**FACULTY OF ELECTRICAL ENGINEERING**

**FINAL YEAR PROJECT REPORT**

# MODELLING AND ANALYSIS MICROTURBINE WITH BATTERY STORAGE MICROGRID SYSTEM BASED ON GREEN ENERGY

**NurfaezatulAqmaBintiDahlan**

**Bachelor of Electrical Engineering**

**(Industrial Power) with Honours**

**30th MAY 2016**

SUPERVISOR DECLARATION

"I hereby declare that I have read through this report entitle "Modelling and Analysis Microturbine with Battery Storage Microgrid System Based on Green Energy" and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power)."



Signature : …………………………………………….

Supervisor's Name : Mr. Alias Bin Khamis

Date :

**MODELLING AND ANALYSIS MICROTURBINE WITH BATTERY STORAGE MICROGRID SYSTEM BASED ON GREEN ENERGY**

**NURFAEZATUL AQMA BINTI DAHLAN**

**A report submitted in partial fulfillment of the requirements for the degree of Bachelor in Electrical Engineering (Industrial Power) with Honours**



**Faculty of Electrical Engineering**

**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**2016**

# DECLARATION

I declare that this report entitle "Modelling and Analysis Microturbine with Battery Storage Microgrid System Based on Green Energy" is the result of my own research except as citied in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.



Signature : ..........................................................

Name : NurfaezatulAqmaBintiDahlan

Date :

**To my beloved mother and father**

*For their endless love, support and encouragement*

## ACKNOWLEDGEMENT

All praises to Allah with the name of Him, the Most Merciful, the Most Gracious I have started this research and able to accomplished within the period of time. Alhamdulillah for all the strengths I have gained from Him, His blessing that keeps me going in completing my research with good health and wellbeing which is necessary. First and foremost, I have to thank my parents for their loving obsession to me. They have given me durability in chasing my dreams. My special appreciation goes to my supervisor, Mr. Alias bin Khamis, for his supervision for the whole one year in any development I have concluded. I am extremely thankful and indebted to him for sharing expertise, sincere and valuable guidance and encouragement extended to me. Finally, I place on record, my sense of gratitude to one and all, who directly or indirectly have lent their hand in this venture.

# ABSTRACT

Nowadays, distributed generation technology had gained more popularity by many countries. Recently, there are many problem with power system. One of the problem is high electricity price. The price in power generation rely largely on the type and market price of the fuel used, government subsidies, government and industry regulation, and even local climate patterns. Other than that, usage of fossil fuel needed to be reduced.By using the fossil fuel, it will cause the smog and acid rain. Afterwards that, it will cause the greenhouse emission and earth's climate will shift.In order to supply a better power system, this research study introduce a model of MicroTurbine (MT) and a battery storage MicroGrid (MG) system based on green energy. The MG is the small scale which widely used in power generation system. MG can operate with renewable and non-renewable energy. Through this project, MG will be modelling by using MT as Distribution Generation (DG) and battery storage system as Distribution Storage (DS).The MG system will simulated by using MATLAB Simulink (R2014a). The MG system will be analysis in grid connected or grid-disconnected mode. The simulation shows the result of different mode of MG system and the factors and causes affecting the MG system will discussed. From the simulation, the voltage and current in grid-connected is higher than during grid-disconnected mode. Since this system did not have suitable control such as PQ (Active and Reactive power) control and VSI (Voltage Source Inverter) control, the system did not achieved the required voltage. For furtherstudies, this system required more attention in designing especially its control.

## ABSTRAK

Pada masa kini, teknologi generasi pengedaran telah mendapat populariti lebih oleh banyak negara. Baru-baru ini, terdapat banyak masalah dengan sistem kuasa. Salah satu masalahnya ialah harga elektrik yang tinggi. Harga dalam penjanaan tenaga bergantung sebahagian besarnya kepada jenis dan pasaran harga bahan api yang digunakan, subsidi kerajaan, peraturan kerajaan dan industri, dan juga corak iklim tempatan. Selain daripada itu, penggunaan bahan api fosil yang diperlukan dikurangkan. Dengan menggunakan bahan api fosil, ia akan menyebabkan kabut dan hujan asid. Selepas itu, ia akan menyebabkan pelepasan rumah hijau dan iklim bumi akan berubah. Untuk membekalkan sistem kuasa yang lebih baik, kajian penyelidikan ini memperkenalkan model mikroturbin berkeupayaan (MT) dan sistem penyimpanan bateri MicroGrid (MG) berdasarkan tenaga hijau. MG adalah skala kecil yang digunakan secara meluas dalam sistem penjanaan kuasa. MG boleh beroperasi dengan tenaga boleh diperbaharui dan tidak boleh diperbaharui. Melalui projek ini, MG akan model dengan menggunakan MT dan sistem penyimpanan bateri. Sistem MG akan disimulasikan dengan menggunakan MATLAB Simulink (R2014a). Sistem MG akan dianalisis dalam mod grid disambungkan atau mod grid diputuskan. Keputusan simulasi menunjukkan keputusan mod yang berbeza sistem MG dan faktor-faktor dan sebab-sebab yang mempengaruhi sistem MG akan dibincangkan. Daripada simulasi, voltan dan arus lebih tinggi semasa grid disambungkan daripada apabila grid tidak disambungkan. Oleh kerana sistem ini tidak mempunyai kawalan yang sesuai seperti PQ kawalan dan kawalan VSI, sistem ini tidak mencapai voltan yang diperlukan. Untuk penambahbaikan seterusnya, sistem ini memerlukan perhatian yang lebih dalam mereka bentuk terutamanya elemen kawalan.

# TABLE OF CONTENTS

## LIST OF TABLES

# LIST OF FIGURES

## LIST OF SYMBOL AND ABBREVATIONS

| | | |
|---|---|---|
| FYP | - | Final Year Project |
| UTeM | - | UniversitiTeknikal Malaysia Melaka |
| DER | - | Distribution Energy Storage |
| DG | - | Distribution Generation |
| DS | - | Distribution Storage |
| MT | - | Microturbine |
| MG | - | Microgrid |
| PV | - | Photovoltaic |
| NiMH | - | Nickel Metal Hydride |
| NiCD | - | Nickel Cadmium |
| PMSG | - | Permanent Magnet Synchronous Generator |
| PMSM | - | Permanent Magnet Synchronous Machine |
| VSI | - | Voltage Source Inverter |

# CHAPTER 1

## 1.1 Introduction

Chapter 1 will explained on the background research of this project research. This chapter will also including the problem statement, the objectives, scope, and project significance.

## 1.2 Project Background

The Distributed Generation (DG) and Distributed Storage (DS) are included into Distributed Energy Resources (DER). DG and DS act as sources of energy located near local loads and can give many benefits if this system function properly in electrical distribution system. Microgrid (MG) are system that that contain at least one type of DER and associated load and can form intentional islands in the electrical system. DG technologies such as MicroTurbines (MT), PhotoVoltaics (PV) and fuel cells are gaining broad range attention.It is because of the DG technologies, has many good sake such as well-founded and better condition, power supply, environment protection and can reduce energy usage. But DG technologies also have some bad consequences as it may solve.The possibility of parts of the network comprising sufficient generating resources to operate generating resources to operate in isolation from the main grid, in a considered and restrain way[1]. The MGis the small scale which widely used in power generation system. A fundamental capacity of MG is to rise the less dependent of energy supplies by not connected from the grid in the case network faults.

In future, MT based on DG will be great role in this distribution network. The MT generation will gives excellently impact in terms of system management and planning. There are two different type of MT design which are single shaft design and split shaft design. The DS technologies also used in MG applications where generation and loads of MG cannot be matched. It gives link in meeting power and energy requirement of the MG. There are many forms of energy storages such as batteries, supercapacitors and flywheel.

## 1.3 Project Motivation

In this current years, the DG is very suitable for electrical power system due to the friendly to environment and its reliability. The usage and demand energy also increase day by day. The MT can gives more power that reliable power as have the source of fuel. The emission from the combustion fuel can be reduced by implementation of MG by using MT. This MGsystem can lesser the emission, lesser the pollution and increase power quality since MT using natural gas. The efficiency of electrical power system also increase.

The MG comprise low voltage distribution system with a group interconnected load and DER which can operate in both grid connected and islanded mode.The MG are small-scale version of centralized electricity system where mainly used Capacity Hydro Units, Ocean Energy and Biogas Plants, wind , diesel generation, PV ,energy storage that used as resources in MG. The MG are expected to gives environmental and economic advantage for customers, utilities and society [2].

In usual MG, the micro-sources may be rotating generator or DER that interfaced by power electronics inverter. The installed DERs may be biomass, fuel cells, geothermal and others. The MG structure consists of DG, DS which is energy reserves from the battery and loads. In grid-connected mode, the MG is connected to the main grid. The power management of grid-connected is stable because it sharing a power from the main grid. The frequency and voltage of MG must be synchronizing with the main grid. When the MG in islanded mode, its excess power is supplied to the main grid and in the event that the demand surpasses the power being generated at a certain time, the extra power is provided by main grid. The DER which connect to the DC/AC inverter must controlled in load-following mode. The operational in islanded mode must fulfilled good power balance between generation and consumption and a proper control of main parameter of MG such voltage and frequency.

## 1.4 Problem Statement

There are several problems that can be stated in the project research. The most obvious one is usage of fossil fuel need to be reduced. Fossil fuels such as coal, oil and natural gas are currently the world main energy source.When the fossil fuels are burned,nitrogen oxides dispersed into the atmosphere. The nitrogen oxide affect the formation smog and acid rain. The burning from fossil fuels also cause greenhouse gas emissions. These gasses can insulate the earth and potentially changes the earth's climate. To reduce these emissions, the electricity generation need to decrease the usage of fossil fuels [3].

Besides that, a common problem in industries when using traditional grid is the grid is only one way of flow electricity and communication. There are another way other than using traditional grid is by using MG [1]. MG can provide the reliability and secure the networks and loads, provide efficiency and friendly to environment.



## 1.5 Objectives

This study stated the following objectives to be achieve:

- To modelling and simulatedmodel of MG system by using MT and battery energy by using MATLAB Simulink Software

- To analysis the model of MT and battery storage system MG in grid-connected and grid-disconnectby using MATLAB Simulink Software

## 1.6 Scope of Work

This project will design the MT with battery storage MG system by using MATLAB Simulink (R2014a). This design will be referred to previous research. The MT act as distributed generation and battery storage act as distributed storage. Other than MT and battery storage, MG system also need its control element. The control element that used for this design are inverter and LC filter. From this design, the MG system will simulated and analyses. The system will analyses in grid-connected and grid-disconnect mode. The function of breaker that obtained from MATLAB Simulink is to connect and disconnect supply from the grid. The performance of this MG system will be analyses and discussed.

# CHAPTER 2

# LITERATURE REVIEW



## 2.1 Introduction

The literature review is a review of a research that has been made regarding particular problem which has been identified and need to be solved. This review should be able to describe, evaluate and clarify the project. On the other hand, it also goes beyond the research of information and includes the identification and articulation of relationships between the literature and the field of research.

In this Chapter 2, reviews of the previous researches that are related to this project research will be discussed. All of the information from the literature review will act as additional sources to ensure the project can be improved and successful. This chapter will describe the related reviews.

## 2.2 Microgrid System

Microgrid (MG)is a system which designed to have low voltage or medium voltage distribution network that surround by the distribution generator, energy storage systems and loads, and operated as a single controllable system. Basically,MG can be powered off in a state of emergency such as lightning strike or storms, without disturbing the main supply to the loads. Thus, it can supply connection of the loads with the DG. DG is a used for capacity support, voltage support and regulation, and line loss reduction [4]. If MG is implemented in electrical distribution system, it should be planned properly to avoid any problem in future[5].



### 2.2.1 Microgrid Technologies

MG system consists a few basics of technologies for operation. These include DG, DS and interconnection switches and control system. DG units are small resources of energy such as PV, MT and fuel cell. Most of this DG using fossil or renewable energy. Some DG likes MT also provides combine heat and power by recovering some of the waste heat generated by the sources. Almost all the DG needs power electronics interface in order to convert the energy into compatible alternate current power. This converter is includes inverter and rectifier or inverter. This DS provides a bridge that will be used in the process of meeting the power and energy requirements of MG when generations and loads of MG cannot be matched. There are a lot of energy storages can be used such as batteries,supercapacitors and flywheels [5]. Batteries are in dc power systems that needed to convert dc power to ac power. The interconnection switch can be linked to the connection between MG and the rest of distribution system. The control system in MG is designed to be safely operated in the system either in grid-connected or stand-alone mode [5].

### 2.2.2 Operation of Microgrid

Based on research that has been made, the MG system contains composition which is shown in Figure 2.1 where a PV generator acts as the main references of power and also known as a modular system. The small wind turbines are added time by time. By using DC/AC PWM inverters, both micro-sources are combined together with single phase AC bus. A battery bank also included, so it will be combined to the AC system via bi-directional PWM voltage source converter. Then, the MG is connected to the local low voltage grid. When this MG system is devoted to the grid, the local load will receive power both from the grid and the local micro-sources. The central component of the MG system is the battery inverter. The function of the battery inverter is to regulate the voltage and frequency when the system is operating in island mode. Besides that, it can control the reactive power and active power. The battery unit power electronics combined that consists of Cuk DC/DC converter and a voltage source, PWM inverter, both bi-directional. After that, it can be authorized. Then, the batteries will charge and discharge. When MG is operating in island mode, the battery inverter works in a voltage control mode and act as a grid-forming unit. The PV inverter accomplish the Maximum Power Point Tracker (MPPT) function of the photovoltaic generator. It also acts as grid-parallel unit. Besides, it also in charge for limiting the PV power output, but without voltage or frequency regulation engage[6].

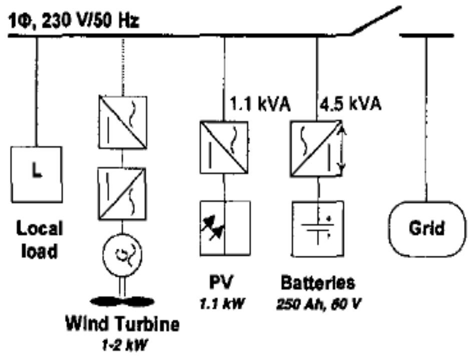



Figure 2.1: Schematic diagram of MG system

### 2.2.3 Microgrid and Distributed Generation

Abetter way to realize the emerging potential of Distributed Generation (DG) is to take system approach which views generation and correlated load as a subsystem or a MG. This MG can be operated either in islanded mode or grid-connected mode. Then, the whole system will be disconnected from utility during faults, voltage collapse or other problems. During disturbances, the generation and load can be separated from distribution system to isolate the load of MG from disturbances without harming the transmission system[7].



## 2.3 Microturbine

Microturbine (MT) is compact and basic-cycle gas turbine which consumes gaseous or liquid fuels. It can lower the emission and pollution since the MT have recuperator that can increases efficiency that means they use less fuel. By using less fuel, less emission into the air. These products will makes high energy gas stream and used to generate the electricity. The output range is typically from 25kW to 300 kW. They are a part of a general evolution of conventional gas turbine technology. These technique include recuperation, low $NO_x$ emission technologies and the use of developed element such as ceramics that use for hot parts.MT is modelling to works for longer times and involve little maintenance[8]. Because of their design uncomplicated and have a small number of moving part, MT caneasily positioned, higher reliability, reduced noise and vibration, low observance, low emissions and low costs.

### 2.3.1 Type and Components of Microturbine systems

High speed single shaft turbine and split shaft turbines are two kinds of turbines. Both are small gas turbines. The single shaft turbine was integrated by alternator. The rotor have two or four pole permanent magnet design. Meanwhile, the stator is conventional copper wound design. In the split shaft design, the gearbox will induce conventional that raised by power turbine. In the single shaft design, the alternator leads to high up frequency three phase voltages, range from 1500 to 4000 Hz. This high frequency voltage is first resolved and after that it reversed to normal frequency; 50 or 60 Hz. Meanwhile, in the split shaft design, the power inverter is not involved. Both turbines have recuperator and control and communication system. Before the exhaust gas enter the combustor, recuperator must transfer heat from the exhaust gas to the expelled air before it enter the combustor. It is for lessen the number of fuel to eject air temperature that needed by turbine. This amplify the regulation of energy. Control and communication system include full control of the turbine, power inverter and start-up electronics [8]. The MT model is shown in Figure 2.2.

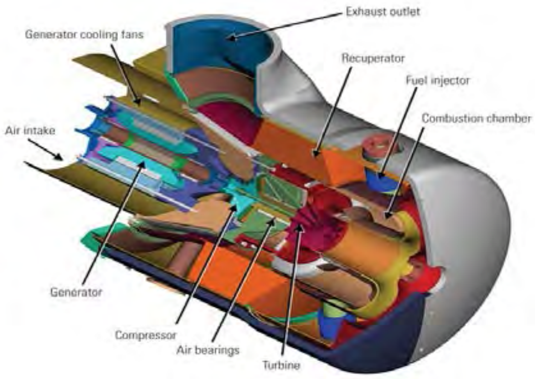



Figure 2.2: The MT model



### 2.3.2 Basic Process of MicroturbineGeneration System

The fundamental element of a MT generation systemare compressor, turbine, recuperator, high speed generator and interfacing of power electronic. Figure 2.3 shows a schematic diagram of a single shaft MT based generation system.

MT works based on thermodynamics cycle known as Brayton Cycle .The compressed air is assorted with fuel and burned in a combustor below constant pressure. The resulting hot gas is permitted to expand through a turbine to perform work. The combustion gas expanded in the turbine section and produce rotating mechanical power to manage the compressor and the electric generator that mounted on the same shaft. A sheet metal heat exchanger also known as recuperator is used to recuperate some of heat from the exhaust stream and convey it to arriving air stream. The preheated air is then used in combustion process. The rest of exhaust stream is passed through a waste heat recovery devise. Then, the heat is used for industrial process and building heating. Therecuperator can increase the overall efficiency. The Permanent Magnet Synchronous Generator (PMSG) needed high frequency AC output for general use, then rectifying high frequency

AC to DC then inverting to DC to 60Hz. Then, the power electronic is to handle transient and voltage spike [9].

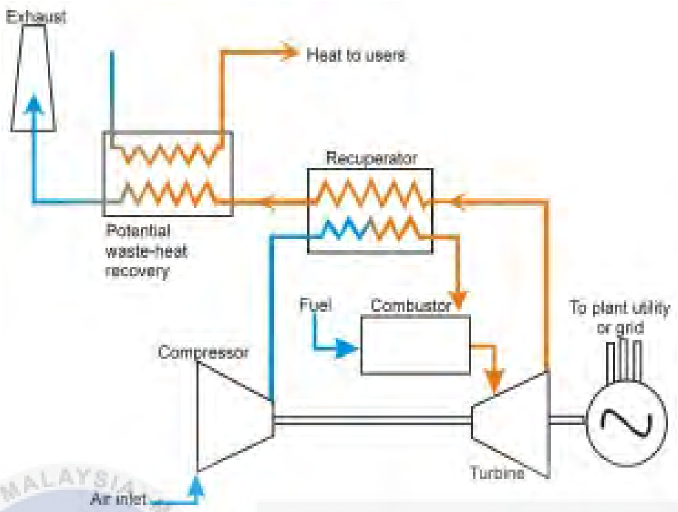



Figure 2.3: The basic process of MT generation system

### 2.3.3 Mathematical Representation for Microturbine

The simplified single shaft gas turbine, including all its control system which is implemented in Simulink of the MATLAB is shown in Figure 2.4. The model composed of temperature control, fuel control, turbine dynamics, speed governor and acceleration control block. The three control functions of the MT are speed control, temperature control and acceleration control. The speed control acting under part load conditions. Meanwhile the temperature control acting as an upper output power limit. Last, the acceleration control will constraint the speed from over speeding.

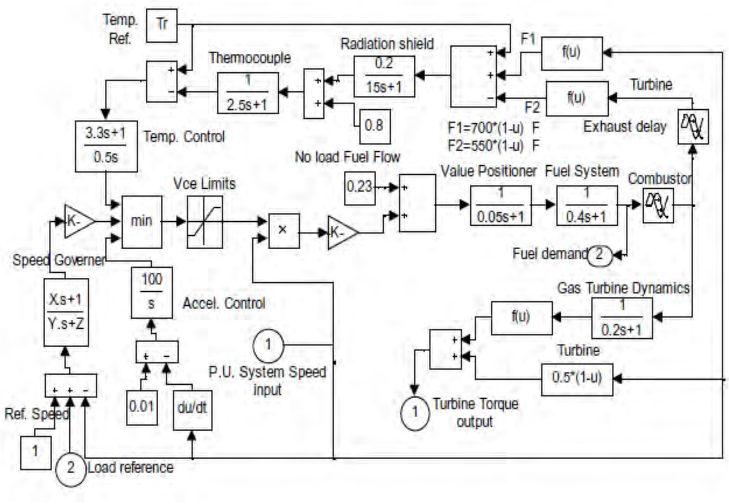



Figure 2.4: Simulink implementation of MTsystem

The speed control operates on the speed error occurred between a reference (one per unit) speed and the MTGS rotor speed. The control for the MT works under part load condition. For speed controller used lead-lag transfer function. During turbine begin up to limit the rate of the rotor acceleration prior to get operating speed, acceleration control is used. Figure 2.5 shows the speed controller for the MT [10].



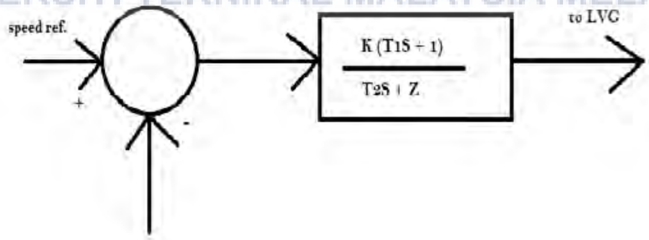



Figure 2.5: Speed controller for the MT

The fuel system made up of the fuel valve and actuator .The fuel circulate from the fuel system results from the inertia of the fuel system actuator and of the valve positioner. The valve positioner transfer function is

$$E_1 = \frac{K_V}{T_V S + C} F_d \quad (2.1)$$

and the fuel system actuator transfer function is:

$$W_f = \frac{K_f}{T_f S + C} F_1 \quad (2.2)$$

The fuel flow, blazed in combustor gives turbine torque and in exhaust gas temperature measured by a thermocouple. The output from the thermocouple is differentiate with reference values. Generally, the reference value is higher than the thermocouple output. Then, this exert the output from the temperature control to remain on maximum limit let the uninhibited governor or speed control[11].

The compressor turbine is the heart of MT. It is straight and non-dynamics device. Figure 2.6 is shows the compressor turbine package of MT.



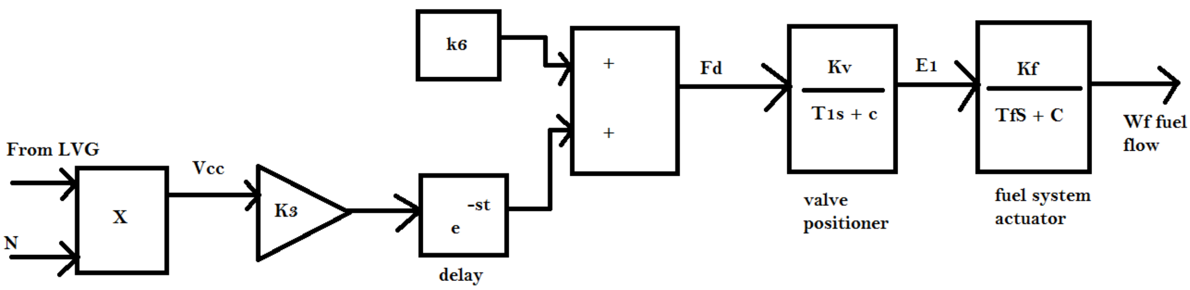



Figure 2.6: Compressor –turbine package of MT

The feature of torque and exhaust temperature for the single shaft gas turbine are necessary straight with respect to fuel flow and turbine speed. The input from this subsystem is fuel demand signal (pu). Meanwhile the output is turbine torque (pu) and exhaust temperature ($^{O}$F) [11].

The temperature control is at usual stage, it means that controlling gas turbine output power at a present firing temperature, independent of different in ambient temperature. The exhaust temperature comes from fuel burned in combustor and measured using series of thermocouple. Figure 2.7 shows the block diagram of temperature controller. The input for this controller is exhaust temperature ($T_X$) and the output is temperature control signal to LVG [11].

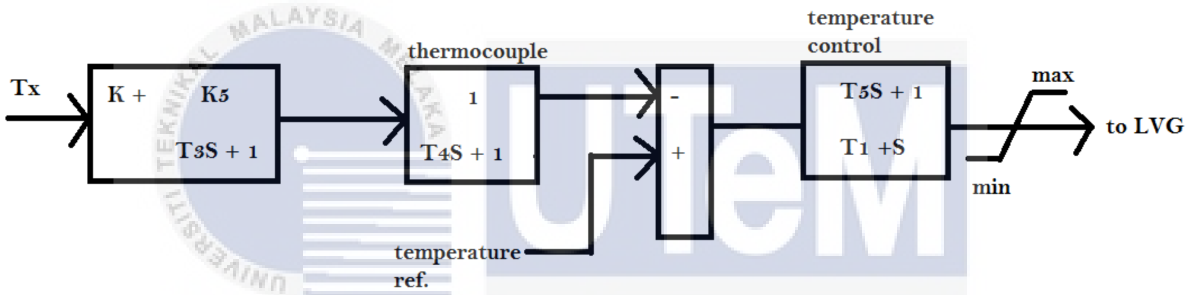



Figure 2.7: Block diagram of temperature control



Based on previous research, most of the PMSG model is adopted for the generator is two poles. This generator along with its machine with non-salient rotor. The MT directly driven by the turbo-compressor shaft to give electrical power from the generator with high speed. In PMSG machine, the dc field winding of the rotor is takes place by permanent magnet. The drawbacks are loss of flexibility of filed flux control and demagnetization. This makesmachine more efficient that induction motor.The power electronic interfacing is critical elements for MTGS, in other word in suit the turbine output to the required load. The power conditioning unit consist of a three-phase diode rectifier, a Voltage Source Inverter (VSI) and LC filter. [12]

### 2.3.4 Advantages and Disadvantage of Microturbines

There are some benefits which make the MT appealing. The MT generators are low in cost for the part of building and running compare to the larger conventional gas or diesel powered generators [13]. Other than that, it is also relatively inexpensive, easy to build and have less in amount moving parts. Moreover, the MT is high in durability and reliability. The MT alsorequires less maintenance. These systems can also be operated only ten minutes after being turned on. It can also be placed on the site, low security and maintenance due to its size. Moreover, it has the ability to work alone or in groups. These MT pollute less since it have higher efficiency. The increasing efficiency that they use is less fuel, which means fewer emissions into the air. One impediment of a MT is a bound on the times they can be turned on. MT also can be run at high speeds and temperatures, producing noise pollution for nearby residents and potential risks for operators and maintenance staff [13].



### 2.3.5 The Microturbine Generation Systemin MicrogridSystem

Based on research, the MT generation systemis very good among the other small scale distribution generations based on the trade applications and scientific research due to control pliability, fast response speed and very efficiently in cooling, heating and power production combination. Thus, the MT generation system in MG system can give a huge enhancement to MG. Within the MG, the load and micro sources can disconnected and reconnected to the power system. MG can works in normal and islanded mode. The single shaft and high speed of MT generation system is not suitable for direct connection to power system. It is because the high frequency AC energy power that produced by PMSG. The power electronic interfaces (AC/DC/AC) are needed to lessen the high frequency. The inverter control is big effect in MG operation. There are two methods of control and operate the inverter which are Voltage Source Inverter (VSI) and PQ (Real Power and Reactive Power) inverter control. The VSI controlled to follow the required of load variations for voltage and frequency and as voltage support when MG in islanded mode. Meanwhile, the PQ inverter control used active and reactive power set point. The other problem to implementing MT is harmonics which makes the load waveform disputed. These harmonic are the effects when the inverter exchange.A suitable filtering system should be design to conquer this complication[14].

## 2.4 Battery System Storage

Batteries can be operated in assorted utility applicationswhich in the areas of generation and customer services. Batteries recently have the largest range of application differentiate to other energy storage technologies. Battery system gives the most advantages for utilities when providing power management support and the response for immediate voltage spike or sags and outrages.



### 2.4.1 Operation of Battery Storage System

Battery system consists of cells which have a characteristics operating voltage and maximum current potential. Majority of battery energy storage system have power conditioning system that handle electricity from the battery and makes it acceptable for AC loads. This include altering the current and voltages to maximize the power output, matching the converted AC electricity to AC electrical network and comes to the halt current flow from the system into grid during outages. The transformation from DC to AC power in power conditioning system is done by an inverter[15].

### 2.4.2 Type of Batteries Storage

There are many different type of batteries storage for different purposes. For example, lithium-ion for residential use and redox-flow used for long-term storage for bigger stationary applications.

A. Lead Acid Battery

Lead acid battery is widely used in the worldwide and commercially in mobile and stationary. The battery stating is largely from the porous active materials with high internal surface area. Different plate designs are available in different designs. A battery cell has two leads of plates, a positive plate covered with lead dioxide paste. Meanwhile, the negative plate is made from a sponge lead. Positive and negative plates are together with an electrolyte from the battery cell [16]. The advantages of lead acid batteries are available in large quantities, available in different type of size and design and have high efficiency. It also havelow costs. Meanwhile, the disadvantages of these batteries have low life cycle, limited energy sources and density. Other than that, it requires high maintenance costs[17].



B. Lithium ion battery

Lithium ion batteries conquer the market in the field of mobile application such as cameras, mobile phones, laptop and computers. It’s had a nominal voltage of 3.6V/cell, which are common today. This technology has the potential to solve most problems in portable and mobile application. But, the cells with 100Ah are hard to find on the market [15]. It has higher energy density than lead acid and NiCD batteries. It also has long shelf time and has a high power to capacity ratio and high energy efficiency. But, it has a high initial cost that includes a battery pack for safety. The battery pack is needed for protective circuit [17].

C. Nickel-metal-hyride (NiMH) and nickel-cadmium (NiCD) battery

Nickel-cadmium (NiCD) batteries have been available for more than 100 years as commercial products. The development of nickel-metal hydride (NiMH) batteries is for replacing NiCD. It is because the cadmium is poisonous-heavy metal. The cadmium electrode has been replaced with a metal hydride, which can absorb hydrogen during discharge. The NiMH is very functional in all hybrid electric vehicles. But, the lithium ion battery technology takes over the NiMH batteries. It is because the nickel is an expensive raw material so it will increase the costs. Furthermore, the NiMH has maximal nominal capacity compared to lead acid and NiCD batteries. On today market, the NiMH batteries used in almost hybrid vehicles. This is because they are robust and safer than lithium ion batteries [16].



## 2.5 Review of Previous Related Works

The MG consists several basic technologies for operation. It can be seen based on paper by Benjamin Kroposki on 2008 [5]. These including DG, DS, interconnection switches and control system.

Based on paper by AK SAHA on 2011 [9], the MT are small and simple-cycle gas turbine that give power output ranging from 25 – 300 KW. There are two type of MT which is single-shaft and split-shaft. The basic component of MT are compressor, recuperator, turbine, generator and power electronic interfacing.

The mathematical model for MT are referred by SreedharR.Guda and C.Wang in 2005 [11]. The simplified single shaft gas turbine including all its control system implemented by using MATLAB Simulink. The model consists of temperature control, fuel control, and acceleration control.

The main concern to implementing MT in capable to dispatch with grid was discussed by R.Rahmani, M.Tayyebi, M.S Mahmodian and A.A. Shojaei on 2011 [14]. The concerns that need to give attention is controlling system which consists inverter and the harmonic that cause load wave forms disputed.

There are many type of batteries that used in MG system. These type of batteries have their own advantages and disadvantages. It had been discussed by Simon Schwunk on 2011 [17].



**CHAPTER 3**

# METHODOLOGY

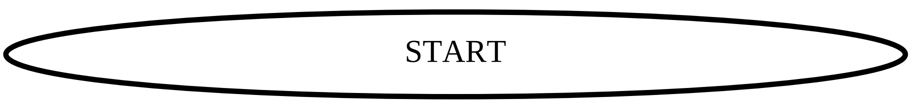
## 3.1 Introduction

This chapter will will mainly indicate the process of work in order to achieve the objectives stated in Chapter 1. This chapter will also include the software requirement and the design procedure. The methodology will briefly express the ideas of detail procedure that will be performed during this research.

## 3.2 The Overall Methodology



The flow chart of this project is to arrange process in a systematic. The Figure 3.1 shows the process flow chart for this project. The flow chart shows the method for the overall project for whole FYP. The method for FYP is started with doing literature reviews by read the previous research that related to this project. After that, the model of MG system which are combination of MT, battery and grid will be design by using MATLAB Simulink Software. Next, the design will be simulated and the output of simulation will be analyzed. After the simulation succeed, the breaker will be located before the grid to analyses this MG system either in grid-connected mode or grid-disconnected mode. Last but not least, the result of analysis will be presented.



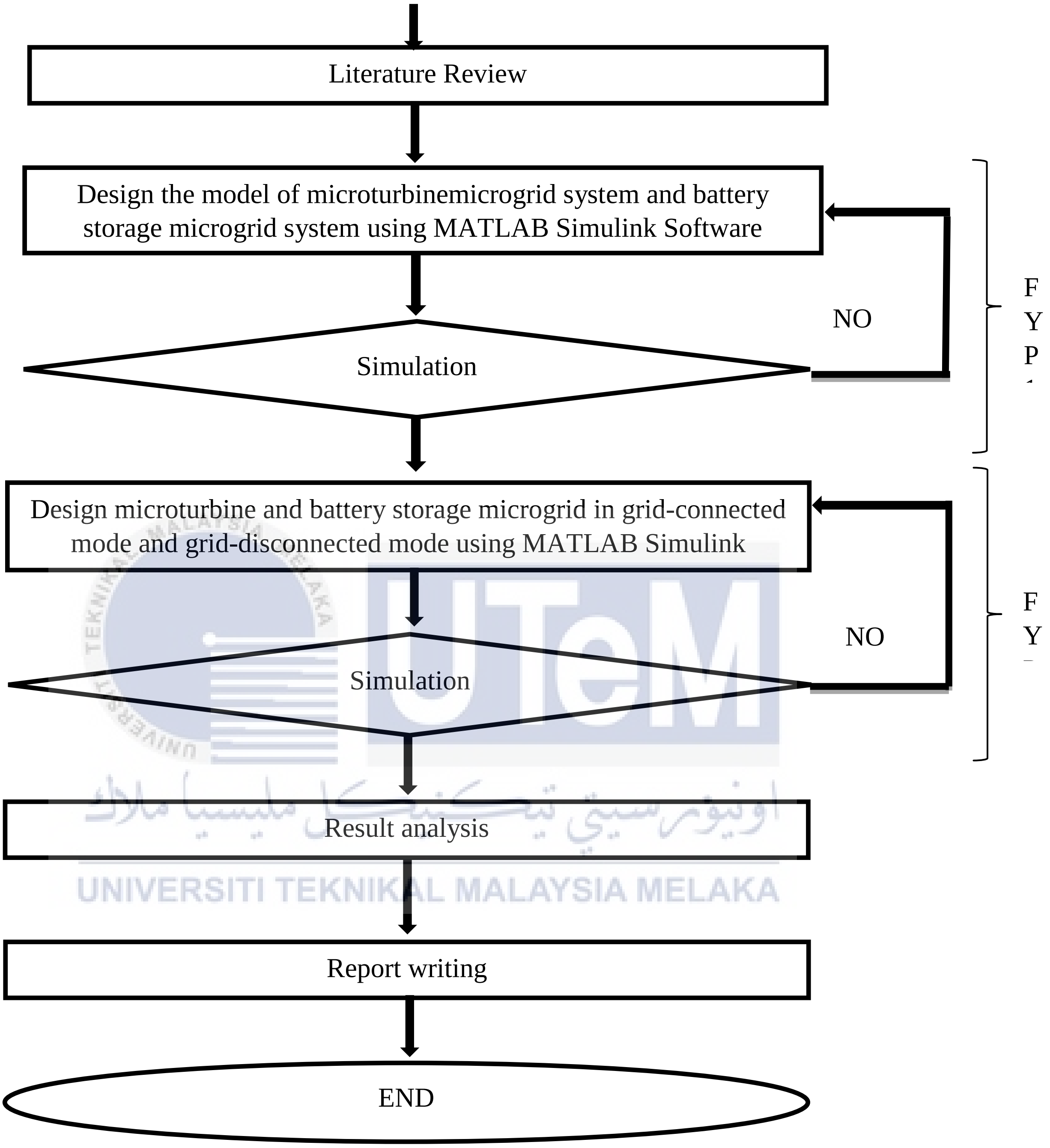



Figure 3.1: Flow ChartProcess



## 3.3 Literature Reviews

Literature review is a research study that has been made about a problem that has been identified and need to be answered. In the flow chart, the first method is basically a literature review. The study was based on journals and past research papers obtained from IEEE website. In the methods of conducting a literature review, the first important step to be taken is to master all the definition and the basic knowledge regarding MT and battery storage system. First, the study will focus more on every information about MT system and proceed to the operation of MT. After that, the study of analysis of MT in distributed energy resources more emphasized. Second, the study will focus on battery storage that can be used as DG power. There are many types of batteries that have their own advantages and disadvantages. Third, the study focus on the effect to the MG system when the system either in grid-connected mode or grid-disconnected mode. These type of mode will effect to the MG system in aspect the changes of voltage, current, power and frequency.

## 3.4 Design of MicroturbineMicrogrid

In this method, the MT will be designed using MATLAB Simulink Software R2014a. The design of MT will designed by referring to the previous research. The design of MT model that used is single shaft gas turbine simulated in Simulink of MATLAB. The Figure 3.2 shows the design of MT. This model consist of fuel control, temperature control, speed governor and acceleration control blocks. The controller used PID controller or lag-lead controller. The PMSM would be used to produce high-speed generator for MT. The time delay would precede the fuel flow control. The fuel flow burned in combustor and produce turbine torque and flow to exhaust gas temperature. After that, the thermocouple would measure and compare with references output.

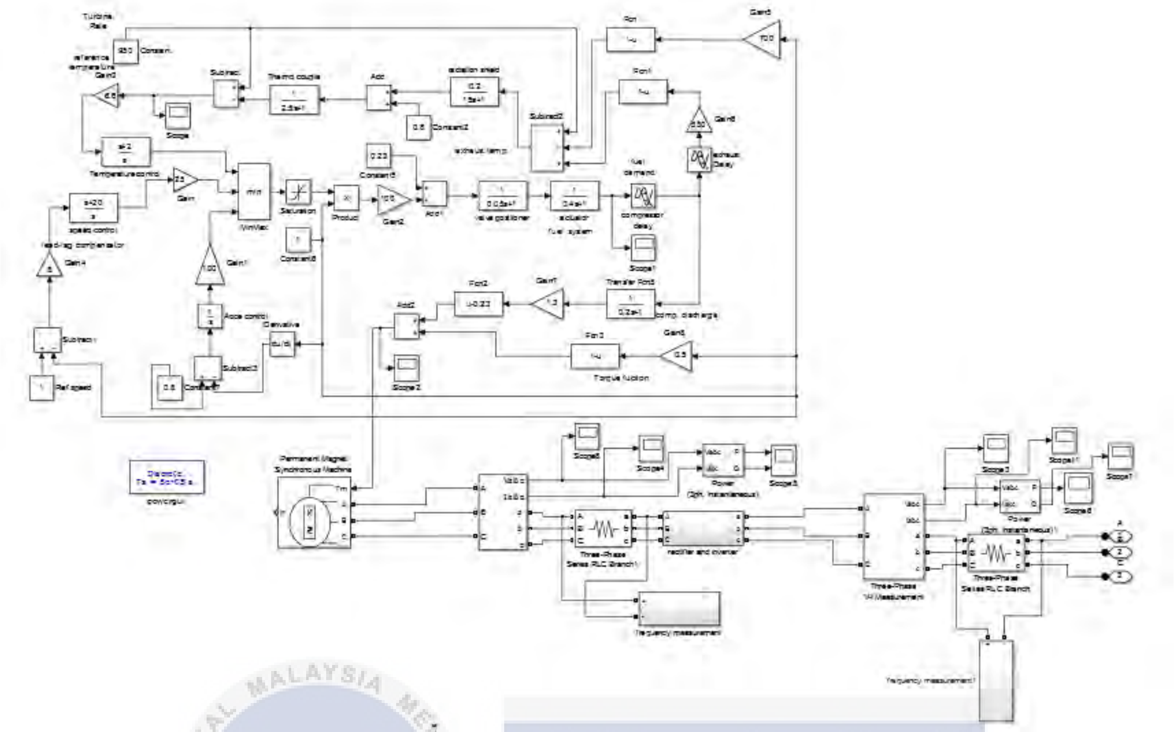


Figure 3.2: Design of MT

The Figure 3.3 shows the PMSM block. It can operates either in generator or motor mode. If the PMSM operates as generator, the mechanical torque will be negative and if the PMSM operates in motor mode, the mechanical mode will be positive. The sinusoidal model assumes that flux established by permanent magnet in stator is sinusoidal, so the electromotive forces also sinusoidal.

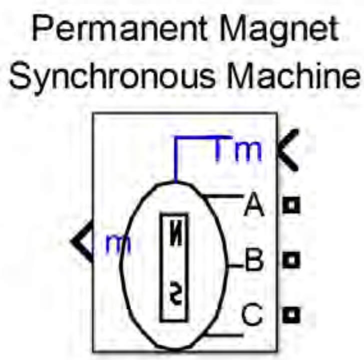



Figure 3.3: The PMSM Block

The Figure 3.2 shows the subsystem that consists of MT. The MG system that consists of MT connects with grid shown in Figure 3.4 Now, the MT are in grid-connected mode. The three phase source is use as the source for transmission line. The three phase transformer is used to step-up or step-down the voltage and current. The three phase load is used as resistance or load demand.

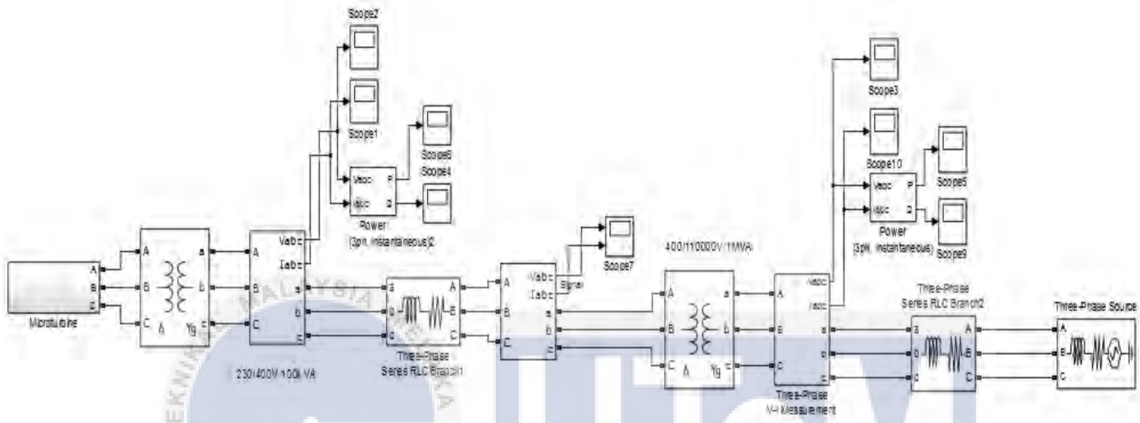



Figure 3.4: Design of MicroturbineMicrogrid System



## 3.5 Design of Battery Storage SystemMicrogrid

The model of battery stack is designed based on example on MATLAB Simulink. The battery used for this design is Lithium-ion. The Figure 3.5 show the battery block and Figure 3.6 show the block parameter of battery. The nominal battery voltage is set to 400V (DC) and 50Ah. The state of charge was set for 100 %.

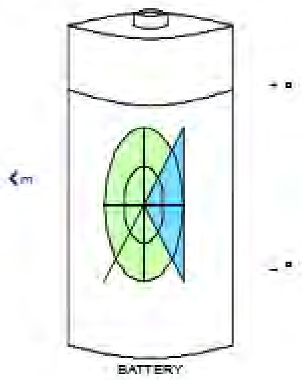



Figure 3.5: Battery Storage Stack

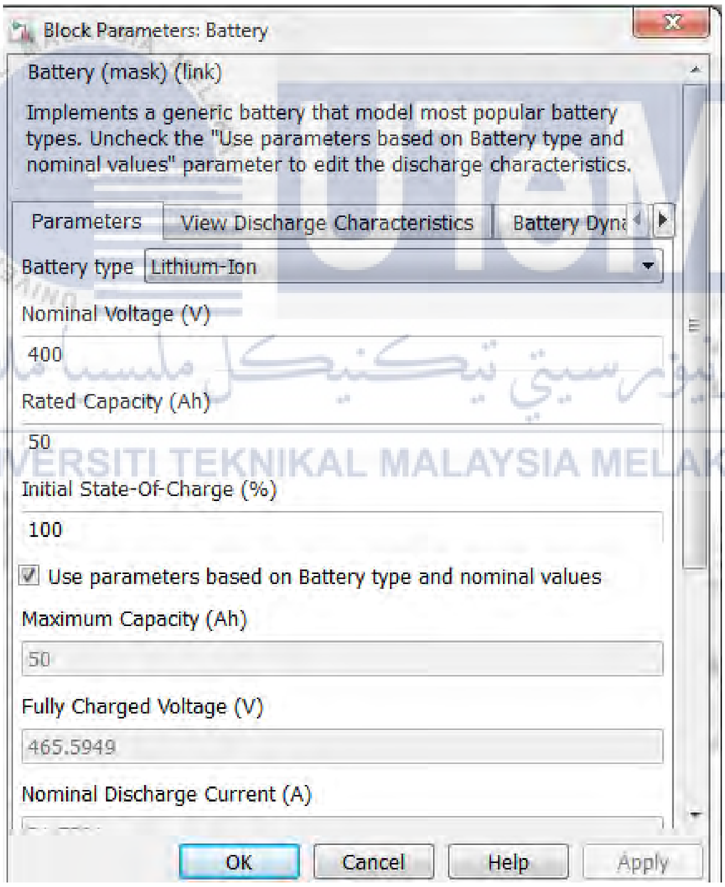





Figure 3.6 Block Parameter of Battery Storage Stack

The three phase inverter shown in Figure 3.7. The power electronic that used for inverter is MOSFET. All power electronic device in this inverter operated simultaneously in this simulation. The function of inverter is to invert the DC to AC voltage.

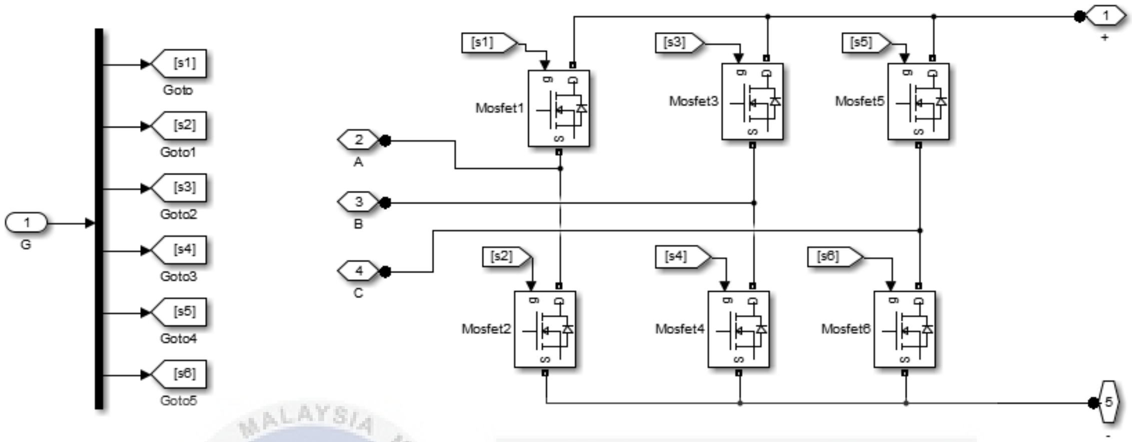



Figure 3.7: Three-Phase Inverter

The battery storage MG system shown in Figure 3.8. From this design, there are inverter which is to convert DC voltage to AC voltage, three-phase transformer which is to step-up and step-down the voltage and current and three-phase series RLC load. The three phase source, known as grid used as the source for transmission line.



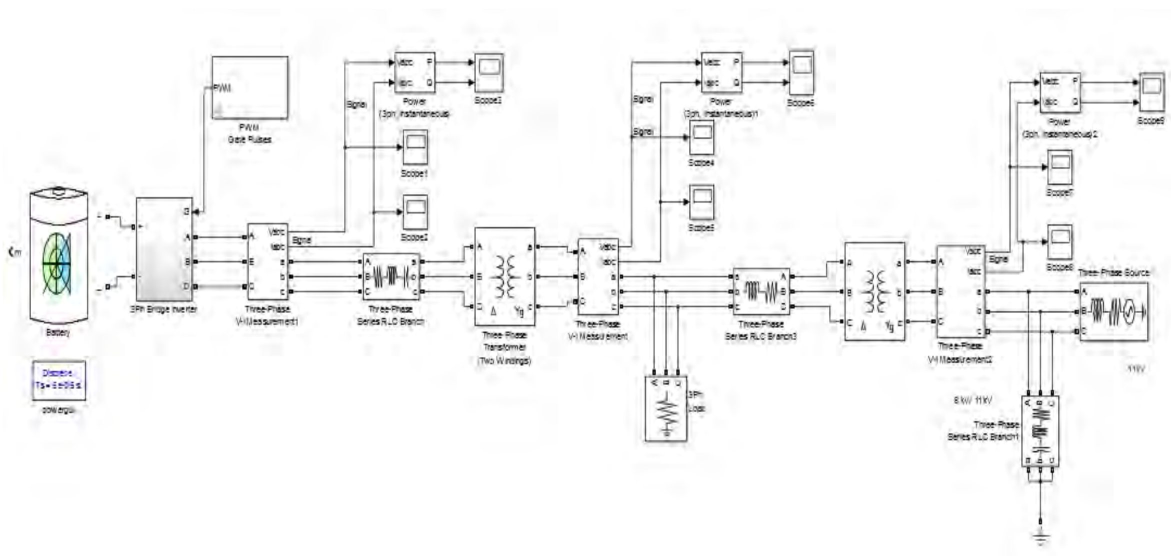



Figure 3.8: Design of Battery Storage Microgrid

## 3.6 Design of Microturbine and Battery Storage System Microgrid in Grid-Connected Mode and Grid-Disconnected Mode

The Figure 3.9 show the distributed generation of MT and battery storage system are connected to grid. Each distributed generation connected to delta-wye transformer to step-up the three phase voltage and current. The grid connected to delta-wye transformer to step-down the three phase voltage and current. This power system connected to the load and supply the load demand. This power system is running for two seconds. The three phase voltage and current are measured by three phase VI measurement block. Meanwhile, for the active power and reactive power were measured by power measurement block. The frequency at the load measured by frequency measurement block. There are rectifier and converter that used after MT subsystem. Its function to compatible in voltage and frequency with electronic power system to which it will be connected and contain necessary output filter. The filters used is LC filter which to filter noise to obtain synchronous voltage and frequency. The inverter after battery storage system used to convert DC voltage to AC voltage.



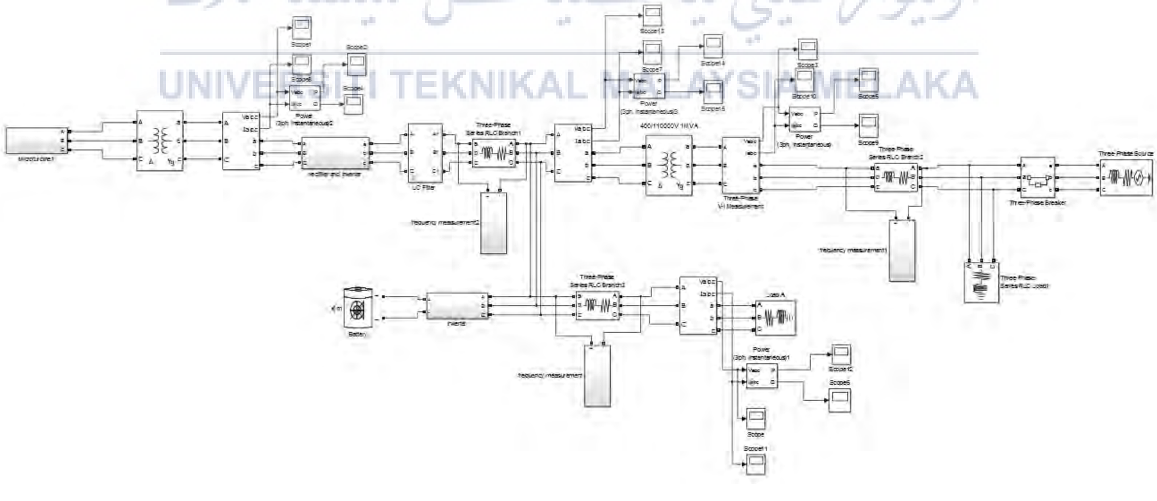


Figure 3.9: Design of Microturbine and Battery Storage System Microgrid

Figure 3.10 shows the three-phase breaker that used in the model. The breaker was used for open or closed the grid. When the three-phase breaker is closed, the MG system in the grid-connected mode and if the breaker is open, the MG system in islanded-mode.

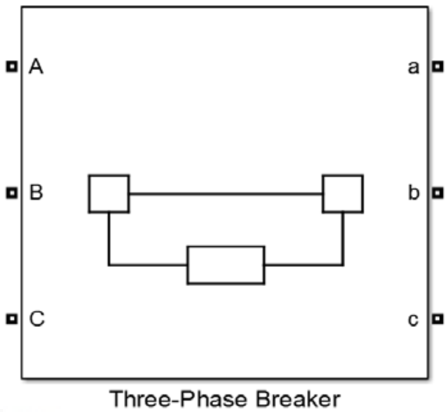



Figure 3.10: Three-phase Breaker

## 3.7 Simulation Stage



Each design will designed and simulated by using MATLAB Simulink Model R014a. Each block model will be studied and inserted with parameter or equation. The simulation will have two possible conditions either successful or not. If successful, the analysis and discussion can be proceed. If not, the design will be repaired according the error and will simulated again until success. Figure 3.10 shows the MATLAB Simulink Software R2014a that used for this project.

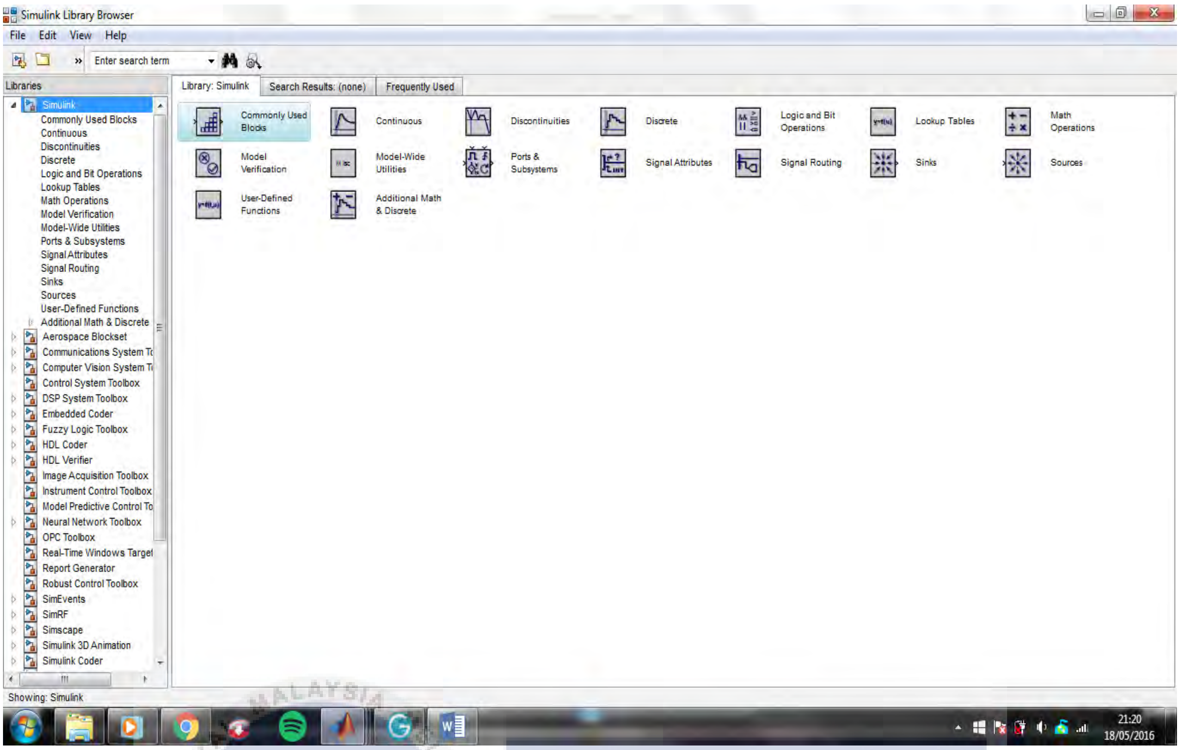



Figure 3.11: MATLAB Simulink Software

## 3.8 Result analysis



FYP 1 this project only design the MT MG system and the battery storage MG system. The both design then simulated and the result would analyzed. Meanwhile for FYP2, the MT and battery storage MG system designed then simulated. The design will be simulated in grid-connected mode and grid-disconnected mode. From the simulation for both mode, the result will compared and analyzed. The parameters that will be discussed which are voltage, current, real power, reactive power and frequency. This design will shows either this design have synchronous voltage and frequency or not. If not, the factors and causes will be discussed. The discussion of the result and analysis will be discussed in Chapter 4.

### 3.9 Report Writing

Writing a report is the final stage in the methodology. All the initial results or the preliminary result will be discussed in the project report. The format to be followed in report writing is the format given by the supervisor and the faculty.

# CHAPTER 4

# RESULTS AND DISCUSSION

## 4.1 Introduction

This chapter represented the modelling design MT MG system, battery storage MG system and MT and battery storage MG system. In this chapter also, it will demonstrate the results obtained from the simulation. All the information will be briefly displayed and explained



## 4.2. MicroturbineMicrogrid System

The design of MT by using MATLAB Simulink had shown in Figure 4.1. From this design, MT consists the three control function. The three control function are speed control, temperature control and acceleration control. Other than that, the MT also consists fuel system, compressor turbine and PMSG.The output from this MT is 25 V and 1.5 A. The active power and reactive power from this design are 53.2 W and 30.66 VAR.

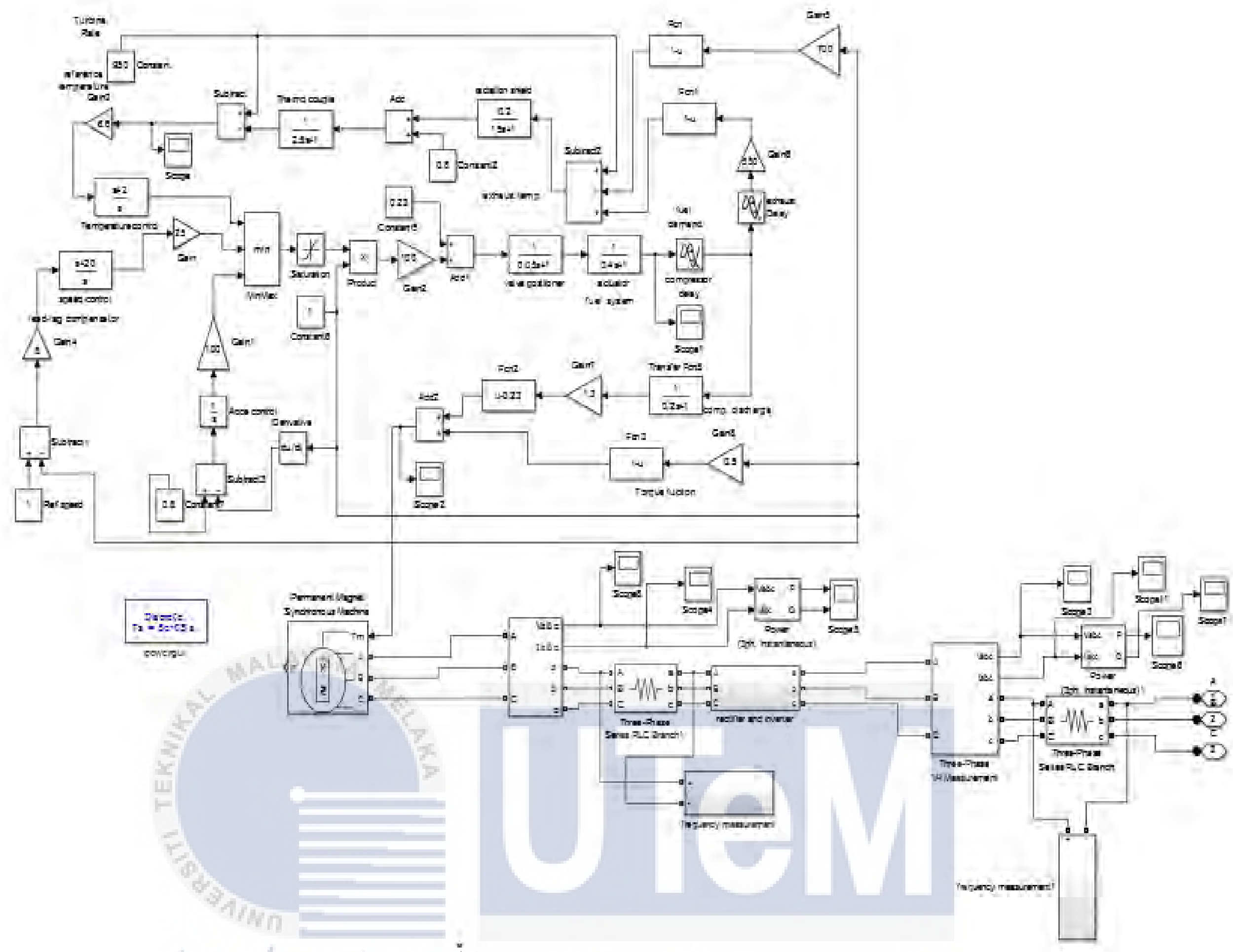


Figure4.1: Modelling design of MT



The design of MT that connected with grid by using MATLAB Simulink had shown in Figure 4.2. From this design, the MT subsystem gives 25 V and 1.5 A. The voltage and current will step-up to achieve 415 V and 11 KV distribution system. Between MT and grid, there are two unit transformers, three phase RLC load, and three-phase source. The transformer is used for step-up or step down the voltage and current. The transformer after MT is used to step-up the voltage and current from the MT and the three-phase RLC load as resistance to achieve 415V for distribution system. The second transformer used to step-up voltage and current from 415 V to 11 KV for distribution system. The three phase RLC load is use as resistance or load demand. The three-phase source is act as grid and source from the transmission line.

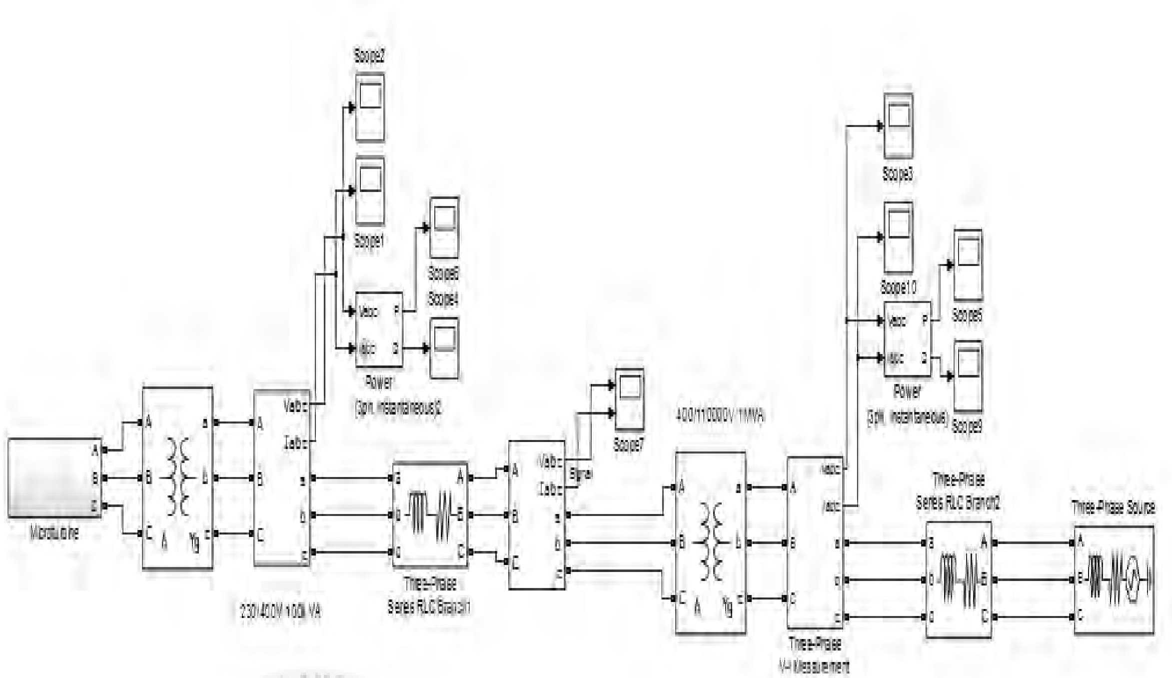



Figure 4.2: Modelling design of MT with grid

The results that obtained from this simulation is shown below:

<u>415 V Distribution System</u>



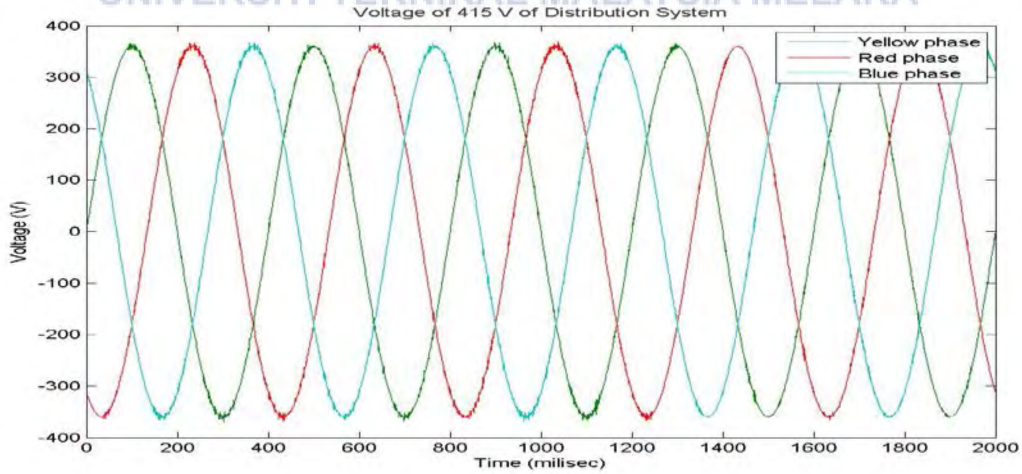



Figure 4.3 : Three-phase primary voltage

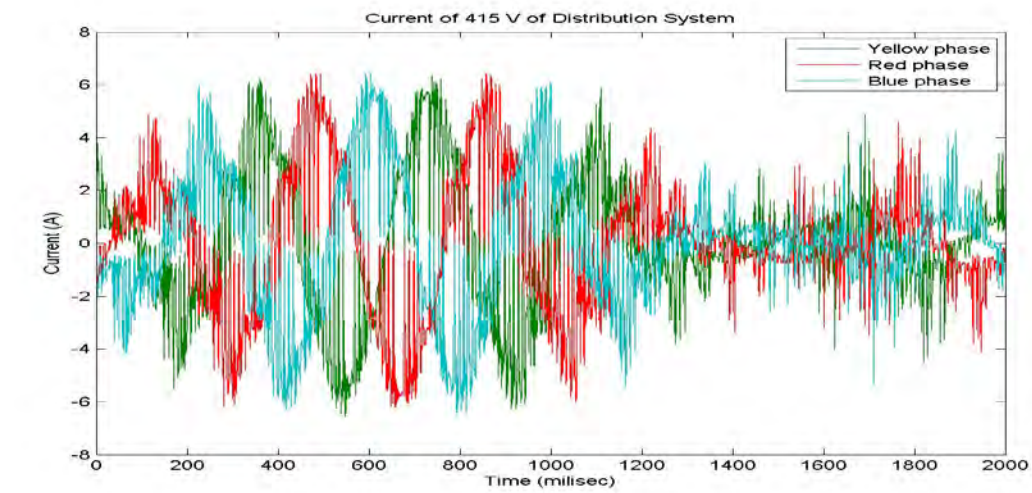



Figure 4.4 : Three-phase primary current

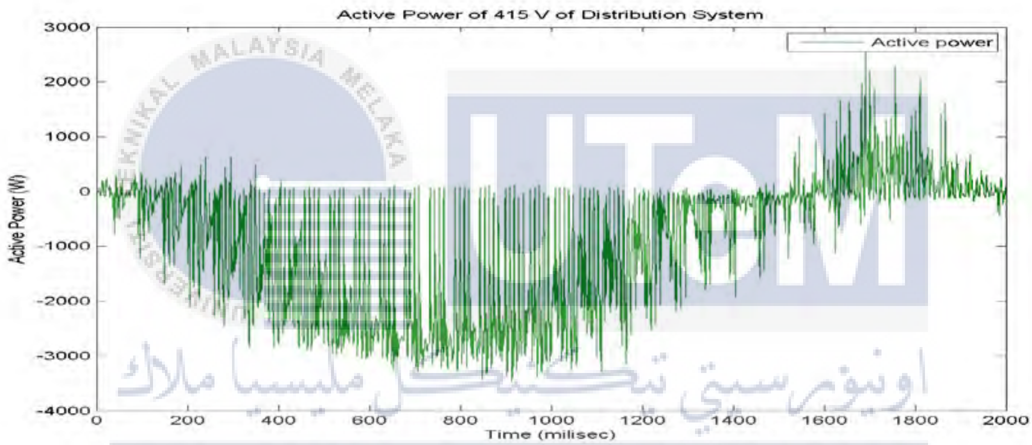





Figure 4.5 : Primary active power

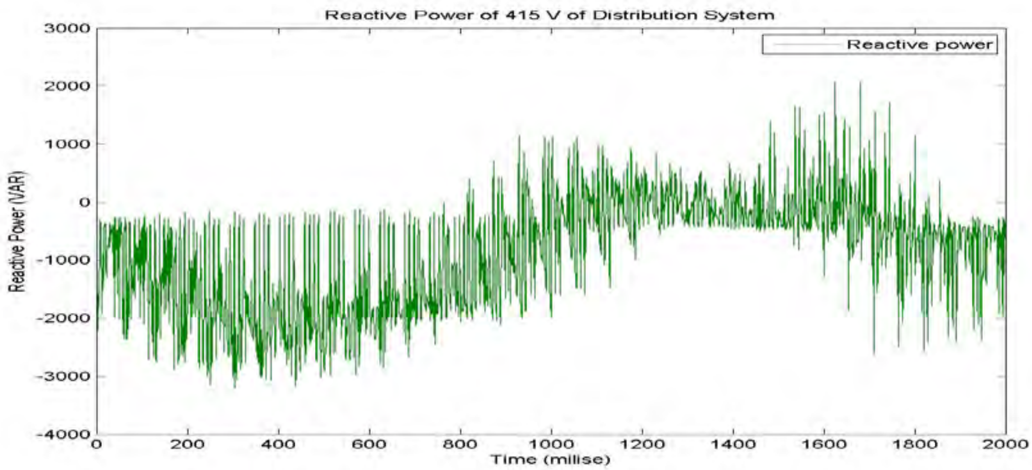



Figure 4.6 : Primary reactive power

From Figure 4.3, the three phase primary voltage is 380V. From Figure 4.4, the three phase primary current is 6 A. From Figure 4.5, the active power is 1000 W and from the Figure 4.6, the reactive power is 1500 VAR.

<u>11 KV of Distribution System</u>

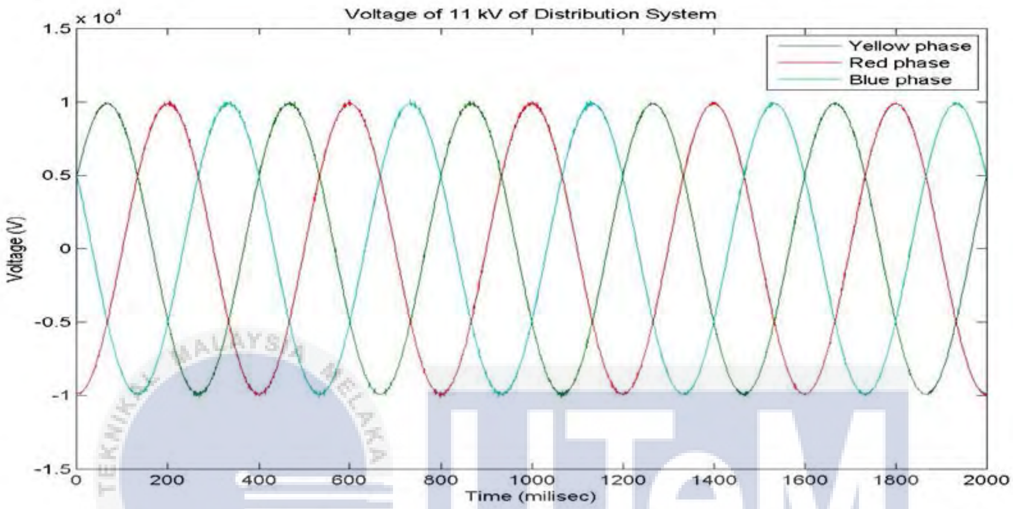



Figure 4.7 : Three-phase secondary voltage

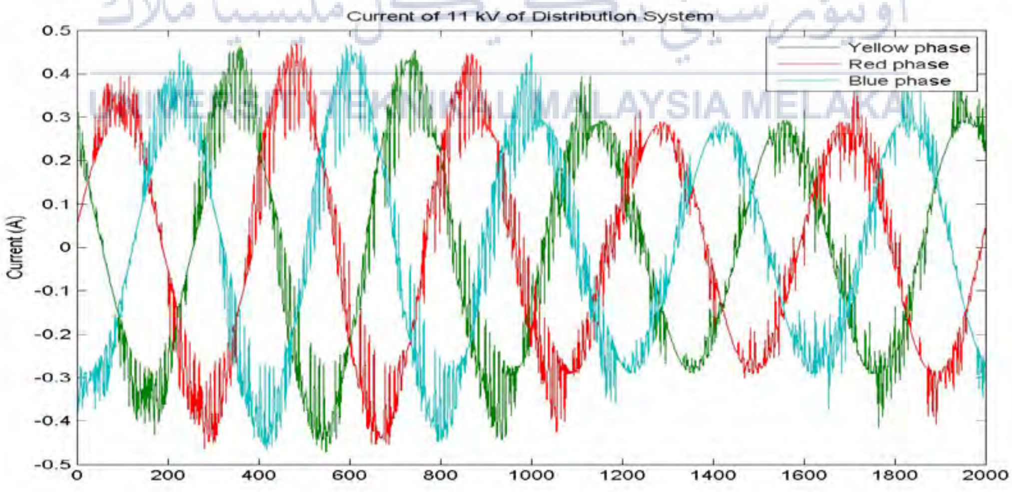



Figure 4.8: Three-phase secondary current

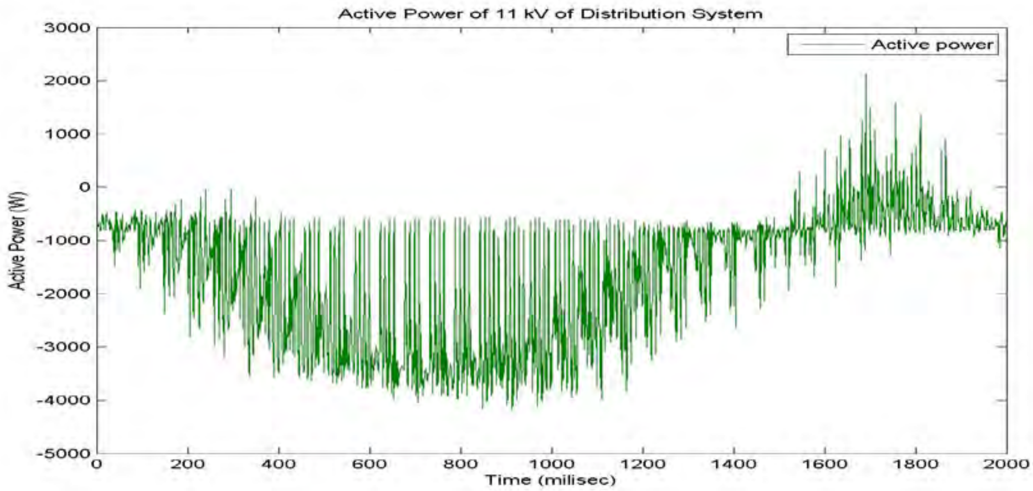



Figure 4.9 : Secondary active power

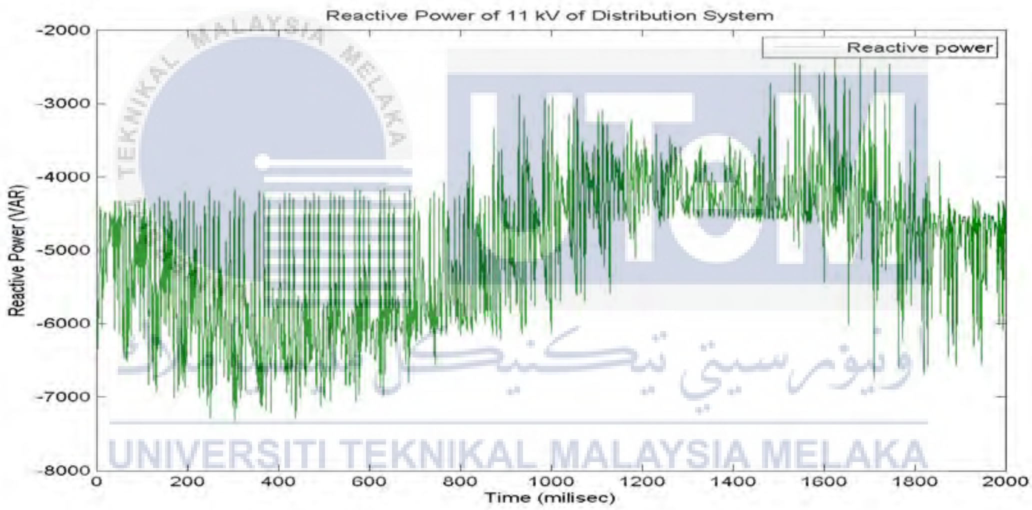



Figure 4.10 : Secondary reactive power

From Figure 4.7, the three phase secondary voltage is 10 kV. From Figure 4.8, the three phase secondary current is 0.6 A. From Figure 4.9, the active power is 500 W and from Figure 4.10, the reactive power is -3000 VAR.

The voltage from the MT was step-up by transformer from 53.2 V to 380 V. The required voltage is 415. Then, the 380 V was step- up to 10 kV. But, the voltage required is 11 kV. This design cannot achieved the required voltage due the output voltage that had inverted cannot step-up to the required voltage. It is because the design of inverter is critical component and challenging.

## 4.3. Design of Battery Storage Microgrid System

The design of battery storage that connected with grid by using MATLAB Simulink had shown in Figure 4.9. The battery that used for this design is Lead Acid battery. From this design, between the battery storage and grid, there are converter and inverter, three-phase transformer and three-phase series RLC load. The transformer is used to step up the output voltage and current. The transformer is used for step-up or step down the voltage and current. The transformer after battery is used to step-up the voltage and current from the battery and the three-phase RLC load as resistance to achieve 415V for distribution system. The second transformer used to step-up voltage and current from 415 V to 11 KV for distribution system. The converter and inverter used for convert DC voltage to AC voltage. The three-phase series RLC load as resistance or load demand. The three-phase source is act as grid and source from the transmission line.

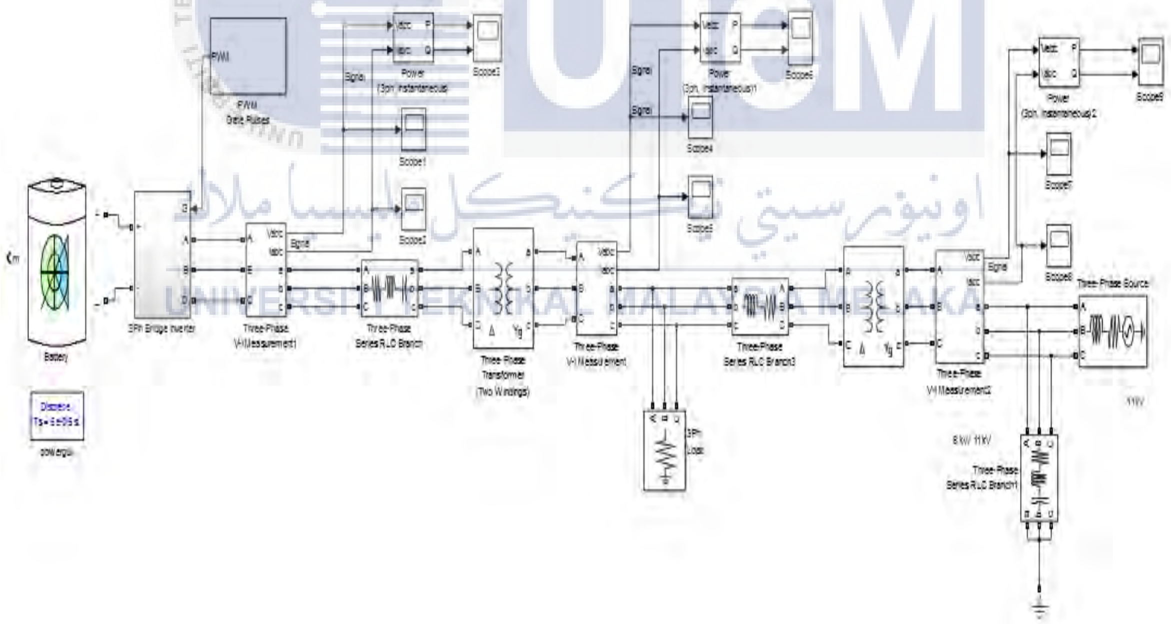



Figure 4.11: Modelling design of battery with grid

The results that obtained from this simulation is shown below:

<u>415 V of Distribution System</u>

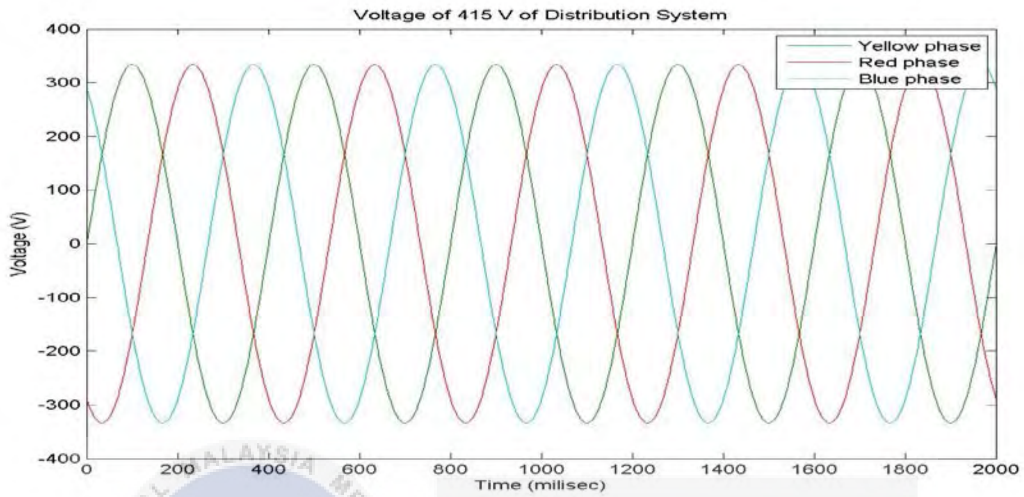



Figure 4.12: Three-phase primary voltage

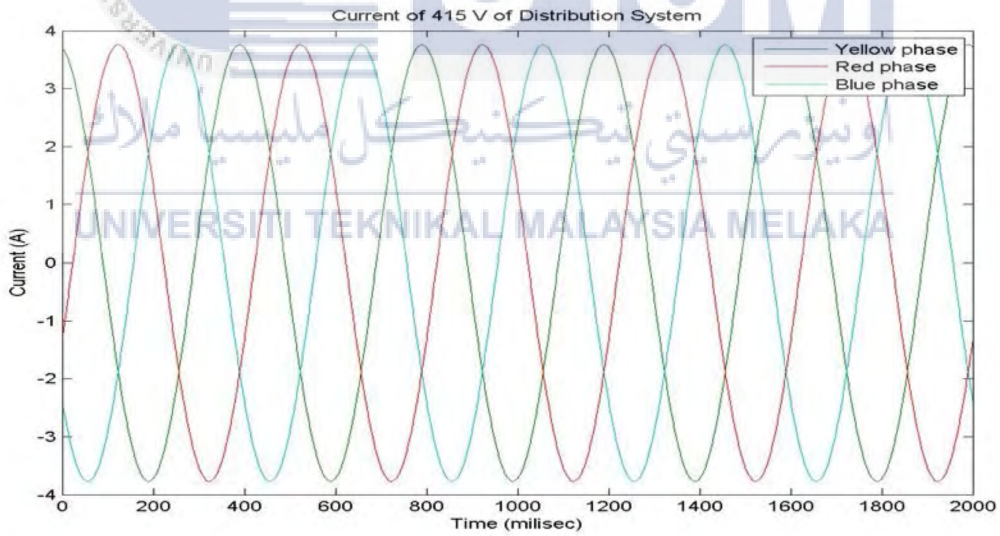



Figure 4.13: Three-phase primary current

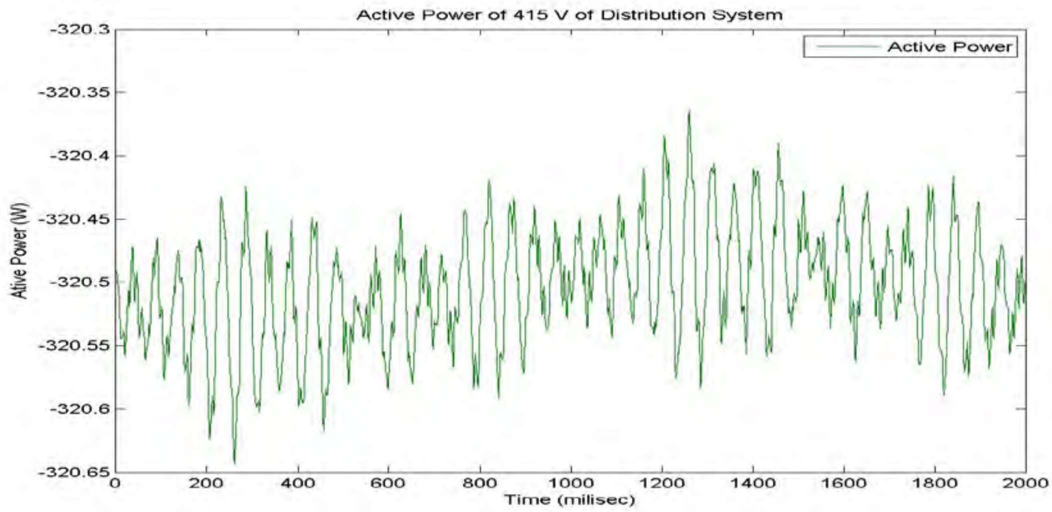



Figure 4.14: Primary active power

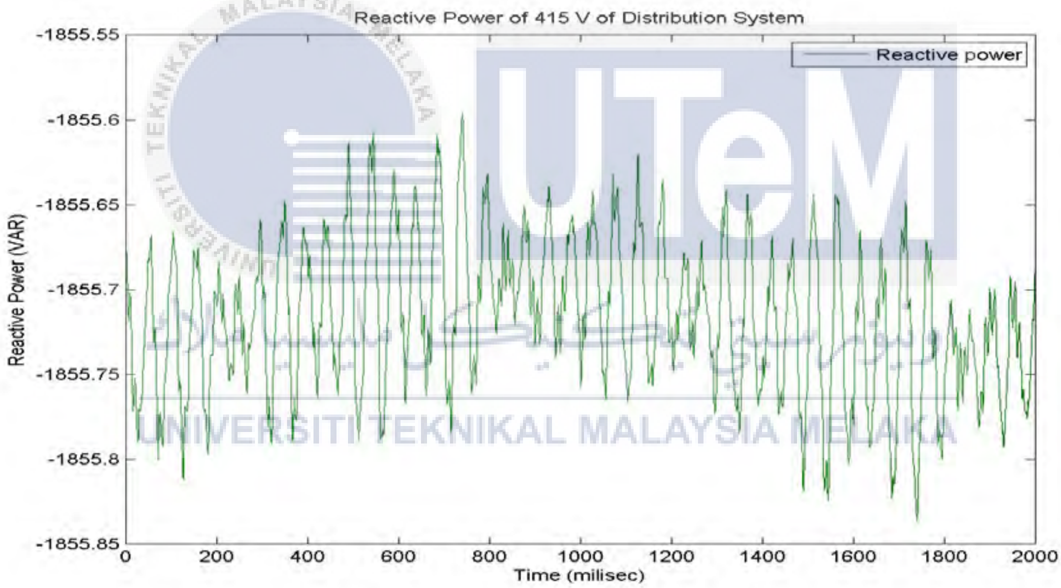





Figure 4.15: Primary reactive power

From Figure 4.12, the three phase primary voltage is 300V. From Figure 4.13, the three phase primary current for is 3.8 A. From Figure 4.14, the active power is -320.4 kW and from Figure 4.15, the reactive power is -1800.6 VAR.

<u>11 KV of Distribution System</u>

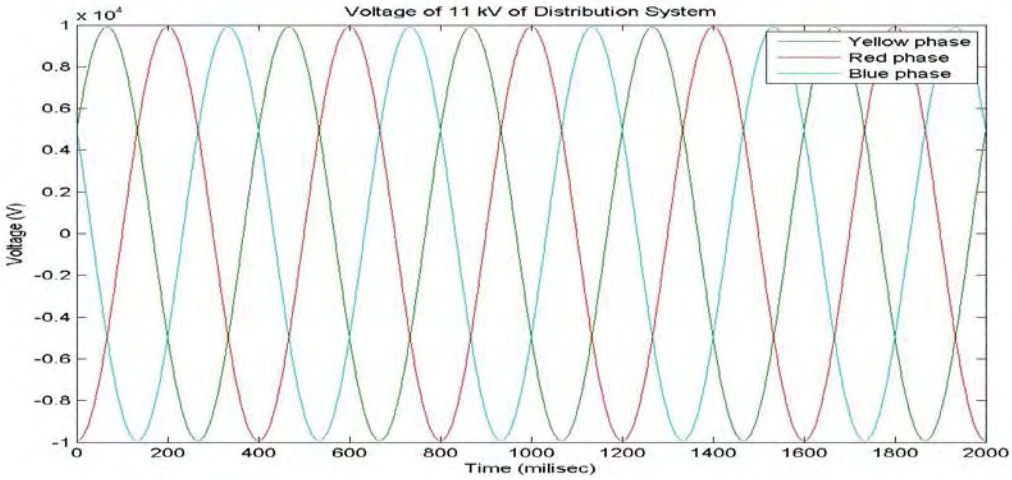



Figure 4.16 : Three-phase secondary voltage

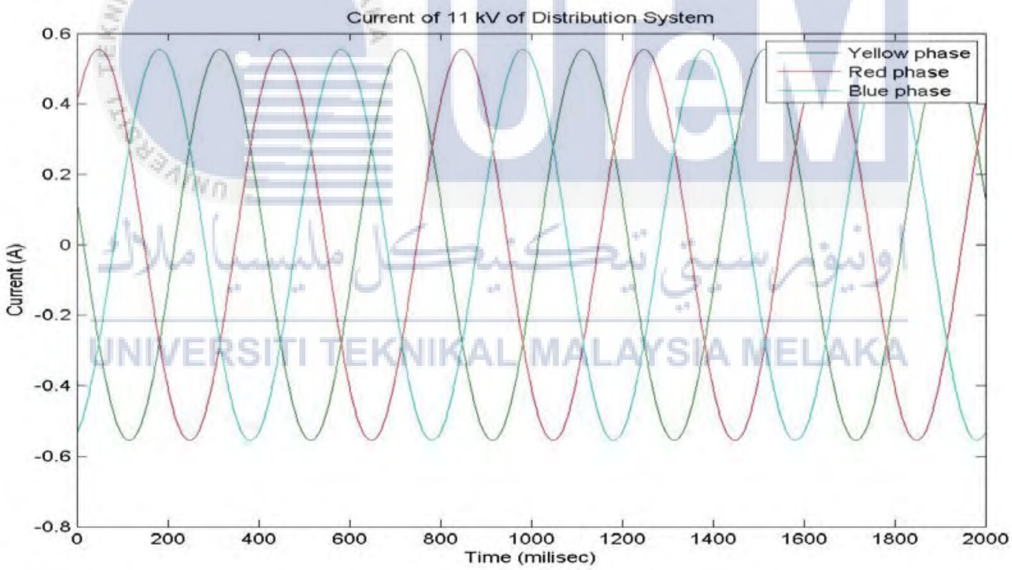



Figure 4.17 : Three-phase secondary current

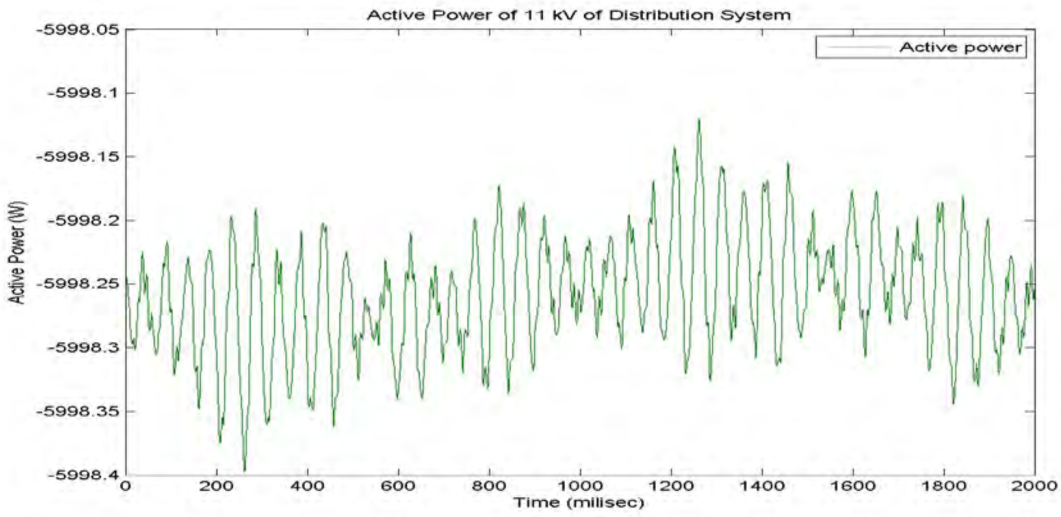



Figure 4.18: Secondary active power

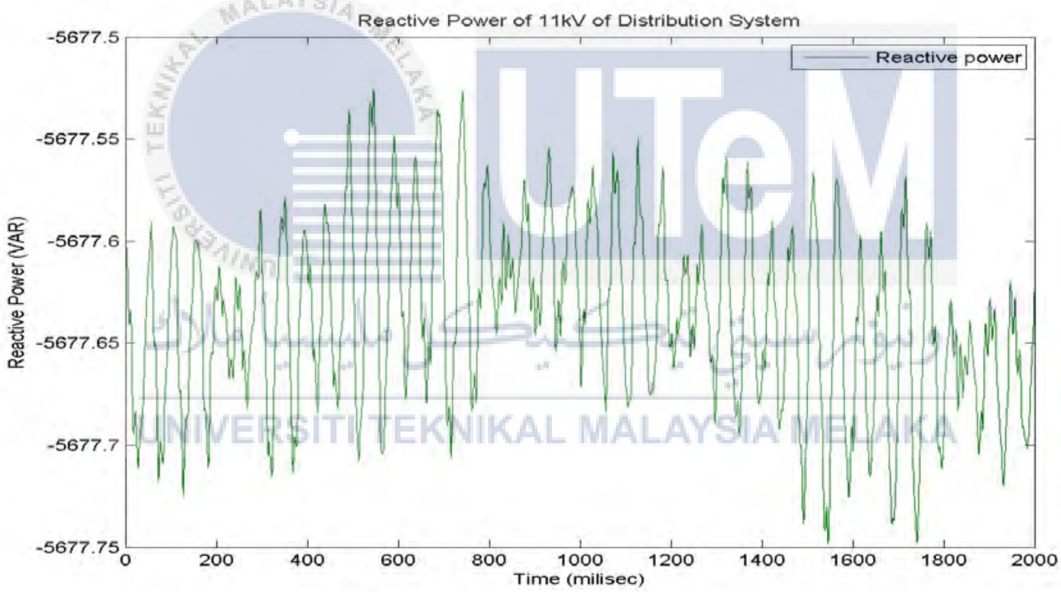



Figure 4.19: Secondary reactive power

From Figure 4.16, the three phase secondary voltage is 10 kV. From Figure 4.17, the three phase secondary current is 0.4 A. Th active power from Figure 4.18 is -5998.15 W and from the Figure 4.19, the reactive power is -5677.55 VAR

The voltage from the battery storage system wasconverter from 400 V in DC to 230 V AC The 230was step-up by transformer to 300 V AC. The required voltage is 415 V. Then, the 300 V was step- up to 10 KV. But, the voltage supply for the microgrid is 11kV. This design cannot achieved the required voltage due the output voltage that had inverted cannot step-up to the required voltage.

## 4.4. Design of Microturbine and Battery Storage System Microgrid with Grid- Connected Mode and Grid-Disconnected Mode

The Figure 4.20 show the distributed generation of MT and battery storage system are connected to grid. The voltage and current from the MT was step-up, then rectified, inverted and filtered. The rectifier and inverter used to compatible the voltage and frequency with the electric power system to which it will connected and contains the necessary output filters. The DC voltage of battery was inverted to AC voltage. The RLC series load act as load or resistance. The voltage from the MT and battery is transmit to 415 V power distribution. After that, the voltage and current step-up to 11 KV. The three-phase source as grid and source from the transmission line. When this MG system in grid-connected, the breaker will closed. So, grid can gives supply for the system. Meanwhile, if the MG system in grid-disconnected, the breaker will open. So, the grid cannot give supply for this system.

.

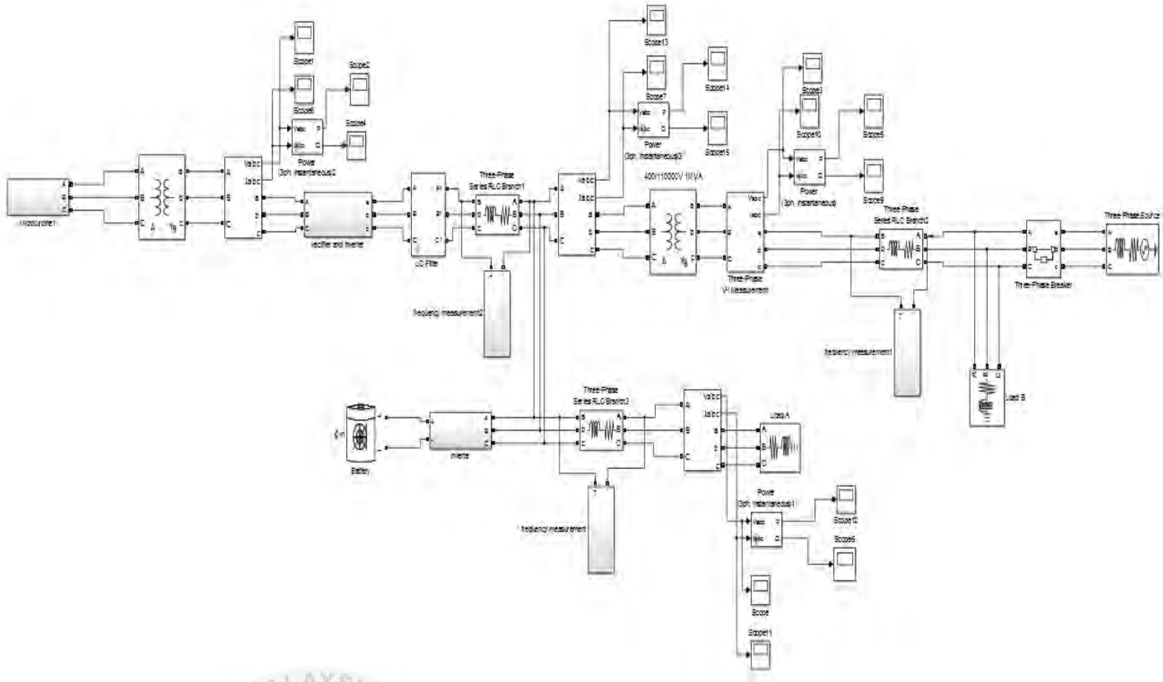


Figure 4.20(a):Microturbine and Battery Storage System Microgrid in Grid-Connected



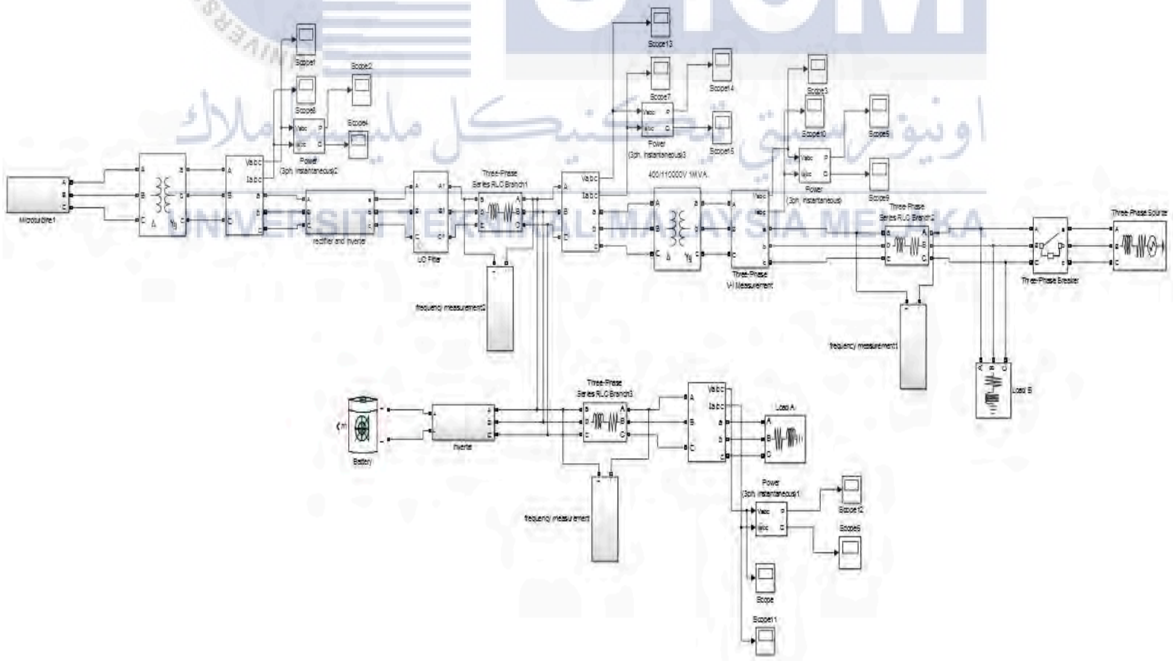


Figure 4.20(b):Microturbine and Battery Storage System Microgrid in Grid-Disconnected

**<u>Case 1: Grid Connected Mode</u>**

For grid-connected mode, the breaker is closed. The voltage of MT is 40 V then step-up to 60 V. The active power of MT is 80 W then after step-up, the active power is 50W. The voltage of battery is 240 V. The active power of battery is 2620 W. The frequency for this system is 50.04 Hz. Figure 4.21 shows the frequency during grid-connected. The result that obtained from this simulation as shown as below:

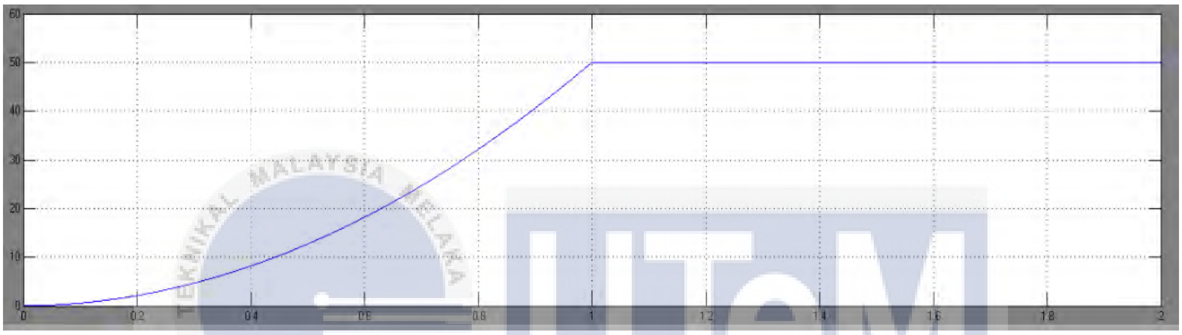


Figure 4.21: Frequency in grid-connected



<u>For 415 V Distribution System</u>

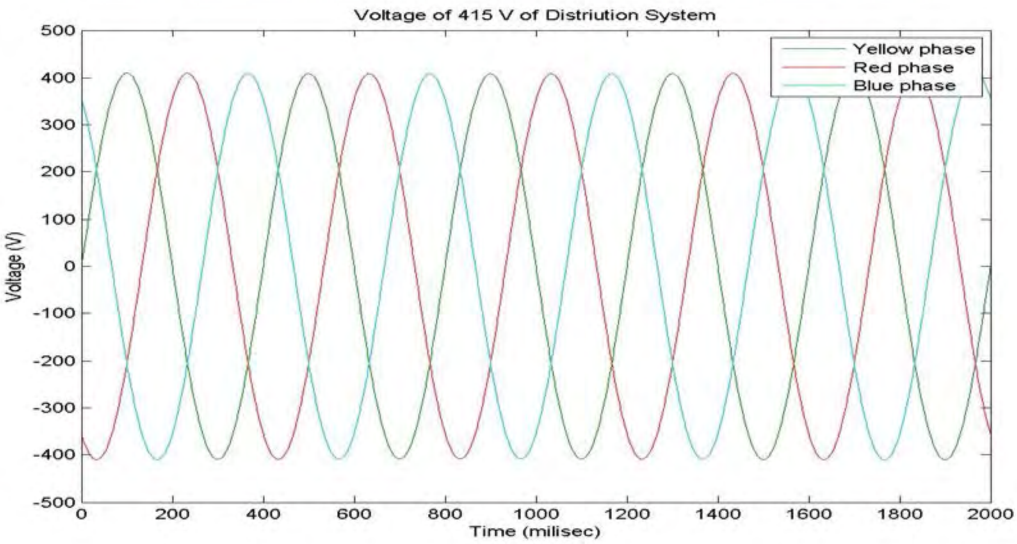



Figure 4.22: Three-phase primary voltage

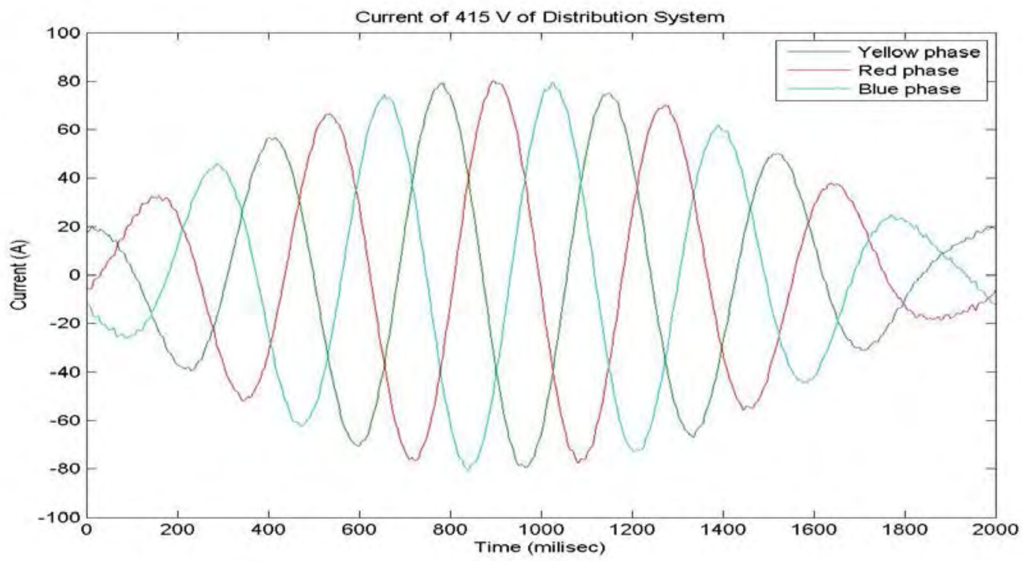



Figure 4.23: Three-phase primary current

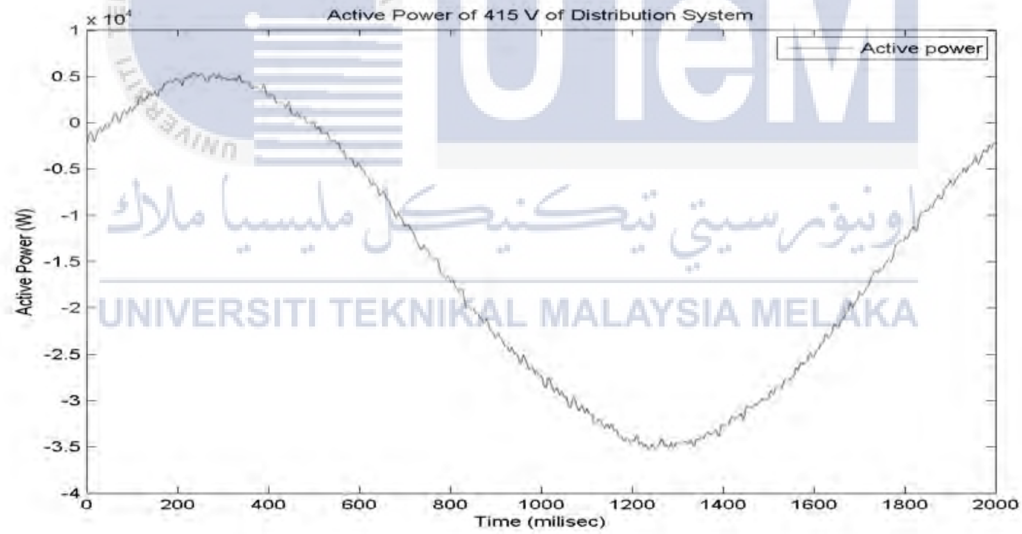



Figure 4.24: Primary active power

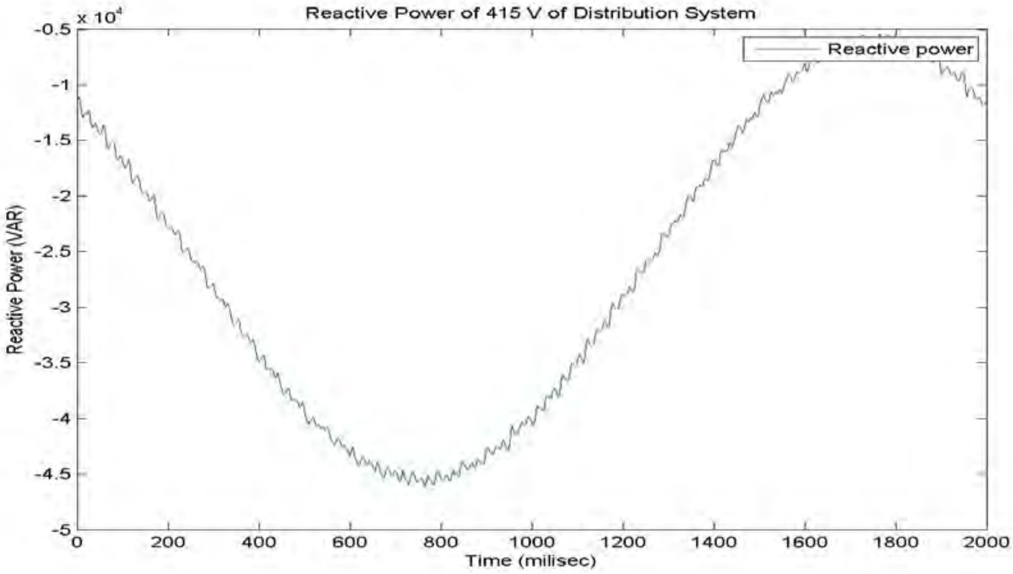



Figure 4.25: Primary reactive current

From Figure 4.2, the three phase primary voltage is 415 V. From Figure 4.23, the three phase secondary current is 80 A. From Figure 4.24, the active power is 5000 W and from the Figure 4.25, the reactive power is -5000 VAR. This result is shown at 415 V of distribution system.



For 11 KV Distribution System

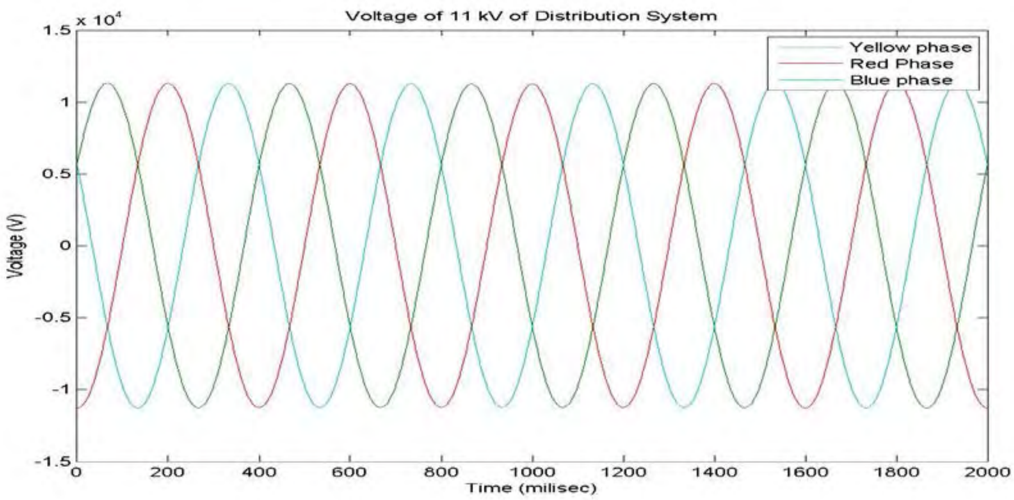



Figure 4.26: Three-phase secondary voltage

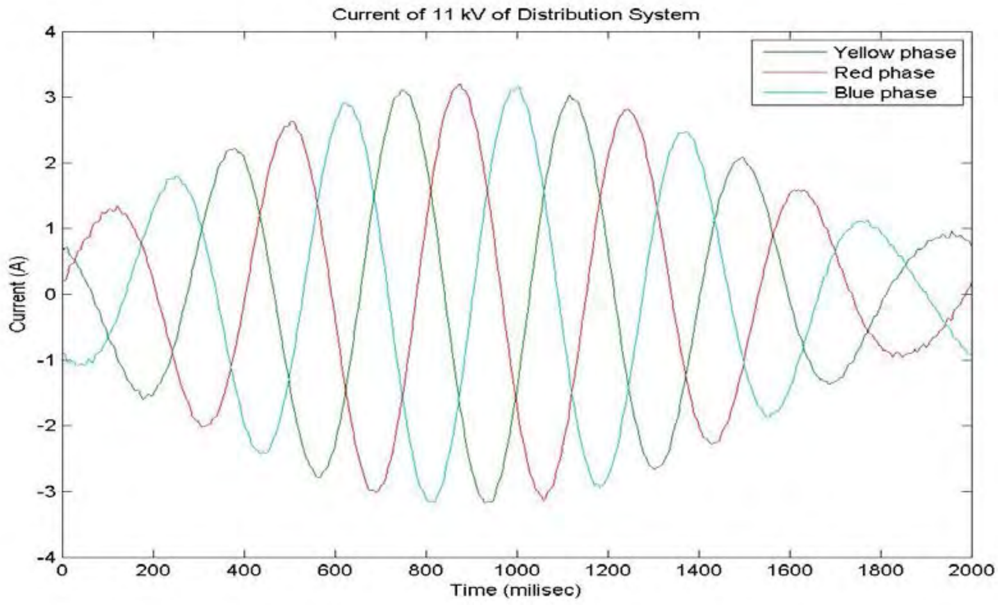



Figure 4.27: Three-phase secondary current

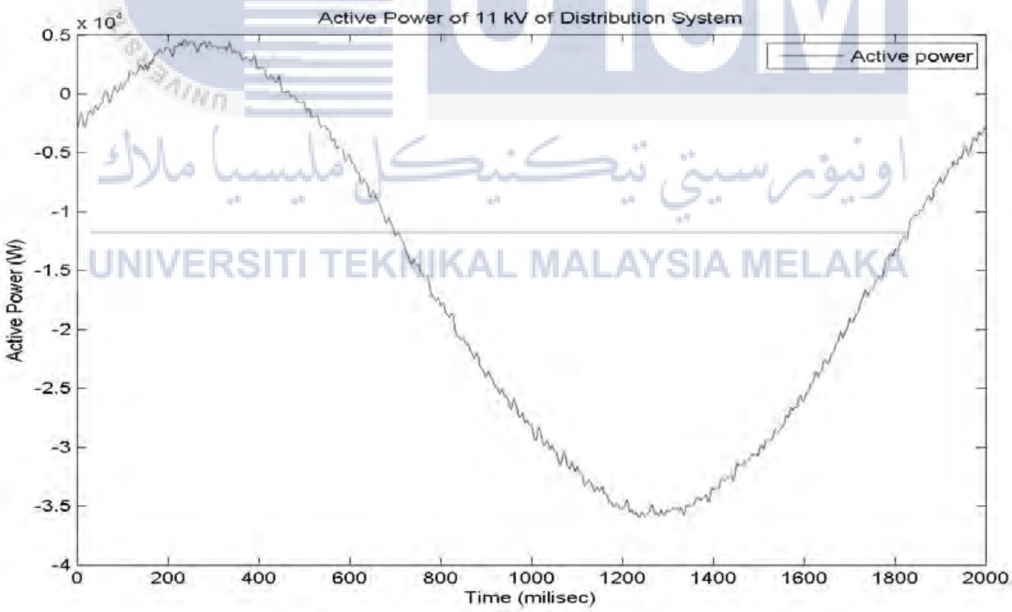



Figure 4.28: Secondary active power

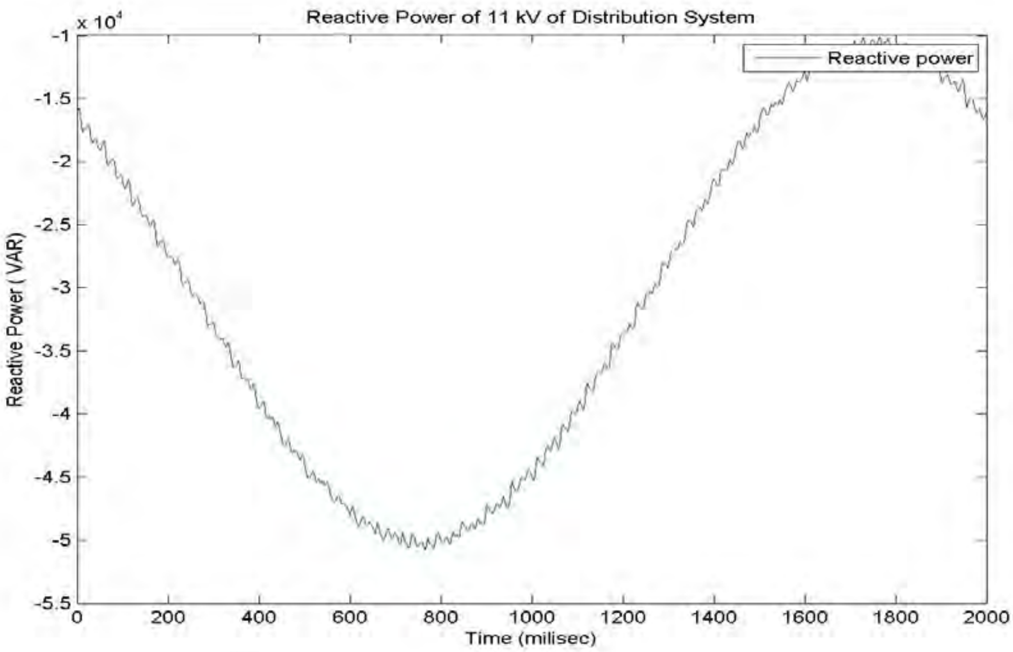



Figure 4.29: Secondary reactive power

From Figure 4.26, the three phase primary voltage is 11 kV. From Figure 4.27, the three phase secondary current is 3 A. From Figure 4.28, the active power is 5000 W and from the Figure 4.29, the reactive power is -10kVAR. This result is shown at 11 kV of distribution system.



**Case 1: GridDisconnected Mode**

For grid-disconnected mode, the breaker is open. The voltage of MT is 30 V then step-up to 50 V. The active power of MT is 80 W then after step-up, the active power is 40W. The voltage of battery is 130 V and the current is 4 A. The active power of battery is 780 W. The frequency for this system is 59.89 Hz. Figure 4.25 shows the frequency during grid-disconnected mode. The result that obtained from this simulation as shown as below:

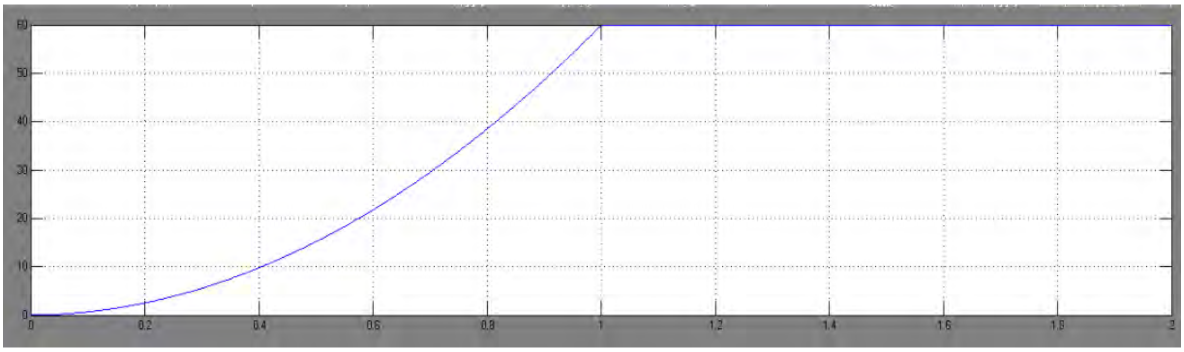


Figure 4.30: The frequency in grid-disconnected

For 415 V Distribution System

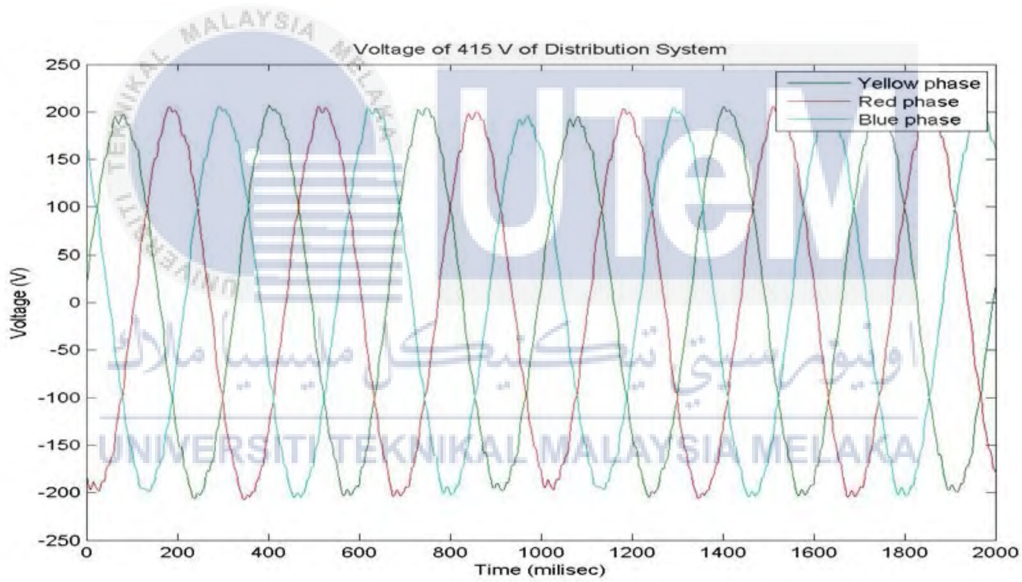



Figure 4.31: Three-phase primary voltage

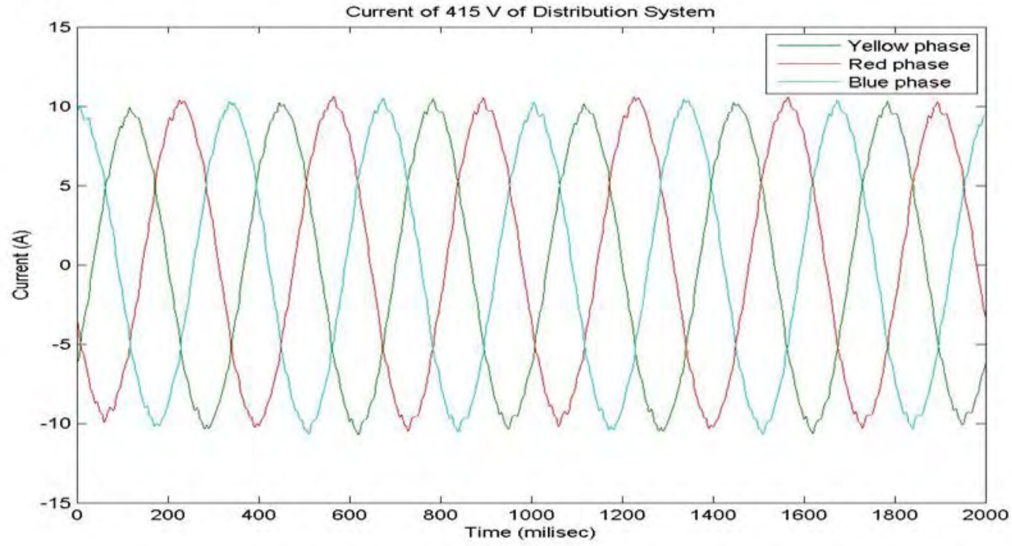



Figure 4.32: Three-phase primary current

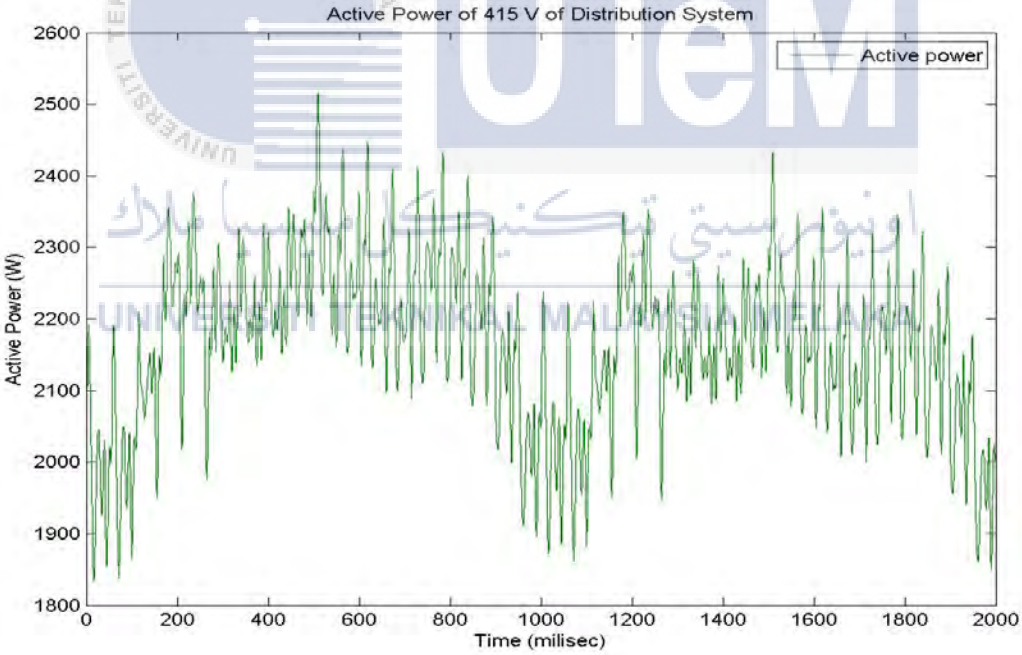



Figure 4.33: Primary active power

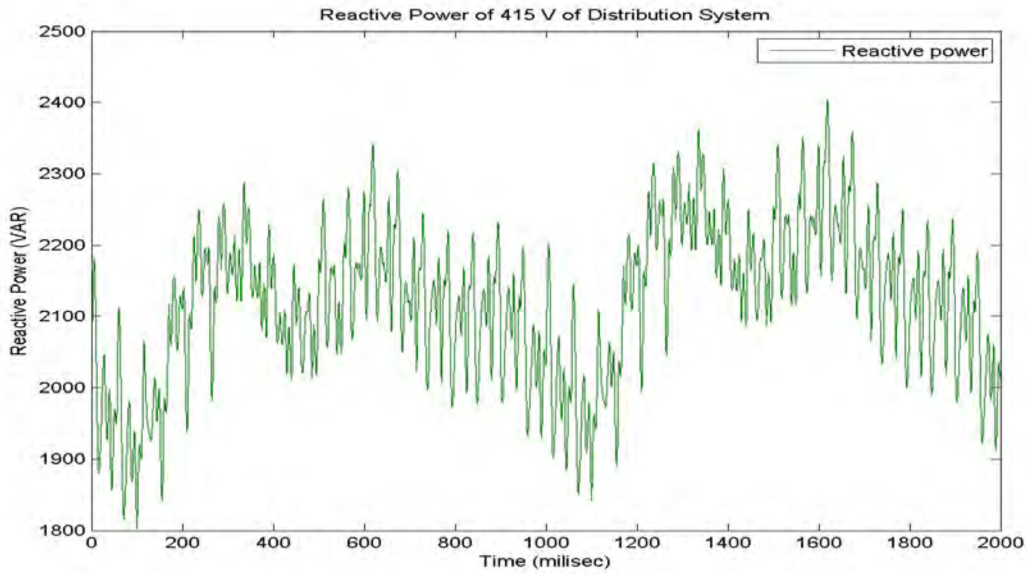



Figure 4.34: Primary reactive power

From Figure 4.31, the three phase primary voltage is 200 V. From Figure 4.32, the three phase secondary current is 10 A. From Figure 4.33, the active power is 2500 W and from the Figure 4.34, the reactive power is 2300 VAR. This result is shown at 415 V of distribution system.

For 11 KV Distribution System

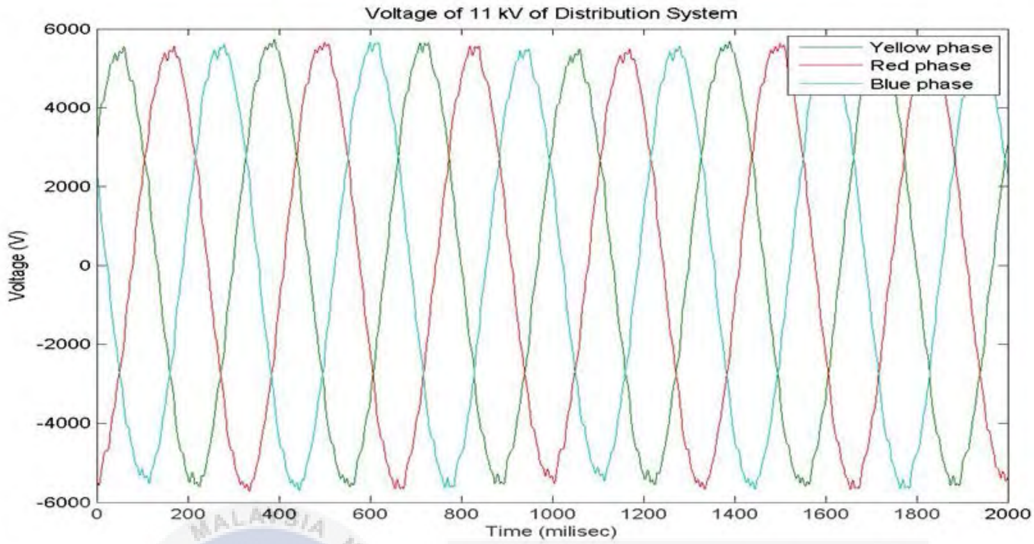



Figure 4.35: Three-phase secondary voltage

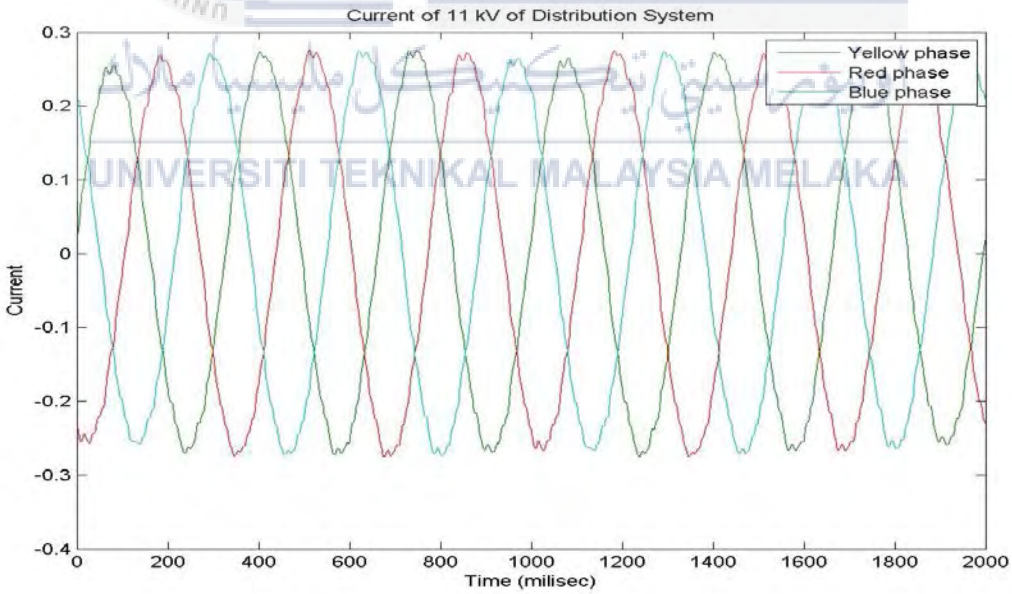



Figure 4.36: Three-phase secondary current

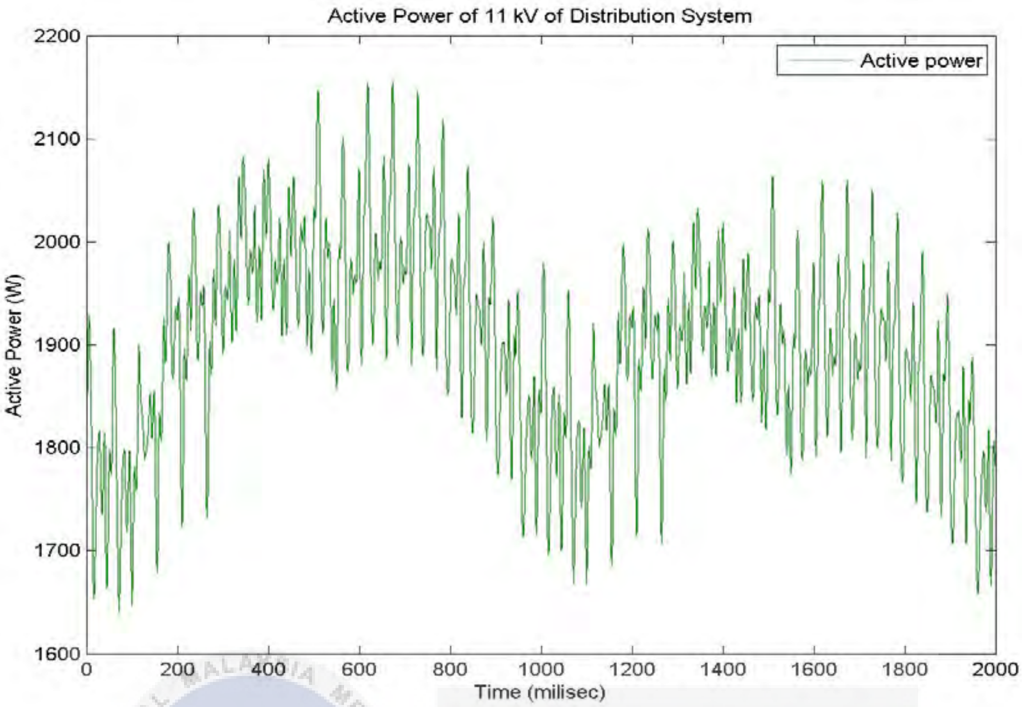



Figure 4.37: Secondary active power

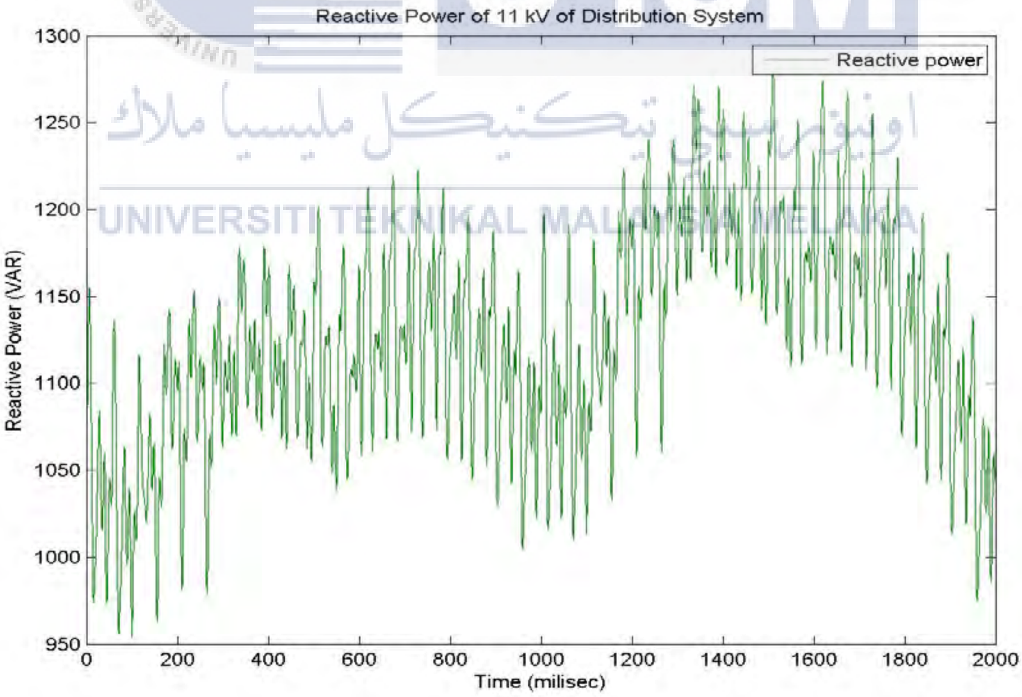



Figure 4.38: Secondary reactive power

From Figure 4.35, the three phase primary voltage is 6000 V. From Figure 4.36, the three phase secondary current is 0.3 A. From Figure 4.37, the active power is 2100 W and from the Figure 4.38, the reactive power is 1250 VAR. This result is shown at 11 kV of distribution system.

Comparison between grid-connected and grid-disconnected

Table 4.1 below shows the comparison of system in grid-connected and grid-disconnected at 415 V and 11 KV distribution system. Table 4.2 below shows the frequency for this system either in grid connected or grid-disconnected.

Table 4.1: Comparison of System in Grid-Connected or Grid-Disconnected

| Distribution system | Parameter | Grid-connected | Grid-disconnected |
|---|---|---|---|
| 415 V | Voltage | 415 V | 200 V |
| | Current | 80 A | 10 A |
| | Active Power | 5000 W | 2500 W |
| | Reactive power | -5000 VAR | 2300 VAR |
| 11 Kv | Voltage | 11 Kv | 6 KV |
| | Current | 3A | 0.3 A |
| | Active Power | 5000 W | 2100 W |
| | Reactive Power | -10 kVAR | 1250 VAR |



From Table 4.1, the voltage at 415 V and 11 KV distribution system in grid-connected is satisfied with required voltage which 415 V and 11 kV.For grid-connected, the voltage and current at 415 V distribution system are 415 V and 80 A. The voltage and current at 11 KV distribution system are 11 KV and 3 A. For grid-disconnected, the voltage and current at 415 V distribution system are 250 V and 0.4 A. Meanwhile, for the voltage and current at 11 KV distribution system are 7 KV and 0.01 A. The voltages at grid connected are higher than grid-disconnected. It is because due to high load demand and did not have voltage support from the grid.

The active power in grid-connected are higher than system in grid-disconnected. It is because, the voltages at grid connected are higher than grid-disconnected. The load demand A is 10 kW. The power supply to the load A are 2620 W in grid-connected and 780 W in grid-disconnected.Meanwhile, the load demand B is also 10 kW. The power supply to the load B are 5000 W in grid-connected and 2100 W in grid-disconnected. It shows that, the power supply cannot supply enough power to the load demand A and B. In order to get enough supply, the power load need to reduce. The power output can be increased by adjust the value of load. The reactive power in grid connected is negative. Negative reactive power generated means that reactive power is flowing from the grid to the MT. It happened when MT field is under-excited or induction MT is being used.

To get the proper and synchronous system, there are many important part that make the system works well. For example, the important concern for making MT as DG are controlling the inverter that make micro-sources capable to deliver with the grid. There are two work plan to control the inverter which is PQ inverter control and voltage source inverter (VSI) control. PQ controlling are fitting for connected to grid in dealing the active and reactive power. The second concern is harmonic which makes the load waveforms are disputed. These harmonics are the effect from switching in inverter.

Table 4.2 below shows the frequency for this system either in grid connected or grid-disconnected.

Table 4.2: Frequency of MG System

| Frequency | Grid-connected | Grid-disconnected |
|---|---|---|
| | 50.04 Hz | 59.26 Hz |

The frequency when grid connected is 50.04 Hz. It is shows there compatible frequency between distribution generation and grid. The frequency of grid had been set in load frequency control. The frequency when grid-disconnect is 59.26 Hz. The frequency is a bit higher than required frequency, which is 50 Hz. It shows the frequency are not synchronized since both inverter of MT and battery also not synchronized. The inverter had pulse generator and filter connected to set the frequency of system. The noise and total harmonic distortion also affect the frequency.

# CHAPTER 5

# CONCLUSION & RECOMMENDATION

## 5.1 Introduction

This chapter will summarize all the methods, results and discussion of the study. Also, conclusion of the achievement or finding in order to help the improvement of prosthesis control purposes.



## 5.2 Conclusion

In conclusion, the objectives(i) was achievedThe MT MG systemby using MT and battery storage system MG had been designed by using MATLAB Simulink Software. The model of MG system consists of MT, battery storage, inverter, the three-phase RLC load block, and many more. Each block parameter has its own functions. The system had simulated and analysis. The objective (ii) also achieved. This MG system had been simulated in grid-connected and grid-disconnected mode. The results from this both mode had compared and analyzed. If the system not synchronous, the causes had been analyzed.

## 5.3 Recommendation

In order to complete the overall FYP, there are several future works that need to be done. The MG system must be designed carefully in many aspect such as synchronous voltage and frequency and their control element. So, the system can be use without any faults. The designing of MG system can be used by another software such as PSCAD. Besides that, another DG likes PV and wind turbine can be used as energy source in MG system.

**REFERENCES**

[1] Chen Jian; CheYanbo; Zhang Jijie, *Optimal configuration and analysis of isolated renewable power systems*, Power Electronics Systems and Applications (PESA), 2011 4th International Conference,June 2011, vol., no., pp.1-4, 8-10

[2] Singh, A., &Surjan, B. S. (2014*). MICROGRID : A REVIEW*, 185–198

[3] B. Lasseter, *Microgrids [distributed power generation]*, Power Engineering Society Winter Meeting, 2001. IEEE, Columbus, OH, 2001, pp. 146-149 vol.1

[4] Rajdeep Chowdhury, Tilok Boruah, *Design of a Microgrid System Matlab/Simulink*, July 2015, Vol.4, Issue 7.

[5] Benjamin Kroposki; et.al, *Making Microgrid Works*, IEEE Power & Energy, 2008 IEEE, vol May/ June, 2008, pg40-53

[6] Georgakis, D.; Papathanassiou, S. Hatziargyriou, N. Engler, A.Hardt, C., *Operation of a prototype microgrid system based on micro-sources quipped with fast-acting power electronics interfaces,*Power Electronics Specialists Conference, 2004. PESC 04. 2004 IEEE 35th Annual,2004, vol.4, no., pp.2521-2526 Vol.4,

[7] Lasseter,R.H, *Microgrid and Distributed Generation*, Journal of Engineering, 2007

[8] Saha A.K, *Study of Microturbine Models in Islanded and Grid Connected Mode*, Journal of Energy & Power Engineering/19348975, 20110901

[9] Saha, A.K. Chowdhury, S. Chowdhury, S.P. Crossley, P.A., *Modeling and Performance Analysis of a Microturbine as a Distributed Energy Resource*, Energy Conversion, IEEE Transactions, June 2009, vol.24, no.2, pp.529-538,

[10] Gaonkar, D.N. Patel, R.N., *Modeling and Simulation of Microturbine based Distributed Generation System,* Power India Conference, 2006 IEEE , vol., no., pp.5 pp.-, 0-0 0

[11] Guda, S.R., Wang, C.Nehrir, M.H., *A Simulink-based microturbine model for distributed generation studies,*Power Symposium, 2005. Proceedings of the 37th Annual North American, 23-25 Oct. 2005, vol., no., pp.269-274

[12] Nayak, S.K., Gaonkar, D.N., *Modeling and performance analysis of microturbine generation system in grid connected/islanding mode*,Power Electronics, Drives and Energy Systems (PEDES), 2012 IEEE International Conference, 16-19 Dec. 2012, vol., no., pp.1-6,

[13] States, U., & Protection, E. *Renewable Energy Fact Sheet : Microturbines,* August, 2013

[14] Rahmani, R., Tayyebi, M., Mahmodian, M. S., & Shojaei, A. A. (2011). *Designing Dynamic Controller and Hybrid Active Filter for a Grid Connected Micro- Turbine to Analyze the Harmonic Effects,5*(11), 2219–2229.

[15] Joseph, a, & Shahidehpour, M. (2006). *Battery storage systems in electric power systems. Power Engineering Society General Meeting*, 1–8.

[16] D SAUER. *Storage System for Reliable Future Power Supply Networks̋ , Urban Energy Transition*, 2008

[17] Simon Schwunk: *Battery System for Storing Renewable Energy, Report, Fraunhofer-InstitutefurSolareEnergie*, April 2011