Optimal Planning of Wind-Based Distributed Generation and Reactive Power Management in A Distribution System

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การวางแผนเหมาะที่สุดของการผลิตแบบกระจายอิงพลังงานลมและการจัดการกำลังรีแอกทิฟในระบบจำหน่าย

น.ส.โอวี อีคะ พูทรี

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โอวี อีคะ พูทรี : การวางแผนเหมาะที่สุดของการผลิตแบบกระจายอิงพลังงานลมและการจัดการกำลังรีแอกทิฟในระบบจำหน่าย. (Optimal Planning of Wind-Based Distributed Generation and Reactive Power Management in A Distribution System) อ.ที่ปรึกษาหลัก : โสตถิพงศ์ พิชัยสวัสดิ์

ในปัจจุบันนี้ ความต้องการบริโภคของโหลดเพิ่มมากขึ้น นำไปสู่การใช้พลังงานการผลิตไฟฟ้าแบบกระจายตัว (Distribution Generation: DG) ในระบบจำหน่าย. การใช้พลังงานหมุนเวียนแบบการผลิตไฟฟ้าแบบกระจายตัว เป็นอีกหนึ่งทางเลือกที่มีความเหมาะสม มีความเป็นมิตรต่อสภาพแวดล้อมและประโยชน์ทางเทคนิคด้านเศรษฐศาสตร์ การผลิตไฟฟ้าแบบกระจายตัวด้วยพลังงานลม คือหนึ่งในทางเลือกที่มีความคาดหวังสูงที่สุดของการผลิตไฟฟ้าหมุนเวียนแบบกระจายตัว ถึงอย่างไรก็ตามในมุมมองทางด้านเทคนิค การวางแผนระบบการผลิตไฟฟ้าแบบกระจายตัวด้วยระบบการผลิตไฟฟ้าพลังงานลมเพียงอย่างเดียว ไม่เพียงพอต่อความต้องการเนื่องจากมีการจำกัดการควบคุมของกำลังงานไฟฟ้าเสมือน โดยตัวเก็บประจุ (Capacitor Bank) ในระบบการกระจายตัวไฟฟ้ากำลังซึ่งสามารถเป็นอีกหนึ่งทางเลือก ในการแก้ปัญหาเพื่อพัฒนาระบบปฏิบัติการไฟฟ้ากำลังในรูปแบบ การพิจารณาลักษณะแรงดันในระบบ (Voltage Profile)และพลังงานสูญเสียในระบบ (Power Loss) แต่ถึงอย่างไรก็ตาม การจะทำให้ประโยชน์ทางด้าน สิ่งแวดล้อม เศรษฐศาสตร์ และเทคโนโลยีประสบความสำเร็จได้นั้น การประเมิณรูปแบบการติดตั้งและ ขนาดที่เหมาะสมของกังหันลม และตัวเก็บประจุ เป็นสิ่งที่จำเป็นต่อการนำมาพิจารณาตามความเหมาะสม. จุดประสงค์ของการศึกษาแบบจำลองนี้ เพื่อต้องการกำหนดรูปแบบการติดตั้งที่เหมาะสมและขนาดของกังหันลมที่ใช้ในการผลิตไฟฟ้าพลังงานหมุนเวียนแบบกระจายตัว การวางแผนแบบจำลองสามารถทำได้ โดยพิจารณาการจัดการผลประโยชน์ที่ได้รับจากการวางระบบทาง เศรษฐศาสตร์ สิ่งแวดล้อมและเทคนิค ยกตัวอย่างเช่น การพัฒนาลักษณะแรงดันในระบบ การลดพลังงานสูญเสีย การบรรเทามลพิษก๊าซคาร์บอนไดออกไซด์ และการหาค่าที่ต่ำที่สุดของราคาประจำปีในระบบไฟฟ้ากำลัง (Annualized Cost of System: ACS) ยิ่งไปกว่านั้นความไม่แน่นอนของความเร็วลมยังถูกนำมาพิจารณาเพื่อที่จะกำหนดจำนวนของตัวกังลมที่จะนำมาติดตั้งโดยการเลือกบัสในระบบการกระจายตัวอีกด้วย แบบจำลองนี้มีประสิทธิภาพสูงสุดโดยใช้ตรวจสอบระบบทดสอบ IEEE 33 บัส ด้วยโปรแกรมสำเร็จรูป MATLAB R2018b.

สาขาวิชา	วิศวกรรมไฟฟ้า	ลายมือชื่อนิสิต	....
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Ovi Eka Putri : Optimal Planning of Wind-Based Distributed Generation and Reactive Power Management in A Distribution System. Advisor: Assoc. Prof. SOTDHIPONG PHICHAISAWAT, Ph.D.

In recent years, the incremental load demand leads to the higher presence of distributed generation (DG) in distribution system. Renewable energy-based DG has been much appreciated due to the techno-eco-environmental benefit. Wind-based DG is one of most promising renewable energy based-DG. However, in the technical aspect, distribution system planning with wind-based DG alone is not fruitful enough due to limited reactive power support. Capacitor bank is one of available devices for reactive power management in distribution system. So, installing wind-based DG and capacitor bank in distribution system is one of alternative solutions to improve electrical power system performance in term of voltage profile and power loss. However, to achieve techno-eco-environmental benefit, an appropriate place and a suitable size of wind-based DG and capacitor bank requires to be determined optimally. This study proposes a model to determine an optimal placement and sizing of wind-based DG and capacitor bank in distribution system. The planning model is managed considering techno-eco-environmental benefit such as voltage profile improvement, power loss reduction, carbon-di-oxide emission mitigation, and annualized cost of system (ACS) minimization. Wind speed uncertainty is also considered to define the number of wind-based DG requires to be installed in distribution system. The effectiveness of proposed model is verified in 33-bus IEEE test system using MATLAB R2018b.

Field of Study:	Electrical Engineering	Student's Signature ....
Academic Year:	2019	Advisor's Signature ....

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Ovi Eka Putri

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CHAPTER 1
INTRODUCTION

Chapter 1 presents the introduction of the research. The introduction begins with the problem statement, which determines the problem requires to be solved. The following parts include a description of the aim and the scope of the research. Then, the last part of the chapter presents the expected benefits of the research.

1.1 Problem Statement

In recent years, the incremental demand leads to the increasing penetration of distributed generation (DG) into distribution system. The DG ability in terms of exploring renewable energy encourages all the countries to utilize the renewable energy resource. Renewable energy-based DG has been much appreciated in the technical, environmental, and economic benefits. The deployment of renewable energy-based DGs can overcome problems related to the global warming threat, the economic and infrastructural boundaries to upgrade the power plant, and the restricted transmission and distribution system. Wind-based DG is one of the fastest-developing and most encouraging renewable energy-based distributed generations due to the recent surge of capacity, the installation, and the application [2]. However, a wind-based DG has a drawback due to the uncertainty of wind speed. Therefore, the utilities require an appropriate planning model to install the wind-based DG into distribution system. A planning model of distribution system by installing wind-based DG alone is not very fruitful due to the limited reactive power support. A capacitor is one of available devices for reactive power management in distribution system. Thus, installing wind-based DG together with capacitor bank is one of alternative to support for both active power demand and reactive power demand in the distribution system. The parallel apply of capacitor bank strengthening the quality of distribution system performance in terms of voltage profile betterment by infusing the reactive power into distribution system at a low cost.

The betterment of voltage profile, active power loss, and reactive power loss indicates an effective solution to install wind-based DG and capacitor bank in the distribution system. Wind-based DG and capacitor bank can discharge the capacity of transmission and distribution system by reducing active and reactive power loss in the system. Therefore, the new investment can be deferred and the lead-time of the existing transmission and distribution system can be elongated. However, the appropriate placement and the suitable sizing of wind-based DG and capacitor bank are required to be specified accurately. Improper placement and sizing of wind-based DG and capacitor bank lead to poor system performance. The installation of DG and capacitor bank at large capacity with the aim of transporting the larger active and reactive power compared to the substation leads to the reverse power flow that results in the excessive power loss [3]. The coresponding system condition happens due to the fact that the distribution system was primarily designed such that active and reactive power streams down from the sending end to the receiving end and the conductor size decreases in stages from the sending end to the receiving end [3]. So, without the system reinforcement, the utilization of large capacity of DG and capacitor bank results in the exaggerated power flow through small capacity of conductor and results in the higher active and reactive power loss [3].

Several methodologies have been developed to define the optimal location of DG and reactive power support device in the distribution system. Hung [4] has proposed an analytical approach to discover the optimal size and place of DG in achieving the highest energy loss reduction in the distribution system. A modified particle swarm optimization is applied in [5] to assess the optimal placement of multiple wind DGs and capacitors with the aims of achieving technical and environmental benefits. Kayal and Chanda [6] have presented a non-dominated sorting based multiple objective particle swarm optimization algorithm on finding the best allocation of mix RES and capacitor in the distribution system in terms of obtaining its techno-eco-environmental benefits. The optimization algorithm is established in [2] to estimate the optimal penetration degree of combined large-scale wind DG and VAr compensation in the distribution system to lessen the total investment cost by taking the voltage stability limit into account. A loss sensitivity factor with dragonfly optimizer is represented in [7] to obtain the optimal location of DG and shunt capacitor in the distribution system to reduce the power loss and upgrading the voltage profile.

Limited works are found in determining optimal placement and sizing of wind-based DG and reactive power support device, considering techno-eco-environmental benefits. Therefore, this research represents a strategic planning model for determining the optimal location and size of wind-based DG and capacitor bank in the distribution system by considering techno-eco-environmental benefits using the modified multiple objective particle swarm optimization (MMOPSO). The uncertainty of wind speed is quantified with the probability technique corporate with the planning model to define the number of wind-based DG requires to be located at the selected bus. The aims of the research are to improve average active power loss, average reactive power loss, and voltage profile of the system with the minimum annualized cost of system (ACS). Moreover, the environmental aspect is considered to reduce the average carbon-di-oxide emission in the atmosphere. The possible optimal solutions included in the optimization process are the location of wind-based DG, the size of wind-based DG, the number of wind-based DG, the location of capacitor bank, and the size of capacitor bank. All optimal solutions should satisfy the test system constraint in terms of active and reactive power balance, active and reactive power loss, voltage profile, wind-based DG size, and capacitor bank size. The efficacy of the proposed model is verified on a standard 33-bus IEEE test distribution system. The author accomplishes the research entitled with **Optimal Planning of Wind-Based Distributed Generation and Reactive Power Management in A Distribution System.**

1.2 Research Objectives

The aims of the research is to enhance the power system performance in terms of average active and reactive power loss reduction, voltage profile improvement, and average carbon-dioxide emission mitigation with minimum ACS by installing wind-based DG and capacitor bank with the appropriate placement and suitable sizing in the distribution system.

1.3 Scope of Research

The minimization of average power loss for both active and reactive power loss, voltage profile deviation, and average carbon-di-oxide emission with the minimum ACS are the multiple objective of the planning model. The planning model is developed for practical application includes optimally placing and sizing of wind-based DG and capacitor bank in the distribution system in order to obtain the minimum value of the multiple objective. The average power loss for both active and reactive power loss, voltage profile deviation, average carbon-di-oxide emission, and annualized cost of system are maintained within the desired range. Scope and limitation of the proposed planning model are specified as follows:

1. The planning model is primarily applied on a standard 33-bus IEEE test distribution radial system and simulated for the balanced load.
2. The uncertainty of wind speed is considered to determine the number of wind-based DG according to the prevailing wind.
3. The load operation is considered within 24 hours load profile.
4. The constraint of distribution line capacity is not considered
5. The reverse power flow of both active power and reactive power is considered not to be allowed
6. The emission of carbon-di-oxide emitted by wind-based DG is assumed to be zero and the other pollutants are not considered.
7. The economic potential of the study, besides annualized cost of system, is not considered.
8. The wind-based DG is assumed to supply active power only.
9. The generator type utilized by the wind turbine is not considered.
10. The characteristics of the capacitor bank are not considered.

1.4 Expected Benefits

The main contributions of the research are to provide further knowledge related to the planning model of wind-based DG and capacitor bank in the distribution system, which is beneficial in the following practical application:

1. The utilities can utilize the planning model of wind-based DG and capacitor bank in the distribution system to enhance the system performance quality in terms of voltage profile, active power loss, and reactive power loss.
2. The researchers can use the research result as further knowledge related to the optimal strategy to obtain the techno-eco-environmental benefits from the joint penetration of wind-based DGs and capacitor bank in the distribution system.
3. The students can take the research result as further knowledge of the techno-eco-environmental benefits offered by joint penetration of wind-based DGs and capacitor bank in the distribution system.
4. The public can make the research result as a knowledge related to the benefits

provided by the application of wind-based DGs and capacitor bank in the distribution system.

In the next chapter, the supporting literature of the research related to the focus of the problems requires to be solved in the research are presented. The first part is the description of a radial distribution system and wind-based DG. Then, in the following sections, the load flow calculation for radial system, load modeling, wind power modeling, objective functions, and MPSO are mathematically described. The satisfaction of the planning model requires to be managed within the constraint which mentioned as well in chapter 2.

CHAPTER 2
LITERATURE REVIEW

Chapter 2 introduces the literatures review related to the focus of the research. This chapter encloses seven parts. The first part is the description of the distribution system, then, followed by the next section with the description of DG. This part includes the description of wind-based DG and the impact of DG in terms of power loss reduction and voltage profile improvement in the system. The third part explains mathematically the load flow calculation for the radial distribution system. Then, the following section defines a method to model the uncertainty of wind speed. In the fifth part, the multiple objective functions are formulated to obtain the optimal place and size of wind-based DG and capacitor bank in the distribution system. The multiple objective function includes the reduction of average active power loss and reactive power loss, the improvement of system voltage profile, the mitigation of average carbon-di-oxide emission, and the minimization of the annualized cost of system (ACS). The next part explains the optimization method used in this research. This part includes the description of Modified Particle Swarm Optimization Method (MPSO). Then, the last section defines the constraints that planning model should satisfy. This part consists of the constraint of power balance, voltage profile, DG capacity, capacitor capacity, and system power loss.

2.1 Distribution System

The distribution system is the one of the power system part after the transmission system, which is dedicated to delivering electric power to an end-user. The power generated by the power plant has a typical voltage of 22 kV. It is boosted up to the level of 70 kV, 150 kV, and 500 kV through the step-up transformer for the power transmission. The main substation steps the voltage down to 22 kV through a step-down transformer for the primer distribution system. As shown in Figure 2.1, step down transformer in distribution substation steps the voltage down to the level of 380/220 volt for delivering the power to the individual load through the secondary distribution system. The electrical power distribution system can be categorized as per its feeder connection topologies.

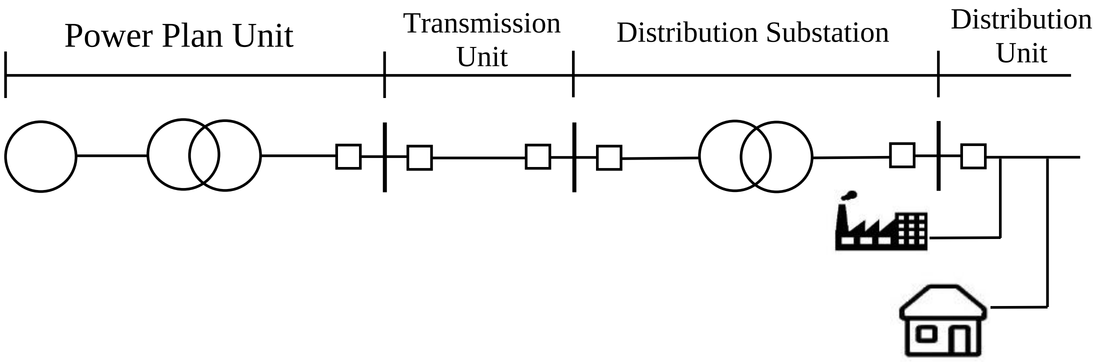

Figure 2.1 Electrical Power System

Three typical feeder connection topologies of the distribution system are radial distribution system, loop distribution system, and network distribution system. Each of them has its characteristics with the advantages and disadvantages. The most common feeder topology used to be utilized in distribution system is a radial feeder topology. This type of connection topology has the simplest connection system and the least expensive installation cost. Furthermore, a radial feeder connection has a low failure rate, which eases for voltage profile control and commonly has merely single power supplier for a group of consumers as seen in Figure 2.2.

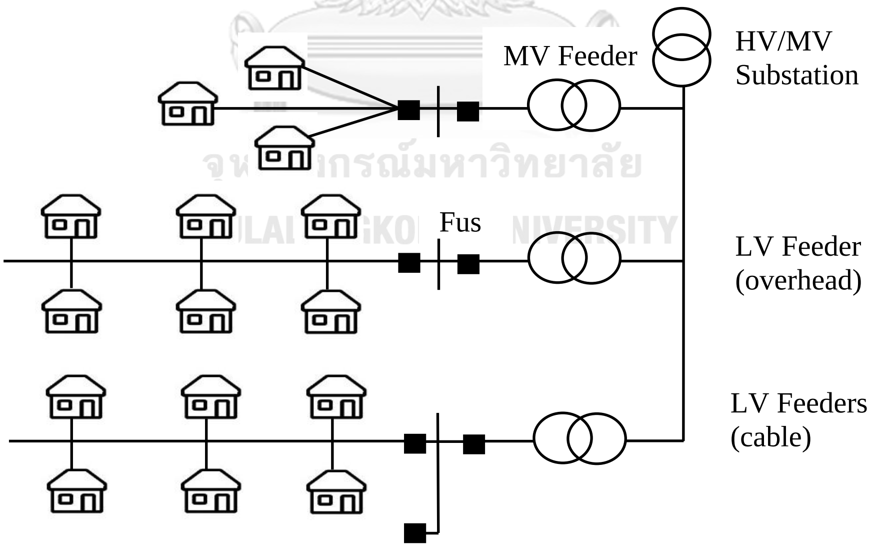

Figure 2.2 Radial distribution system

2.2 Distributed Generation

Many kinds of literature determined the definition of DG in many forms according to their perspective. Therefore, there is no universally agreed definition of how it differs from a traditional power system. Due to this condition, a general definition can be approached by these three common attributes of DG, such as size, location, and operation. The size of DG can be categorized into four different ratings as listed below [8]:

- Micro-scaled DG : ~1 W < 5 kW
- Small-scaled DG : 5 kW < 5 MW
- Medium-scaled DG : 5 MW < 50 MW
- Large-scaled DG : 50 MW < 300 MW

In term of DG location, DG is located at the distribution system or hooked up to the system on the customer side [8]. In general, the supportive power system impact offered by DG is called as "system support benefits" [9].

- System voltage and power quality improvement
- Power loss reduction
- Transmission and distribution line capacity discharge
- New or upgraded T&D infrastructure postponement
- Utility system reliability strengthening

According to the DG operation, DG can be categorized into a dispatchable DG and non-dispatchable DG. Dispatchable DG means an operator can control the primary energy generated by DG, such as gas turbines, combustion engines, and hydro generation [10]. Otherwise, non-dispatchable DG means an operator cannot control the primary energy generated by DG, such as renewable energy DG. Renewable energy is notably influenced by environmental trim such as sunlight and wind speed [10].

2.2.1 Wind Turbine

A wind turbine is one of DG technology utilizing renewable energy. A wind turbine parts are a rotor, turbine blades, and a generator [10]. Wind turbine is classified into one of the environmentally friendly power plants since they reduce greenhouse gas emission by offering clean and efficient energy. A wind turbine can generate electricity as individuals or as wind farms. The wind rotates the blades, which in return rotate their connected shaft, then operate a generator to produce electricity [10].

Wind turbine offers several benefits, as listed below [10]:

- Contributing to the clean air from the pollution, in contrast with the traditional fuel that used to contributes to the environmental issues.
- A sustainable primary energy for producing clean electricity in future.
- By the improvement of technology, wind turbine results in the lower cost.

Thus, wind-based DG is one of the fastest-developing and most encouraging renewable energy-based distributed generations due to the recent surge of capacity, installation, and application [2]

2.2.2 Power Losses

The installation of DG and capacitor bank in the distribution system offers the decrement of power loss, for both active power loss and reactive power loss. DG, as an active power compensator reduces the active power demand of the main supplier so that the active power losses in the system reduces as well. Then, the capacitor as the reactive power compensator also reduces the reactive power demand of the main supplier that results in the recution of power loss.

A load flow analysis is a method that effectively analyzes the active power loss and the reactive power loss in the system under condition with or without DG. In general, the active power loss and the reactive power loss can be obtained using the following equations [11]:

$$P_{Li} = (R_i I_{Li}^2) \tag{2.1}$$

$$Q_{Li} = (X_i I_{Li}^2) \tag{2.2}$$

$$P_L = \sum_{i=1}^{N} P_{Li} \tag{2.3}$$

$$Q_L = \sum_{i=1}^{N} Q_{Li} \tag{2.4}$$

where

i : 1, …, N

P_{Li} : The active power loss at ith line section

Q_{Li} : The reactive power loss at ith line section
P_L : The total active power losses in the system
Q_L : The total reactive power losses in the system
R_i : The resistance of ith line section
X_i : The reactance of ith line section
I_{Li} : The flowing current through ith line section

2.2.3 Voltage Profile

The bi-directional power flow due to DG installation may interfere voltage profile in the distribution system. Figure 2.3 shows the voltage profile that occurs under a condition with and without DG installation. In this example, the voltage profile once the system has DG is lower than the voltage profile once system has no DG. This voltage behavior shows the opposite effect of "voltage support" as one of the benefits of DG installation.

DG may also cause an increment of voltage profile. As an example, a small-scaled DG system that utilizes a typical distribution transformer together with other residences causes voltage increase at these customers [9]. This kind of condition may happen once that distribution transformer is placed at the feeder where the primary voltage is out of the ANSI standard.

Therefore, for achieving the effect of "voltage support" by DG, one of strategies that needs to be fulfilled is to specify the optimal placement and sizing of DG. In this research accurately, capacitor bank will be installed together with DG in the distribution system to help achieve voltage profile advancement. Thus, the optimal placement and sizing of capacitor bank need to be determined as well. An effective method to investigate the behavior of voltage profile in the system under condition with and without DG is by running a calculation of distribution system load flow explained in 2.3

2.3 Radial Distribution System Load Flow

The system is considered to be operated in stable and one phase condition to solve the

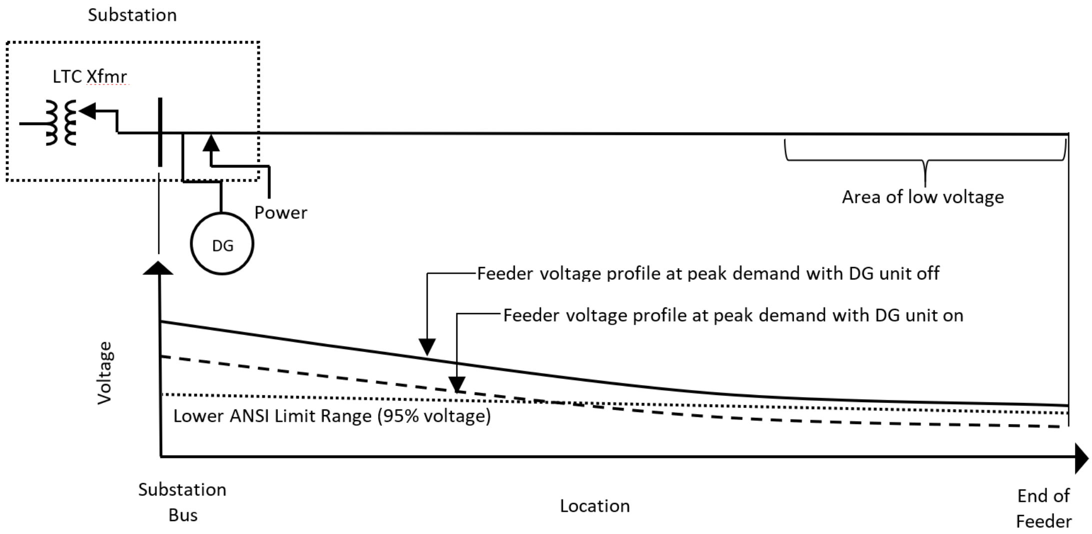

Figure 2.3 Example of DG unit interfering with voltage regulation

load flow problem. There are four quantities resulting from each bus, such as the active power P, the reactive power Q, the voltage magnitude |V|, and the voltage angle θ. The bus system can be classified into three types, as listed below [12]:

a. Reference/slack/swing bus

The bus of the system at which the voltage angle is set as a reference for the angle of all other bus voltages. The voltage magnitude is also kept constant. The active power P and the reactive power Q injected to the load are the two unidentified quantities that need to be calculated for the bus.

b. Load/PQ bus

At each non-generator bus, named a load bus in which the active power P and the reactive power Q injected to the load are constant, respectively, with negative inputs into the system. The voltage magnitude |V| and the voltage angle θ are the two unidentified quantities that need to be calculated for the bus.

c. Generator/PV bus

The bus of the system at which the voltage magnitude and active power P injected to the load are kept constant. The voltage angle θ and the reactive power Q injected to the load are the two unidentified quantities that need to be calculated for the bus.

2.3.1 Network Topology Based Method

A simple radial distribution system shown in Figure 2.4 can be represented using a matrix of BBIC, BCBV, and DLF [13, 14].

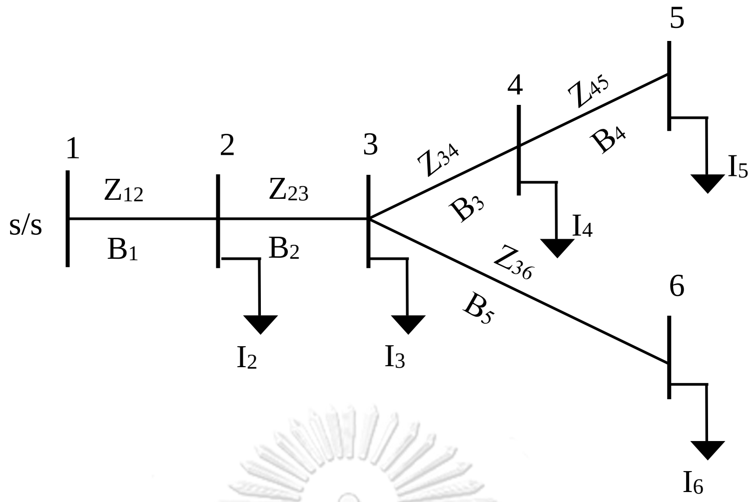

Figure 2.4. A Simple Radial Distribution System with 6 Buses

2.3.1.1 Bus Injection to Branch Current Matrix (BIBC)

The BBIC matrix illustrates the correlation between bus current injections and branch current. The associated changes at branch current, resulted by the changes at bus current injections, can be measured directly using BBIC matrix [14]. The complex power at each bus i and the corresponding current injection at bus i can be represented by (2.5) and (2.6), respectively.

$$S_i = (P_i + Q_i) \qquad i = 1,2, \dots, N \tag{2.5}$$

$$I_i = (S_i / V_i) \tag{2.6}$$

The current injection vector of the system in Figure 2.4 can be illustrated in Table 2.1.

Table 2.1. Injection current vector

Bus Number	2	3	4	5	6
Injection Current	I_2	I_3	I_4	I_5	I_6

By applying Kirchhoff's Current Law (KCL), the branch current given by the corresponding current injection can be obtained by using the following equations:

$$B_1 = I_2 + I_3 + I_4 + I_5 + I_6 \tag{2.7}$$

$$B_2 = I_3 + I_4 + I_5 + I_6 \tag{2.8}$$

$$B_3 = I_4 + I_5 \tag{2.9}$$

$$B_4 = I_5 \tag{2.10}$$

$$B_5 = I_6 \tag{2.11}$$

$$\begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I_2 \\ I_3 \\ I_4 \\ I_5 \\ I_6 \end{bmatrix} \tag{2.12}$$

Then, the equation of the branch current can be derived as:

$$[B] = [BIBC][I] \tag{2.13}$$

2.3.1.2 Branch Current to Bus Voltage Matrix (BCBV)

BCBV matrix illustrates the correlation between current injection and bus voltage as expressed using the following equations:

$$V_2 = V_1 - B_1 Z_{12} \tag{2.14}$$

$$V_3 = V_2 - B_2 Z_{23} \tag{2.15}$$

$$V_4 = V_3 - B_3 Z_{34} \tag{2.16}$$

$$V_5 = V_4 - B_4 Z_{45} \tag{2.17}$$

$$V_6 = V_3 - B_5 Z_{36} \tag{2.18}$$

By substituting (2.14) and (2.15) into (2.16), the voltage of bus 4 can be written as:

$$V_4 = V_1 - B_1 Z_{12} - B_2 Z_{23} - B_3 Z_{34} \tag{2.19}$$

The same as the other bus, the voltage bus can be expressed in the following equations:

$$V_3 = V_1 - B_1 Z_{12} - B_2 Z_{23} \tag{2.20}$$

$$V_5 = V_1 - B_1Z_{12} - B_2Z_{23} - B_3Z_{34} - B_4Z_{45} \quad (2.21)$$

$$V_6 = V_1 - B_1Z_{12} - B_2Z_{23} - B_3Z_{34} - B_4Z_{45} - B_5Z_{36} \quad (2.22)$$

(2.13 - 2.14) and (2.19 - 2.22) can be derived as:

$$\begin{bmatrix} V_1 \\ V_1 \\ V_1 \\ V_1 \\ V_1 \end{bmatrix} - \begin{bmatrix} V_2 \\ V_3 \\ V_4 \\ V_5 \\ V_6 \end{bmatrix} = \begin{bmatrix} Z_{12} & 0 & 0 & 0 & 0 \\ Z_{12} & Z_{23} & 0 & 0 & 0 \\ Z_{12} & Z_{23} & Z_{34} & 0 & 0 \\ Z_{12} & Z_{23} & Z_{34} & Z_{45} & 0 \\ Z_{12} & Z_{23} & 0 & 0 & Z_{36} \end{bmatrix} \begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix} \quad (2.23)$$

$$[\Delta \mathrm{V}] = [BCBV][B] \quad (2.24)$$

By substituting (2.13) into (2.24), the relationship between the bus current injections and bus voltage can be rewritten as:

$$[\Delta \mathrm{V}] = [BCBV][BIBC][I] \quad (2.25)$$

$$[\Delta \mathrm{V}] = [DLF][I] \quad (2.26)$$

where DLF is the Distribution Load Flow matrix shown in (2.27).

$$\begin{bmatrix} Z_{12} & Z_{12} & Z_{12} & Z_{12} & Z_{12} \\ Z_{12} & Z_{12}+Z_{23} & Z_{12}+Z_{23} & Z_{12}+Z_{23} & Z_{12}+Z_{23} \\ Z_{12} & Z_{12}+Z_{23} & Z_{12}+Z_{23}+Z_{34} & Z_{12}+Z_{23}+Z_{34} & Z_{12}+Z_{23} \\ Z_{12} & Z_{12}+Z_{23} & Z_{12}+Z_{23}+Z_{34} & Z_{12}+Z_{23}+Z_{34}+Z_{45} & Z_{12}+Z_{23} \\ Z_{12} & Z_{12}+Z_{23} & Z_{12}+Z_{23} & Z_{12}+Z_{23} & Z_{12}+Z_{23}+Z_{36} \end{bmatrix} \quad (2.27)$$

2.3.2 Load Flow Method for Radial Distribution Network

Conventional load flow methods, such as Newton-Raphson and Fast –Decoupled, are well applied in the transmission system. Otherwise, the conventional load flow method is not well applied in the distribution system in consequence of the high line R/X ratio and radial feeder connection scheme which generally used in the distribution system.

Load flow method named backward and forward sweep proposed as an efficient method to tackle the load flow problem at the distribution system [15]. For the backward sweep, the initial calculation starts from the far end of the network to determine the load injection current. Then, the subsequent current flow through the line section is obtained according to the obtained voltage by the prior iteration. After the current flow in each line is obtained, the forward sweep updates the voltage at each bus starts from the original node. The converge standard should be inspected. There is various type of converge standard adapted to the node voltage, load or line currents, and power flow to the network.

The root node is assumed to be the slack node with the measured voltage magnitude and voltage angle. The initial voltages at all other nodes are considered to be equal to the voltage at the root node. Based on this assumption, the iterant solution method is adopted in three steps as given below[16]:

1. Nodal current calculation

   After calculating the voltage at ith node from iteration $k-1$, at iteration k, the nodal current injection at ith node can be determined using equation (2.28) [16]:

$$I_{ldi}{}^{(k)} = \left[\frac{P_i + jQ_i}{V_i{}^{(k-1)}}\right]^* \tag{2.28}$$

   where

   I_{ldi} : The nodal current injection at ith node at iteration k appropriate to constant power load

   P_i : The active power load at ith node

   Q_i : The reactive power load at ith node

   $V_i{}^{(k-1)}$: The voltage at ith node at iteration $k-1$

2. Backward sweep

   At iteration k, initiating from the branches in the far end network and shoving towards the branch attached to the origin node, the current at branch L, J_L, is determined using the following equation [16]:

$$J_L{}^{(k)} = -I_{L2}^{(k)} - \sum \begin{matrix}(current\ in\ branches \\ emanating\ from\ node\ L2)\end{matrix} \qquad \text{L=b, b-1,..,1} \tag{2.29}$$

where, $I_{L2}^{(k)}$ is the current injection to the load connected node $L2$. In this case, the node of a branch L closest to the origin node is assumed to be $L1$ and the other node is considered to be $L2$, as shown in Figure 2.5.

3. Forward Sweep

In the forward sweep, initiating from the primary source at the origin node, the voltage at each bus is updated. The voltage at node L2 is obtained utilizing the updated voltage at node L1 and the branch current obtained in the other backward sweep as given in (2.30).

$$V_{L2}{}^{(k)} = V_{L1}{}^{(k)} - Z_L I_L{}^{(k)} \qquad \text{L=1, 2, …, b} \qquad (2.30)$$

where

V_{L2} : The voltage at node L2

V_{L1} : The updated voltage at node L1

Z_L : The series impedance of branch L

I_L : The flowing current through branch L

The load flow method at the distribution system can be explained briefly in Figure 2.6. Steps 1, 2, and 3 are reiterated up to the convergence is attained.

However, the standard of convergence utilizes the maximum real and reactive power imbalance at the system nodes [16]. The power injection for node i at iteration k, S_i^k can be calculated using the equation given in (2.31).

$$S_i^k = V_i^k \,(I_i^k)^* - Y_i^k |V_i^k|^2 \qquad (2.31)$$

The real and reactive power imbalance at node i can be calculated using the following equation:

$$\Delta P_i^k = Re|S_i^k - S_i| \qquad (2.32)$$

$$\Delta Q_i^k = Im|S_i^k - S_i| \qquad (2.33)$$

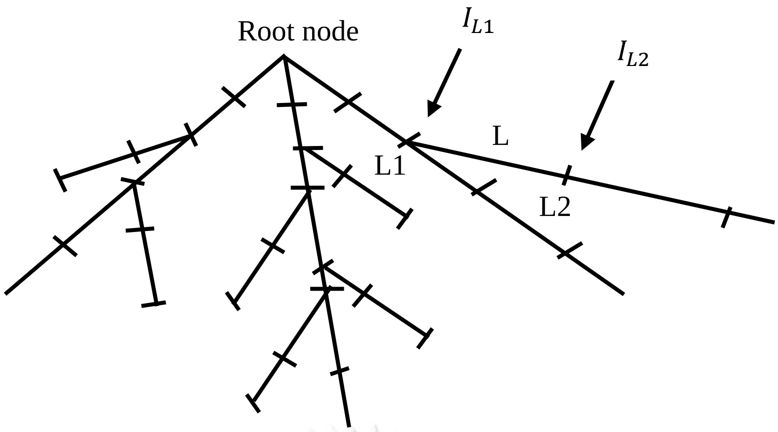

Figure 2.5 A typical radial distribution network with a single voltage source [1]

2.4 Wind Power Modelling

This section determines the proposed model of wind generation. A study period of one day is divided into 24-h segments (time segments). The seasonal aspect is disregarded. The wind power generation and load profile are independent of each other for the sake of simplicity. Wind generation behaviour is followed utilizing the Weibull probability density function (pdf).

The Weibull pdf is a recommended good expression used to illustrate model the behavior of wind speed [17]. The Weibull pdf is an estimation on the basis of a comparison between the actual wind speed profile at variety sites and wind speed profiles given in (2.34).

$$F_w(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} exp\left[-\left(\frac{v}{c}\right)^{k}\right] \tag{2.34}$$

where $f_w(v)$, k and c are the Weidbull pdf, the shape index, and the scale index, respectively. In this research, the shape index k is assumed to be equal to 2. This particular case of Weibull pdf is called as Rayleigh pdf $f(v)$ given in (2.35). Based on many works of literature, the Rayleigh pdf is a recommended good expression to illustrate the performance of the wind speed.

$$f(v) = \left(\frac{2v}{c^2}\right) exp\left[-\left(\frac{v}{c}\right)^2\right] \tag{2.35}$$

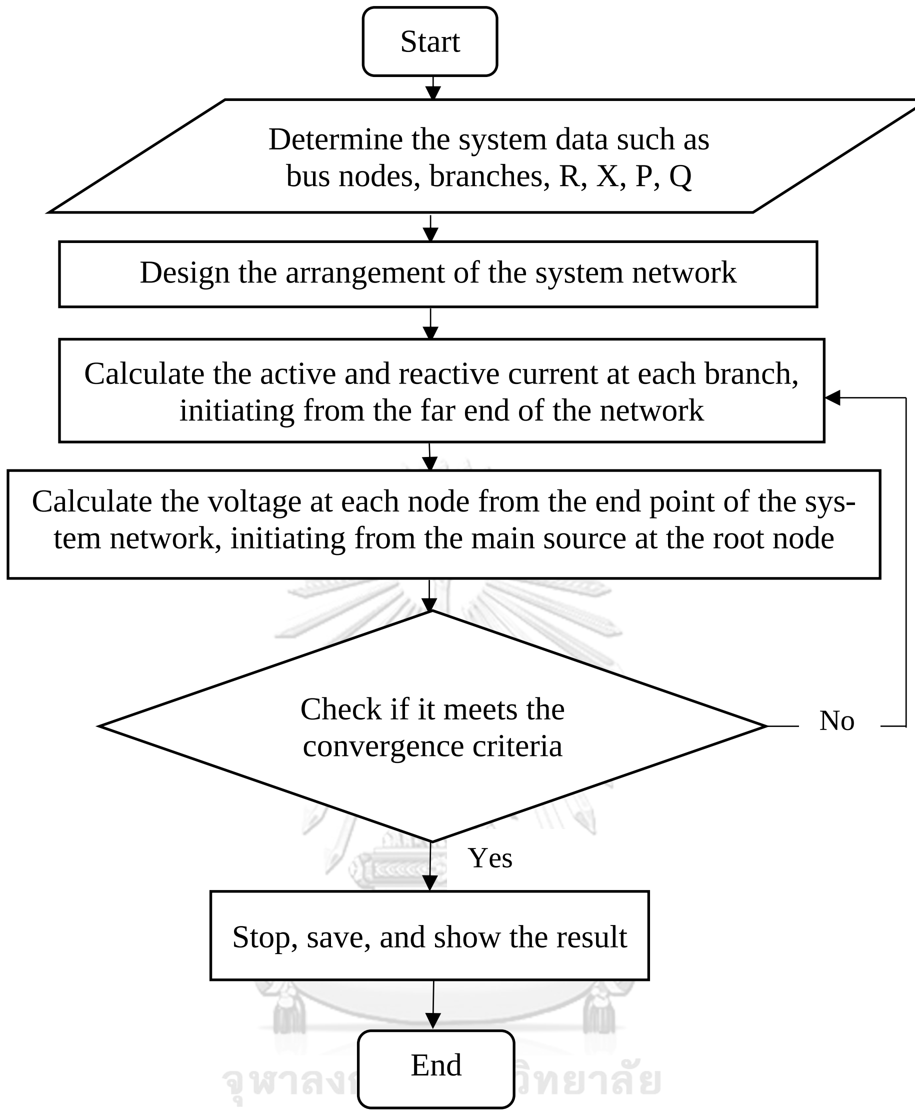

Figure 2.6 Flowchart of load flow calculation with backward and forward sweep

In case, the mean value of the wind speed, V_m is specified, the scaling index, c can be calculated as shown in (2.36) and (2.37)

$$V_m = \int_0^{\infty} vf(v)\ dv = \int_0^{\infty} \left(\frac{2v^2}{c^2}\right) exp\left[-\left(\frac{v}{c}\right)^2\right] dv = \frac{\sqrt{\pi}}{2} c \qquad (2.36)$$

$$c \approx 1.128\ v_m \qquad (2.37)$$

In order to merge the generated power of the wind-based DG as a multiple states variable in the planning formularization, the continue pdf has been splitted into 24 states, in each of which the wind speed is within particular limits [18]. The number of states should be conscientiously preferred for the Rayleigh distribution since a small number of states impact to the accuracy, in other hand, a large number escalate the complexity [18]. In this research, the step is assumed as 1 m/s as shown in Table 2.2 below.

Table 2.2 Selected wind speed states

Wins speed state (w)	Wind speed limit, m/s
1	0-1
2	1-2
.	.
Last state	$V_{max} - 1$ to V_{max}

The each state probability, $P(G_W)$, is determined utilizing the following equation:

$$P(G_W) = \int_{V_{w1}}^{V_{w2}} f(v)\, dv \tag{2.38}$$

where v_{w1} and v_{w2} are the speed limit of w, respectively.

The generated power from a wind turbine concerning the wind speed for various states $P_o(w)$ is obtained by applying the selected wind turbine power characteristic as given in (2.39).

$$P_o(w) = \begin{cases} 0\,, & 0 \le v_{av} \le v_{ci} \\ P_r \times \dfrac{v_{av} - v_{ci}}{v_r - v_{ci}}, & v_{ci} \le v_{av} \le v_r \\ P_r\,, & v_r \le v_{av} \le v_{co} \\ 0\,, & v_{co} \le v_{av} \end{cases} \tag{2.39}$$

where, v_{av}, v_{ci}, v_r, and v_{co} are the average wind speed of each state, the cut-in wind speed, the rated wind speed, and the cut-off wind speed, respectively. The wind turbine characteristic is selected with 2.5 m/s, 12.5 m/s, 25 m/s, and 100 kW as v_{ci}, v_r, v_{co}, and

P_r, respectively [19].

The average power in the wind, P_{av}, at speed v for any state is given in (2.40).

$$P_{av} = P_o(w) \times P(G_W) \tag{2.40}$$

Then, the required number of a wind turbine installed in the distribution system can be calculated using the aftermath equations:

$$number\ of\ wind\ turbine = \frac{CF \times PF \times P_{load}}{P_{av}} \tag{2.41}$$

$$Capacity\ Factor = CF = \frac{P_{av}}{P_{rated}} \tag{2.42}$$

$$Penetration\ Factor = PF = \frac{P_{DG}}{P_{load}} \tag{2.43}$$

where, P_{DG} and P_{load} are the resulted optimal size of DG required by a specific bus at distribution system and the load demand in specific bus, respectively.

2.5 Multiple objective Function

In this research, the objectives of the placement wind-based DG and capacitor bank in the distribution system is achieving the maximum potential benefits in term of system power losses reduction for both active power loss and reactive power loss and system voltage profile improvement with minimum annualized cost of system (ACS). Moreover, the environmental benefit from the wind-based DG installation in the distribution system in mitigating carbon-di-oxide emission is taken into account as well. $Ploss_{avg}, Qloss_{avg}, VD,\ ACE_{avg}$, and ACS are objective functions of sizing and placement of wind-based DG and capacitor bank that need to be minimized optimally [5, 6, 20].

Then, the multiple objective function can be formulated mathematically by the following expression:

$$\begin{aligned}\min(f_m) = [&\alpha_1(Ploss_{avg}) + \alpha_2(Qloss_{avg}) + \alpha_3(VD) + \alpha_4(ACE) \\ &+ \alpha_5(ACS)]\end{aligned} \tag{2.44}$$

Where

f_m : The multiple objective function (MOF)

α : The relevance factor of MOF

$0 \leq \alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5 \leq 1;\ \alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 + \alpha_5 = 1$

${Ploss_{avg}}_1$: The average active power loss

$Qloss_{avg}$: The average reactive power loss

VD : The deviation of system voltage profile

ACE : The average carbon-di-oxide emission

ACS : The annualized cost of system

The relevance factor is responsible for offering the equal importance of each impact concordance in consequence of the presence of wind-based DG and capacitor bank in distribution system according to the required analysis. The relevance factor should be flexible as the utilities have diverse concerns about technical aspect, environmental aspect, and economic aspect. This flexibility offers the proposed model even more compatible as a tool to obtain the most optimal placement and sizing of wind-based DG and capacitor bank in distribution system. However, technical aspect is more beneficial for the utilities in this study.

The objective functions will be minimized optimally concerning the variation location and size of wind-based DGs and capacitor bank in the distribution system.

2.5.1 Average Active Power Loss

One of the objectives of the placement wind-based DG and capacitor in the distribution system is to decrease the active power loss. Average active power loss in the presence of wind-based DG and capacitor bank can be expressed below:

$$Ploss_{avg} = \frac{\sum_{y=1}^{N_y=1} \sum_{sn=1}^{N_{sn}=4} \sum_{t=1}^{N_t=24} (((Ploss^t)^{sn})^y)}{N_y \times N_{sn} \times N_t} \tag{2.45}$$

where

$Ploss^t$: The active power loss (MW) at time t

N_t : The number of time segments

N_{sn} : The number of seasons in a year

N_y : The planning period in years

The value of f_1 requires to be minimized in order to indicate the reduction of active power loss in the system due to the installation of wind-based DG and capacitor bank in the distribution system.

2.5.2 Average Reactive Power Loss

The other aims of the placement wind-based DG and capacitor in the distribution system is to reduce the reactive power line loss with the expression is given below:

$$Qloss_{avg} = \frac{\sum_{y=1}^{N_y=1} \sum_{sn=1}^{N_{sn}=4} \sum_{t=1}^{N_t=24} (((Qloss^t)^{sn})^y)}{N_y \times N_{sn} \times N_t} \tag{2.46}$$

where

$Qloss^t$: The reactive power loss (MVar) at time t

The value of f_2 requires to be minimized so that the reactive power loss in the system in consequence of the installation of wind-based DG and capacitor bank in the distribution system reduces.

2.5.3 System Voltage Profile Deviation

The other significant benefit of the placement wind-based DG and capacitor in the distribution system is to improve the system voltage profile. f_3 is a function represents the voltage deviation in the system measured utilizing the following expression:

$$VD = \sum_{y=1}^{N_{y=1}} \sum_{sn=1}^{N_{sn}=4} \sum_{t=1}^{N_t=24} \sum_{bus\_i=1}^{bus\_i=N_{bus}} |\, 1 - \min\,(V_{bus\_i,t})\,| \tag{2.47}$$

where, V_{bus_i} and N_{bus} are the bus voltage at bus i and the sum of buses in the distribution system, respectively. Thus, the value of f_3 requires to be minimized in order to indicate the improvement of voltage profile in the system and to keep the system operate with a voltage managed within the acceptable range.

2.5.4 Average Carbon-di-oxide Emission

One of the environmental good offered by the wind-based DG placement is reducing the emission of carbon-di-oxide, which mainly comes from the conventional power plant. According to the report of International Energy Agency [21], the excessive carbon-di-oxide emissions will escalate the temperature of earth's surface which is approximately 3.6 ^{o}C by the next 25 years. The accumulation of carbon-di-oxide in the atmosphere contributes a significant portion to the global climate change by heating the face of earth. Worldwide encourages to reduce greenhouse gas emissions has intesified the pressure to transform the conventional generation to the distribution generation [6]. Because of this, the deployment of renewable energy generations is proliferating against the existing power generation.

The average carbon-di-oxide emission can be expressed as:

$$ACE = \frac{\sum_{y=1}^{N_y=1} \sum_{sn=1}^{N_{sn}=4} \sum_{t=1}^{N_t=24} (((PG_{SS}^{t})^{sn})^{y}) \times \left(\frac{24}{N_t}\right) \times \left(\frac{365}{N_{sn}}\right) \times GR_{ss}}{N_y} \quad (2.48)$$

where

PG_{SS}^{t} : The rest of the active power generated by substation at time t

GR_{ss} : The gas emission rate from the power generated by the conventional power plant supply (kg/MWh)

Thus, the value of f_4 requires to be minimized in order to indicate a reduction of carbon-di-oxide emission into the atmosphere due to the existence of wind-based DG and capacitor bank in the distribution system.

2.5.5 Annualized Cost of System (ACS)

The economical approach is evolved according to the concept of the annualized capital cost. According to the study of integration wind-based DG and capacitor bank, ACS is only established by the annualized capital cost of wind-based DG and capacitor bank C_{acap} and the annualized maintenance cost of wind-based DG and capacitor bank C_{amain}. Thus, the ACS can be expressed by the following equation:

$$ACS = min\left(C_{acap}(DG + Cap.Bank) + C_{amain}(DG + Cap.Bank)\right) \quad (2.49)$$

2.5.5.1 Annualized Capital Cost

Each component has the annualized cost obtained using equation (2.50).

$$C_{acap} = C_{cap} \times CRF\left(i, Y_{proj}\right) = C_{cap} \times \frac{i\,(1+i)^{Y_{proj}}}{(1+i)^{Y_{proj}} - 1} \tag{2.50}$$

$$i = \frac{(i' - IF)}{(1 + IF)} \tag{2.51}$$

where C_{cap}, Y_{proj}, CRF, i, i', and IF are the initial capital cost of each component, the component lifetime, the capital recovery factor, the real annual interest, the nominal interest rate, and the inflation rate, respectively.

2.5.5.2 Annualized Maintenance Cost

The maintenance cost of the system is assumed to be constant every year. The ACS with the lowest value is considered as the optimal one, which secures the required system reliability.

2.6 Modified Particle Swarm Optimization (MPSO)

Particle Swarm Optimization (PSO) is inspired by nature optimization method initially established by James Kennedy and Russell Eberhart in 1995. This optimization method is derived from the swarming behaviour of animals such as bird flocking of fish schooling. The swarm of particles flying over a multidimensional search area to obtain the best location corresponding to the objective function, limited by the given velocity and the problem-specific constraint. At each iteration, each particle in search area updates its best individual position in accordance with its own flying experience called as Pbest and updates its best global position in accordance with the flying experience of contiguous particles called as Gbest. Therefore, each particle updates both its best individual position and its best global position in accordance with the particle's current position, the particle's current velocity, the distance from the particle's current position to Pbest, and the distance from its particle's current position to Gbest as shown in Figure 2.7. The concept of particle's velocity update can represent the modification. Then, the particle's velocity can be updated applying the following equation:

$$v_{i+1}^{d} = w \times v_{i}^{d} + c_1 \times rand_1^{d} \times \left[Pbest_i^{d} - X_i^{d}\right] \tag{2.52}$$

$$+ c_2 \times rand_2^d \times \left[Gbest^d - X_i^d\right]$$

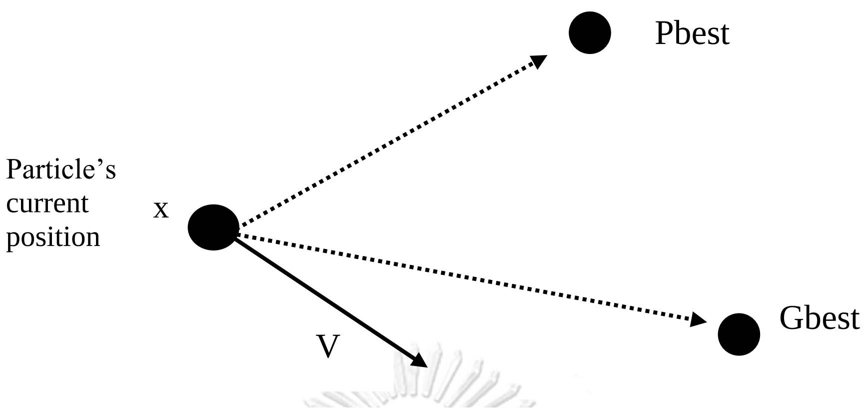

Figure 2.7 Concept of A Searching Point By PSO

(2.53) is applied for searching the updated velocity. The equations have three primary components [22]. The first component is indicated to a "habit" that illustrates the tendency of the particle to keep flying in the corresponding direction. This component can be managed by the inertia weight factor (w). The second component is a linear traction for the particle's best, Pbest, managed by c_1 and $rand_1$. Then, the third component of is linear traction for the global best position, Gbest, scaled by c_2 and $rand_2$.

After updating the velocity of the particles, the updated position of the particle can be determined by using equation (2.53):

$$x_{i+1}^d = x_i^d + V_{i+1}^d \tag{2.53}$$

where

w	: The inertia weight factor
c_1, c_2	: The acceleration weight factor, $0 \leq c_1, c_2 \leq 2$
$rand_1^d, rand_2^d$	: The random value for the dth dimension, $0 \leq r_1, r_2 \leq 1$
v_{i+1}^d	: The velocity of $i + 1_{th}$ particle for the dth dimension
x_{i+1}^d	: The position of $i + 1_{th}$ particle for the dth

dimension

$Pbest_i^d$: The individual best fitness value of particle i for the dth dimension

$Gbest^d$: The global best fitness value of particles for the dth dimension

The inertia weight factor (w) is a factor that influencing the inertia related to the movement of the particles. Therefore, the inertia weight factor controls the exploration in the search space. The larger it is, the higher the global searchability and the smaller it is, the greater individual searchability. The appropriate control of global and individual search is a fundamental for determining the optimum location. The value of the inertia weight factor can be adapted dynamically according to the search stage during the iteration. Chen, Huang [23] proposed a linearly decreasing inertia weight strategies which the inertia weight is reduced linearly over iterations. Then, the mathematical presentation of w is written in the following equation [23]:

$$w = w_{max} - \frac{w_{max} - w_{min}}{iter_{max}} \times iter \tag{2.54}$$

where $iter_{max}$ and $iter$ are the iteration number and the current iteration, respectively. It is assumed that w_{max} controls the search in the search space with 0.9 as the higher value of w, which allows the particles fly to find the global optimum value [22]. Then, if the optimal location is obtained, the inertia weight value decreases to 0.4 as its lowest value to narrow the search [22].

Apart from the inertia weight factor (w), the acceleration weight factor (c_1, c_2) also affects the movement of the particles. If c_1 is greater than c_2, the global search ability will be greater and if c_2 is larger than c_1, the individual search ability will be greater as well.

In the Gbest area, the particles are appealed to the best solution obtained by any particles [22]. It shows a entirely connected network in which each particle can access all information of all other members in the search area [22]. However, the utilizing of Pbest approach, each particle can access all information in accordance with its prompt neighbours and swarm topology. Eberhart and Kennedy [24] suggested that Gbest converges faster, although it may be snared in the local nethermost, whereas Pbest converges slower, but it has a higher opportunity to gain the best solution. The flowchart of PSO is given in Figure 2.8.

2.7 The System Constraint

The objective function minimization given in (2.44) is required to satisfy to the system constrains as given below:

2.7.1 Power Balance Constraint

The power balance in the system, both active power and reactive power at every bus are assumed to remain constant as shown below:

$$P_{ss} + \sum_{i=2}^{Nbus} P_{DGi} - \sum_{i=2}^{Nbus} P_{Di} - \sum_{x=1}^{n_l} P_{L(x)} = 0 \tag{2.55}$$

$$Q_{ss} + \sum_{i=2}^{Nbus} Q_{CAPi} - \sum_{i=2}^{Nbus} Q_{Di} - \sum_{x=1}^{n_l} Q_{L(x)} = 0 \tag{2.56}$$

where, P_{ss} and Q_{ss} are the active power and the reactive power supplied by the substation, respectively. P_{Di} and Q_{Di} are the constant active power and the constant reactive power demanded by the load at bus ith, respectively. Q_{CAPi} is the reactive power supplied by capacitor at bus ith.

2.7.2 Voltage Constraint

Each bus voltage requires to be kept within the constraint of the voltage as given below:

$$V_{min} \leq V_{bus} \leq V_{max} \tag{2.57}$$

Where, V_{bus} is a voltage at each bus.

2.7.3 DG Capacity Constraint

The capacity of DG requires to be kept within the constraint as given below:

$$0 \leq P_{DG} \leq \sum_{i=2}^{Nbus} P_{Di} \tag{2.58}$$

2.7.4 Capacitor Capacity Constraint

The capacitor bank size is assured to be kept within the constraint as given below:

$$0 \leq Q_{cap} \leq \sum_{i=2}^{Nbus} Q_{Di} \tag{2.59}$$

2.7.5 Power Loss Constraint

The active power loss and reactive power loss under condition of the system with DG and capacitor bank should be less compared to the base case. The constraints of power loss are expressed in (2.59 – 2.60).

$$\sum_{x=l}^{n_l} P_{L(x)DG} \leq \sum_{x=l}^{n_l} P_{L(x)0} \tag{2.60}$$

$$\sum_{x=l}^{n_l} Q_{L(x)DG} \leq \sum_{x=l}^{n_l} Q_{L(x)0} \tag{2.61}$$

So, the fruitfulness of the optimization method can be measured by the value of active power loss, reactive power loss, and voltage profile that satisfy the constraint formulated in (2.56 - 2.60).

In the next chapter, the methodology used in the research is described. The chapter has four primary parts. The first part describes about the research area. Then, the following parts describe the research analysis framework, the system modeling, and the case study observed in the research.

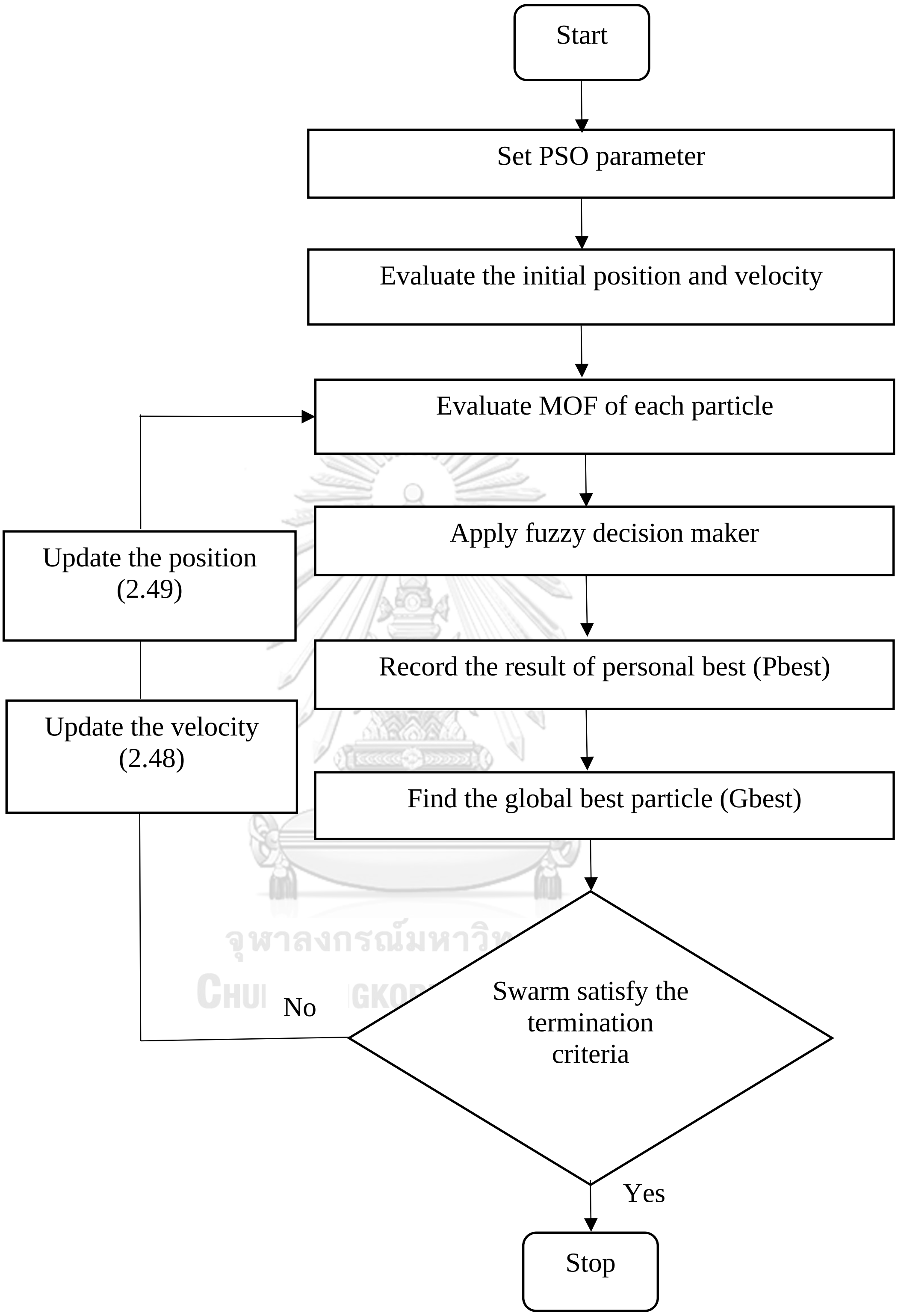

Figure 2.8 A flowchart of PSO with fuzzy decision maker

CHAPTER 3
RESEARCH METHODOLOGY

3.1 Research Area

The research area consists of 3 main parts. The first part describes about the test system utilized in the study, which is the standard IEEE 33-bus test system. The following section provides the data of hourly wind speed adopted in the study. Then, the last section gives in detail the load demand per hour data adopted in the study.

3.1.1 A IEEE Standard 33-Bus Test System

The methodology utilized in this research is verified in a 12.66 kV, IEEE standard 33-bus test radial distribution system. The single line diagram of the test system is given in Figure 3.1. Then, the system data such as line and peak load data at each bus are represented in Table 3.1 [25-27]:

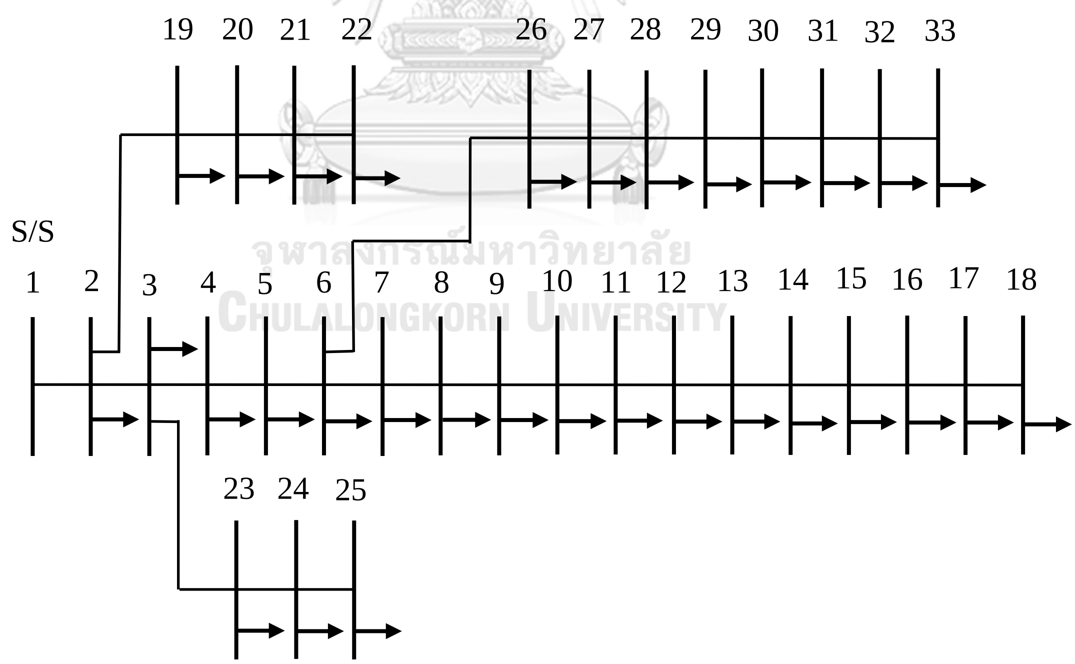

Figure 3.1 A Single Line Diagram of 33-bus IEEE Test System

Table 3.1 The Data of Line and Load of 33-Bus IEEE Test System

Branch No.	From bus	To bus	R(Ω)	X(Ω)	Peak load at to bus	
					P (kW)	Q (kVAr)
1	1	2	0.0922	0.0477	0	0
2	2	3	0.4930	0.2511	100	60
3	3	4	0.3660	0.1864	90	40
4	4	5	0.3811	0.1941	120	80
5	5	6	0.8190	0.7070	60	30
6	6	7	0.1872	0.6188	60	20
7	7	8	1.7114	1.2351	200	100
8	8	9	1.0300	0.7400	200	100
9	9	10	1.0400	0.7400	60	20
10	10	11	0.1966	0.0650	60	20
11	11	12	0.3744	0.1238	45	30
12	12	13	1.4680	1.1550	60	35
13	13	14	0.5416	0.7129	60	35
14	14	15	0.5910	0.5260	120	80
15	15	16	0.7463	0.5450	60	10
16	16	17	1.2890	1.7210	60	20
17	17	18	0.7320	0.5740	60	20
18	2	19	0.1640	0.1565	90	40
19	19	20	1.5042	1.3554	90	40
20	20	21	0.4095	0.4784	90	40
21	21	22	0.7089	0.9373	90	40
22	3	23	0.4512	0.3083	90	40
23	23	24	0.8980	0.7091	90	50
24	24	25	0.8960	0.7011	420	200
25	6	26	0.2030	0.1034	420	200
26	26	27	0.2842	0.1447	60	25
27	27	28	1.0590	0.9337	60	25

Branch No.	From bus	To bus	R(Ω)	X(Ω)	Peak load at to bus	
					P (kW)	Q (kVAr)
28	28	29	0.8042	0.7006	60	20
29	29	30	0.5075	0.2585	120	70
30	30	31	0.9744	0.9630	200	600
31	31	32	0.3105	0.3619	150	70
32	32	33	0.3410	0.5302	210	100
Total					3650	2260

3.1.2 Wind Generation Data

The data for wind generation applied in Weibull pdf is given in Table 3.2 as shown below:

Table 3.2 Wind generation data

Parameter	Value
k	2
V_m	8.6380 m/s
c	9.7437

3.1.3 Wind turbine data

The study only applies one type of wind turbine characteristic for the sake of simplicity as given in Table 3.3 as shown below:

Table 3.3 Wind turbine data

Parameter	Value
P_r	100 kW
v_{ci}	2.5 m/s
v_r	12.5 m/s
v_{co}	25 m/s

3.1.4 Load Demand Data

The test system is presumed to adopt the IEEE-RTS load pattern. The system provides a load profile that varies over time presented as the percentage of peak load demand. The seasonal component is excluded in this research, as given in Table 3.4 [18].

Table 3.4 The load per hour as a percentage of peak load demand

Hour	Load (%)	Hour	Load (%)
12-1 AM	0.64	12-1	0.99
1-2	0.6	1-2	1.00
2-3	0.58	2-3	1.00
3-4	0.56	3-4	0.97
4-5	0.56	4-5	0.96
5-6	0.58	5-6	0.96
6-7	0.64	6-7	0.93
7-8	0.76	7-8	0.92
8-9	0.87	8-9	0.92
9-10	0.95	9-10	0.93
10-11	0.99	10-11	0.87
11-12 PM	1.00	11-12 AM	0.72

3.2 Research Analysis Framework

This research proceeds with three steps as listed below

1. Preliminary studies

   In the early stage of the study, a literature review related to the placement and sizing of wind-based DG and capacitor bank in the distribution system is carried out. After reviewing some literature, the literature references and the hypothesis of this research are established. The main aim of having a literature review is to enhance the knowledge related to the methodology and impact of determining the optimal placement and sizing of wind-based DG and capacitor bank in the distribution system.

2. System modeling and simulation

   System modeling of the research is managed in this step. The study aims to establish the optimal location and size for wind-based DGs and capacitor bank in the distribution system considering power loss minimization, voltage profile improvement, and carbon di-oxide emission reduction at minimum value of system annualized cost. The system is modeled in the form of mathematical modeling, represents a real field in the mathematical approach in order to give an accurate result. MATLAB software used for constructing the source code after the mathematical modeling. MPSO, as modified optimization algorithm is applied to the source code to define the optimal location and capacity of wind-based DGs and capacitor bank in the distribution system. After that, the source code including MPSO is simulated with the specific case study to determine the optimal placement and sizing of wind-based DGs and capacitor bank with the objective functions such as power loss minimization, system voltage improvement, and carbon di-oxide emission reduction with annualized cost of system minimization.

3. Analysis and reporting

Based on the result, the system performance is analyzed due to the impact of the wind-based DG and capacitor bank's installation in the distribution system. Then, a report and a conclusion can be arranged according to the research objectives. Furthermore, the suggestion for further development of this research is proposed to enhance the quality of this research. The step of this research is summarized into a flow chart given in Figure 3.2

3.3 System Modelling

The flowchart of research methodology, according to the optimization of the placement and sizing of wind-based DGs and capacitor bank in the distribution system is given in Figure 3.3. It shows that the initial step of this research is determining the input of the load flow calculation, such as the bus data, the line data, the hourly load demand data, and the hourly mean wind speed data. The bus represents a node where the load is connected. The line parameter shows the relationship between bus represented by the

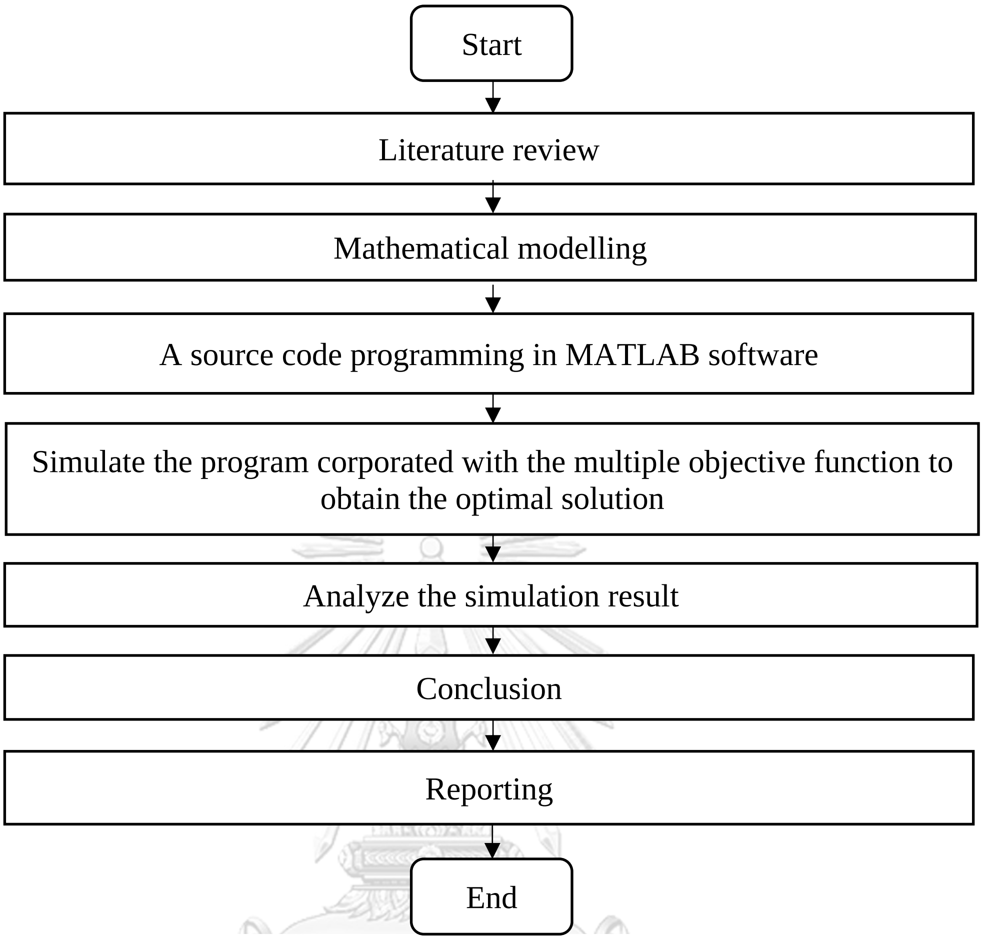

Figure 3.2. Research step

resistance and reactance. The load data indicates the demand for active and reactive power in the system. The hourly mean wind speed data represents the wind speed on the average during specific time. In this research, the probabilistic technique is applied to obtain the wind power from hourly mean wind speed data.

Then, for the optimization process, PSO parameters need to be defined are the inertia weight factor w_{min}, w_{max}, the acceleration weight factor c, the number of the swarm, the iteration number, initial P_{best}, initial G_{best}, and constraints. The inertia weight factor is a factor that influences the balance between the global search and the individual search. The more significant the inertia weight factor, the higher the global searchability. The smaller inertia weight factor, the greater the individual searchability. Another factor that affects the global and the individual search is the acceleration factor which are c_1 and c_2. If c_1 is greater than c_2, the global search ability will be greater and if c_2 is larger than c_1, the individual search ability will be greater. The swarm is the number of particles, and the number of iterations is maximum number of iterations for the swarms to get the optimal and converged solution.

The two decision variables incorporated in the optimization process for obtaining the optimal solution are the location and the capacity of wind-based DGs and capacitor bank in the distribution system. Thus, the initial position and velocity of the swarm represent location and size of wind-based DG and the capacitor bank in the distribution system needs to be specified. The location is represented by the bus where DGs and capacitor bank are installed. The capacity is represented by the amount of active power injected by wind-based DG and the amount of reactive power injected by a capacitor bank. The optimal location and size of wind-based DG and capacitor bank in the distribution system are specified considering the minimum objective functions. In the optimization process, the constraints are taken into accounts to maintain the optimal solution.

The following step is running the load flow calculation employing a forward and backward sweep method. It results in the value of current flowing through line section ith, the voltage at node ith, active power loss, and reactive power loss. The value of average power loss, voltage profile deviation, average carbon-di-oxide emission, and annualized cost of system as the objective functions can be determined. After that, the optimization process is executed to define the optimal placement and sizing of wind-based DG and capacitor bank by minimizing the objective functions. If the current P_{best} is less than the initial P_{best}, the value will be set as the current P_{best}. Then, if the current P_{best} is less than the initial G_{best}, the current P_{best} will be set as the current G_{best}. Thus, G_{best} is always updated until the optimal solution according to the minimum objective function and the constraints are obtained.

3.4 Case Study

To determine the impact of wind-based DGs and capacitor bank in the distribution system in term of the techno-eco-environmental benefits, some case study is carried out as given below:

1. Base Case

Observing the distribution system performance under condition without wind-based DG and capacitor bank in terms of active power loss, reactive power loss, system voltage profile, and carbon-di-oxide emission.

2. Case 1

   Repeating case 1 with one size of wind-based DG installed at the distribution system and determining the minimum ACS.

3. Case 2

   Repeating case 1 with one size of wind-based DG and one size of capacitor bank installed at the distribution system and determining the minimum ACS.

4. Case 3

   Repeating case 1 with two sizes of wind-based DGs and two sizes of capacitor bank installed at the distribution system and determining the minimum ACS.

5. Case 4

   Repeating case 1 with three sizes of wind-based DGs and three sizes of capacitor bank installed at the distribution system and determining the minimum ACS.

The five-case study above is assumed to be able to show the effectiveness of the planning model in achieving the optimal place and size of wind-based DG and capacitor bank in the distribution system. Then, the result of the four-cases mentioned above is represented in the following chapter.

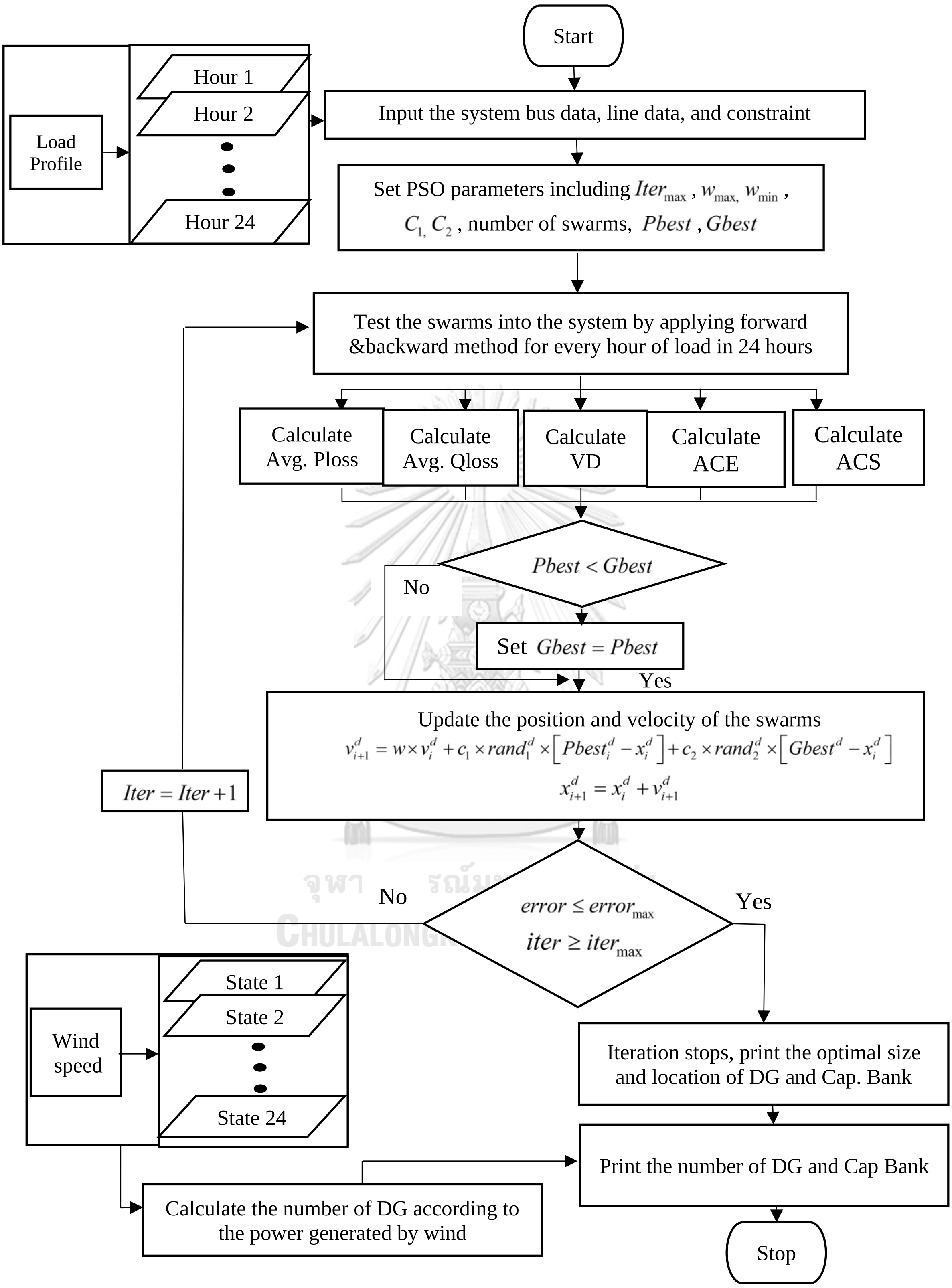

Figure 3.3 Flowchart to generate the optimal solution from multiple objective wind-based DG and capacitor bank planning problem

CHAPTER 4
RESULT AND DISCUSSION

The research presents a multiple objective optimization model for the joint integration of wind-based DGs and capacitor bank in the distribution system. The MMPSO algorithm is used to determining the possible solution by taking all technical, economic, and environmental objectives into account to obtain the optimal model of wind-based DG and capacitor bank in the distribution system. The possible solutions must satisfy the constraint of active and reactive power balance, active and reactive power loss, system voltage profile, and capacity of wind-based DG and capacitor bank. The variable of decisions included in the optimization process is the location of wind-based DG and capacitor bank, the capacity of wind-based DG and capacitor bank, and the number of wind-based DG. The optimization result denotes forceful impacts toward the system, such as the decrease of active and reactive power loss, the improvement of system voltage, the mitigation of carbon-di-oxide emission with ensuring the minimum value of annualized cost of system.

The work of the planning model is verified on the IEEE standard 33-bus radial distribution system implemented under the MATLAB environment. The required data of test system data are the line resistance (R), the line reactance (X), the active power demand (P), and the reactive power demand (Q) [28]. The MMPSO parameter, including the number of swarms, w_{max}, w_{min}, $iter_{max}$, c_1, and c_2, are assumed to be 150, 0.9, 0.4, 1000, 2, and 2, respectively. These parameters are specified based on simulated probation on the test system. The initial capital cost of \$3,500/kW and \$5/kVAr are applied for the wind-based DG and capacitor bank, respectively. Then, \$95/kW and \$1.2/kVAr are employed as the cost for the maintenance of wind-based DG and capacitor bank per year, respectively. The lifetime of wind-based DG and capacitor bank are assumed to be 25 years and 10 years, respectively. Then, the rate of interest and inflation adopted for ACS calculation are 3.75% and 1.5%, respectively.

4.1 Case 1: one size of wind-based DG

In this case, one size of wind-based DG is penetrated to the distribution system with 449 kW as the optimal size. By considering wind speed uncertainty and wind turbine characteristic, the optimal number of wind-based DG installed at bus-15 is five.

The modeling of the wind generation, considering wind speed uncertainty and wind turbine characteristics are provided in Table 4.1. The minimum bus voltage in each hour for 24 hours load profile in case 1 increases in comparison to the base case. Table 4.2. shows the comparison of minimum bus voltage in each hour for 24 hours load profile between base case and case 1. The enhancement of the system voltage profile is caused by the reduction of current supplied by the main substation in the presence of wind-based DG, which eventually results in the decrease of both active power line loss and reactive power line loss. The average active power loss and average reactive power loss reduces from 2.354 kW and 1.596 kVAr become 1.720 kW and 1.115 kVAr, respectively. The value is less compared to the value in the base case. This study also proposes a model to define the trade-off between wind-based DG's annualized cost of system and size to achieve the optimal solution. The obtained result for the optimal annualized cost of system in Case 1 is $1,315,570. The summary of case 1 is given in Table 4.3. Besides, the betterment of system bus voltage during time period 13.00-14.00 h is shown in Figure 4.1.

Table 4.1 The wind generation modeling in Case 1

States	Wind speed limit		V_{av}	$P(G_W)$	$P_o(w)$	P_{av}	CF	PF	n
	Min.	Max.							
1	0	1	0.5	0.0105	0	0.0000	0.0000	11.69271	0
2	1	2	1.5	0.0308	0	0.0000	0.0000	11.69271	0
3	2	3	2.5	0.0492	0	0.0000	0.0000	11.69271	0
4	3	4	3.5	0.0647	0.01	0.0006	0.0065	11.69271	5
5	4	5	4.5	0.0764	0.02	0.0015	0.0153	11.69271	5
6	5	6	5.5	0.0841	0.03	0.0025	0.0252	11.69271	5
7	6	7	6.5	0.0876	0.04	0.0035	0.0350	11.69271	5
8	7	8	7.5	0.0872	0.05	0.0044	0.0436	11.69271	5
9	8	9	8.5	0.0835	0.06	0.0050	0.0501	11.69271	5
10	9	10	9.5	0.0773	0.07	0.0054	0.0541	11.69271	5
11	10	11	10.5	0.0692	0.08	0.0055	0.0554	11.69271	5
12	11	12	11.5	0.0601	0.09	0.0054	0.0541	11.69271	5

States	Wind speed limit		V_{av}	$P(G_W)$	$P_o(w)$	P_{av}	CF	PF	n
	Min.	Max.							
13	12	13	12.5	0.0508	0.1	0.0051	0.0508	11.69271	5
14	13	14	13.5	0.0417	0.1	0.0042	0.0417	11.69271	5
15	14	15	14.5	0.0334	0.1	0.0033	0.0334	11.69271	5
16	15	16	15.5	0.026	0.1	0.0026	0.0260	11.69271	5
17	16	17	16.5	0.0198	0.1	0.0020	0.0198	11.69271	5
18	17	18	17.5	0.0147	0.1	0.0015	0.0147	11.69271	5
19	18	19	18.5	0.0106	0.1	0.0011	0.0106	11.69271	5
20	19	20	19.5	0.0075	0.1	0.0008	0.0075	11.69271	5
21	20	21	20.5	0.0052	0.1	0.0005	0.0052	11.69271	5
22	21	22	21.5	0.0035	0.1	0.0004	0.0035	11.69271	5
23	22	23	22.5	0.0023	0.1	0.0002	0.0023	11.69271	5
24	23	24	23.5	0.0038	0.1	0.0004	0.0038	11.69271	5

Table 4.2 The minimum bus voltage for 24 hours load profile in Base Case and Case 1 in p.u..

h	Min. Volt.at Base Case	at Bus	Min. Volt at Case 1	at Bus
1	0.9405	18	0.9548	33
2	0.9444	18	0.9581	33
3	0.9464	18	0.9598	33
4	0.9483	18	0.9615	33
5	0.9483	18	0.9615	33
6	0.9464	18	0.9598	33
7	0.9405	18	0.9548	33
8	0.9287	18	0.9447	33
9	0.9177	18	0.9353	33
10	0.9096	18	0.9284	33
11	0.9055	18	0.9249	33
12	0.9044	18	0.9240	33
13	0.9055	18	0.9249	33
14	0.9044	18	0.9240	33
15	0.9044	18	0.9240	33
16	0.9075	18	0.9267	33
17	0.9085	18	0.9275	33

h	Min. Volt.at Base Case	at Bus	Min. Volt at Case 1	at Bus
18	0.9085	18	0.9275	33
19	0.9116	18	0.9302	33
20	0.9126	18	0.9310	33
21	0.9126	18	0.9310	33
22	0.9116	18	0.9302	33
23	0.9177	18	0.9353	33
24	0.9327	18	0.9481	33

Table 4.3 Simulation result of wind-based DG and capacitor bank placement in Base Case and Case 1

	DG/ Capacitor bank size	Bus No.	Average loss		ACS
			kW	kVAr	
Base Case	-	-	2.354	1.596	-
Case 1	449 kW	15	1.720	1.115	$1,315,570

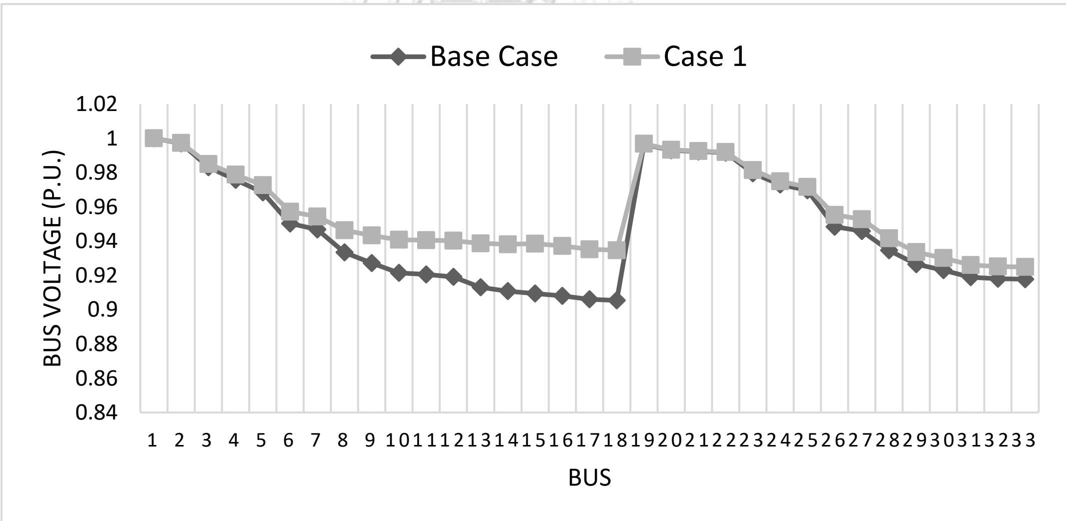

Figure 4.1 A bus voltage during time period 13.00-14.00 h (100% of peak load) in Base Case and Case 1

4.2 Case 2: one size of wind-based DG and one size of capacitor bank

In this case, one size of wind-based DG and one size of capacitor bank are penetrated to the distribution system with 457 kW and 500 kVAr as the optimal size, respectively. The optimal bus for locating capacitor bank is in bus-32. According to the wind speed uncertainty and wind turbine characteristic, the optimal number of wind-based

DG installed at bus-15 is five. Table 4.4 shows the modeling of wind generation, considering wind speed uncertainty and wind turbine characteristic. The reduction of both average active power loss and reactive power loss is higher compared to the previous cases due to the capacitive compensation provided by one size of capacitor bank installed in the distribution system.

Furthermore, the decrease of average power loss leads to the higher minimum system bus voltage in 24 hours load profile as shown in Table 4.5. The obtained result for the optimal annualized cost of system in Case 2 is $1,340,415. The summary of case 2 is provided in Table 4.6. Besides, the enhancement of system bus voltage during time period 13.00-14.00 h shown in Figure 4.2.

Table 4.4 The wind generation modeling in Case 2

States	Wind speed limit		V_{av}	$P(G_W)$	$P_o(w)$	P_{av}	CF	PF	n
	Min.	Max.							
1	0	1	0.5	0.0105	0	0.0000	0.0000	11.90104	0
2	1	2	1.5	0.0308	0	0.0000	0.0000	11.90104	0
3	2	3	2.5	0.0492	0	0.0000	0.0000	11.90104	0
4	3	4	3.5	0.0647	0.01	0.0006	0.0065	11.90104	5
5	4	5	4.5	0.0764	0.02	0.0015	0.0153	11.90104	5
6	5	6	5.5	0.0841	0.03	0.0025	0.0252	11.90104	5
7	6	7	6.5	0.0876	0.04	0.0035	0.0350	11.90104	5
8	7	8	7.5	0.0872	0.05	0.0044	0.0436	11.90104	5
9	8	9	8.5	0.0835	0.06	0.0050	0.0501	11.90104	5
10	9	10	9.5	0.0773	0.07	0.0054	0.0541	11.90104	5
11	10	11	10.5	0.0692	0.08	0.0055	0.0554	11.90104	5
12	11	12	11.5	0.0601	0.09	0.0054	0.0541	11.90104	5
13	12	13	12.5	0.0508	0.1	0.0051	0.0508	11.90104	5
14	13	14	13.5	0.0417	0.1	0.0042	0.0417	11.90104	5
15	14	15	14.5	0.0334	0.1	0.0033	0.0334	11.90104	5
16	15	16	15.5	0.026	0.1	0.0026	0.0260	11.90104	5
17	16	17	16.5	0.0198	0.1	0.0020	0.0198	11.90104	5

States	Wind speed limit		V_{av}	$P(G_W)$	$P_o(w)$	P_{av}	CF	PF	n
	Min.	Max.							
18	17	18	17.5	0.0147	0.1	0.0015	0.0147	11.90104	5
19	18	19	18.5	0.0106	0.1	0.0011	0.0106	11.90104	5
20	19	20	19.5	0.0075	0.1	0.0008	0.0075	11.90104	5
21	20	21	20.5	0.0052	0.1	0.0005	0.0052	11.90104	5
22	21	22	21.5	0.0035	0.1	0.0004	0.0035	11.90104	5
23	22	23	22.5	0.0023	0.1	0.0002	0.0023	11.90104	5
24	23	24	23.5	0.0038	0.1	0.0004	0.0038	11.90104	5

Table 4.5 The minimum bus voltage of 24 hours load profile in Base Case, Case 1, and Case 2 in P.U.

h	Min. Volt.at Base Case	at Bus	Min. Volt at Case 1	at Bus	Min. Volt. at Case 2	at Bus
1	0.9405	18	0.9548	33	0.9699	18
2	0.9444	18	0.9581	33	0.9729	18
3	0.9464	18	0.9598	33	0.9744	18
4	0.9483	18	0.9615	33	0.9759	18
5	0.9483	18	0.9615	33	0.9759	18
6	0.9464	18	0.9598	33	0.9744	18
7	0.9405	18	0.9548	33	0.9699	18
8	0.9287	18	0.9447	33	0.9607	18
9	0.9177	18	0.9353	33	0.9517	18
10	0.9096	18	0.9284	33	0.9440	18
11	0.9055	18	0.9249	33	0.9402	18
12	0.9044	18	0.9240	33	0.9392	18
13	0.9055	18	0.9249	33	0.9401	18
14	0.9044	18	0.9240	33	0.9392	18
15	0.9044	18	0.9240	33	0.9392	18
16	0.9075	18	0.9267	33	0.9421	18
17	0.9085	18	0.9275	33	0.9431	18
18	0.9085	18	0.9275	33	0.9431	18
19	0.9116	18	0.9302	33	0.9460	18
20	0.9126	18	0.9310	33	0.9469	18
21	0.9126	18	0.9310	33	0.9469	18
22	0.9116	18	0.9302	33	0.9460	18
23	0.9177	18	0.9353	33	0.9517	18
24	0.9327	18	0.9481	33	0.9637	18

Table 4.6 Simulation result for wind-based DG and capacitor bank placement in Base Case, Case 1, and Case 2

	DG/ Capacitor bank size	Bus No.	Avg. power loss		ACS
			kW	kVAr	
Base Case	-	-	2.354	1.596	-
Case 1	449 kW	15	1.720	1.115	$1,315,570
Case 2	457 kW 500 kVAr	15 32	1.281	0.856	$1,340,416

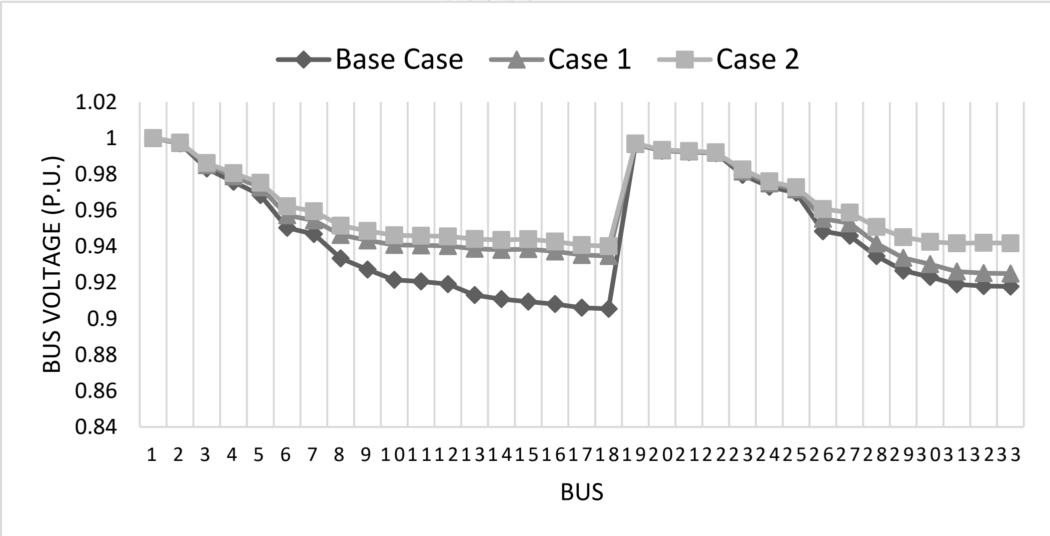

Figure 4.2 A bus voltage during time period 13.00-14.00 h (100% of peak load) in Base Case, Case 1, and Case 2

4.3 Case 3: two size of wind-based DGs and two sizes of capacitor bank

In this case, two sizes of wind-based DG and two sizes of capacitor bank are penetrated to the distribution system. 487 kVAr and 256 kVAr of capacitor bank are installed at bus-8 and bus-31, respectively. According to the wind turbine characteristic, the optimal number of wind-based DGs installed at bus-32 with 392 kW as the total size is four and installed at bus-14 with 457 kW as the total size is five. The modeling of wind generation considering wind speed uncertainty and wind turbine characteristics is provided in Table 4.7 and Table 4.8. The lowest bus voltage in each hour for 24 hours load profile is significantly improved, caused by the extra reactive power has been infused into the distribution system as represented in Table 4.9. Then, the reduction of average value of active and reactive power loss is also much higher in comparison to the base case due to the auxiliary active power injected by wind-based DG. The obtained result for the optimal annualized cost of system in Case 3 is $2,494,068. The summary of case 3 is given in Table 4.10. Besides, the improvement of system bus voltage during time period 13.00-14.00 h shown in Figure 4.3.

Table 4.7 The wind generation modeling in Case 2 for 392 kW of wind-based DG

States	Wind speed limit		V_{av}	$P(G_W)$	$P_o(w)$	P_{av}	CF	PF	n
	Min.	Max.							
1	0	1	0.5	0.0105	0	0.0000	0.0000	2.916667	0
2	1	2	1.5	0.0308	0	0.0000	0.0000	2.916667	0
3	2	3	2.5	0.0492	0	0.0000	0.0000	2.916667	0
4	3	4	3.5	0.0647	0.01	0.0006	0.0065	2.916667	4
5	4	5	4.5	0.0764	0.02	0.0015	0.0153	2.916667	4
6	5	6	5.5	0.0841	0.03	0.0025	0.0252	2.916667	4
7	6	7	6.5	0.0876	0.04	0.0035	0.0350	2.916667	4
8	7	8	7.5	0.0872	0.05	0.0044	0.0436	2.916667	4
9	8	9	8.5	0.0835	0.06	0.0050	0.0501	2.916667	4
10	9	10	9.5	0.0773	0.07	0.0054	0.0541	2.916667	4
11	10	11	10.5	0.0692	0.08	0.0055	0.0554	2.916667	4
12	11	12	11.5	0.0601	0.09	0.0054	0.0541	2.916667	4
13	12	13	12.5	0.0508	0.1	0.0051	0.0508	2.916667	4
14	13	14	13.5	0.0417	0.1	0.0042	0.0417	2.916667	4
15	14	15	14.5	0.0334	0.1	0.0033	0.0334	2.916667	4
16	15	16	15.5	0.026	0.1	0.0026	0.0260	2.916667	4
17	16	17	16.5	0.0198	0.1	0.0020	0.0198	2.916667	4
18	17	18	17.5	0.0147	0.1	0.0015	0.0147	2.916667	4
19	18	19	18.5	0.0106	0.1	0.0011	0.0106	2.916667	4
20	19	20	19.5	0.0075	0.1	0.0008	0.0075	2.916667	4
21	20	21	20.5	0.0052	0.1	0.0005	0.0052	2.916667	4
22	21	22	21.5	0.0035	0.1	0.0004	0.0035	2.916667	4
23	22	23	22.5	0.0023	0.1	0.0002	0.0023	2.916667	4

States	Wind speed limit		V_{av}	$P(G_W)$	$P_o(w)$	P_{av}	CF	PF	n
	Min.	Max.							
24	23	24	23.5	0.0038	0.1	0.0004	0.0038	2.916667	4

Table 4.8 The wind generation modeling in Case 2 for 457 kW of wind-based DG

States	Wind speed limit		V_{av}	$P(G_W)$	$P_o(w)$	P_{av}	CF	PF	n
	Min.	Max.							
1	0	1	0.5	0.0105	0	0.0000	0.0000	5.950521	0
2	1	2	1.5	0.0308	0	0.0000	0.0000	5.950521	0
3	2	3	2.5	0.0492	0	0.0000	0.0000	5.950521	0
4	3	4	3.5	0.0647	0.01	0.0006	0.0065	5.950521	5
5	4	5	4.5	0.0764	0.02	0.0015	0.0153	5.950521	5
6	5	6	5.5	0.0841	0.03	0.0025	0.0252	5.950521	5
7	6	7	6.5	0.0876	0.04	0.0035	0.0350	5.950521	5
8	7	8	7.5	0.0872	0.05	0.0044	0.0436	5.950521	5
9	8	9	8.5	0.0835	0.06	0.0050	0.0501	5.950521	5
10	9	10	9.5	0.0773	0.07	0.0054	0.0541	5.950521	5
11	10	11	10.5	0.0692	0.08	0.0055	0.0554	5.950521	5
12	11	12	11.5	0.0601	0.09	0.0054	0.0541	5.950521	5
13	12	13	12.5	0.0508	0.1	0.0051	0.0508	5.950521	5
14	13	14	13.5	0.0417	0.1	0.0042	0.0417	5.950521	5
15	14	15	14.5	0.0334	0.1	0.0033	0.0334	5.950521	5
16	15	16	15.5	0.026	0.1	0.0026	0.0260	5.950521	5
17	16	17	16.5	0.0198	0.1	0.0020	0.0198	5.950521	5
18	17	18	17.5	0.0147	0.1	0.0015	0.0147	5.950521	5
19	18	19	18.5	0.0106	0.1	0.0011	0.0106	5.950521	5
20	19	20	19.5	0.0075	0.1	0.0008	0.0075	5.950521	5
21	20	21	20.5	0.0052	0.1	0.0005	0.0052	5.950521	5
22	21	22	21.5	0.0035	0.1	0.0004	0.0035	5.950521	5
23	22	23	22.5	0.0023	0.1	0.0002	0.0023	5.950521	5
24	23	24	23.5	0.0038	0.1	0.0004	0.0038	5.950521	5

Table 4.9 The minimum bus voltage for 24 hours load profile in Base Case, Case 1, Case 2, and Case 3 in P.U.

h	Min. Volt.at Base Case	at Bus	Min. Volt at Case 1	at Bus	Min. Volt. at Case 2	at Bus	Min. Volt. at Case 3	at Bus
1	0.9405	18	0.9548	33	0.9699	18	0.9819	18
2	0.9444	18	0.9581	33	0.9729	18	0.9848	18
3	0.9464	18	0.9598	33	0.9744	18	0.9862	18
4	0.9483	18	0.9615	33	0.9759	18	0.9877	18
5	0.9483	18	0.9615	33	0.9759	18	0.9877	18
6	0.9464	18	0.9598	33	0.9744	18	0.9862	18
7	0.9405	18	0.9548	33	0.9699	18	0.9819	18
8	0.9287	18	0.9447	33	0.9607	18	0.9725	18
9	0.9177	18	0.9353	33	0.9517	18	0.9639	18
10	0.9096	18	0.9284	33	0.9440	18	0.9564	18
11	0.9055	18	0.9249	33	0.9402	18	0.9525	18
12	0.9044	18	0.9240	33	0.9392	18	0.9516	18
13	0.9055	18	0.9249	33	0.9401	18	0.9525	18
14	0.9044	18	0.9240	33	0.9392	18	0.9516	18
15	0.9044	18	0.9240	33	0.9392	18	0.9516	18
16	0.9075	18	0.9267	33	0.9421	18	0.9545	18
17	0.9085	18	0.9275	33	0.9431	18	0.9554	18
18	0.9085	18	0.9275	33	0.9431	18	0.9554	18
19	0.9116	18	0.9302	33	0.9460	18	0.9583	18
20	0.9126	18	0.9310	33	0.9469	18	0.9592	18
21	0.9126	18	0.9310	33	0.9469	18	0.9592	18
22	0.9116	18	0.9302	33	0.9460	18	0.9583	18
23	0.9177	18	0.9353	33	0.9517	18	0.9639	18
24	0.9327	18	0.9481	33	0.9637	18	0.9755	18

Table 4.10 Simulation result of wind-based DG and capacitor bank placement in Base Case, Case 1, and Case 3

	DG/ Capacitor bank size	Bus No.	Avg. power loss		ACS
			kW	kVAr	
Base Case	-	-	2.354	1.596	-
Case 1	449 kW	15	1.720	1.115	$1,315,570
Case 2	457 kW 500 kVAr	15 32	1.281	0.856	$1,340,416

	DG/ Capacitor bank size	Bus No.	Avg. power loss		ACS
			kW	kVAr	
Case 3	392 kW; 457 kW 487 kVAr; 256 kVAr	32; 14 8; 31	0.821	0.542	$2,494,068

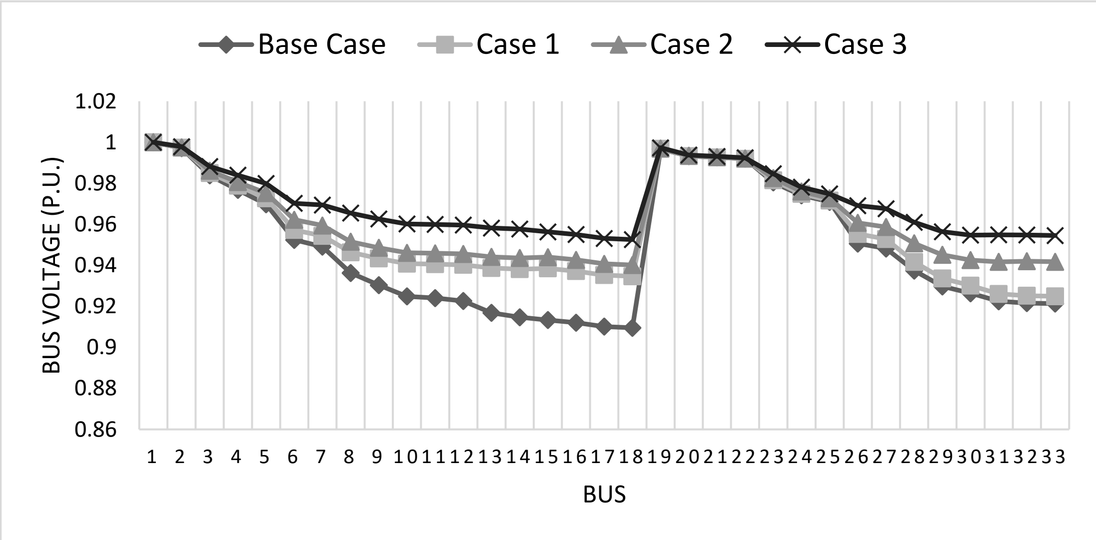

Figure 4.3 A bus voltage during time period 13.00-14.00 h (100% of peak load) in Base Case, Case 1, Case 2, and Case 3

4.4 Case 4: three size of wind-based DGs and three sizes of capacitor bank

In this case, three sizes of wind-based DG and three sizes of capacitor bank are penetrated to the distribution system. 403 kVAr, 494 kVAr, and 155 kVAr of capacitor bank are installed at bus-31, bus-30, and bus-26, respectively. Based on the wind turbine characteristic and wind speed characteristic, the optimal number of wind-based DGs installed at bus-32 with 384 kW as the total optimal size, installed at bus-14 with 458 kW as the total optimal size, and installed at bus-15 with 139 kW as the total optimal size are four, five, and two, respectively. The modeling of wind generation considering wind speed uncertainty and wind turbine characteristics is represented in Table 4.11, Table 4.12, and Table 4.13. The minimum bus voltage in each hour for 24 hours load profile is drastically improved, caused by the more extra reactive power has been injected into the distribution system as given in Table 4.14. The reduction of average active and reactive power loss is significantly much more compared to the previous case. So, much higher penetration of wind-based DG and capacitor bank supported with the optimal place and size in distribution system significantly improves the system performance. The obtained result for the optimal annualized cost of system in Case 3 is \$2,879,234. The summary of case 4 is given in Table 4.15. Besides, the improvement of system bus voltage during time period 13.00-14.00 h shown in Figure 4.4.

Table 4.11 The wind generation modeling in Case 3 for 384 kW of wind-based DG

States	Wind speed limit		V_{av}	$P(G_W)$	$P_o(w)$	P_{av}	CF	PF	n
	Min.	Max.							
1	0	1	0.5	0.0105	0	0.0000	0.0000	2.857143	0
2	1	2	1.5	0.0308	0	0.0000	0.0000	2.857143	0
3	2	3	2.5	0.0492	0	0.0000	0.0000	2.857143	0
4	3	4	3.5	0.0647	0.01	0.0006	0.0065	2.857143	4
5	4	5	4.5	0.0764	0.02	0.0015	0.0153	2.857143	4
6	5	6	5.5	0.0841	0.03	0.0025	0.0252	2.857143	4
7	6	7	6.5	0.0876	0.04	0.0035	0.0350	2.857143	4
8	7	8	7.5	0.0872	0.05	0.0044	0.0436	2.857143	4
9	8	9	8.5	0.0835	0.06	0.0050	0.0501	2.857143	4
10	9	10	9.5	0.0773	0.07	0.0054	0.0541	2.857143	4
11	10	11	10.5	0.0692	0.08	0.0055	0.0554	2.857143	4
12	11	12	11.5	0.0601	0.09	0.0054	0.0541	2.857143	4
13	12	13	12.5	0.0508	0.1	0.0051	0.0508	2.857143	4
14	13	14	13.5	0.0417	0.1	0.0042	0.0417	2.857143	4
15	14	15	14.5	0.0334	0.1	0.0033	0.0334	2.857143	4
16	15	16	15.5	0.026	0.1	0.0026	0.0260	2.857143	4
17	16	17	16.5	0.0198	0.1	0.0020	0.0198	2.857143	4
18	17	18	17.5	0.0147	0.1	0.0015	0.0147	2.857143	4
19	18	19	18.5	0.0106	0.1	0.0011	0.0106	2.857143	4
20	19	20	19.5	0.0075	0.1	0.0008	0.0075	2.857143	4
21	20	21	20.5	0.0052	0.1	0.0005	0.0052	2.857143	4
22	21	22	21.5	0.0035	0.1	0.0004	0.0035	2.857143	4
23	22	23	22.5	0.0023	0.1	0.0002	0.0023	2.857143	4
24	23	24	23.5	0.0038	0.1	0.0004	0.0038	2.857143	4

Table 4.12 The wind generation modeling in Case 2 for 458 kW of wind-based DG

States	Wind speed limit		V_{av}	$P(G_W)$	$P_o(w)$	P_{av}	CF	PF	n
	Min.	Max.							
1	0	1	0.5	0.0105	0	0.0000	0.0000	5.963542	0
2	1	2	1.5	0.0308	0	0.0000	0.0000	5.963542	0
3	2	3	2.5	0.0492	0	0.0000	0.0000	5.963542	0
4	3	4	3.5	0.0647	0.01	0.0006	0.0065	5.963542	5
5	4	5	4.5	0.0764	0.02	0.0015	0.0153	5.963542	5
6	5	6	5.5	0.0841	0.03	0.0025	0.0252	5.963542	5
7	6	7	6.5	0.0876	0.04	0.0035	0.0350	5.963542	5
8	7	8	7.5	0.0872	0.05	0.0044	0.0436	5.963542	5
9	8	9	8.5	0.0835	0.06	0.0050	0.0501	5.963542	5
10	9	10	9.5	0.0773	0.07	0.0054	0.0541	5.963542	5
11	10	11	10.5	0.0692	0.08	0.0055	0.0554	5.963542	5
12	11	12	11.5	0.0601	0.09	0.0054	0.0541	5.963542	5
13	12	13	12.5	0.0508	0.1	0.0051	0.0508	5.963542	5
14	13	14	13.5	0.0417	0.1	0.0042	0.0417	5.963542	5
15	14	15	14.5	0.0334	0.1	0.0033	0.0334	5.963542	5
16	15	16	15.5	0.026	0.1	0.0026	0.0260	5.963542	5
17	16	17	16.5	0.0198	0.1	0.0020	0.0198	5.963542	5
18	17	18	17.5	0.0147	0.1	0.0015	0.0147	5.963542	5
19	18	19	18.5	0.0106	0.1	0.0011	0.0106	5.963542	5
20	19	20	19.5	0.0075	0.1	0.0008	0.0075	5.963542	5
21	20	21	20.5	0.0052	0.1	0.0005	0.0052	5.963542	5
22	21	22	21.5	0.0035	0.1	0.0004	0.0035	5.963542	5
23	22	23	22.5	0.0023	0.1	0.0002	0.0023	5.963542	5
24	23	24	23.5	0.0038	0.1	0.0004	0.0038	5.963542	5

Table 4.13 The wind generation modeling in Case 2 for 139 kW of wind-based DG

States	Wind speed limit		V_{av}	$P(G_W)$	$P_o(w)$	P_{av}	CF	PF	n
	Min.	Max.							
1	0	1	0.5	0.0105	0	0.0000	0.0000	3.619792	0
2	1	2	1.5	0.0308	0	0.0000	0.0000	3.619792	0
3	2	3	2.5	0.0492	0	0.0000	0.0000	3.619792	0
4	3	4	3.5	0.0647	0.01	0.0006	0.0065	3.619792	2
5	4	5	4.5	0.0764	0.02	0.0015	0.0153	3.619792	2
6	5	6	5.5	0.0841	0.03	0.0025	0.0252	3.619792	2
7	6	7	6.5	0.0876	0.04	0.0035	0.0350	3.619792	2
8	7	8	7.5	0.0872	0.05	0.0044	0.0436	3.619792	2
9	8	9	8.5	0.0835	0.06	0.0050	0.0501	3.619792	2
10	9	10	9.5	0.0773	0.07	0.0054	0.0541	3.619792	2
11	10	11	10.5	0.0692	0.08	0.0055	0.0554	3.619792	2
12	11	12	11.5	0.0601	0.09	0.0054	0.0541	3.619792	2
13	12	13	12.5	0.0508	0.1	0.0051	0.0508	3.619792	2
14	13	14	13.5	0.0417	0.1	0.0042	0.0417	3.619792	2
15	14	15	14.5	0.0334	0.1	0.0033	0.0334	3.619792	2
16	15	16	15.5	0.026	0.1	0.0026	0.0260	3.619792	2
17	16	17	16.5	0.0198	0.1	0.0020	0.0198	3.619792	2
18	17	18	17.5	0.0147	0.1	0.0015	0.0147	3.619792	2
19	18	19	18.5	0.0106	0.1	0.0011	0.0106	3.619792	2
20	19	20	19.5	0.0075	0.1	0.0008	0.0075	3.619792	2
21	20	21	20.5	0.0052	0.1	0.0005	0.0052	3.619792	2
22	21	22	21.5	0.0035	0.1	0.0004	0.0035	3.619792	2
23	22	23	22.5	0.0023	0.1	0.0002	0.0023	3.619792	2
24	23	24	23.5	0.0038	0.1	0.0004	0.0038	3.619792	2

Table 4.14 The minimum bus voltage for 24 hours load profile in Base Case, Case 1, Case 2, and Case 3 in P.U.

h	Min. Volt. at Base Case	at Bus	Min. Volt at Case 1	at Bus	Min. Volt. at Case 2	at Bus	Min. Volt. at Case 3	at Bus	Min. Volt. at Case 4	At bus
1	0.9405	18	0.9548	33	0.9699	18	0.9775	18	0.9806	18
2	0.9444	18	0.9581	33	0.9729	18	0.9805	18	0.9836	18
3	0.9464	18	0.9598	33	0.9744	18	0.9819	18	0.9852	18
4	0.9483	18	0.9615	33	0.9760	18	0.9834	18	0.9867	18
5	0.9483	18	0.9615	33	0.9760	18	0.9834	18	0.9867	18
6	0.9464	18	0.9598	33	0.9744	18	0.9819	18	0.9852	18
7	0.9405	18	0.9548	33	0.9699	18	0.9775	18	0.9806	18
8	0.9287	18	0.9447	33	0.9607	18	0.9662	18	0.9703	18
9	0.9177	18	0.9353	33	0.9518	18	0.9559	18	0.9614	18
10	0.9096	18	0.9284	33	0.9442	18	0.9483	18	0.9547	18
11	0.9055	18	0.9249	33	0.9403	18	0.9444	18	0.9514	18
12	0.9044	18	0.9240	33	0.9393	18	0.9435	18	0.9506	18
13	0.9055	18	0.9249	33	0.9403	18	0.9444	18	0.9514	18
14	0.9044	18	0.9240	33	0.9393	18	0.9435	18	0.9506	18
15	0.9044	18	0.9240	33	0.9393	18	0.9435	18	0.9506	18
16	0.9075	18	0.9267	33	0.9422	18	0.9463	18	0.9531	18
17	0.9085	18	0.9275	33	0.9432	18	0.9473	18	0.9539	18
18	0.9085	18	0.9275	33	0.9432	18	0.9473	18	0.9539	18
19	0.9116	18	0.9302	33	0.9461	18	0.9502	18	0.9564	18
20	0.9126	18	0.9310	33	0.9471	18	0.9511	18	0.9572	18
21	0.9126	18	0.9310	33	0.9471	18	0.9511	18	0.9572	18
22	0.9116	18	0.9302	33	0.9461	18	0.9502	18	0.9564	18
23	0.9177	18	0.9353	33	0.9518	18	0.9559	18	0.9614	18
24	0.9327	18	0.9481	33	0.9638	18	0.9709	18	0.9745	18

Table 4.15 Simulation result for wind-based DG and capacitor bank placement in Base Case, Case 1, Case 3, and Case 4

	DG/ Capacitor bank size	Bus No.	Avg. power loss		ACS
			kW	kVAr	
Base Case	-	-	2.354	1.596	-
Case 1	449 kW	15	1.720	1.115	$1,315,570
Case 2	457 kW 500 kVAr	15 32	1.281	0.856	$1,340,416

	DG/ Capacitor bank size	Bus No.	Avg. power loss		ACS
			kW	kVAr	
Case 3	392 kW; 457 kW 487 kVAr; 256 kVAr	32; 14 8; 31	0.821	0.542	$2,494,068
Case 4	384; 458; 139 Kw 403; 494; 155 kVAr	32; 14; 15 31; 30; 26	0.636	0.429	$2,879,234

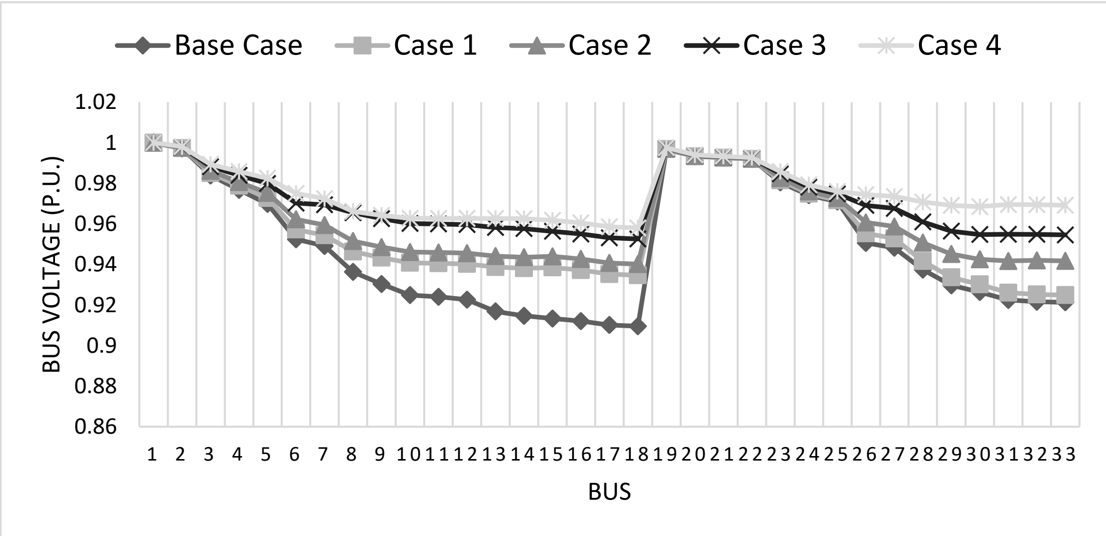

Figure 4.4 A bus voltage during time period13.00-14.00 h (100% of peak load) in Base Case, Case 1, Case 2, Case 3, and Case 4

4.5 Environmental Benefit Analysis

It is commonly acknowledged that a conventional power plant exudes more gas pollutants into the atmosphere compared to the wind power plant [5]. The existence of wind-based DG in the distribution system contributes to environmental benefit in terms of carbon-di-oxide emission reduction. The work of paper assumes that the carbon-di-oxide emission rate by wind-based DG is zero and the carbon-di-oxide emission rate by conventional power plant is 921.25 kg/MW h. In Case 1, the average carbon-di-oxide emission due to one size of wind-based DG penetrated in the distribution system is about 6080 tons/year. The value reduces compared to the average carbon-di- oxide emission in the base case which is 7158 tons/year. This condition is supported by the decrease of supplied power from the conventional power plant. The reduction of average carbon-di-oxide emission in Case 2 due to one size of wind-based DG and one size of capacitor bank penetrated in distribution system is slightly higher compared to the base case, which becomes 6005 tons/year. In Case 3, the average carbon-di-oxide emission significantly reduces become 5101 tons/year compared to the base case. In Case 4, the average carbon-di-oxide emission much more reduces become 4734 tons/year. This condition caused by the higher number of wind-based DGs and capacitor bank penetrated in distribution system that results in the extra reduction of supplied power both active power and reactive power from the conventional power plant. The more reduced power supplied by conventional, the more reduced carbon-di-oxide emission emitted by conventional power plants into the atmosphere. The summary of environmental benefit analysis in this study is shown in Figure 4.5.

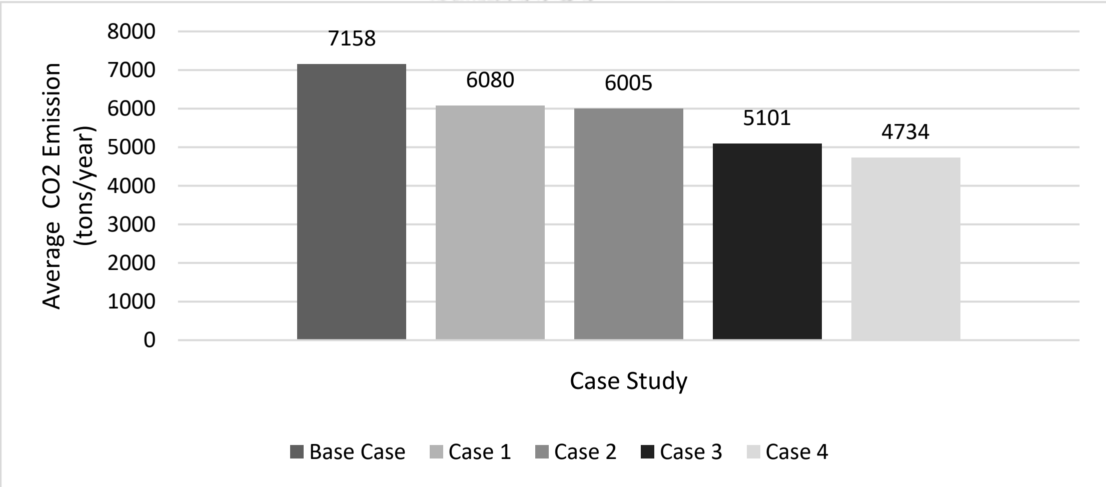

Figure 4.5 A comparison of average carbon-di-oxide emission between Base Case, Case 1, Case 2, Case 3, and Case 4

CHAPTER 5
SUMMARY AND CONCLUSION

This chapte provides a summary of the study. The main contribution of the proposed model and some conclusions based on the simulation results are summarized. Then, some suggestions for improvement of the proposed method are also presented in this chapter.

5.1 Study Summary and Conclusion

The study presents a multiple objective optimization model of wind-based DG and reactive power management in the distribution system. The capacitor bank is one of devices available for reactive power management. The proposed model defines the proper placement and appropriate sizing of wind-based DG and capacitor bank in the distribution system. Besides, the required unit of wind-based DG is determined considering wind speed uncertainty and wind turbine characteristic. The MMPSO algorithm is applied to reach potential solutions considering technical, economic, and environmental objectives. The potential solution should be satisfying the constraint of active and reactive power balance, active and reactive power loss, system voltage profile, DG capacity, and capacitor bank capacity. According to the result of cases study, case 1 shows the most minimum value of ACS that results in the fair to middling improvement of power system performance. Case 2 presents the much better enhancement of the power system performance with a slightly higher value of ACS compared to case 1. The significant improvement of power system performance is given in case 3 by the two times more of the ACS value compared to the ACS value in case 2. At last, the much more significant improvement of power system performance is offered by case 4 in line with the highest value of ACS among the cases. So, based on the case study, the proper placement and appropriate sizing of wind-based DG and capacitor bank in the distribution system strengthen the system performance in terms of average power loss reduction and voltage profile improvement. The much higher penetration of wind-based DG and capacitor bank in distribution system offers better performance of the system. However, the higher penetration of wind-based DG and capacitor bank in distribution system results in the higher value of ACS. In environmental aspect, the penetration of wind-based DG in distribution system reduces the average carbon-di-oxide emission into the atmosphere. This condition caused by the reduction of power supplied by conventional power plants that are used to emitting any pollutants into the atmosphere.

5.2 Recommendation for Research Development

Some improvement and development of this study are recommended as follows:

1. In the technical aspect, to obtain a more optimal solution, the generator type of wind turbine and the type of capacitor bank can also be considered in order to reduce the inexpedient parameter effect. The performance of generator and capacitor bank may affect the obtained optimal solution.
2. In the environmental aspect, to obtain a more optimal solution, besides carbon-di-oxide emission mitigation, the mitigation of other pollutants emitted by conventional power plants can also be investigated and formulated into objective function.
3. In the economic aspect, to obtain a more optimal solution, the other financial issue related to the study can also be investigated and formulated into objective function, such as: annualized purchased power cost saving.
4. For further study, the proposed model is better to be adopted in the real power system so that it can be evaluated in terms of wind-based DG and capacitor bank penetration in the distribution system and offer actual benefits.

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