AVERAGE DYNAMICAL FREQUENCY BEHAVIOUR FOR ISLANDED MICRO-GRID SYSTEM WITH MULTIPLE GENERATORS

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DECLARATION

I declare that this thesis entitled "AVERAGE DYNAMICAL FREQUENCY BEHAVIOUR FOR ISLANDED MICRO-GRID SYSTEM WITH MULTIPLE GENERATORS is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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APPROVAL

I hereby declare that I have checked this report entitled "AVERAGE DYNAMICAL FREQUENCY BEHAVIOUR FOR ISLANDED MICRO-GRID SYSTEM WITH MULTIPLE GENERATORS" and in my opinion, this thesis it complies the partial fulfillment for awarding the award of the degree of Bachelor of Electrical Engineering with Honours

Signature : ....

Supervisor Name : ....

Date : ....

DEDICATIONS

To my beloved mother and father

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In the name of Allah, the most Gracious and the most Merciful

Alhamdulillah, graceful praises to Allah for the strengths and His blessing in completing this project. In preparing this report, I was in contact with many people. They have contributed towards my understanding and thought. In particular, I wish to express my biggest appreciation to my main project supervisor, Mohd Saifuzam Bin Jamri for his guidance, patience, enthusiasm and constant support. He invaluable help of constructive comments and suggestions throughout this project have contributed a lot to the success of this project. I am truly grateful for his tolerance and for all the time that he had spent proofreading and correcting my mistakes throughout the making of this very project.

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ABSTRACT

A microgrid is a part of a power system which can operates in grid connected and islanding mode with multiple generators connected to the microgrid. When the microgrid operates in island mode, the load is dominantly supplied by the local sources. The crucial situation is supply and demand need to be balance while the generators in the same system is actually not in coherent. If there are any imbalance in the network, the system can lead to significant frequency deviations. This is why this project need to be done to study the behavior effect of the frequency. In order to analyses the network, lots of mathematical equations has been derived to model the physical network. The objective of this paper is to investigate how to model on islanding of microgrid system with multiple generators and to identify an approach in finding the average dynamical frequency, also to analyze the frequency behaviour with variation of load demand. The literature review, reviews other people papers on the understanding of microgrid and distributed generation which related to the power system study involved the large electrical power system network with multiple generator. The two generator model involving tie-line bias control is simulated in linear time invariant through state space equation using Simulink. All the parameters are set and substitute in the state space equation. The simulation results show the frequency behavior of the generator in the system when there is load change occur to the system. The frequency of the generator that is near to the load change will drop more compare to the other generator and with the presence of automatic generation control, the frequency will return back to its nominal value. The average dynamical frequency is find using similarity method and compared with the conventional method.

ABSTRAK

Mikrogrid adalah sebahagian daripada sistem kuasa yang boleh beroperasi dalam mod bersambung dan mod "islanded" dengan beberapa penjana yang disambungkan ke mikrogrid. Apabila mikrogrid beroperasi di mod "islanded", bebannya dibekalkan oleh sumber-sumber tempatan. Keadaan yang kritikal adalah bekalan dan permintaan perlu seimbang manakala penjana dalam sistem yang sama sebenarnya tidak sepadan. Sekiranya terdapat ketidakseimbangan dalam rangkaian, sistem ini boleh menyebabkan penyimpangan kekerapan yang ketara terhadap frekuensi. Inilah sebabnya mengapa projek ini perlu dilakukan untuk mengkaji kesan kelakuan frekuensi. Untuk menganalisis rangkaian, persamaan-persamaan matematik telah diperoleh untuk model rangkaian fizikal. Objektif projek ini adalah untuk menyiasat bagaimana untuk membuat model di mikrogrid dengan pelbagai generator dan untuk mengenalpasti pendekatan dalam mencari frekuensi dinamik purata, juga untuk menganalisis kelakuan frekuensi dengan variasi permintaan beban. Semakan kesusasteraan, mengkaji kertas orang lain mengenai pemahaman tentang mikrogrid dan generasi yang diedarkan yang berkaitan dengan kajian sistem kuasa melibatkan rangkaian sistem kuasa elektrik yang besar dengan pelbagai generator. Model dua penjana yang melibatkan kawalan bias talian tali disimulasikan dalam invarian linier melalui persamaan ruang menggunakan Simulink. Semua parameter ditetapkan dan menggantikan persamaan ruang. Hasil simulasi menunjukkan kelakuan frekuensi penjana dalam sistem apabila terdapat perubahan beban berlaku pada sistem. Kekerapan penjana yang mendekati perubahan beban akan menurun berbanding dengan penjana yang lain dan dengan kehadiran kawalan generasi automatik, frekuensi akan kembali kepada nilai nominalnya. Frekuensi dinamik purata telah dicari menggunakan kaedah persamaan dan dibandingkan dengan kaedah konvensional.

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CHAPTER 1

INTRODUCTION

1.1 Project Background and Motivation

Microgrid is a part of a power system which used an electricity sources consist dispatchable generation and non-dispatchable renewable energy that are capable of operating in either parallel or independent towards the main power grid (macro grid). The microgrid can operate in both grids connected and islanded mode. When the microgrid is operates in island mode, the load is dominantly supplied by the local sources. The crucial situation in this case is supply and demand need to be balance. If there are any imbalance in the network, the system can lead to significant frequency deviations. Many researches which related to the power system study with variety of motivation has been done and most of the research work involved the large electrical power system network with multiple generator. In order to analyses the network, lot of mathematical equations has been derived to model the physical network. These mathematical models are crucial to implement and make the researcher think about the way to simplify by removing the unwanted parameter and put some assumption and approximation. According to page 511 of [2], generators that belong in the same area are said to be coherent and one equivalent generator can represents the group of coherent generators. One of the steps in controlling the microgrid in islanded mode are having coherent generators because it is easier to simplify and to analyze. However, in reliability of the data analysis, the machine that swings together in the same station is actually not coherent because, each of the generators is connected in different distance of transmission line. Therefore, this project considered the transmission line model and also the different parameters for each generator. Hence, an average dynamical behavior of system frequency is determined.

1.2 Problem Statement

When the islanded microgrid system with multiple generators are not coherent, the transmission line in the microgrid system and the parameters of the generator need to be considered. Also, during islanded mode, the microgrid is very sensitive to the disturbance or varying of loads. Load disturbance will affect the system frequency which correspond to the change of generator's dynamical behaviour and may causing to the stability problem.

1.3 Objective

1. To develop linear model for islanded micro-grid system consist of multiple generators
2. To analyze the effect of each generator in terms of frequency dynamical behavior
3. To anzlyze the average dynamical frequency behavior under sudden variation of load demand
4. To identify an approach in finding average dynamical frequency of the microgrid system

1.4 Scope

The scope of the project is to model multiple generators for islanded microgrid system in order to study and analyze the average frequency behavior. Also, the microgrid system is described through state-space linear time invariant. Simulation program that can be used for this project is SIMULINK.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter explains on the theories related to the microgrid power system. The understanding on the theories and operation of microgrid power system, is important before the simulation starts. This chapter includes the operation and theories of islanded microgrid, distributed generation, and islanded microgrid system with multiples generators.

2.2 Islanded Microgrid

According to the operating characteristics of Microgrid, the islanded Microgrid stability mainly depends on the structure of Microgrid, the capacity of stored-energy DGs, and the control strategy of DGs [1]. Figure 2.1 shows an example of islanded microgrid network.

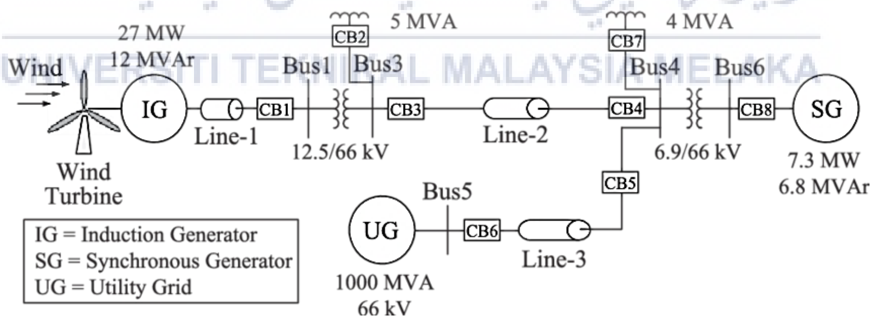

Figure 2.1: Example of islanded microgrid

In order for the consumers to be able to utilize their electrical appliance and electronics in daily life, the consumers loads are connected to the power sources through the main grid. When there are utility disturbance or fault occur in the grid system, the main grid will breakdown and it will affect all the consumers if there are no backup energy[2][3]. With microgrid system, when the main grid is disconnected due to disturbance occur, the microgrid can operate independently and able to supply power to the consumer. This will lead to the islanding mode of the microgrid. A microgrid operation can be operated in both grids connected and islanded modes of operation [4][5]. Microgrid operated in islanded mode is very sensitive to power imbalance between supply and demand and can cause frequency deviation. If the demand is more than the supply and the microgrid network operating in severe condition even after the secondary control, the separation of less important load need to be performed [6][7].

2.3 Distributed Generation

Distributed energy resources are demand and supply side resources that is distributed throughout the electric distribution system to meet the energy needs by the customers [8]. There are two types in distributed generation units which are dispatchable and non-dispatchable sources. A dispatchable DG source can quickly response to the system and has a capacity to meet the real and reactive power commands. In the grid-connected mode, the dispatchable DG units are expected to supply pre-specified power, similar to a conventional utility system [9]. In the autonomous mode of operation. The Non-dispatchable DG on the other hand unable to response quickly because the source is depending to the power that is provided by the main source from the main grid [10]. Therefore, when the microgrid is disconnected from the main grid, only dispatchable sources can quickly response and backup the rest connected system so that the local loads can have continuously supply.

2.4 Islanded microgrid with multiple generators

An islanded microgrid may consists of multiple numbers of local distributed generators [11]. A formation of the microgrid with multiples generators is far more economical than a single generator that serve a single load [12][13]. If there are two distributed generators connected in the islanded microgrid, the generators are commanded to each other to supply power to the demand when the power from main grid is disconnected. Both of the generators will generate active and reactive powers based on the demand from the local loads of the system [14]. The generators on the system might not be stable and can cause the frequency of in each of them to deviate.

2.5 Micro-grid network Frequency Response

During islanding condition, the frequency in the network can deviate below the nominal system frequency [15]. This is due to the large load variation in the system. The load can suddenly change and the system may become unstable. When the load demand is higher than the supply, the frequency will drop. On the other hand, When the supply is more than the load demand, the frequency will increase. When the frequency critically drops because of generator outage, this will lead to microgrid breakdown [22]. The location of the load variation also will affect the frequency response in each generator. If the variation of load increase near the first generator, the frequency at the first generator will oscillate more than the other generator. The frequency stability of an islanded microgrid and its sensitivity is different for the certain changes in system configuration [23][24].

2.6 State Space

The state space of a dynamical system is consist of the set of all possible states that describe the behavior of that system. Each coordinate is a state variable, and the values of all the state variables completely describes the state of the system[25]. In other words, each point in the state space is corresponds to a different state of the system The state of a dynamic system is in refer to a minimum set of variables that is known as state variables which are fully describe the system and its response to any given set of inputs[26]. A standard form for the state equations is used throughout system dynamics. For standard form, a mathematical description for the system is expressed as a set of n coupled first-order ordinary differential equations which are known as the state equations. This is where the time derivative of each state variable is expressed in terms of the state variables x1(t),...,xn(t) and the system inputs u1(t),...,u r(t).According to [26], each of the functions fi (x,u,t), (i =1,...,n) may be a general nonlinear, time varying function of the state variables, the system inputs, and time. Hence, the general case the form of the n state equations for linear system is written as:

$$\dot{x}_n = fn\ (x,u,t) \tag{2-1}$$

2.7 Two Area with Tie-Line Connection

The load variation on a power system causes changes in frequency from their nominal values resulting in loss of generation due to tripping of lines and even blackouts [15][16]. The reactive power is less sensitive to the changes in frequency and is mainly dependent on the changes in voltage magnitude. While, changes in real power mainly affect the system frequency [15][17]. Interconnection of electrical power systems has been the main trend in modern power grid construction [18][19]. Distributed power systems can assist each other in case of emergencies due to their varied load demand [20][21].

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter contains method of modelling an islanded microgrid system with multiple generators. The work was divided into two phases. In the first phase, the microgrid network was modelled with involve only one generator without automatic generation control (AGC). In the second phase, multiple generator, tie-line and automatic generation control (AGC) was considered. Both of modelling phases was using the state space averaging technique. At the end of the process, average dynamical behavior of the frequency was determined using decomposition and similarity transformation approach.

3.2 Flowchart

Below in Figure 3.1 shows the flowchart of overall project

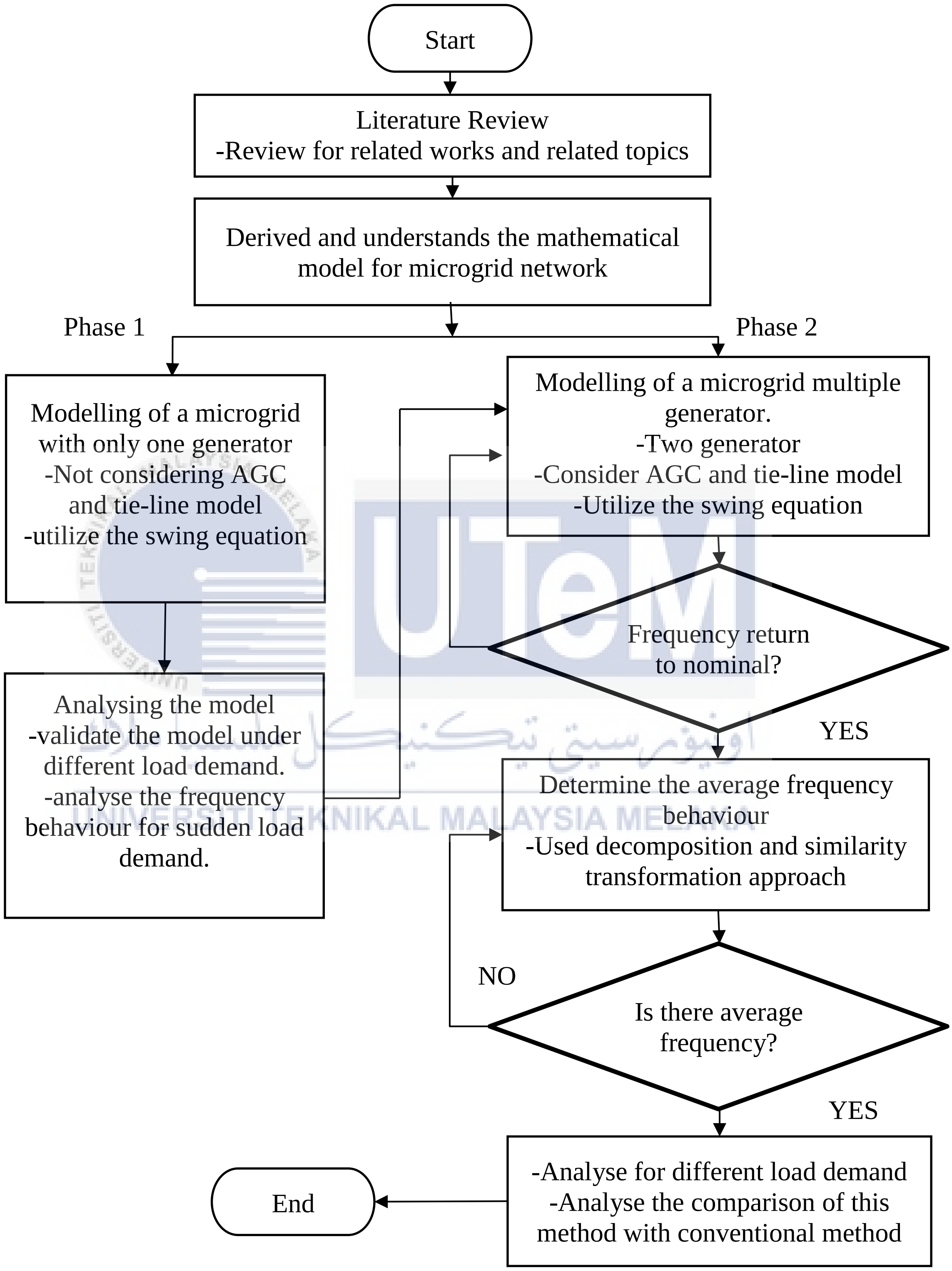

Figure 3.1: Flowchart of overall process

3.3 Mathematical Modelling

3.3.1 Generator Model

Swing equation is used in this model in order to describe the behavior of generator.

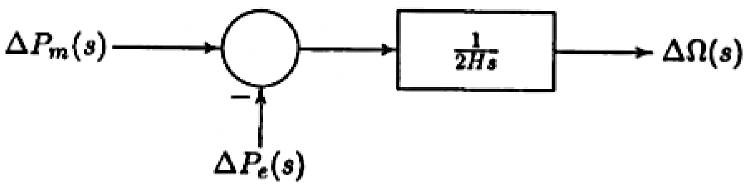

Figure 3.2: Generator Model

Where,

$\Delta\Omega(s) = \Delta\omega$, ΔP_m is mechanical power deviation, ΔP_e is electrical power deviation and $\Delta\omega$ is rotation speed deviation. By applying the swing equation of synchronous generation:

$$\frac{2H}{\omega_S}\frac{d^2\Delta\delta}{dt^2} = \Delta Pm - \Delta Pe \quad (3\text{-}1)$$

In terms of small deviation in speed:

$$\frac{d\Delta\frac{\omega}{\omega_s}}{dt} = \frac{1}{2H}[\Delta Pm - \Delta Pe] \quad (3\text{-}2)$$

With the speed expressed in per unit and without explicit per unit notation:

$$\frac{d\Delta\omega}{dt} = \frac{1}{2H}[\Delta Pm - \Delta Pe] \quad (3\text{-}3)$$

The real power transferred over the tie-line is described by

$$P_{12} = \frac{|E_1||E_2|}{X_{12}} \sin\delta_{12} \quad (3\text{-}4)$$

Where $X_{12} = X_1 + X_{tie} + X_2$ and $\delta_{12} = \delta_1 - \delta_2$. Linearizing this equation by assuming the small deviation in the tie line power flow ΔP_{12} from the nominal value,

$$\Delta P_{12} = \frac{dP_{12}}{d\delta_{12}}|_{\delta 12}\ \delta_{12} = P_s \Delta\delta_{12} \tag{3-5}$$

Ps = P1 is the slope of the power angle at the initial operating angle δ_{12°

As shown in Figure 3.3

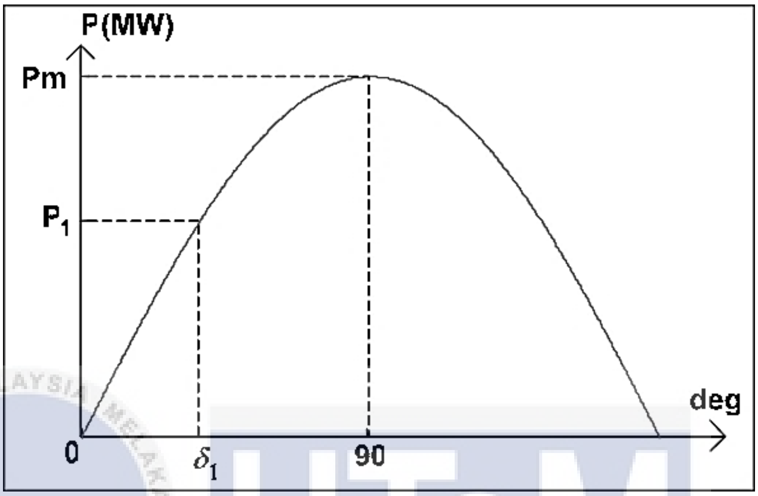

Figure 3.3: Power angle curve

The tie line power deviation:

$$\Delta P_{12} = P_s(\Delta\delta_1 - \Delta\delta_2) \tag{3-6}$$

The Eq.(3-6) and Eq.(3-3) is combine and become complete equation for rotating generator as follows

Generator 1:

$$\frac{d\Delta}{dt}\omega_1 = \frac{1}{2H_1}(\Delta P_{m1} - P_s(\Delta\delta_1 - \Delta\delta_2) - D_1\Delta\omega_1 - \Delta P_{L1}) \tag{3-7}$$

$$\frac{d\Delta}{dt}\omega_1 = \frac{1}{2H_1}(\Delta P_{m1} - P_s\Delta\delta_1 - P_s\Delta\delta_2 - D_1\Delta\omega_1 - \Delta P_{L1}) \tag{3-8}$$

Where,

$$D_1\Delta\omega_1 - \Delta P_{L1} = \Delta P_e \tag{3-9}$$

Therefore,

$$\frac{d\Delta}{dt}\omega_1 = \frac{\Delta P_{m1}}{2H_1} - \frac{P_s\Delta\delta_1}{2H_1} - \frac{P_s\Delta\delta_2}{2H_1} - \frac{D_1\Delta\omega_1}{2H_1} - \frac{\Delta P_{L1}}{2H_1} \tag{3-10}$$

Generator 2:

$$\frac{d\Delta}{dt}\omega_2 = \frac{1}{2H_2}(\Delta P_{m2} - P_s(\Delta\delta_2 - \Delta\delta_1) - D_2\Delta\omega_2 - \Delta P_{L2}) \quad (3\text{-}11)$$

$$\frac{d\Delta}{dt}\omega_2 = \frac{1}{2H_2}(\Delta P_{m2} - P_s\Delta\delta_2 - P_s\Delta\delta_1 - D_2\Delta\omega_2 - \Delta P_{L2}) \quad (3\text{-}12)$$

Where,

$$D_2\Delta\omega_2 - \Delta P_{L2} = \Delta P_e \quad (3\text{-}13)$$

Therefore,

$$\frac{d\Delta}{dt}\omega_2 = \frac{\Delta P_{m2}}{2H_2} - \frac{P_s\Delta\delta_2}{2H_2} - \frac{P_s\Delta\delta_1}{2H_2} - \frac{D_2\Delta\omega_2}{2H_2} - \frac{\Delta P_{L2}}{2H_2} \quad (3\text{-}14)$$

3.3.2 Prime Mover Model

This prime mover model is for describing behavior of turbine

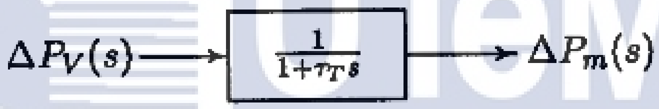

Figure 3.4: Prime Mover Model

$$\frac{\Delta P_m(s)}{\Delta P_V(s)} = \frac{1}{1 + \tau_T s} = \frac{1/Tt}{s + 1/Tt} \quad (3\text{-}15)$$

$$\Delta Pm\left(s + \frac{1}{Tt}\right) = \Delta Pm\left(\frac{1}{Tt}\right) \quad (3\text{-}16)$$

$$\Delta\dot{P}m + \frac{\Delta\dot{P}m}{Tt} - \frac{\Delta Pv}{Tt} = 0 \quad (3\text{-}17)$$

Choosing the state variable,

$$x_1 = Pm, \qquad x_2 = \dot{P}m \quad (3\text{-}18)$$

Then, differentiate it

$$\dot{x}_1 = \dot{P}m, \qquad \dot{x}_2 = \ddot{P}m \quad (3\text{-}19)$$

The equations are substitute (eq 3.7. into eq.3.8)

$$\dot{x_1} = x_2 = \dot{Pm} \quad (3\text{-}20)$$

$$\dot{Pm} = \frac{Pv}{Tt} - \frac{Pm}{Tt} \quad (3\text{-}21)$$

$$\frac{d\Delta Pm}{dt} = \frac{1}{Tt}(\Delta Pv - \Delta Pm) \quad (3\text{-}22)$$

Prime mover 1:

$$\frac{d\Delta}{dt}P_{m1} = \frac{1}{\tau_{T1}}\left(\Delta P_{gv1} - \Delta P_{m1}\right) \quad (3\text{-}23)$$

Therefore,

$$\frac{d\Delta}{dt}P_{m1} = \frac{\Delta P_{gv1}}{\tau_{T1}} - \frac{\Delta P_{m1}}{\tau_{T1}} \quad (3\text{-}24)$$

Prime mover 2:

$$\frac{d\Delta}{dt}P_{m2} = \frac{1}{\tau_{T2}}\left(\Delta P_{gv2} - \Delta P_{m2}\right) \quad (3\text{-}25)$$

Therefore,

$$\frac{d\Delta}{dt}P_{m2} = \frac{\Delta P_{gv2}}{\tau_{T2}} - \frac{\Delta P_{m2}}{\tau_{T2}} \quad (3\text{-}26)$$

3.3.3 Speed Governer Model

Governor model is used to present primary control and how the turbine been control.

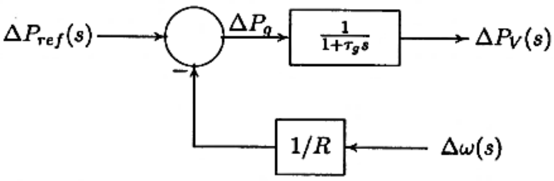

Figure 3.5: Governor Model

$$\frac{\Delta Pv}{\Delta Pg} = \frac{1}{Tgs + 1} \quad (3\text{-}27)$$

$$\Delta Pv = \frac{\Delta Pg / Tg}{s + 1/Tg} \quad (3\text{-}28)$$

$$\Delta Pv\left(s + \frac{1}{Tg}\right) = \frac{\Delta Pg}{Tg} \quad (3\text{-}29)$$

$$\dot{Pv} + \frac{Pv}{Tg} = \frac{Pg}{Tg} \quad (3\text{-}30)$$

Choosing the state variables,

$$x_1 = Pv, \qquad x_2 = \dot{Pv} \quad (3\text{-}31)$$

Differentiate the variables,

$$\dot{x_1} = \dot{Pv}, \qquad \dot{x_2} = \ddot{Pv} \quad (3\text{-}32)$$

The equations (3.16) and (3.17) are substitute,

$$\dot{x_1} = x_2 = \dot{Pv} \quad (3\text{-}33)$$

$$\dot{Pv} = \frac{\Delta Pg}{Tg} - \frac{\Delta Pv}{Tg} \quad (3\text{-}34)$$

$$\frac{dPv}{dt} = \frac{1}{Tg}(\Delta Pg - \Delta Pv)\ ;\ \Delta Pg = \Delta Pref - \frac{\Delta\omega}{R} \quad (3\text{-}35)$$

Since we assume $\Delta Pref = 0$;

$$\frac{d\boldsymbol{Pv}}{\boldsymbol{dt}} = \frac{\mathbf{1}}{\boldsymbol{Tg}}\left(-\frac{\Delta\boldsymbol{\omega}}{\boldsymbol{R}} - \Delta\boldsymbol{Pv}\right) \tag{3-36}$$

For speed governor behavior in multi-area system, $\Delta Pref$ is not equal to 0,

Governor 1:

$$\frac{\boldsymbol{d}\Delta}{\boldsymbol{dt}}\boldsymbol{P}_{\boldsymbol{gv1}} = \frac{\mathbf{1}}{\boldsymbol{\tau}_{\boldsymbol{gv1}}}\left(\boldsymbol{K}_{\mathbf{1}}\Delta\boldsymbol{P}_{\boldsymbol{ref1}} - \frac{\Delta\boldsymbol{\omega}_{\mathbf{1}}}{\boldsymbol{R}_{\mathbf{1}}} - \Delta\boldsymbol{P}_{\boldsymbol{gv1}}\right) \tag{3-37}$$

Therefore,

$$\frac{\boldsymbol{d}\Delta}{\boldsymbol{dt}}\boldsymbol{P}_{\boldsymbol{gv1}} = \frac{\boldsymbol{K}_{\mathbf{1}}\Delta\boldsymbol{P}_{\boldsymbol{ref1}}}{\boldsymbol{\tau}_{\boldsymbol{gv1}}} - \frac{\Delta\boldsymbol{\omega}_{\mathbf{1}}}{\boldsymbol{R}_{\mathbf{1}}\boldsymbol{\tau}_{\boldsymbol{gv1}}} - \frac{\Delta\boldsymbol{P}_{\boldsymbol{gv1}}}{\boldsymbol{\tau}_{\boldsymbol{gv1}}} \tag{3-38}$$

Governor 2:

$$\frac{\boldsymbol{d}\Delta}{\boldsymbol{dt}}\boldsymbol{P}_{\boldsymbol{gv2}} = \frac{\mathbf{1}}{\boldsymbol{\tau}_{\boldsymbol{gv2}}} = \left(\boldsymbol{K}_{2}\Delta\boldsymbol{P}_{\boldsymbol{ref2}} - \frac{\Delta\boldsymbol{\omega}_{\mathbf{2}}}{\boldsymbol{R}_{\mathbf{2}}} - \Delta\boldsymbol{P}_{\boldsymbol{gv2}}\right) \tag{3-39}$$

Therefore,

$$\frac{\boldsymbol{d}\Delta}{\boldsymbol{dt}}\boldsymbol{P}_{\boldsymbol{gv2}} = \frac{\boldsymbol{K}_{2}\Delta\boldsymbol{P}_{\boldsymbol{ref2}}}{\boldsymbol{\tau}_{\boldsymbol{gv2}}} - \frac{\Delta\boldsymbol{\omega}_{\mathbf{2}}}{\boldsymbol{R}_{2}\boldsymbol{\tau}_{\boldsymbol{gv2}}} - \frac{\Delta\boldsymbol{P}_{\boldsymbol{gv2}}}{\boldsymbol{\tau}_{\boldsymbol{gv2}}} \tag{3-40}$$

3.3.4 The tie-line bias control

To derive the mathematical model of two generator system, the two areas need to be connected to ensure the system operating so that the demands of areas are satisfied at the nominal frequency. Therefore, the tie-line equations are as follows

Tie-line 1:

$$\frac{d\Delta}{dt}P_{ref1} = \frac{d\Delta}{dt}ACE_1 = \Delta P_{12} + \frac{\Delta\omega_1}{R_1} - D_1\Delta\omega_1 \tag{3-41}$$

P is the tie line power deviation,

$$\Delta P_{12} = P_s(\Delta\delta_1 - \Delta\delta_2) \tag{3-42}$$

Let,

$$\Delta B_1 = \frac{\Delta\omega_1}{R_1} - D_1\Delta\omega_1 \tag{3-43}$$

Therefore,

$$\frac{d\Delta}{dt}P_{ref1} = \Delta P_{12} + \Delta B_1\Delta\omega_1 \tag{3-44}$$

Pref is feedback,

$$\frac{d\Delta}{dt}P_{ref1} = -(\Delta P_{12} + \Delta B_1\Delta\omega_1) \tag{3-45}$$

Sub (3-42) into (3-45),

$$\frac{d\Delta}{dt}P_{ref1} = -[P_s(\Delta\delta_1 - \Delta\delta_2) + \Delta B_1\Delta\omega_1] \tag{3-46}$$

$$\frac{d\Delta}{dt}P_{ref1} = -[P_s\Delta\delta_1 - P_s\Delta\delta_2 + \Delta B_1\Delta\omega_1] \tag{3-47}$$

Therefore,

$$\frac{d\Delta}{dt}P_{ref1} = -P_s\Delta\delta_1 + P_s\Delta\delta_2 - \Delta B_1\Delta\omega_1 \tag{3-48}$$

Tie-line 2:

$$\frac{d\Delta}{dt}P_{ref2} = \frac{d\Delta}{dt}ACE_2 = \Delta P_{21} + \frac{\Delta\omega_2}{R_2} - D_2\Delta\omega_2 \tag{3-49}$$

P is the tie line power deviation,

$$\Delta P_{21} = P_s(\Delta\delta_2 - \Delta\delta_1) \tag{3-50}$$

Let,

$$\Delta B_2 = \frac{\Delta\omega_2}{R_2} - D_2\Delta\omega_2 \tag{3-51}$$

Therefore,

$$\frac{d\Delta}{dt}P_{ref2} = \Delta P_{21} + \Delta B_2\Delta\omega_2 \tag{3-52}$$

Pref is feedback,

$$\frac{d\Delta}{dt}P_{ref2} = -(\Delta P_{21} + \Delta B_2\Delta\omega_2) \tag{3-53}$$

Sub (3-50) into (3-53),

$$\frac{d\Delta}{dt}P_{ref2} = -[P_s(\Delta\delta_2 - \Delta\delta_1) + \Delta B_2\Delta\omega_2] \tag{3-54}$$

$$\frac{d\Delta}{dt}P_{ref2} = -[P_s\Delta\delta_2 - P_s\Delta\delta_1 + \Delta B_2\Delta\omega_2] \tag{3-55}$$

Therefore,

$$\frac{d\Delta}{dt}P_{ref2} = -P_s\Delta\delta_2 + P_s\Delta\delta_1 - \Delta B_2\Delta\omega_2 \tag{3-56}$$

3.3.5 Average behavior equation

The average behavior is determined by using similarity transformation method so that the new states behavior is created which describe the plus-minus average behavior as shown in Eq.(3-57), (3-58), (3-59), (3-60), (3-61), (3-62), (3-63), (3-64), (3-65) and (3-66) below

$$\boldsymbol{\omega_a = \frac{1}{2}\omega_1 + \frac{1}{2}\omega_2} \tag{3-57}$$

$$\boldsymbol{\omega_b = \frac{1}{2}\omega_1 - \frac{1}{2}\omega_2} \tag{3-58}$$

$$\boldsymbol{\delta_a = \frac{1}{2}\delta_1 + \frac{1}{2}\delta_2} \tag{3-59}$$

$$\boldsymbol{\delta_b = \frac{1}{2}\delta_1 - \frac{1}{2}\delta_2} \tag{3-60}$$

$$\boldsymbol{P_{ma} = \frac{1}{2}P_{m1} + \frac{1}{2}P_{m2}} \tag{3-61}$$

$$\boldsymbol{P_{mb} = \frac{1}{2}P_{m1} - \frac{1}{2}P_{m2}} \tag{3-62}$$

$$\boldsymbol{P_{gva} = \frac{1}{2}P_{gv1} + \frac{1}{2}P_{gv2}} \tag{3-63}$$

$$\boldsymbol{P_{gvb} = \frac{1}{2}P_{gv1} - \frac{1}{2}P_{gv2}} \tag{3-64}$$

$$\boldsymbol{P_{refa} = \frac{1}{2}P_{ref1} + \frac{1}{2}P_{ref2}} \tag{3-65}$$

$$\boldsymbol{P_{refb} = \frac{1}{2}P_{ref1} - \frac{1}{2}P_{ref2}} \tag{3-66}$$

3.4 Parameters

The parameters that is used in this project is taken from [2] as shown in the Table 1 and Table 2 below :

Table 1 : Table of Parameter of a microgrid with single generator

Speed Regulation	R = 0.05
Frequency-sense load coefficient	D = 0
Inertia constant	H =1
Governor time constant	τ_{gv} = 0.2sec
Turbine time constant	τ_T = 0.5sec

Table 2 : Table of Parameter of a microgrid with two generator

Area	1	2
Speed regulation, R	0.05	0.0625
Frequency-sensitivity, D	0.6	0.9
Inertia constant, H	5	4
Governor time constant, τ_{gv}	0.2	0.3
Turbine time constant, τ_T	0.5	0.6
Integrator gain, Ki = 0.3		

3.1 Simulation Model for single generator

Based on the 3 equations from the mathematical modelling as shown below:

Refer from equation (3-3), Generator model

$$\frac{d\Delta\omega}{dt} = \frac{1}{2H}[\Delta Pm - \Delta Pe] \tag{3-3}$$

Refer from equation (3-22) , Prime mover model

$$\frac{d\Delta Pm}{dt} = \frac{1}{Tt}(\Delta Pv - \Delta Pm) \tag{3-22}$$

Refer from equation (3-36), Governor model

$$\frac{dPv}{dt} = \frac{1}{Tg}\left(-\frac{\Delta\omega}{R} - \Delta Pv\right) \tag{3-36}$$

These equation are translated into statespace. A simulation model of the single generators is modelled in linear time invariant through state space.The statespace equation is translated into block in simulink. All the parameters in Table 1 is used in the simulation and substituted in the state space equation that has translate into simulink as shown in Figure 3.6.

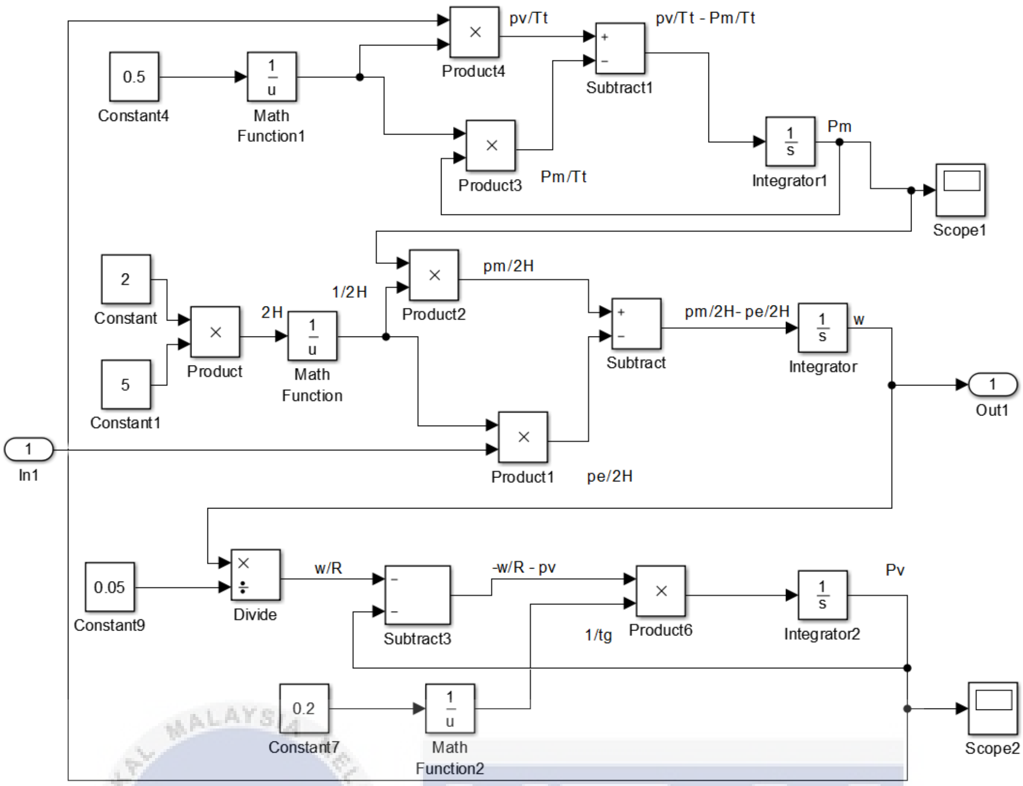

Figure 3.6: Simulation model of single generator

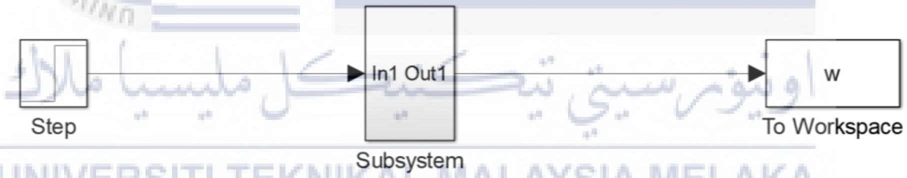

Figure 3.7: The subsystem of the simulation

Figure 3.7 shows the subsystem of the simulation from Figure 3.6. The subsystem's function is to make the simulation more organized and easier to simulate when all the simulation development for two generators is complete. Output for the simulation is put in the block diagram to workspace in order for the graph to be executed as shows in chapter 4 of this report.

3.2 The generator behaviour in multi area system

3.2.1 State-space Representation

This system is represented in state-space as

$$\dot{\boldsymbol{x}} = \boldsymbol{A}\boldsymbol{x} + \boldsymbol{B}\boldsymbol{u} \tag{3-67}$$

Applying the substitution on Eq. (3-10), (3-14), (3-24), (3-26), (3-38), (3-40), (3-48), (3-56) and equations below

$$\frac{d\Delta}{dt}\boldsymbol{\omega_1} = \Delta\boldsymbol{\delta_1} \tag{3-68}$$

$$\frac{d\Delta}{dt}\boldsymbol{\omega_2} = \Delta\boldsymbol{\delta_2} \tag{3-69}$$

These equations show the arrangement of all equation in state space representation.

$$
\begin{bmatrix} \omega_1 \\ \omega_1 \\ \delta_1 \\ \delta_2 \\ P_{m1} \\ P_{m2} \\ P_{gv1} \\ P_{gv2} \\ P_{ref1} \\ P_{ref2} \end{bmatrix}
=
\begin{bmatrix}
-D_1/2H_1 & 0 & -P_s/2H_1 & P_s/2H_1 & 1/2H_1 & 0 & 0 & 0 & 0 & 0 \\
0 & -D_2/2H_2 & P_s/2H_2 & -P_s/2H_2 & 0 & 1/2H_1 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & -1/\tau_{T1} & 0 & 1/\tau_{T1} & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & -1/\tau_{T2} & 0 & 1/\tau_{T2} & 0 & 0 \\
-1/\tau_{gv1}R_1 & 0 & 0 & 0 & 0 & 0 & -1/\tau_{gv1} & 0 & K_1/\tau_{gv1} & 0 \\
0 & -1/\tau_{gv2}R_2 & 0 & 0 & 0 & 0 & 0 & -1/\tau_{gv2} & 0 & K_2/\tau_{gv2} \\
-B_1 & 0 & -P_s & P_s & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & -B_2 & P_s & -P_s & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}
\begin{bmatrix} \Delta\omega_1 \\ \Delta\omega_1 \\ \Delta\delta_1 \\ \Delta\delta_2 \\ \Delta P_{m1} \\ \Delta P_{m2} \\ \Delta P_{gv1} \\ \Delta P_{gv2} \\ \Delta P_{ref1} \\ \Delta P_{ref2} \end{bmatrix}
+
\begin{bmatrix} -1/2H_1 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} u
$$

3.2.2 Simulation model

Based on equation system (3-67), a simulation model of two generators in multi-area is modelled in linear time invariant through state space. The statespace equation is translated into block in simulink. All the parameters in Table 2 is used in the simulation and substituted in the state space equation that has translate into simulink as shown in Figure 3.8,Figure 3.9,Figure 3.10,Figure 3.11,Figure 3.12 and Figure 3.13.

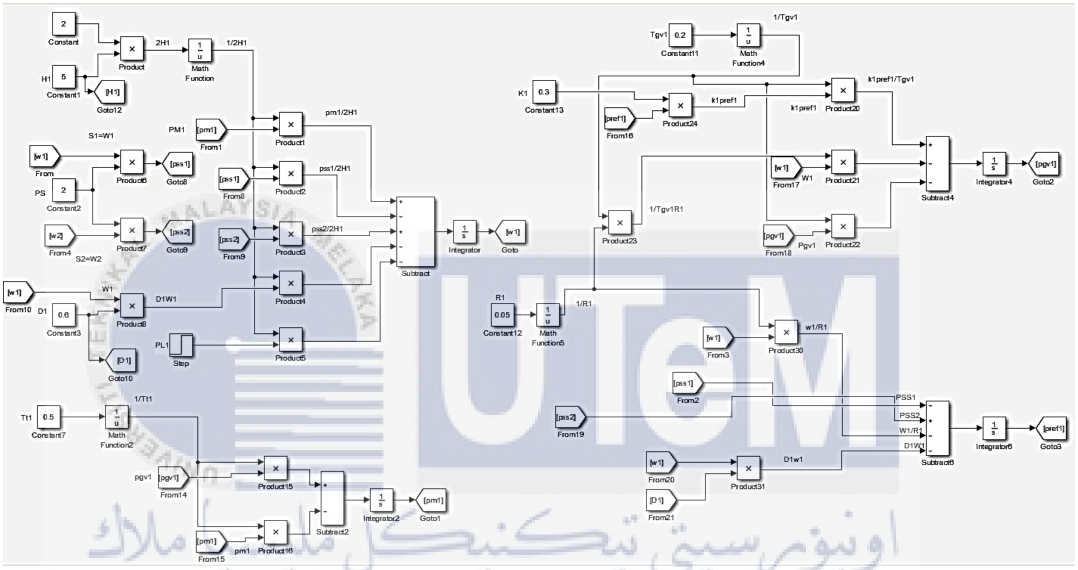

Figure 3.8: Generator 1 model

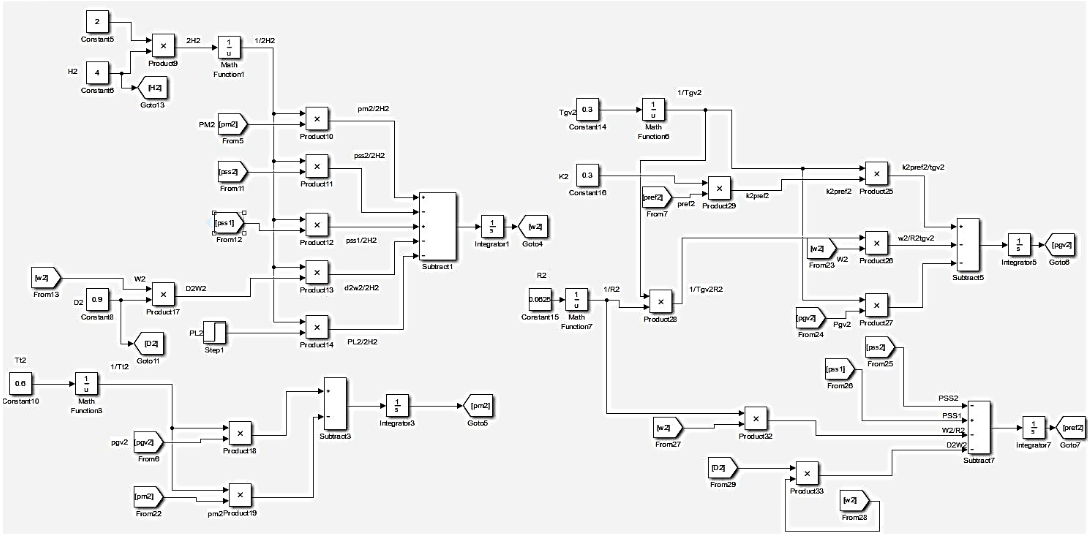

Figure 3.9: Generator 2 model

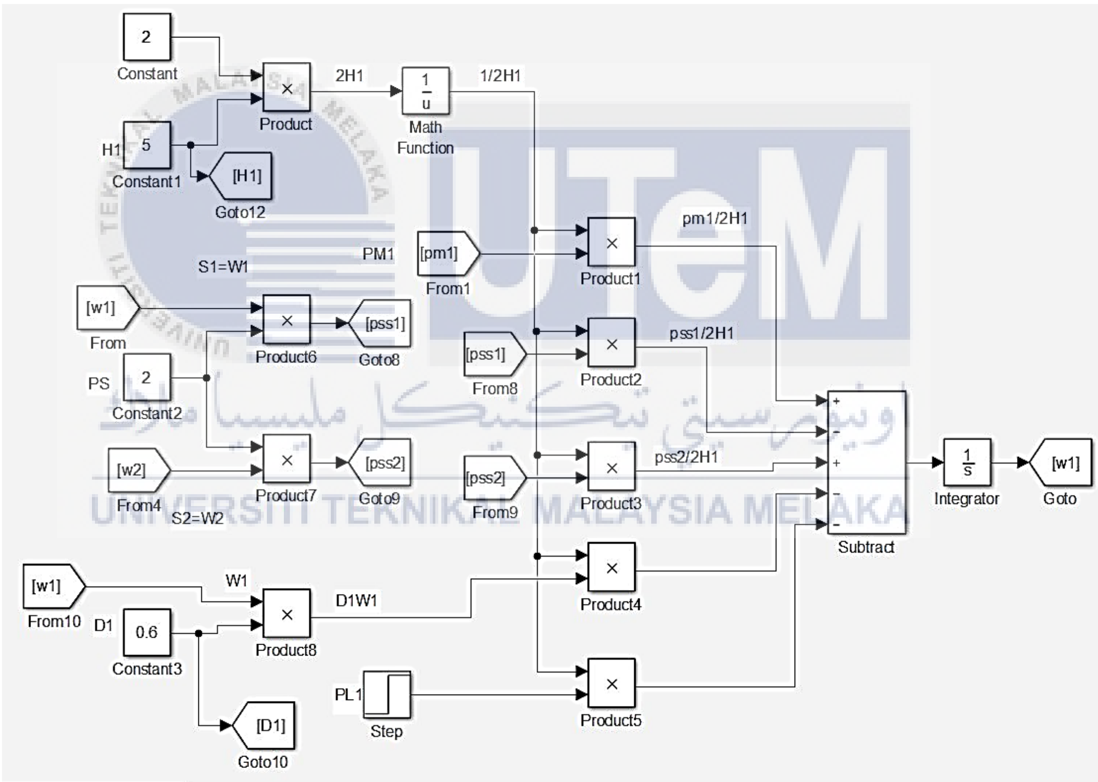

Figure 3.10: Rotating generator model

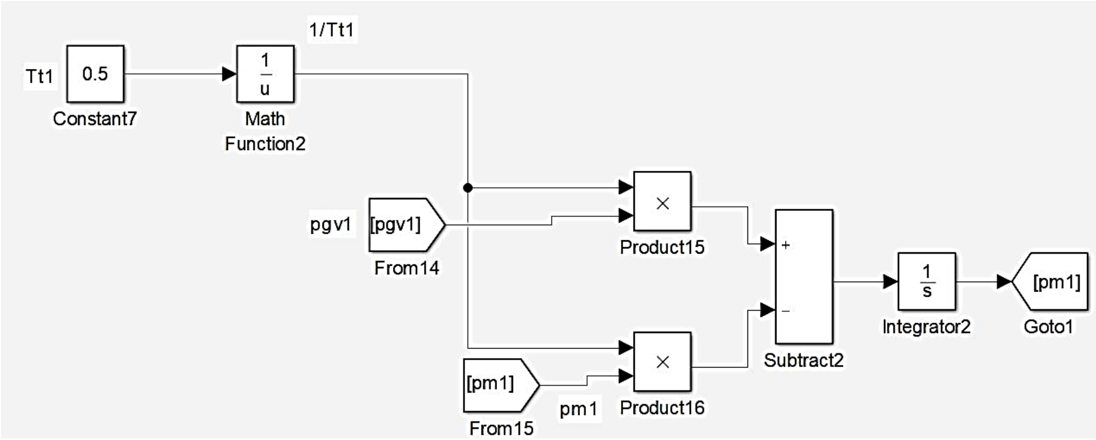

Figure 3.11: Prime mover model

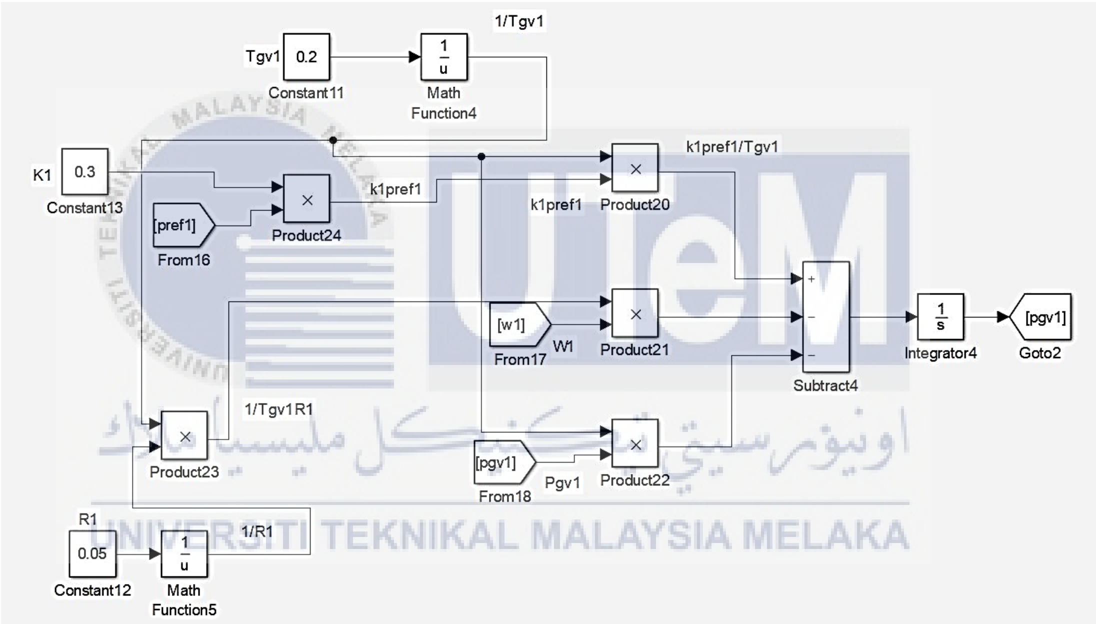

Figure 3.12: Speed governor model

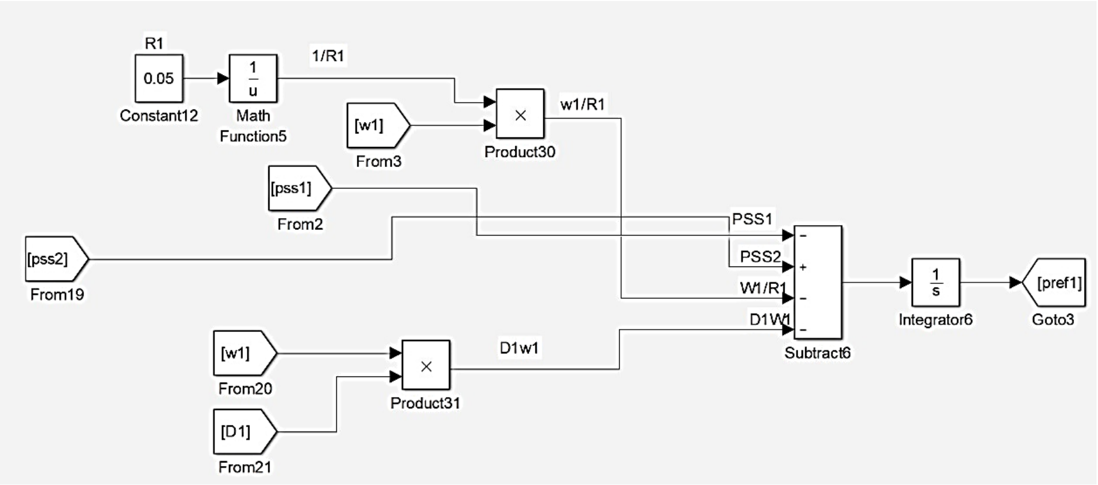

Figure 3.13: Tie-line model

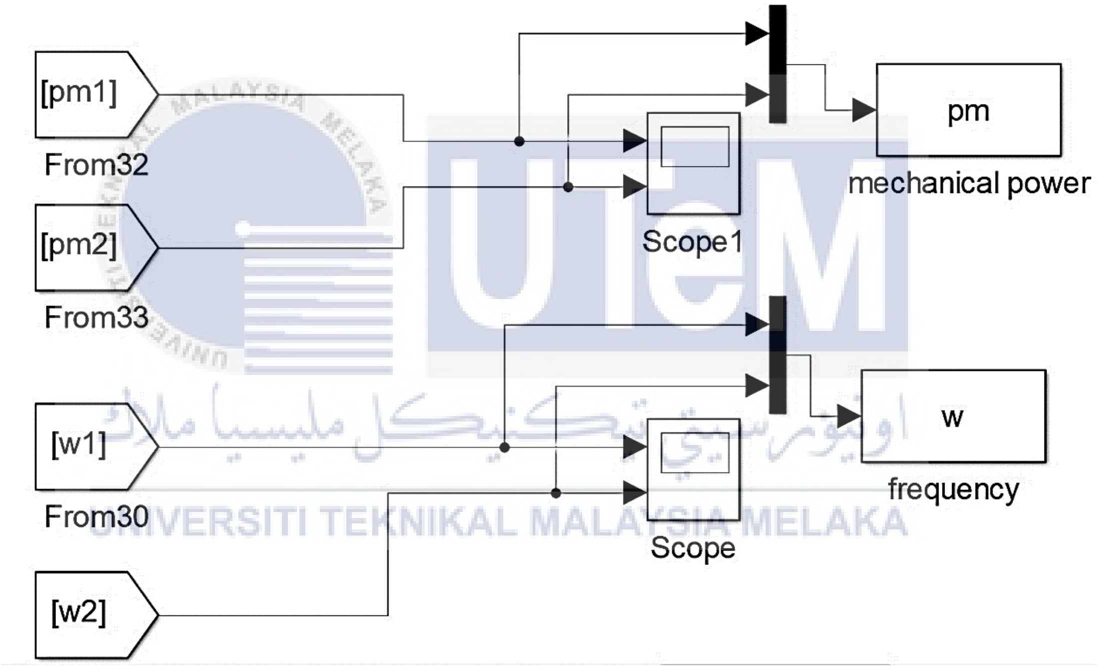

Figure 3.14: Output simulation

Figure 3.14 shows the simulation to get the output for the generators modelled. The output results are shown in chapter 4 of this report.

3.3 Average Behavior

Generator 1 and generator 2 are assumed to have different parameters so that their behavior towards any load change is not identical. So, the two generators model from state space representation of (3-67) is derive to be only one generator model by using similarity transformation method. The method is creating the new state variable by decomposing and change the state matrix, in order to get the output behavior of the generator. The new state variables describe the plus-minus average behavior as shown in Eq (3-57),(3-58),(3-59),(3-60),(3-61),(3-62),(3-63),(3-64),(3-65) and (3-66).

3.3.1 State-space representation

The average behavior equation in state-space representation as shown below is base from Eq.(3-57), (3-58), (3-59), (3-60), (3-61), (3-62), (3-63), (3-64), (3-65) and (3-66)

$$T=\begin{bmatrix}\omega_a\\ \delta_a\\ P_{ma}\\ P_{gva}\\ P_{refa}\\ \omega_b\\ \delta_b\\ P_{mb}\\ P_{gvb}\\ P_{refb}\end{bmatrix}=\begin{bmatrix}\frac{1}{2} & \frac{1}{2} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & \frac{1}{2} & \frac{1}{2} & 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & \frac{1}{2} & \frac{1}{2} & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{2} & \frac{1}{2} & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{2} & \frac{1}{2}\\ \frac{1}{2} & -\frac{1}{2} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & \frac{1}{2} & -\frac{1}{2} & 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 00 & 0 & \frac{1}{2} & -\frac{1}{2} & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{2} & -\frac{1}{2} & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{2} & -\frac{1}{2}\end{bmatrix}\begin{bmatrix}\omega_1\\ \omega_2\\ \delta_1\\ \delta_2\\ P_{m1}\\ P_{m2}\\ P_{gv1}\\ P_{gv2}\\ P_{ref1}\\ P_{ref2}\end{bmatrix}$$

To find the new state space representation, the system is represented in:

$$\dot{\boldsymbol{z}} = \boldsymbol{TAT^{-1}} + \boldsymbol{TBu} \tag{3-70}$$

$$
\begin{bmatrix} \omega_1 \\ \omega_1 \\ \delta_1 \\ \delta_2 \\ P_{m1} \\ P_{m2} \\ P_{gv1} \\ P_{gv2} \\ P_{ref1} \\ P_{ref2} \end{bmatrix}
=
\begin{bmatrix}
-0.0862 & 0 & 0.1125 & 0 & 0 & 0.0263 & 0.0050 & -0.0125 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1.8333 & 1.8333 & 0 & 0 & 0 & 0.1667 & 0.1667 & 0 \\
-76.6667 & 0 & 0 & -4.1667 & 1.2500 & -23.3333 & 0 & 0 & -0.8333 & 0.2500 \\
-18.7500 & 0 & 0 & 0 & 0 & -1.8500 & 0 & 0 & 0 & 0 \\
0.0263 & 0 & -0.0125 & 0 & 0 & -0.0862 & -0.0450 & 0.1125 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1.0000 & 0 & 0 & 0 & 0 \\
0 & 0 & 0.1667 & 0.1667 & 0 & 0 & 0 & 1.8333 & 1.8333 & 0 \\
-23.3333 & 0 & 0 & -0.8333 & 0.2500 & -76.6667 & 0 & 0 & -4.1667 & 1.2500 \\
-1.8500 & 0 & 0 & 0 & 0 & -18.7500 & -0.4000 & 0 & 0 & 0
\end{bmatrix}
\begin{bmatrix} \Delta\omega_1 \\ \Delta\omega_2 \\ \Delta\delta_1 \\ \Delta\delta_2 \\ \Delta P_{m1} \\ \Delta P_{m2} \\ \Delta P_{gv1} \\ \Delta P_{gv2} \\ \Delta P_{ref1} \\ \Delta P_{ref2} \end{bmatrix}
+
\begin{bmatrix} -1/2H_1 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} u
$$

The new state space representation in Eq.(3-70) is calculated using MATLAB coding as below

```
>> T = [ 1/2,1/2,0,0,0,0,0,0,0,0 ;
    0,0,1/2,1/2,0,0,0,0,0,0 ;
    0,0,0,0,1/2,1/2,0,0,0,0 ;
    0,0,0,0,0,0,1/2,1/2,0,0 ;
    0,0,0,0,0,0,0,0,1/2,1/2 ;
    1/2,-1/2,0,0,0,0,0,0,0,0;
    0,0,1/2,-1/2,0,0,0,0,0,0;
    0,0,0,0,1/2,-1/2,0,0,0,0;
    0,0,0,0,0,0,1/2,-1/2,0,0 ;
    0,0,0,0,0,0,0,0,1/2,(-1/2)];

Tinv = inv(T);
TB = T*B;
TATinv = T*A*Tinv

TATinv =

   -0.0862         0    0.1125         0         0    0.0263    0.0050   -0.0125         0         0
    1.0000         0         0         0         0         0         0         0         0         0
         0         0    1.8333    1.8333         0         0         0    0.1667    0.1667         0
  -76.6667         0         0   -4.1667    1.2500  -23.3333         0         0   -0.8333    0.2500
  -18.7500         0         0         0         0   -1.8500         0         0         0         0
    0.0263         0   -0.0125         0         0   -0.0862   -0.0450    0.1125         0         0
         0         0         0         0         0    1.0000         0         0         0         0
         0         0    0.1667    0.1667         0         0         0    1.8333    1.8333         0
  -23.3333         0         0   -0.8333    0.2500  -76.6667         0         0   -4.1667    1.2500
   -1.8500         0         0         0         0  -18.7500   -0.4000         0         0         0
```

Figure 3.15: Command for new statespace representation

Eq.(3-66) is the state-space equation for describing the average behavior of two generator systems. The command for the new state space representation is executed in MATLAB as shown in Figure 3.15. Then, the state vectors of the equation are divided into two partitions which related to the plus-minus average. In order to group the system and become as one generator behavior, it is able to reduce order by only taking the upper half of the state vectors and state matrix. This approximation will ignore the minus average at the lower half of state vectors and the equation will become as follow

$$\dot{xave} = Aave\ x + Baveu \tag{3-71}$$

$$\begin{bmatrix} \omega_a \\ \delta_a \\ P_{ma} \\ P_{gva} \\ P_{refa} \end{bmatrix} = \begin{bmatrix} -0.0862 & 0 & 0.1125 & 0 & 0 \\ 1.0000 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1.8333 & 1.8333 & 0 \\ -76.6667 & 0 & 0 & -4.1667 & 1.2500 \\ -18.7500 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \Delta\omega_1 \\ \Delta\delta_a \\ \Delta P_{ma} \\ \Delta P_{gva} \\ \Delta P_{refa} \end{bmatrix} + \begin{bmatrix} -0.05 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} u$$

3.3.2 Simulink Simulation

Parameters from Eq.(3-71) is transfer into the state space simulation as shown in Figure 3.16 and Figure 3.17.

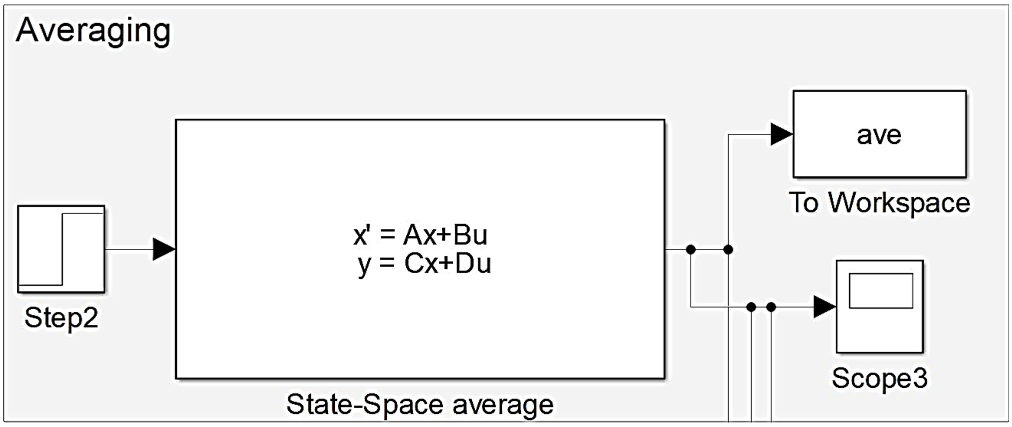

Figure 3.16: Statespace simulation

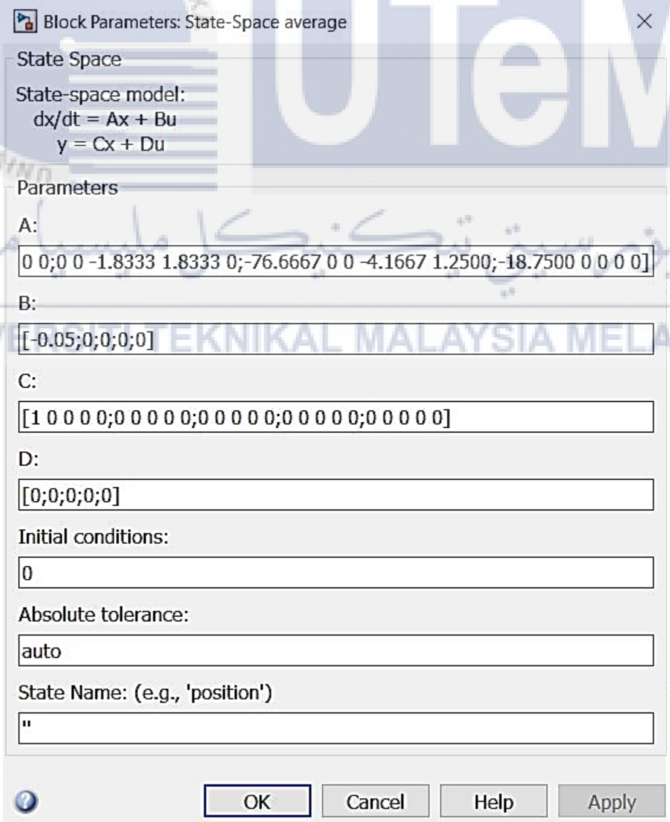

Figure 3.17: Parameter for average behaviour

The output result of the simulation can be seen in Chapter 4.

Then, the result of averaging frequency is put together in one graph with the frequency result of generator 1 and generator 2. The simulation is as shown in Figure 3.18 and the output is shown in chapter 4.

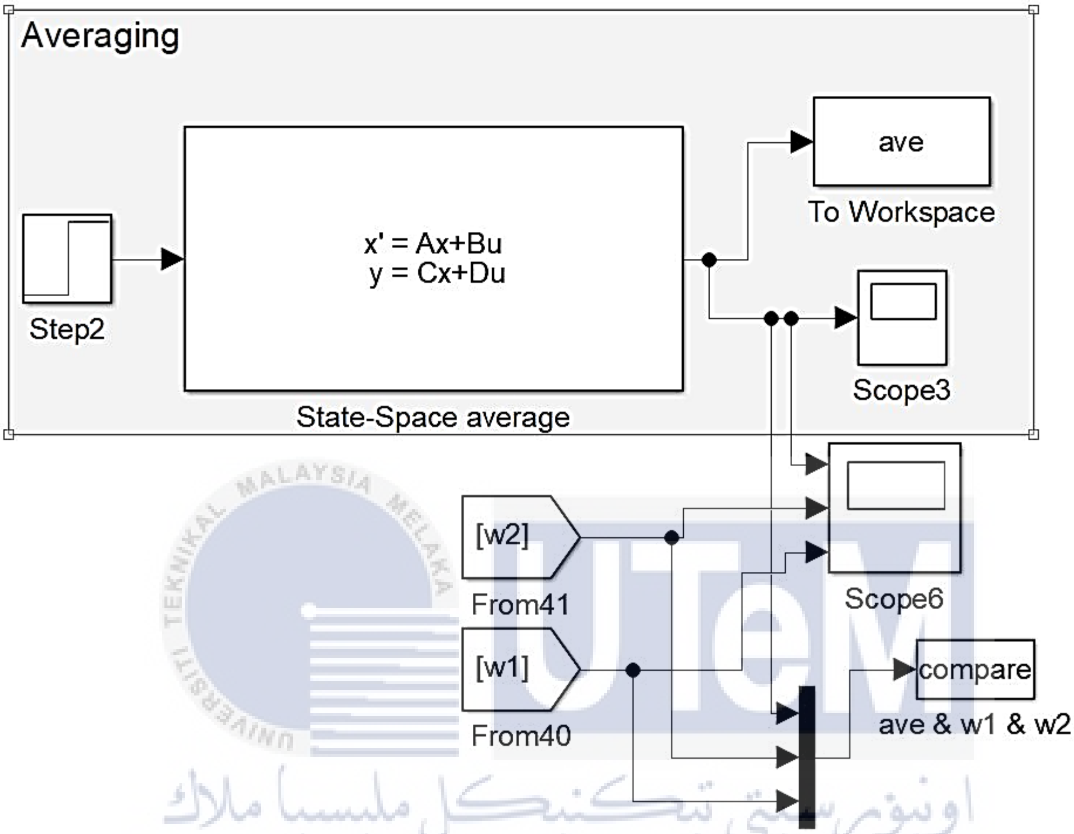

Figure 3.18: Output simulation for average frequency

3.4 Conventional method

3.4.1 Simulink Simulation

The conventional method for average behavior of the generators is simulated base on equation below

$$\Delta w_{coi} = \frac{H_1\omega_1 + H_2\omega_2}{H_1 + H_2} \tag{3-72}$$

Then, Eq.(3-72) is translated into the Simulink block diagram as shown in Figure 3.19 and Figure 3.20 shows the output simulation executed to compare the conventional method of averaging with the method used in this project.

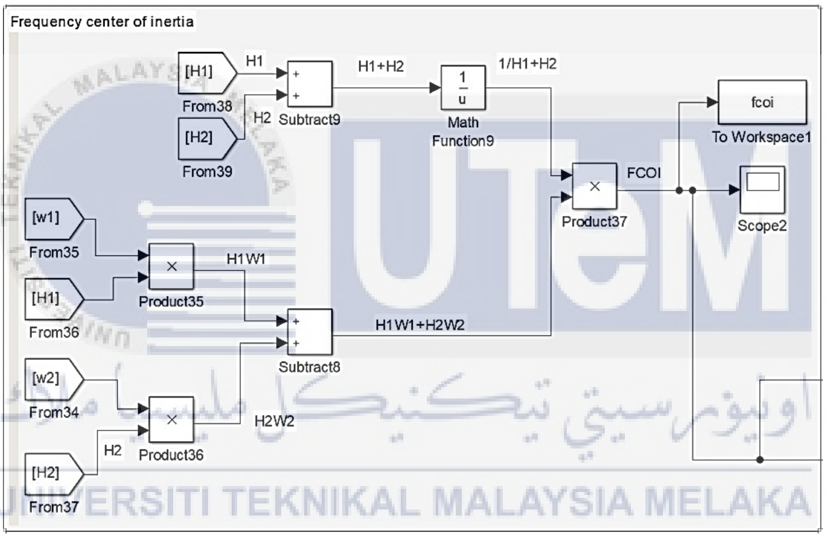

Figure 3.19: Conventional method of averaging

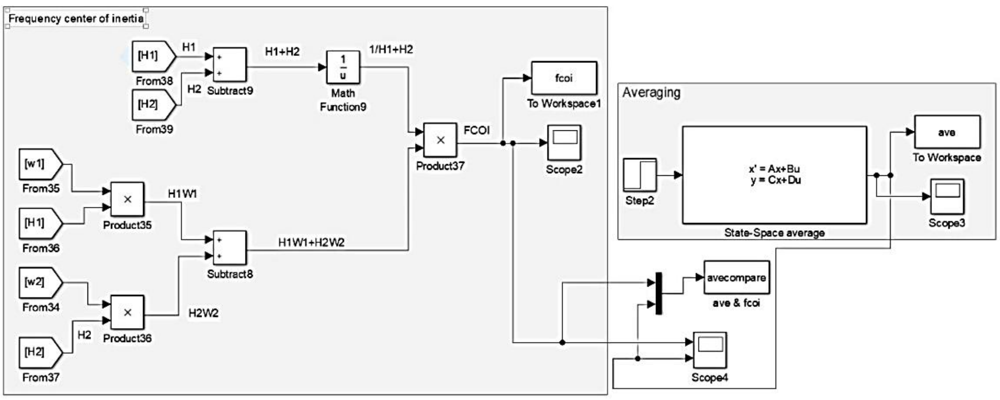

Figure 3.20: Output simulation for comparison

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter discuss the results obtain by the method conducted for this project. The results are analyzed so that the objective can be achieved.

4.2 Simulation results of a microgrid with single generator.

The graph in Figure 4.1 is the output simulation of the model in Figure 3.6.

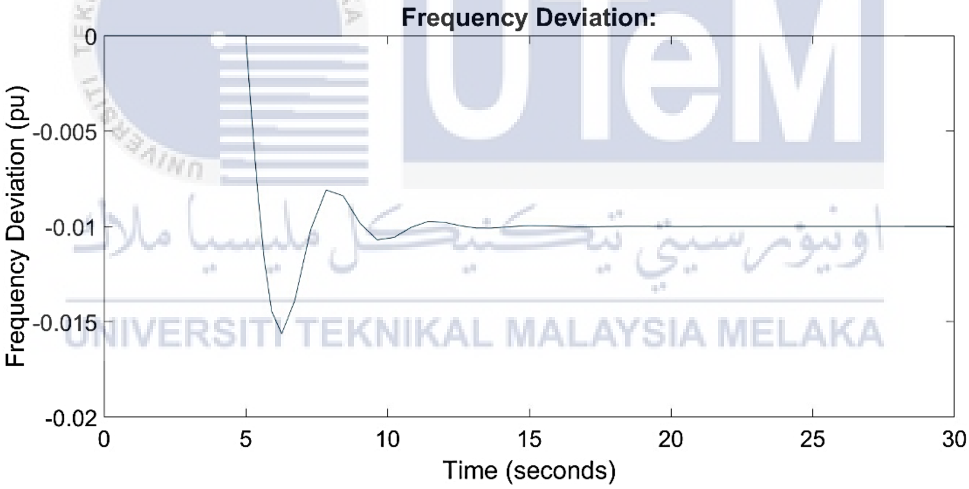

Figure 4.1: Frquency Deviation during sudden load change

The graph in Figure 4.1 shows the result of frequency deviation when there is sudden load change in the system. By running the simulation for 30 seconds, and increasing 0.2pu load change after 5 seconds time, the frequency drops because of the sudden load change in the system. From this result, it can be observed that the frequency deviate 0.01 pu under 0.2pu load change.

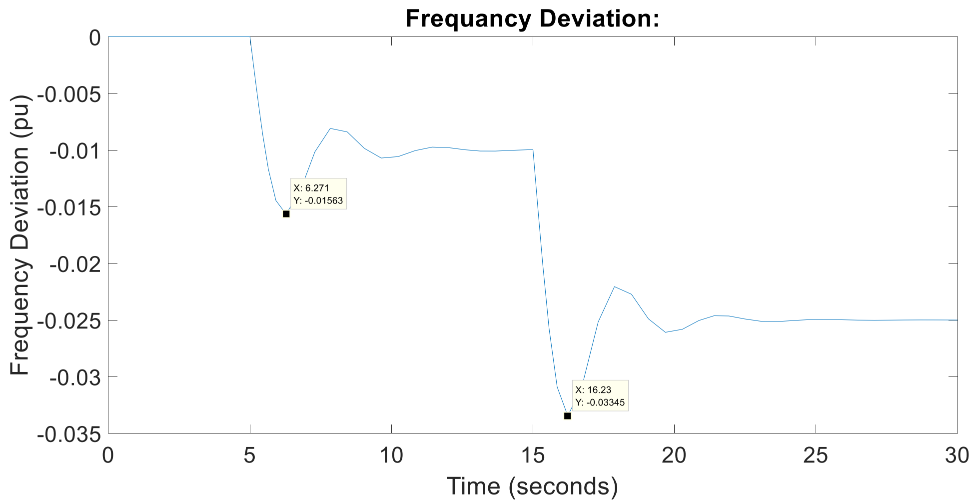

Figure 4.2: Frequency deviation when multiple increase of load demand

Figure 4.2 shows that at 15 second time, the load demand further increases for 0.3 pu and the frequency drop even more. As for this simulation, there is no controller to control the frequency back to the nominal. Hence, the frequency will drop with the load demand changes in the system. This Figure also shows that when the load change with 0.2 pu, the maximum frequency will drop to 0.0156pu before it reaches the steady state condition. When there is another load demand change, the frequency will drop from the steady state value of the first condition. In this condition, the maximum frequency drop until 0.03345 pu and then it will go to the steady state condition.

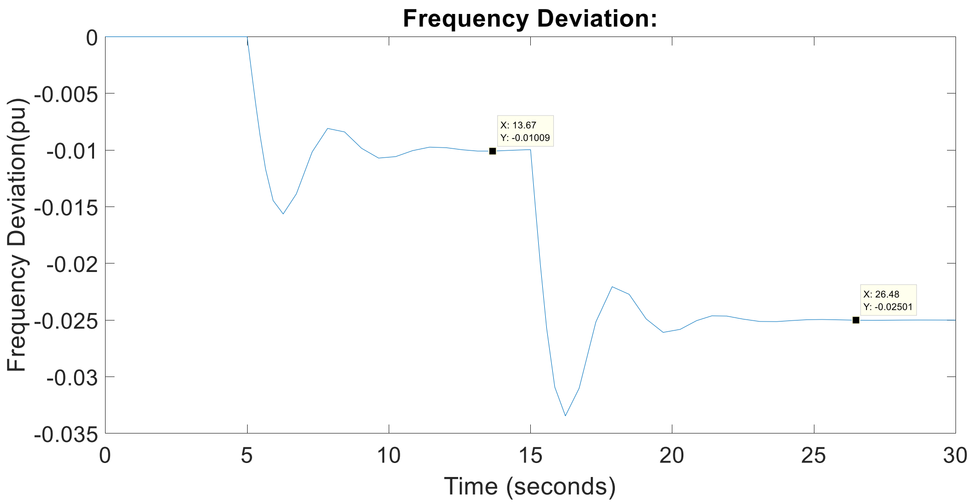

Figure 4.3: Steady state value for sudden load change

Figure 4.3 shows the value of the steady state during the first load demand change and also when the load demand change increases. The first sudden load change, the value of frequency deviation is -0.01009 when the frequency achieved the steady state condition. Then, when the load demand increases, and the frequency drop, the value of the frequency deviation is -0.02501pu when the frequency achieved the steady state condition. The frequency will not return to the nominal value as there are no controller for the frequency stability. For both conditions, the time taken for the frequency to achieved the steady state condition is round 5 to 8 seconds.

4.2.1 Results Calculation

All the calculation and parameters for this simulation is taken from [2], The turbine rated output is 250 MW at nominal frequency 50Hz. A sudden load change for first condition is 50MW (0.2 per unit), and the second condition when the load demand increases is when the load is 75Mw (0.3 per unit). The steady state deviation due to step input is

$$\Delta\omega_{ss} = \lim_{s-0} s\Delta\Omega(s) = \frac{1}{20.8}(-0.2) = -0.0096\,pu \qquad (4\text{-}1)$$

Based on Figure 4.3, the simulation result is -.01009pu, which is slightly different from the calculation results.

4.3 Simulation results of generator behaviour in multi area system

4.3.1 Multi generator response

Figure 4.4 and Figure 4.5 shows the output result for the model shows in Figure 3.14.

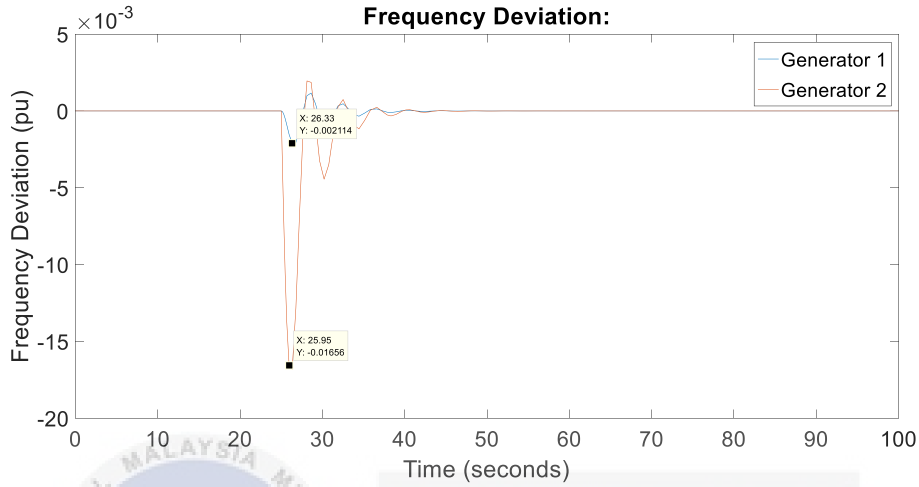

Figure 4.4: Frequency Deviation for Generator 1 and Generator 2

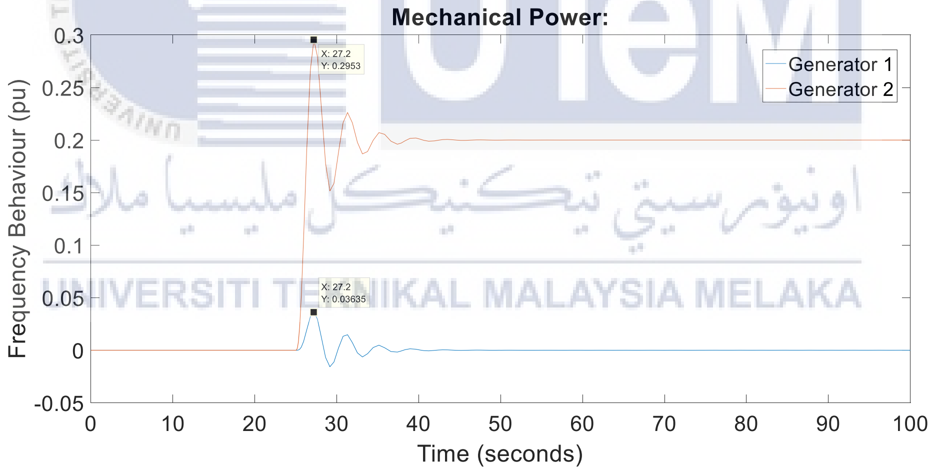

Figure 4.5: Mechanical output

In Figure 4.4, the frequency results show that the generator that is near to the busbar that happen to have sudden load demand change in the system will oscillate more. The other generator which is far from the busbar that have sudden load demand change will only give inertia response. The generator will undershoot when there is sudden load demand change. The generator that is far from the busbar will also undershoot to support the first generator. This phenomenon happen is to prevent the first generator from shutting down due the drop-in frequency. The Frequency drop of the generator that is near to the load change will actually drop even more but due to the supports of the other generator, the generator drop is still in control. Figure 4.5 shows that there is power flow from the first generator to support the other generator. After some time, when the generator has achieved steady state. The first generator will return to 0 due to automatic generation control and will only supply the load demand at its own load demand.

4.3.2 Average behaviour

Figure 4.6 and Figure 4.7 shows the output result for simulation shows in Figure 3.18.

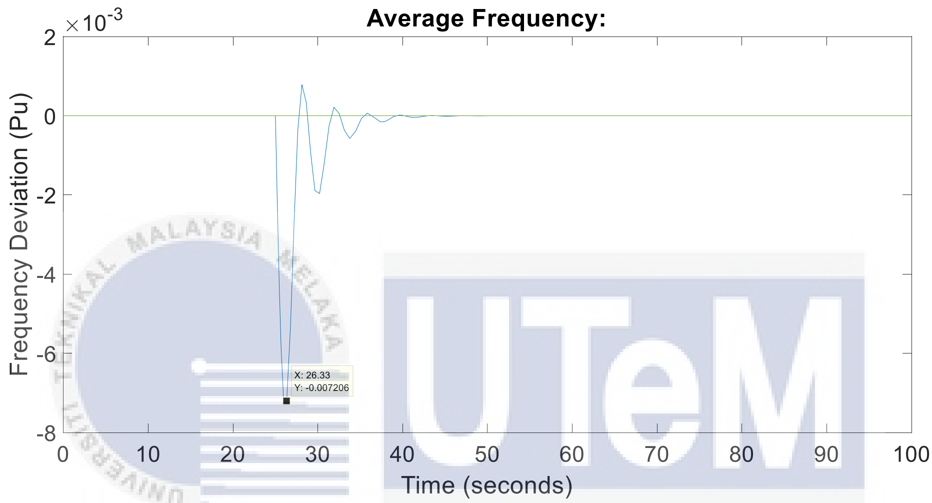

Figure 4.6: Average Frequency Behavior

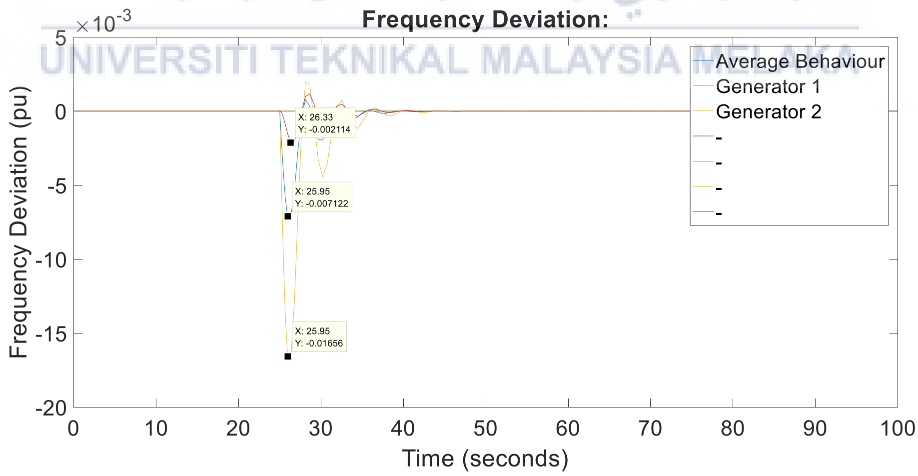

Figure 4.7: Comparison of Average Frequency with Generator 1 and 2

Figure 4.6 shows the frequency result of average behavior that is executed in Figure 3.16 and Figure 3.17. The frequency is representing the frequency of the two generators when there is sudden load change in the system. The frequency represented the frequency of the system by averaging both the frequencies of the generators. Figure 4.7 shows the comparison of frequencies generator 1 and generator 2 with average frequency. Generator 2 is where the load change occurs that results in the undershoot of the frequency until -0.01683 pu. Then the other generator also undershoots to -0002114 in order to support Generator 2.

4.3.3 Multi response of Load changes

Different value of load is injected into the system to see the overshoot of the generator and when it goes back to nominal as shown in Figure 4.8.

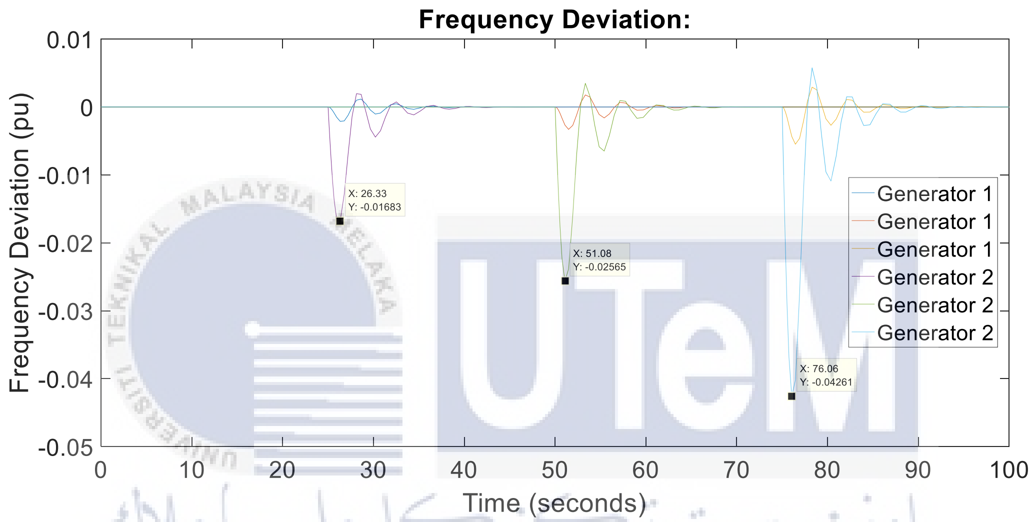

Figure 4.8: Multiple response of load changes

By running the simulation for 100 seconds, the load change is injected at 0.2pu during 25 seconds time, 0.3pu during 50 seconds time and 0.5pu during 75 seconds time. The frequency drops because of the sudden load change in the system and back to its nominal value can be observed in Figure 4.8. When the load demand increase for 0.3 pu, the frequency will drop even more same goes to when the load increase to 0.5pu. With the presents of secondary control, the frequency goes back to the nominal value.

4.3.4 Conventional method

Figure 4.9 and Figure 4.10 is the output for simulation simulate in Figure 3.19 and Figure 3.20 in chapter 3.

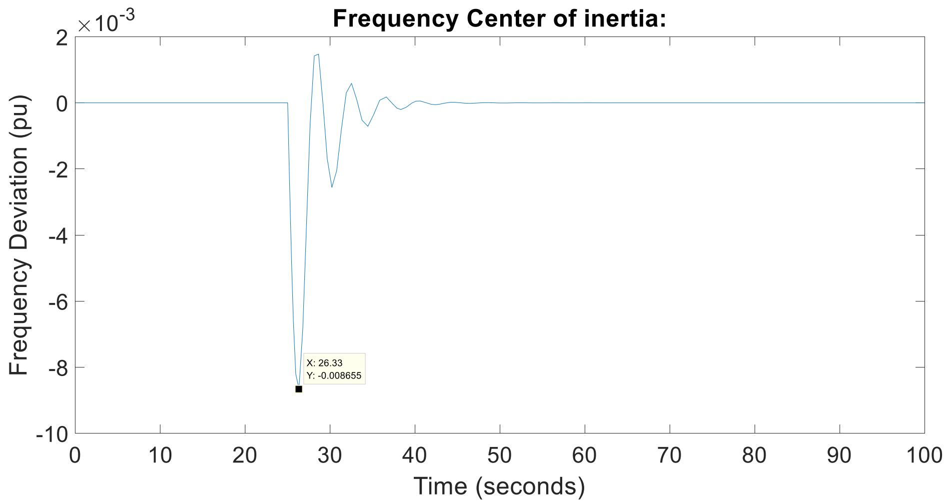

Figure 4.9: Average frequency using conventional method

By using the conventional method, the average frequency can be seen in Figure 4.9 with the undershoot of -0.008655.

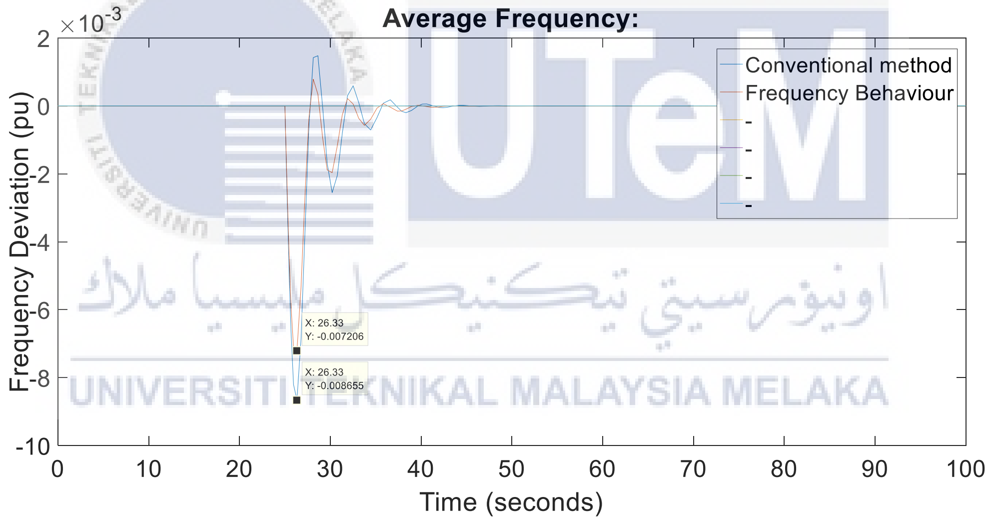

Figure 4.10: Comparison of average frequencies

Figure 4.10 shows the comparison of average frequency using similarity transformation method and the conventional method. From the output results shows in the figure, it can be observed that the similarity transformation methods which considering the active power yield the similar shape compare to the conventional method. However, the proposed method gives the lower undershoot and little bit fast oscillation compare to the conventional method.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

When the microgrid in islanded mode, we can conclude that the system is suddenly disconnected from the main grid that lead the microgrid to change to islanded mode. It can be conclude that the load demand will affect the area that the load change occurs even more. When the load increase, the frequency of the generator that is near to the load change will drop more compare to the other generator. The other generator's frequency will also drop to support the other generator. With the presence of secondary control, the frequency will return back to its nominal value. The approach in finding the average dynamical frequency of the microgrid system is identified and used to find the average dynamical frequency for the islanded microgrid system with multiple generators. In conclusion, all the objective is achieved.

5.2 Future Works

For future works, in order to observe the frequency behavior of the microgrid system more details, reactive power and voltage control should take into consideration. The detailed model, exciter model should be involved. This will result into more details of the frequency behavior. This also can observe the effect of terminal voltage under deviation of reactive power.

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APPENDICES

APPENDIX A GANTT CHART

No	Task	Months									
		Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
1	FYP1 briefing	■									
2	FYP1 registration	■									
3	Literature review		■	■							
4	Study of mathematical modelling		■	■							
5	Modelling of a microgrid with single generator		■	■							
6	Result analysis		■	■							
7	FYP1 Report Writing		■	■							
8	FYP1 Seminar			■							
9	Progress report submission				■						
10	Study of mathematical modelling for FYP 2					■	■	■	■	■	

No	Task	Months									
		Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
11	Modelling of microgrid with multiple generators										
12	Result analysis										
13	FYP 2 Report Writing										
14	FYP2 Draft Report Submission										
15	FYP2 Seminar										
16	Last check of FYP2 report										
17	Submission of report										