UNIVERSITI TEKNIKAL MALAYSIA MELAKA

FAKULTI KEJURUTERAAN ELEKTRIK

FINAL YEAR PROJECT REPORT

BEKU 4792

PV DC MICROGRID DESIGN FOR APPLICATIONS ON REMOTE AREAS

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This Progress Report is submitted to Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka in partial fulfillment for Bachelors of Electrical Engineering

Faculty of Electrical Engineering
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(2018)

DECLARATION

"I hereby declared that this report is a result of my own work except for the excerpts that have been cited clearly in the references"

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"I hereby declared that I have read through this progress report entitled 'PV DC Microgrid Design For Applications On Remote Areas"

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Supervisor's Name : ………………………………………..

Date : ………………………………………..

ACKNOWLEDGEMENT

First and foremost, thanks to Allah for giving me the strength to be devoted to the community as well as gaining new knowledge, experience and be able to finish this report in the allotted time. Nothing can be done except with the permission of Allah.

I would also like to express my deepest appreciation to those who are involved in this Final Year Project especially to my supervisor Encik Kyairul Azmi bin Baharin for giving me his guidance tirelessly. I am highly indebted to Universiti Teknikal Malaysia Melaka for giving me the opportunity to pursue my Bachelors in Electrical Engineering.

I would also like to express my gratitude to my parents and all my friends for their encouragement and support throughout my education process. I believe that their support will not end here and I will always be grateful for their sacrifice, generosity and love.

ABSTRACT

In this report, a microgrid distribution system was studied. This microgrid provides power in the form of direct current (DC) and uses a renewable energy source as its generation. The renewable energy source implemented is the solar power harvested by photovoltaic panels. This project proposes a DC microgrid that is suitable to be used in rural areas, since most rural areas do not have their own source of electricity. The problem with using a standard microgrid is that it has an inverter embedded into the system, which could cause unnecessary power loss. As scope of this project, the designed DC microgrid can only supply power for common household loads and it provides power directly into DC form without the use of an inverter. The calculation method used in this project is to determine the parameters of the needed components for the microgrid to provide stable and reliable power within the boundaries of the design.

ABSTRAK

Dalam laporan ini, sistem pengedaran kuasa mikrogrid dikaji dengan lebih mendalam. Mikrogrid ini memberikan kuasa dalam bentuk “direct current” (DC) dan menggunakan sumber tenaga boleh diperbaharui sebagai penjanaannya. Sumber tenaga boleh diperbaharui yang dilaksanakan adalah tenaga solar yang dituai oleh panel fotovoltaik. Projek ini mencadangkan mikrogrid DC yang sesuai untuk digunakan di kawasan luar bandar, kerana kebanyakan kawasan luar bandar tidak mempunyai sumber elektrik sendiri. Masalah dengan menggunakan mikrogrid standard ialah ia mempunyai “inverter” yang dimasukkan ke dalam sistem, yang boleh menyebabkan kehilangan kuasa yang boleh dielakkan. Sebagai skop projek ini, mikrogrid DC yang direka hanya boleh membekalkan kuasa untuk beban isi rumah yang biasa dan ia memberikan kuasa terus ke bentuk DC tanpa menggunakan penyongsang. Kaedah pengiraan yang digunakan dalam projek ini adalah untuk menentukan parameter komponen yang diperlukan untuk micrograd untuk menyediakan kuasa yang stabil dan boleh dipercayai dalam sempadan reka bentuk.

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LIST OF ABBREVIATIONS

DC	-	Direct Current
AC	-	Alternating Current
PV	-	Photovoltaic
IEA	-	International Energy Agency
DER	-	Distributed Energy Resource
LV	-	Low Voltage
HOMER	-	Hybrid Optimization Model for Electric Renewable
PMU	-	Power Management Unit

CHAPTER 1

INTRODUCTION

1.1 Overview

Electricity is a very important commodity to have in a world where technological advancements are rapidly growing. But not everyone currently has access to electricity. Without access to electricity, these people will also not have access to current news of the outside world which includes the advancements in technology that are being discovered on a daily basis.

According to the International Energy Agency (IEA), the number of people that does not have access to electricity in 2016 is 1.1 billion people ~ which is about 14.47% of the total world population. Although there is decrease since 2014, which is about 1.3 billion people ~ 17.1% of the world population without electricity, that is still a large number of people that does not have access to the development of the rest of the world. This can cause some adverse effects on the education and economical aspects of a country [11].

While there are no official reports saying how many people in Malaysia currently do not have access to electricity, the news site “FMT News” reports that 36% of the rural populace in Malaysia still does not have access to electricity. That is 36% of 31 million people without access to electricity. Imagine the possibility if that amount of people had electrical access, that would no doubt cause a staggering level of knowledge increase in Malaysia’s population alone [12].

Providing electricity to rural areas are also not cost effective since the nearest power plant could probably be located at quite a distance away. This makes the grid installation cost to be high. Grid operators would also face disadvantageous factors if they were to connect these rural areas with electricity such as very high transmission losses and unreliable electricity supply to the users. To generate electricity, they would need a power plant close enough to their location in the rural regions. Most power plants run on fossil fuels, which could cause negative effects on the people and the environment.

With the cost of solar panels being quite cheap since the past few years, it presents a new viable option rather than the grid connected electricity. Recent field studies showed that an exclusively dc photovoltaic-powered system that has its own distributed storage increases the efficiency of the system while reducing the cost [1], [2].

It is best to design the solar photovoltaic system to deliver electrical power in dc form since most of the loads in a common household nowadays uses dc power. Since remote areas are usually small, there would be no need to convert the dc power generated by the photovoltaic panels to ac, then converting it back to dc for the end user because this can create more unnecessary losses [3].

1.2 Problem Statement

A microgrid does not depend on electricity from the main/national grid. It contains certain characteristics of a main grid such as generation and distribution. But it does all of these within a small area. Most microgrids are installed with an inverter to support loads that will eventually revert back to DC. But this could lead the system to have unneeded power loss that can be prevented.

The design of this microgrid will be influenced by a few factors. These factors are the reliability of the microgrid system to generate electricity, the physical design of the system and the cost for producing said system. In this project, a solar photovoltaic microgrid is designed to generate, transmit and distribute power in DC form. Taking into factor that this design will be used in remote areas where there is likely to be no electricity, it needs to be a reliable system to produce and maintain power for usage. The physical design needs to be simple but also durable to operate in rural conditions. Lastly, it should also be as inexpensive as possible so that it can be afforded.

1.2 Objective

Based on the problem statement, this project aims to build a solar photovoltaic microgrid that is able to generate electricity that can power DC loads directly without the use of inverters. This dc microgrid can be used in rural or remote areas without depending on the main grid network. The microgrid network should also be as simple as it can in terms of construction so that the maintenance cost could be lowered. The main objectives can be summarized as : -

1. Determine the parameters of a dc microgrid through calculation.
2. Build a dc microgrid fit to operate in remote areas.
3. Run the system to determine its power output and performance.

In order for the microgrid to properly operate during emergency conditions, it should be able to provide power without any disturbances. The key factor for the microgrid to be able to maintain power is in the design of the system itself. Thus, the design calculation is a very prominent factor for the microgrid system.

Although this project aims to provide electrical power for remote areas, it can also prove to be useful in emergency conditions such as during natural disasters. Therefore, secondary objectives are set. The microgrid system should be able to provide electricity for important appliances during emergency conditions. Such appliances are electrical fans, lighting, charging ports and radios.

Taking into consideration that this system would be used in emergency conditions, the design factors that should be taken as secondary objectives are that the system should be robust in its construction and the total weight of the whole system should be an amount that is possible for people to carry around.

1.3 Project Scope

The scope of this project is to make a solar photovoltaic microgrid specifically designed to generate power to run DC loads. The loads will be small and likely to be for everyday use such as televisions and fans. This project will have limitations in that it will not supply power for bigger loads and that it will not use an inverter to transmit the power. This is because the system will provide power only for critical/important loads and that it will only transmit power over very short distances, thus the transmission losses are negligible.

CHAPTER 2

LITERATURE REVIEW

In this section of the report, the project title will briefly be discussed, which is "Photovoltaic DC microgrid". There will be three parts in this chapter. The first part will discuss about the solar photovoltaic panel, which includes it's working principle, the construction of the panel and the different types of panels. The second part will discuss about the microgrid itself, each type of microgrids and advantages and disadvantages of each. The third part delves into the previous work done on the DC microgrid and how each of them achieve the objectives that they set.

2.1 The Solar Photovoltaic Panel

The word 'photovoltaic' is actually a term that describes the conversion of light into electricity by using semiconducting materials that shows the characteristics of the 'photovoltaic effect'. A solar panel essentially uses this property to generate electrical power by converting the light energy from the sun. This method of generating electrical power is very advantageous since it does not create any type of pollution nor does it create any greenhouse emission effects. It is also advantageous that the material needed to make these panels are quite abundant in the Earth's crust, which is silicon.

Though the solar panel is not in any sense a perfect power generator. It has quite a number of disadvantages. Solar panels depend solely on the presence of the sun, even it's direction. A solar panel that is installed in a static position will not have the same output as a solar panel that has a sun tracking system in it. This is because solar panels require direct sunlight to produce the optimum rated power set by the manufacturers. Other things in the atmosphere such as the clouds, dust and impurities will also reduce the power output[4].

Solar panels produce electrical power in DC form. This makes it easy for applications such as charging a battery. Solar panels had first been used to generate power for satellites orbiting the earth. Then as market demand for renewable energy increases, they start to incorporate this technology for commercial use.

2.1.1 The Construction

A solar panel is actually made up of a few solar cells being connected in series. Each of these cells consists of two layers of doped silicon, one being the n-type and the other is the p-type. These two layers are set to be in contact to create a junction, where each layer having an electrical connection [9]. Each of these cells are capable to produce voltages of up to 0.7 volt, while providing maximum power at 0.4 volt.

The solar panel or module is made up of a few of these cells to increase the output. If a manufacturer would want to make a panel to have a nominal voltage of 36 volts, the panel will have to have 90 cells within the panel.

$$Number\ of\ cells\ in\ a\ panel = 0.4 \times 90 = 36\text{ V} \qquad (2.1)$$

The construction of the solar panel will usually make sure that it is protected from the weather. The solar cells are placed on a hard backing plate, while the electrical connections are above and below the cells. The positive connection of one cell will be connected to the negative connection of another cell to create series connection. On top of these cells will be a non-reflective coat so as to increase the absorption of light. The final top layer will be a piece of durable glass, then the whole construction will be encased in an aluminum frame to make it protected from weather conditions.

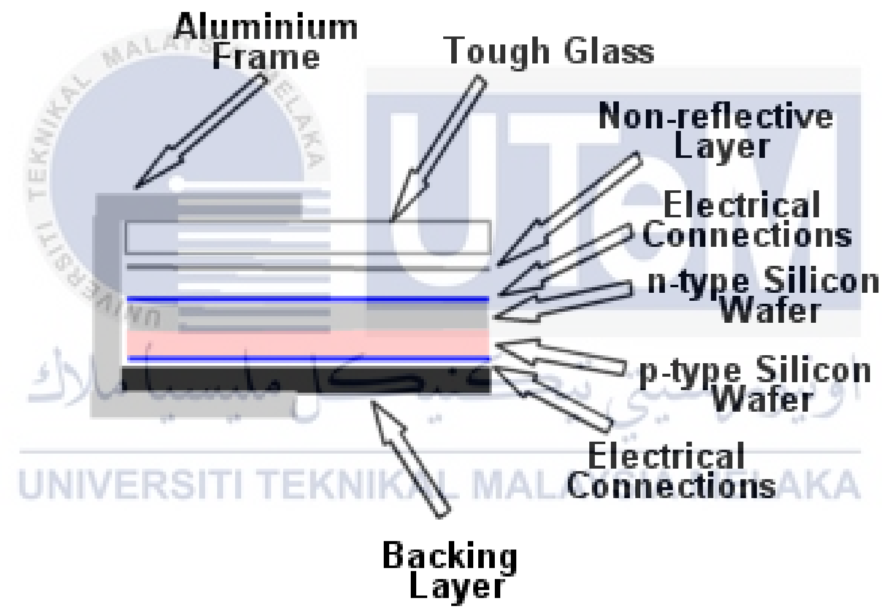

Figure 2.1 : Illustration of solar panel construction

2.1.2 Types Of Solar Panels

With the increase of commercial use of solar panels, there is also the varying types of solar panels in the market. With almost 90% of the worlds solar panels are made with some form of silicon, manufacturers try to take this as an advantage to make more types of solar panels based on the purity of the silicon[10].

The purity of silicon is the main factor of the efficiency of a solar panel. The alignment of the silicon molecules will show how good it is in converting sunlight into electrical energy. If the solar molecules are more perfectly aligned, then the better the solar panel will be in converting sunlight into electrical energy. The same applies for the inverse of the alignment of the solar molecules.

It might sound easy to just make a solar panel to have perfect alignment of silicon molecules, but the key factor is cost. Since the process of enhancing the purity of silicon are quite expensive. Most customers would focus on the total cost of installing a PV system and the space that is required for such installation.

There are basically three main types of solar panels available in the market today and probably a few new types that are currently being researched upon. The three main types are the Monocrystalline silicon solar cells, Polycrystalline silicon solar cells and the Thin-Film solar panels.

2.1.2.1 Monocrystalline Silicon Solar Cell

Monocrystalline silicon (mono-Si) cells, also known as single-crystalline silicon (single-crystal-Si) can be easily distinguished by the uniform look of the panel, which indicates a high concentration of pure silicon. Cylindrical shaped silicon ingots are used to make monocrystalline solar cells. To increase the performance and decrease the cost for each monocrystalline cell, four sides of the silicon ingot are cut out to make thin wafers. This gives the monocrystalline solar cells its distinctive look. It is an easy way to differentiate between monocrystalline and polycrystalline cells, since polycrystalline cells does not have the rounded edges like the monocrystalline.

In terms of advantage, the monocrystalline solar cells are rated to have the highest efficiency because they are made out of the purest silicon. Since they are the most efficient, they are also very space-efficient. It would take only one monocrystalline solar panel to produce the same amount of electricity as four thin-film solar panels. On top of all these, it also has the longest life time out of the other types of solar panels.

But with all it's advantages, it comes to the user whether to choose the monocrystalline solar panel or not, since it is the most expensive out of all the other types of solar panels. Another significant disadvantage of the monocrystalline panel is that if a part of the panel is covered in shade, there is a possibility that the entire circuit will break down. The monocrystalline solar panels efficiency depends on the weather temperature. If the temperature goes too high, the performance of the panel will noticeably be lower. This is because this type of panel is more efficient in warm weather.

2.1.2.2 Polycrystalline Silicon Solar Cell

The polycrystalline silicon (p-Si) solar cell does not require the Czochralski process. It is the process used to create silicon ingots to produce the monocrystalline solar cells. To make the polycrystalline solar cell, raw silicon is heated until its melting temperature which then the melted silicon is poured into a square shaped mold. This mold is then chilled until the silicon hardens and then it will be cut into wafers.

By not using the Czochralski process, the cost for producing a polycrystalline panel is less than that of the monocrystalline and the process is much simpler. But it seems that the advantage ends there, because unlike the monocrystalline panels, polycrystalline panels have a minor heat tolerance. This can affect the panels' lifespan. The efficiency of these panels are also lower, which means it has lower space-efficiency.

2.1.2.3 Thin-Film Solar Cells

The process of manufacturing a thin-film solar cell is not the same as the previous two. The process involves depositing a few thin layers of photovoltaic elements on an underlying layer. These types of cells are also known as thin-film photovoltaic cells (TFPV). Thin-film type cells can be categorized by the photovoltaic elements being deposited on the underlying layer. They are either Amorphous silicon (a-Si), Cadmium Telluride (CdTe), Copper Indium Gallium selenide (CIS/CIGS) and organic photovoltaic cells (OPC).

With the method of manufacturing thin-film cells not as tedious as the crystalline cells, it makes mass productions for thin-film cells easy. Not to mention making it potentially cheaper than producing crystalline cells. With the amount of research going into these thin-film type cells, manufacturers have found a way to make these cells flexible, which in turn creates more possibility for its application. Another advantage is that high levels of temperature and shading does not give a considerable impact on these types of panels.

While the disadvantages of thin-film panels are that they require so much space that it would be considered useless to use them on residential areas. With the factor of space-efficiency being low, that also means that the cost for the other equipment for the PV system will increase. Thin-film solar panels also tend to degrade much faster than the crystalline type panels.

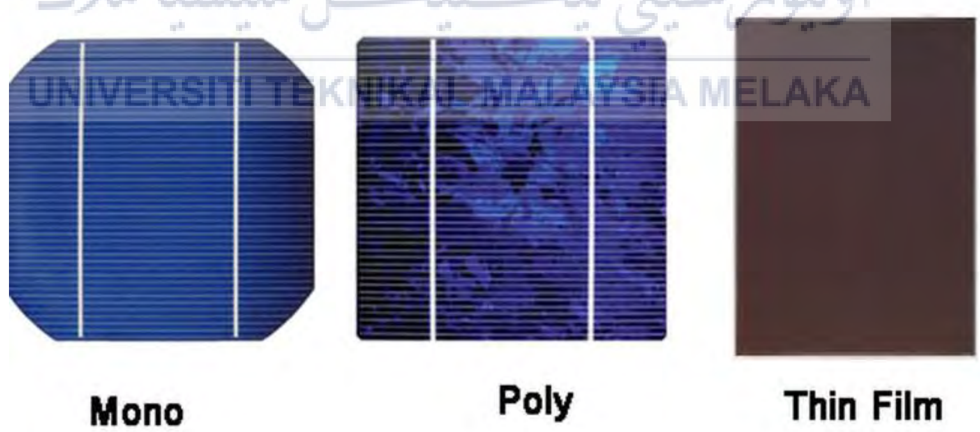

Figure 2.2 : Physical difference between types of solar cells

2.2 The Microgrid

A microgrid, according to the EU research project is described as a low-voltage (LV) distribution system which has its own distributed energy resource (DER), energy storage elements and flexible loads [13]. In essential, a microgrid can generate and provide electricity to localized loads within the boundaries of the design of the microgrid. Microgrids can operate in two modes; either islanded-mode (disconnected from main grid) or grid-connected mode [14].

A microgrid system consists of a few similarities to a main grid. But a microgrid can only distribute power to loads that are within close proximity of the generation of the microgrid itself. Since microgrids usually use renewable energy sources as their power generation, they can be implemented in almost any location.

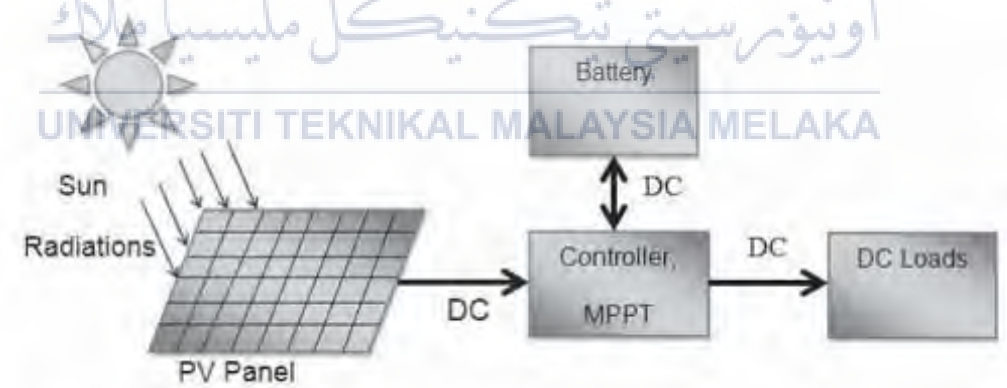

Figure 2.3 : The main components in a solar DC microgrid

The main components in a DC microgrid are shown as in figure 2.3. In this case, the PV panel is the generation element of the microgrid. The controller of the microgrid is as it implies, which it controls and regulates the output from the generation then providing the regulated energy to the storage element and the load. The storage element, which is the battery, is to provide reliable supply of electricity if there is no source of generation available for the day, which is the sun. Finally, the load is where users would connect an appliance to, so as to harness the power generated by the microgrid system.

2.2.1 Types Of Microgrids

The microgrids can be classified into four types, where each of them has their own operation modes and functionalities. Not all microgrids have the same robustness in terms of their build and design because different types of microgrids will be designed according to the condition of the site of operation it is based upon.

The four types of the microgrids are the institutional microgrids, remote microgrids, military based microgrids and commercial and industrial microgrids [15]. The institutional microgrids focus is to accumulate local generation with numerous loads so that the owner of said system can easily manage [16]. While the remote microgrid will not connect to the main grid because of geographical or economic issues, since these types of grids are usually installed in areas that are quite a distance away from any transmission and distribution system. The military based microgrid focuses on the physical and cyber security aspect since these grids are relied on to provide power without connecting to the main grid. Finally, the commercial and industrial microgrid are used for providing power in the industrial field for power supply security and reliability [17].

2.3 Previous Works On DC Microgrid In Rural Areas

Many works involving designing and implementing a DC microgrid system in rural/remote areas had been done in the past. Most of these past works focus on sustainability of said system. Such as in [5], the microgrid system's sustainability will only be questioned when there is a proper load growth being predicted. The work done in [5] focus heavily on the Hybrid Optimization Model for Electric Renewable (HOMER) software to simulate a microgrid system that will run on the lowest net present cost. The microgrid in [5] were widely accepted for reducing the costs of solar PV and the battery technology. With the use of DC microgrid, more costs are reduced in terms of the energy consumption and with the absence of inverters and converters[5].

The work in [6] is quite similar to the work in [5], which further supports the effectivity of applying a DC microgrid in rural areas. With the use of the Hybrid Optimization Model for Electric Renewable (HOMER) software, many simulations were done to obtain the best option they can gain with the technical constraints in place, which is a system with the least life-cycle cost and hence the least net present cost[6]. The design of microgrid used in [6] is also quite similar to the design in [5], since the objective is also quite similar, which is to design a DC microgrid for rural electrification with inclination of cost optimization.

The base work presented in [7] is also similar to the work presented in [5] and [6]. The only difference being that the country research [7] is based on has many more options of renewable energy resources. With the use of HOMER software, they designed a hybrid microgrid system consisting of hydro turbine generators, solar PV panels and an AC/DC converter. They had also succeeded in developing a microgrid that is suitable to be used in the Amazonian jungles, though the system developed is not fully in DC[7].

The case study in paper [3] further supports the results shown in [5],[6] and [7]. But instead of developing a DC microgrid, this paper only shows a suitable design for optimal performance of the microgrid by implementing the use of energy efficient devices. Two modes of operation were considered, which is entrepreneur level mode and community level mode. These two modes of operation basically mean the ownership of the microgrid and the maintenance of said grid will either be responsible by a village entrepreneur or the whole village community.

The DC microgrid design in [8] focuses on making the microgrid to be scalable, which means that there is an option for users to increase their load capacity by installing more energy storage banks. The design in [8] also relies on the concept of power sharing between users by using a Power Management Unit (PMU). This is unlike in [3],[5],[6] and [7], which focuses on only providing power for rural areas at an acceptable cost. The work done in [8] also takes into account the system protection needed to be applied to such a system so as to provide reliable electricity.

CHAPTER 3

METHODOLOGY

This section of the report presents the methods used to implement the project. A flowchart is presented to show the workflow of the project. A Gantt chart is also presented to show the schedule of implementation of the project. Methods used to determine the parameters of the microgrid components are also explained in detail.

3.1 Research Methodology

The steps and processes used to complete this project was followed sequentially so that the project can be completed within the allotted time. Provided within this chapter are flowcharts, milestones and Gantt chart. These are used to explain the steps and procedures in conducting and completing this project.

3.1.1 Flowchart

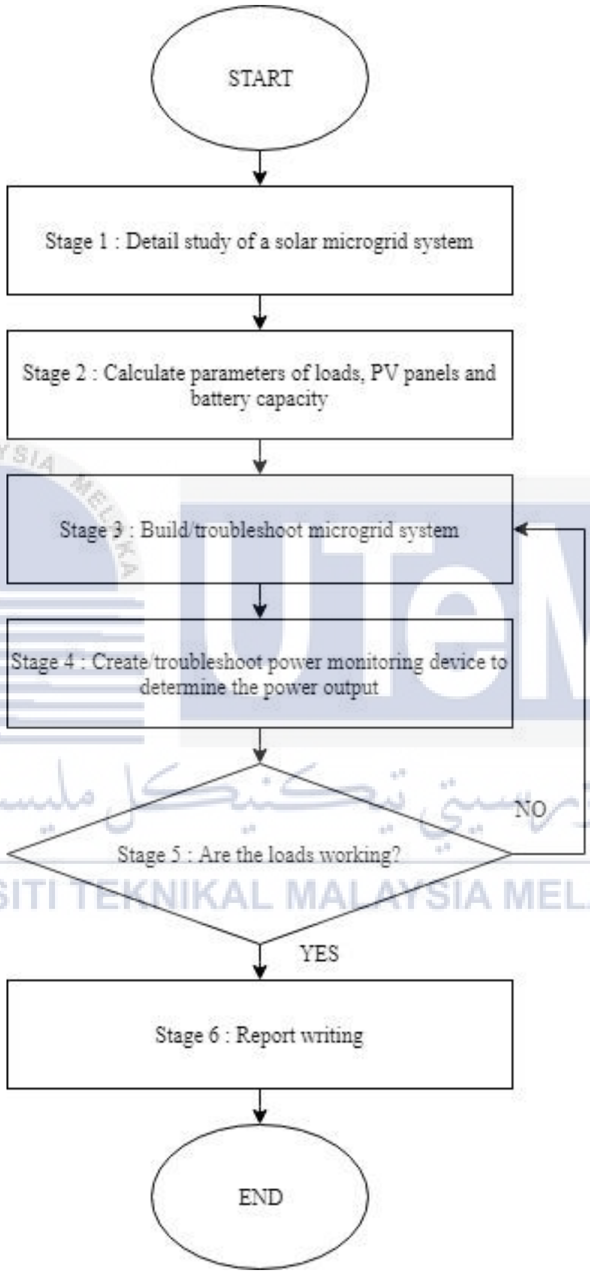

Figure 3.1 : Flowchart for project implementation

3.1.2 Project Milestone

There are a few milestones set for this project. These milestones are to ensure that the project implementation can be run systematically. These milestones are :-

1. Study the concepts of a solar microgrid system running DC loads.
2. Do the calculation design for the system.
3. Build the microgrid system.
4. Create a power monitoring device using an Arduino.
5. Run the system and monitor the power.
6. Report writing.

3.2 Project Schedule

The project schedule of the work done is put in the Gantt chart below to give the general gist of how the work for the project progresses. The Gantt chart is projected in table 3.1.

Milestone	Year	2017			2018				
	Task	10	11	12	1	2	3	4	5
1	Research on solar microgrid								
2	Grid parameters calculation								
3	Building the grid								
4	Making a power monitoring device								
5	Running the loads on the grid								
6	Report writing								

Table 3.1 : Gantt chart for project implementation

3.3 Calculation Method For Component Parameters

Determining the component parameters is one of the main parts of designing the DC microgrid. To determine the parameters, there are a few steps needed to be done.

The first step is to calculate the total size of the load. This is done by adding all the rated power consumption of the appliances being taken into consideration [18].

$$Total\ load(W) = load\ A + load\ B + load\ C + \cdots + other\ loads \tag{3.1}$$

Once the load sizing is complete, determine the power consumption demand of the total load. The total load must be times with the total hours per day usage that must be supplied to the appliances. Then times it by 1.3 to take into consideration of energy losses in the system [18].

$$Energy\ demand\ (Wh) = total\ load \times hours\ of\ usage \times 1.3 \tag{3.2}$$

With the power demand calculation complete, the photovoltaic panel sizing can be calculated next. To calculate the panel sizing, divide the power demand in (3.2) by the daily irradiance factor. Irradiance factor is different for every geographical location in the world, since this factor depend on the climate. Then, after calculating the irradiance factor, divide it by the peak Watt (Wp) output of the panels to get the amount panels needed for the microgrid.

$$Peak - Watt\ of\ panel\ capacity\ needed(W) = \frac{Energy\ demand}{Irradiance\ factor} \quad (3.3)$$

$$No.of\ panels = \frac{Peak{-}Watt\ panel\ capacity\ needed}{Peak{-}Watt\ output\ of\ panel} \quad (3.4)$$

Then the calculation of the battery sizing is done to provide reserve power for night time use or if it is cloudy during the day. To calculate the battery sizing for the microgrid, divide the total power demand in (3.2) with the battery loss factor, then divide it by depth of discharge of the battery and then divide it with the nominal system voltage. Finally, multiply this answer by the amount of reserve days the system would operate when there is no power output from the photovoltaic panels [18], [19].

$$Battery\ sizing\ (Ah) = \frac{Power\ demand}{battery\ loss\ factor \times discharge\ depth \times nominal\ voltage} \times reserve\ days \quad (3.5)$$

The final step is to determine the charge controller rating to be used in the microgrid system. Since the system being built should also be economical, a simple PWM series charge controller will be considered because a MPPT charge controller is quite expensive. To get the charge controller rating, simply multiply the total short circuit current of the photovoltaic panels by 1.3 since this is the standard practice [17].

$$Charge\ controller\ rating\ (A) = I_{sc}\ of\ PV\ panels \times 1.3 \quad (3.6)$$

3.4 Power Monitoring Using an Arduino

Arduino is a microcontroller that is based on the ATMega328P controller chip. In this project, the Arduino controller board is used as the main component in making the power monitoring device.

The Arduino acts as the controller, which means it is used to run and execute programmable codes to achieve the purpose of power monitoring. Then there are 3 other components used to make the power monitoring device.

3.4.1 Components of Power Monitoring Device

There are four components used to make the power monitoring device. The components are :-

- Arduino UNO R3 controller board
- ACS712 hall effect current sensor module
- SD card module
- 16X2 LCD display

The connections between the components are shown in figure 3.2 with descriptions of each functionality of these components.

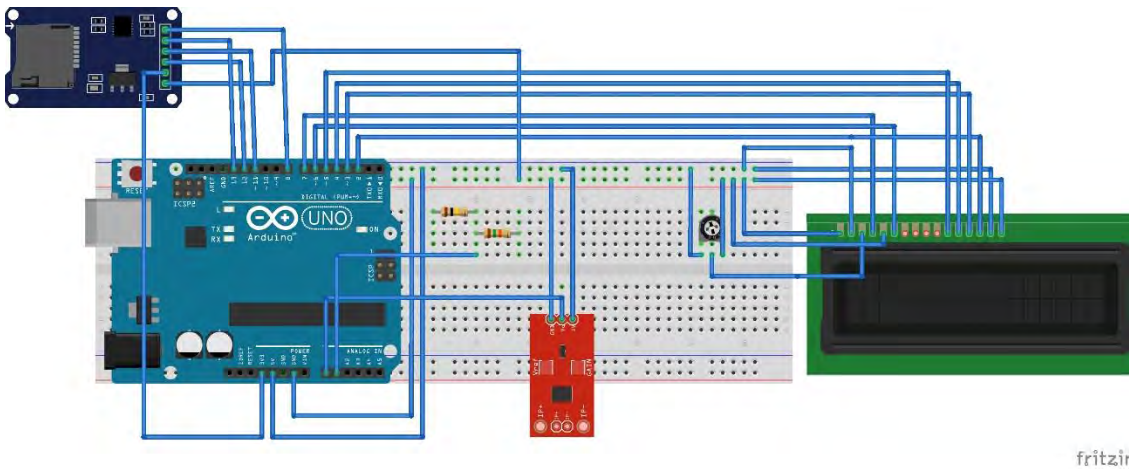

Figure 3.2 : Circuit connection for Arduino power meter

3.4.1.1 The Arduino Board

The Arduino board is used to run and execute the codes needed to measure current and voltage within the microgrid system. From the current and voltage readings, the power reading can be obtained. All of this is being executed within the program code.

Figure 3.3 : Arduino UNO controller board

3.4.1.2 ACS712 Hall-Effect Current Sensor

This device is used to monitor the current in a system, which basically makes it a type of ammeter. There are a few versions of this sensor, where each version has a different range and limit of current that it can measure. In this project, the sensor being used is able to measure currents up to 30 A.

Figure 3.4 : ACS 712 sensor

3.4.1.3 LCD (Liquid Crystal Display) – 16X2

These types of crystal display are very easy to use and implement into any project. It can show live readings or measurements of the values that the user needs. A 16X2 display means that it has two rows and 16 columns of display space.

Figure 3.5 : A 16X2 liquid crystal display

3.4.1.4 SD Card Module for Arduino

The SD card module is a module used to enable the Arduino board to interact with an SD card, or also known as a memory card. The use of this module is to log certain types of data, such as the voltage and current within the microgrid system, into a memory card so that the user can review these data at a later time to determine the system's performance.

Figure 3.6 : SD card module

3.5 Hardware Setup

The setup for the hardware focuses on the operation of the DC loads. The power monitoring device is hooked up within the microgrid to monitor the power output and to log the required data for reference and determine its performance.

Figure 3.7 : Setting up the microgrid

3.5.1 The Arduino Power Logger

The connection for the power logger to the microgrid is the same as any commercial multimeter. To measure the current, the sensor is connected in series. While to measure the voltage, the sensor is shunted.

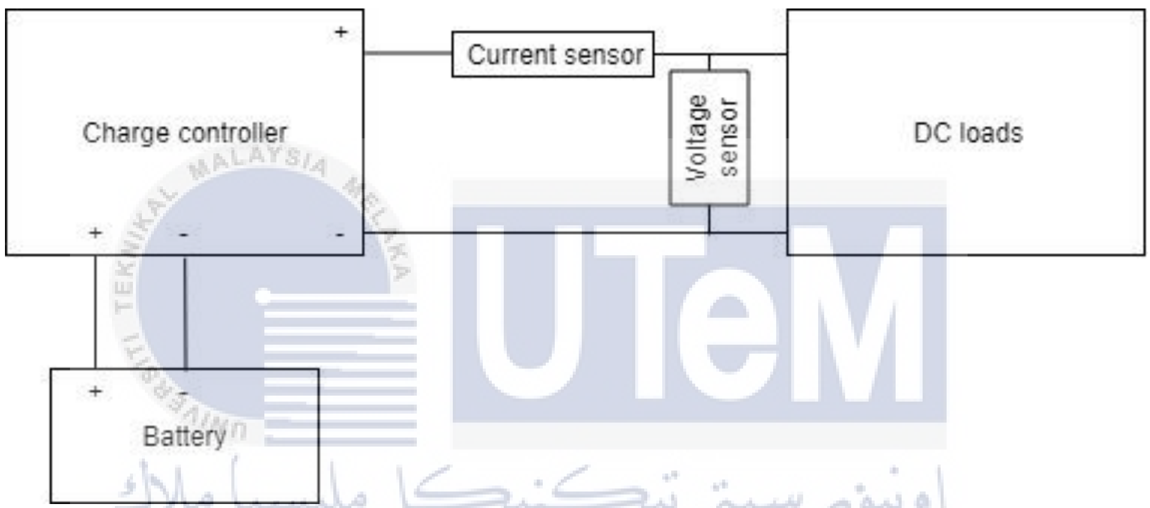

Figure 3.8 : Block Diagram for the power logger connection

The Arduino power monitor is put inside a casing to avoid any damage and any outside noises/disturbances that can deviate the readings.

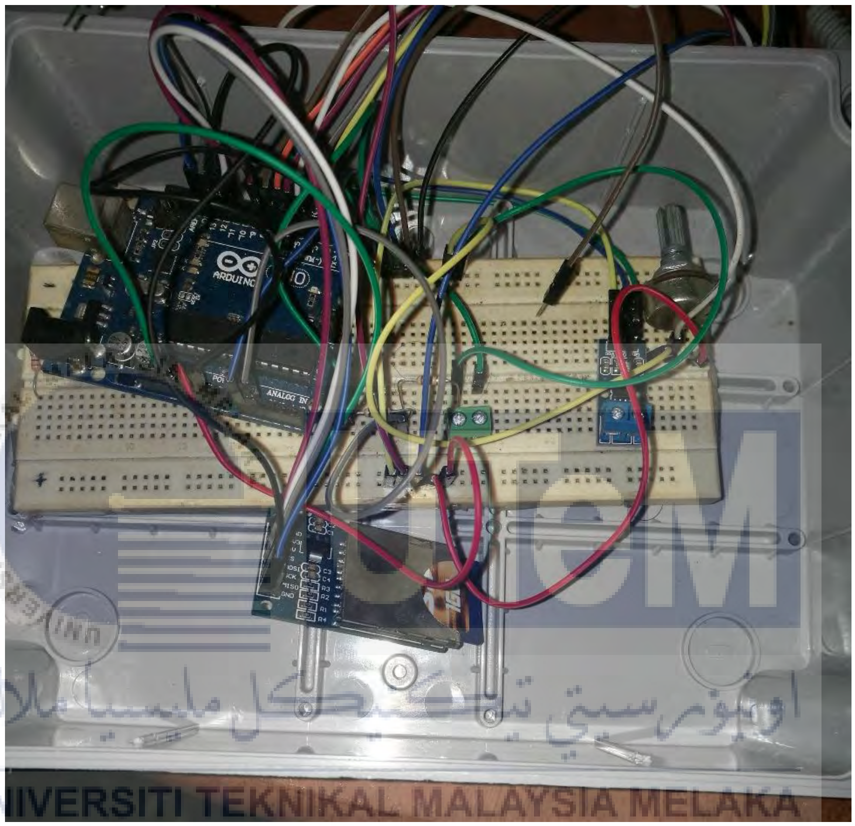

Figure 3.9 : Arduino power monitor (Hardware setup)

By installing the power monitoring device to the microgrid, the load power can be recorded and the microgrid performance can be analyzed.

3.5.2 Power Monitor Device Readings

After running the loads on the microgrid, the readings for current, voltage and power can be obtained from the SD card inside the monitoring system. The readings are recorded every 15 seconds. This means there are 4 readings for every minute and 240 readings for every hour. The source code for the power monitoring device is as shown in figure below.

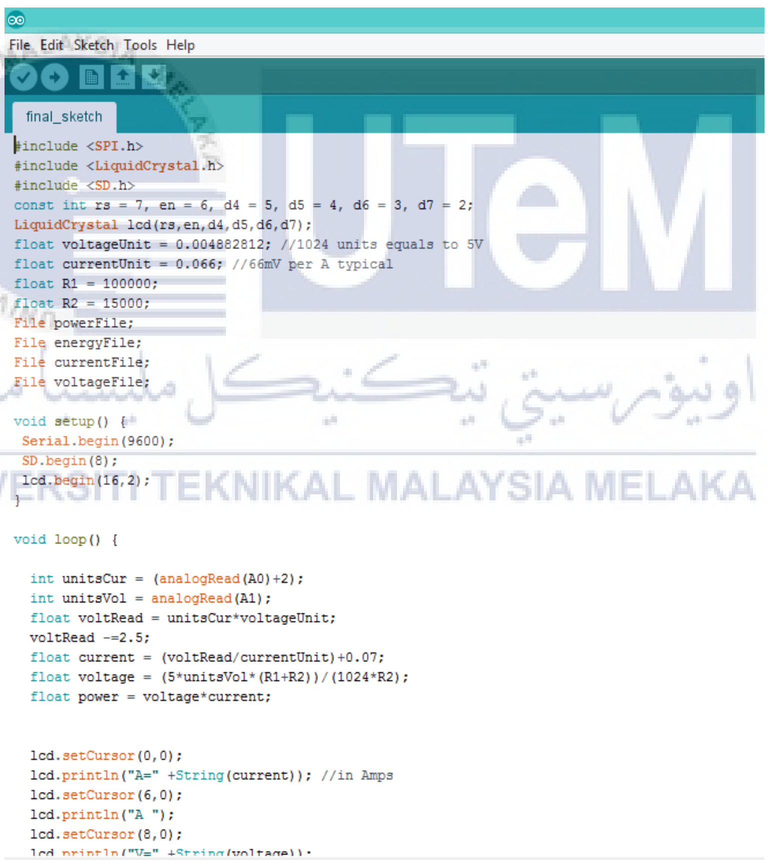

Figure 3.10 : Source programming code for the power monitor/logger

CHAPTER 4

RESULTS AND DISCUSSION

In this chapter, the parameters of the microgrid was determined by using the calculation method shown in the previous chapter. The results obtained from the hardware setup is then compared with the results from the calculation.

4.1 Microgrid Block Diagram

The microgrid is shown as a block diagram in figure 4.1, because it is a simple method to understand how to connect the microgrid and to implement each component of the microgrid.

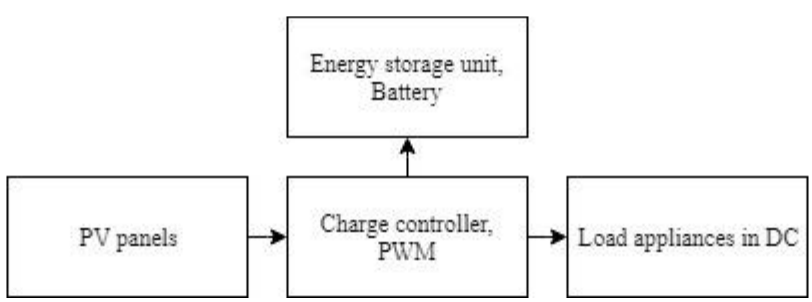

Figure 4.1 : Simple block diagram of DC microgrid

4.2 Calculation Results

Using the calculation method presented in the previous chapter, but with slight modifications so as to know the standby time of the microgrid and the maximum amount of power the microgrid can supply within the calculated boundaries.

4.2.1 Microgrid Parameters

Since there are limitations in the equipment provided, the microgrid must be able to provide power for critical loads (important loads). The equipment provided are as follows:

- Photovoltaic panel rated at 180 W.
- Battery with capacity of 89 Ah.
- Solar charge controller rated at 20 A.

With the provided equipment parameters and from equation (3.4), the Peak-Watt of the panel:

$$Peak - watt\ of\ panel = 1 \times 180W = 180W \tag{4.1}$$

From there, the energy demand is calculated as:

$$Energy\ demand = 180W \times 4h = 720Wh \tag{4.2}$$

After the energy demand is calculated, the total load power can then be calculated by setting the hours of usage per day to 6 hours:

$$Total\ load = \frac{720Wh}{6\times1.3} = 92.3W \tag{4.3}$$

With an energy demand of 720Wh and with the provided battery capacity of 89Ah, the amount of reserve days would be:

$$Reserve\ days = \frac{89Ah\times0.8\times0.6\times12V}{720Wh} = 0.7 \tag{4.4}$$

Since the usage per day is set to 6 hours, the value above can be interpreted as:

$$Reserve\ day(in\ hours) = 6h \times 0.7 = 4.2h \tag{4.5}$$

This means that for the next day, this microgrid can only provide power for roughly around 4 hours if a total load of around 90W is connected. This is only if the battery is not charged, in example, the sun is not visible during the day so the battery does not charge.

The total amount of loads connected can actually change the number of reserve days for the microgrid system. Since the total amount of loads available for the hardware setup has a total of roughly 50 W, thus the reserve days would be:

$$Energy\ demand = 50W \times 6 \times 1.3 = 390Wh \quad (4.6)$$

$$Reserve\ days = \frac{89Ah \times 0.8 \times 0.6 \times 12}{390Wh} = 1.3 \quad (4.7)$$

$$Reserve\ day(in\ hours) = 1.3 \times 6 = 7.8h \quad (4.8)$$

The findings of the calculation above is presented in table form in Table 4.1.

Total Load (W)	50
Reserve days (6 hours/day usage)	1.3

Table 4.1 : Calculation results

In theory based on the table above, this shows that with a total connected load of 50 W, the loads can be operated for 6 hours on the first day. Then for the next day, the loads can be run for another 1.8 hours before the battery needs to be recharged.

4.3 Hardware Results

There are two devices at work in this part. The first device is a general type multimeter that is able to read voltages up to 500 Vdc and currents up to 10 A. Since this type of multimeter does not have a power measuring and a measurement recording capability, the current and voltage readings were recorded in every 10 minutes. From these readings, the value of power can be obtained.

With the Arduino power monitoring device, the data from the hardware setup can be easily recorded and analyzed. The SD card contains three text files where each of them records voltage, current and power respectively.

The battery for the microgrid system was charged for 1 day, between 7 A.M. until 7 P.M. The loads were turned on after the batteries were charged and the measurements were then taken.

4.3.1 Microgrid Reading With A Multimeter

The readings from the multimeter are taken once every 10 minutes. This means for the first reserve day, there will be 36 readings of voltage and current. While for the second day, there will be approximately about readings 14 before the battery gets completely depleted.

4.3.1.1 First Day Reserve

For the first day of use, the calculated design suggests that the microgrid can provide power to a total rated load of 50 W for 6 hours. The current and voltage readings are as follows:

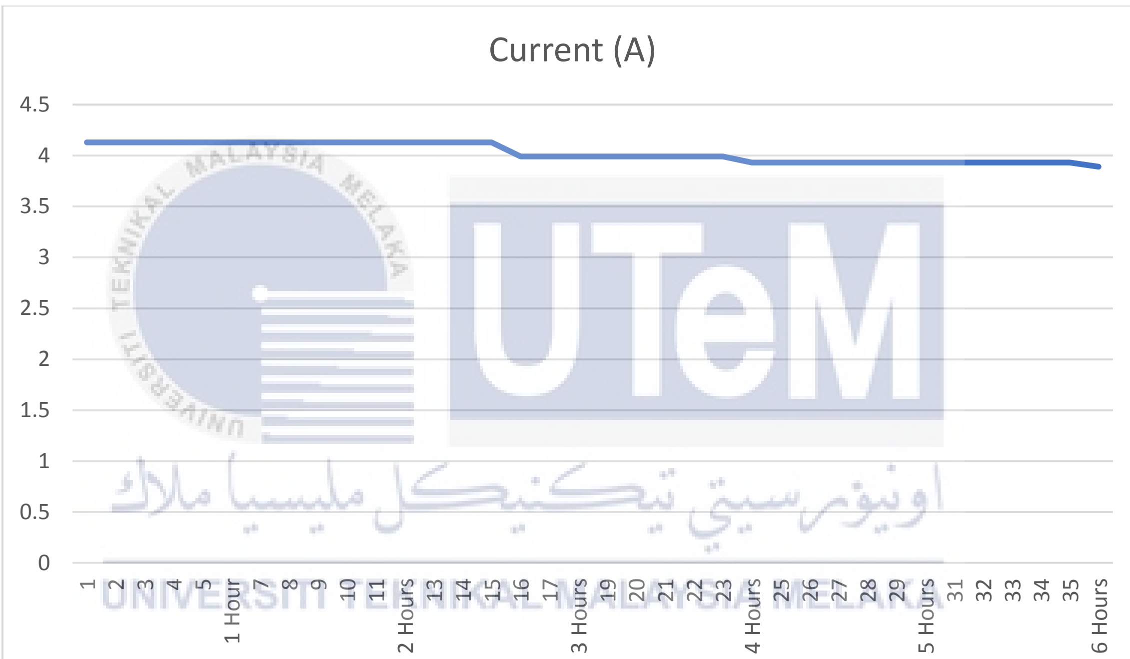

Figure 4.2 : The current profile of the microgrid system

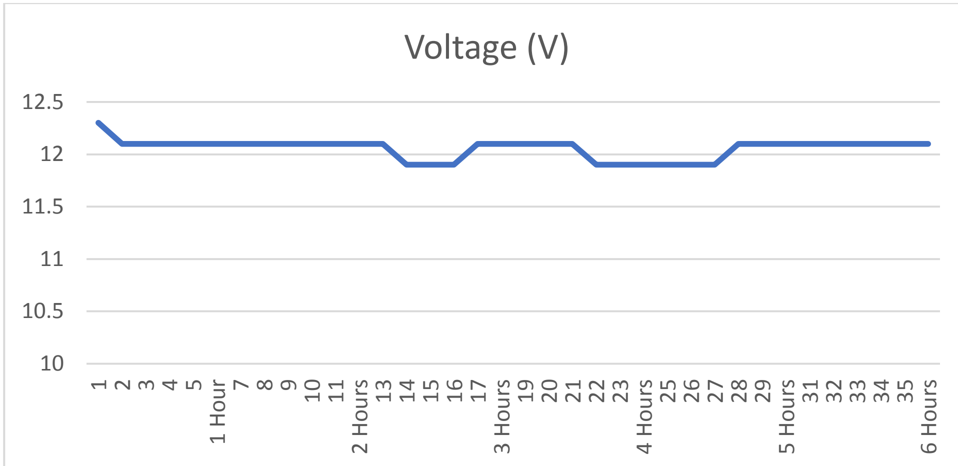

Figure 4.3 : The voltage profile of the microgrid system

After retrieving the voltage and current readings, the power can be easily calculated using Microsoft Excel. Thus, the power profile is shown in figure 4.4 below.

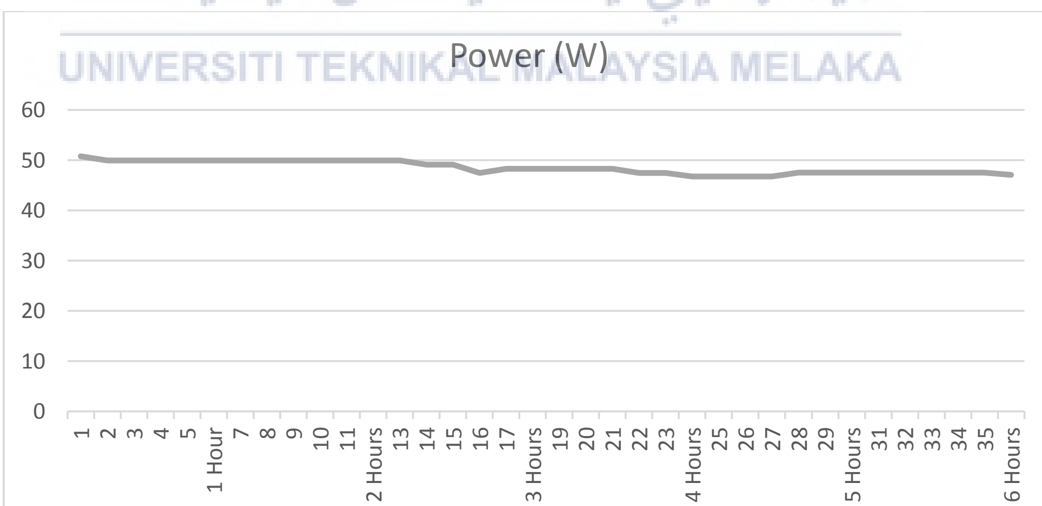

Figure 4.4 : Power profile of the microgrid

The power values from the measurement seems to indicate that the system can still sustain the loads.

4.3.1.2 Second Day Reserve

For the second day, the measurements were only being recorded for 2 hours and 30 minutes. This is based on the calculated design presented in 4.2 above. The current readings for the second day reserve is as shown below:

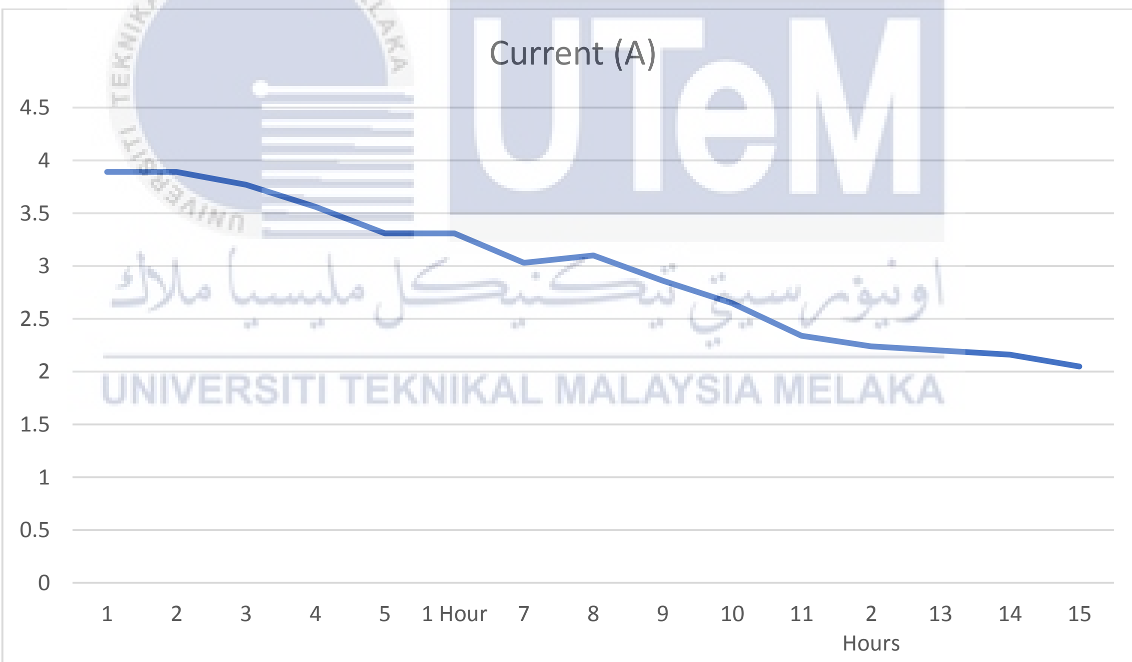

Figure 4.5 : The current profile for the second day

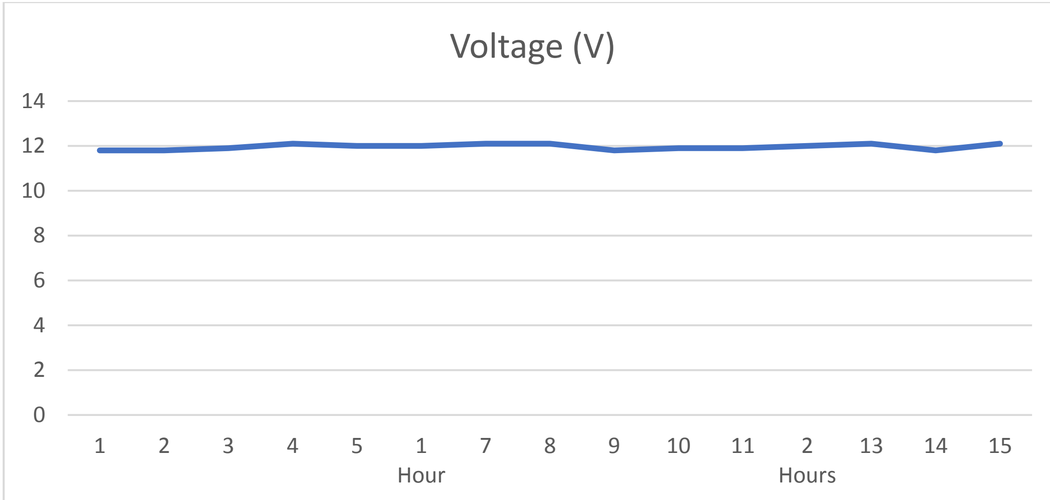

Figure 4.6 : The voltage profile for the second day

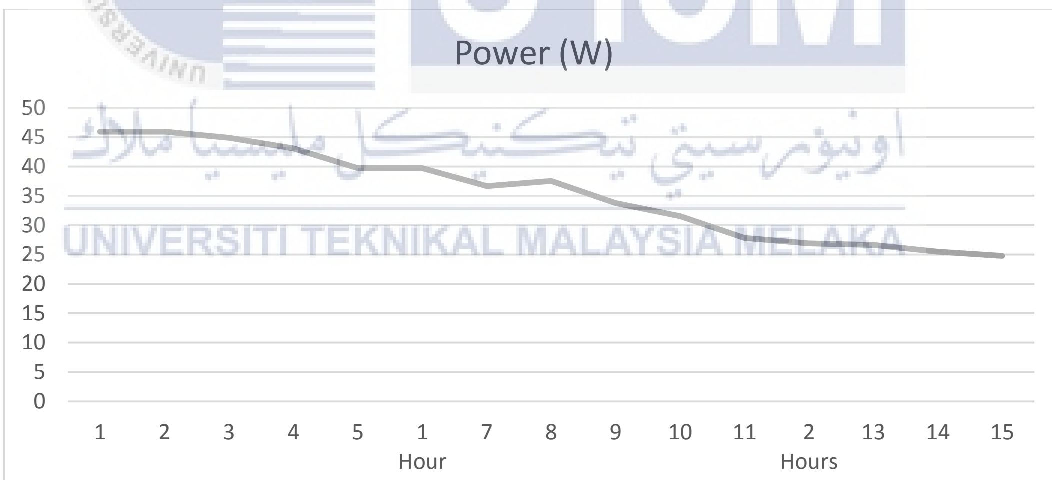

Figure 4.7 : Power profile for the second day

The current measurement can be seen to clearly decline at 1 hour and it further declines until the battery depletes. The decline in current output also affects the power output of the microgrid.

Figure 4.8 : Multimeter reading at 2 hours and 30 minutes

Figure 4.9 : The lights started to dim and the fan spins slower

4.3.2 Microgrid Reading With Arduino Power Monitor

After running the loads in the microgrid system for 6 hours, the current, voltage and power readings were taken. They are as follows:

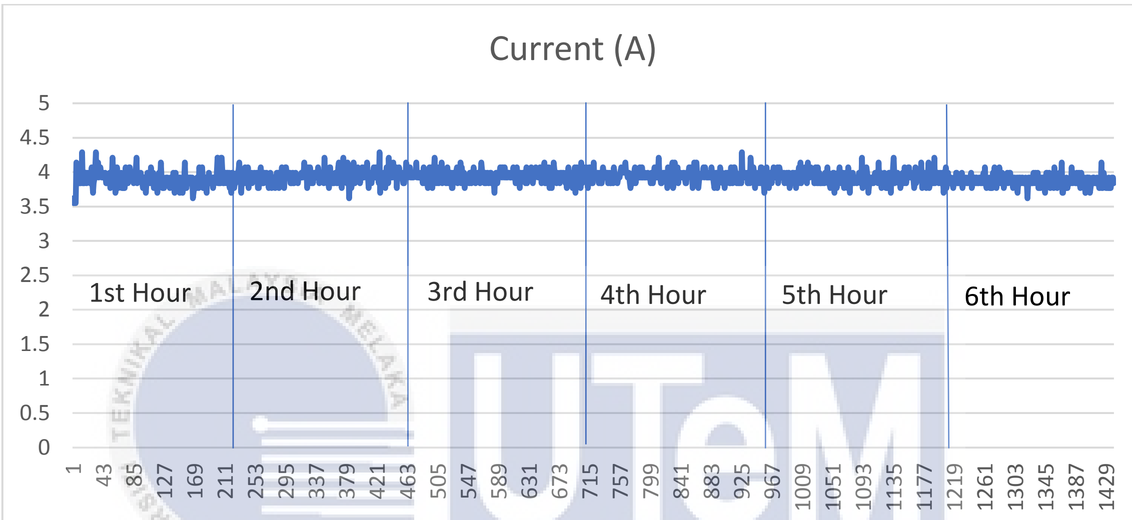

Figure 4.10 : The current profile of the microgrid system

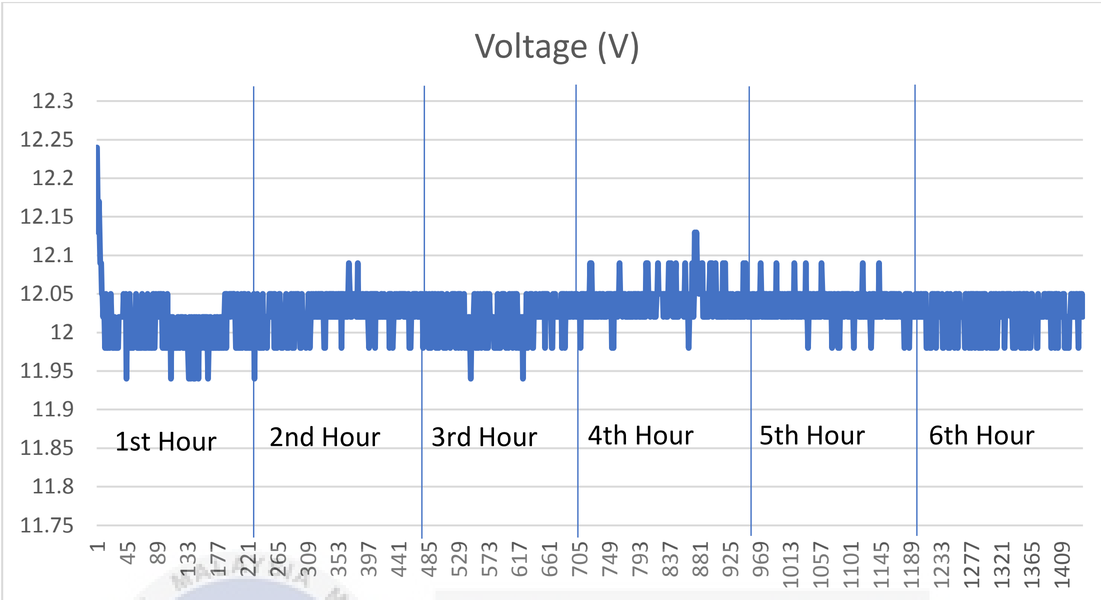

Figure 4.11 : Voltage profile of the microgrid system

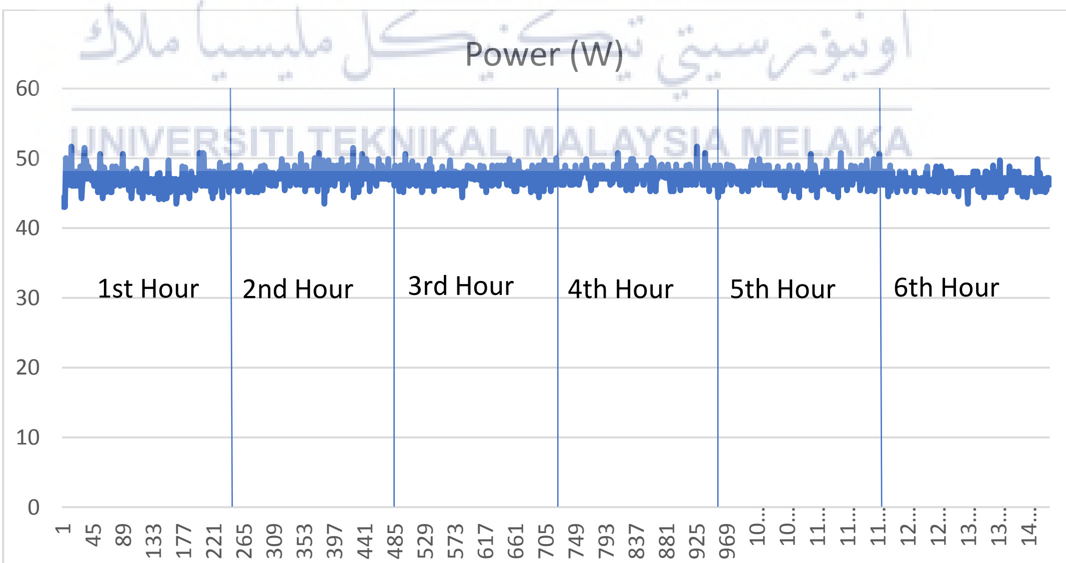

Figure 4.12 : Power profile of the microgrid system

The charts shown above indicates that the system runs the loads without any problems, continuously for 6 hours. The amount of power being used by the loads are approximate to 50 W.

4.3.2.1 Measurements for the second reserve day (with Arduino power monitor)

Based on the calculated values in section 4.2 of this chapter, the loads can be operated close to 2 hours for the next day, without charging the battery. The results of load operation are presented below.

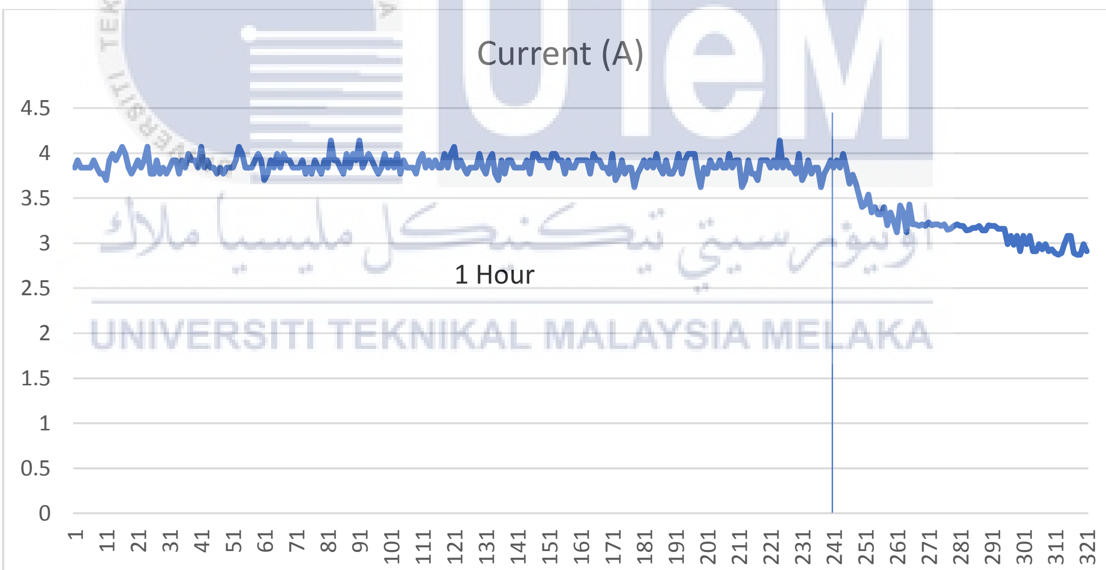

Figure 4.13 : Current profile for second day

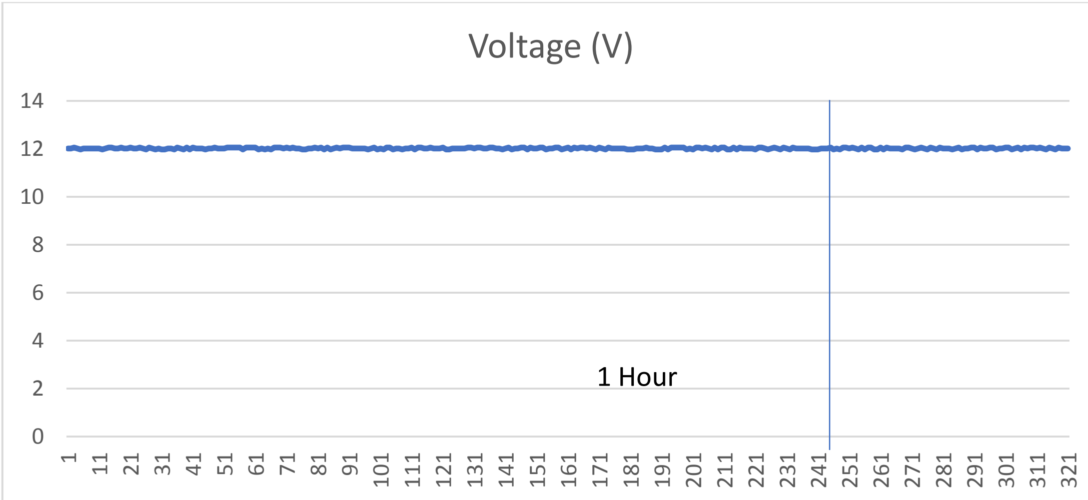

Figure 4.14 : Voltage profile for second day

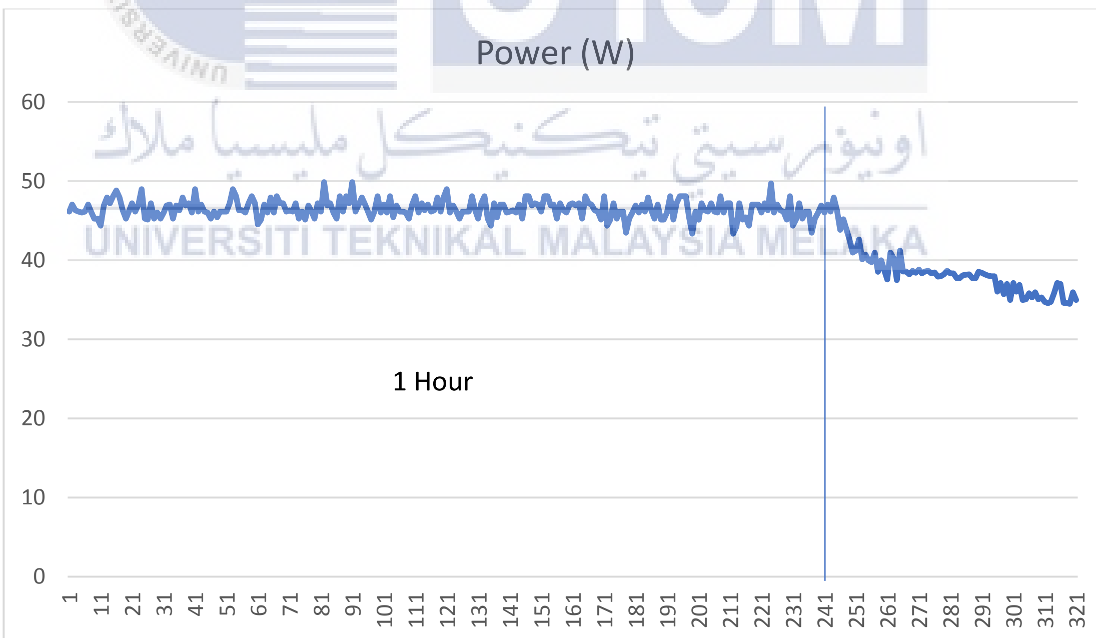

Figure 4.15 : Power profile for second day

The figures show a decline in current output, where it also affects the power output. The power output further declines as the battery reaches a discharge depth of 80% of its total capacity.

4.3.2.2 Taking Recorded Measurements from The Arduino

Since the Arduino source code had been incorporated with an SD card module, it is easier to get and analyze the readings. The steps are shown below.

Figure 4.16 : Step 1 – plug the SD card into a computer

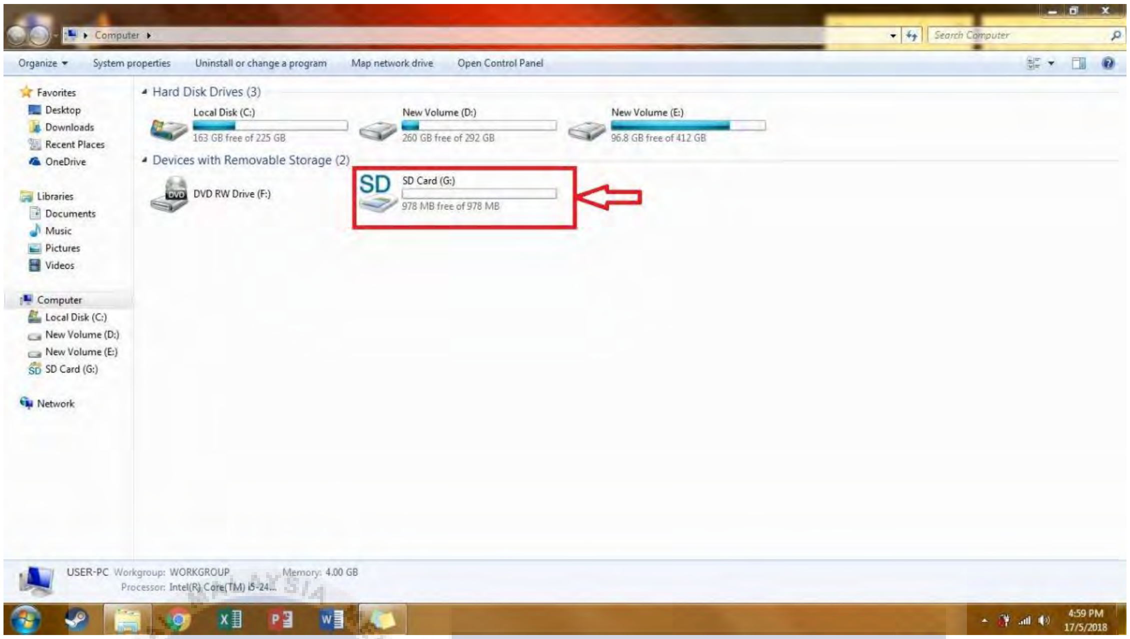

Figure 4.17 : Step 2 – click open the SD card

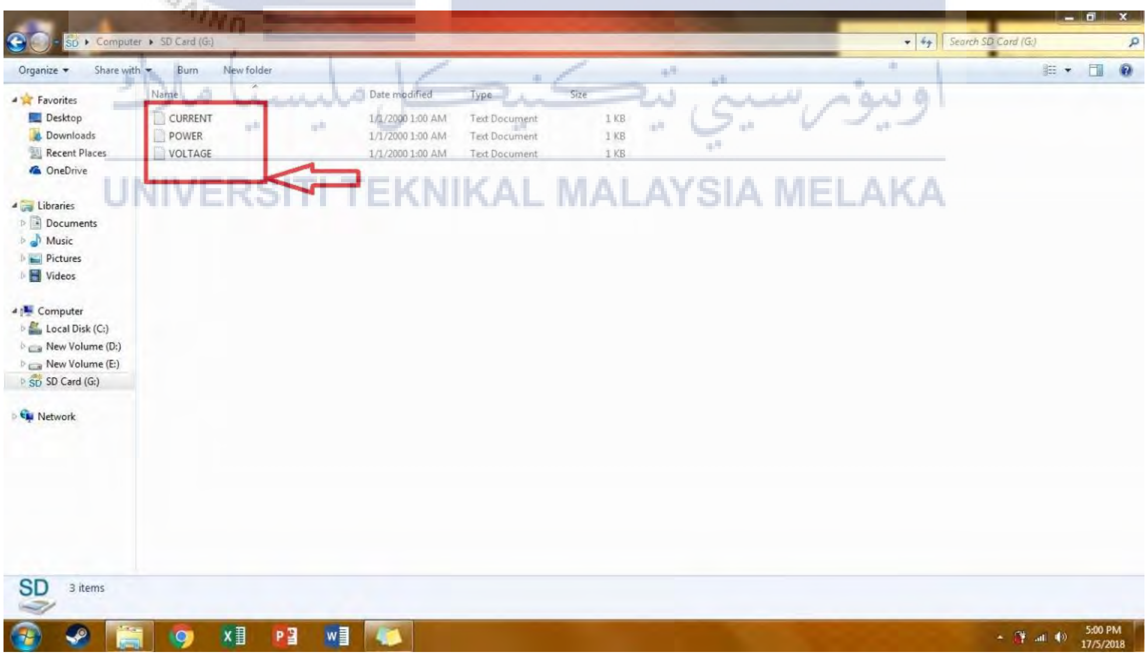

Figure 4.18 : Step 3 – take the readings from each file

4.4 Discussion of Results

From the results obtained in the hardware setup and from the calculation design, the microgrid performs as it is intended. Through the calculation design, the microgrid can provide power for 6 hours of usage on the first day and 1.8 hours (1 hour and 48 minutes) on the second day before the battery needs to be recharged.

There were 2 types of measurements done, one using the multimeter and the other uses the Arduino based power monitor. In both cases, the loads were successfully operated for 6 hours on the first day. But on the second day, the loads will run for approximately 1 hour and 20 minutes before the current output and power output starts to decline.

In order to protect the energy storage element of the microgrid, which is the battery, from any damages, the loads were turned off before the battery can be completely discharged. This protects the battery from any type of internal damage and does not decrease the battery's life span.

CHAPTER 5

CONCLUSION

5.1 Conclusion

This report proposes a viable option of providing electrical power for rural areas by use of a solar powered DC microgrid. With the use of a DC microgrid, there will be no need to incorporate an inverter into the system which can create unnecessary power loss. The implementation of a properly designed DC microgrid can also be economically advantageous since compared to the cost of providing power to rural areas using the main grid would need so much resource. The results obtained shows that the microgrid can sustain critical loads such as lamps and fans. These critical loads are very common in households even in rural areas. Before the hardware was setup, the parameters of the microgrid were thoroughly calculated to avoid any mistakes in the system design. The hardware has been successfully made to run the loads recognized for the system. The DC microgrid system was operated successfully and the results coincide with the calculation design.

5.2 Recommendations

With the use of one 180 W solar panel and an 89 Ah battery, the DC microgrid system can only run critical loads. It is recommended to increase the solar panel power output and increase the battery capacity to run other loads such as televisions, coolers and washing machines.

The use of a power monitoring device is very useful in this project because the user can determine the systems performance and monitor any anomalies within the system. With a good quality power monitoring system, any errors that may occur can be quickly handled.

The final recommendation is to make the DC microgrid scalable. This basically means that, instead of providing power for a single house, the microgrid is able to provide power for several houses situated in small area. This also involves the concept of load and storage sharing between houses and the importance of a Power Management Unit (PMU).

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APPENDIX A

Milestone	Year	2017			2018				
	Task	10	11	12	1	2	3	4	5
1	Research on solar microgrid								
2	Grid parameters calculation								
3	Building the grid								
4	Making a power monitoring device								
5	Running the loads on the grid								
6	Report writing								

APPENDIX B