. This thesis showed a cheap and reliable energy system that contributes to solving energy challenges by using a high switching frequency device. That device is an automatic changeover switch. It was designed here in Rwanda during this project.

With this device, you can connect the solar home system to the national grid at the consumer level. It is a new technology that academics will use for more improvement of cheap and reliable energy systems.

6.3 Recommendation

6.3.1 Adopting the results

Many companies invested in solar energy before the arrival of the national grid in many areas of Rwanda. After the Rwanda energy group (REG) expanded nationally, many people shifted to the national grid. According to the results from this thesis project, solar energy companies are recommended to adopt this hybrid system to sustain their businesses. They will use an automatic changeover switch to connect their energy systems to the national grid so that their customers use solar energy with the national grid as a backup.

Secondly, different institutions are recommended to adopt this new technology of using an automatic changeover switch in connecting their different backup energy systems for the purpose of reliability, low energy cost, minimizing time of outage during cut-off and so on. Moreover, the university of Rwanda's strategic energy plan of reliability, energy security and economics cannot be achieved without the use of an automatic changeover switch. All campuses have good generators, but when there are national grid cutoffs technicians use a long time to run those generators.

6.3.2 Recommendation for further work

This project worked only on a single-phase energy system, for future work, it will be better to work on a three-phase energy system. Other work in the future is to install these automatic changeover switches in many areas of the country to see if climate changes do not affect their performance.

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APPENDICES

Appendix A: Questionnaire designed to identify the energy needed

To carry out the said above method there have to be a consultation of beneficial (household owners), the following research questions was established to gather the basic information to design an affordable system:

1) How many kWh (unit) consumed at your home per month?

a) 0-15 kWh or unit

b) 15-50 kWh or unit

c) Above 50 kWh, Specify in kWh or unit

2) How many KWh (unit) consumed at your institution per month?

a) 0-100kWh or unit

b) Above 100kWh (unit), Specify in kWh or unit

3) What is your home/institution appliances often used consume above 500 watt-hours?

ITEM	WATTAGE	TOTAL

4) Does the cost of electricity limit the use of various household appliances?

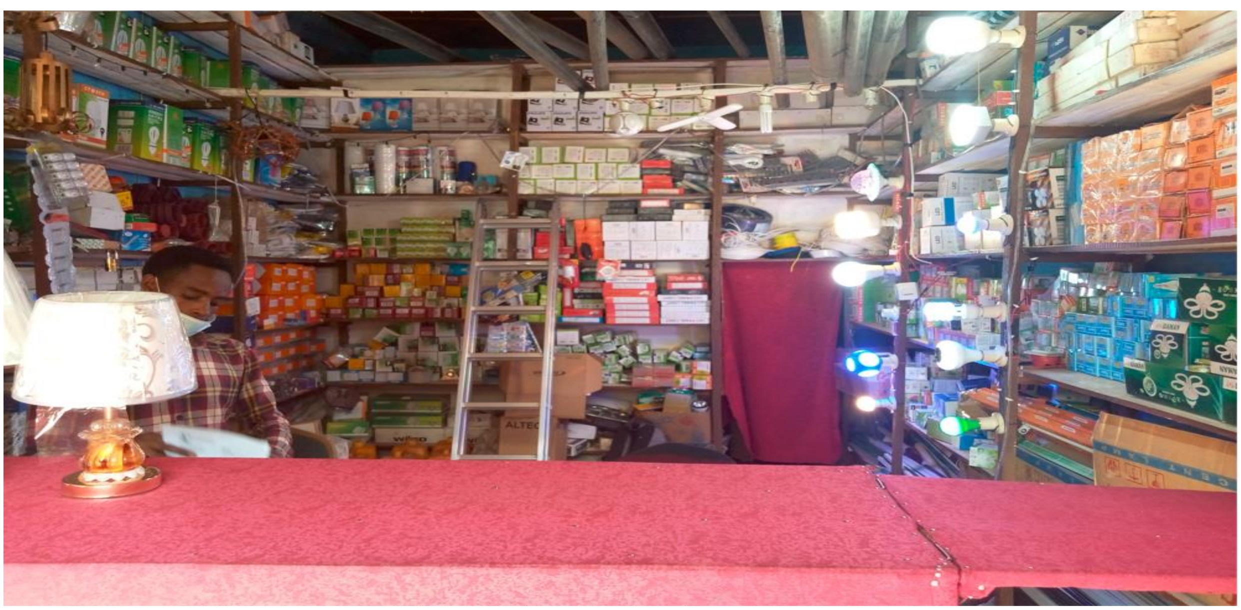
a) Yes

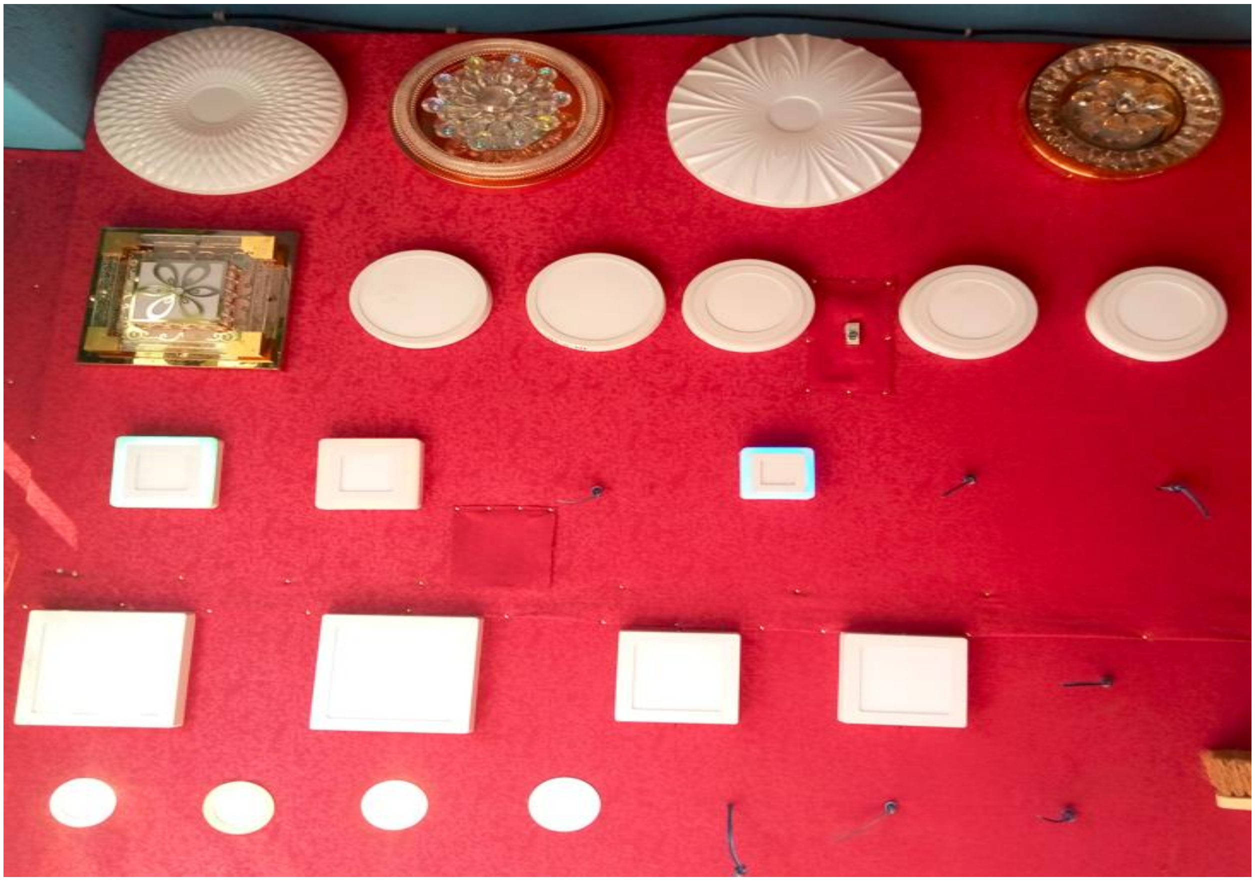
b) No

5) If yes, which appliances affected?

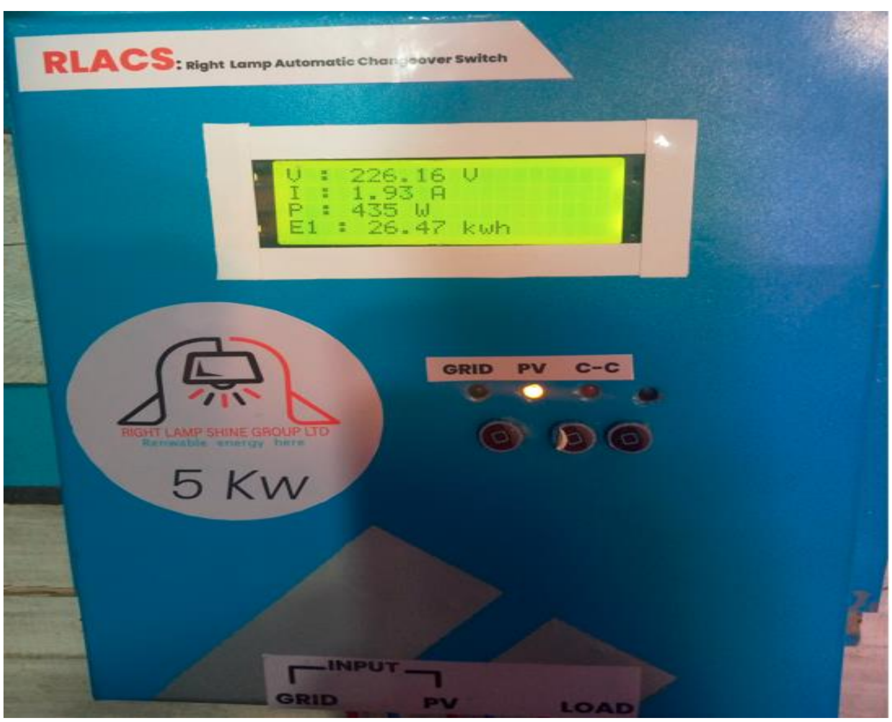
ITEM	WATTAGE	TOTAL

Appendix B: pictures of electrical shop selected





Appendix C: pictures of the component of the PV system


RLACS: Right Lamp Automatic Changeover Switch
V : 226.16 V
I : 1.93 A
P : 435 W
E1 : 26.47 kwh
GRID PV C-C
RIGHT LAMP SHINE GROUP LTD
5 Kw
INPUT
GRID PV LOAD

Appendix D: Data from ACS saving system in September from 1/sept/2021

PV					REG				
	8:00:00	1/9/2021	16.7679653	0.464081		8:00:00	1/9/2021	3.28559	0
	9:00:00	1/9/2021	17.2320461	0.481373		9:00:00	1/9/2021	3.28559	0
	10:00:00	1/9/2021	17.7134189	0.480249		10:00:00	1/9/2021	3.28559	0
	11:00:00	1/9/2021	18.1936683	0.471386		11:00:00	1/9/2021	3.28559	0
	12:00:00	1/9/2021	18.6650543	0.46775		12:00:00	1/9/2021	3.28559	0
	13:00:00	1/9/2021	19.1328048	0.532127		13:00:00	1/9/2021	3.28559	0
	14:00:00	1/9/2021	19.6649322	0.47628		14:00:00	1/9/2021	3.28559	0
	15:00:00	1/9/2021	20.1412124	0.483871		15:00:00	1/9/2021	3.28559	0
	16:00:00	1/9/2021	20.6250839	0.465536		16:00:00	1/9/2021	3.28559	0
	17:00:00	1/9/2021	21.09062	0.453793		17:00:00	1/9/2021	3.28559	0
	18:00:00	1/9/2021	21.5444126	0.471275		18:00:00	1/9/2021	3.28559	0
	19:00:00	1/9/2021	22.0156879	0.475904		19:00:00	1/9/2021	3.28559	0
	20:00:00	1/9/2021	22.4915924	0.492613		20:00:00	1/9/2021	3.28559	0
	21:00:00	1/9/2021	22.9842052			21:00:00	1/9/2021	3.28559	
	8:00:00	2/9/2021	23.550913	0.454139		8:00:00	2/9/2021	3.28559	0
	9:00:00	2/9/2021	24.005052	0.491372		9:00:00	2/9/2021	3.28559	0
	10:00:00	2/9/2021	24.496424	0.495566		10:00:00	2/9/2021	3.28559	0
	11:00:00	2/9/2021	24.99199	0.441876		11:00:00	2/9/2021	3.28559	0
	12:00:00	2/9/2021	25.433866	0.472391		12:00:00	2/9/2021	3.28559	0
	13:00:00	2/9/2021	25.906257	0.521117		13:00:00	2/9/2021	3.28559	0
	14:00:00	2/9/2021	26.427374	0.437228		14:00:00	2/9/2021	3.28559	0

15:00:00	2/9/2021	26.864602	0.470089	15:00:00	2/9/2021	3.28559	0
16:00:00	2/9/2021	27.334691	0.500002	16:00:00	2/9/2021	3.28559	0
17:00:00	2/9/2021	27.834693	0.467399	17:00:00	2/9/2021	3.28559	0
18:00:00	2/9/2021	28.302092	0.470119	18:00:00	2/9/2021	3.28559	0
19:00:00	2/9/2021	28.772211	0.465532	19:00:00	2/9/2021	3.28559	0
20:00:00	2/9/2021	29.237743	0.482231	20:00:00	2/9/2021	3.28559	0
21:00:00	2/9/2021	22.9842052		21:00:00	2/9/2021	3.28559	
8:00:00	3/9/2021	23.013016	0.466022	8:00:00	3/9/2021	3.28559	0
9:00:00	3/9/2021	23.479038	0.470033	9:00:00	3/9/2021	3.28559	0
10:00:00	3/9/2021	23.949071	0.491129	10:00:00	3/9/2021	3.28559	0
11:00:00	3/9/2021	24.4402	0.478125	11:00:00	3/9/2021	3.28559	0
12:00:00	3/9/2021	24.918325	0.501992	12:00:00	3/9/2021	3.28559	0
13:00:00	3/9/2021	25.420317	0.458977	13:00:00	3/9/2021	3.28559	0
14:00:00	3/9/2021	25.879294	0.480023	14:00:00	3/9/2021	3.28559	0
15:00:00	3/9/2021	26.359317	0.447111	15:00:00	3/9/2021	3.28559	0
16:00:00	3/9/2021	26.806428	0.492221	16:00:00	3/9/2021	3.28559	0
17:00:00	3/9/2021	27.2986486	0.488719	17:00:00	3/9/2021	3.28559	0
18:00:00	3/9/2021	27.7873676	0.511113	18:00:00	3/9/2021	3.28559	0
19:00:00	3/9/2021	28.2984806	0.499211	19:00:00	3/9/2021	3.28559	0
20:00:00	3/9/2021	28.7976916	0.479021	20:00:00	3/9/2021	3.28559	0
21:00:00	3/9/2021	29.2767126		21:00:00	3/9/2021	3.28559	
8:00:00	4/9/2021	29.279791	0.434528	8:00:00	4/9/2021	3.28559	0
9:00:00	4/9/2021	29.714319	0.472243	9:00:00	4/9/2021	3.28559	0

10:00:00	4/9/2021	30.186562	0.51	10:00:00	4/9/2021	3.28559	0
11:00:00	4/9/2021	30.696562	0.47299	11:00:00	4/9/2021	3.28559	0
12:00:00	4/9/2021	31.169552	0.488291	12:00:00	4/9/2021	3.28559	0
13:00:00	4/9/2021	31.657843	0.499111	13:00:00	4/9/2021	3.28559	0
14:00:00	4/9/2021	32.156954	0.420009	14:00:00	4/9/2021	3.28559	0
15:00:00	4/9/2021	32.576963	0.473226	15:00:00	4/9/2021	3.28559	0
16:00:00	4/9/2021	33.050189	0.46773	16:00:00	4/9/2021	3.28559	0
17:00:00	4/9/2021	33.517919	0.52112	17:00:00	4/9/2021	3.28559	0
18:00:00	4/9/2021	34.039039	0.460029	18:00:00	4/9/2021	3.28559	0
19:00:00	4/9/2021	34.499068	0.456698	19:00:00	4/9/2021	3.28559	0
20:00:00	4/9/2021	34.955766	0.486112	20:00:00	4/9/2021	3.28559	0
21:00:00	4/9/2021	35.441878		21:00:00	4/9/2021	3.28559	
8:00:00	5/9/2021	35.54321	0.462239	8:00:00	5/9/2021	3.28559	0
9:00:00	5/9/2021	36.005449	0.47992	9:00:00	5/9/2021	3.28559	0
10:00:00	5/9/2021	36.485369	0.482276	10:00:00	5/9/2021	3.28559	0
11:00:00	5/9/2021	36.967645	0.499882	11:00:00	5/9/2021	3.28559	0
12:00:00	5/9/2021	37.467527	0.456228	12:00:00	5/9/2021	3.28559	0
13:00:00	5/9/2021	37.923755	0.52815	13:00:00	5/9/2021	3.28559	0
14:00:00	5/9/2021	38.451905	0.483344	14:00:00	5/9/2021	3.28559	0
15:00:00	5/9/2021	38.935249	0.510041	15:00:00	5/9/2021	3.28559	0
16:00:00	5/9/2021	39.44529	0.489926	16:00:00	5/9/2021	3.28559	0
17:00:00	5/9/2021	39.935216	0.497211	17:00:00	5/9/2021	3.28559	0
18:00:00	5/9/2021	40.432427	0.531179	18:00:00	5/9/2021	3.28559	0

19:00:00	5/9/2021	40.963606	0.469992	19:00:00	5/9/2021	3.28559	0
20:00:00	5/9/2021	41.433598	0.482341	20:00:00	5/9/2021	3.28559	0
21:00:00	5/9/2021	41.915939		21:00:00	5/9/2021	3.28559	
8:00:00	6/9/2021	41.996736	0.470231	8:00:00	6/9/2021	3.28559	0
9:00:00	6/9/2021	42.466967	0.493762	9:00:00	6/9/2021	3.28559	0
10:00:00	6/9/2021	42.960729	0.459119	10:00:00	6/9/2021	3.28559	0
11:00:00	6/9/2021	43.419848	0.498239	11:00:00	6/9/2021	3.28559	0
12:00:00	6/9/2021	43.918087	0.467175	12:00:00	6/9/2021	3.28559	0
13:00:00	6/9/2021	44.385262	0.528101	13:00:00	6/9/2021	3.28559	0
14:00:00	6/9/2021	44.913363	0.478212	14:00:00	6/9/2021	3.28559	0
15:00:00	6/9/2021	45.391575	0.476521	15:00:00	6/9/2021	3.28559	0
16:00:00	6/9/2021	45.868096	0.468792	16:00:00	6/9/2021	3.28559	0
17:00:00	6/9/2021	46.336888	0.500002	17:00:00	6/9/2021	3.28559	0
18:00:00	6/9/2021	46.83689	0.47658	18:00:00	6/9/2021	3.28559	0
19:00:00	6/9/2021	47.31347	0.53192	19:00:00	6/9/2021	3.28559	0
20:00:00	6/9/2021	47.84539	0.456834	20:00:00	6/9/2021	3.28559	0
21:00:00	6/9/2021	48.302224		21:00:00	6/9/2021	3.28559	
8:00:00	7/9/2021	48.34367	0.453889	8:00:00	7/9/2021	3.28559	0
9:00:00	7/9/2021	48.797559	0.4761	9:00:00	7/9/2021	3.28559	0
10:00:00	7/9/2021	49.273659	0.472397	10:00:00	7/9/2021	3.28559	0
11:00:00	7/9/2021	49.746056	0.491219	11:00:00	7/9/2021	3.28559	0
12:00:00	7/9/2021	50.237275	0.456234	12:00:00	7/9/2021	3.28559	0
13:00:00	7/9/2021	50.693509	0.471022	13:00:00	7/9/2021	3.28559	0

14:00:00	7/9/2021	51.164531	0.486774	14:00:00	7/9/2021	3.28559	0
15:00:00	7/9/2021	51.6513051	0.486509	15:00:00	7/9/2021	3.28559	0
16:00:00	7/9/2021	52.1378141	0.53281	16:00:00	7/9/2021	3.28559	0
17:00:00	7/9/2021	52.6706241	0.492693	17:00:00	7/9/2021	3.28559	0
18:00:00	7/9/2021	53.1633171	0.497052	18:00:00	7/9/2021	3.28559	0
19:00:00	7/9/2021	53.6603691	0.467798	19:00:00	7/9/2021	3.28559	0
20:00:00	7/9/2021	54.1281672	0.500128	20:00:00	7/9/2021	3.28559	0
21:00:00	7/9/2021	54.6282952		21:00:00	7/9/2021	3.28559	
8:00:00	8/9/2021	54.73193	0.467777	8:00:00	8/9/2021	3.28559	0
9:00:00	8/9/2021	55.199707	0.480231	9:00:00	8/9/2021	3.28559	0
10:00:00	8/9/2021	55.6799384	0.503342	10:00:00	8/9/2021	3.28559	0
11:00:00	8/9/2021	56.1832804	0.476309	11:00:00	8/9/2021	3.28559	0
12:00:00	8/9/2021	56.6595894	0.482102	12:00:00	8/9/2021	3.28559	0
13:00:00	8/9/2021	57.1416914	0.47689	13:00:00	8/9/2021	3.28559	0
14:00:00	8/9/2021	57.6185814	0.459999	14:00:00	8/9/2021	3.28559	0
15:00:00	8/9/2021	58.0785806	0.491021	15:00:00	8/9/2021	3.28559	0
16:00:00	8/9/2021	58.5696016	0.512231	16:00:00	8/9/2021	3.28559	0
17:00:00	8/9/2021	59.0818326	0.492104	17:00:00	8/9/2021	3.28559	0
18:00:00	8/9/2021	59.5739366	0.498303	18:00:00	8/9/2021	3.28559	0
19:00:00	8/9/2021	60.0722394	0.463799	19:00:00	8/9/2021	3.28559	0
20:00:00	8/9/2021	60.5360384	0.471008	20:00:00	8/9/2021	3.28559	0
21:00:00	8/9/2021	61.0070464		21:00:00	8/9/2021	3.28559	
8:00:00	9/9/2021	61.10170464	0.45902	8:00:00	9/9/2021	3.28559	0

9:00:00	9/9/2021	61.56072464	0.475391	9:00:00	9/9/2021	3.28559	0
10:00:00	9/9/2021	62.03611564	0.492164	10:00:00	9/9/2021	3.28559	0
11:00:00	9/9/2021	62.52827964	0.479928	11:00:00	9/9/2021	3.28559	0
12:00:00	9/9/2021	63.00820764	0.479982	12:00:00	9/9/2021	3.28559	0
13:00:00	9/9/2021	63.48818964	0.498201	13:00:00	9/9/2021	3.28559	0
14:00:00	9/9/2021	63.98639064	0.459999	14:00:00	9/9/2021	3.28559	0
15:00:00	9/9/2021	64.44638974	0.512117	15:00:00	9/9/2021	3.28559	0
16:00:00	9/9/2021	64.95850674	0.49254	16:00:00	9/9/2021	3.28559	0
17:00:00	9/9/2021	65.45104674	0.494424	17:00:00	9/9/2021	3.28559	0
18:00:00	9/9/2021	65.94547064	0.481201	18:00:00	9/9/2021	3.28559	0
19:00:00	9/9/2021	66.42667164	0.47102	19:00:00	9/9/2021	3.28559	0
20:00:00	9/9/2021	66.89769164	0.49001	20:00:00	9/9/2021	3.28559	0
21:00:00	9/9/2021	67.38770114		21:00:00	9/9/2021	3.28559	
8:00:00	10/9/2021	67.38870115	0.450027	8:00:00	10/9/2021	3.28559	0
9:00:00	10/9/2021	67.83872815	0.48721	9:00:00	10/9/2021	3.28559	0
10:00:00	10/9/2021	68.32593815	0.453924	10:00:00	10/9/2021	3.28559	0
11:00:00	10/9/2021	68.77986215	0.476093	11:00:00	10/9/2021	3.28559	0
12:00:00	10/9/2021	69.25595515	0.48111	12:00:00	10/9/2021	3.28559	0
13:00:00	10/9/2021	69.73706535	0.487261	13:00:00	10/9/2021	3.28559	0
14:00:00	10/9/2021	70.22432635	0.471094	14:00:00	10/9/2021	3.28559	0
15:00:00	10/9/2021	70.69542035	0.481117	15:00:00	10/9/2021	3.28559	0
16:00:00	10/9/2021	71.17653735	0.492229	16:00:00	10/9/2021	3.28559	0
17:00:00	10/9/2021	71.66876635	0.470473	17:00:00	10/9/2021	3.28559	0

18:00:00	10/9/2021	72.13923935	0.468223	18:00:00	10/9/2021	3.28559	0
19:00:00	10/9/2021	72.60746235	0.39172	19:00:00	10/9/2021	3.28559	0
20:00:00	10/9/2021	72.99918235	0.310087	20:00:00	10/9/2021	3.28559	0.173639
21:00:00	10/9/2021	73.30926935		21:00:00	10/9/2021	3.459229	
8:00:00	11/9/2021	73.3097697	0.470024	8:00:00	11/9/2021	3.459229	0
9:00:00	11/9/2021	73.7797937	0.45621	9:00:00	11/9/2021	3.459229	0
10:00:00	11/9/2021	74.2360037	0.485022	10:00:00	11/9/2021	3.459229	0
11:00:00	11/9/2021	74.7210257	0.470004	11:00:00	11/9/2021	3.459229	0
12:00:00	11/9/2021	75.1910297	0.465045	12:00:00	11/9/2021	3.459229	0
13:00:00	11/9/2021	75.6560747	0.476091	13:00:00	11/9/2021	3.459229	0
14:00:00	11/9/2021	76.1321657	0.500038	14:00:00	11/9/2021	3.459229	0
15:00:00	11/9/2021	76.6322037	0.51231	15:00:00	11/9/2021	3.459229	0
16:00:00	11/9/2021	77.1445137	0.493201	16:00:00	11/9/2021	3.459229	0
17:00:00	11/9/2021	77.6377147	0.47851	17:00:00	11/9/2021	3.459229	0
18:00:00	11/9/2021	78.1162247	0.45208	18:00:00	11/9/2021	3.459229	0
19:00:00	11/9/2021	78.5683047	0.46661	19:00:00	11/9/2021	3.459229	0
20:00:00	11/9/2021	79.034915	0.48112	20:00:00	11/9/2021	3.459229	0
21:00:00	11/9/2021	79.5160353		21:00:00	11/9/2021	3.459229	
8:00:00	12/9/2021	79.5180356	0.461121	8:00:00	12/9/2021	3.459229	0
9:00:00	12/9/2021	79.9791565	0.465309	9:00:00	12/9/2021	3.459229	0
10:00:00	12/9/2021	80.4444655	0.462111	10:00:00	12/9/2021	3.459229	0
11:00:00	12/9/2021	80.9065765	0.465934	11:00:00	12/9/2021	3.459229	0

12:00:00	12/9/2021	81.3725105	0.453321	12:00:00	12/9/2021	3.459229	0
13:00:00	12/9/2021	81.8258315	0.453329	13:00:00	12/9/2021	3.459229	0
14:00:00	12/9/2021	82.27916	0.4756	14:00:00	12/9/2021	3.459229	0
15:00:00	12/9/2021	82.75476	0.468023	15:00:00	12/9/2021	3.459229	0
16:00:00	12/9/2021	83.222783	0.480001	16:00:00	12/9/2021	3.459229	0
17:00:00	12/9/2021	83.7027842	0.470232	17:00:00	12/9/2021	3.459229	0
18:00:00	12/9/2021	84.1730159	0.460389	18:00:00	12/9/2021	3.459229	0
19:00:00	12/9/2021	84.6334049	0.453002	19:00:00	12/9/2021	3.459229	0
20:00:00	12/9/2021	85.0864069	0.500001	20:00:00	12/9/2021	3.459229	0
21:00:00	12/9/2021	85.5864079		21:00:00	12/9/2021	3.459229	
8:00:00	13/9/2021	85.5867345	0.451133	8:00:00	13/9/2021	3.459229	0
9:00:00	13/9/2021	86.0378675	0.45792	9:00:00	13/9/2021	3.459229	0
10:00:00	13/9/2021	86.4957875	0.476003	10:00:00	13/9/2021	3.459229	0
11:00:00	13/9/2021	86.9717905	0.467201	11:00:00	13/9/2021	3.459229	0
12:00:00	13/9/2021	87.4389915	0.420389	12:00:00	13/9/2021	3.459229	0
13:00:00	13/9/2021	87.8593805	0.419359	13:00:00	13/9/2021	3.459229	0
14:00:00	13/9/2021	88.2787395	0.47012	14:00:00	13/9/2021	3.459229	0
15:00:00	13/9/2021	88.7488595	0.473927	15:00:00	13/9/2021	3.459229	0
16:00:00	13/9/2021	89.2227865	0.492001	16:00:00	13/9/2021	3.459229	0
17:00:00	13/9/2021	89.7147875	0.453041	17:00:00	13/9/2021	3.459229	0
18:00:00	13/9/2021	90.1678285	0.490001	18:00:00	13/9/2021	3.459229	0
19:00:00	13/9/2021	90.6578295	0.42183	19:00:00	13/9/2021	3.459229	0
20:00:00	13/9/2021	91.0796595	0.45997	20:00:00	13/9/2021	3.459229	0

21:00:00	13/9/2021	91.5396295		21:00:00	13/9/2021	3.459229	
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9:00:00	14/9/2021	91.9943027	0.48091	9:00:00	14/9/2021	3.459229	0
10:00:00	14/9/2021	92.4752127	0.470322	10:00:00	14/9/2021	3.459229	0
11:00:00	14/9/2021	92.9455343	0.473109	11:00:00	14/9/2021	3.459229	0
12:00:00	14/9/2021	93.4186433	0.476392	12:00:00	14/9/2021	3.459229	0
13:00:00	14/9/2021	93.8950353	0.491111	13:00:00	14/9/2021	3.459229	0
14:00:00	14/9/2021	94.3861463	0.462101	14:00:00	14/9/2021	3.459229	0
15:00:00	14/9/2021	94.8482476	0.459024	15:00:00	14/9/2021	3.459229	0
16:00:00	14/9/2021	95.3072716	0.463209	16:00:00	14/9/2021	3.459229	0
17:00:00	14/9/2021	95.7704806	0.490435	17:00:00	14/9/2021	3.459229	0
18:00:00	14/9/2021	96.2609156	0.460143	18:00:00	14/9/2021	3.459229	0
19:00:00	14/9/2021	96.721059	0.43907	19:00:00	14/9/2021	3.459229	0
20:00:00	14/9/2021	97.160129	0.455537	20:00:00	14/9/2021	3.459229	0
21:00:00	14/9/2021	97.61566602		21:00:00	14/9/2021	3.459229	
8:00:00	15/9/2021	97.6357629	0.460982	8:00:00	15/9/2021	3.459229	0
9:00:00	15/9/2021	98.0967449	0.465321	9:00:00	15/9/2021	3.459229	0
10:00:00	15/9/2021	98.5620659	0.47609	10:00:00	15/9/2021	3.459229	0
11:00:00	15/9/2021	99.0381559	0.451103	11:00:00	15/9/2021	3.459229	0
12:00:00	15/9/2021	99.4892589	0.520001	12:00:00	15/9/2021	3.459229	0
13:00:00	15/9/2021	100.0092599	0.473028	13:00:00	15/9/2021	3.459229	0
14:00:00	15/9/2021	100.4822879	0.453218	14:00:00	15/9/2021	3.459229	0
15:00:00	15/9/2021	100.9355055	0.46983	15:00:00	15/9/2021	3.459229	0

16:00:00	15/9/2021	101.4053357	0.469023	16:00:00	15/9/2021	3.459229	0
17:00:00	15/9/2021	101.8743587	0.444321	17:00:00	15/9/2021	3.459229	0
18:00:00	15/9/2021	102.3186797	0.492108	18:00:00	15/9/2021	3.459229	0
19:00:00	15/9/2021	102.8107877	0.453218	19:00:00	15/9/2021	3.459229	0
20:00:00	15/9/2021	103.2640057	0.493914	20:00:00	15/9/2021	3.459229	0
8:00:00	16/9/2021	103.7593	0.48722	8:00:00	16/9/2021	3.459229	0
9:00:00	16/9/2021	104.24652	0.45732	9:00:00	16/9/2021	3.459229	0
10:00:00	16/9/2021	104.70384	0.453218	10:00:00	16/9/2021	3.459229	0
11:00:00	16/9/2021	105.157058	0.487301	11:00:00	16/9/2021	3.459229	0
12:00:00	16/9/2021	105.644359	0.473424	12:00:00	16/9/2021	3.459229	0
13:00:00	16/9/2021	106.117783	0.47852	13:00:00	16/9/2021	3.459229	0
14:00:00	16/9/2021	106.596303	0.456371	14:00:00	16/9/2021	3.459229	0
15:00:00	16/9/2021	107.052674	0.486298	15:00:00	16/9/2021	3.459229	0
16:00:00	16/9/2021	107.538972	0.473265	16:00:00	16/9/2021	3.459229	0
17:00:00	16/9/2021	108.012237	0.467382	17:00:00	16/9/2021	3.459229	0
18:00:00	16/9/2021	108.479619	0.491112	18:00:00	16/9/2021	3.459229	0
19:00:00	16/9/2021	108.9707311	0.45387	19:00:00	16/9/2021	3.459229	0
20:00:00	16/9/2021	109.4246011	0.45111	20:00:00	16/9/2021	3.459229	0
21:00:00	16/9/2021	109.8757111		21:00:00	16/9/2021	3.459229	
8:00:00	17/9/2021	109.8757325	0.468101	8:00:00	17/9/2021	3.459229	0
9:00:00	17/9/2021	110.3438335	0.476302	9:00:00	17/9/2021	3.459229	0
10:00:00	17/9/2021	110.8201355	0.465302	10:00:00	17/9/2021	3.459229	0
11:00:00	17/9/2021	111.2854375	0.4329	11:00:00	17/9/2021	3.459229	0

12:00:00	17/9/2021	111.7183375	0.48291	12:00:00	17/9/2021	3.459229	0
13:00:00	17/9/2021	112.2012475	0.465398	13:00:00	17/9/2021	3.459229	0
14:00:00	17/9/2021	112.6666457	0.512101	14:00:00	17/9/2021	3.459229	0
15:00:00	17/9/2021	113.1787467	0.408932	15:00:00	17/9/2021	3.459229	0
16:00:00	17/9/2021	113.5876787	0.465902	16:00:00	17/9/2021	3.459229	0
17:00:00	17/9/2021	114.0535807	0.453108	17:00:00	17/9/2021	3.459229	0
18:00:00	17/9/2021	114.5066887	0.467201	18:00:00	17/9/2021	3.459229	0
19:00:00	17/9/2021	114.9738897	0.491101	19:00:00	17/9/2021	3.459229	0
20:00:00	17/9/2021	115.4649908	0.432123	20:00:00	17/9/2021	3.459229	0
21:00:00	17/9/2021	115.8971138		21:00:00	17/9/2021	3.459229	
8:00:00	18/9/2021	115.8991138	0.470213	8:00:00	18/9/2021	3.459229	0
9:00:00	18/9/2021	116.3693268	0.469002	9:00:00	18/9/2021	3.459229	0
10:00:00	18/9/2021	116.8383288	0.410112	10:00:00	18/9/2021	3.459229	0
11:00:00	18/9/2021	117.2484408	0.487201	11:00:00	18/9/2021	3.459229	0
12:00:00	18/9/2021	117.7356418	0.492231	12:00:00	18/9/2021	3.459229	0
13:00:00	18/9/2021	118.2278728	0.48307	13:00:00	18/9/2021	3.459229	0
14:00:00	18/9/2021	118.7109428	0.45553	14:00:00	18/9/2021	3.459229	0
15:00:00	18/9/2021	119.1664729	0.476309	15:00:00	18/9/2021	3.459229	0
16:00:00	18/9/2021	119.6427819	0.49332	16:00:00	18/9/2021	3.459229	0
17:00:00	18/9/2021	120.1361019	0.43219	17:00:00	18/9/2021	3.459229	0
18:00:00	18/9/2021	120.5682919	0.456734	18:00:00	18/9/2021	3.459229	0
19:00:00	18/9/2021	121.0250259	0.45824	19:00:00	18/9/2021	3.459229	0

20:00:00	18/9/2021	121.4832659	0.34728	20:00:00	18/9/2021	3.459229	0.13518
21:00:00	18/9/2021	121.8305459		21:00:00	18/9/2021	3.594409	
8:00:00	19/9/2021	121.830764	0.47321	8:00:00	19/9/2021	3.594409	0
9:00:00	19/9/2021	122.303974	0.453729	9:00:00	19/9/2021	3.594409	0
10:00:00	19/9/2021	122.757703	0.487201	10:00:00	19/9/2021	3.594409	0
11:00:00	19/9/2021	123.244904	0.44371	11:00:00	19/9/2021	3.594409	0
12:00:00	19/9/2021	123.688614	0.45982	12:00:00	19/9/2021	3.594409	0
13:00:00	19/9/2021	124.1484341	0.46792	13:00:00	19/9/2021	3.594409	0
14:00:00	19/9/2021	124.6163541	0.43218	14:00:00	19/9/2021	3.594409	0
15:00:00	19/9/2021	125.0485341	0.476198	15:00:00	19/9/2021	3.594409	0
16:00:00	19/9/2021	125.5247325	0.500017	16:00:00	19/9/2021	3.594409	0
17:00:00	19/9/2021	126.0247495	0.43628	17:00:00	19/9/2021	3.594409	0
18:00:00	19/9/2021	126.4610295	0.453203	18:00:00	19/9/2021	3.594409	0
19:00:00	19/9/2021	126.9142325	0.47686	19:00:00	19/9/2021	3.594409	0
20:00:00	19/9/2021	127.3910925	0.455553	20:00:00	19/9/2021	3.594409	0
21:00:00	19/9/2021	127.8466455		21:00:00	19/9/2021	3.594409	
8:00:00	20/9/2021	127.8567	0.45812	8:00:00	20/9/2021	3.594409	0
9:00:00	20/9/2021	128.31482	0.49361	9:00:00	20/9/2021	3.594409	0
10:00:00	20/9/2021	128.80843	0.476663	10:00:00	20/9/2021	3.594409	0
11:00:00	20/9/2021	129.2850933	0.484329	11:00:00	20/9/2021	3.594409	0
12:00:00	20/9/2021	129.7694223	0.42618	12:00:00	20/9/2021	3.594409	0
13:00:00	20/9/2021	130.1956023	0.48001	13:00:00	20/9/2021	3.594409	0

14:00:00	20/9/2021	130.6756123	0.473281	14:00:00	20/9/2021	3.594409	0
15:00:00	20/9/2021	131.1488933	0.473082	15:00:00	20/9/2021	3.594409	0
16:00:00	20/9/2021	131.6219753	0.490004	16:00:00	20/9/2021	3.594409	0
17:00:00	20/9/2021	132.1119793	0.41903	17:00:00	20/9/2021	3.594409	0
18:00:00	20/9/2021	132.5310093	0.44291	18:00:00	20/9/2021	3.594409	0
19:00:00	20/9/2021	132.9739193	0.46328	19:00:00	20/9/2021	3.594409	0
20:00:00	20/9/2021	133.4371993	0.46392	20:00:00	20/9/2021	3.594409	0
21:00:00	20/9/2021	133.9011193		21:00:00	20/9/2021	3.594409	
8:00:00	21/9/2021	133.9122	0.46509	8:00:00	21/9/2021	3.594409	0
9:00:00	21/9/2021	134.37729	0.498321	9:00:00	21/9/2021	3.594409	0
10:00:00	21/9/2021	134.875611	0.45914	10:00:00	21/9/2021	3.594409	0
11:00:00	21/9/2021	135.334751	0.462093	11:00:00	21/9/2021	3.594409	0
12:00:00	21/9/2021	135.796844	0.467773	12:00:00	21/9/2021	3.594409	0
13:00:00	21/9/2021	136.264617	0.48312	13:00:00	21/9/2021	3.594409	0
14:00:00	21/9/2021	136.747737	0.471925	14:00:00	21/9/2021	3.594409	0
15:00:00	21/9/2021	137.219662	0.47329	15:00:00	21/9/2021	3.594409	0
16:00:00	21/9/2021	137.692952	0.485444	16:00:00	21/9/2021	3.594409	0
17:00:00	21/9/2021	138.178396	0.43762	17:00:00	21/9/2021	3.594409	0
18:00:00	21/9/2021	138.616016	0.47912	18:00:00	21/9/2021	3.594409	0
19:00:00	21/9/2021	139.095136	0.443427	19:00:00	21/9/2021	3.594409	0
20:00:00	21/9/2021	139.538563	0.500021	20:00:00	21/9/2021	3.594409	0
21:00:00	21/9/2021	140.0385843		21:00:00	21/9/2021	3.594409	
8:00:00	22/9/2021	140.0496	0.46988	8:00:00	22/9/2021	3.594409	0

9:00:00	22/9/2021	140.51948	0.465312	9:00:00	22/9/2021	3.594409	0
10:00:00	22/9/2021	140.984792	0.467835	10:00:00	22/9/2021	3.594409	0
11:00:00	22/9/2021	141.452627	0.476032	11:00:00	22/9/2021	3.594409	0
12:00:00	22/9/2021	141.928659	0.483219	12:00:00	22/9/2021	3.594409	0
13:00:00	22/9/2021	142.411878	0.443235	13:00:00	22/9/2021	3.594409	0
14:00:00	22/9/2021	142.855113	0.47923	14:00:00	22/9/2021	3.594409	0
15:00:00	22/9/2021	143.3343431	0.483277	15:00:00	22/9/2021	3.594409	0
16:00:00	22/9/2021	143.8176202	0.455539	16:00:00	22/9/2021	3.594409	0
17:00:00	22/9/2021	144.2731594	0.470923	17:00:00	22/9/2021	3.594409	0
18:00:00	22/9/2021	144.7440824	0.479054	18:00:00	22/9/2021	3.594409	0
19:00:00	22/9/2021	145.2231364	0.455376	19:00:00	22/9/2021	3.594409	0
20:00:00	22/9/2021	145.6785126	0.39754	20:00:00	22/9/2021	3.594409	0.0833
21:00:00	22/9/2021	146.0760526	0	21:00:00	22/9/2021	3.677709	0.46112
22:00:00	22/9/2021	146.0760526		22:00:00	22/9/2021	4.138829	
8:00:00	23/9/2021	146.0771	0.470092	8:00:00	23/9/2021	4.138829	0
9:00:00	23/9/2021	146.547192	0.455538	9:00:00	23/9/2021	4.138829	0
10:00:00	23/9/2021	147.0027298	0.467529	10:00:00	23/9/2021	4.138829	0
11:00:00	23/9/2021	147.4702588	0.453211	11:00:00	23/9/2021	4.138829	0
12:00:00	23/9/2021	147.9234698	0.437623	12:00:00	23/9/2021	4.138829	0
13:00:00	23/9/2021	148.3610928	0.47698	13:00:00	23/9/2021	4.138829	0
14:00:00	23/9/2021	148.8380728	0.490234	14:00:00	23/9/2021	4.138829	0
15:00:00	23/9/2021	149.3283068	0.456987	15:00:00	23/9/2021	4.138829	0

16:00:00	23/9/2021	149.7852938	0.5411	16:00:00	23/9/2021	4.138829	0
17:00:00	23/9/2021	150.3263938	0.444564	17:00:00	23/9/2021	4.138829	0
18:00:00	23/9/2021	150.7709576	0.49802	18:00:00	23/9/2021	4.138829	0
19:00:00	23/9/2021	151.2689776	0.48273	19:00:00	23/9/2021	4.138829	0
20:00:00	23/9/2021	151.7517076	0.48342	20:00:00	23/9/2021	4.138829	0
21:00:00	23/9/2021	152.2351276	0.465021	21:00:00	23/9/2021	4.138829	0
22:00:00	23/9/2021	152.7001486		22:00:00	23/9/2021	4.138829	
8:00:00	24/9/2021	152.702317	0.466655	8:00:00	24/9/2021	4.138829	0
9:00:00	24/9/2021	153.1689718	0.48702	9:00:00	24/9/2021	4.138829	0
10:00:00	24/9/2021	153.6559918	0.476021	10:00:00	24/9/2021	4.138829	0
11:00:00	24/9/2021	154.1320128	0.454387	11:00:00	24/9/2021	4.138829	0
12:00:00	24/9/2021	154.5863998	0.444003	12:00:00	24/9/2021	4.138829	0
13:00:00	24/9/2021	155.0304028	0.487211	13:00:00	24/9/2021	4.138829	0
14:00:00	24/9/2021	155.5176138	0.498003	14:00:00	24/9/2021	4.138829	0
15:00:00	24/9/2021	156.0156167	0.476124	15:00:00	24/9/2021	4.138829	0
16:00:00	24/9/2021	156.4917407	0.432109	16:00:00	24/9/2021	4.138829	0
17:00:00	24/9/2021	156.9238497	0.400123	17:00:00	24/9/2021	4.138829	0
18:00:00	24/9/2021	157.3239729	0.45337	18:00:00	24/9/2021	4.138829	0
19:00:00	24/9/2021	157.7773429	0.47921	19:00:00	24/9/2021	4.138829	0
20:00:00	24/9/2021	158.2565529	0.29873	20:00:00	24/9/2021	4.138829	0.16711
21:00:00	24/9/2021	158.5552829	0	21:00:00	24/9/2021	4.305939	0.50143
22:00:00	24/9/2021	158.5552829		22:00:00	24/9/2021	4.807369	

8:00:00	25/9/2021	158.55896	0.47421	8:00:00	25/9/2021	4.807369	0
9:00:00	25/9/2021	159.03317	0.45693	9:00:00	25/9/2021	4.807369	0
10:00:00	25/9/2021	159.4901	0.476309	10:00:00	25/9/2021	4.807369	0
11:00:00	25/9/2021	159.966409	0.48111	11:00:00	25/9/2021	4.807369	0
12:00:00	25/9/2021	160.447519	0.465872	12:00:00	25/9/2021	4.807369	0
13:00:00	25/9/2021	160.913391	0.478634	13:00:00	25/9/2021	4.807369	0
14:00:00	25/9/2021	161.3920254	0.476319	14:00:00	25/9/2021	4.807369	0
15:00:00	25/9/2021	161.8683444	0.500034	15:00:00	25/9/2021	4.807369	0
16:00:00	25/9/2021	162.3683784	0.410939	16:00:00	25/9/2021	4.807369	0
17:00:00	25/9/2021	162.7793174	0.470924	17:00:00	25/9/2021	4.807369	0
18:00:00	25/9/2021	163.2502414	0.48792	18:00:00	25/9/2021	4.807369	0
19:00:00	25/9/2021	163.7381614	0.43523	19:00:00	25/9/2021	4.807369	0
20:00:00	25/9/2021	164.1733914	0.44872	20:00:00	25/9/2021	4.807369	0
21:00:00	25/9/2021	164.6221114	0.31045	21:00:00	25/9/2021	4.807369	0.15539
22:00:00	25/9/2021	164.9325614		22:00:00	25/9/2021	4.962759	
8:00:00	26/9/2021	164.9325	0.470091	8:00:00	26/9/2021	4.96275	0
9:00:00	26/9/2021	165.402591	0.487219	9:00:00	26/9/2021	4.96275	0
10:00:00	26/9/2021	165.88981	0.467543	10:00:00	26/9/2021	4.96275	0
11:00:00	26/9/2021	166.357353	0.49812	11:00:00	26/9/2021	4.96275	0
12:00:00	26/9/2021	166.8554731	0.465329	12:00:00	26/9/2021	4.96275	0
13:00:00	26/9/2021	167.3208021	0.454344	13:00:00	26/9/2021	4.96275	0
14:00:00	26/9/2021	167.7751461	0.41908	14:00:00	26/9/2021	4.96275	0

15:00:00	26/9/2021	168.1942261	0.47233	15:00:00	26/9/2021	4.96275	0
16:00:00	26/9/2021	168.6665561	0.492134	16:00:00	26/9/2021	4.96275	0
17:00:00	26/9/2021	169.1586901	0.477762	17:00:00	26/9/2021	4.96275	0
18:00:00	26/9/2021	169.6364521	0.468231	18:00:00	26/9/2021	4.96275	0
19:00:00	26/9/2021	170.1046831	0.49812	19:00:00	26/9/2021	4.96275	0
20:00:00	26/9/2021	170.6028031	0.45238	20:00:00	26/9/2021	4.96275	0
21:00:00	26/9/2021	171.0551831	0.467321	21:00:00	26/9/2021	4.96275	0
22:00:00	26/9/2021	171.5225041		22:00:00	26/9/2021	4.96275	
8:00:00	27/9/2021	171.5327	0.47223	8:00:00	27/9/2021	4.96275	0
9:00:00	27/9/2021	172.0049301	0.476302	9:00:00	27/9/2021	4.96275	0
10:00:00	27/9/2021	172.4812321	0.459231	10:00:00	27/9/2021	4.96275	0
11:00:00	27/9/2021	172.9404631	0.486921	11:00:00	27/9/2021	4.96275	0
12:00:00	27/9/2021	173.4273841	0.478931	12:00:00	27/9/2021	4.96275	0
13:00:00	27/9/2021	173.9063151	0.472713	13:00:00	27/9/2021	4.96275	0
14:00:00	27/9/2021	174.3790281	0.473874	14:00:00	27/9/2021	4.96275	0
15:00:00	27/9/2021	174.8529021	0.48709	15:00:00	27/9/2021	4.96275	0
16:00:00	27/9/2021	175.3399921	0.4182	16:00:00	27/9/2021	4.96275	0
17:00:00	27/9/2021	175.7581921	0.47832	17:00:00	27/9/2021	4.96275	0
18:00:00	27/9/2021	176.2365121	0.498929	18:00:00	27/9/2021	4.96275	0
19:00:00	27/9/2021	176.7354411	0.499981	19:00:00	27/9/2021	4.96275	0
20:00:00	27/9/2021	177.2354222	0.47944	20:00:00	27/9/2021	4.96275	0
21:00:00	27/9/2021	177.7148622	0.483211	21:00:00	27/9/2021	4.96275	0
22:00:00	27/9/2021	178.1980732		22:00:00	27/9/2021	4.96275	

8:00:00	28/9/2021:	178.1991	0.479912	8:00:00	28/9/2021:	4.96275	0
9:00:00	28/9/2021:	178.679012	0.487603	9:00:00	28/9/2021:	4.96275	0
10:00:00	28/9/2021:	179.166615	0.48121	10:00:00	28/9/2021:	4.96275	0
11:00:00	28/9/2021:	179.647825	0.482344	11:00:00	28/9/2021:	4.96275	0
12:00:00	28/9/2021:	180.130169	0.490012	12:00:00	28/9/2021:	4.96275	0
13:00:00	28/9/2021:	180.620181	0.48723	13:00:00	28/9/2021:	4.96275	0
14:00:00	28/9/2021:	181.107411	0.48709	14:00:00	28/9/2021:	4.96275	0
15:00:00	28/9/2021:	181.594501	0.4201	15:00:00	28/9/2021:	4.96275	0
16:00:00	28/9/2021:	182.014601	0.454442	16:00:00	28/9/2021:	4.96275	0
17:00:00	28/9/2021:	182.469043	0.465711	17:00:00	28/9/2021:	4.96275	0
18:00:00	28/9/2021:	182.934754	0.487204	18:00:00	28/9/2021:	4.96275	0
19:00:00	28/9/2021:	183.421958	0.477245	19:00:00	28/9/2021:	4.96275	0
20:00:00	28/9/2021:	183.899203	0.487321	20:00:00	28/9/2021:	4.96275	0
21:00:00	28/9/2021:	184.386524	0.487291	21:00:00	28/9/2021:	4.96275	0
22:00:00	28/9/2021:	184.873815		22:00:00	28/9/2021:	4.96275	
8:00:00	29/9/2021:	184.8747	0.47009	8:00:00	29/9/2021:	4.96275	0
9:00:00	29/9/2021:	185.34479	0.451114	9:00:00	29/9/2021:	4.96275	0
10:00:00	29/9/2021:	185.795904	0.473217	10:00:00	29/9/2021:	4.96275	0
11:00:00	29/9/2021:	186.2691213	0.478321	11:00:00	29/9/2021:	4.96275	0
12:00:00	29/9/2021:	186.7474423	0.46759	12:00:00	29/9/2021:	4.96275	0
13:00:00	29/9/2021:	187.2150323	0.481211	13:00:00	29/9/2021:	4.96275	0
14:00:00	29/9/2021:	187.6962435	0.46509	14:00:00	29/9/2021:	4.96275	0
15:00:00	29/9/2021:	188.1613335	0.470913	15:00:00	29/9/2021:	4.96275	0

16:00:00	29/9/2021:	188.6322465	0.476309	16:00:00	29/9/2021:	4.96275	0
17:00:00	29/9/2021:	189.1085557	0.49031	17:00:00	29/9/2021:	4.96275	0
18:00:00	29/9/2021:	189.5988657	0.423443	18:00:00	29/9/2021:	4.96275	0
19:00:00	29/9/2021:	190.0223087	0.498502	19:00:00	29/9/2021:	4.96275	0
20:00:00	29/9/2021:	190.5208107	0.465231	20:00:00	29/9/2021:	4.96275	0
21:00:00	29/9/2021:	190.9860418	0.482314	21:00:00	29/9/2021:	4.96275	0
22:00:00	29/9/2021:	191.4683558		22:00:00	29/9/2021:	4.96275	
8:00:00	30/9/2021:	191.4695	4.60983	8:00:00	30/9/2021:	4.96275	0
9:00:00	30/9/2021:	196.07933	0.456287	9:00:00	30/9/2021:	4.96275	0
10:00:00	30/9/2021:	196.535617	0.45213	10:00:00	30/9/2021:	4.96275	0
11:00:00	30/9/2021:	196.987747	0.5763	11:00:00	30/9/2021:	4.96275	0
12:00:00	30/9/2021:	197.564047	0.55321	12:00:00	30/9/2021:	4.96275	0
13:00:00	30/9/2021:	198.117257	0.45637	13:00:00	30/9/2021:	4.96275	0
14:00:00	30/9/2021:	198.573627	0.46589	14:00:00	30/9/2021:	4.96275	0
15:00:00	30/9/2021:	199.039517	0.456548	15:00:00	30/9/2021:	4.96275	0
16:00:00	30/9/2021:	199.4960648	0.487903	16:00:00	30/9/2021:	4.96275	0
17:00:00	30/9/2021:	199.9839678	0.5321	17:00:00	30/9/2021:	4.96275	0
18:00:00	30/9/2021:	200.5160678	0.487651	18:00:00	30/9/2021:	4.96275	0
19:00:00	30/9/2021:	201.0037188	0.49821	19:00:00	30/9/2021:	4.96275	0
20:00:00	30/9/2021:	201.5019288	0.53128	20:00:00	30/9/2021:	4.96275	0
21:00:00	30/9/2021:	202.0332088	0.3231	21:00:00	30/9/2021:	4.96275	0.19174
22:00:00	30/9/2021:	202.3563088		22:00:00	30/9/2021:	5.15449	

Appendix E: Data from Rwanda meteorology on solar irradiation 1/Sept/2021

	Solar Irradiation at GMT time	
Meteo		to:
Data	From: 01/09/2021	14/10/2021
		(3-GITEGA AWS) (3) Global Solar Irradiation
Date	Hour	Average - W/m2
1/9/2021	04.00.00	0.8
1/9/2021	04.10.00	4.5
1/9/2021	04.20.00	11.8
1/9/2021	04.30.00	22.9
1/9/2021	04.40.00	42.3
1/9/2021	04.50.00	60.4
1/9/2021	05.00.00	65.6
1/9/2021	05.10.00	75.1
1/9/2021	05.20.00	108.5
1/9/2021	05.30.00	172.7
1/9/2021	05.40.00	218.4
1/9/2021	05.50.00	171.3
1/9/2021	06.00.00	162.7
1/9/2021	06.10.00	168.5
1/9/2021	06.20.00	226
1/9/2021	06.30.00	268.8
1/9/2021	06.40.00	351.1
1/9/2021	06.50.00	371.8
1/9/2021	07.00.00	409.1
1/9/2021	07.10.00	536.9
1/9/2021	07.20.00	558.4
1/9/2021	07.30.00	591.7
1/9/2021	07.40.00	617.6

1/9/2021	07.50.00	648.5
1/9/2021	08.00.00	676.3
1/9/2021	08.10.00	704.8
1/9/2021	08.20.00	713.5
1/9/2021	08.30.00	795.1
1/9/2021	08.40.00	419.6
1/9/2021	08.50.00	262.3
1/9/2021	09.00.00	308.4
1/9/2021	09.10.00	781.2
1/9/2021	09.20.00	379.5
1/9/2021	09.30.00	253.7
1/9/2021	09.40.00	287.8
1/9/2021	09.50.00	376.4
1/9/2021	10.00.00	277.9
1/9/2021	10.10.00	362.2
1/9/2021	10.20.00	949.2
1/9/2021	10.30.00	821.8
1/9/2021	10.40.00	919.3
1/9/2021	10.50.00	917.2
1/9/2021	11.00.00	960.1
1/9/2021	11.10.00	814.3
1/9/2021	11.20.00	733.6
1/9/2021	11.30.00	575
1/9/2021	11.40.00	348.1
1/9/2021	11.50.00	506.4
1/9/2021	12.00.00	572.8
1/9/2021	12.10.00	780.4
1/9/2021	12.20.00	684.8
1/9/2021	12.30.00	705.9
1/9/2021	12.40.00	695.3
1/9/2021	12.50.00	644.8

1/9/2021	13.00.00	540.2
1/9/2021	13.10.00	458.4
1/9/2021	13.20.00	378.8
1/9/2021	13.30.00	187.9
1/9/2021	13.40.00	144.8
1/9/2021	13.50.00	138.6
1/9/2021	14.00.00	131.8
1/9/2021	14.10.00	132.9
1/9/2021	14.20.00	177.9
1/9/2021	14.30.00	210
1/9/2021	14.40.00	140.2
1/9/2021	14.50.00	75.4
1/9/2021	15.00.00	44.4
1/9/2021	15.10.00	31.6
1/9/2021	15.20.00	28.5
1/9/2021	15.30.00	19.4
1/9/2021	15.40.00	17.4
1/9/2021	15.50.00	11.1
1/9/2021	16.00.00	3.7
1/9/2021	16.10.00	0.1
1/9/2021	16.20.00	0
1/9/2021	16.30.00	0
1/9/2021	16.40.00	0
1/9/2021	16.50.00	0
1/9/2021	17.00.00	1.4
1/9/2021	17.10.00	0.1
1/9/2021	17.20.00	0.2
1/9/2021	17.30.00	1.3
1/9/2021	17.40.00	0.8
1/9/2021	17.50.00	0
1/9/2021	18.00.00	0

1/9/2021	18.10.00	0
1/9/2021	18.20.00	0
1/9/2021	18.30.00	0
1/9/2021	18.40.00	0.5
1/9/2021	18.50.00	0
1/9/2021	19.00.00	0
1/9/2021	19.10.00	0.1
1/9/2021	19.20.00	0.2
1/9/2021	19.30.00	0
1/9/2021	19.40.00	0
1/9/2021	19.50.00	0.1
1/9/2021	20.00.00	0.2
1/9/2021	20.10.00	0.4
1/9/2021	20.20.00	0.2
1/9/2021	20.30.00	0.8
1/9/2021	20.40.00	0.8
1/9/2021	20.50.00	1
1/9/2021	21.00.00	0.9
1/9/2021	21.10.00	0.3
1/9/2021	21.20.00	0
1/9/2021	21.30.00	0
1/9/2021	21.40.00	0
1/9/2021	21.50.00	0
1/9/2021	22.00.00	0
1/9/2021	22.10.00	0
1/9/2021	22.20.00	0
1/9/2021	22.30.00	0
1/9/2021	22.40.00	0
1/9/2021	22.50.00	0
1/9/2021	23.00.00	0
1/9/2021	23.10.00	0

1/9/2021	23.20.00	0
1/9/2021	23.30.00	0
1/9/2021	23.40.00	0
1/9/2021	23.50.00	0

For more data on solar irradiation of the remaining days, see in the following link.

https://docs.google.com/spreadsheets/d/1eFTxFePz9QChwuDLlUjgrr0mB77kUKM7-qc5r0nja04/edit?usp=sharing