OPTIMISATION OF AUTOMATIC GENERATION CONTROL PERFORMANCE IN TWO-AREA POWER SYSTEM WITH PID CONTROLLERS USING MEPSO

LU LI

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RESEARCH REPORT SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF POWER SYSTEM ENGINEEERING

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ABSTRACT

Automatic Generation Control (AGC) is used for regulating the electrical power supply in two-area power system and changing the system frequency and tie-line load. The performance of AGC has to be tuned properly so that the performance can be optimized. In this project, modified evolutionary particle swarm optimisation (MEPSO) -time varying acceleration coefficient (TVAC) is proposed for an AGC of two-area power system to optimize its performance by tuning parameters of the PID controllers. Comparison of the performance by using the proposed algorithm and other algorithms was made to identify which algorithm is better in controlling the performance of the AGC. The AGC in two-area power system was constructed and simulated by using MATLAB R2017b software. From the simulation results, it was found that with the same number of PID controllers, the performance of AGC optimised by using MEPSO-TVAC algorithm is better in terms of overshoot and fitness value than using EPSO and PSO algorithms. Also, using MEPSO-TVAC algorithm, the performance of AGC by using two PID controllers is better in terms of rise time and settling time than using one PID controller. Therefore, via implementation of optimisation method, the performance of AGC can be improved by varying the parameters of PID controller.

Keywords: Automatic generation control (AGC), modified evolutionary particle swarm optimisation-time varying acceleration coefficient (MEPSO-TVAC), PID controller.

ABSTRAK

"Kawalan Penjanaan Automatik" digunakan untuk mengawal selia bekalan kuasa elektrik dalam sistem kuasa dua kawasan dan mengubah kekerapan sistem dan beban talian tali. Prestasi AGC perlu ditala dengan betul supaya prestasi dapat dioptimumkan. Dalam projek ini, "Pengoptimuman Kawanan Zarah Evolusi Diubahsuai-Pekali Pecutan Berbeza Maza" akan dicadangkan untuk AGC sistem kuasa dua kawasan untuk mengoptimumkan prestasinya dengan menala parameter pengawal PID. Oleh itu, perbandingan prestasi dengan menggunakan algoritma yang dicadangkan dan algoritma lain akan dibuat untuk mengenal pasti algoritma mana yang lebih baik dalam mengawal prestasi AGC. AGC dalam sistem kuasa dua kawasan dibina dan disimulasikan dengan menggunakan perisian MATLAB R2017b. Dari hasil simulasi, didapati bahawa dengan jumlah pengawal PID yang sama, prestasi AGC dengan menggunakan algoritma MEPSO-TVAC lebih baik dari segi "overshoot" dan nilai kecergasan daripada menggunakan algoritma EPSO dan PSO. Selain itu, di bawah algoritma MEPSO-TVAC, prestasi AGC dengan menggunakan dua pengawal PID adalah lebih baik dari segi "rise time" dan "settling time" daripada menggunakan satu pengawal PID. Oleh itu, melalui pelaksanaan kaedah pengoptimuman, prestasi AGC dapat ditingkatkan dengan mengoptimumkan parameter pengawal PID.

Kata kunci: Kawalan penjanaan automatik, pengoptimuman kawanan zarah evolusi diubahsuai-pekali pecutan berbeza maza, pengawal PID.

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LIST OF SYMBOLS AND ABBREVIATIONS

ACE	:	Area control error
ΔP_{V1}	:	Real power command signal in Area 1
ΔP_{V2}	:	Real power command signal in Area 2
ΔP_{L1}	:	Non-frequency-sensitive load change in Area 1
ΔP_{L2}	:	Non-frequency-sensitive load change in Area 2
ΔP_{m1}	:	Mechanical power change in Area 1
ΔP_{m2}	:	Mechanical power change in Area 2
ΔP_{12}	:	Tie-line power change between Area 1 and Area 2
$\Delta\omega_1$	:	Frequency deviation change in Area 1
$\Delta\omega_2$	:	Frequency deviation change in Area 2
ΔP_{ref1}	:	Reference set power in Area 1
ΔP_{ref2}	:	Reference set power in Area 2

CHAPTER 1: INTRODUCTION

1.1 Overview

In recent years, modern power systems are becoming more complex with multi-area and various sources of power generation (Barisal, Mishra, & Chitti Babu, 2018). The large electric power system consists of many control areas interconnected, which are related to the tie-line (Garg & Kaur, 2014). Therefore, the frequency and the tie-line power of control areas can be disturbed from its scheduled value due to the continuous variation in the load (Sahu, Gorripotu, & Panda, 2016). To avoid this undesirable situation for the power systems, automatic generation control (AGC) mechanism is commonly recommended to be used in the system (Venkatachalam, 2013). It is used to balance the generated power and the demand power in each control area, so that the frequency and tie-line power of the system can be maintained at nominal value or scheduled value (Salman, 2015). Also, a fast speed and accurate controller is necessary to be used in the electric power system. This is due to a mismatch may happen between demand and generation. Then, this mismatch results in the deviation in the frequency from its desired value. The worst thing is that system collapse may be caused by the high frequency deviation (Patel, Singh, & Sahoo, 2013). Hence, the proportional-integral-derivative (PID) controller is normally recommended to use to maintain the desired system frequency.

Regarding to AGC, many investigations have been conducted in the past. The early works on AGC was introduced by Cohn control theory, which is about AGC designs of interconnected systems (Elgerd & Fosha, 1970). In present days, different control strategies such as adaptive, robust and variable structure have been introduced (P. Kumar & Kothari, 2005). These strategies are based on the different techniques i.e. genetic algorithm (GA) (Jadhav, Vadirajacharya, & Toppo, 2013). In this project, modified evolutionary particle swarm optimisation-time varying acceleration coefficient (MEPSO-TVAC) algorithm method was implemented to optimize the performance of AGC for a two-area interconnected power system by finding suitable parameters of PID controllers. Evolutionary particle swarm optimisation (EPSO) and particle swarm optimisation (PSO) algorithms were compared with MEPSO-TVAC algorithm in terms of the rise time, settling time, overshoot and fitness function.

1.2 Problem Statement

Automatic generation control (AGC) is one of the most important aspect in power system operation and becomes more pronounced recently by increasing the size, structure and complexity of change in the recovery, especially in two-area power system. Normally, for large-scale power systems of interconnected subsystems or multi-area power control, the connection between control areas is done by using a tie-line. Each region has its own generator or it is responsible for interchange power with neighboring areas. To ensure the quality of supply, AGC is required to maintain the system frequency at nominal value. Hence, optimisation of automatic generation control performance in multi-area power system is important. One of the methods for AGC optimisation is by using optimisation algorithms.

1.3 Objectives

The objectives of this project are:

i. To construct an automatic generation control (AGC) of two-area power system with PID controllers
ii. To propose optimization of AGC using modified evolutionary particle swarm optimisation (MEPSO)-time varying acceleration coefficient (TVAC)

iii. To compare the performance of AGC between without using optimisation, with optimisation and with other optimisation techniques (PSO and EPSO).

1.4 Project Methodology

The project methodology has 3 main procedures. The first procedure is literature review, which includes relevant theoretical study and previous work. The second procedure is MATLAB simulation which includes the circuit construction, the code writing and system simulation. The last procedure is report writing.

1.5 Thesis Outline

The thesis has five chapters. Chapter 1 presents the overall introduction of this project, problem statement, objectives and simple explanation of project methodology.

Chapter 2 shows the relevant study on the PID controller, automatic generation control (AGC) and all models in the power system. AGC in a single area system and AGC in multi-area power system are included.

Chapter 3 describes the overall process of project methodology. Parameters selection of PSO, EPSO, MEPSO-TVAC algorithm method is set. The circuit diagram in MATLAB of this project is performed.

Chapter 4 explains the simulation results of a two-area power system for different cases. Also, it shows some discussions in terms of the simulation results.

Chapter 5 summarises the main findings of this project and recommends some possible work for the future.

CHAPTER 2: LITERATURE REVIEW

2.1 Overview

The literature review includes relevant information about components of main models in the power system and structure of the PID controllers. AGC block diagram in one area system was studied, which is the basic component for constructing the block diagram of AGC in two-area power system or multi-area power system.

2.2 Automatic Generation Control (AGC)

Automatic generation control (AGC) system plays an essential role in maintaining system frequency and tie-line power at the nominal value in the large scale multi-area interconnected power system (Sharma, 2016). It means that the balance between the total generations and load losses of the system is required all the time when there is a continuous change in the load (Farshi, Shenava, & Sadeghzadeh, 2015). This balance is judged by frequent measurements on the system frequency. The system will generate more power than being used when the system frequency is increasing, which can accelerate the speed of all the machines. However, when the system frequency is reducing, more load is on the system, making all generators to slow down the speed (Ramakrishna & Sharma, 2010).

In a power system, prime mover drives the electrical generator to convert the mechanical power to electrical power. Hence, there are three major features of AGC in the electric power system. The first is to keep system frequency at a specified nominal value (Rao & Duvvuru, 2014). The second is to control power flow between interconnected control areas. The control areas are used for controlling generation and load of an interconnected system. The final one is to maintain the generation of each unit at the most economic level (Chandravanshi & Thakur, 2017).

2.3 The Models of Power System

Basically, a power system comprises generator, turbine, load and governors. The characteristics of each model for power system are shown in the following sections.

2.3.1 Generator Model

In a power system, power generating units converts the mechanical power to the electrical power (Ganthia & Rout, 2016). The source of mechanical power comes from turbine. There is a difficulty in storing the electricity power in a bulk. Hence, it should be sustained between generated power and load demand.

The following swing equation of a synchronous machine is applied to small perturbation:

$$\frac{2H}{\omega_s}\frac{d^2\Delta\delta}{dt^2} = \Delta P_m - \Delta P_e \tag{2.1}$$

where, H = equivalent inertia ω_s= mechanical angular velocity

ΔP_m = mechanical power change

ΔP_e = electrical power change

Using small deviation in speed:

$$\frac{d\Delta\frac{\omega}{\omega_s}}{dt} = \frac{1}{2H}(\Delta P_m - \Delta P_e) \tag{2.2}$$

The Laplace Transform function of (2.2) is obtained by:

$$\Delta\Omega(s) = \frac{1}{2H_s}[\Delta P_m(s) - \Delta P_e(s)] \tag{2.3}$$

Hence, according to eq. (2.3), the block diagram of generator is shown in Figure 2.1.

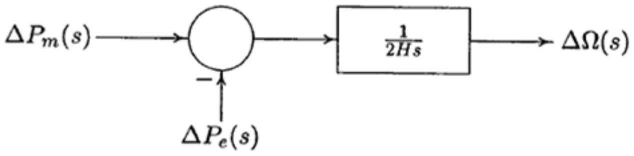

Figure 2.1: Generator block diagram (Saadat,1999)

2.3.2 Load Model

In a power system, the load comprises diverse of electrical devices. The electrical power is independent of frequency due to resistive loads such as lighting loads and heating loads. However, motor loads are sensitive to changes in frequency. Hence, the composite of all the driven devices' speed-load characteristics will determine the sensitivity to frequency (Saadat, 1999).

The speed-load characteristic of composite load is presented by:

$$\Delta P_e = \Delta P_L + D\Delta\omega \tag{2.4}$$

where, ΔP_L= non-frequency-sensitive load change

$D\Delta\omega$ = frequency-sensitive load change

D = percent change in load divided by percent change in frequency

Figures 2.2 and 2.3 show the block diagram of generator and load.

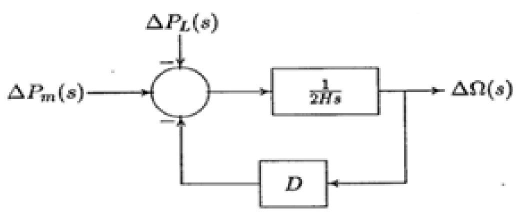

Figure 2.2: The block diagram of generator and load (Saadat, 1999)

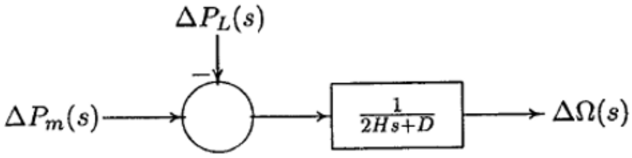

Figure 2.3: The simplified block diagram of generator and load (Saadat, 1999)

2.3.3 Prime Mover Model

In general, the source of mechanical power is called as prime mover. They can be gas turbines, hydraulic turbines at waterfalls or power generates from burning of gas, coal, nuclear fuel for steam turbines. The characteristics vary broadly for different types of the turbines (Saadat,1999).

The following transfer function presents the simplest prime mover model for the non-reheat steam turbine:

$$G_T(s) = \frac{\Delta P_m(s)}{\Delta P_V(s)} = \frac{1}{1+\tau T s} \qquad (2.5)$$

where, ΔP_m = changes in mechanical power output

ΔP_V = changes in steam valve position

τT = a single time constant is in the range of 0.2 to 2 seconds

Figure 2.4 shows the block diagram for a simple turbine.

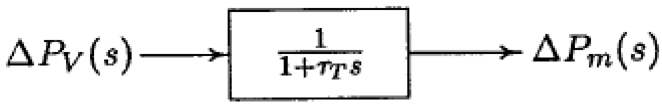

Figure 2.4: A steam turbine block diagram (Saadat, 1999)

2.3.4 Governor Model

The governor is the essential component of the power system. It can help to alter the mechanical power output to bring the speed back to a new steady-state level by adjusting the turbine valve when governor detects the changes in speed. Figure 2.5 expresses the block diagram of main elements of the speed governing system.

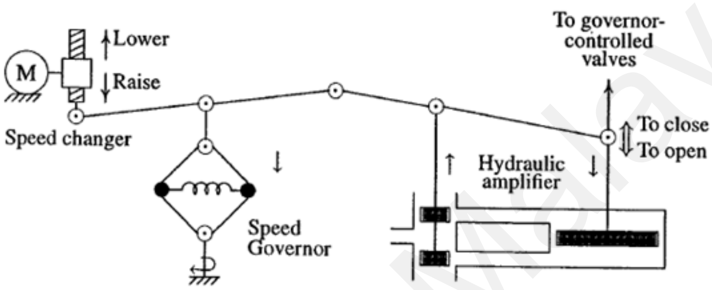

Figure 2.5: The speed governing system block diagram (Saadat, 1999)

Figure 2.6 shows governor steady-state speed characteristics. The governors are usually designed to allow the speed to drop for ensuring the stable operation when the load is increased.

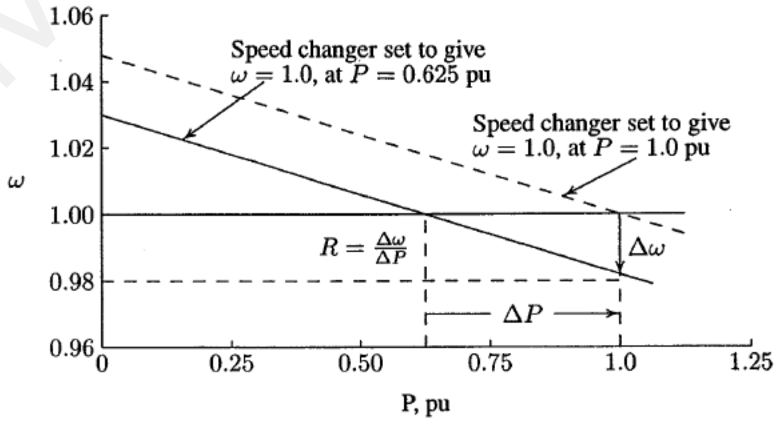

Figure 2.6: The steady-state speed characteristics of the governor (Saadat, 1999)

It can be seen from Figure 2.6 that the slope of curve stands for the speed regulation R. Generally, speed regulation of governors is 5%-6% from 0 to full load. The difference between ΔP_{ref} (reference set power) and $\frac{1}{R}\Delta\omega$ (the power) is ΔP_g (output), which is from speed governor that acts as a comparator (Saadat,1999).

The relationship between ΔP_{ref} and $\frac{1}{R}\Delta\omega$ is presented by:

$$\Delta P_g = \Delta P_{ref} - \frac{1}{R}\Delta\omega \qquad (2.6)$$

he relation is presented in s-domain is:

$$\Delta P_g(s) = \Delta P_{ref}(s) - \frac{1}{R}\Delta\Omega(s) \qquad (2.7)$$

The output ΔP_g is converted to steam valve position command ΔP_V by the hydraulic amplifier. The simple time constant τ_g is considered. Hence, updated relation of s-domain is shown as:

$$\Delta P_V(s) = \frac{1}{1+\tau_g}\Delta P_g(s) \qquad (2.8)$$

Depending on the updated s-domain relation as in eq. (2.8), the speed governing system of steam turbine can be shown as Figure 2.7.

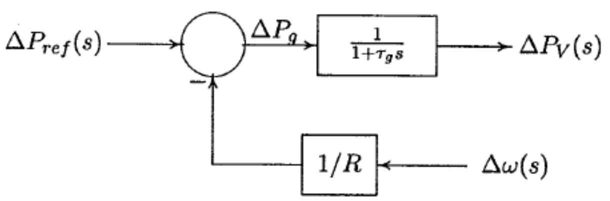

Figure 2.7: The speed governing system of steam turbine block diagram (Saadat, 1999)

2.4 AGC in One Area System

Based on the descriptions for each model of power system, the block diagram of load frequency control in one-area system is shown as Figure 2.8 by combining all models together. The frequency deviation $\Delta\Omega(s)$ and the $-\Delta P_L(s)$ act as the output and input respectively.

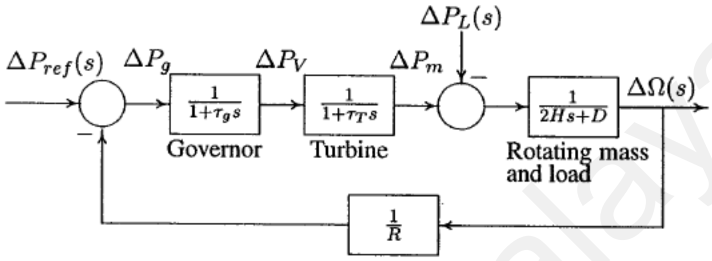

Figure 2.8: The block diagram of load frequency control in one-area system (Saadat, 1999)

From the primary load frequency control loop in Figure 2.8, according to speed regulation of governor, a steady-state frequency deviation will be caused by a change in the system load. Hence, a reset action can be implemented by the process that an integral controller acts on the load reference setting to change the setpoint of the speed. Then, a reset action is used for reducing the frequency deviation to 0. In order to obtain a stationary transient response, K_I integral controller gain is necessary to be adjusted. Figure 2.9 presents block diagram of AGC in one-area power system.

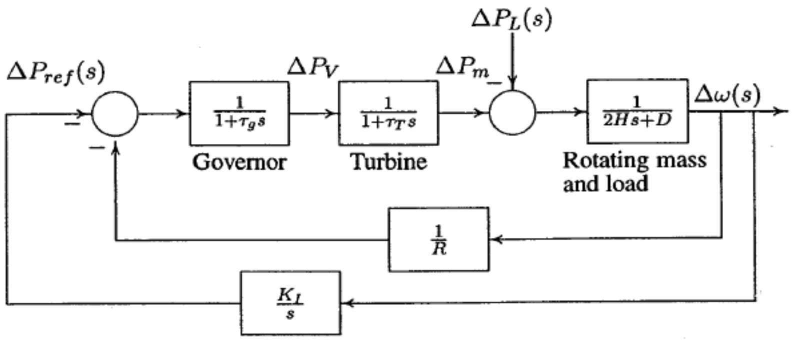

Figure 2.9: AGC in one-area system block diagram (Saadat, 1999)

2.5 AGC in Multi-Area (Two-Area) System

At the beginning of realizing AGC in the multi-area system, the AGC for a two-area power system can be studied first. Figure 2.10 shows the equivalent circuit for two area power system.

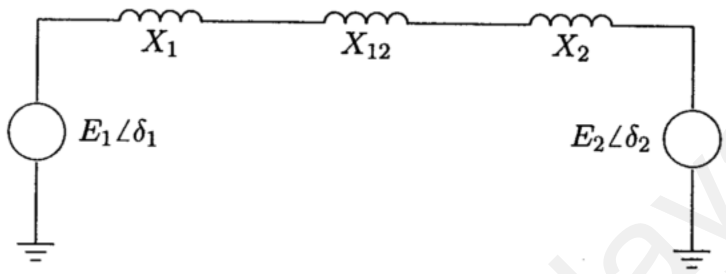

Figure 2.10: The equivalent circuit of a two-area power system (Saadat, 1999)

The following formula states the real power transferred via tie-line when system is at normal operation:

$$P_{12} = \frac{|E_1||E_2|}{X_{12}} \sin \delta_{12} \tag{2.9}$$

where, $X_{12} = X_1 + X_{tie} + X_2$ X_{tie} = tie-line reactance

$$\delta_{12} = \delta_1 - \delta_2 \tag{2.10}$$

Equation (2.9) is used to linearize for a small deviation in ΔP_{12} (tie-line flow), the updated model is shown as Equation (2.11):

$$\Delta P_{12} = \frac{dP_{12}}{d\delta_{12}}|_{\delta 12_0} \Delta\delta_{12} = P_s \Delta\delta_{12} \tag{2.11}$$

where, P_s = The slope of power angle curve

$\delta_{12_0} = \delta_{1_0} - \delta_{2_0}$ δ_{12_0}=The initial operating angle

Then, the updated equation is

$$P_s = \frac{dP_{12}}{d\delta_{12}}|_{\delta 12_0} = \frac{|E_1||E_2|}{X_{12}} \cos \Delta\delta_{12_0} \tag{2.12}$$

The equation for tie-line power deviation is defined as:

$$\Delta P_{12} = P_s(\Delta\delta_1 - \Delta\delta_2) \tag{2.13}$$

It can be seen from equation (2.13) that the phase angle can determine the direction of the flow. For example, when $\Delta\delta_1 > \Delta\delta_2$, it means that the power will flow from area 1 to area 2, and vice versa. Now, considering ΔP_{L1} load change in area one, the steady-state frequency deviation for two areas will be the same when the system is in a steady-state status. i.e.,

$$\Delta\omega = \Delta\omega_1 = \Delta\omega_2 \tag{2.14}$$

$$\Delta P_{m1} - \Delta P_{12} - \Delta P_{L1} = \Delta\omega D_1 \tag{2.15}$$

$$\Delta P_{m2} + \Delta P_{12} = \Delta\omega D_2 \tag{2.16}$$

The characteristics of governor speed can determine the change in mechanical power by

$$\Delta P_{m1} = \frac{-\Delta\omega}{R_1} \tag{2.17}$$

$$\Delta P_{m2} = \frac{-\Delta\omega}{R_2} \tag{2.18}$$

Solving equations (2.15) and (2.17) due to common parameter ΔP_{m1}, $\Delta\omega$ will be:

$$\Delta\omega = \frac{-\Delta P_{L1}}{\left(\frac{1}{R_1} + D_1\right) + \left(\frac{1}{R_2} + D_2\right)}$$

$$= \frac{-\Delta P_{L1}}{B_1 + B_2} \quad (2.19)$$

B_1 and B_2 are frequency bias factors, given by

$$B_1 = \frac{1}{R_1} + D_1 \quad (2.20)$$

$$B_2 = \frac{1}{R_2} + D_2 \quad (2.21)$$

The following mathematical model stands for the change in the tie-line power:

$$\Delta P_{12} = -\frac{(\frac{1}{R_2} + D_2)\Delta P_{L1}}{\left(\frac{1}{R_1} + D_1\right)\left(\frac{1}{R_2} + D_2\right)} \quad (2.22)$$

$$= \frac{B_2}{B_1 + B_2}(-\Delta P_{L1})$$

The steady-state frequency deviation in per unit is shown by:

$$\Delta\omega_{SS} = \frac{-\Delta P_{L1}}{\left(\frac{1}{R_1} + D_1\right) + \left(\frac{1}{R_2} + D_2\right)} \quad (2.23)$$

Therefore, the steady-state frequency deviation states is:

$$\Delta f = (\Delta\omega_{SS})(f) \quad (2.24)$$

The updated frequency can be expressed as:

$$f = \Delta f + f_0 \quad (2.25)$$

The advantages of multi-area power system are (Sharmili & Livingston, 2015):

- Reliable
- Continuity of supply
- The Cost/KW for larger generators is less
- Optimisation of generation

2.6 Tie-Line Bias Control

For each area, the control error comprises the tie-line error and a linear frequency combination. The mathematical model is shown by equation (2.26),

$$ACE_i = \sum_{j=1}^{n} \Delta P_{ij} + K_i \Delta\omega \quad (2.26)$$

ACE is called as area control error. The amount of interaction can be determined by K_i area bias when a disturbance happens in the neighboring-areas. If K_i is the same with the frequency bias factor of that neighboring-area, the overall performance can be acceptable. Hence, the equations of ACEs for two area system are shown:

$$ACE_1 = \Delta P_{12} + B_1 \Delta\omega_1 \quad (2.27)$$

$$ACE_2 = \Delta P_{21} + B_2 \Delta\omega_2 \quad (2.28)$$

Figure 2.11 shows a AGC block diagram for two-area power system. In order to avoid the area to enter into a chase mode, it is necessary for the integrator gain constant to maintain at very small level.

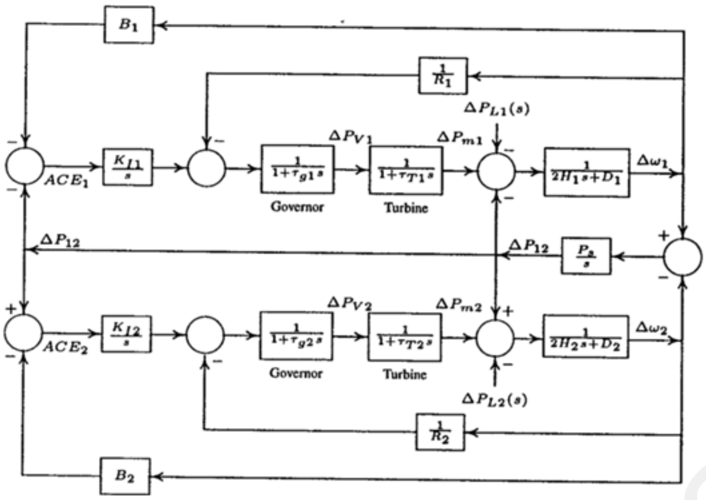

Figure 2.11: AGC in two-area system block diagram (Saadat, 1999)

Two single areas are connected through the tie-line power to construct a two-area inter-connected power system. Each area has its own user pool, electric power can be allowed to flow between areas via the tie-line (Arya, 2018). Figure 2.12 shows a block diagram of AGC for two-area power system with two controllers.

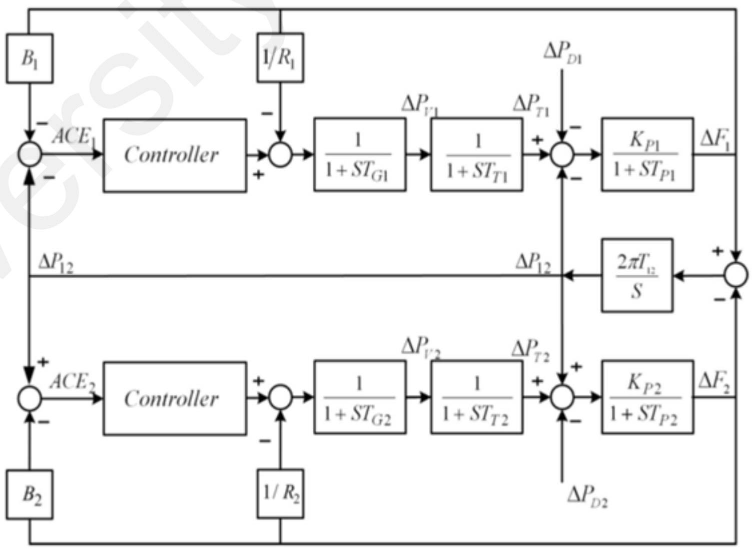

Figure 2.12: AGC in two-area system with two PID controllers block diagram (Shakarami, Faraji, Asghari, & Akbari, 2013)

2.7 PID Controller

2.7.1 Introduction

The PID controller is called as proportional-integral-derivative controller. It is widely used in process industries as feedback controller (Khodabakhshian & Hooshmand, 2010). The PID controller is robust and can be easily understood. Even though it has varied dynamic characteristics in the process plant, it can still offer excellent control performance (Yusoff & Senawi, 2007). As the name mentions, PID has the proportional term, the integral term and the derivate term, which are denoted as P, I and D respectively (A. Kumar & Gupta, 2013). The PID controller can improve the transient response through reducing the settling time and overshoot of a system (Daood & Bhardwaj, 2016). Figure 2.13 describes the block diagram of the PID controller.

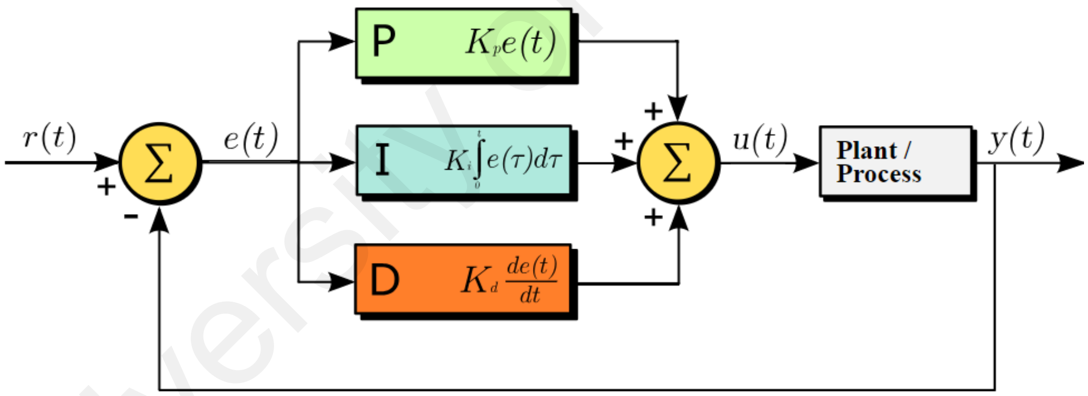

Figure 2.13: The block diagram of PID controller (Ikhe, 2013)

$$u(t) = K_p e(t) + K_i \int_0^t e(t)dt + K_d \frac{de(t)}{dt} \quad (2.29)$$

where, $u(t) = control\ output$ $e(t) = error\ signal$

$K_p = proportional\ gain$, a tuning parameter

$K_i = integral\ gain$, a tuning parameter

$K_d = derivative\ gain$, a tuning parameter

Taking equation (2.29) into Laplace Transfer Function,

$$U(s) = K_p e(s) + (K_i/s)e(s) + (K_d s)e(s) \tag{2.30}$$

2.7.2 Proportional Control

P is proportional to the current error value. The proportional gain constant K_p multiply with the error can adjust the proportional response. Hence, the proportional control part can be given by

$$P_{\boldsymbol{out}} = K_p e(t) \tag{2.31}$$

The advantage of proportional controller is that it can reduce the rise time but the drawback is that it does not work on eliminating the steady-state error (S. Kumar & Nath, 2015). The system will be unstable when the proportional gain is very high. However, the control action may make a very weak response to system disturbances when the proportional gain becomes too low. The controller can become less sensitive or responsive due to a small gain, which causes a small output response to a large input error. Hence, based on the tuning theory and a lot of industrial practical, most of the output change should be contributed by the proportional control.

2.7.3 Integral Control

I is proportional to the magnitude and duration of the error respectively. In the PID controller, the integral is the sum of the instantaneous error over time. It provides the accumulated offset, which has been previously corrected. The integral gain K_i multiply with the accumulated error. Hence, the integral part is given by

$$I_{out} = K_i \int_0^t e(t)dt \tag{2.32}$$

The integral part can eliminate the steady-state error and accelerate process movement towards setpoint, but the transient response may become worse due to the response of accumulated errors from the past (S. Kumar & Nath, 2015).

2.7.4 Derivative Control

D is a best estimate of the predicted future values of the control error, which is based on the current rate of change. The magnitude of the derivative term to the entire control action is defined as the derivative gain K_d. The derivative part is given by

$$D_{out} = K_d \frac{de(t)}{dt} \tag{2.33}$$

The derivative control is not only beneficial to improve the system stability but also the transient response. Also, it can reduce the overshoot. Increasing the proportional gain and decreasing the integral gain allowed by the derivative mode will improve the controller response speed (S. Kumar & Nath, 2015).

CHAPTER 3: METHODOLOGY

3.1 Introduction

The project consists of three main parts; literature review, MATLAB software simulation and writing report. The literature review is very helpful in doing a successful research. This is due to most of the relevant information regarding two-area power system components and parameters can be obtained from this part, which is used as the references in the project. The MATLAB R2017b software is used for constructing the circuit diagram and implementing the codes of optimisation methods for this project. Figure 3.1 presents the overall process of this project.

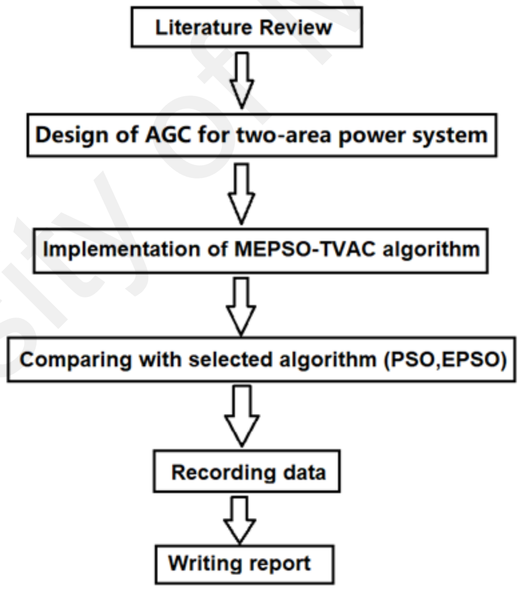

Figure 3.1: The project methodology

- **Literature Review:** The information of Automatic Generation Control, PID controller, MEPSO-TVAC algorithm, EPSO algorithm and PSO algorithm is gathered from the journal papers and books.

- **Design of AGC for two-area power system:** Table 3.1 illustrates parameters of each block for a two-area system connected by a tie-line on a 1000MVA common base (Saadat, 1999). According to parameters from Table 3.1, a basic model of AGC for two-area power system was designed in Matlab Simulink and is shown in Figure 3.2.

Table 3.1: Parameters of a two-area power system (Saadat, 1999)

Area	1	2
Speed Regulation	$R_1 = 0.05$	$R_2 = 0.0625$
Frequency-sens. Load Coeff.	$D_1 = 0.6$	$D_1 = 0.9$
Inertia Constant	$H_1 = 5$	$H_2 = 4$
Governor Time Constant	$\tau_{g1} = 0.2sec$	$\tau_{g2} = 0.3sec$
Turbine Time Constant	$\tau_{T1} = 0.5sec$	$\tau_{T2} = 0.6sec$
Base Power	1000 MVA	
Synchronizing Power Coeff.	$P_s = 2.0pu$	
Load Change in Area 1	$\Delta P_{L1} = 0.1875pu$	
Integrator Gain Constants	$K_{I1} = K_{I2} = 0.3$	

- **Implementation of MEPSO-TVAC algorithm:** The created MEPSO-TVAC algorithm was used in the AGC of two-area power system.
- **Comparing with other algorithms:** The other algorithms, PSO (Particle Swarm Optimisation) and EPSO (Evolutionary Particle Swarm Optimisation) were employed in the AGC of two-area power system. Then, performance of MEPSO-TVAC was compared with these two selected algorithms.
- **Recording data:** The obtained results were recorded after implementing the simulation properly.
- **Writing report:** The last process is writing report.

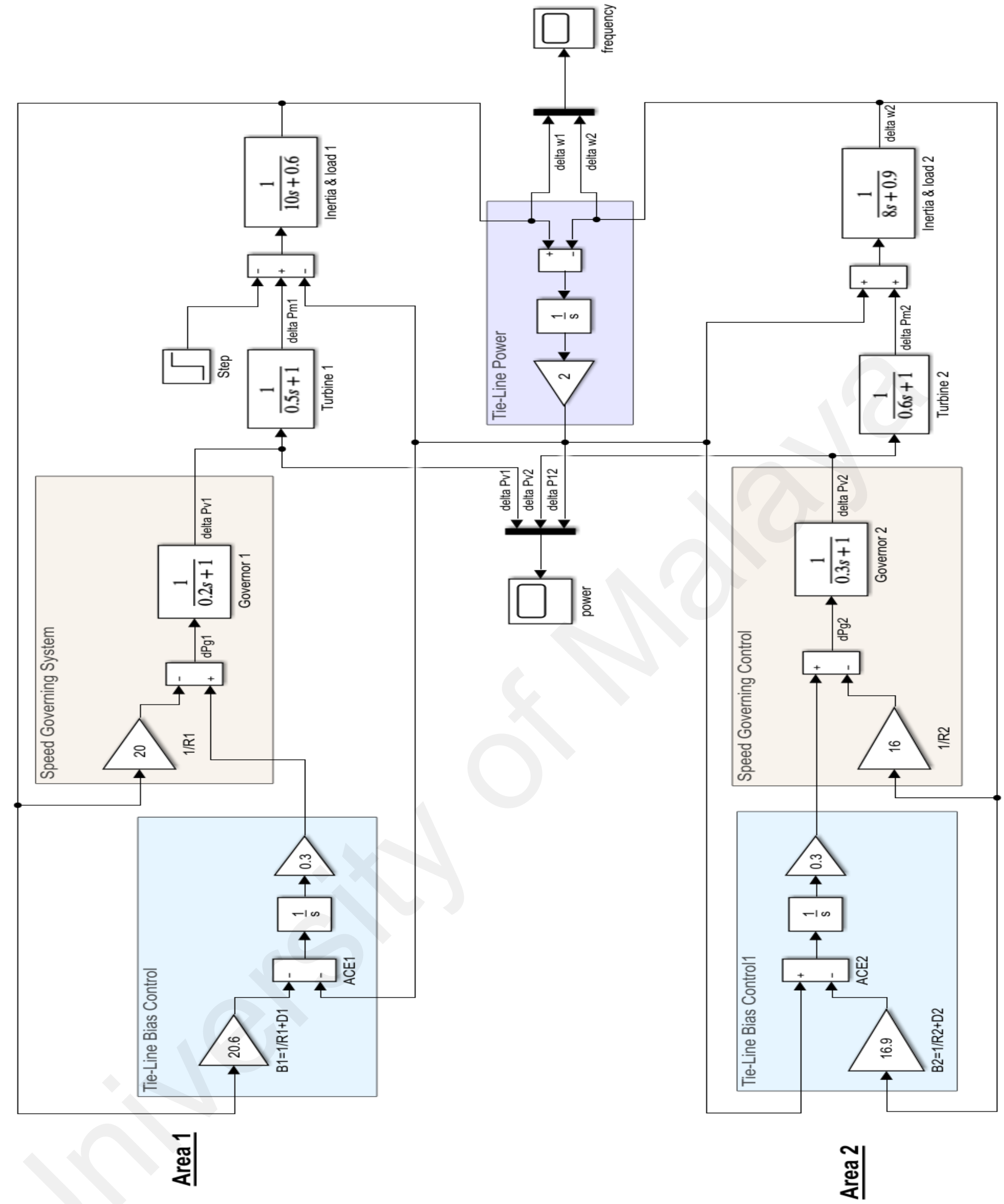

Figure 3.2: Model of AGC for two-area power system in Matlab

3.2 Design AGC in two-area power system with PID controllers

Based on Figure 3.2, two integrators ($\frac{1}{s}$ and 0.3) in tie-line control blocks were replaced with two PID controllers respectively. Hence, Figure 3.3 shows the updated AGC model for two-area power system with PID controllers.

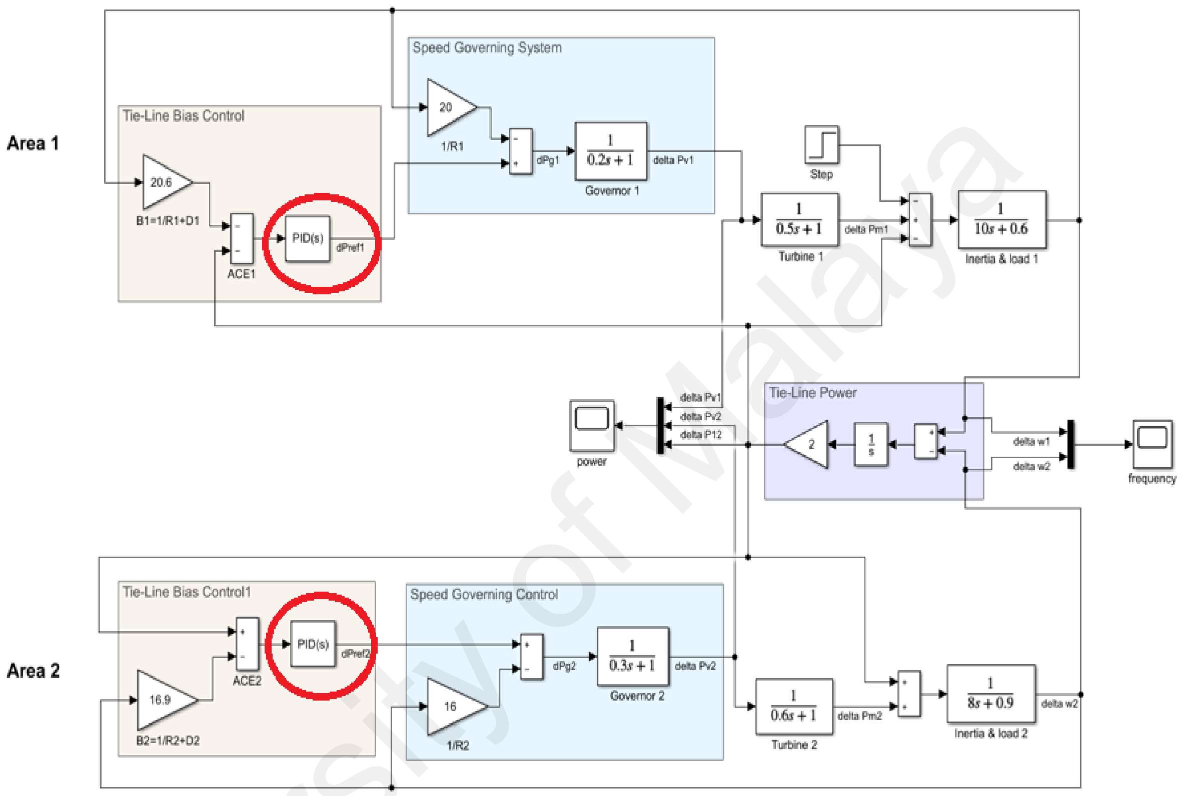

Figure 3.3: Simulink model of AGC for two-area power system with two PID controllers in Matlab

3.3 Particle Swarm Optimisation (PSO)

Particle swarm optimisation is an algorithm optimization method, which was originally invented by Dr. Kennedy and Dr. Eberhart in 1995 (Xing & Pan, 2018). PSO is used for simulating the social behaviors of animals herding, insects and birds flocking, these swarms are normally searching for food in a collaborative and competition way among the entire population (Seekuka, Rattanawaorahirunkul, & Sansri, 2016).

PSO is a population-based optimization tool (Su, Cheng, & Sun, 2011). It can be used for achieving the optimized objective function. In PSO, each particle has a velocity and a position (Solihin, Lee, & Kean, 2011). Firstly, with certain velocity and position, the particle solutions are initialized randomly. Depending on these positions and velocities, fitness value for each particle is determined. Then, fitness value of each particle is used to compare with $pbest_{id}^{j}$, which is called the personal best. The $pbest_{id}^{j}$ and the X_{id}^{j+1} named current position of particle will be considered when the fitness value is better than the $pbest_{id}^{j}$. Hence, among the entire particles, the best fitness value will be set as $gbest_{id}^{j}$ or the global best value (Illias, Chai, & Abu Bakar, 2016).

The updated velocity and position for all particles in the PSO are given by:

$$V_{id}^{j+1} = wV_{id}^{j} + c_1 r_1 \left(pbest_{id}^{j} - X_{id}^{j}\right) + c_2 r_2 \left(gbest_{id}^{j} - X_{id}^{j}\right) \tag{3.1}$$

$$X_{id}^{j+1} = X_{id}^{j} + V_{id}^{j+1} \tag{3.2}$$

where, c_1 and c_2 = acceleration factors

r_1 and r_2 = random constants from 0 to 1

V_{id}^{j+1}= updated velocity at particle i in dimension d search region

V_{id}^{j} = at iteration j, the velocity of particle i

X_{id}^{j} and X_{id}^{j+1}= current position and updated position respectively of particle i at iteration j in search region of dimension d

w = inertia weight

$$w = w_{max} - j(\frac{w_{max} - w_{min}}{j_{max}}) \tag{3.3}$$

w_{max} = maximum weight

w_{min} = minimum weight

j_{max} = maximum iteration number

The steps of PSO algorithm can be described with flowchart shown in Figure 3.4.

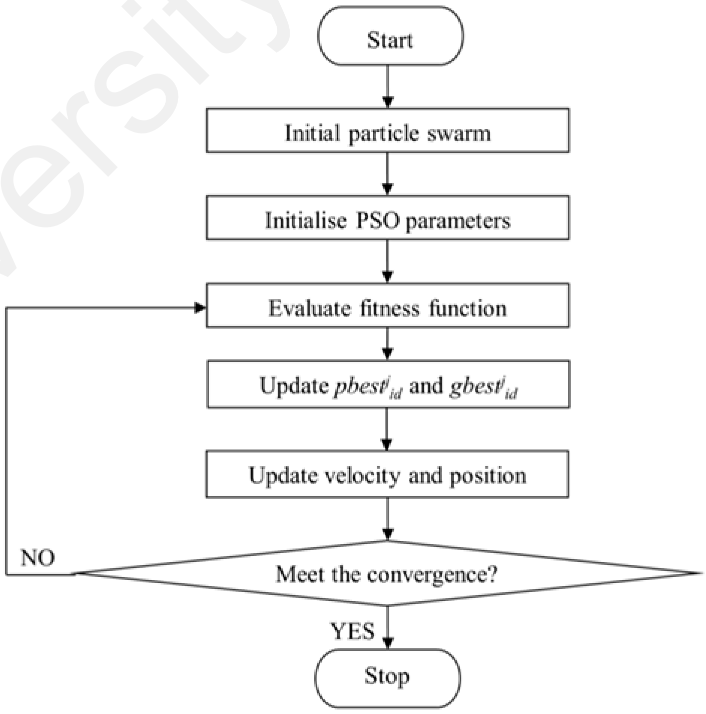

Figure 3.4: The flowchart of PSO algorithm technique (Malik & Dutta, 2014)

3.4 Evolutionary Particle Swarm Optimisation (EPSO)

EPSO optimisation technique was invented by Miranda (Illias & Zhao Liang, 2018). It is a combination of the evolutionary strategies and particle swarm optimisation. Compared with PSO method, EPSO method is more effective and diverse despite starting like PSO. In EPSO, the region of global best fitness value will not be focused by the search of particle. However, the optimum may be found in the neighborhood when the optimal value is not there (Illias, Chai, Abu Bakar, & Mokhlis, 2015).

Hence, the updated velocity is modified from equation (3.1) and is given as

$$V_{id}^{j+1} = w_{i0}^{*} V_{id}^{j} + w_{i1}^{*}\left(pbest_{id}^{j} - X_{id}^{j}\right) + w_{i2}^{*}\left(gbest_{id}^{*} - X_{id}^{j}\right) \qquad (3.4)$$

where, $gbest_{id}^{*}$ = mutated global best position

$$= gbest_{id}^{j} + \tau' N \qquad (3.5)$$

w_{ik}^{*} = mutated weight, k = 0, 1 and 2

$$= w_{ik} + \tau N \qquad (3.6)$$

τ' = noise dispersion factor

τ = learning dispersion factor

N = a random value between 0 and 1

In EPSO, the updated position is obtained using equation (3.2).

EPSO algorithm uses the concept of replication, mutation and reproduction (Jumaat & Musirin, 2012). Each particle is replicated for replication. For mutation, the weight of each replicated particle is mutated. For reproduction, each particle reproduces an offspring. Then, based on the current position, each particle is evaluated (Illias, Zahari, & Mokhlis, 2016). Figure 3.5 shows the flowchart of EPSO overall process.

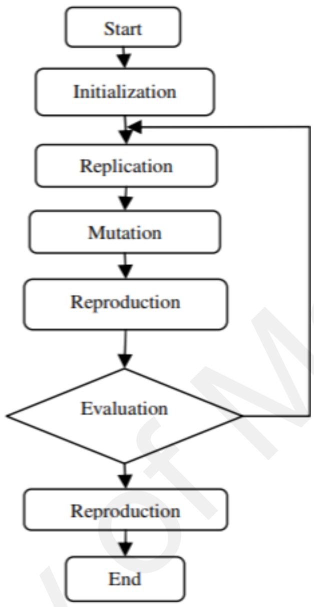

Figure 3.5: The flowchart of EPSO process (Jumaat & Musirin, 2012)

3.5 MEPSO-TVAC

The proposed modified evolutionary particle swarm optimization with time varying acceleration coefficient (MEPSO-TVAC) is based on evolutionary particle swarm optimization (EPSO). Based on equation (3.4), a new parameter $rbest$ is introduced, which is used for providing an extra information to each particle. The advantage of this new term is that it can diversify movement of particles, improve the exploration capability and behavior of searching for particles. It also can avoid premature convergence (Illias, Chai, et al., 2016).

The updated velocity for each particle in the MEPSO is given by:

$$V_{id}^{j+1} = w_{i0}^{*}V_{id}^{j} + w_{i1}^{*}\left(pbest_{id}^{j} - X_{id}^{j}\right) + w_{i2}^{*}\left(gbest_{id}^{*} - X_{id}^{j}\right) + w_{i3}^{*}\left(rbest_{id}^{*} - X_{id}^{j}\right) \quad (3.7)$$

Based on equation (3.6), time-varying acceleration coefficient (TVAC) in the MEPSO is introduced as follows:

$$w_{i0}^{*} = w + \tau N \quad (3.8)$$

$$w_{i1}^{*} = c_1 + \tau N \quad (3.9)$$

$$w_{i2}^{*} = c_2 + \tau N \quad (3.10)$$

$$w_{i3}^{*} = c_3 + \tau N \quad (3.11)$$

where, c_1 = cognitive coefficient

c_2 = social coefficient

c_3 = TVAC for $rbest$ component

w_{i1}^{*}, w_{i2}^{*} and w_{i3}^{*} are all called as mutated weight, where

$$c_1 = c_{1i} + (c_{1f} - c_{1i})(j/j_{max}) \tag{3.12}$$

$$c_2 = c_{2i} + (c_{2f} - c_{2i})(j/j_{max}) \tag{3.13}$$

$$c_3 = c_1[1 - \exp(-c_2 j)] \tag{3.14}$$

where, c_{1i} = initial value of cognitive component

c_{2i} = initial value of social component

c_{1f} = final value of cognitive component

c_{2f} = final value of social component

The steps of MEPSO-TVAC algorithm can be described with the flowchart, which is shown in Figure 3.5.

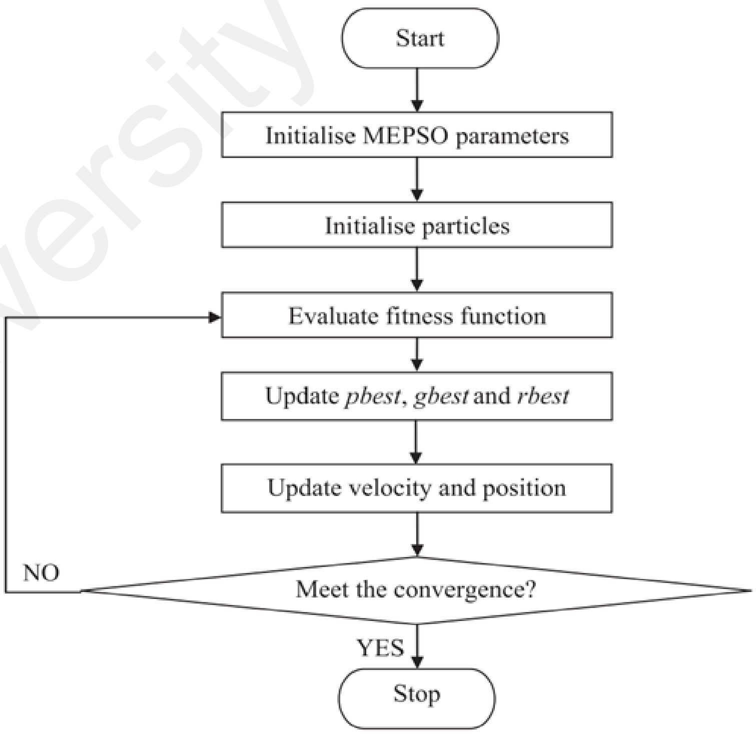

Figure 3.6: The flowchart of MEPSO-TVAC (Illias, Chai, et al., 2016)

In MEPSO-TVAC algorithm, cognitive coefficient c_1 is unequal to social coefficient c_2 at each iteration. From equations (3.12) and (3.13), in the initial iteration, when c_1 is large and c_2 is small, it will push the particles to move around the total solution space. With the number of iteration, when c_2 increases but c_1 reduces, each particle's exploitation and exploration can be improved by the TVAC. The reason for the improvement is that it pulls the particles towards the global solution. However, the particle will be pulled by c_3 towards $rbest$, it will keep on improving the particle's exploration to achieve a better optimum solution. The maximum number of iteration (the stopping criterion) or the cost function is checked to decide whether the steps of updating $pbest_{id}^{j}$ and $gbest_{id}^{j}$, updating position and velocity and evaluating the cost function should be repeated or not (Illias, Chai, et al., 2016).

3.6 MEPSO-TVAC, PSO and EPSO parameters selection

At the starting of implementing optimisation methods, some relevant parameters should be declared. The parameters selection is necessary to find the optimized values of K_p, K_i and K_d. For different optimisation methods, the same size of population and number of iteration were used. Table 3.2 presents the values of parameters used in MEPSO-TVAC, EPSO and PSO for two area power system.

Table 3.2: The parameters in PSO, EPSO and MEPSO-TVAC for a two-area interconnected power system

Parameters	Algorithm		
	PSO	EPSO	MEPSO-TVAC
Population size n	10	10	10
Maximum number of iteration	100	100	100
Acceleration factors c_1, c_2	0.2	0.2	0.2
Inertia weight minimum value w_{min}	0.1	0.1	0.1
Inertia weight maximum value w_{max}	0.5	0.5	0.5
Learning dispersion factor τ	-	0.25	0.25
Noise dispersion factor τ'	-	0.25	0.25
Initial value of cognitive component c_{1i}	-	-	0.5
Initial value of social component c_{2i}	-	-	1.0
Final value of cognitive component c_{1f}	-	-	1.0
Final value of social component c_{2f}	-	-	0.5

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 Introduction

In order to find the optimum parameters for PID controllers, MEPSO-TVAC optimisation technique was used. PSO and EPSO methods are used for comparing the performance with MEPSO-TVAC method under different cases, which are 2 PID controllers in two areas respectively, 1 PID controller in area 1 and 1 PID controller in area 2. The only variable that shows a step response is power in area 1 due to a load step in area 1. Hence, the performance can be expressed by settling time, rise time and overshoot of power deviation in area 1. Also, the cost function is defined to determine the best algorithm among the three optimisation methods when the system was run with same number of PID controllers. The definition of each term is as follows:

- **Settling time:** It is the time taken for power system to achieve its steady-state status.
- **Rise time:** It is the time taken for the response to increase from 10% to 90% of steady-state response.
- **Overshoot:** The overshoot can express how much the peak level is higher than the steady-state. For example, power system can be damaged when the overshoot is very high. Hence, the overshoot of power system should maintain as low as possible, which is helpful to protect the power system.
- **Fitness:** The fitness is the cost function for the optimisation, which is the error of frequency deviation. It is also the tie-line power. However, this deviation (or error) can be quantified in different ways i.e. overshoot, rise time, settling time. Fitness is a quantity that tells how good the controller is or how good the response of the controller is.

4.2 AGC with Two PID Controllers (Without Optimisation)

Figure 4.1 presents AGC with two PID controllers for two-area power system block diagram in Matlab Simulink. At the beginning of MEPSO-TVAC algorithm codes, two PID controllers are assumed as the integrator gain constants to reproduce the same waveforms as the reference in (Saadat,1999).

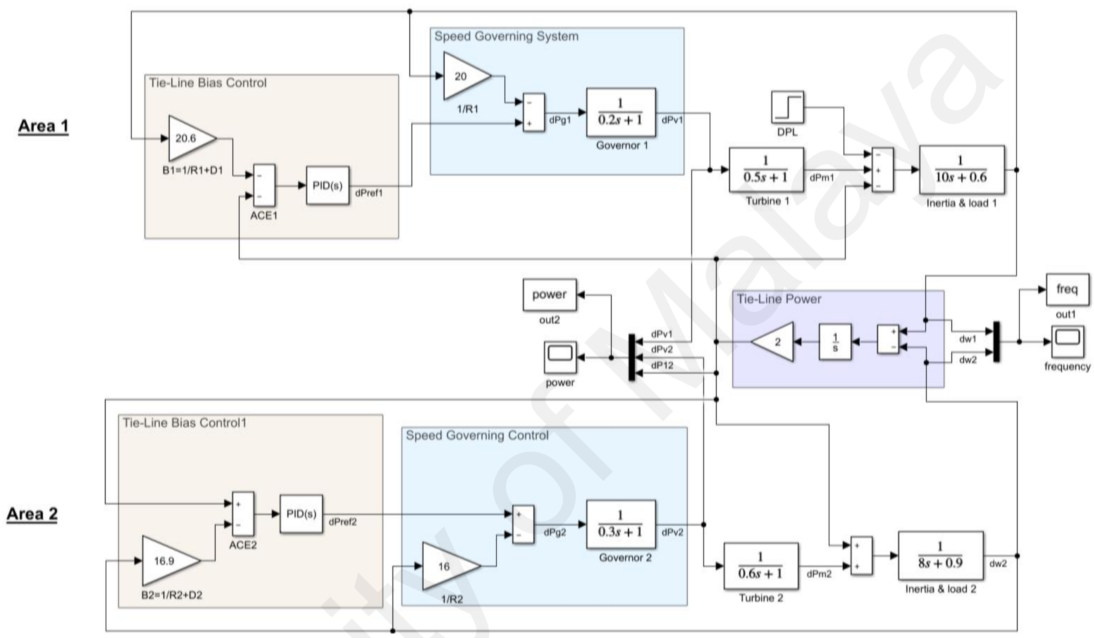

Figure 4.1: The block diagram of AGC with two PID controllers

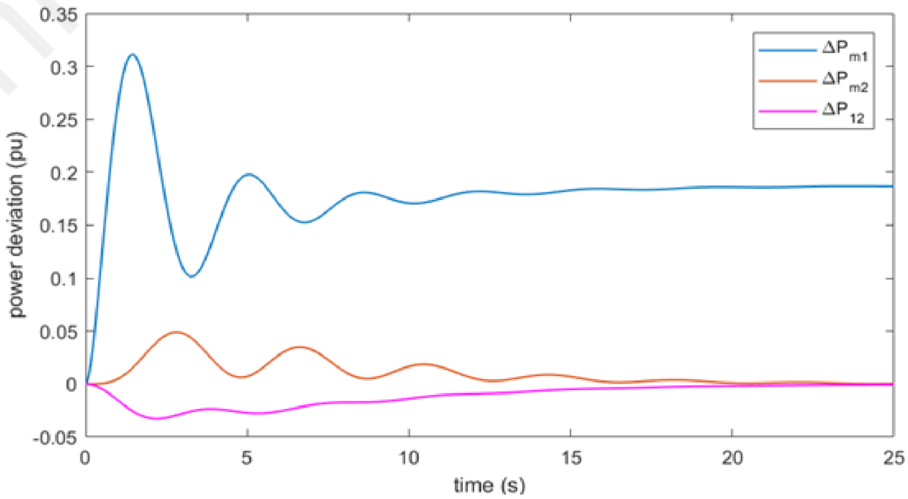

Figure 4.2: Power deviation for AGC with two PID controllers

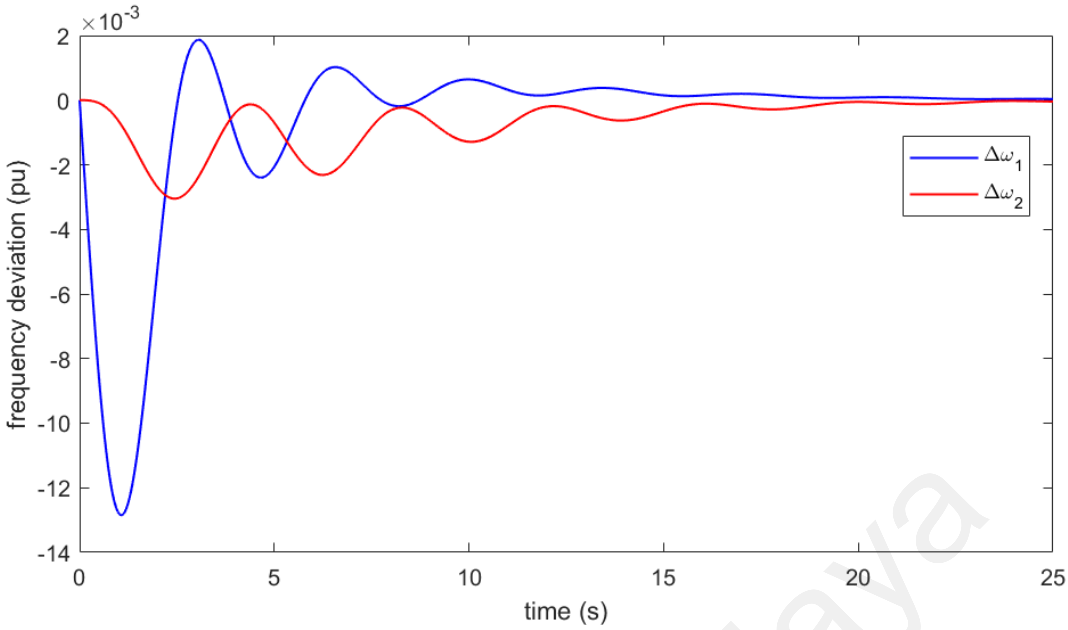

Figure 4.3: Frequency deviation for AGC with Two PID controllers

Figure 4.2 and 4.3 show power deviation and frequency deviation for AGC with two PID controllers in two-area power system. ΔP_{m1} and ΔP_{m2} represents power deviation in area 1 and area 2 respectively. ΔP_{12} stands for tie-line power deviation between area 1 and area 2. Besides, $\Delta\omega_1$ and $\Delta\omega_2$ are frequency deviation in area 1 and area 2 respectively. For the following section 4.3 and 4.4, above mentioned parameters represent the same meaning such as ΔP_{m1} and $\Delta\omega_1$.

Without optimisation, the values of K_p, K_i and K_d for AGC with two PID controllers in area 1 and area 2 are shown in Table 4.1.

Table 4.1: Values of K_p, K_i and K_d for area 1 and area 2

Without Optimisation					
Area 1			**Area 2**		
K_{p1}	K_{i1}	K_{d1}	K_{p2}	K_{i2}	K_{d2}
0	0.3	0	0	0.3	0

4.3 AGC with Two PID Controllers (with MEPSO-TVAC Optimisation)

Figure 4.4 shows block diagram of AGC with two PID controllers, which is used in MEPSO-TVAC optimization technique.

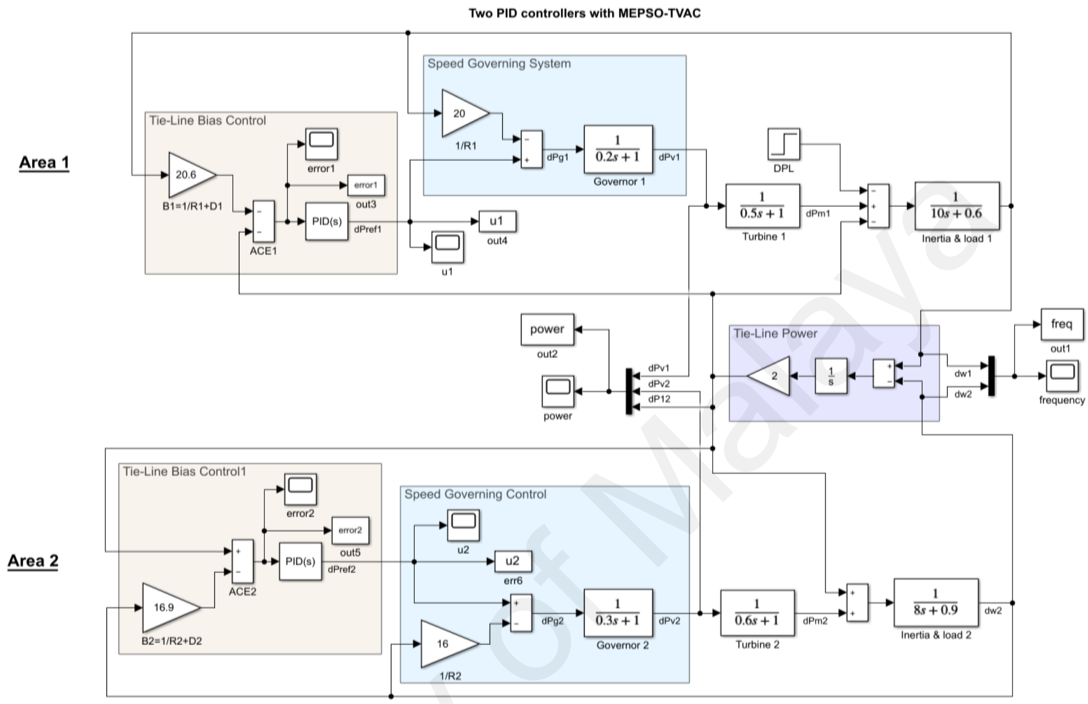

Figure 4.4: The block diagram of AGC with two PID controllers

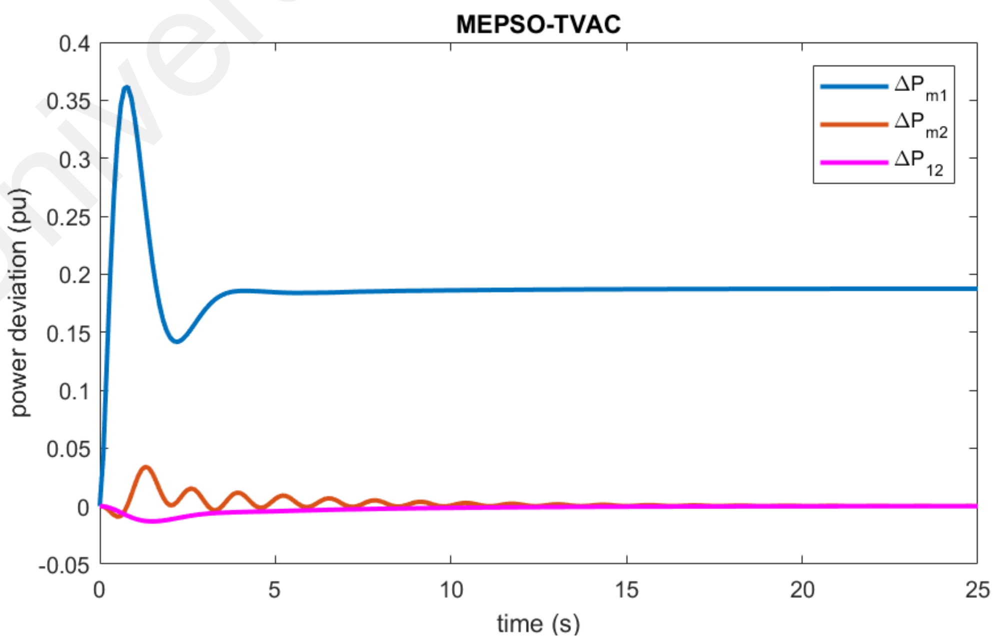

Figure 4.5: Power deviation for AGC with two PID controllers

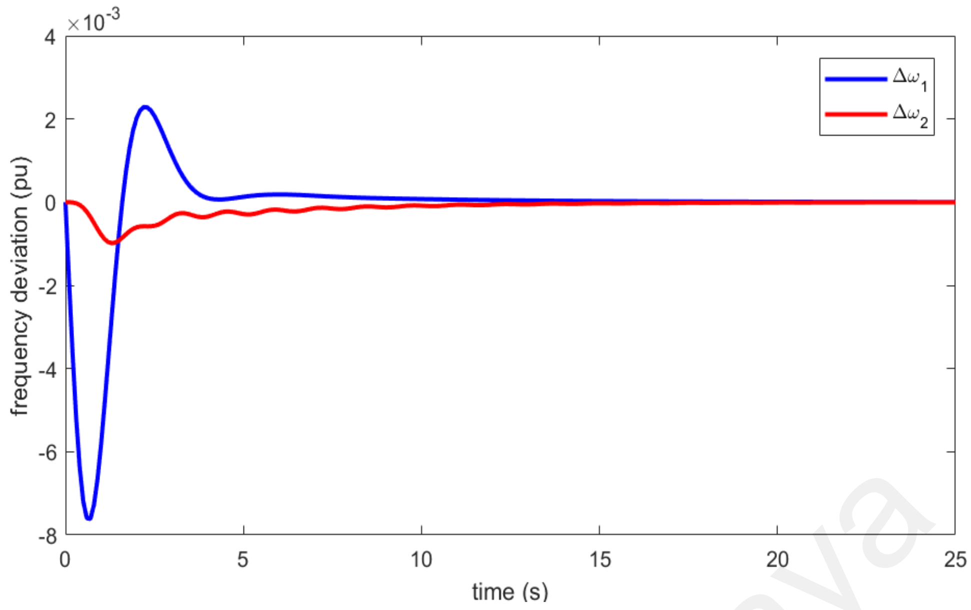

Figure 4.6: Frequency deviation for AGC with two PID controllers

Figure 4.5 and 4.6 show power deviation and frequency deviation for AGC with two PID controllers in two-area power system using MEPSO-TVAC algorithm respectively. Figure 4.7 shows the fitness for this power system. The fitness value starts from 22.6733 and achieves a steady-state value 16.7952 at the iteration number 56.

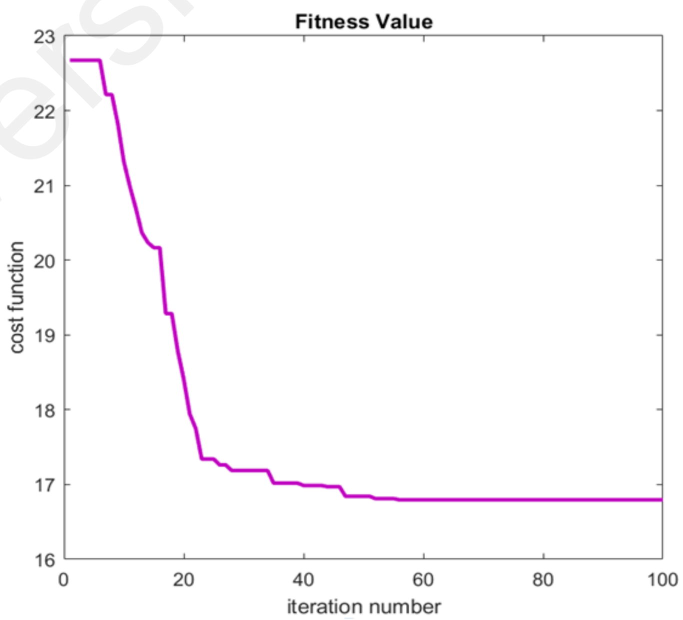

Figure 4.7: The fitness curve for AGC with two PID controllers

4.4 Performances of comparing MEPSO-TVAC with EPSO and PSO for 3 cases

4.4.1 Case I: Two PID Controllers in Both Areas

a) EPSO algorithm vs MEPSO-TVAC algorithm

Figure 4.8 and 4.9 present power deviation and frequency deviation using EPSO and MEPSO-TVAC algorithm for area 1 and area 2 respectively.

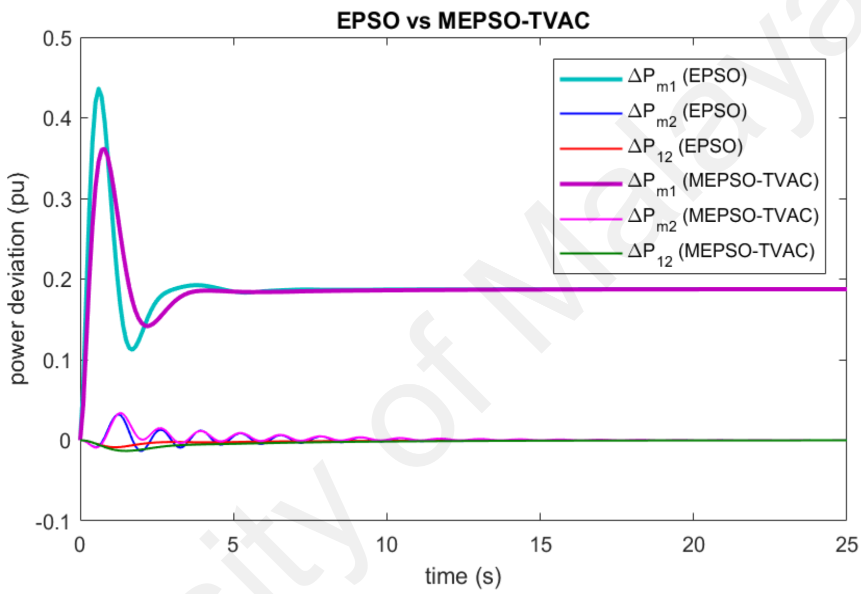

Figure 4.8: Difference between EPSO and MEPSO-TVAC on power deviation

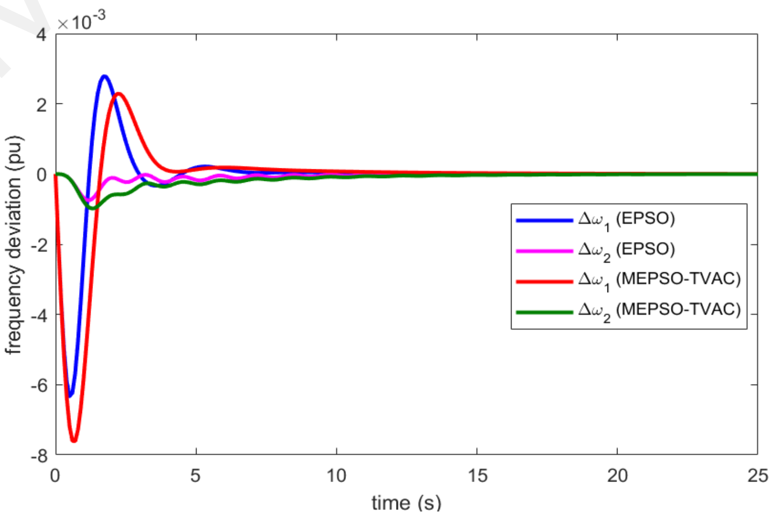

Figure 4.9: Difference between EPSO and MEPSO-TVAC on frequency deviation

b) PSO algorithm vs MEPSO-TVAC algorithm

Figure 4.10 and 4.11 present power deviation and frequency deviation using PSO and MEPSO-TVAC algorithm on both areas respectively.

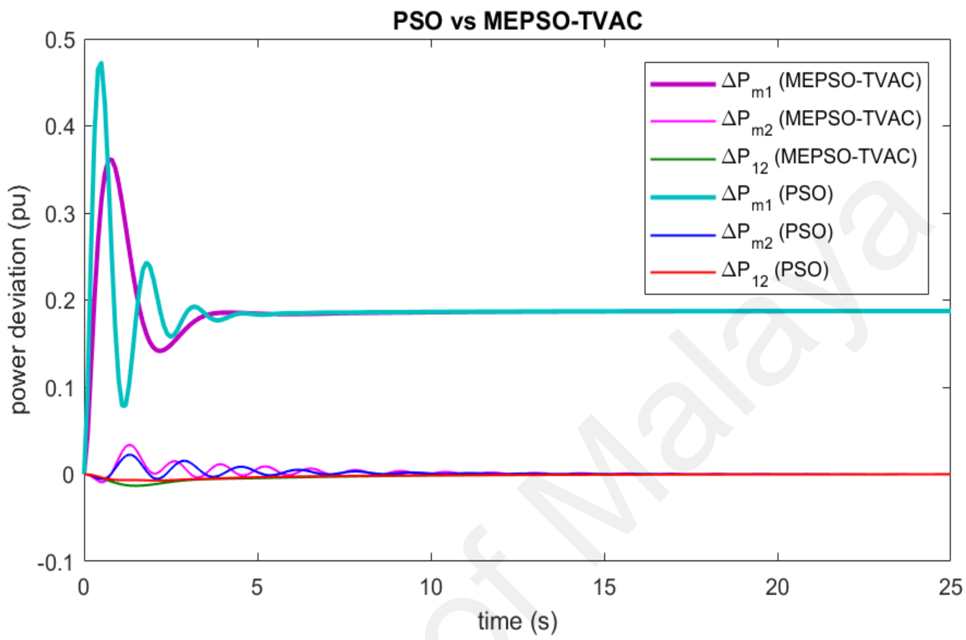

Figure 4.10: Difference between PSO and MEPSO-TVAC on power deviation

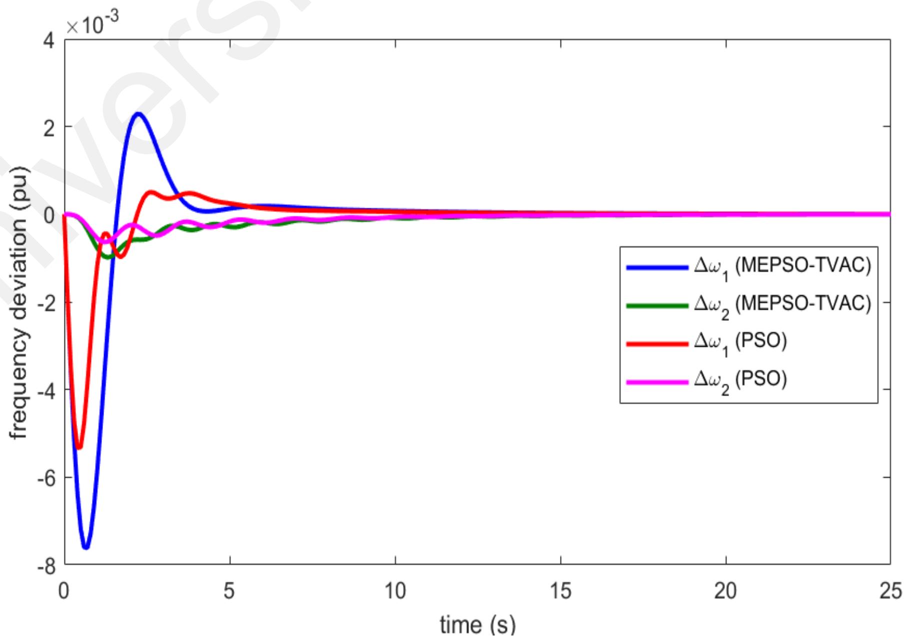

Figure 4.11: Difference between PSO and MEPSO-TVAC on frequency deviation

c) The fitness among EPSO, MEPSO-TVAC and PSO

Figure 4.12 shows the different fitness for AGC with two PID controllers by using EPSO, MEPSO-TVAC and PSO. It can be clearly seen that fitness value for MEPSO-TVAC algorithm is the lowest among three algorithms.

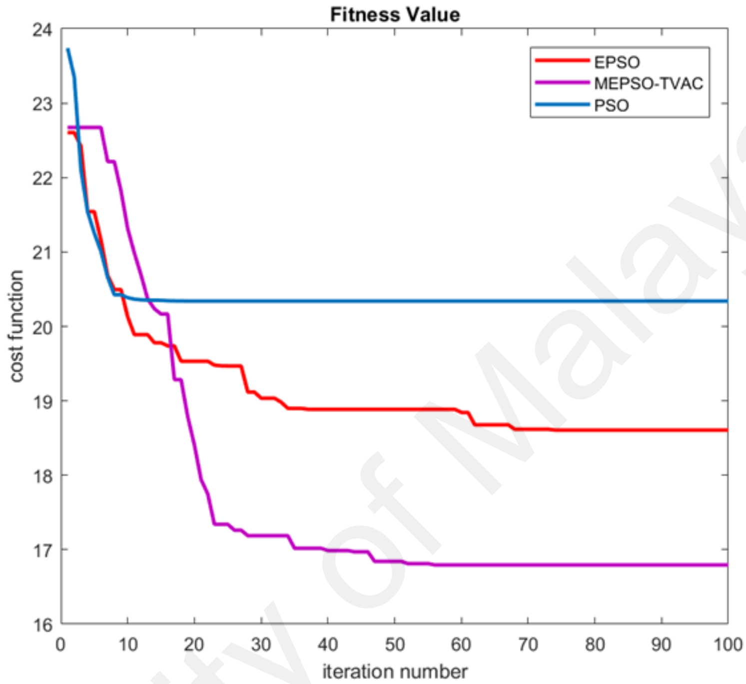

Figure 4.12: The fitness curves for AGC among EPSO, MEPSO-TVAC and PSO

In the case of two PID controllers on both areas using EPSO, MEPSO-TVAC and PSO, optimization values of K_p, K_i and K_d for each area are shown in Table 4.2.

Table 4.2: Optimization values of K_p, K_i and K_d with different optimization methods

Types of Optimisation	Case I: Two PID Controllers					
	Area 1			Area 2		
	K_{p1}	K_{i1}	K_{d1}	K_{p2}	K_{i2}	K_{d2}
EPSO	0.88975	3	0.80531	4	0.72455	2
MEPSO-TVAC	0.49899	1.4737	0.51572	4	0.09589	2
PSO	1.4453	2.0412	1.2427	2.7252	1.3335	1.1795

4.4.2 Case II: Only One PID Controller in Area 1

Figure 4.13 shows block diagram of AGC with only one PID controller in area 1, which is used in EPSO, MEPSO-TVAC and PSO algorithms.

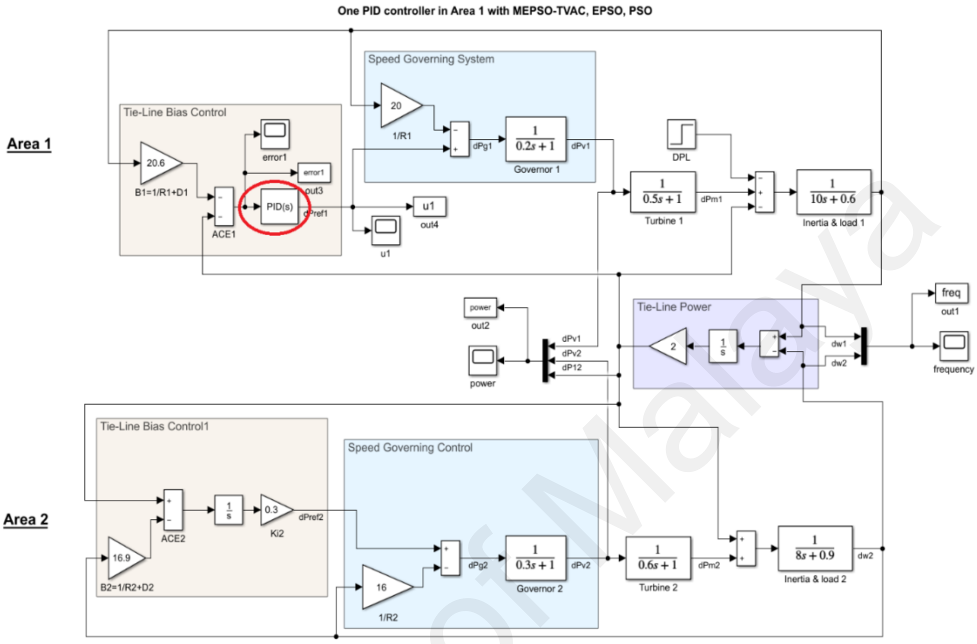

Figure 4.13: The block diagram of AGC with only one PID controller in area 1

a) EPSO algorithm vs MEPSO-TVAC algorithm

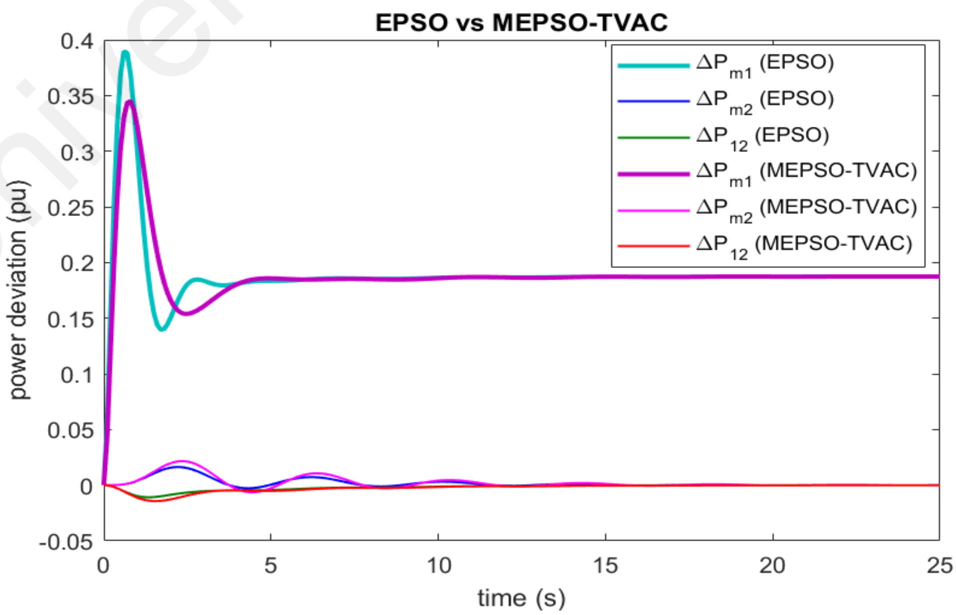

Figure 4.14: Difference between EPSO and MEPSO-TVAC on power deviation

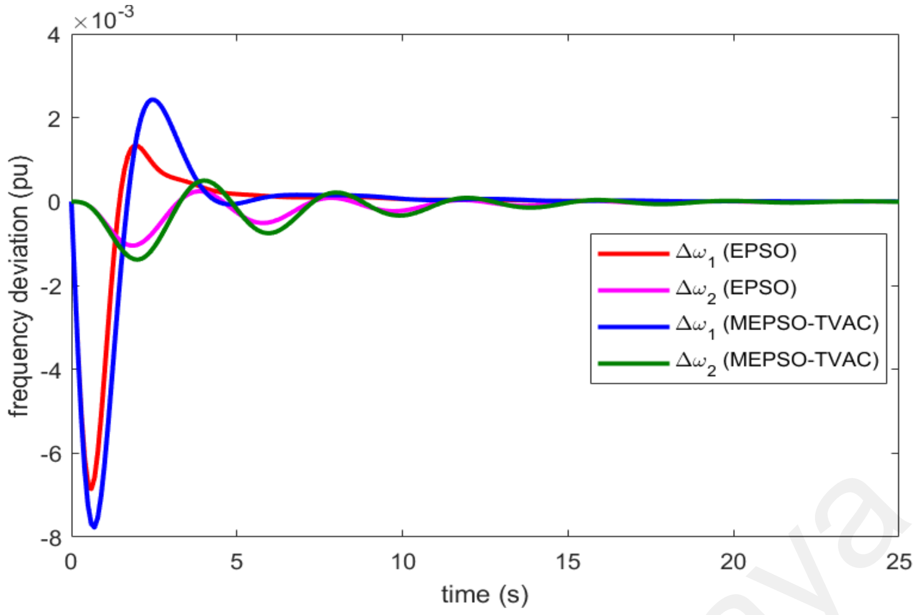

Figure 4.15: Difference between EPSO and MEPSO-TVAC on frequency deviation

Figure 4.14 and 4.15 show power deviation and frequency deviation using EPSO and MEPSO-TVAC algorithm for area 1 respectively.

b) PSO algorithm vs MEPSO-TVAC algorithm

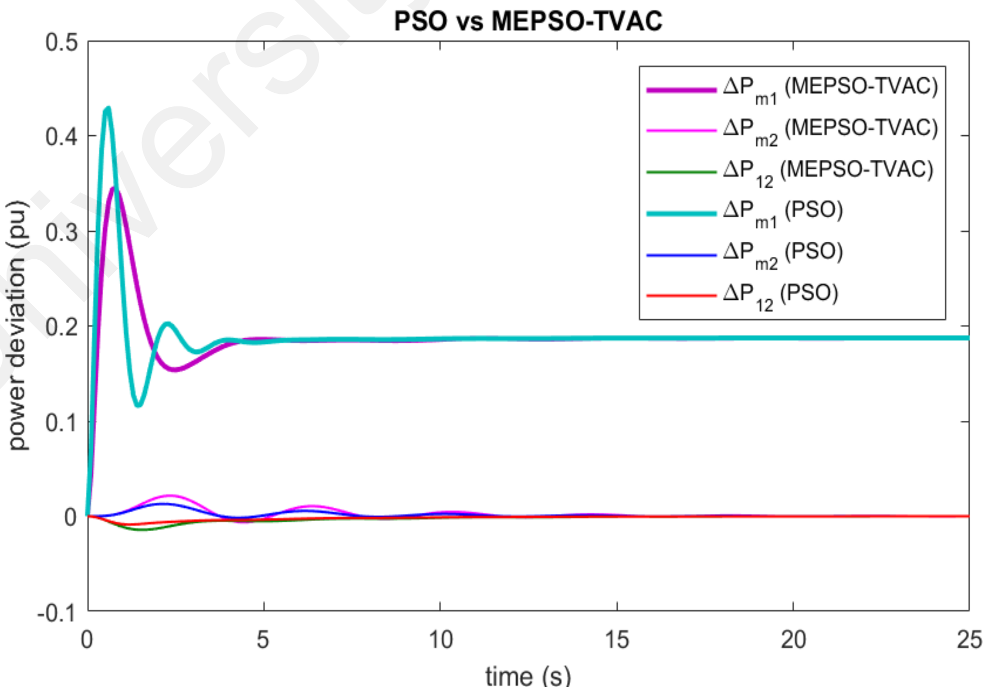

Figure 4.16: Difference between PSO and MEPSO-TVAC on power deviation

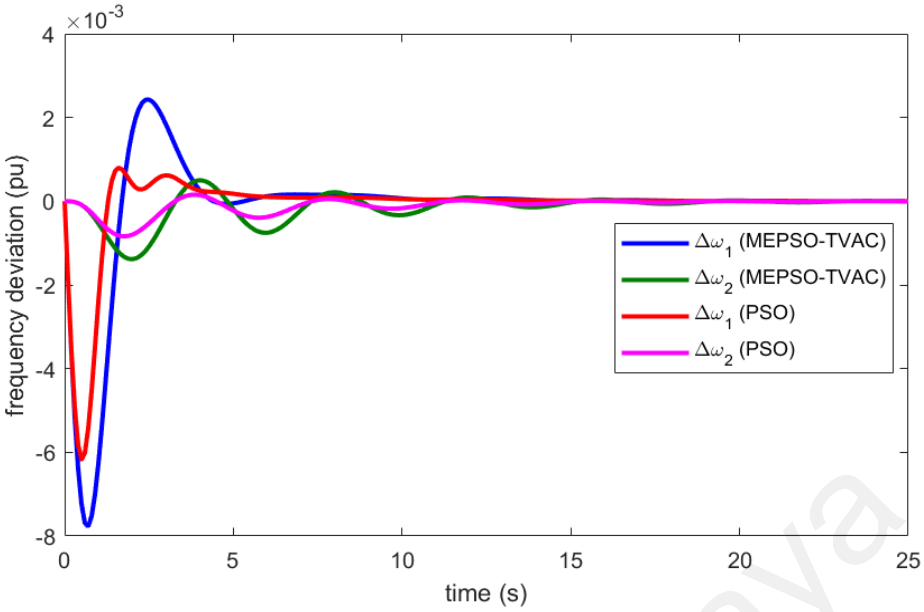

Figure 4.17: Difference between PSO and MEPSO-TVAC on frequency deviation

Figure 4.16 and 4.17 show power deviation and frequency deviation using PSO and MEPSO-TVAC algorithm in area 1 respectively.

c) The fitness among EPSO, MEPSO-TVAC and PSO

Figure 4.18 shows the different fitness for AGC with only one PID controller in area 1 by using EPSO, MEPSO-TVAC and PSO. It can be seen clearly that the fitness value for MEPSO-TVAC algorithm is the lowest despite slower convergence speed.

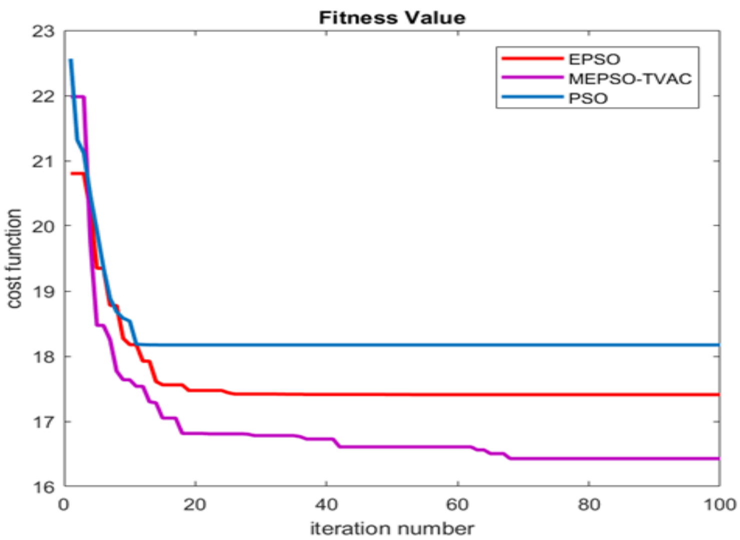

Figure 4.18: The fitness for AGC among EPSO, MEPSO-TVAC and PSO in area 1

In the case of only one PID controller in area 1 by using EPSO, MEPSO-TVAC and PSO, optimization values of K_p, K_i and K_d in area 1 are shown in Table 4.3.

Table 4.3: Optimization values of K_p, K_i and K_d with different optimization methods

Types of Optimisation	**Case II: Only one PID Controller in Area 1**		
	Area 1		
	K_{p1}	K_{i1}	K_{d1}
EPSO	0.781	1.7297	0.67008
MEPSO-TVAC	0.33564	1.4281	0.53169
PSO	1.1403	2.0691	0.85228

4.4.3 Case III: Only One PID Controller in Area 2

Figure 4.19 shows block diagram of AGC with only one PID controller in area 2, which is used in EPSO, MEPSO-TVAC and PSO algorithms.

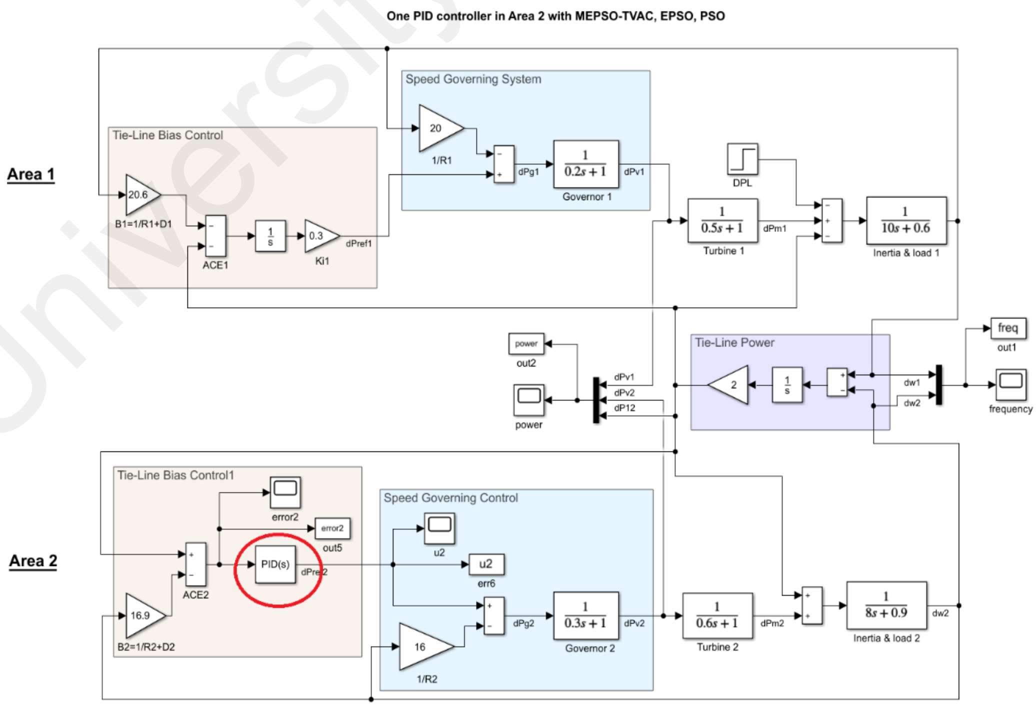

Figure 4.19: The block diagram of AGC with only one PID controller in area 2

a) EPSO algorithm vs MEPSO-TVAC algorithm

Figure 4.20 and 4.21 show power deviation and frequency deviation using EPSO and MEPSO-TVAC algorithm for area 2 respectively.

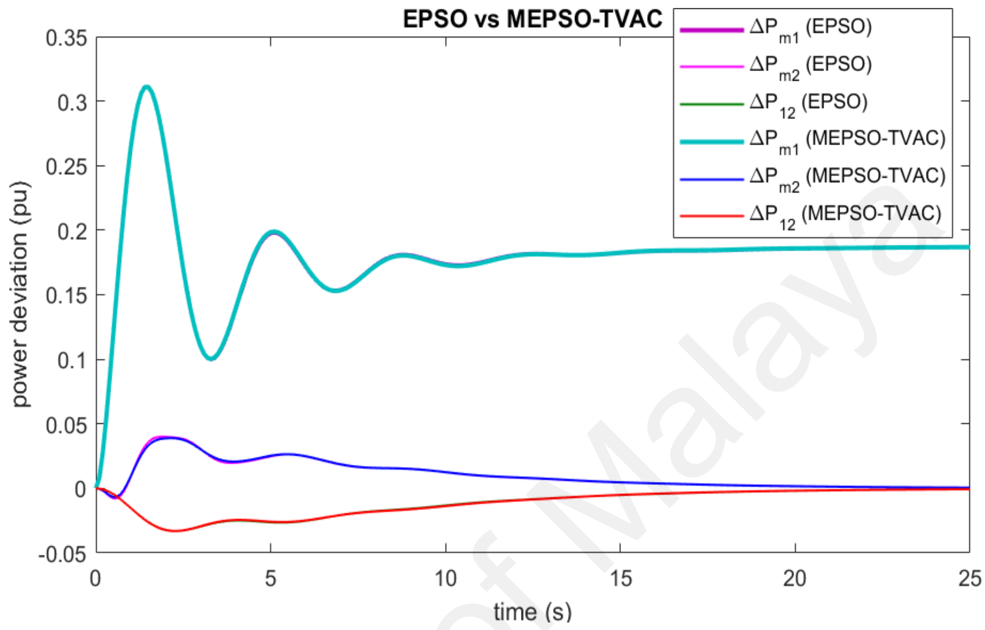

Figure 4.20: Difference between EPSO and MEPSO-TVAC on power deviation

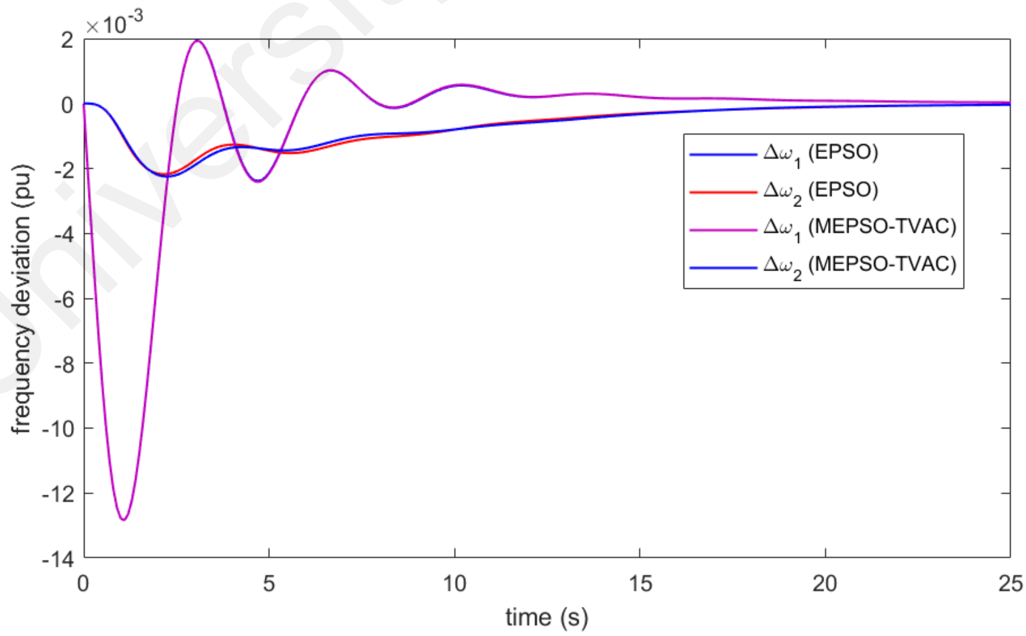

Figure 4.21: Difference between EPSO and MEPSO-TVAC on frequency deviation

b) PSO algorithm vs MEPSO-TVAC algorithm

Figure 4.22 and 4.23 show power deviation and frequency deviation using PSO and MEPSO-TVAC algorithm for area 2 respectively.

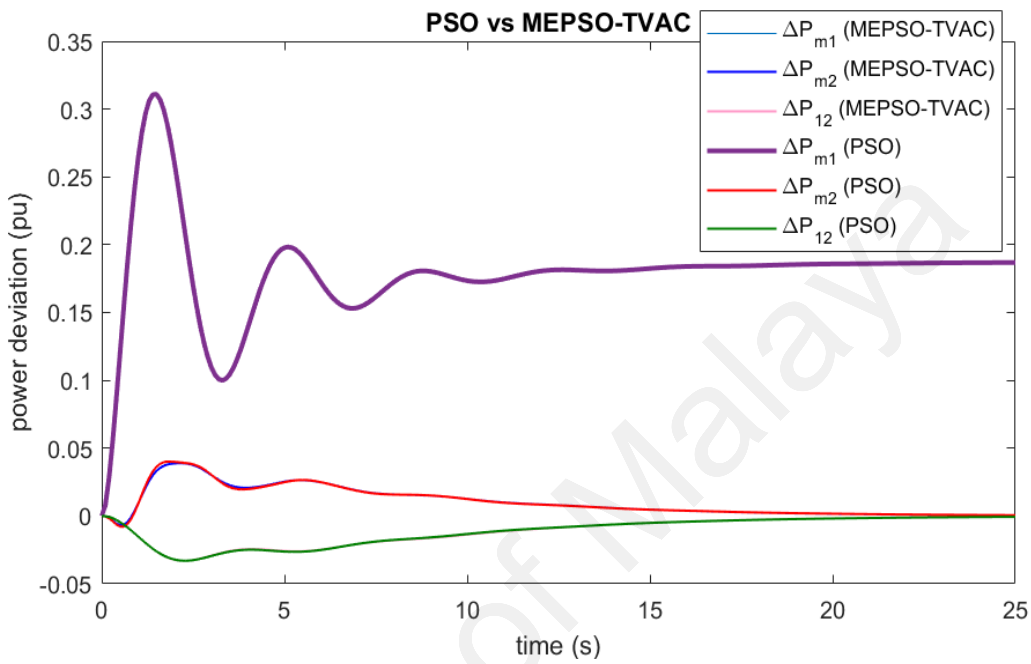

Figure 4.22: Difference between PSO and MEPSO-TVAC on power deviation

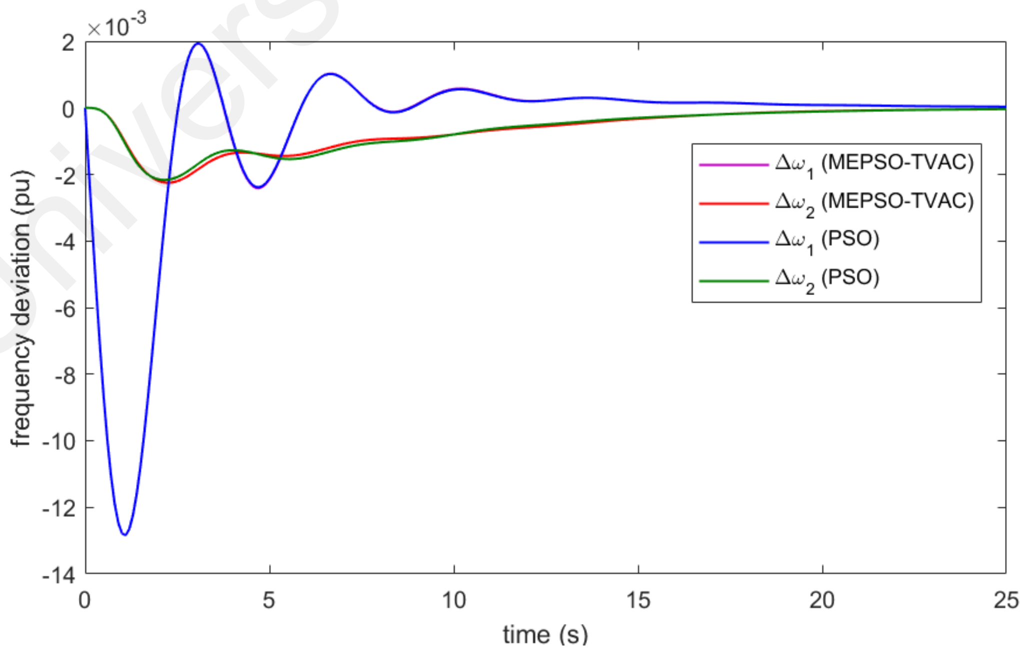

Figure 4.23: Difference between PSO and MEPSO-TVAC on frequency deviation

c) The fitness among EPSO, MEPSO-TVAC and PSO

Figure 4.24 shows the different fitness for AGC with only one PID controller in area 2 by using EPSO, MEPSO-TVAC and PSO. It shows that fitness value for MEPSO-TVAC algorithm is the lowest.

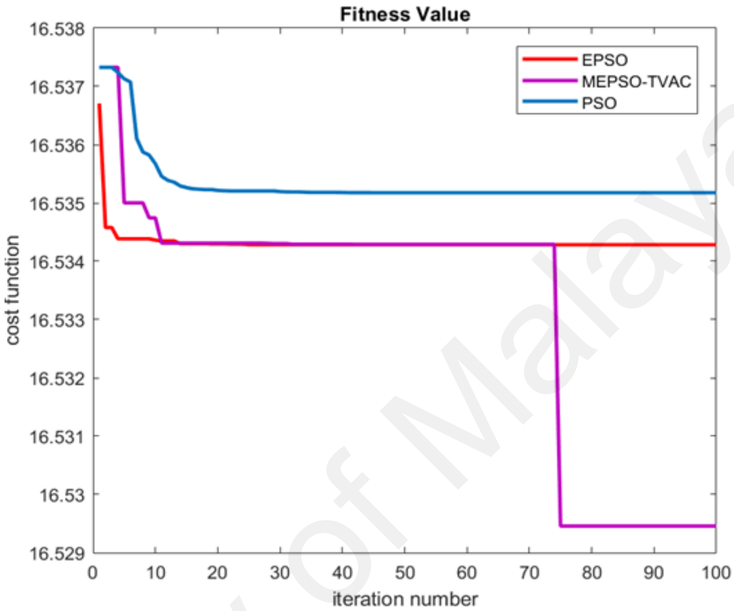

Figure 4.24: The fitness for AGC among EPSO, MEPSO-TVAC and PSO in area 2

In the case of only one PID controller in area 2 by using EPSO, MEPSO-TVAC and PSO, optimization values of K_p, K_i and K_d in area 2 are shown in Table 4.4.

Table 4.4: Optimization values of K_p, K_i and K_d with different optimization methods

Types of Optimisation	Case III: Only one PID Controller in Area 2		
	Area 2		
	K_{p2}	K_{i2}	K_{d2}
EPSO	0.87735	1.8052	2
MEPSO-TVAC	0	0.6812	2
PSO	1.0448	1.8461	1.9847

4.5 Results and Discussions for each case

4.5.1 Comparison among 3 algorithms under same number of PID controller

Based on the simulation results, the important parameters of different cases such as overshoot, fitness and settling time are shown in Tables 4.5 to 4.8. Table 4.5 shows the results without optimisation technique for two-area power system with 2 PID controllers. Table 4.6 presents three algorithms results for 2 PID controllers in both areas. Table 4.7 shows three algorithms results for only one PID controller in area 1. Table 4.8 presents three algorithms results for only one PID controller in area 2. Without optimisation method, the rise time and settling time are 0.4873s and 14.9948s respectively. The overshoot is 66.6061.

Table 4.5: Results without optimisation for two-area power system

Without optimization		
Rise time	Settling time	Overshoot
0.4873	14.9948	66.6061

Table 4.6: Case I results of 3 algorithms for 2 PID controllers in both areas

Case I: 2 PID controllers	Rise time	Settling time	**Overshoot**	Convergence		
				start	final	iteration
EPSO	0.1618	2.7672	132.7221	22.6046	18.6069	95
MEPSO-TVAC	0.2156	3.6208	**92.7875**	22.6733	**16.7952**	56
PSO	0.1262	4.2374	152.0031	23.7388	20.3402	66

From Table 4.6, it can be seen that the rise time and settling time for EPSO algorithm are 0.1618s and 2.7672s respectively. The rise time and settling time for MEPSO-TVAC algorithm are 0.2156s and 3.6208s respectively. The rise time and settling time for PSO algorithm are 0.1262s and 4.2374s respectively. Hence, the rise time and settling time for each optimisation algorithm reduced significantly, compared to the results from Table 4.5 (0.4873s and 14.9948s respectively). With optimisation techniques, the performance of a two-area interconnected power system with 2 PID controllers improves obviously regarding to the rise time and setting time.

When it comes to comparison among 3 different optimisation methods for the same number of PID controllers (one PID controller or two PID controllers), the shortest overshoot and the lowest fitness value is considered in this project compared to rise time and settling time. This is due to there are many parameters and not all are the best for one algorithm. Therefore, using these parameters directly to compare is undesirable. For example, if the overshoot is higher, then a shorter rise time and settling time can be expected or the other way around. However, a short convergence time is desirable but the lower final cost function value for the optimisation algorithm is preferred. This is also due to the main objective of this project is to achieve the lowest cost function value. Hence, it is important to consider that the best optimisation algorithm is the one that obtains the lowest overall fitness value.

In Table 4.6, the overshoot of MEPSO-TVAC algorithm is 92.7875, which is much lower than the other two algorithms. The overshoots of EPSO algorithm and PSO algorithm are 132.7221 and 152.0031 respectively. Then, the final fitness value for MEPSO-TVAC is 16.7952 with the convergence iteration 56, which is much lower than the other two methods. The final fitness values for EPSO and PSO are 18.6069 with the convergence iteration 95 and 20.3403 with the convergence iteration 66. Hence, for Case I (2 PID controllers on both areas), it is evident that the performance of MEPSO-TVAC method is better than EPSO and PSO methods in terms of the lowest overshoot, the lowest fitness value and fastest convergence speed.

In Table 4.7, the overshoot of MEPSO-TVAC algorithm is 83.9833, which is much lower than the other two algorithm methods. The overshoots of EPSO algorithm and PSO algorithm are 107.9056 and 128.9041 respectively. The final fitness value for

MEPSO-TVAC is 16.4276. The final fitness values for EPSO and PSO are 17.4090 with the convergence iteration 66 and 18.1720 with the convergence iteration 17. The most important objective for this project is that achieve the lowest fitness value, which is already mentioned before. Therefore, for Case II (only one PID controller in area 1), it is clearly that performance of MEPSO-TVAC method is better than EPSO and PSO methods in terms of the lowest overshoot and the lowest fitness value.

Table 4.7: Case II results of 3 algorithms for only one PID controller in area 1

Case II: One PID controller in area 1	Rise time	Settling time	**Overshoot**	Convergence		
				start	final	iteration
EPSO	0.1817	4.6958	107.9056	20.8029	17.4090	66
MEPSO-TVAC	0.2206	4.2916	**83.9833**	21.9811	**16.4276**	68
PSO	0.1545	3.6646	128.9041	22.5648	18.1720	17

In Table 4.8, the overshoot of MEPSO-TVAC algorithm is 66.3430, which is slightly lower than the other two algorithm methods. The overshoots of EPSO algorithm and PSO algorithm are 66.3604 and 66.3619 respectively. The final fitness value for MEPSO-TVAC is 16.5295, which is slighter smaller than the other two algorithm methods. The final fitness values for EPSO and PSO are 16.5343 and 16.5352 respectively. Therefore, for Case III (only one PID controller in area 2), the performance of MEPSO-TVAC method is better than EPSO and PSO methods in terms of the lowest overshoot and the lowest fitness value.

Table 4.8: Case III results of 3 algorithms for only one PID controller in area 2

Case III: One PID controller in area 2	Rise time	Settling time	**Overshoot**	Convergence		
				start	final	iteration
EPSO	0.4936	15.3441	66.3604	16.5367	16.5343	11
MEPSO-TVAC	0.4936	15.2993	**66.3430**	16.5373	**16.5295**	75
PSO	0.4936	15.3442	66.3619	16.5373	16.5352	16

4.5.2 Comparison of different number of PID controllers under MEPSO-TVAC

For comparison of the different number of PID controllers under the same optimisation method, the rise time and settling time can be determined for distinguishing one PID controller or two PID controllers works better in a two-area interconnected power system. This is due to the cost function is different due to different number of PID controllers. For example, less parameters will be considered for one PID controller case than the case of two PID controllers. Hence, using rise time and settling time for this case is desirable. The main objective for this project is to evaluate the effectiveness of MEPSO-TVAC. Hence, different number of PID controllers under MEPSO-TVAC method is used for analysis.

In Table 4.9, for Case I (2 PID controllers on both areas), the rise time and settling time for MEPSO-TVAC algorithm are 0.2156s and 3.6208s respectively, which are both much shorter than the other two cases. For Case II (only one PID controller in area 1), the rise time and settling time are 0.2206s and 4.2916s respectively. For Case III (only one PID controller in area 2), the rise time and settling time are 0.4936s and 15.2993s respectively. Hence, under MEPSO-TVAC optimisation method, the performance of 2 PID controllers is better than the case of one PID controller in area 1 and the case of one PID controller in area 2 in terms of shortest rise time and shortest settling time.

Table 4.9: Results for different number of PID controllers under MEPSO-TAVC

Different Cases	MEPSO-TVAC	
	Rise time	Settling time
Case I: 2 PID controllers	0.2156	3.6208
Case II: One PID in area 1	0.2206	4.2916
Case III: One PID in area 2	0.4936	15.2993

4.5.3 Comparison of the proposed work and previous work

Table 4.10 presents that comparison of the proposed work and previous work. Based on the results from the table, it can be seen that the performance of AGC of two-area power system for MEPSO-two PID controllers, MEPSO-one PID controller is better than the performance of previous work in terms of the shortest settling time (3.6208s and 4.2916s respectively). Hence, this shows that the proposed work has an obvious improvement than the past developed work.

Table 4.10: Results for the proposed work and previous work

Algorithm	Settling time (s)	Rise time (s)
PSO-one PID controller (Illias, 2016)	17.3	0.2005
EPSO-one PID controller (Illias, 2016)	17.2	0.1700
MEPSO-two PID controllers	3.6208	0.2156
MEPSO-one PID controller	4.2916	0.2206

CHAPTER 5: CONCLUSIONS AND RECOMMDATIONS

5.1 Conclusion

In this project, MEPSO-TVAC algorithm has been successfully implemented on Automatic Generation Control (AGC) with PID controllers for a two-area interconnected power system in MATLAB Simulink software. PSO and EPSO algorithm methods were selected to compare with MEPSO-TVAC algorithm under different cases.

Based on the obtained results, comparison of three cases (Case I: 2 PID controllers on both areas, Case II: one PID controller in area 1, Case III: one PID controller in area 2) shows that the performance for each case of MEPSO-TVAC method is better than EPSO and PSO methods in terms of the overshoot and the final fitness value. Also, with the aid of optimisation methods such as MEPSO-TVAC, the rise time and settling time for power system are reduced significantly compared to without optimisation case.

Comparison of different number of PID controllers under MEPSO-TVAC algorithm shows that the performance for MEPSO-two PID controllers is better than MEPSO-one PID controller in area 1 and MEPSO-one PID controller in area 2 in terms of the shortest rise time and the shortest settling time.

5.2 Recommendations for Future Work

Here are some recommendations for future work.

I. Implement the proposed methods on Automatic Generation Control (AGC) for more than a two-areas in a power system.

II. Implement other optimisation methods such as MPSO, MRPSO and GA-PSO in the power system with AGC-PID controllers.

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