AN OPTIMAL POWER FLOW ALGORITHM TO REDUCE POWER LOSS BY PLACEMENT OF DG IN DISTRIBUTION SYSTEM

Rajapaksha Mudiyanselage Tharangani Lakmali

(178519D)

Degree of Master of Science

Department of Electrical Engineering

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Thesis submitted in partial fulfilment of the requirements for the degree Master of Science in Electrical Engineering

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DECLARATION OF THE CANDIDATE AND SUPERVISOR

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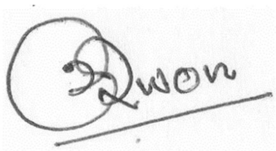

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(Prof. K. T. M. U. Hemapala)

ABSTRACT

Distributed generation is a small-scale and renewable-based energy source (ex: solar/ wind/ biomass) near to loads in distribution networks. It is becoming more prominent in the present world due to incremental demands for electricity. The integration of DGs in the distribution system is profitable, loss reduction and voltage-profile improvement if it is optimally sized and optimally placed. Research work included in this thesis focuses on using an optimization methodology for identifying the most appropriate location and size of DG.

Initially, detailed study of optimal DG planning was carried regarding objective functions, constraints, load and design variables, and mathematical approaches. In this dissertation, a novel combined methodology for optimal DG planning is presented by Newton Raphson's (NR) power-flow solution and optimization algorithm named Particle Swarm Optimization(PSO). A multi-objective function has been modified by considering real and reactive power loss minimization and cost minimization to attain the optimal size and optimal location of DGs. Moreover, voltage-profile improvement and power system stability improvements are obtained.

The performance of the proposed methodology is tested on the IEEE-30 bus system and program is developed and simulated from MATLAB software. Two types of DGs are evaluated using the proposed model which is called a single DG source delivering only real-power and a single DG source delivering both real and reactive power. The method is executed on the same 30-test bus system for different weighting factors.

Results in the test bus system show the effectiveness of the developed mathematical model with higher power loss reduction and cost reduction percentages.

Furthermore, the proposed methodology is applied to select two distribution feeders in Sri Lanka with time-varying loads to allocate solar PV and biomass as DGs. In order to have a techno-economic solution for optimal size of DG and best location, the proposed algorithm can be used on any MV distribution feeder providing relevant line and load details.

Keywords : optimal size of DG, best location, multi objective function, power loss reduction, cost reduction, Newton Raphson (NR), Particle Swarm Optimization (PSO), MV distribution system, MATLAB

ACKNOWLEDGEMENT

I would like to take this opportunity to convey my sincere gratitude to all those who were behind me in successfully completing this research.

First and foremost, I would like to deeply express my sincere gratitude to my supervisor Prof. K. T. M. U. Hemapala, Head, Department of Electrical Engineering, University of Moratuwa for the continuous support, proper guidance, constructive feedback, and encouragement from starting of this research up to writing this dissertation.

This work would have not been successful without the support of the course coordinators and lecturers of the post-graduate program at the Department of Electrical Engineering, University of Moratuwa. Therefore, I appreciate the guidance and advice given by the evaluation panel.

I also would like to express my sincere thanks to Ms. Iresha Jayasundara, Chief Electrical Engineer (Planning and Development) NWP-2, CEB and Ms. Zahra Marzook, Electrical Engineer, NWP- 1, CEB for providing valuable details required for this study.

Further, I thank my friends in our MSc batch who helped me to complete this work.

My special thanks go to my parents and brother for their understanding, patience, and immense support.

Finally, I would like to express my heartiest gratitude to my loving husband for his unlimited support and encouragement throughout my research.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

DG - Distributed Generation

NR - Newton Raphson

PSO - Particle Swarm Optimization

OPF - Optimal Power Flow

PV - Photo Voltaic

NPV - Net Present Value

CEB - Ceylon Electricity Board

PF - Power Factor

CHAPTER 01

1. INTRODUCTION

1.1 Background Study

The electricity requirement is steadily increased. Therefore, capacities of power generation have to be increased to fulfil the demand in countries with technical, economical and environmentally feasible solutions. Recently, penetration of the renewable (solar, wind, geothermal, ocean, fuel cell) and nonrenewable (microturbines, combined-cycles, internal combustion-engines, combustion-turbines) distributed generations (DG) are developed to fulfill the electrical energy consumption.[1]

Distributed generation (DG) can be defined as a small scale generation used to achieve the ever increasing electrical demand at or near to the premises of utility customers and interconnected to the distribution system.

The technical benefit of DG integration includes support for voltage, reduction of energy loss, system reliability improvement and release of the system capacity. The economical benefit of DG comprises a hedge against the high electricity prices. When improper DG integrates to the distribution system, performance of the distribution network will be changed being increased the system losses, increased DG cost, voltage and stability problems can happen. Therefore, the DGs impacts on operating characteristics of system are voltage profile, reliability-stability and electrical-losses need to properly evaluate and determination of the optimal size , location for DG units in distribution system are important aspects. The use of optimized DG planning is helped in order to achieve the maximum techno-economical benefits of DG integration.

1.2 Sri Lankan Distribution Network with DG

Sri Lanka is a small island with a peak demand of around 3000 MW. In SriLanka, Electricity generation is mainly covered by ‘conventional energy sources’ such as hydro, coal and petroleum. The plants are vested by the Ceylon Electricity Board and some private companies.

According to Sustainable Energy Authority, “SriLanka is aspiring to become a carbon-neutral country by 2050”. To obtain the achievement, the Ministry of Power and Energy, Ceylon Electricity Board, SriLanka Sustainable- Energy Authority and Public-Utilities Commission of SriLanka is working jointly and encouraging private developers to invest in renewable energy-based distributed generation. Future capacity development of renewable energy technologies in Sri Lanka is indicated in the figure 1.1.

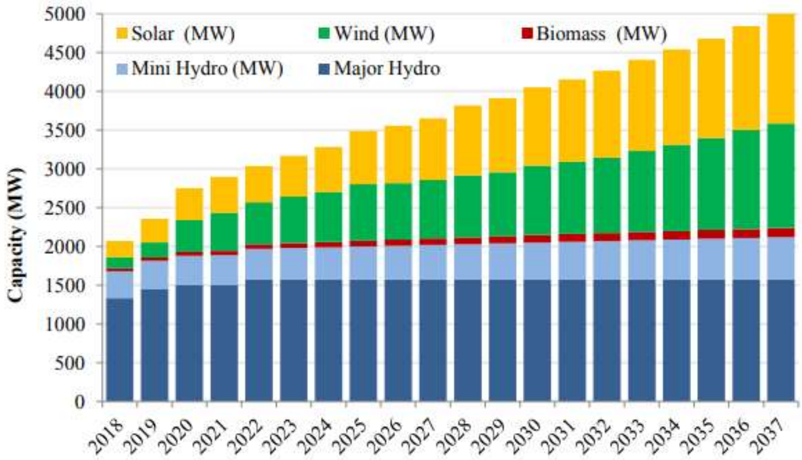


Figure 1.1: Renewable-Energy Capacity Development [2]

Due to geo-climate conditions in Sri Lanka, main renewable energy resources for electricity generation are hydro, solar, biomass and wind. The above generating units are located at resource focus; plants are inter-connected to national grid as DG units. Also, some amount of combustion diesel engines placed in different locations are considered as distributed generation. The present status of Non- Conventional Renewable Energy (NCRE) in Sri Lanka is mentioned in table 1.1

Table 1.1: Present Status for NCRE as at 31st May 2020 [3]

Technologies	No. of DG Plants	Total Capacity (MW)
Small-hydro	181	353.744
Wind	15	128.85
Biomass	9	24.10
Solar	8	51.36

1.2.1 Small Hydro Power

A few kW to 10 MW small-hydro power plants are integrated to distribution network at Sri Lanka. Hydro power is the most attractive renewable source which is highly expanded in the country and it converts potential energy in the water into electricity. Mainly, these types of power plants are located in the hill country areas in Sri Lanka. The small hydro plants are mainly used for stand-alone and base load applications and rural area electrification. Both active and reactive power are concerned as small-hydro generation.

1.2.2 Wind Power

There are a number of wind plants located around the county such as Ambewela, Puttalam, Kilinochchi and Hambantota areas. Wind turbines are converted kinetic energy of wind to electricity. Wind plants are free of emissions and no fuel costs requirement. A few hundred W to 10 MW wind power plants are located in Sri Lanka and are mainly used for Stand-alone and base load applications. Active and reactive power both are provided by wind turbines according to wind speed.

1.2.3 Biomass Power

Biomass is one of the new trending technologies in Sri Lanka to feed electrical energy to the distribution network. At the plant, biomass materials are transformed to bio-gas. The bio-gas is cleaned and up-graded to natural -gas when it becomes bio-methane. The bio-gas is used in gas turbines or piston driven engines to electricity generation. Biomass electrical power generation can handle active power, reactive power from synchronous generators. Few kW to 10 MW biomass plants are available in the country to produce electricity in stand-alone and base load applications.

1.2.4 Solar Power

Solar power generation is another trending technology in present Sri Lanka. Solar PV technologies directly convert sunlight into electrical energy. It also requires very low operating costs and no fuel cost. Solar PV is a unity p.f. generation technology which can generate ‘active-power’. In PUCSL and CEB definition, most solar PV systems tend to have two types. Utility-scale solar installations with a capacity usually more than 1 MW to 10 MW and small-scale ground-mounted and rooftop generation a few W to 1MW. Lots of rooftop solar power generators are located around the country and utility-scale ground-mounted solar plants are mainly discovered at Hambantota, Polonnaruwa and Vavuniya areas.

1.3 Motivation

According to the last two decades' data and the Long-Term Generation Expansion Plan of Sri Lanka, DG connected to the distribution system in Sri Lanka has increased rapidly.

There are no agreeable geological and technical limitations for location for the DG in distribution network and the main limitations emerge from electrical necessities. Also, clear guidelines are never included in the selection of the DG size to be introduced in a feeder in the distribution network. The main aspect is guided to select DG size and location is voltage criteria, it is to check whether the voltage at the node is within an acceptable range (± 6%) after adding DG unit.

Inappropriate placement and sizing of DG would lead to an increment of system losses and installing and operating costs. It would also occur reliability, stability and voltage profile problems. Proper siting and sizing of DG could enhance network potential in the terms on voltage-profile; minimize losses of system while improving quality of the power supply.

Worldwide, many researchers developed mathematical approaches to DG allocation in distribution networks. However, there is no highly efficient, proper and fast method to solve this problem with appropriate variables and constraints related to Sri Lanka. My research is focused to fulfil this requirement. And the study would have more beneficial to the up-coming distribution network and microgrid applications as well.

1.4 Research Objectives

The goal of this thesis is to develop a multi-objective optimal power flow algorithm to achieve an optimal performance in the distribution system by best sitting and sizing of DGs.

The specific objective of the research are highlighted as below.

1. To propose an optimal power loss reduction algorithm to the distribution system by applying different constraints of distributed generation

2. To find the economical cost of DGs

3. To compute and analyze results of the proposed multi-objective mathematical formulation using MATLAB

4. To apply the developed algorithm for practical scenario

1.5 Proposed Methodology

Proposed- methodology go along with my research is noted below.

1. Select suitable OPF methods for hybrid optimization by analyzing existing methods
2. Identify objective functions, DG variables and constraints
3. Develop a mathematical model of a multi-objective algorithm in MATLAB interface
4. Simulate and analyze results using IEEE bus system
5. Enhance and validate algorithm by considering results
6. Apply the mathematical model to selected distribution feeders in Sri Lanka for optimal DG planning

1.6 Outline of the Thesis

My thesis is organized on below.

Chapter2 introduces the background-knowledge of optimal placement and sizing of DG. Also, the chapter included a comprehensive literature-review on the formulation ofDG planning and mathematical approaches of DG planning.

Chapter 3 describes a proposed methodology for optimal DG. The chapter contains input, output and constraints data for modeling and the proposed mathematical approach.

Chapter 4 provides optimal placing and sizing of DG for the test bus system using the proposed model. Two types of DG are modeled with different weighing factors in this chapter and analyzed the results.

Chapter 5 is presented the application of the proposed model in a practical scenario. The mathematical model is applied for selected two distribution feeders in Sri Lanka. There are Kalubowila feeder and Mallawapitiya feeder 8.

Finally, Chapter 6 concludes the summary of research in this thesis and limitations and recommendations of the research is presented on the chapter.

CHAPTER 02

2. LITERATURE REVIEW

2.1 Formulate Optimal Placement and Sizing of DG

The following subsections are given in mathematical-formulations which have been included on literature to attain the optimal DG planning. It includes appropriate objective functions, DG variables, load variables and constraints.

2.1.1 Single Objective Functions

The objective functions for optimal placement and sizing of DG have been listed below. A mathematical model has been developed from below single-objective functions or multi-objective functions.

a) Minimization of the power losses of the system

The DG placement at the power system is induced impacts on electrical power system losses. Power losses are identified in two types, real and reactive power system losses. The real-power loss is happened by resistance of the line-conductors and value of real-power loss is indicated by overall efficiency of the power system. The reactive loss is happened by reactive-elements in power system and reactive-power flow is helped to maintain a fixed voltage-level of the system properly.

Certain DG-technologies are able to deliver active-power such as 'solar PV, micro-turbines and fuel-cells'. Optimal placement, sizing on these DGs are capable to reduce active-power loss in the network significantly. Number of DG-technologies are adept for delivering reactive-power, one example is 'synchronous-compensators'. Therefore, optimal placement and sizing for these DG-units are capable of reducing the reactive-power loss of power system considerably. Also, synchronous generators are able of providing active and reactive powers and the DG-units that have optimally placed and sized help to achieve minimization of active and reactive power losses significantly. [1], [4].

b) Minimization of total costs in power system

The Investing and operating cost make a significant-role in determining DG capacity. Consideration of investment cost, it is containing the cost for installing a DG technology at specific-locations. Operational-cost has two components; first cost is for real power supplied from the substation and the second cost is the cost of real power supplied by the DG installed. Due to optimal placement and sizing of DG, the total costs of the system can be minimized properly. Also, the maintenance cost of DG can be minimized. Planning of cost minimization is provided a quick screening of different investment possibilities of DG. [1], [5]

c) Minimization of the voltage deviation

DGs are caused on voltage-profile variation in power system. The voltage-profile is identified as a changes of the voltage in distribution system as load changes; further voltage-level are dropping along the length of feeders. And improper placing and DG sizing in the feeder may create voltage rise above to appropriate voltage-limit. Also, minimization of voltage deviation reduces excessive automated tap changing on distribution transformers in the distribution system.[5]

d) Minimization of average interruption

Optimal DG planning is caused to enhance the reliability of the distribution system. The main reliability-indices are 'systems average-interruption duration index'(SAIDI) and 'systems average-interruption frequency index'(SAIFI). By minimizing these interruptions, customers can obtain a reliable power supply with DG installation.[5]

e) Maximization of profit

By considering the DG owner's point of view, profit maximization is a more important factor. Optimal Sizing of DG provides a considerable effect on profit. [5]

2.1.2 Methodology for Mulli-Objective Formulation

The technical merits and economical merits can be achieved by optimal DG planning with multi-objectives. It is a complex combinatorial optimization issue due to concurrent optimization of multiple objectives. Multi-objectives optimization is generally solved by using one of following methodologies. [1]

a) Transforming into single objective functions with weights

Selected objective functions are multiplied by a factor which is called 'weighting factor' and an optimal solution can be obtained from a single multi-objective function.

b) Using Goal multi-objectives index

The multi-objectives formulation is converted into a single-objective function by providing goal-programming method.

2.1.3 DG Variables

a) No. of DG units

The no. of DGs that can be introduced in distribution system can be taken as free-variable parameters. Therefore, predefined single or multiple DG can be considered during the modeling.

b) Size and Location

Size and Locationof DGs are dependent on primary fuel availability with geological conditions, investment cost and profit for DG and the existing distribution system. In my study, this will be optimized in accordance with given conditions and limits.

c) Primary Energy

Primary energy of DG is illustrated in DG technology which can be used for power generation. Technologically, DG is varied with commercial availability and geological conditions. Solar, wind, mini-hydro, biomass and reciprocating engines are currently used as primary energy of DG in Sri Lanka. Also, some of the newest technology is still under testing.

d) DG type

Type of DG is dependent on DG technology. To facilitate optimal DG modeling, DG types are categorized into four types based on real-power and reactive-power delivering capacities. [1],[6]

- Type 01: DGs capable to inject active-power only
- Type 02: DGs capable to inject real and reactive powers
- Type 03: DGs capable to inject reactive-power only
- Type 04: DGs capable to inject real-power but consume reactive-power

2.1.4 Load Variables

An accurate load profile is an important factor for DG planning. But it is very difficult to obtain a proper load profile in the distribution system due to continuous load varying conditions. To minimize the load varying error, followings are considered for load modeling according to a variety of loads. [1]

a) One-loads level

b) Multi-loads level

c) Times-varying load

d) Probabilistic loads

e) fuzzy-loads

2.1.5 Constraint

Constraints of the design are most-important parameters for DG modeling. Objective functions should be satisfied specified constraints, otherwise malfunction of performance in the distribution system will occur. Constraints are mainly identified in two types as Equity constraints and Inequity constraints. [1], [4]

a) Equity-constraints

'Power-balance' constraint of power flows equation is considered in an equality-constraint and the constraint helps to keep the balanced system in the distribution network.

b) Inequity constraints

The following constraints are considered as this category. For optimal DG modeling, parameters in the inequity constraints should be varied within prescribed limits to keep system stability and to keep DG with geological conditions.

- Bus-voltage or voltage-drop limits
- Total harmonic voltage distortion limit
- Line / transformer overloading/capacity limit
- Real and reactive power limits of generations
- Max. number of DG
- DG type
- Budget limit

2.2 Mathematical Methods for Optimal DG Planning

Distributed generation is a solution for higher demand in the present world. Optimal planning of DG is more important and most researchers have been involved in optimal DG planning in the DG systems using OPF methods. The classification of OPF methods is shown in figure 2.1. [1],[5]

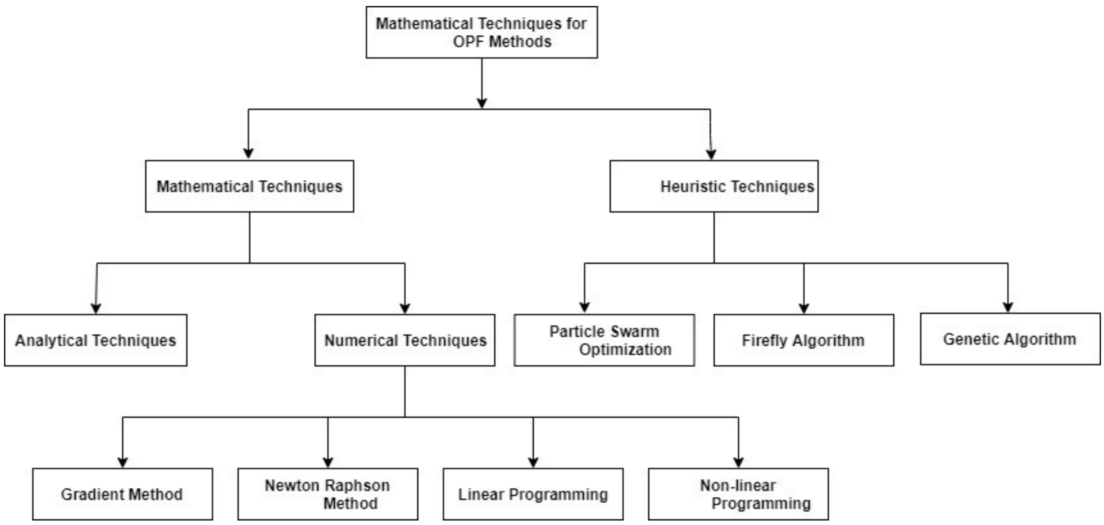


Figure 2.1: OPF Methods for Optimal DGs Planning

Mainly, two types of approaches named as mathematical methods and heuristic methods.

The analytical approach is one of the OPF methods in optimal DG planning. The approach is applied for a radial-feeder with uniformly-distributed loads and the technique may not be effective on nonuniformly-distributed loads. By this method, “2/3 - rule” introduces to installing a DG of “2/3 capacity” of incoming generation at “2/3 of length of the line”. Optimized results of the method are lower than other methods. Also, the method have not be directly used due to complexity and specific characteristics in the distribution system. [1]

There are different numerical methods that used in optimal sizing and placing of DGs. In [7], a numerical approach has been introduced using the gradient method to lower losses and improve the voltage profiles in electrical microgrids with distributed generation. It is shown about 12% of loss reduction by applying this method for fixed DG size. Further, Newton Raphson based approach for optimal placement of DG in an electrical distribution system has been proposed in [8]. It was able to reduce power loss by about 15 % and fixed 20MW solar PV installed in this paper.

In a linear programming method, the objective problem should be characterized as linear function and constraints are only linear inequalities. For non-linear problems, the problem should be contained with discrete and continuous variables and constraints should be in a non-linear form. These approaches are not suitable for objective functions which have more decision variables and long-time computation.[9]

Heuristic methods are computed-oriented techniques for optimization problems. The particle swarm optimization (PSO) method is one of the heuristic methods used in optimal DG planning. The technique has been used in [10] to decide the optimal location and size of SPV in a microgrid. This was modeled using the IEEE bus system and an around 42% loss reduction has been obtained.

In [11], a loss minimization approach for microgrids has been introduced using the analytical- firefly algorithm and it is identified as 8.67% power loss reduction in optimal placing and sizing of DGs. The firefly algorithm has a high probability to be trapped in locally optimal solutions; it is one of the main drawbacks of the approach.

GA-based optimal DG planning solution is proposed in [12]. It is identified around 47% power loss reduction with a single DG placemat. Computation time for GA is higher than other methods and convergence problems can happen due to unguided mutation.

Higher efficiency can be identified from hybrid optimization models by combining two different approaches. Further, a comparison of features in two main OPF techniques is listed under table 2.1.

Table 2.1: Comparison of OPF Methods [1],[4], [5]

Technique	Features	Limitations
Numerical Technique (NR)	• Accurate values of losses can be identified for optimal solution • Can use DG for optimal placement only	• Difficult to control distribution power-system equations as an optimization model • Percentage reduction around 15-20%
Heuristic Technique (PSO)	• Simple and flexible in solving optimization problems with large-search space and discrete-properties • Can search for a near optimal DG solutions • Does not require converting t power system models into an optimization-programming models • Can handle multi-objective optimization	• Requires computational time • Percentage reduction around 25% - 48%

2.3 Discussion on Problem Formulation and Mathematical Methods

To suitable input, output parameters and OPF methods for the proposed model are identified by analyzing literature review and analyzing suitable conditions in Sri Lanka. Parameters are selected as below.

The multi-objective formulation is used to develop my model by transforming objectives into a single multi-objectives function with weights. Following single objective functions are considered to develop a techno-economical optimization model.

- Minimization of active-power losses of system
- Minimization of reactive-power losses of system
- Minimization of cost of system

Also, the following main equity and inequity constraints are considered in the modeling for proper operation.

- Power balanced equation
- Bus voltage limits
- DG type
- Power generation limits of DG

Further, type 01 and type 02 DGs are analyzed by mathematical model considering one-load level and multi-load level data.

Another important consideration is selecting suitable mathematical approaches for the hybrid model. By qualitative and quantitative analysis of the literature survey, selected methods are listed below.

- Newton Raphson Method (NR)
- Particle Swarm Optimization Method (PSO)

The design variables of my model are optimal location and the optimal size of DG.

3. THE OPTIMIZATION METHODOLOGY

3.1 Overview

A new approach is presented in this section for optimal-sizing and suitable placement of distributed generation in a distribution system by considering multi-objective optimization with selected constraints. Summary of the input, output and OPF method for the proposed model is illustrated in figure 3.1.

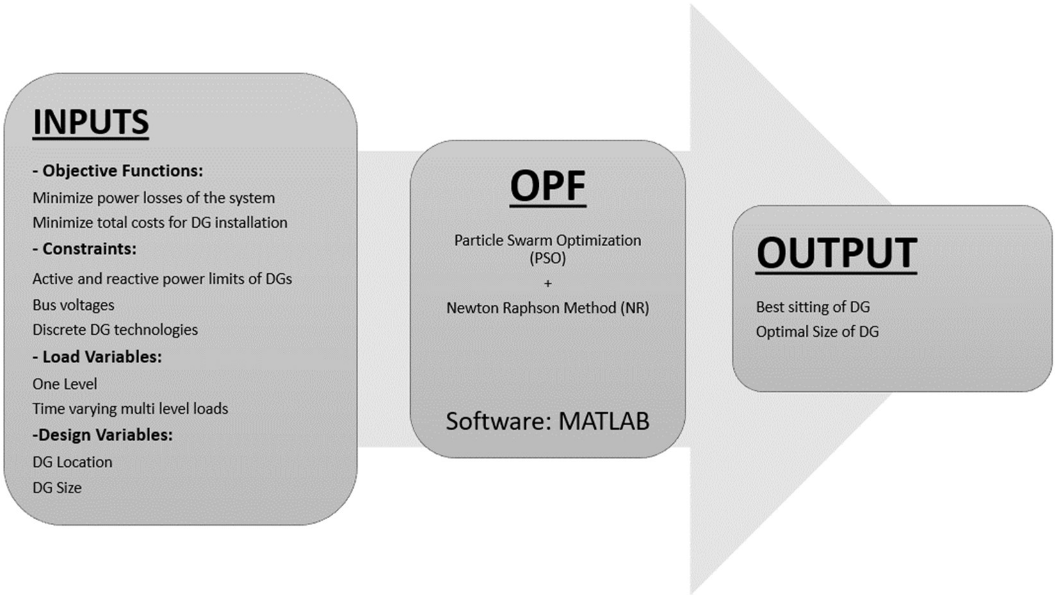


Figure 3.1: Summary of the Proposed Model

3.2 Newton Raphson Load Flow Method for Optimal DG Allocation

The 'Newton-Raphson' method is defined as an iterative-approach which is applied to solve a group of non-linear equations from 'Taylor's series expansion' and terms are finite to the 1st approximation. Origin and formulation of Newton-Raphson approach was dated back to the late 1960s from Isaac Newton and Joseph Raphson.

One of the objectives of the study is to minimize the power losses in the power system. To determine the power loss and voltage magnitude at each-bus, the Newton Raphson technique is used for load flow analysis. From this method, voltage magnitudes and angles of each bus can be identified and hence the power injections at all the buses and power flow through the system can be calculated and power losses can be obtained. The main steps of power loss calculation from the Newton-Raphson Method are described in 3.2.1 and the flowchart of the Newton-Raphson method is shown in figure 3.2.[13]

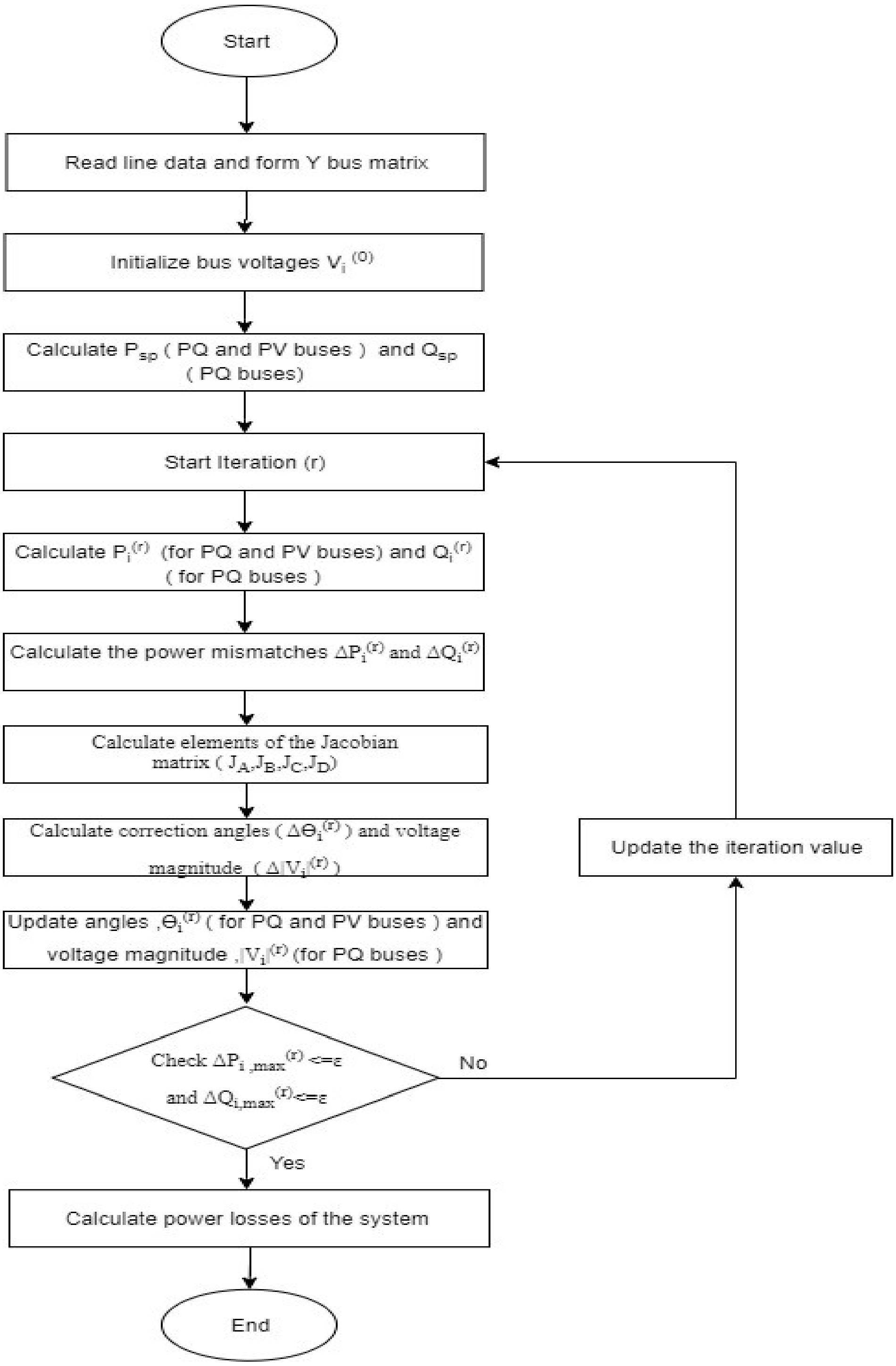


Figure 3.2: Flow Chart of Newton-Raphson Method

3.2.1 Mathematical Approach of Newton Raphson Method

Step 01: Formulate the YBUS from line resistance and reactance

Step 02: Classify the type of each bus in the power system and identify known and unknown parameters.

Table 3.1: Bus Classification for Load Flow Analysis

Classification	Known Parameters	Unknown Parameters
Slack-Bus(Swing Bus)	|V|, δ	P, Q
PV-Bus(Generator Bus)	P, |V|	Q, δ
PQ-Bus (Load Bus)	P, Q	|V|, δ

Step 03: Choose the initial values of the voltage magnitudes and angles for all buses except the slack bus

$V_i = |V_{i,sp}| \angle 0^0$ (At all PV buses)

$V_i = 1\angle 0^0$ (At all PQ buses)

Step 04: Compute P_i and Q_i for each PQ bus and P_i for each PV bus

$$P_{i,cal} = \sum_{j=1}^{N} V_i V_j (G_{ij} \cos(\theta_i - \theta_j) + B_{ij} \sin(\theta_i - \theta_j)) \quad (3\text{-}1)$$

$$Q_{i,cal} = \sum_{j=1}^{N} V_i V_j (G_{ij} \sin(\theta_i - \theta_j) - B_{ij} \cos(\theta_i - \theta_j)) \quad (3\text{-}2)$$

Here,

$P_{i,cal}$ = The real power injected at the i-thabus

$Q_{i,cal}$ = The reactive power injected at the i-th bus

V_i and V_j = The magnitude of voltage at node i and j

θ_i and θ_j = The voltage-angle at i-th bus and j-th bus respect to reference-angle

G_{ij} = The real-component or conductance of bus-admittance matrixY between node i and j

B_{ij} = The imaginary-component, acceptance of bus-admittance matrixY between node i and j

Step 05: Calculate the power mismatches

$$\Delta P_i^r = P_{i,sp}^r - P_{i,cal}^r \tag{3-3}$$

$$\Delta Q_i^r = Q_{i,sp}^r - Q_{i,cal}^r \tag{3-4}$$

Step 06: Calculate the elements in Jacobian matrix

$$J = \begin{bmatrix} \frac{\delta \Delta P}{\delta \theta} & \frac{\delta \Delta P}{\delta |V|} \\ \frac{\delta \Delta Q}{\delta \theta} & \frac{\delta \Delta Q}{\delta |V|} \end{bmatrix} \tag{3-5}$$

Step 07: Obtain the value of $\Delta\delta$ and $\Delta|V^r|$

$$\begin{bmatrix} \Delta \delta^r \\ \frac{\Delta |V^r|}{|V|} \end{bmatrix} = \left[J^r\right]^{-1} \begin{bmatrix} \Delta P^r \\ \Delta Q^r \end{bmatrix} \tag{3-6}$$

Step 08: Update magnitude and phase angle of voltage at all load buses

$$\left|V_i^{r+1}\right| = \left|V_i^r\right| + \Delta\left|V_i^r\right| \tag{3-7}$$

$$\left|\delta_i^{r+1}\right| = \left|\delta_i^r\right| + \Delta\left|\delta_i^r\right| \tag{3-8}$$

Step 09: Go to step 03 and iterate till the power mismatches are within the acceptable tolerance

$$\Delta P_i^r < \varepsilon_p$$

$$\Delta Q_i^r < \varepsilon_Q$$

3.3 Particle Swarms Optimization(PSO) Technique for Optimal DGs Sizing and Allocation

'PSO algorithm' is one of the modern heuristic algorithms in optimization and invented by 'Kennedy and Eberhart' in 1995. This algorithm is an iterative search technique based on swarm's social behavior of birds flocking and fish schooling in world to find foods and only moves in one-direction to moves for the best foods in groups of them.

In PSO, particles move throughout the search space as an objective function to find the best solution. Moment of particle-based on own experience and neighbors experience. Basic elements used in PSO are listed below.

- Particle: In technical term of each bird/fish is called as a particle/individual swarm
- Population: In the technical term of a flock of the particle (group of swarms) is called particle population.
- Search Space: A set of possible solutions for all variables of a given function is called search space. Search space is limited by the boundary condition of the variables by considering upper bound and a lower bound for each variable
- Local best: The best position of particle among its all positions visited sofar is called local best/personal best (P_{best})
- Global best: The position where the best-fitness is achieved among all particles visited sofar in the solution space is called global best(G_{best})

The main steps for the PSO-algorithm is described under 3.3.1 and a flow chart of the PSO algorithm is shown in figure 3.3. [14],[15]

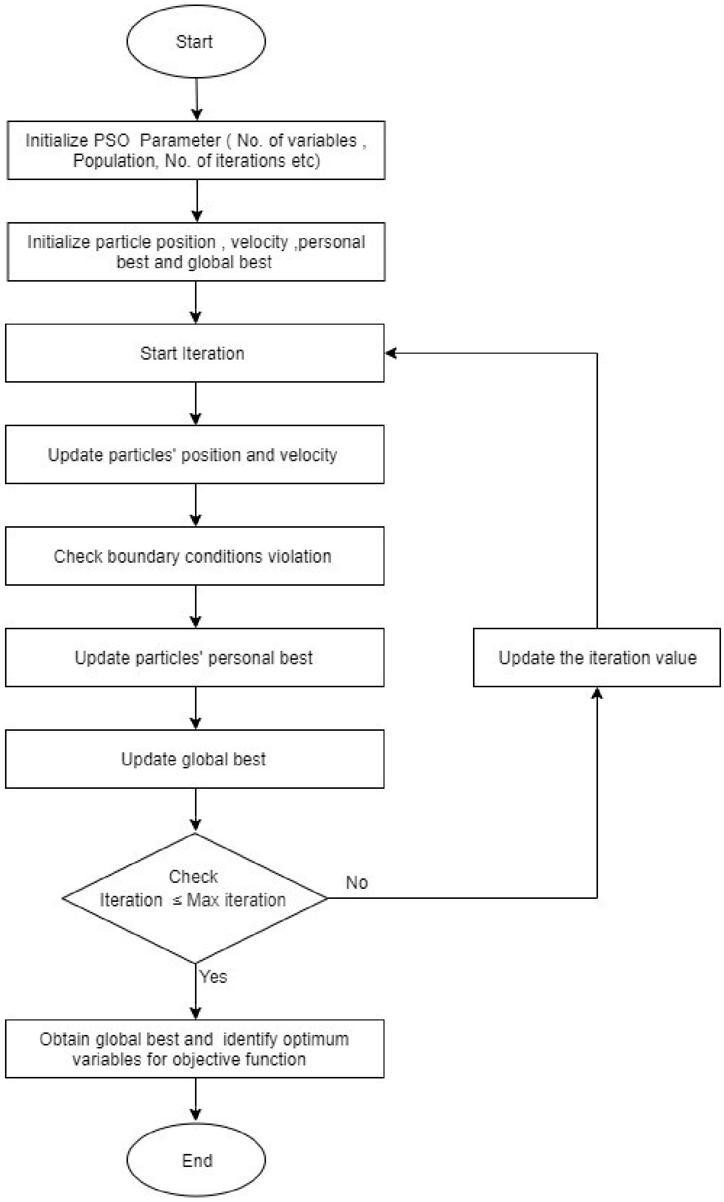


Figure 3.3 : FlowChart of PSO Method

3.3.1 Mathematical Approach of PSO

Step 01: Develop an objective function

$$f(x) = f(x_1, x_2, \ldots x_n) \tag{3-9}$$

At the beginning of PSO, the objective function is needed to identify clearly. Here, x_i represents the optimizing variables and n is the number of variables. f(x) is the objective function that needs to maximize or minimize.

Step 02: Initialize PSO Parameters

It is important to correct choice of PSO parameters for given problem; the selections have a considerable impact on PSO performance. Therefore, parameters given below are required to be initialized.

- No. of variables

A number of variables are dependent on the objective function. Also, upper and lower boundaries of variables are needed to be initialized.

- Size of Population

No. of particles in the swarm is called population size and moderate population size must be selected according to the problem because a large population may decrease the iteration number while the increasing complexity of the one iteration and small size of the population is taken more iteration to converge the problem.

- No. of iterations

A number of iteration is affected by the convergence of the problem. The small size of the iteration number may cause termination of the algorithm without acquiring better convergence and the large size iteration number increases computational time. The selection of the iteration number also depended on the nature of the problem.

- Acceleration coefficients (c_1 and c_2):

Acceleration coefficients are used to change the velocity of particles towards personal and global best together. Generally, all agents in PSO are considered to get attracted towards the average of P_{best} and G_{best} then $c_1 = c_2$.

- Inertia Weights

Inertia weight (ω) helps to develop a balanced between global-explorations, local-explorations which mean it controls the influence of the previous history of the velocities on the current one. $\omega_{\max}$ and $\omega_{\min}$ are initialized under this step and ω is calculated using the following equation for each iteration.

$$\omega = \omega_{\max} - \frac{\omega_{\max} - \omega_{\min}}{i_{\max}} \times i \qquad (3\text{-}10)$$

Here,

$\omega_{\max}$, $\omega_{\min}$: Initial and final inertia factor weight

i : Current iteration number

$i_{\max}$: Maximum iteration number

Step 03: Initialize particle position, velocity and obtain personal best and global best from objective function

Initial particle population (x_0) is predefined randomly using boundary values of variables and initial velocity (v_0) is defined by considering x_0. Initial values for P_{best} and G_{best} can be identified from x_0 and v_0.

Step 04: Start iteration

Step 05: Update position and velocity of each particle

To identify best variable values, each particle in the population tries to change its position to a better position by considering the below factors.

- The current position
- The current velocity
- The distance between current position and P_{best}
- The distance between current position and G_{best}

Equations for updated PSO velocity and position,

$$v_i^{k+1} = \omega v_i^k + c_1 r_1 (P_{best.i} - x_i^k) + c_2 r_2 (G_{best.i} - x_i^k) \tag{3-11}$$

$$x_i^{k+1} = x_i^k + v_i^{k+1} \tag{3-12}$$

Here,

c_1, c_2 : Weighting coefficients

r_1, r_2 : Randomly generating numbers from 0 to 1

ω : Weighting factor

v_i^k : Current velocity of i-th particle at k-th iteration

v_i^{k+1} : Modified velocity of particle i

x_i^k : Current position of i-th particle at k-th iteration

x_i^{k+1} : Modified position of particle i

$P_{best.i}$: Personal best of particle i

$G_{best.i}$: Global best of the group

Step 06: Check the criteria of boundary violation

Step 07: Evaluate the objective function and update P_{best} and objective value

Step 08: Update G_{best} and best objective value

Step 09: Check the stopping criteria and repeat from step 04 until the satisfaction of stopping criteria

3.4 Problem Formulation

3.4.1 Selection of Objective Functions and Constraints

To obtain a techno- economical optimal solution, the following objective functions and constraints are identified based on the Sri Lankan distribution system. [16],[17],[18]

Objective 01: Minimize Sum of Active Power Losses (F_1)

$$P_L = \sum_{k=1}^{N} G_{kj}\left(V_k^2 + V_j^2 - 2V_kV_j\cos\left(\theta_k - \theta_j\right)\right) \tag{3-13}$$

Objective 02: Minimize Sum of Reactive Power Losses (F_2)

$$Q_L = \sum_{k=1}^{N} -B_{kj}\left(V_k^2 + V_j^2 - 2V_kV_j\cos\left(\theta_k - \theta_j\right)\right) \tag{3-14}$$

Objective 03: Minimize Total Costs in Active-Power Produced by DG Unit(F_3)

$$C = C_{DG,i} + C_{substation} \tag{3-15}$$
$$C_{DG,i} = 1.3 \times Fixed\ \text{Costs} + Variable\ \text{Costs}$$
$$Fixed\ \text{Costs} = Capital\,\text{Costs} \times Maximum\ Capacity\ of\ DG$$
$$Variable\ \text{Cost} = (Fuel\text{Cost} + Operation\ \&\ Maintenance\ \text{Cost}) \times P_{DG}$$
$$C_{substation} = \text{Price} \times P_{substation}$$

Constraints:

There are two types of constraints that are selected for DG modeling which is called Equality constraints and Inequality constraint.

- Equity Constraints

Power balance constraint of the power flow equation is considered as the equity constraint of the modeling.

$$P_{Substation} + \sum_{k=1}^{N_{DG}} P_{DG} = P_{Demand} + P_{Losses} \tag{3-16}$$
$$Q_{Substation} + \sum_{k=1}^{N_{DG}} Q_{DG} = Q_{Demand} + Q_{Losses} \tag{3-17}$$

- Inequity Constraints

Voltage limit of bus and power generation limits of DG are considered in DG modeling by considering the proper operation of the power distribution network.

Voltage limit of bus:

$$V_{\min} \le V_i \le V_{\max}$$

Power generation limits of DGs:

$$P_{DG}^{\min} \le P_{DGi} \le P_{DG}^{\max}$$
$$Q_{DG}^{\min} \le Q_{DGi} \le Q_{DG}^{\max}$$

3.4.2 Multi- Objective Planning

The weighting factor method is taken to convert above multi-objectives into a single multi-objectives problem using linear summation of the factors. [1]

Objective Function= Minimize { (Active power loss) , (Reactive power loss), (DG cost) }

Objective Function = Minimize { (W_1 * F_1) + (W_2 * F_2) + (W_3 * F_3)}

Here, W_1, W_2 and W_3 are weighting factors. The values of the weighting-factors are chosen based on importance level of each objective. In order to get a desirable set of non-dominated solutions for DG variables, the proposed algorithm is run multiple times with different weighting factors. For a specific set of weighting values, only the optimal solution for DG is obtained. When selecting the values of weighting factors, the following two considerations are required.

$$W_1 + W_2 + W_3 = 1$$

$$0 \leq W_i \leq 1 \qquad ;i = 1,2,3$$

Each case study of the proposed model, following scenarios for objective functions used by considering different weighting factor values. Scenarios at type 01 are considered only the active power injected DGs and scenarios at type 02 are considered both active and reactive power injected DGs.

Type 01:

Scenario #1 : Base or reference scenario (DGs are not integrated to the system)

Scenario #2 : $W_1 = 0.7$, $W_3 = 0.3$

Scenario #3 : $W_1 = 0.5$, $W_3 = 0.5$

Scenario #4 : $W_1 = 0.3$, $W_3 = 0.7$

Scenario #5 : $W_1 = 1$, $W_3 = 0$

Scenario #6 : $W_1 = 0$, $W_3 = 1$

Type 02:

Scenario #1 : Base or reference scenario (DGs are not integrated to the system)

Scenario #2 : $W_1 = 0.5$, $W_2 = 0.3$ and $W_3 = 0.2$

Scenario #3 : $W_1 = 0.4$, $W_2 = 0.4$ and $W_3 = 0.2$

Scenario #4 : $W_1 = 0.3$, $W_2 = 0.3$ and $W_3 = 0.4$

Scenario #5 : $W_1 = 1$, $W_2 = 0$ and $W_3 = 0$

Scenario #6 : $W_1 = 0$, $W_2 = 1$ and $W_3 = 0$

Scenario #7 : $W_1 = 0$, $W_2 = 0$ and $W_3 = 1$

3.5 The Proposed Algorithm

The flowchart for the proposed mathematical model is shown in figure 3.4. It is combined with PSO and NR methods to determine optimal size and optimal location of DGs.

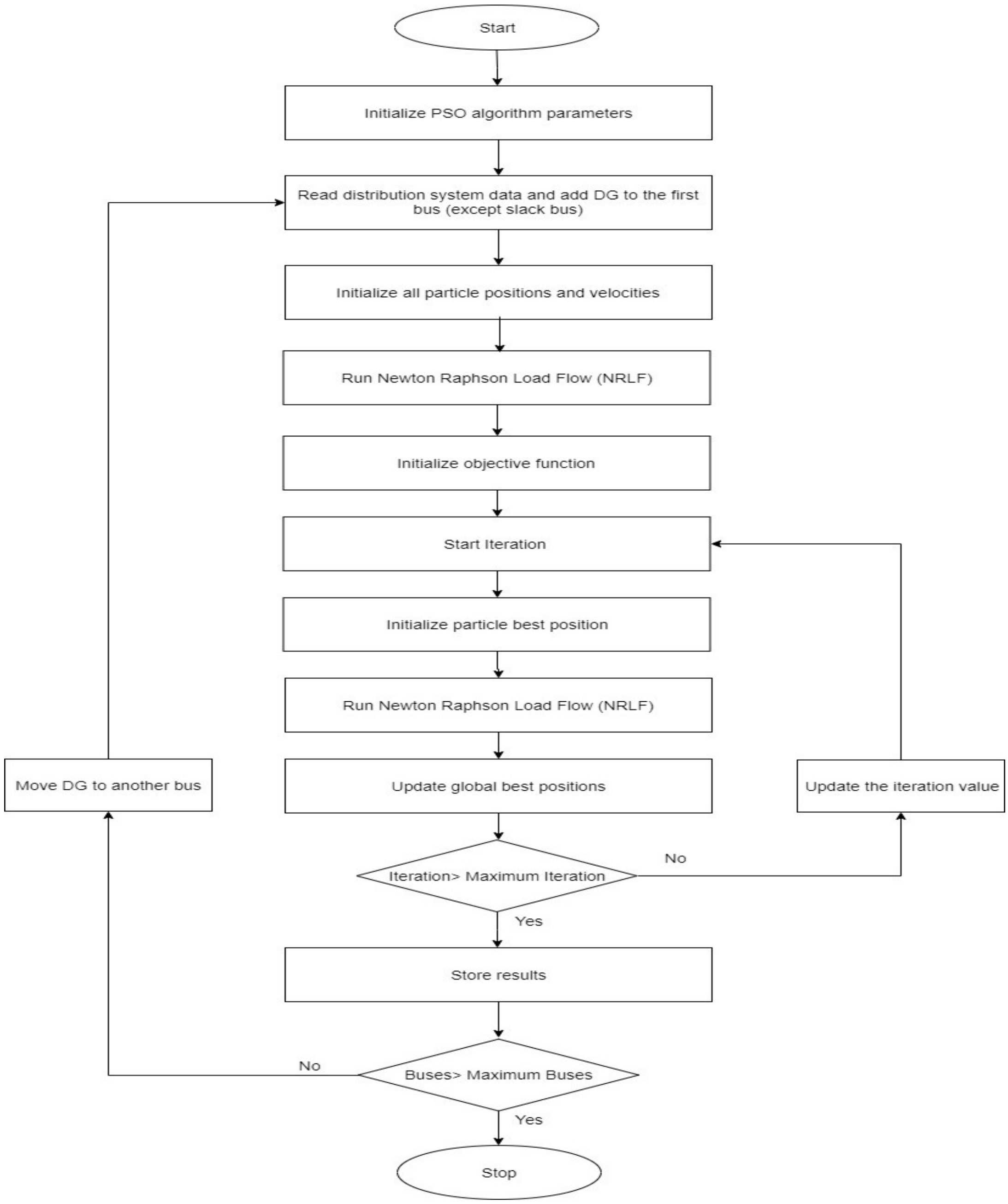


Figure 3.4: Proposed Mathematical Model

3.5.1 Initial Parameters for the proposed Algorithm

Initial parameters for the proposed mathematical model are taken as below.

- No. of variables

The proposed model is applied by considering two types of DGs in the distribution network. Therefore, two numbers of variables are considered throughout the study such as active-power of DG and reactive-power of DG.

- Population size

According to the nature of the problem, the population is taken as 250.

- No. of iterations

The number of iteration is also depended on the nature of the problem. Therefore, it is selected as 10.

- Acceleration coefficients (c_1 and c_2):

Based on the literature of PSO [19], it is selected $c_1 = c_2 = 2$.

- Inertia Weights

Based on the literature of PSO [19],

ω_{max} = 0.9 and ω_{min} =0.4

3.6 Distributed Generator Model

Before applying DG type to the proposed model, it is necessary to identify hours of availability and percentage of the output of DG. Nature of main DG types which can apply for the Sri Lankan distribution systems are described below and solar PV and biomass are selected in my modeling.

3.6.1 Solar Power Generation

Solar PV is a fast-growing renewable-energy technologies in Sri Lanka and new solar energy generation projects are increasing day- by day. Therefore, solar PV generation is selected to apply and validate my proposed mathematical model.

Solar is a non-dispatchable generation and the probabilistic nature of solar irradiance is identified from 'beta-probability density function' from past solar data. The typical output variation of solar PV is illustrated in figure 3.5 and the output is mainly dependent on the solar irradiance.

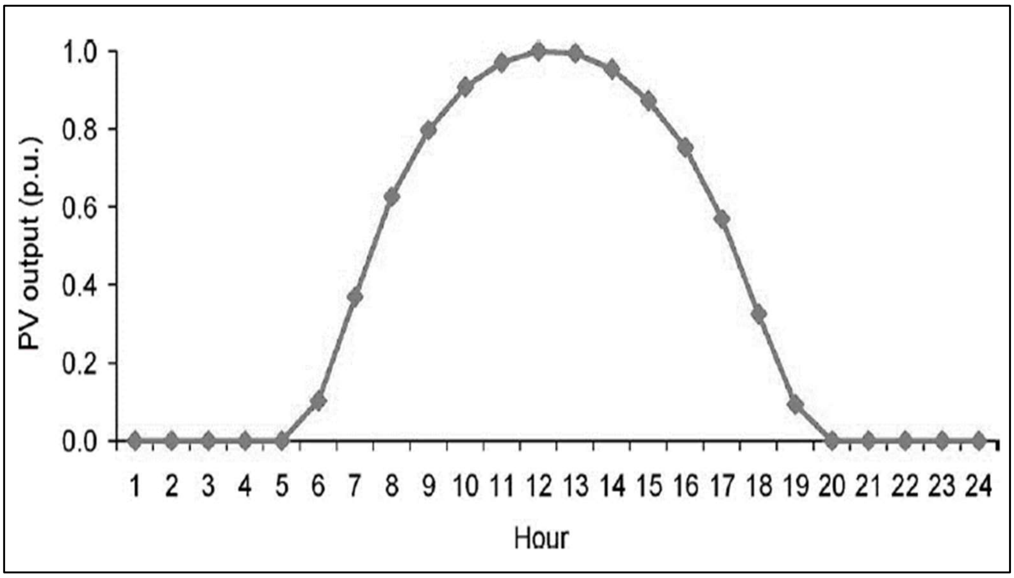


Figure 3.5: Solar Output Variation [20]

3.6.2 Wind Power Generation

Wind power is another technology of DG which is commonly available in Sri Lanka. Wind power production is mainly dependent on wind speed at plant and kinetic energy of wind is converted into electrical energy using wind turbines. Wind power generation can be obtained throughout a day and it varies with speed. As an example, typical wind speed variation Kalpitiya Sri Lanka is shown in figure 3.6.

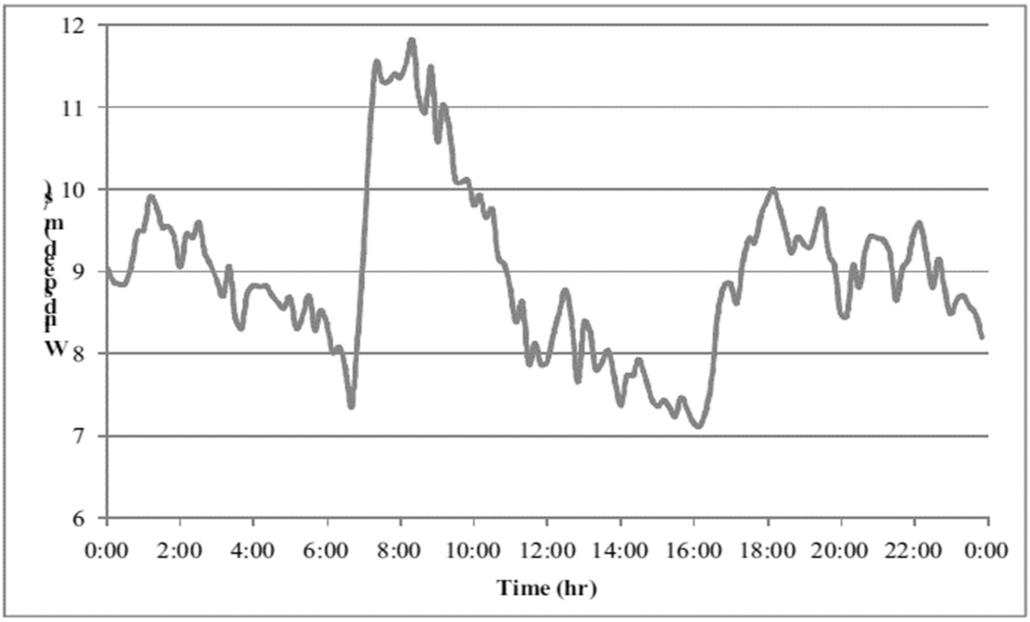


Figure 3.6: Wind Speed Variation [21]

3.6.3 Biomass Power Generation

Biomass is another type of DG that is available in Sri Lanka. According to the generation capacity of biomass generator, constant power output can be obtained throughout a day and an example of the power output variation against time is shown in figure 3.7 .

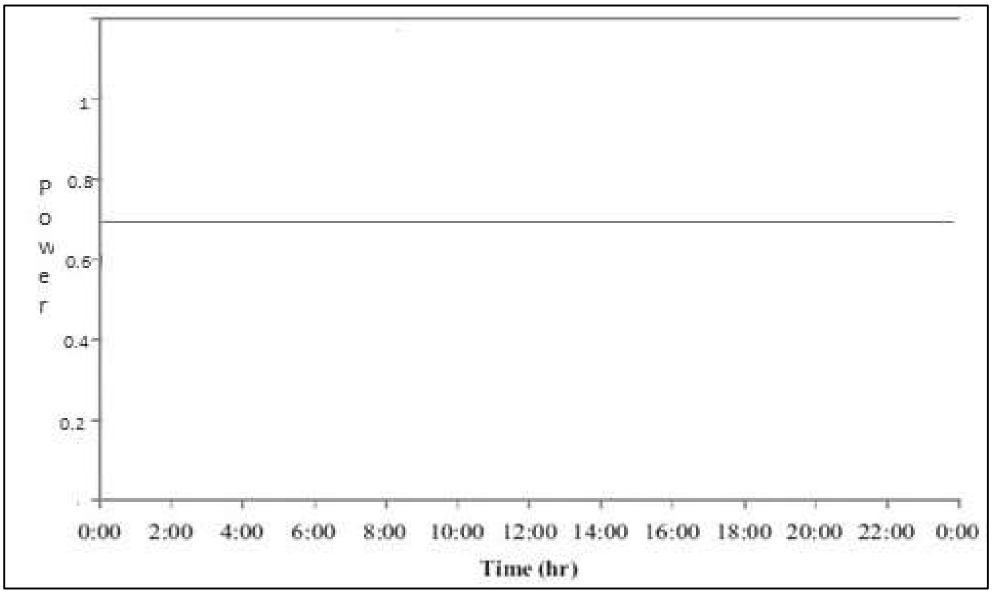


Figure 3.7 : Power Output Variation of Biomass DG

3.7 Load Model

Loads in the distribution network vary throughout the day due to different applications of users. Average load values for following different time intervals are considered as a load model to apply the proposed algorithm.

- 12.00 midnight - 3.00 am
- 3.00 am – 6.00 am
- 6.00 am – 9.00 am
- 9.00 am – 12.00 noon
- 12.00 noon – 3.00 pm
- 3.00 pm – 6.00 pm
- 6.00 pm – 9.00 pm
- 9.00 pm – 12.00 midnight

4. MODELING AND ANALYSIS BY TEST-BUS SYSTEM

4.1 IEEE-30 Test-Bus System

The IEEE-30 bus system is selected to evaluate and validate the proposed algorithm. The basic description for IEEE-30 bus system is listed below.

Table 4.1 : IEEE-30 Bus System

Item	Details
Buses	30
Lines	40
Generator feeders	6
Transformers	5
Slack-Bus	1
PV-Buses	2, 5, ,8,11,13
PQ-Buses	3,4,6,7,9,10,12,14,15,16,17,18,19,20,21,22,23,24,25, 26,27,28, 29, 30

The line characteristics of 30-bus system are illustrated in AppendixA.1. And the generation and load data of the test bus system is found in AppendixA.2.

4.1.1 Constraints Data

- According to the distribution code of Sri Lanka, voltage limits of each bus is considered as ±6%.

$$0.94\ \text{p.u.} \leq V_i \leq 1.06\ p.u.$$

- 'Electric-Power Research Institute' defines a distributed generation as generation size from few kilowatts upto 50MW. For simulation and evaluation purposes, DG sizes are selected below by considering 0.85 lagging p.f. and 0.95 leading p.f.

$$5\ MW \leq P_{DGi} \leq 50\ MW$$
$$-3.1 \leq Q_{DGi} \leq 16.4$$

4.1.2 Cost Characteristics for Test Bus System Modeling

Cost characteristics used for modeling of IEEE-30 bus system are shown in table4.2.

Table 4.2: Cost Characteristics for Modeling [17], [18]

DG Type	Capital Cost ($/kW)	O&M Cost ($/kWh)	Fuel Cost ($/kWh)
PV	3985	0.01207	-
WT	1822	0.00952	-
GT	1224	0.06481	0.0667

4.2 Evaluation of Weighting Factors from IEEE 30 Bus System

Minimization on active and reactive power losses and minimization of cost are used as objective functions to identify a techno-economical solution for placement and sizing of DGs. The most suitable weighting-factors for the proposed multi-objective algorithm are selected by evaluating different weighting factors in the IEEE-30 bus system with an average load level model. Following two types are considered to evaluate weighting factors and validate the proposed algorithm.

- Type 01 : DGs capable of injecting active power only
- Type 02 : DGs capable of injecting real power and reactive power

4.2.1 Modeling and Simulation of DG- Type 1

Six numbers of scenarios are considered and simulated as below. The considered scenarios are,

- Scenario #1 : Base or reference scenario (DGs are not integrated to the system)
- Scenario #2 : $W_1 = 0.7$, $W_3 = 0.3$
- Scenario #3 : $W_1 = 0.5$, $W_3 = 0.5$
- Scenario #4 : $W_1 = 0.3$, $W_3 = 0.7$
- Scenario #5 : $W_1 = 1$, $W_3 = 0$
- Scenario #6 : $W_1 = 0$, $W_3 = 1$

The observed power loss, DG cost, optimal DG size and voltage variation while placing with optimal DG are shown in figure4.1, figure4.2, figure4.3 and figure4.4. When investigating graphs, the variations are mainly dependent on weighting factors. The best characteristics of loss minimization are obtained in scenario 5 and the best characteristics of cost minimization are obtained in scenario 6. And highest DG Size variation occurred in scenario 5 and the lowest DG size variation occurred in scenario 6.

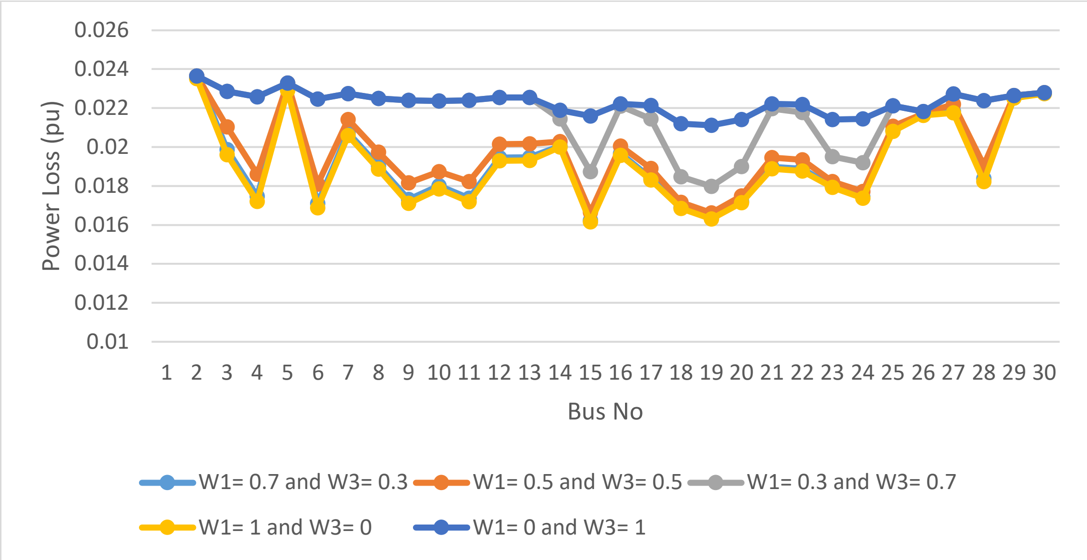


Figure 4.1: Power Loss Variation with Different Weighting Factors- Type 1 DG

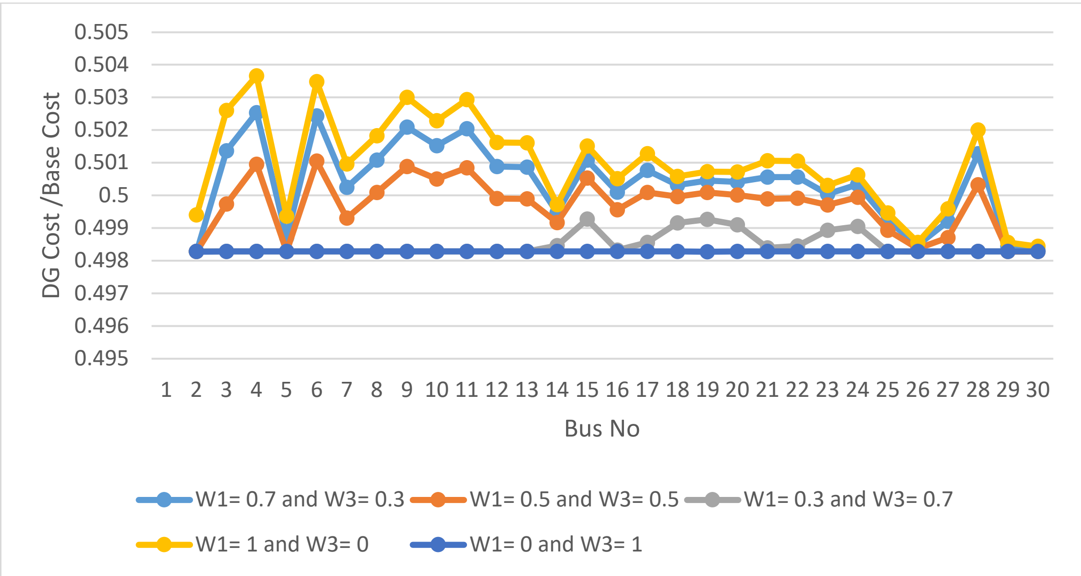


Figure 4.2: DG Cost Variation with Different Weighting Factors- Type 1 DG

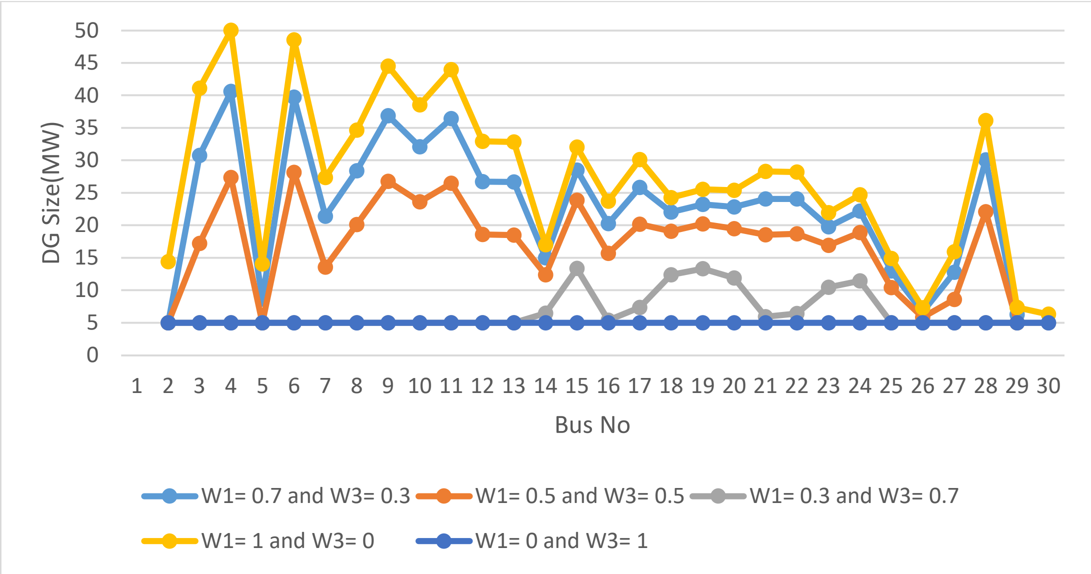


Figure 4.3: Optimal DG Size Variation with Different Weighting Factors- Type 1 DG

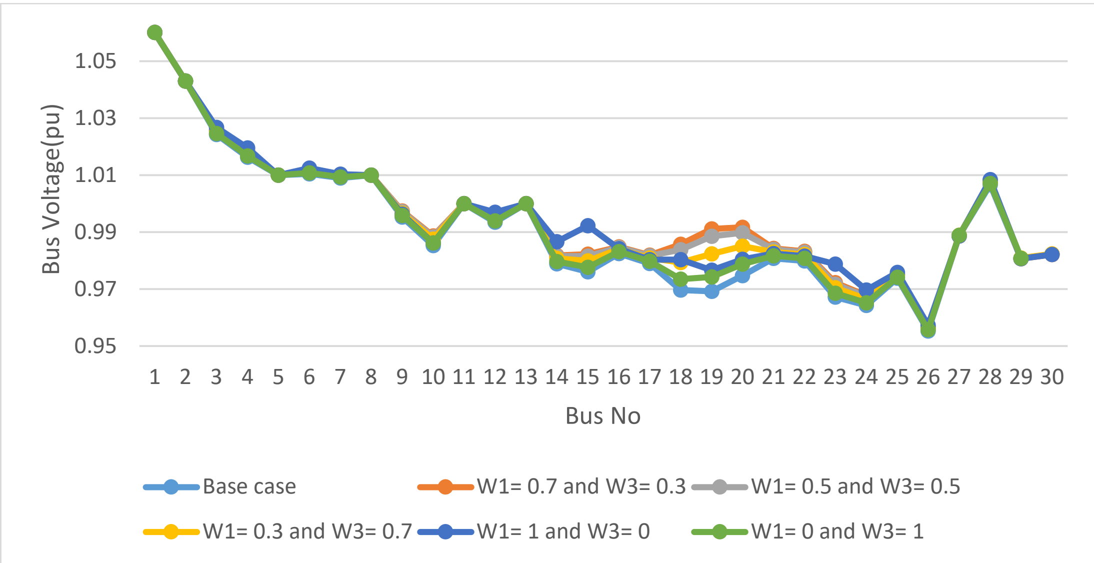


Figure 4.4: Voltage Variation with Different Weighting Factors- Type 1 DG

Voltage profile of the modified IEEE-30 test-bus system before and after deployment of optimal DG for different weighting factor values are shown in table 4.3 .

Table 4.3 : Observed Voltage-Profile of Bus Nodes at Simulation -Type 1 DG

Bus No	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
1	1.0600	1.0600	1.0600	1.0600	1.0600	1.0600
2	1.0430	1.0430	1.0430	1.0430	1.0430	1.0430
3	1.0242	1.0259	1.0257	1.0252	1.0267	1.0246
4	1.0162	1.0184	1.0181	1.0175	1.0195	1.0167
5	1.0100	1.0100	1.0100	1.0100	1.0100	1.0100
6	1.0104	1.0121	1.0119	1.0114	1.0124	1.0108
7	1.0090	1.0101	1.0100	1.0097	1.0103	1.0093
8	1.0100	1.0100	1.0100	1.0100	1.0100	1.0100
9	0.9952	0.9974	0.9972	0.9966	0.9963	0.9958
10	0.9853	0.9886	0.9883	0.9875	0.9862	0.9862
11	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
12	0.9935	0.9949	0.9948	0.9944	0.9969	0.9939
13	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
14	0.9789	0.9818	0.9815	0.9808	0.9866	0.9797
15	0.9761	0.9822	0.9815	0.9799	0.9922	0.9776
16	0.9824	0.9848	0.9846	0.9840	0.9841	0.9831
17	0.9790	0.9819	0.9817	0.9809	0.9803	0.9798
18	0.9697	0.9857	0.9838	0.9793	0.9803	0.9735
19	0.9692	0.9911	0.9885	0.9823	0.9766	0.9743
20	0.9747	0.9917	0.9897	0.9850	0.9804	0.9787
21	0.9808	0.9842	0.9839	0.9830	0.9824	0.9817
22	0.9799	0.9832	0.9829	0.9821	0.9816	0.9808
23	0.9672	0.9722	0.9717	0.9704	0.9787	0.9685
24	0.9643	0.9677	0.9674	0.9665	0.9697	0.9652
25	0.9738	0.9751	0.9750	0.9747	0.9758	0.9742
26	0.9553	0.9566	0.9565	0.9563	0.9573	0.9557
27	0.9887	0.9886	0.9887	0.9888	0.9886	0.9888
28	1.0066	1.0081	1.0079	1.0075	1.0084	1.0070
29	0.9807	0.9807	0.9808	0.9809	0.9807	0.9808
30	0.9822	0.9821	0.9822	0.9823	0.9821	0.9822

Summary of the results for different weighting factors are shown in table 4.4 and table 4.5.

Table 4.4 : Summary ofthe Results -Type 01 DG

Scenario	Node	OF value	Power Loss (p.u.)	DG Cost (p.u.)	Optimal DG Size (MW)
Scenario 1	-	-	0.023831	1.000000	-
Scenario 2	19	0.161588	0.016358	0.500455	23.230
Scenario 3	19	0.258355	0.016617	0.500092	20.191
Scenario 4	19	0.354884	0.017983	0.499269	13.307
Scenario 5	15	0.016155	0.016155	0.501507	32.017
Scenario 6	19	0.498280	0.021122	0.498280	5.000

Table 4.5: Comparison of the Results -Type 1 DG

Scenario	Loss Reduction %	Cost Reduction %	Minimum Voltage (p.u.)
Scenario 1 (Base Case)			0.9553
Scenario 2 (W_1= 0.7 and W_3= 0.3)	31.36	49.95	0.9566
Scenario 3 (W_1= 0.5 and W_3= 0.5)	30.07	49.96	0.9565
Scenario 4 (W_1= 0.3 and W_3= 0.7)	24.54	50.07	0.9563
Scenario 5 (W_1= 1 and W_3= 0)	32.11	47.05	0.9573
Scenario 6 (W_1= 0 and W_3= 1)	11.37	50.17	0.9557

Graphical representation of the above results is shown in figure 4.5.

Figure 4.5: Summary of the Results- Type 1 DG

By evaluating the summary of the results in table 4.5 and figure4.5, optimal DG size and location are identified. The highest power loss reduction is 32.11% at scenario 5 and the highest cost reduction is 50.17% at scenario 6. Scenario 2, scenario 3, scenario 4 and scenario 6 have the same optimal DG location with different sizes.

In regard to the techno-economical optimized solution, scenario 2 is selected as the optimal solution for type 01 DGs installation. Therefore, an optimal of 23.23 MW DG is proposed to bus no 19 with 31.56% power loss reduction and 49.95% cost reduction. Further, W_1= 0.7 and W_3= 0.3 are selected as weighting factors for active power loss reduction and cost reduction for type 01 DGs (DGs capable of injecting active-power only) modeling in real distribution feeders.

4.2.2 Modeling and Simulation of DG- Type 2

Seven numbers of scenarios are considered and simulated as below. The considered scenarios are,

- Scenario #1 : Base or reference scenario (DGs are not integrated to the system)
- Scenario #2 : W_1= 0.5, W_2= 0.3 and W_3= 0.2
- Scenario #3 : W_1= 0.4, W_2= 0.4 and W_3= 0.2
- Scenario #4 : W_1= 0.3, W_2= 0.3 and W_3= 0.4
- Scenario #5 : W_1= 1, W_2= 0 and W_3= 0
- Scenario #6 : W_1= 0, W_2= 1 and W_3= 0
- Scenario #7 : W_1= 0, W_2= 0 and W_3= 1

A DG which can inject both active and reactive power is identified as “Type 2” DG. By considering different weighting factors, active-power loss variations of the test-bus system, reactive-power loss variations, DG cost variation, Optimal DG active power variation, optimal DG reactive power variation and voltage variation are illustrated in figure 4.6, figure 4.7, figure 4.8, figure 4.9, figure 4.10 and figure 4.11 respectively.

The variations of graphs are dependent on different weighting factors. The best characteristics of active-power loss minimization are shown in scenario 5. And best characteristics of reactive- power loss minimization are shown in scenario 6. Also, the best characteristics of DG cost minimization are shown in scenario 7. DG sizes and bus voltages are changed with respect to different objective functions.

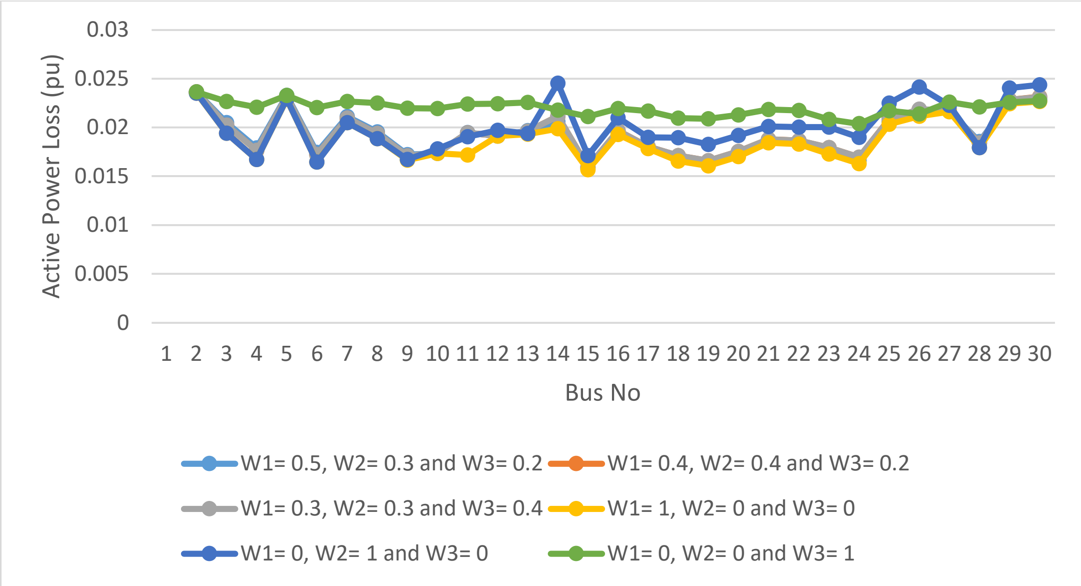


Figure 4.6: Active-Power Loss Variations with Different Weighting Factors-Type 2 DG

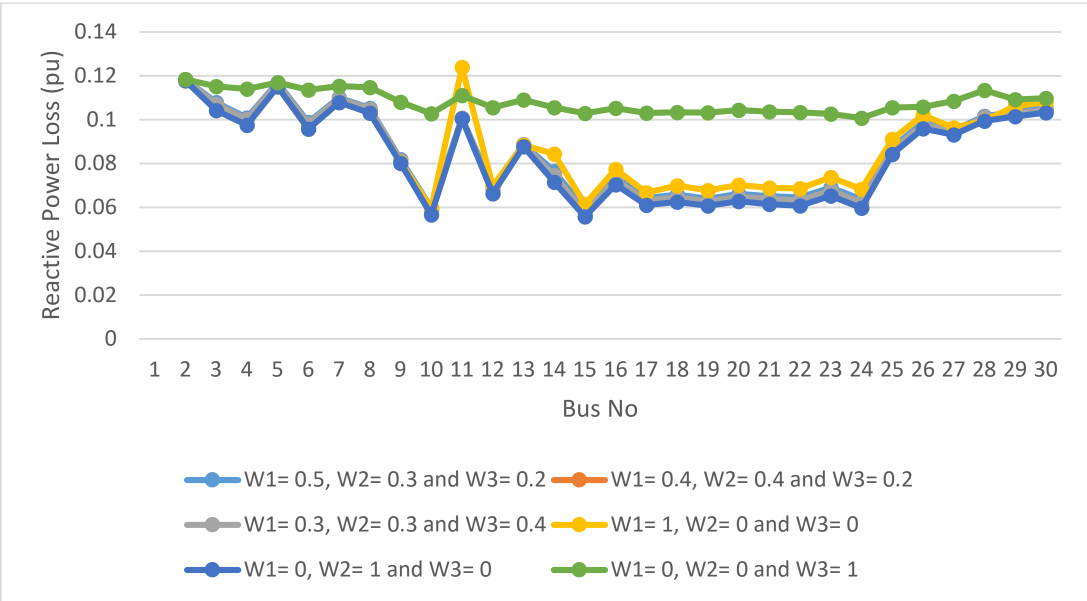


Figure 4.7: Reactive-Power Loss Variation with Different Weighting Factors- Type 2 DG

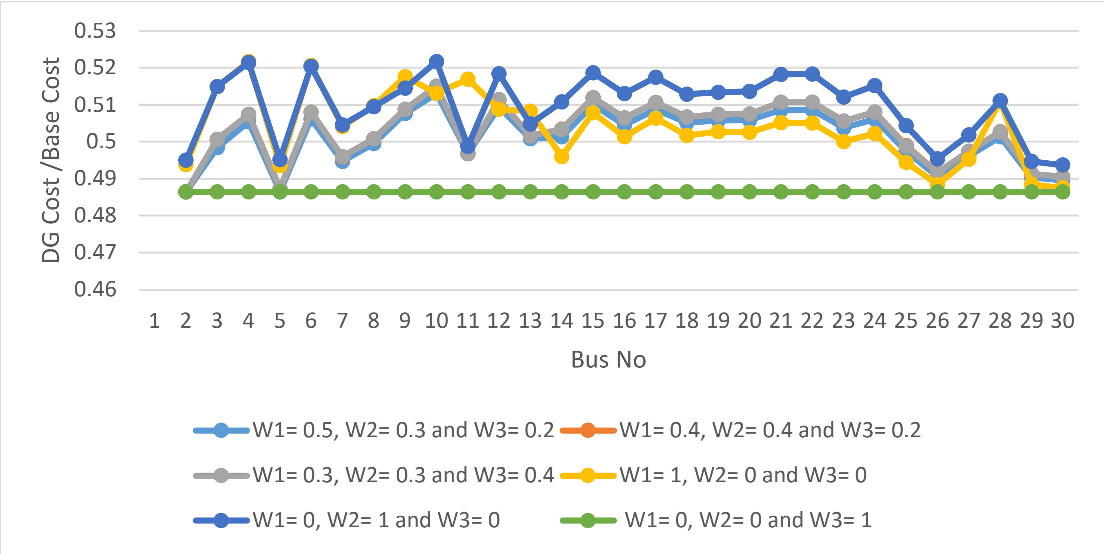


Figure 4.8: DG Cost Variation with Different Weighting Factors- Type 2 DG

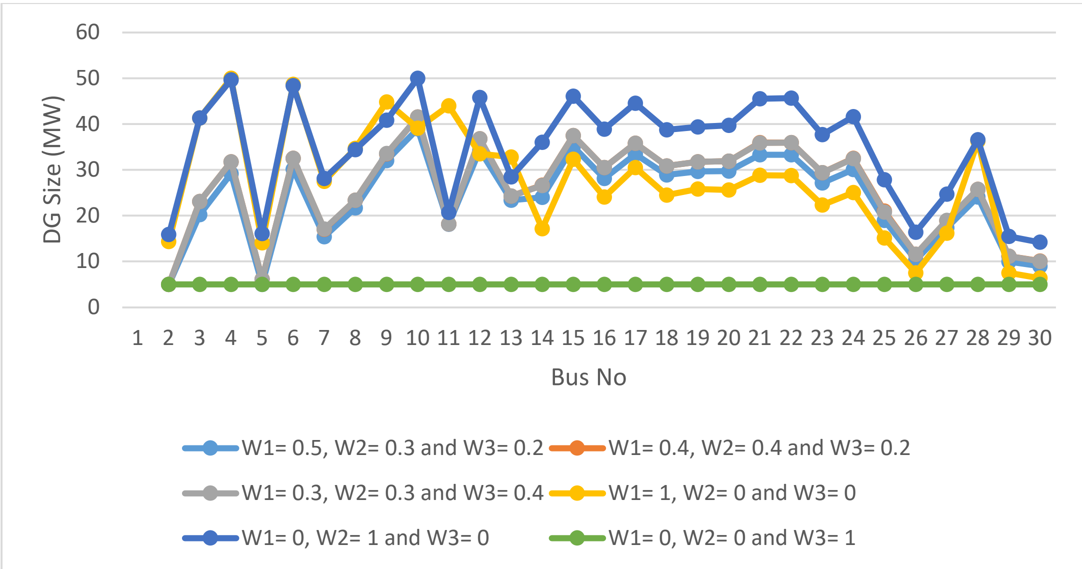


Figure 4.9: Optimal DG Size (MW) Variation with Different Weighting Factors- Type 2 DG

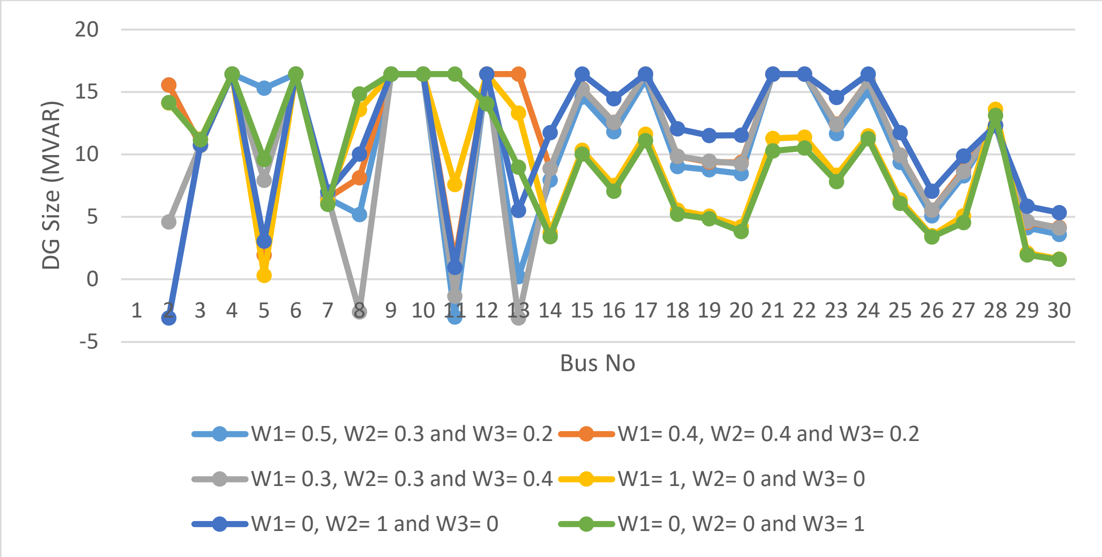


Figure 4.10: Optimal DG Size (MVAR) Variation with Different Weighting Factors- Type 2 DG

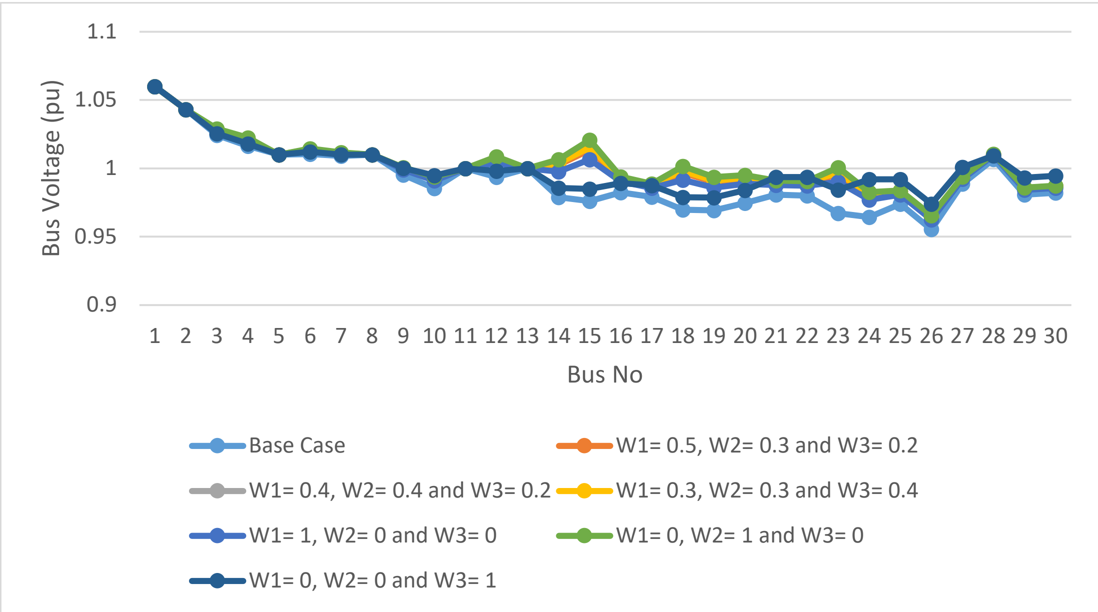


Figure 4.11: Voltage Variation with Different Weighting Factors- Type 2 DG

The voltage profile of the modified IEEE-30 test bus system before and after deployment of optimal DGs for type 2 DG installation at different weighting factor values are shown in table 4.6.

Table 4.6: Observed Voltage Profile of Bus Nodes at Simulation -Type 2 DG

Bus No	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
1	1.0600	1.0600	1.0600	1.0600	1.0600	1.0600	1.0600
2	1.0430	1.0430	1.0430	1.0430	1.0430	1.0430	1.0430
3	1.0242	1.0282	1.0284	1.0284	1.0277	1.0290	1.0255
4	1.0162	1.0214	1.0217	1.0217	1.0207	1.0225	1.0179
5	1.0100	1.0100	1.0100	1.0100	1.0100	1.0100	1.0100
6	1.0104	1.0137	1.0139	1.0139	1.0132	1.0144	1.0120
7	1.0090	1.0111	1.0112	1.0112	1.0108	1.0116	1.0100
8	1.0100	1.0100	1.0100	1.0100	1.0100	1.0100	1.0100
9	0.9952	1.0001	1.0003	1.0003	0.9990	1.0006	1.0002
10	0.9853	0.9931	0.9934	0.9934	0.9911	0.9938	0.9947
11	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
12	0.9935	1.0067	1.0073	1.0073	1.0038	1.0085	0.9980
13	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
14	0.9789	1.0025	1.0036	1.0036	0.9976	1.0064	0.9856
15	0.9761	1.0135	1.0154	1.0154	1.0065	1.0207	0.9850
16	0.9824	0.9927	0.9931	0.9931	0.9902	0.9938	0.9891
17	0.9790	0.9878	0.9881	0.9881	0.9856	0.9887	0.9875
18	0.9697	0.9967	0.9980	0.9980	0.9915	1.0015	0.9789
19	0.9692	0.9901	0.9911	0.9911	0.9859	0.9936	0.9785
20	0.9747	0.9923	0.9931	0.9931	0.9886	0.9950	0.9840
21	0.9808	0.9900	0.9903	0.9903	0.9878	0.9910	0.9935
22	0.9799	0.9894	0.9898	0.9898	0.9872	0.9905	0.9936
23	0.9672	0.9954	0.9968	0.9968	0.9900	1.0005	0.9843
24	0.9643	0.9801	0.9809	0.9808	0.9769	0.9826	0.9920
25	0.9738	0.9828	0.9832	0.9832	0.9807	0.9838	0.9920
26	0.9553	0.9645	0.9649	0.9649	0.9624	0.9655	0.9739
27	0.9887	0.9935	0.9936	0.9936	0.9921	0.9937	1.0008
28	1.0066	1.0099	1.0100	1.0100	1.0094	1.0105	1.0092
29	0.9807	0.9856	0.9857	0.9857	0.9842	0.9858	0.9930
30	0.9822	0.9870	0.9871	0.9871	0.9856	0.9872	0.9944

Summary of the results for type 2 DG at different weighting factors is shown in table 4.7 and table 4.8. For better comparison, a graphical representation of the calculated results is shown in figure 4.12.

Table 4.7: Summary of the Results -Type 2 DG

Scenario	Node	OF value	Active power loss (p.u.)	Reactive power Loss (p.u.)	DG Cost (p.u.)	Optimal DG Size (MW)	Optimal DG Size (MVAR)
Scenario 1			0.023831	0.119065	1.000000		
Scenario 2	15	0.127615	0.015810	0.059039	0.509993	35.092	14.588
Scenario 3	15	0.131861	0.015962	0.057761	0.511862	37.477	15.240
Scenario 4	15	0.131862	0.015959	0.057777	0.511836	37.444	15.229
Scenario 5	15	0.015683	0.015683	0.061377	0.507807	32.300	10.328
Scenario 6	15	0.055761	0.017121	0.055761	0.518616	46.096	16.434
Scenario 7	24	0.486453	0.020385	0.100717	0.486454	5.000	11.248

Table 4.8: Comparison of the Results -Type 2 DG

Scenario	Active power loss Reduction %	Reactive power loss Reduction %	Cost Reduction %	Minimum Voltage (p.u.)
Scenario 1 (Base Case)				0.9553
Scenario 2 (W_1= 0.5, W_2= 0.3 and W_3 = 0.2)	33.96	50.97	49.09	0.9645
Scenario 3 (W_1= 0.4,W_2= 0.4 and W_3 = 0.2)	33.02	51.09	48.61	0.9649
Scenario 4 (W_1= 0.3,W_2= 0.3 and W_3 = 0.4)	33.03	51.17	48.62	0.9649
Scenario 5 (W_1= 1, W_2= 0 and W_3 = 0)	34.19	48.45	49.12	0.9624
Scenario 6 (W_1= 0, W_2= 1 and W_3 = 0)	28.15	53.17	48.14	0.9655
Scenario 7 (W_1= 0, W_2= 0 and W_3 = 1)	14.46	15.41	51.35	0.9739

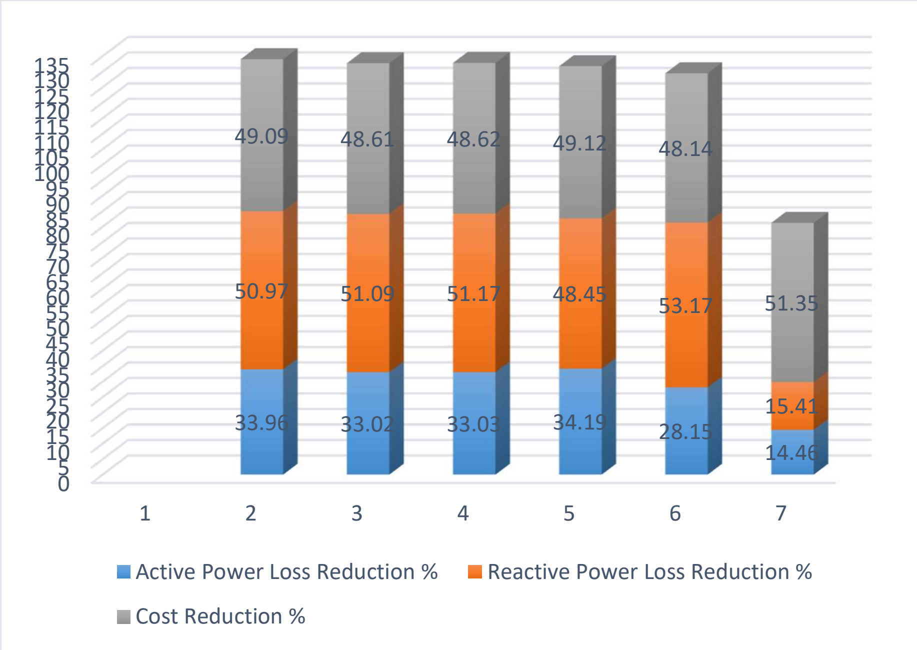


Figure 4.12: Summary of the Results- Type 2 DG

When analyzing the observed results, the maximum percentage of active power loss reduction is 34.19% at scenario 5 and the maximum percentage of reactive power loss reduction is 53.17% at scenario 6. Also, the maximum percentage of cost reduction is obtained as 51.35% in scenario 7. Bus no 15 is selected as the optimal DG location in scenario 2 to scenario 6 and bus no 24 is the DG location for scenario 7.

The results in table 4.8 and figure 4.15 are compared with each scenario to get the techno-economical solution for type 2 DGs installation. Scenario 2 is selected as the optimal solution for type 2 DG. Therefore, 35.09 MW and 14.59 MVVAR size of DG is proposed to be integrated at bus 15 with 33.96% of active power loss reduction, 50.97% of reactive power loss reduction and 49.09% of cost reduction.

Further, $W_1 = 0.5$, $W_2 = 0.3$ and $W_3 = 0.2$ are selected as weighting factors for active power loss reduction, reactive power loss reduction and cost reduction for type 2 DG (DGs capable of injecting active and reactive powers) modeling in real distribution feeders.

4.3 Validation and Analysis of Test Bus System Results

4.3.1 Validation of the Proposed Algorithm by Test Bus System Results

It is necessary to validate the proposed algorithm before applying it to the practical situation. Validations of the proposed model is done in two ways by applying observed results in table 4.9.

- Validate PSO Optimization
- Validate Power Flow Results

Table 4.9: Optimal DG Results in IEEE 30 Bus System

DG type	Optimal DG Location	Optimal DG Size	
		MW	MVAR
Type 01	Bus 19	23.23	-
Type 02	Bus 15	35.09	14.58

<u>Validate PSO Optimization</u>

Optimal results for DG planning are identified by selecting the minimum value of objective function in PSO optimization algorithm. The below steps are followed to validate that criterion of PSO.

Step 01: Randomly select different DG sizes from a given range

Step 02: Identify objective function values with respect to selected DG sizes

Step 03: Plot the graphs and observe results

The plotted graphs to node 19 and node 15 with objective function values of type 1 DGs and type 2 DGs are illustrated in figure 4.13 and figure 4.14. According to the graphs, the minimum values of objective functions are recognized as selected output from the proposed model. Therefore, the PSO optimization part of the proposed model can be validated.

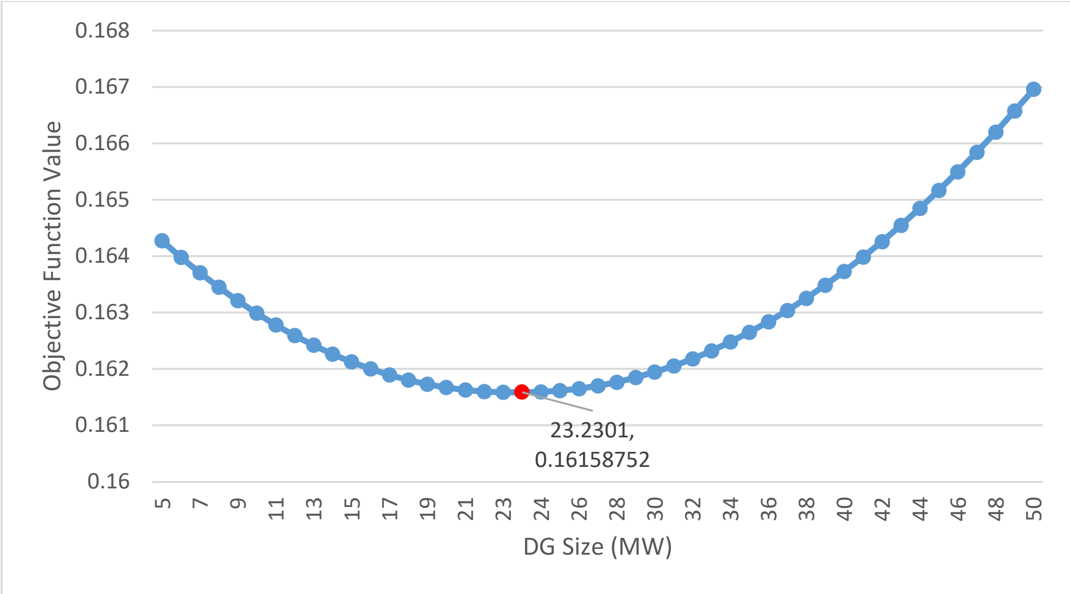


Figure 4.13: Different Objective Function Values for Bus 19- DG Type 01

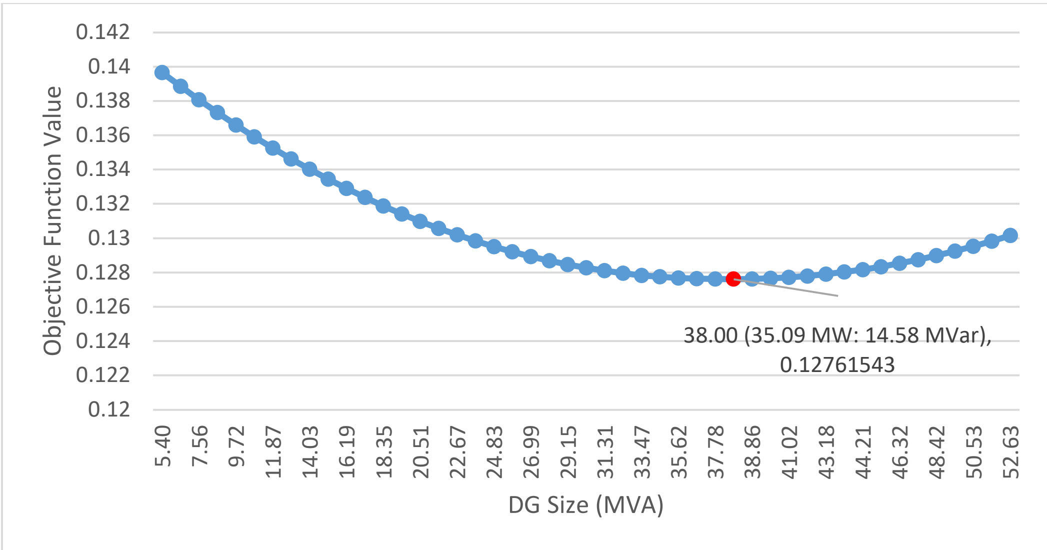


Figure 4.14: Different Objective Function Values for Bus 15- DG Type 02

Validate Power Flow Results

PSS/E Explore 34 simulation software is used to validate power flow results of selected DG size in type 1 and type 2 simulation.

Network diagram, load data and line data of IEEE-30 bus system on PSS/E Explore 34 simulation software are shown in figure 4.15, figure 4.16 and figure 4.17.

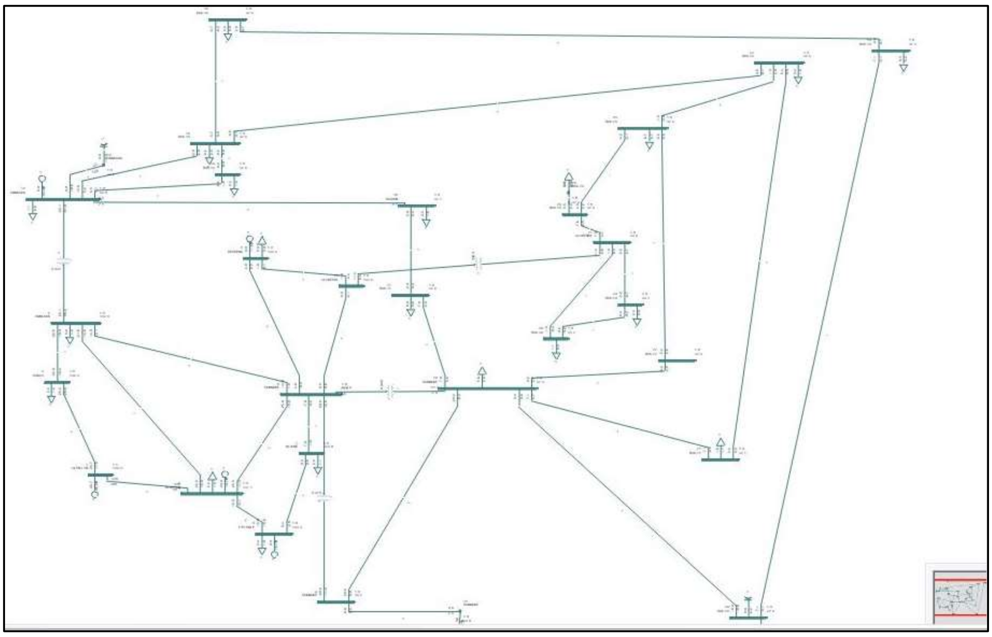


Figure 4.15: Network Diagram on PSS/E Software – IEEE-30 Bus System

Bus Number	Bus Name	Pload (MW)	Qload (Mvar)
2	BUS 02 132.00	2.1700	1.2700
3	BUS 03 132.00	2.4000	1.2000
4	BUS 04 132.00	3.6000	1.6000
5	BUS 05 132.00	3.4200	1.9000
7	BUS 07 132.00	2.2800	1.0900
8	BUS 08 132.00	3.0000	3.0000
10	BUS 10 33.000	5.8000	2.0000
12	BUS 12 33.000	1.1200	0.7500
14	BUS 14 33.000	6.2000	1.6000
15	BUS 15 33.000	8.2000	2.5000
15	BUS 15 33.000	0.0000	0.0000
16	BUS 16 33.000	3.5000	1.8000
17	BUS 17 33.000	9.0000	5.8000
18	BUS 18 33.000	3.2000	0.9000
19	BUS 19 33.000	9.5000	3.4000
19	BUS 19 33.000	0.0000	0.0000
20	BUS 20 33.000	2.2000	0.7000
21	BUS 21 33.000	1.7500	1.1200
23	BUS 13 33.000	3.2000	1.6000
24	BUS 24 33.000	8.7000	6.7000
26	BUS 26 33.000	3.5000	2.3000
29	BUS 29 33.000	2.4000	0.9000
30	BUS 30 33.000	1.0600	0.1900

Figure 4.16: Load Data on PSS/E Software – IEEE-30 Bus System

From Bus Number	To Bus Number	Line R (pu)	Line X (pu)
1	2	0.019200	0.057500
1	3	0.045200	0.165200
2	4	0.057000	0.173700
2	5	0.047200	0.198300
2	6	0.058100	0.176300
3	4	0.013200	0.037900
4	6	0.011900	0.041400
5	7	0.046000	0.116000
6	7	0.026700	0.082000
6	8	0.012000	0.042000
6	28	0.016900	0.059900
8	28	0.063600	0.200000
10	17	0.032400	0.084500
10	20	0.093600	0.209000
10	21	0.034800	0.074900
10	22	0.072700	0.149900
12	14	0.123100	0.255900
12	15	0.066200	0.130400
12	16	0.094500	0.198700
14	15	0.221000	0.199700
15	18	0.107300	0.218500
15	23	0.100000	0.202000
16	17	0.052400	0.192300
18	19	0.063900	0.129200
19	20	0.034000	0.068000
21	22	0.011600	0.023600
22	24	0.115000	0.179000
23	24	0.132000	0.270000
24	25	0.188500	0.329200
25	26	0.254400	0.380000
25	27	0.109300	0.208700
27	29	0.219800	0.415300
27	30	0.320200	0.602700
29	30	0.239900	0.453300

Figure 4.17: Line Data on PSS/E Software – IEEE-30 Bus System

According to table 4.9, 23.23 MW DG is applied to bus no 19 and that is indicated in figure 4.18. And 35.09 MW and 14.58 MVAR DG is applied to bus no 15 and that is indicated in figure 4.19.

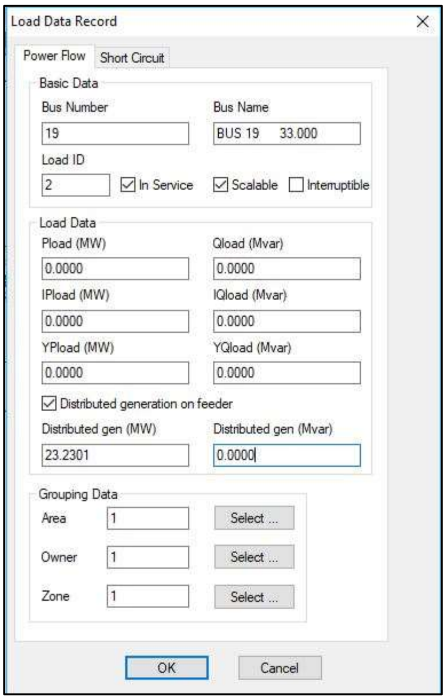


Figure 4.18: DG Integration on PSS/E Software – Type 01 DG

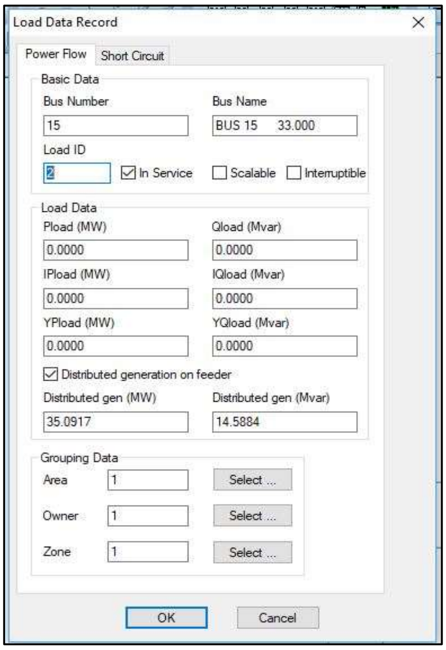


Figure 4.19: DG Integration on PSS/E Software – Type 02 DG

Power generation results on PSS/E are shown in figure 4.20 and figure 4.21. From observed results, power-losses for two different types of DGs are calculated using the power balance equation. The results are tabulated in table 4.10 and it compared with results in the proposed algorithm.

Bus Number	Bus Name	PGen (MW)	QGen (Mvar)	VSched (pu)	Voltage (pu)
1	BUS 01 132.00	24.60424	46.155	1.0600	1.0600
2	BUS 02 132.00	40.00000	9.725	1.0430	1.0430
5	BUS 05 132.00	0.00000	-15.154	1.0100	1.0100
8	BUS 08 132.00	0.00000	-0.329	1.0100	1.0100
11	BUS 11 11.000	0.00000	1.241	1.0000	1.0000
13	BUS 13 11.000	0.00000	3.677	1.0000	1.0000

Figure 4.20: Power Generation Results on PSS/E Software – Type 01 DG

Bus Number	Bus Name	PGen (MW)	QGen (Mvar)	VSched (pu)	Voltage (pu)
1	BUS 01 132.00	12.68722	48.280	1.0600	1.0600
2	BUS 02 132.00	40.00000	6.728	1.0430	1.0430
5	BUS 05 132.00	0.00000	-15.828	1.0100	1.0100
8	BUS 08 132.00	0.00000	-4.999	1.0100	1.0100
11	BUS 11 11.000	0.00000	-0.018	1.0000	1.0000
13	BUS 13 11.000	0.00000	-4.767	1.0000	1.0000

Figure 4.21: Power Generation Results on PSS/E Software – Type 02 DG

Table 4.10 : Comparison of PSS/E and Proposed Model Results

DG type	Ploss (MW)			Qloss (MVAR)		
	PSS/E	Proposed Model	Tolerance	PSS/E	Proposed Model	Tolerance
Type 01	1.6344	1.6358	0.09%	-	-	-
Type 02	1.5789	1.5810	0.085%	5.9604	5.9039	-0.95%

From table 4.10, the proposed model has nearly equal results with PSS/E for power flow solutions. Also, the voltage values obtained from PSS/E and the proposed model are equal for both type 1 and type 2 DG modeling and the PSS/E voltage values are illustrated in figure 4.22 and figure 4.23.

Bus Number	Bus Name	Code	Voltage (pu)	Zone Name
1	BUS 01	3	1.0600	IEEE 30
2	BUS 02	2	1.0430	IEEE 30
3	BUS 03	1	1.0259	IEEE 30
4	BUS 04	1	1.0184	IEEE 30
5	BUS 05	2	1.0100	IEEE 30
6	BUS 06	1	1.0121	IEEE 30
7	BUS 07	1	1.0101	IEEE 30
8	BUS 08	2	1.0100	IEEE 30
9	BUS 09	1	0.9974	IEEE 30
10	BUS 10	1	0.9886	IEEE 30
11	BUS 11	2	1.0000	IEEE 30
12	BUS 12	1	0.9949	IEEE 30
13	BUS 13	2	1.0000	IEEE 30
14	BUS 14	1	0.9818	IEEE 30
15	BUS 15	1	0.9821	IEEE 30
16	BUS 16	1	0.9848	IEEE 30
17	BUS 17	1	0.9819	IEEE 30
18	BUS 18	1	0.9856	IEEE 30
19	BUS 19	1	0.9910	IEEE 30
20	BUS 20	1	0.9916	IEEE 30
21	BUS 21	1	0.9841	IEEE 30
22	BUS 22	1	0.9832	IEEE 30
23	BUS 13	1	0.9722	IEEE 30
24	BUS 24	1	0.9677	IEEE 30
25	BUS 25	1	0.9751	IEEE 30
26	BUS 26	1	0.9566	IEEE 30
27	BUS 27	1	0.9886	IEEE 30
28	BUS 28	1	1.0081	IEEE 30
29	BUS 29	1	0.9807	IEEE 30
30	BUS 30	1	0.9821	IEEE 30

Figure 4.22 : Bus Voltage on PSS/E Software – With Type 01 DG

	Bus Number	Bus Name	Code	Voltage (pu)	Zone Name
	1	BUS 01	3	1.0600	IEEE 30
	2	BUS 02	2	1.0430	IEEE 30
	3	BUS 03	1	1.0282	IEEE 30
	4	BUS 04	1	1.0214	IEEE 30
	5	BUS 05	2	1.0100	IEEE 30
	6	BUS 06	1	1.0137	IEEE 30
	7	BUS 07	1	1.0111	IEEE 30
▶	8	BUS 08	2	1.0100	IEEE 30
	9	BUS 09	1	1.0000	IEEE 30
	10	BUS 10	1	0.9931	IEEE 30
	11	BUS 11	2	1.0000	IEEE 30
	12	BUS 12	1	1.0067	IEEE 30
	13	BUS 13	2	1.0000	IEEE 30
	14	BUS 14	1	1.0025	IEEE 30
	15	BUS 15	1	1.0135	IEEE 30
	16	BUS 16	1	0.9927	IEEE 30
	17	BUS 17	1	0.9877	IEEE 30
	18	BUS 18	1	0.9966	IEEE 30
	19	BUS 19	1	0.9900	IEEE 30
	20	BUS 20	1	0.9921	IEEE 30
	21	BUS 21	1	0.9899	IEEE 30
	22	BUS 22	1	0.9894	IEEE 30
	23	BUS 13	1	0.9954	IEEE 30
	24	BUS 24	1	0.9801	IEEE 30
	25	BUS 25	1	0.9828	IEEE 30
	26	BUS 26	1	0.9645	IEEE 30
	27	BUS 27	1	0.9934	IEEE 30
	28	BUS 28	1	1.0099	IEEE 30
	29	BUS 29	1	0.9855	IEEE 30
	30	BUS 30	1	0.9869	IEEE 30
*					

Figure 4.23: Bus Voltage on PSS/E Software – With Type 02 DG

4.3.2 Analyze Test Bus System Results with Literature Review

Summary of some results for IEEE 30 bus system for optimal DG planning in previous research is listed below. When comparing and analyzing the previous results with observed results, observed results are obtained with higher accuracy for power loss and cost minimization.

Table 4.11: Comparison of Optimal DGs Planning Results in IEEE-30 Bus System

Paper	Qualitative Analysis	Quantitative Analysis
Optimal Placement of Distributed Generation in Electric Distribution Networks [8]	• Newton Raphson algorithm used • Considered optimal DG placement only to minimize power loss with selected 20 MW Solar PV type DG.	• Maximum of 15.3% power loss reduction.
Multi DGPV installation in transmission system for loss minimization [22]	• Considered 20 MW DG with solar power generation only. • Minimize only power losses using adaptive Evolutionary programming (AEP). • Selected optimal DG placement only.	• Maximum of 30.02% power loss reduction.
Application of Analytical - Firefly Algorithm for optimal location and sizing of distributed generator in standard IEEE 30-bus distribution network [11]	• Combined with analytical method and firefly algorithm used. • Optimal location and size are determined by considering power loss minimization.	• 8.67% of loss reduction
Performance Study of a New Modified Differential Evolution Technique Applied for Optimal Placement and Sizing of Distributed Generation [23]	• Used differential evolution technique-based algorithm • Minimize the overall cost of the system and line loss	• Observed 23.88% of power loss reduction with $2561 cost.

5. OPTIMAL DG PLANNING FOR DISTRIBUTION FEEDERS IN SRILANKA

5.1 Case Study- Kalubowila Feeder

Kalubowila feeder is selected for optimal solar PV installation as a case study. The feeder is connected to Ethulkotte grid substation and main details of the feeder are shown in table 5.1 and geographical details of the feeder are shown in figure 5.1

Table 5.1: Details of Kalubowila Feeder

Voltage Level	11 kV
Main line Length	2.752 km
Branch Conductor Length	3.083 km
No of Nodes	70
No of Transformers	51
Feeder Demand	2.02 MW (min) 3.07 MW (max)

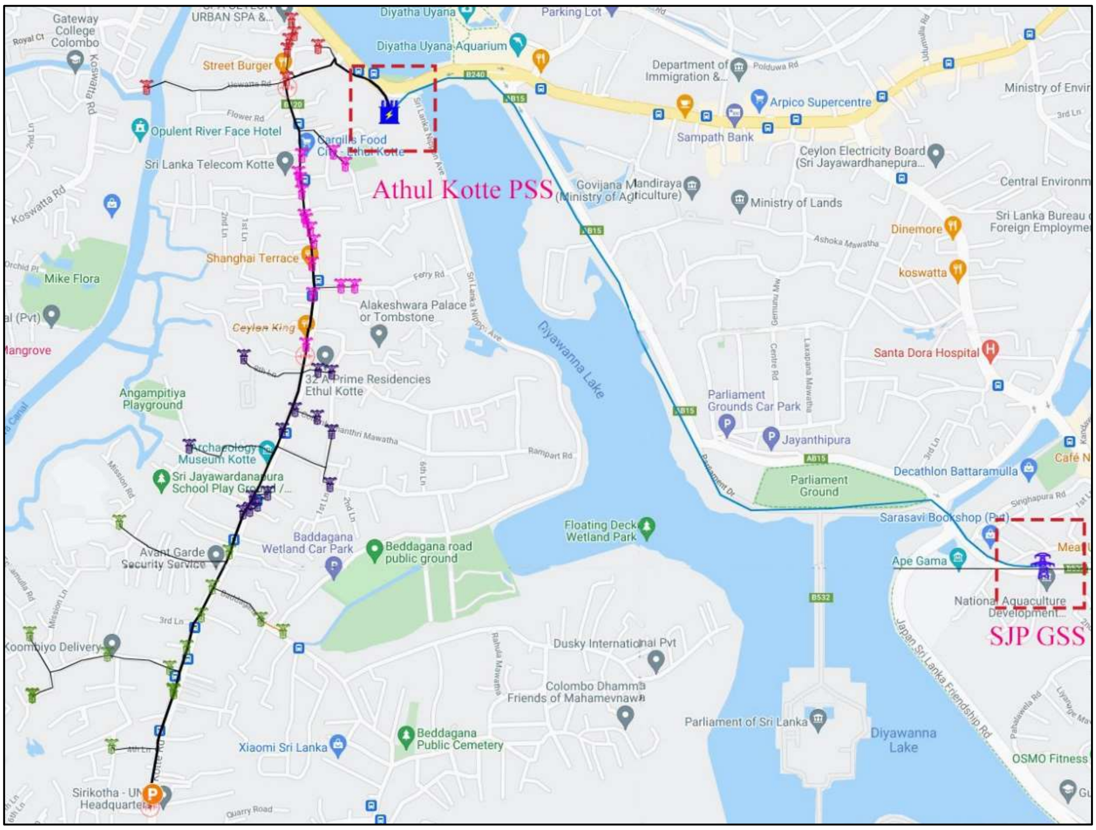


Figure 5.1: Geological View of Kalubowila Feeder

Locations and currently available transformers details of the feeder are found in Appendix B.1.

5.1.1 Feeder Details

Line resistance and reactance details of the feeder are shown in Appendix B.2. Conductor types of the feeder which used for simulation are listed below.

11kV 150mm2 AAC Conductor : R = 0.20457 (Ω / km) ; X = 0.33056 (Ω / km); C=11.2894 (nF / km)

11kV 60mm2 AAC Conductor : R = 0.50498 (Ω / km) ; X = 0.36253 (Ω / km) ; C = 10.3054 (nF / km)

Load data of the feeder for selected time interval periods are attached in Appendix B.3. According to solar power generation, optimal solar PV planning is considered for 6.00 am to 6.00 pm time period. Load variation for 6.00 am to 6.00 pm in different nodes are shown in figure 5.2.

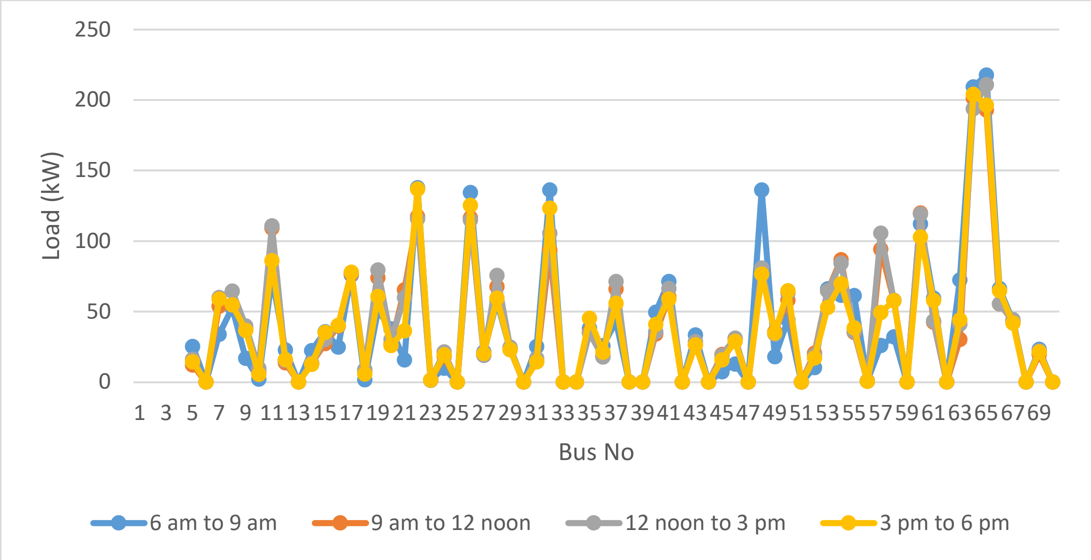


Figure 5.2: Load Variation in Feeder Nodes from 6 am to 6 pm

5.1.2 Constraints Data

- According to the distribution code of Sri Lanka, voltage limits of each bus is considered as ±6%.

  $$0.94 \text{ p.u.} \leq V_i \leq 1.06 \, p.u.$$

- In PUCSL and CEB definitions, most solar PV systems tend to have two types. utility-scale solar installations with a capacity usually more than 1 MW and small-scale ground-mounted and rooftop generation up to 1MW. Therefore, P_{DG} is considered below range and 20% of load variation is considered for optimal Solar PV planning in accordance to P_{DG} variation.

  $$0 \, MW \leq P_{DGi} \leq 1 \, MW$$

- According to geological condition in Sri Lanka, Solar generation is considered from 6.00 am to 6.00 pm. Table 5.2 is illustrated the selected solar PV generation details for the time intervals by considering solar power output variation section 3.6.1.

Table 5.2: Percentage Values of Solar PV Output

Time Interval	Solar PV generation percentage
6.00 a.m – 9.00 a.m	50%
9.00 a.m – 12.00 noon	90%
12.00 noon – 3.00 p.m	95%
3.00 p.m – 6.00 p.m	65%

- Weighting factors are selected by analyzing results in 4.2.1.
  W1= 0.7 and W3=0.3

5.1.3 Results and Analysis- Kalubowila Feeder

Obtained results for Kalubowila feeder are shown below. Load variations at 6.00 am-6.00 pm are considered for Kalubowila feeder due to solar PV integration. Objective function variation, power loss variation, DG cost variation, optimal DG size variation and bus voltage variation with respect to selected DG for different time intervals are shown in figure 5.3, figure 5.4, figure 5.5, figure 5.6 and figure 5.7 respectively.

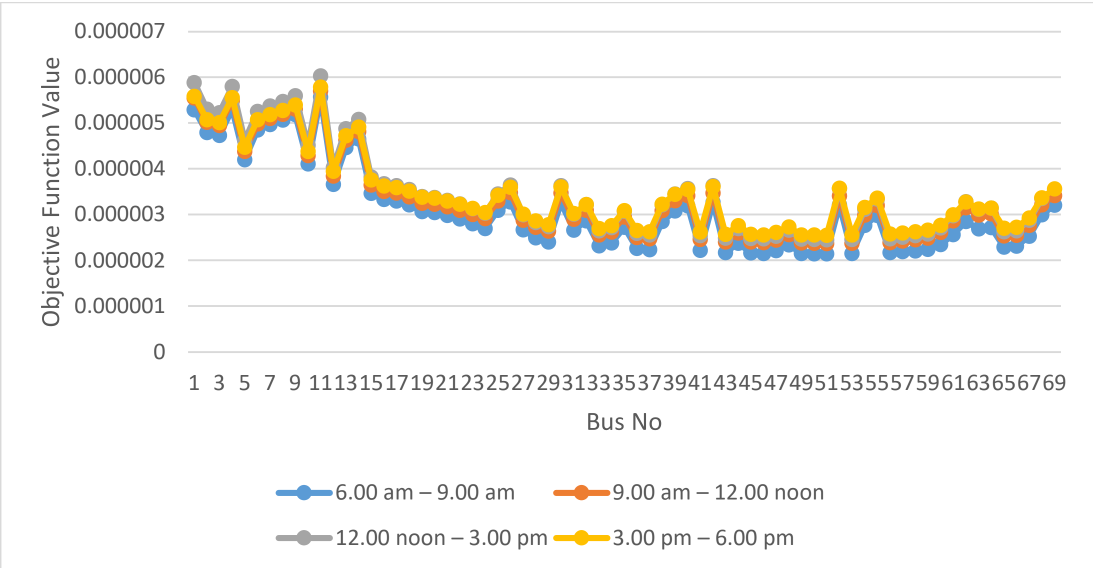


Figure 5.3: Objective Function Variation in Bus 1 to Bus 70

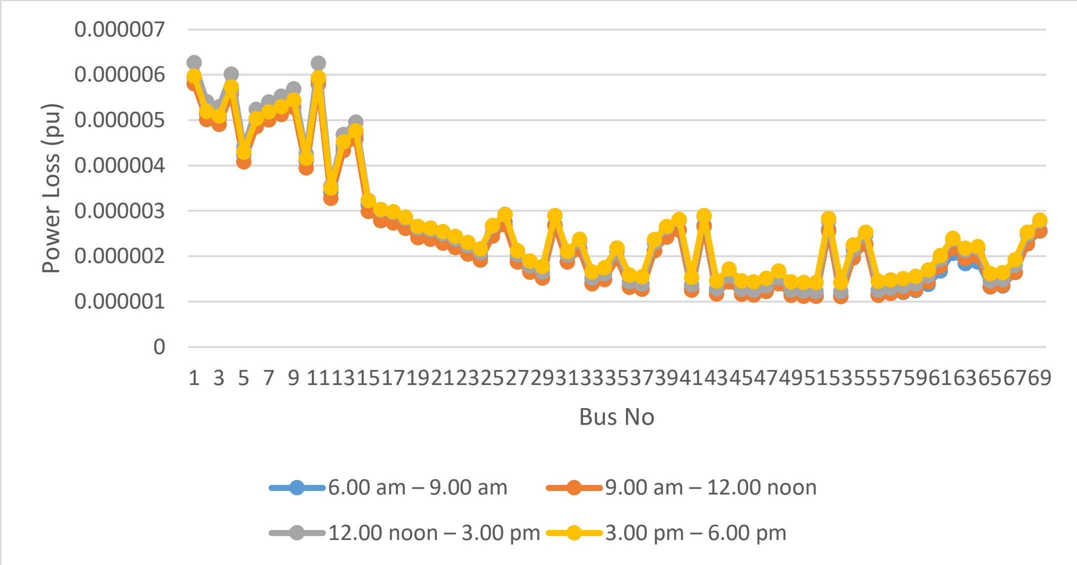


Figure 5.4: Power Loss Variation in Bus 1 to Bus 70

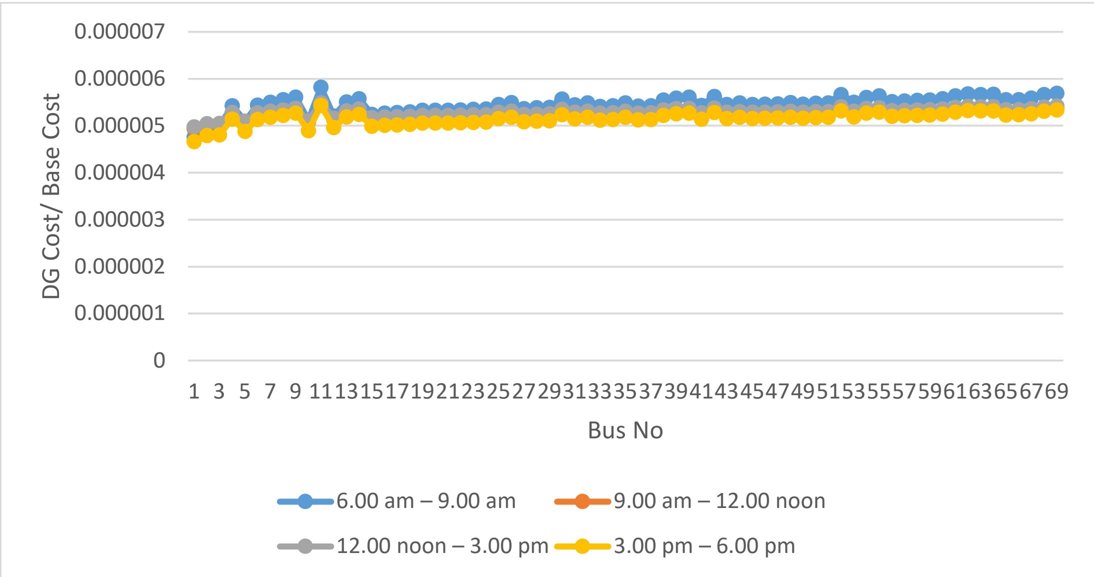


Figure 5.5: DG Cost Variation in Bus 1 to Bus 70

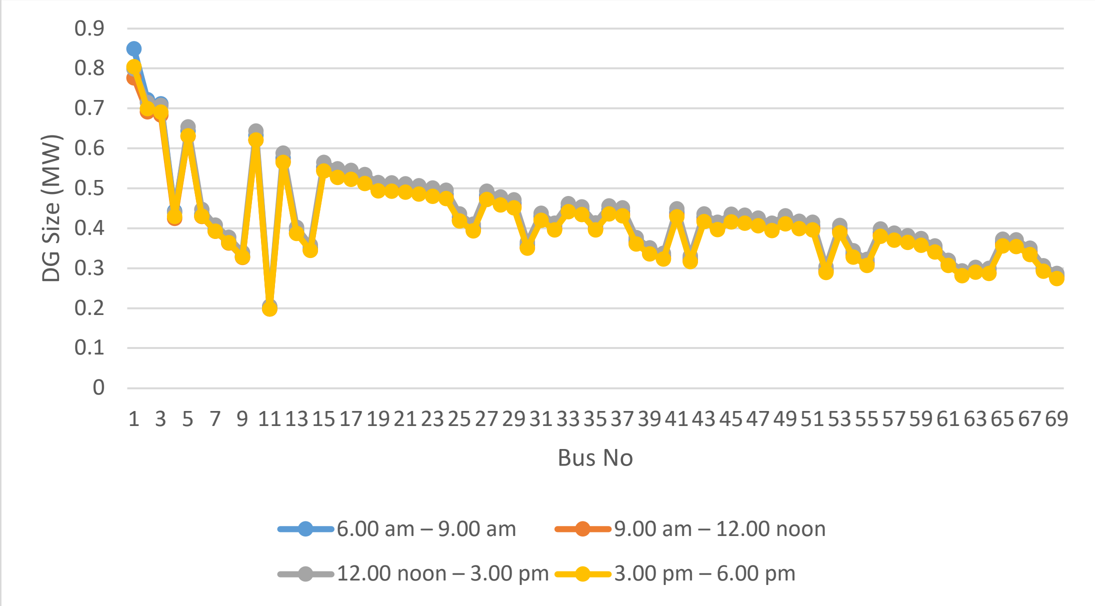


Figure 5.6: Optimal DG Size Variation in Bus 1 to Bus 70

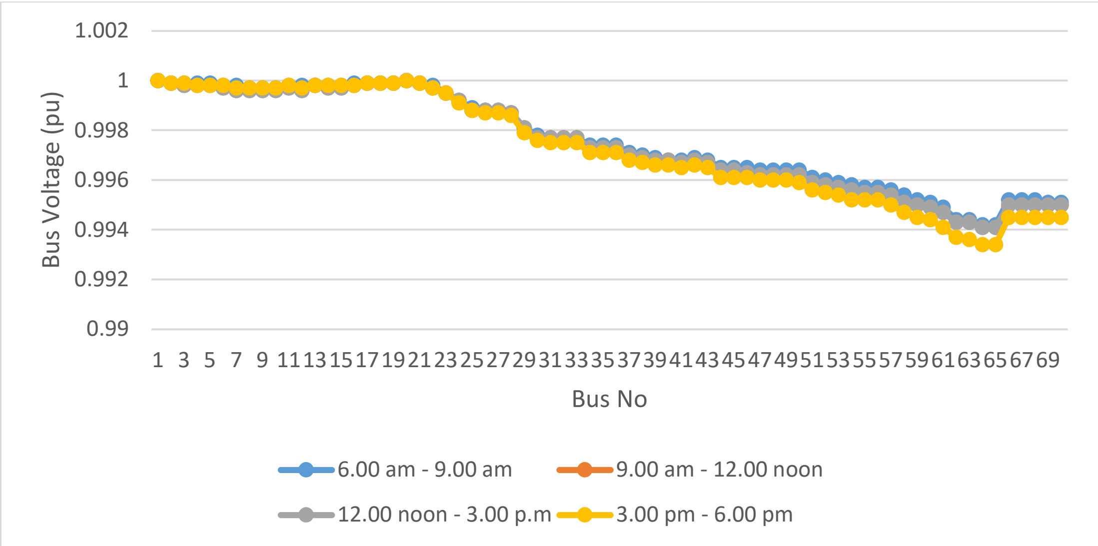


Figure 5.7: Bus Voltage Variation in Bus 1 to Bus 70

By analyzing the observed results, a summary for optimal DG planning in different time intervals are tabulated in table 5.3 and table 5.4. Also, a graphical representation of the summary of the results for the Kalubowila feeder is shown in figure 5.8.

Table 5.3: Optimal DG Planning Results - Kalubowila Feeder

Time Interval	Base Case Loss (kW)	Node	Ploss (kW)	DG Cost (MRs)	DG Size (kW)	Solar PV Output %	Actual DG Size (kW)
6.00 am – 9.00 am	0.674325	52	0.113681	134.82	407.078	50%	814.156
9.00 am – 12.00 noon	0.666977	52	0.111573	113.95	400.687	90%	445.208
12.00 noon – 3.00 pm	0.720877	52	0.122698	113.52	415.377	95%	437.239
3.00 pm – 6.00 pm	0.679029	52	0.142169	116.83	396.151	65%	609.463

Table 5.4: Analysis of Optimal DG Planning Results-Kalubowila Feeder

Time Interval	Optimal DG Location	Actual DG Size (kW)	Loss Reduction %	Cost Reduction %	Minimum Voltage (p.u.)
6.00 am – 9.00 am	52	814.156	83.14	44.93	0.9942
9.00 am – 12.00 noon	52	445.208	83.27	52.98	0.9941
12.00 noon – 3.00 pm	52	437.239	82.38	53.02	0.9941
3.00 pm – 6.00 pm	52	609.463	78.68	51.85	0.9934

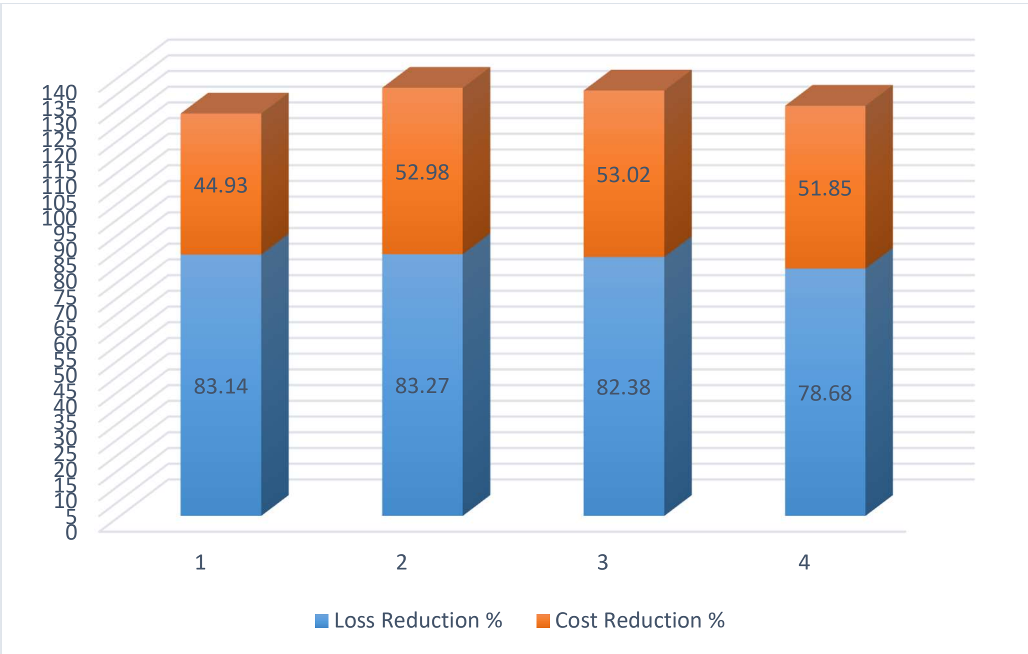


Figure 5.8: Summary of Optimal DG Planning Results- Kalubowila Feeder

In these results, different DG sizes are needed to fulfill optimal DG requirements in 4-time intervals for given constraints. But for optimal DG location is the same for all 4 different cases. By considering all the above results, selected DG of 9.00 am – 12.00 noon is proposed as optimal DG for the Kalubowila feeder considering its loss and cost reduction. The geographical view of the proposed DG location is indicated in figure 5.9.

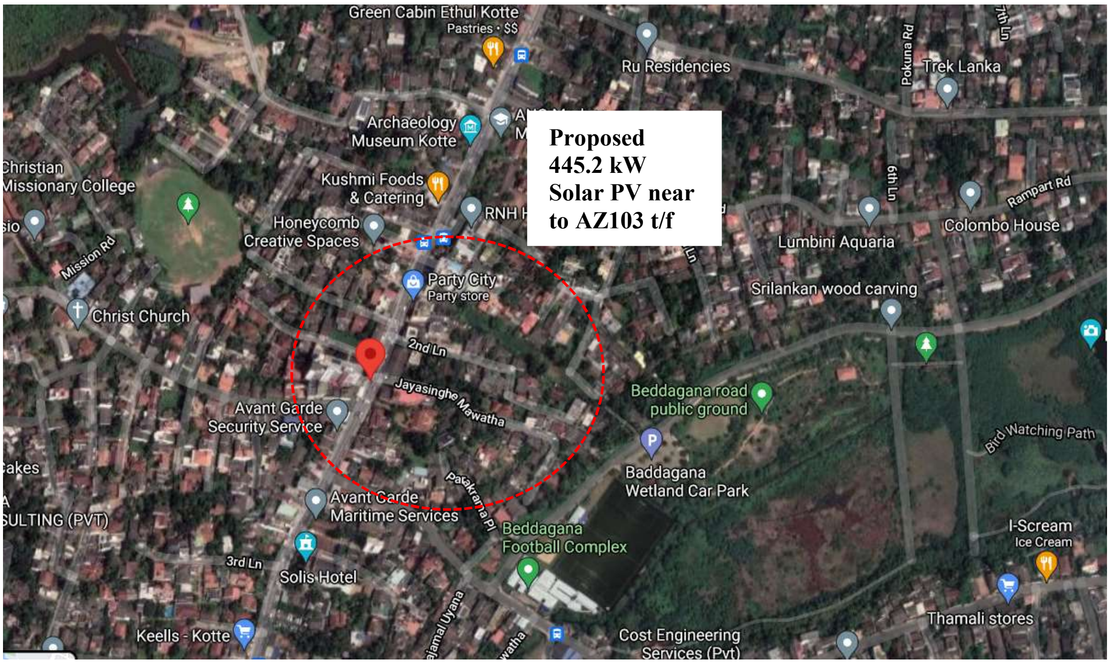


Figure 5.9: Geological View of Proposed DG Plant Location- Kalubowila Feeder

5.1.4 Validation of the Power Flow Results- Kalubowila Feeder

Optimal results obtained from the algorithm are validated using PSS/E software. Network diagram, load data and line data of the Kalubowila feeder on PSS/E are shown in figure 5.10, figure 5.11 and figure 5.12.

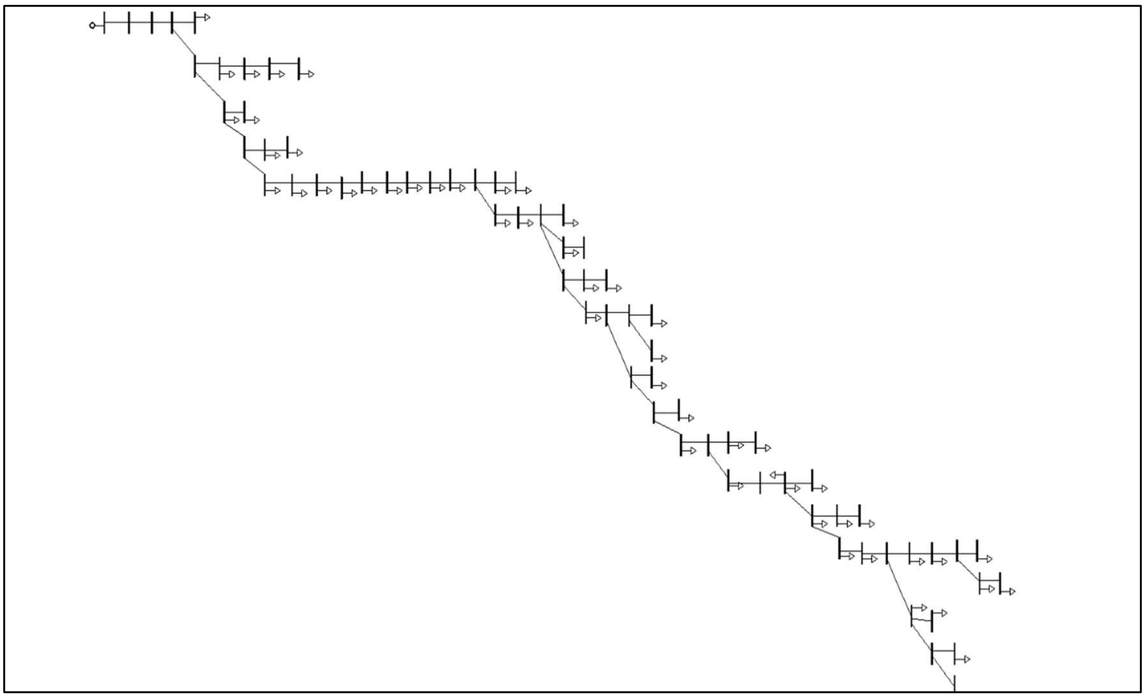
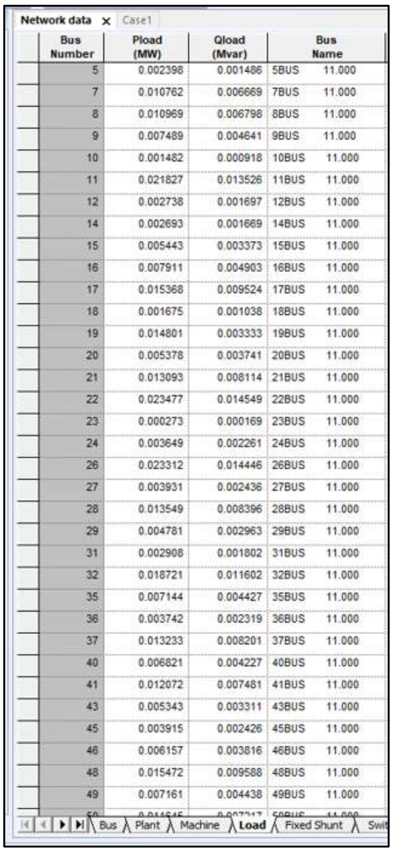


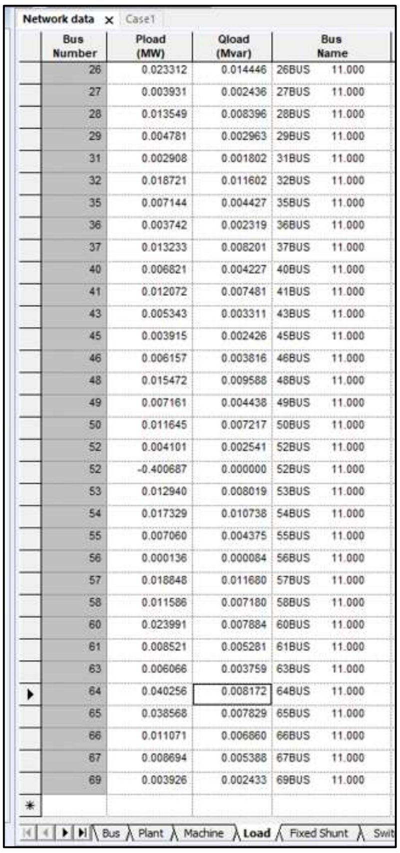
Figure 5.10: Network Diagram on PSS/E Software- Kalubowila Feeder



Network data | Case1

Bus Number	Pload (MW)	Qload (Mvar)	Bus Name
5	0.002398	0.001486	5BUS 11.000
7	0.010762	0.006669	7BUS 11.000
8	0.010969	0.006798	8BUS 11.000
9	0.007489	0.004641	9BUS 11.000
10	0.001482	0.000918	10BUS 11.000
11	0.021827	0.013526	11BUS 11.000
12	0.002738	0.001697	12BUS 11.000
14	0.002693	0.001669	14BUS 11.000
15	0.005443	0.003373	15BUS 11.000
16	0.007911	0.004903	16BUS 11.000
17	0.015368	0.009524	17BUS 11.000
18	0.001675	0.001038	18BUS 11.000
19	0.014801	0.003333	19BUS 11.000
20	0.005378	0.003741	20BUS 11.000
21	0.013093	0.008114	21BUS 11.000
22	0.023477	0.014549	22BUS 11.000
23	0.000273	0.000169	23BUS 11.000
24	0.003649	0.002261	24BUS 11.000
26	0.023312	0.014446	26BUS 11.000
27	0.003931	0.002436	27BUS 11.000
28	0.013549	0.008396	28BUS 11.000
29	0.004781	0.002963	29BUS 11.000
31	0.002908	0.001802	31BUS 11.000
32	0.018721	0.011602	32BUS 11.000
35	0.007144	0.004427	35BUS 11.000
36	0.003742	0.002319	36BUS 11.000
37	0.013233	0.008201	37BUS 11.000
40	0.006821	0.004227	40BUS 11.000
41	0.012072	0.007481	41BUS 11.000
43	0.005343	0.003311	43BUS 11.000
45	0.003915	0.002426	45BUS 11.000
46	0.006157	0.003816	46BUS 11.000
48	0.015472	0.009588	48BUS 11.000
49	0.007161	0.004438	49BUS 11.000

Bus | Plant | Machine | Load | Fixed Shunt | Swit



Network data | Case1

Bus Number	Pload (MW)	Qload (Mvar)	Bus Name
26	0.023312	0.014446	26BUS 11.000
27	0.003931	0.002436	27BUS 11.000
28	0.013549	0.008396	28BUS 11.000
29	0.004781	0.002963	29BUS 11.000
31	0.002908	0.001802	31BUS 11.000
32	0.018721	0.011602	32BUS 11.000
35	0.007144	0.004427	35BUS 11.000
36	0.003742	0.002319	36BUS 11.000
37	0.013233	0.008201	37BUS 11.000
40	0.006821	0.004227	40BUS 11.000
41	0.012072	0.007481	41BUS 11.000
43	0.005343	0.003311	43BUS 11.000
45	0.003915	0.002426	45BUS 11.000
46	0.006157	0.003816	46BUS 11.000
48	0.015472	0.009588	48BUS 11.000
49	0.007161	0.004438	49BUS 11.000
50	0.011645	0.007217	50BUS 11.000
52	0.004101	0.002541	52BUS 11.000
52	-0.400687	0.000000	52BUS 11.000
53	0.012940	0.008019	53BUS 11.000
54	0.017329	0.010738	54BUS 11.000
55	0.007060	0.004375	55BUS 11.000
56	0.000136	0.000084	56BUS 11.000
57	0.018848	0.011680	57BUS 11.000
58	0.011586	0.007180	58BUS 11.000
60	0.023991	0.007884	60BUS 11.000
61	0.008521	0.005281	61BUS 11.000
63	0.006066	0.003759	63BUS 11.000
64	0.040256	0.008172	64BUS 11.000
65	0.038568	0.007829	65BUS 11.000
66	0.011071	0.006860	66BUS 11.000
67	0.008694	0.005388	67BUS 11.000
69	0.003926	0.002433	69BUS 11.000

Bus | Plant | Machine | Load | Fixed Shunt | Swit

Figure 5.11: Load Data on PSS/E Software- Kalubowila Feeder

Network data × Case1

From Bus Number	To Bus Number	Line R (pu)	Line X (pu)
1	2	0.018428	0.029778
2	3	0.018090	0.029231
3	4	0.002536	0.004098
4	5	0.026710	0.019175
4	6	0.021471	0.034695
6	7	0.035891	0.025767
6	11	0.004227	0.006830
7	8	0.010851	0.007790
8	9	0.009599	0.006891
9	10	0.014190	0.010187
11	12	0.166936	0.119845
11	13	0.024346	0.039339
13	14	0.053002	0.038051
13	16	0.011835	0.019123
14	15	0.020867	0.014981
16	17	0.009130	0.014752
17	18	0.002536	0.004098
18	19	0.006255	0.010108
19	20	0.011666	0.018850
20	21	0.002029	0.003278
21	22	0.005241	0.008469
22	23	0.007946	0.012840
23	24	0.010313	0.016665
24	25	0.010482	0.016938
25	26	0.031300	0.022471
25	28	0.004058	0.006557
26	27	0.015859	0.011385
28	29	0.024007	0.038793
29	30	0.013187	0.021309
30	31	0.075538	0.054230
30	32	0.020867	0.014981
30	34	0.017076	0.027592
32	33	0.016694	0.011984
34	35	0.005008	0.003595
34	37	0.011496	0.018577
35	36	0.027544	0.019774
37	38	0.007777	0.012567

Bus | Plant | Machine | Load | Fixed

Network data × Case1

From Bus Number	To Bus Number	Line R (pu)	Line X (pu)
34	37	0.011496	0.018577
35	36	0.027544	0.019774
37	38	0.007777	0.012567
38	39	0.061349	0.044043
38	42	0.003889	0.006283
39	40	0.026710	0.019175
39	41	0.042986	0.030860
42	43	0.108091	0.077599
42	44	0.021302	0.034422
44	45	0.016694	0.011984
44	46	0.001691	0.002732
46	47	0.005748	0.009288
47	48	0.005425	0.003895
47	50	0.002367	0.003825
48	49	0.010851	0.007790
50	51	0.021471	0.034695
51	52	0.004565	0.007376
52	53	0.136887	0.098273
52	54	0.014032	0.022675
54	55	0.070113	0.050335
54	57	0.015216	0.024587
55	56	0.029214	0.020973
57	58	0.016568	0.026773
58	59	0.011327	0.018304
59	60	0.011685	0.008389
59	66	0.010313	0.016665
60	61	0.030094	0.048628
61	62	0.070948	0.050934
62	63	0.048829	0.035055
62	64	0.041734	0.029961
64	65	0.006260	0.004494
66	67	0.002087	0.001498
66	68	0.027558	0.044530
68	69	0.065940	0.047339
68	70	0.034997	0.056550

Bus | Plant | Machine | Load | Fixed

Figure 5.12: Line Data on PSS/E Software- Kalubowila Feeder

The optimal DG size for Kalubowila feeder is obtained as 400.69kW (Actual Size with 90% solar irradiance= 445.2 kW) from the proposed algorithm and the DG is applied to randomly selected locations and power loss reduction is obtained. The observed percentage values of power loss reduction are shown in table 5.5 and analyzed results are shown in figure 5.13. According to the results, maximum power loss reduction is obtained in same as results from the proposed model and the proposed mathematical model is validated.

Table 5.5: P_{Loss} Reduction Results at PSS/E with Optimal DG- Kalubowila

Node	Power from Grid (KW)	Power from DG (kW)	Load (kW)	Power Loss (kW)	Power Loss at BaseCase (kW)	Power Loss Reduction %
5	124.222	400.69	524.43	0.479	0.667	28.12
10	124.236	400.69	524.43	0.483	0.667	27.55
15	124.177	400.69	524.43	0.434	0.667	34.99
20	123.982	400.69	524.43	0.239	0.667	64.15
25	123.929	400.69	524.43	0.187	0.667	71.99
30	123.886	400.69	524.43	0.143	0.667	78.57
35	123.879	400.69	524.43	0.136	0.667	79.61
40	123.988	400.69	524.43	0.245	0.667	63.21
45	123.872	400.69	524.43	0.129	0.667	80.63
47	123.873	400.69	524.43	0.123	0.667	80.52
48	123.876	400.69	524.43	0.131	0.667	80.43
49	123.877	400.69	524.43	0.134	0.667	79.91
50	123.872	400.69	524.43	0.129	0.667	80.67
51	123.863	400.69	524.43	0.120	0.667	81.95
52	123.849	400.69	524.43	0.111	0.667	83.31
53	123.895	400.69	524.43	0.152	0.667	77.20
54	123.933	400.69	524.43	0.191	0.667	71.44
55	123.958	400.69	524.43	0.215	0.667	67.71
56	124.005	400.69	524.43	0.266	0.667	60.64
57	123.919	400.69	524.43	0.177	0.667	73.48
60	123.939	400.69	524.43	0.196	0.667	70.54
65	124.013	400.69	524.43	0.270	0.667	59.50
70	123.979	400.69	524.43	0.237	0.667	64.54

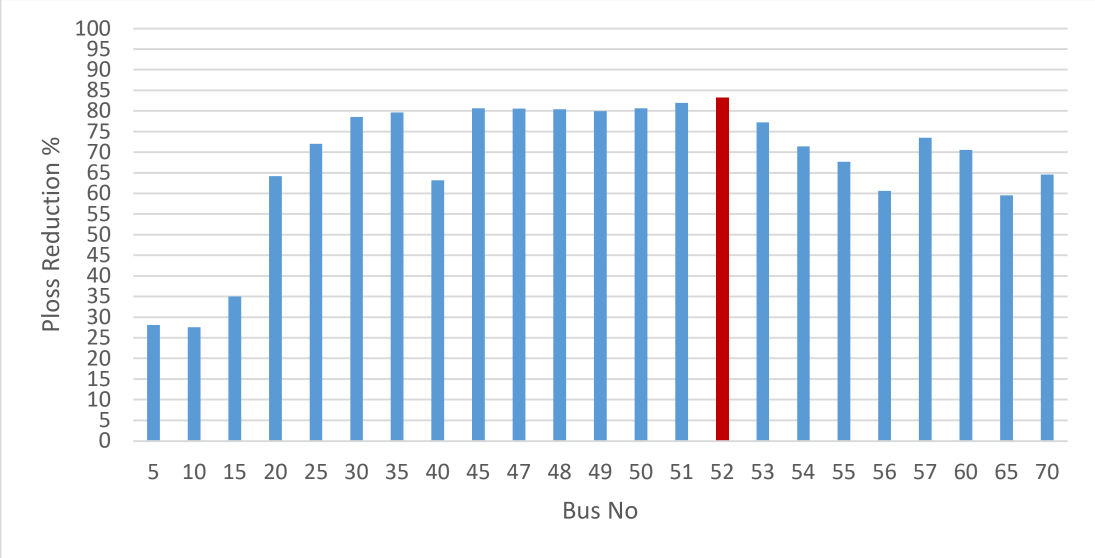


Figure 5.13: P_{Loss} Reduction Results at PSS/E with Optimal DG- Kalubowila

5.2 Case Study- Mallawapitiya Feeder 8

Mallawapitiya-feeder 8 is selected as case study 02 for my study. The feeder is connected to the Mallawapitiya grid substation via the Ibbagamuwa gantry. The feeder details are shown in table 5.6 and the geological locations of the feeder are illustrated in figure 5.14.

Table 5.6: Details of Mallawapitiya Feeder 8

Voltage Level	33 kV
Main line Length	49.326 km
Branch Conductor Length	103.402 km
No of Nodes	75
No of Transformers	53
Feeder Demand	4.15 MW (min) 4..51 MW (max)

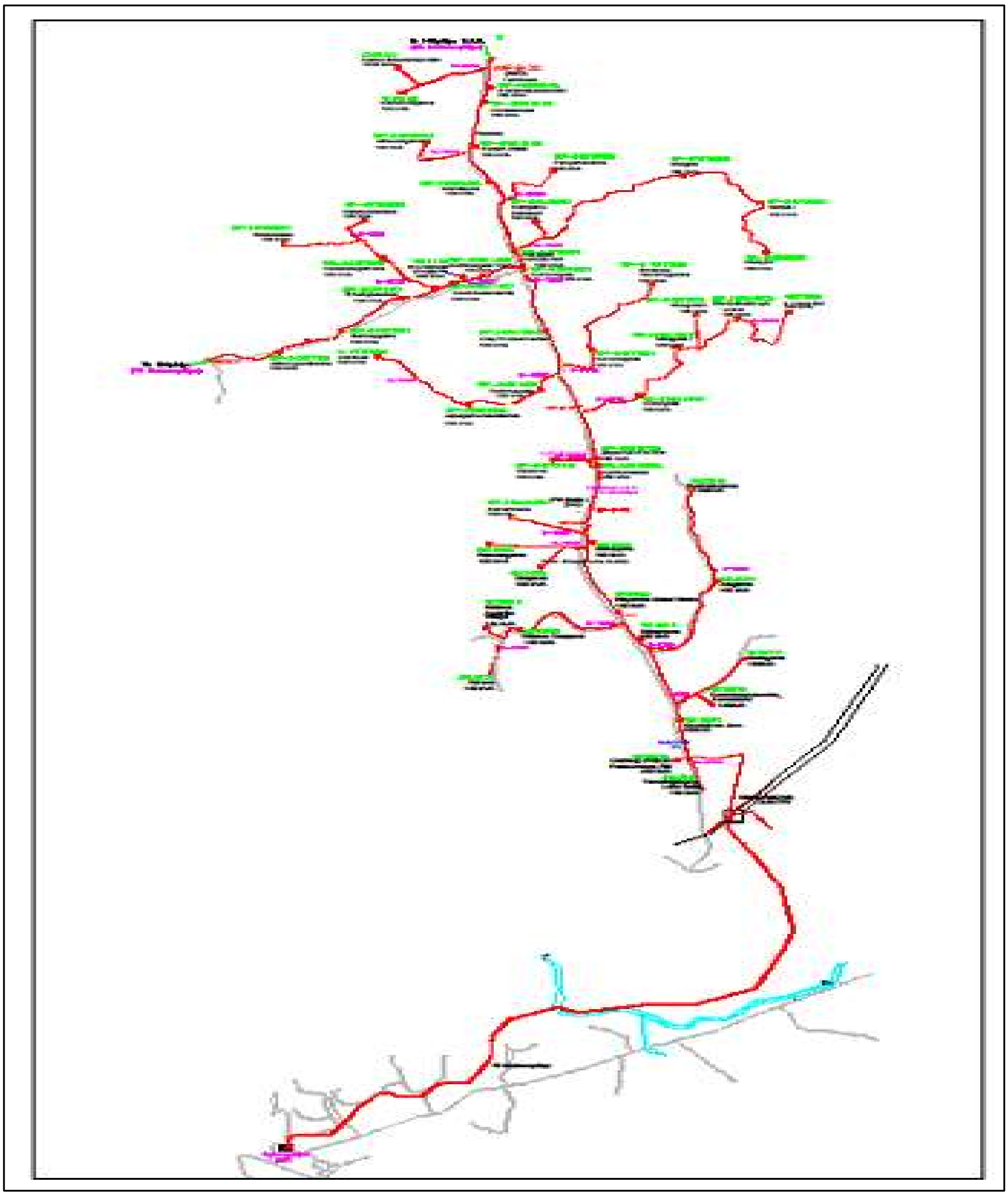


Figure 5.14: Geological View of Mallawapitiya Feeder 8

Locations and currently available transformers details of the selected Mallawapitiya feeder 8 are found in Appendix C.1.

5.2.1 Feeder Details

Line resistance and reactance details of the feeder are shown in Appendix C.2. Conductor types of the feeder which used for simulation are listed below.

33kV Racoon Conductor: R = 0.5192 (Ω / km) ; X = 0.2877 (Ω / km); C=22.36 (nF / km)

33kV Weasel Conductor: R = 1.2963 (Ω / km) ; X = 0.3166 (Ω / km) ; C=24.99 (nF / km)

Load data of the feeder for selected 8-time interval periods are attached in Appendix C.3. Load data variation for 8-time intervals in 75 bus locations are shown in figure 5.15.

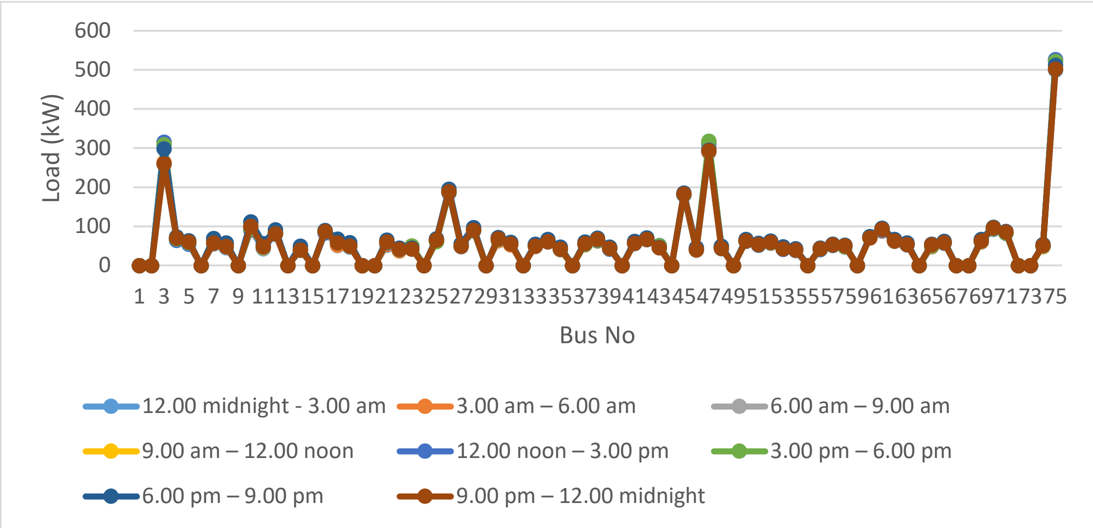


Figure 5.15: Load Variation in Feeder Nodes in a Day (8-Time Intervals)

5.2.2 Constraints Data

- According to the distribution code of Sri Lanka, the voltage limits of each bus are considered as ±6%.

  $0.94 \text{ p.u.} \leq V_i \leq 1.06\, p.u.$

- Consider biomass generation for modeling. According to the currently available capacities of biomass plants in Sri Lanka,

  $0\, MW \leq P_{DGi} \leq 5\, MW$

  $-3.1 \leq Q_{DGi} \leq 1.64$

- Assumed 24 hours availability of the proposed biomass power plant

- Weighting factors are selected by analyzing results in 4.2.2.

  W1= 0.5 , W3=0.3 and W3=0.2

5.2.3 Results and Analysis- Mallawapitiya Feeder 8

Obtained results for the objective function variation, active power loss variation, reactive power loss variation, DG cost variation, optimal DG size(MW)variation, optimal DG size(MVAR) variation and bus voltage variation with respect to selected DG for different 8-time intervals are shown in figure 5.16, figure 5.17, figure 5.18, figure 5.19, figure 5.20, figure 5.21 and figure 5.22 respectively.

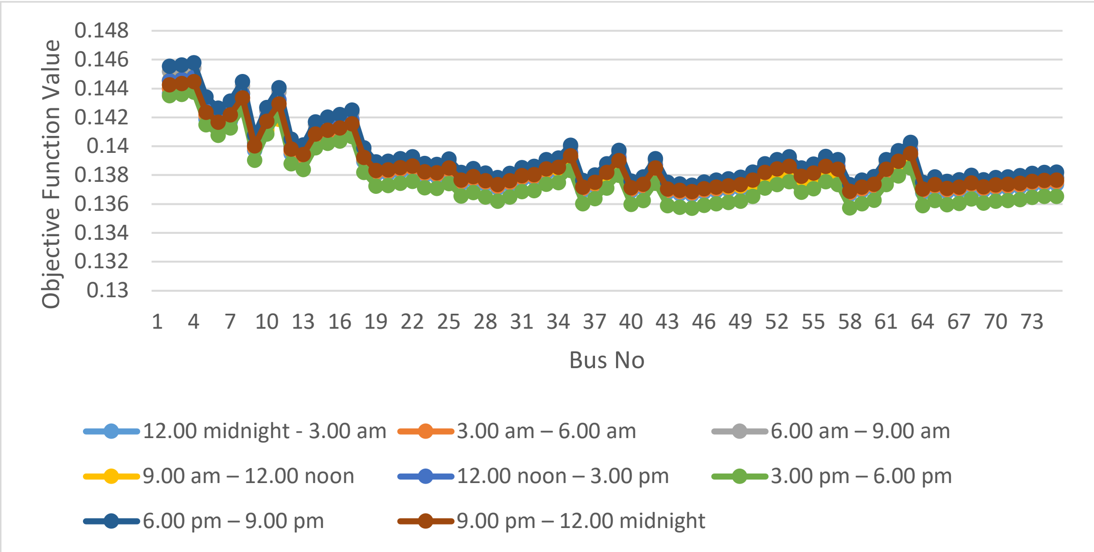


Figure 5.16: Objective Function Variation in Bus 1 to Bus 75

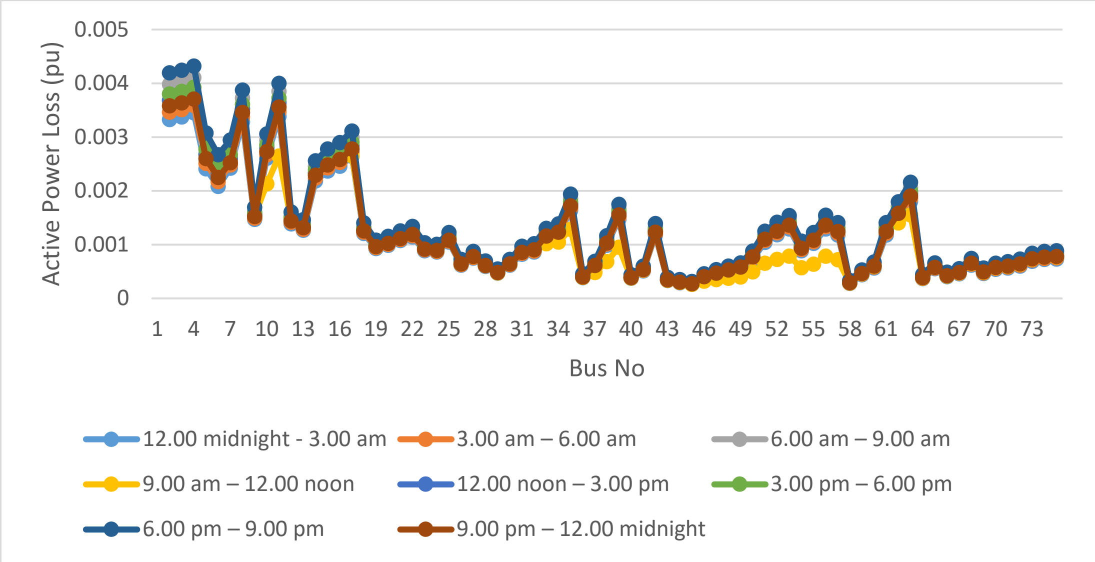


Figure 5.17: Active Power Loss Variation in Bus 1 to Bus 75

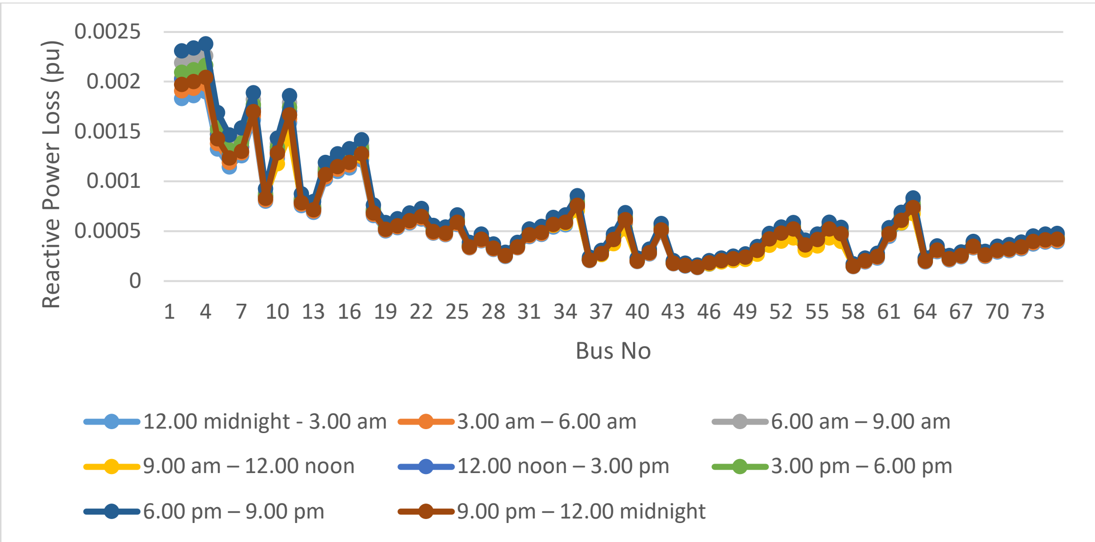


Figure 5.18: Reactive Power Loss Variation in Bus 1 to Bus 75

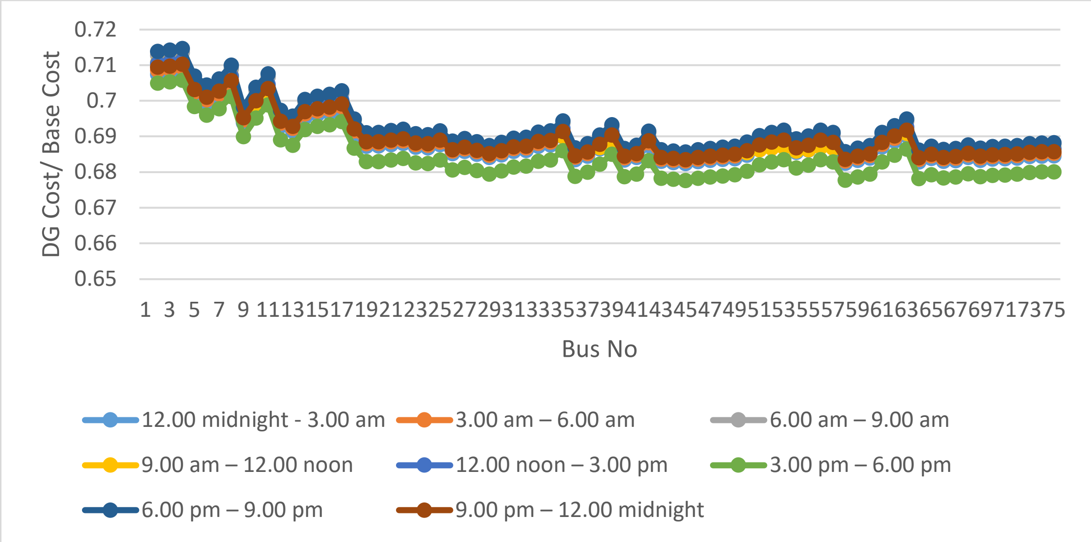


Figure 5.19: DG Cost Variation in Bus 1 to Bus 75

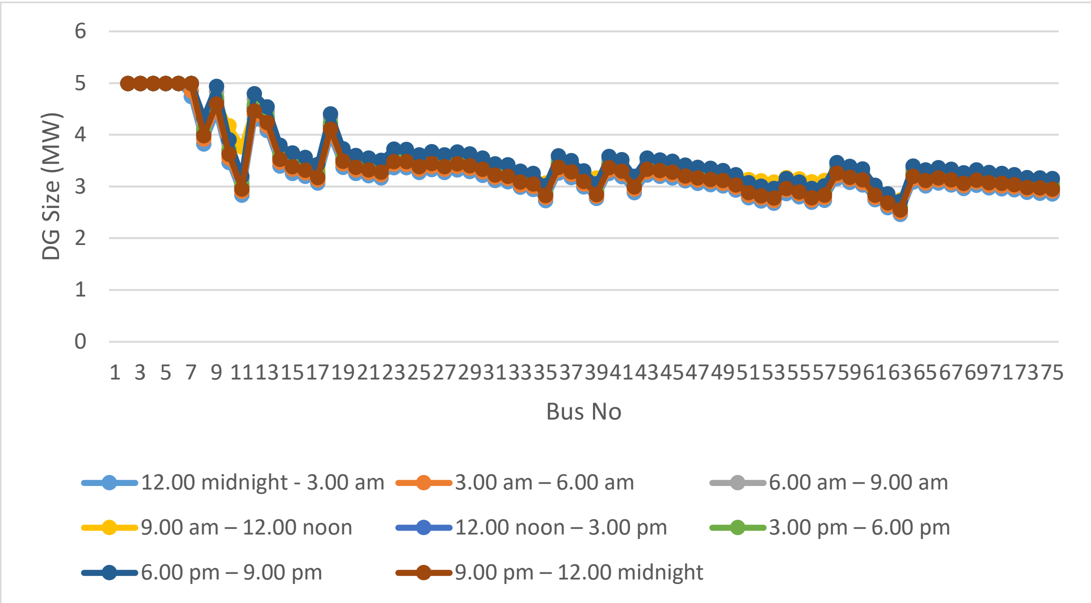


Figure 5.20: Optimal DG Size (MW) Variation in Bus 1 to Bus 75

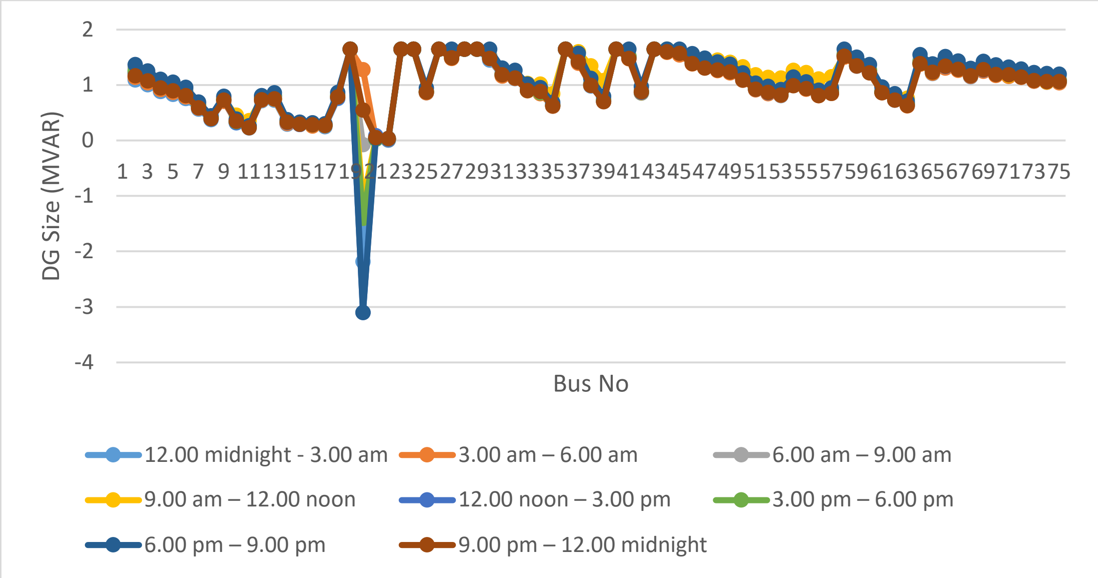


Figure 5.21: Optimal DG Size (MVAR) Variation in Bus 1 to Bus 75

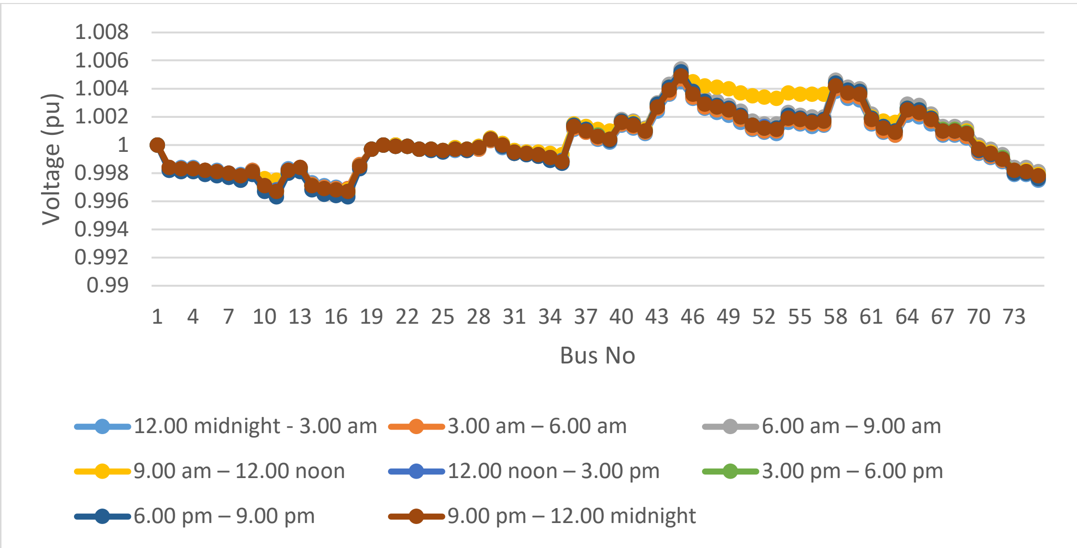


Figure 5.22: Bus Voltage Variation in Bus 1 to Bus 75

By analyzing the observed results, summary for optimal DG planning in different time intervals are tabulated in table 5.7 , table 5.8 and figure 5.23.

Table 5.7: Optimal DG planning Results – Mallawapitiya Feeder 8

Time Interval	Base Case Loss (kW)	Base Case Loss (kVAR)	Node	Ploss (kW)	Qloss (kVAR)	DG Cost (MRs)	DGSize (MW)	DG Size (MVAR)
12.00 midnight - 3.00 am	681.785	376.597	45	26.005	13.283	1659.59	3.174	1.566
3.00 am – 6.00 am	705.690	389.821	45	26.552	13.566	1661.25	3.239	1.540
6.00 am – 9.00 am	793.620	438.406	45	29.631	15.144	1666.99	3.435	1.608
9.00 am – 12.00 noon	744.033	411.949	45	26.120	14.153	1664.42	3.333	1.596
12.00 noon – 3.00 pm	743.291	410.615	45	27.746	14.190	1664.24	3.325	1.582
3.00 pm – 6.00 pm	763.466	421.736	45	28.429	14.514	1648.09	3.368	1.585
6.00 pm – 9.00 pm	826.731	456.658	45	31.255	15.955	1667.42	3.493	1.643
9.00 pm – 12.00 midnight	725.947	401.012	45	27.356	13.980	1662.29	3.282	1.567

Table 5.8: Analysis of Optimal DG planning Results- Mallawapitiya Feeder 8

Time Interval	Optimal DG Loc.	DG Size (MW)	DG Size (MVAR)	Ploss Redu. %	Qlossa Redu. %	Cost Redu. %	Minimum Voltage (p.u.)
12.00 midnight - 3.00 am	45	3.174	1.566	96.19	96.47	31.76	0.9969
3.00 am – 6.00 am	45	3.239	1.540	96.24	96.52	31.69	0.9968
6.00 am – 9.00 am	45	3.435	1.608	96.27	96.53	31.46	0.9965
9.00 am – 12.00 noon	45	3.333	1.596	96.49	96.66	31.96	0.9968
12.00 noon – 3.00 pm	45	3.325	1.582	96.27	96.54	31.57	0.9967
3.00 pm – 6.00 pm	45	3.368	1.585	96.18	96.51	32.23	0.9966
6.00 pm – 9.00 pm	45	3.493	1.643	96.22	96.50	31.44	0.9963
9.00 pm – 12.00 midnight	45	3.282	1.567	96.23	96.49	31.65	0.9967

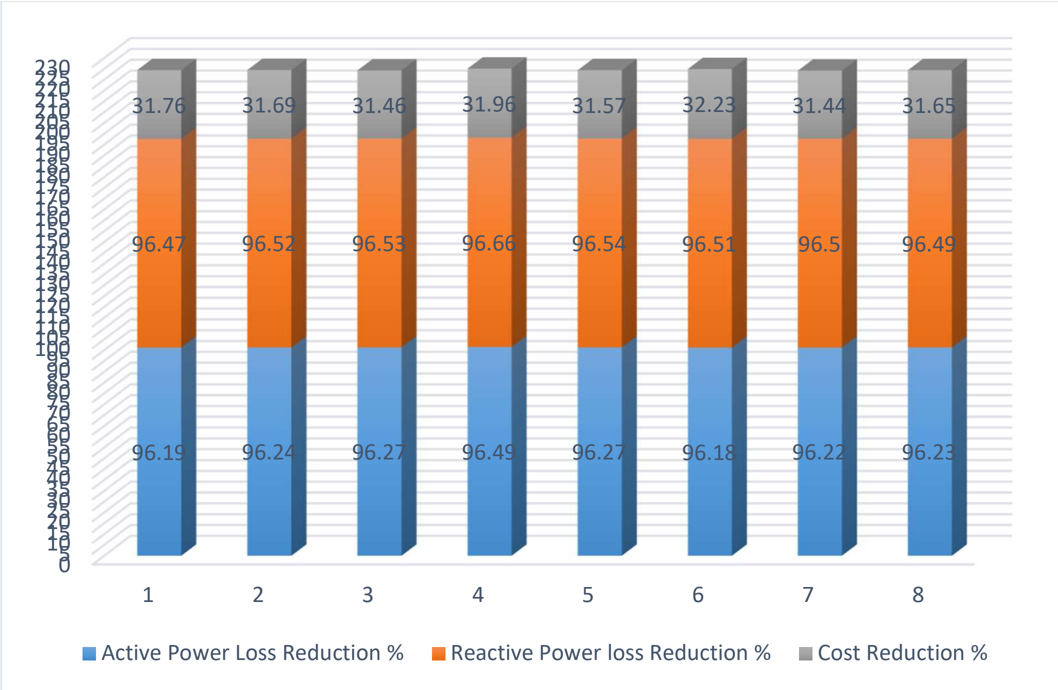


Figure 5.23: Summary of Optimal DG Planning Results- Mallawapitiya Feeder 8

According to the above results, different active and reactive power requirements are needed to fulfill optimal DG requirements in 8-time intervals for given constraints. But optimal DG location is the same for all 8 different cases also. DG with selected active and reactive power at 9.00 am – 12.00 noon is proposed as optimal DG for Mallawapitiya feeder 8 by considering its higher percentages of power losses and cost reduction compared to others. The geographical view of the proposed DG location is indicated in figure 5.24.

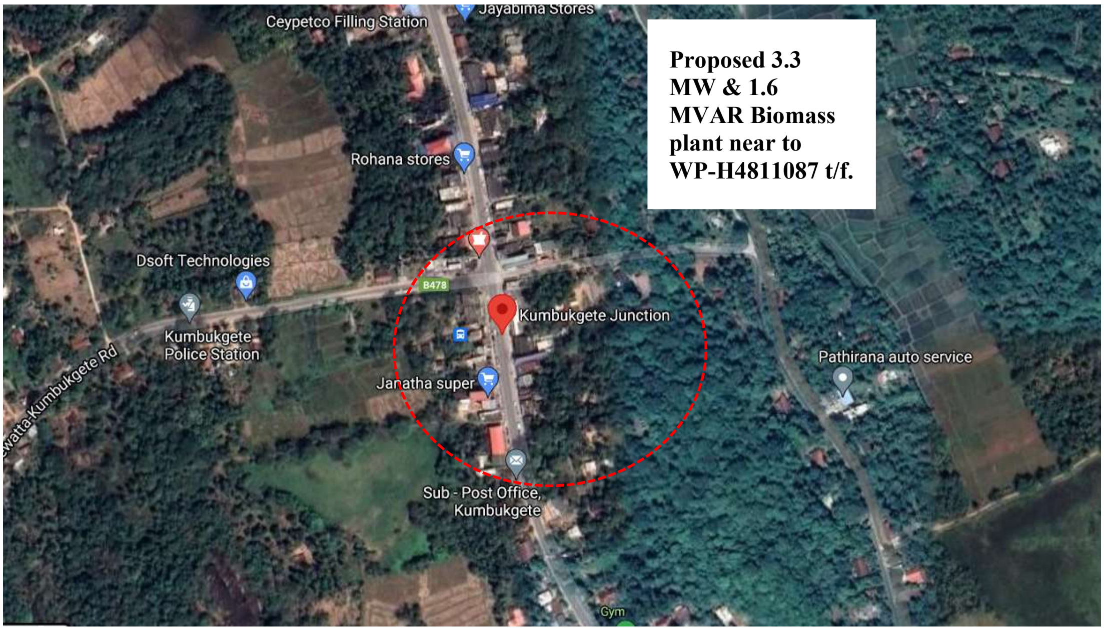


Figure 5.24: Geological View of Proposed DG Plant Location- Mallawapitiya Feeder8

5.1.4 Validation of the Power Flow Results- Mallawapitiya Feeder 8

Optimal results obtained from the algorithm are validated using PSS/E software. Network diagram, load data and line data of the Mallawapitiya feeder 8 on PSS/E are shown in figure 5.25, figure 5.26 and figure 5.27.

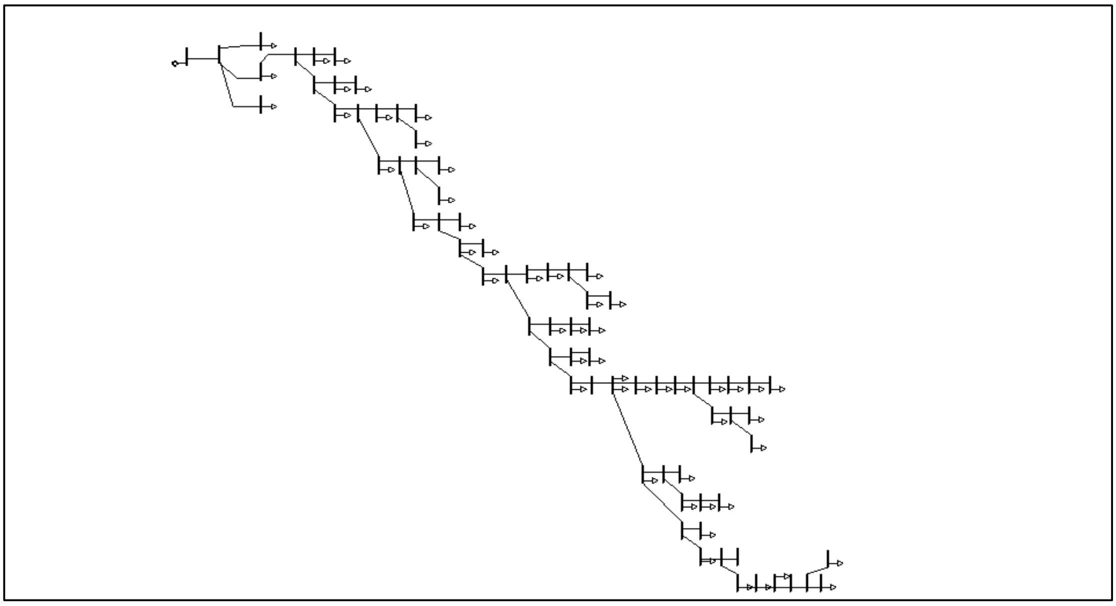


Figure 5.25: Network Diagram on PSS/E Software- Mallawapitiya Feeder 8

Bus Number	Pload (MW)	Qload (Mvar)	Bus Name
3	0.312480	0.193644	3BUS 33.000
4	0.065480	0.040578	4BUS 33.000
5	0.055870	0.034623	5BUS 33.000
7	0.059710	0.037002	7BUS 33.000
8	0.052170	0.032330	8BUS 33.000
10	0.095450	0.059150	10BUS 33.00
11	0.046140	0.028593	11BUS 33.00
12	0.085710	0.053114	12BUS 33.00
14	0.040120	0.024862	14BUS 33.00
16	0.086120	0.053369	16BUS 33.00
17	0.059150	0.036655	17BUS 33.00
18	0.050140	0.031072	18BUS 33.00
21	0.059140	0.036649	21BUS 33.00
22	0.040150	0.024881	22BUS 33.00
23	0.049780	0.030849	23BUS 33.00
25	0.064230	0.039803	25BUS 33.00
26	0.189140	0.117210	26BUS 33.00
27	0.051480	0.031902	27BUS 33.00
28	0.090450	0.056052	28BUS 33.00
30	0.066580	0.041260	30BUS 33.00
31	0.057100	0.035385	31BUS 33.00
33	0.050140	0.031072	33BUS 33.00
34	0.062040	0.038446	34BUS 33.00
35	0.041040	0.025432	35BUS 33.00
37	0.053150	0.032937	37BUS 33.00
38	0.063140	0.039128	38BUS 33.00
39	0.045780	0.028370	39BUS 33.00
41	0.057410	0.035577	41BUS 33.00
42	0.067400	0.041768	42BUS 33.00
43	0.051010	0.031611	43BUS 33.00
45	0.182010	0.112792	45BUS 33.00

Bus | Plant | Machine | Load | Fixed

Bus Number	Pload (MW)	Qload (Mvar)	Bus Name
38	0.063140	0.039128	38BUS 33.00
39	0.045780	0.028370	39BUS 33.00
41	0.057410	0.035577	41BUS 33.00
42	0.067400	0.041768	42BUS 33.00
43	0.051010	0.031611	43BUS 33.00
45	0.182010	0.112792	45BUS 33.00
45	-3.330000	1.596000	45BUS 33.00
46	0.040950	0.025377	46BUS 33.00
47	0.312010	0.193353	47BUS 33.00
48	0.047880	0.029671	48BUS 33.00
50	0.063140	0.039128	50BUS 33.00
51	0.053780	0.033327	51BUS 33.00
52	0.058810	0.036445	52BUS 33.00
53	0.043240	0.026796	53BUS 33.00
54	0.040890	0.025340	54BUS 33.00
56	0.042980	0.026635	56BUS 33.00
57	0.053040	0.032869	57BUS 33.00
58	0.048730	0.030198	58BUS 33.00
60	0.072150	0.044711	60BUS 33.00
61	0.092010	0.057019	61BUS 33.00
62	0.063140	0.039128	62BUS 33.00
63	0.054420	0.033724	63BUS 33.00
65	0.050140	0.031072	65BUS 33.00
66	0.059140	0.036649	66BUS 33.00
69	0.062140	0.038508	69BUS 33.00
70	0.094280	0.058425	70BUS 33.00
71	0.083470	0.051726	71BUS 33.00
74	0.049450	0.030644	74BUS 33.00
75	0.525470	0.325634	75BUS 33.00

Bus | Plant | Machine | Load | Fixed

Figure 5.26: Load Data on PSS/E Software- Mallawapitiya Feeder 8

From Bus Number	To Bus Number	Line R (pu)	Line X (pu)
1	2	0.245111	0.135821
2	3	0.020564	0.011395
2	4	0.047937	0.026563
2	5	0.103232	0.057203
5	6	0.045906	0.025438
6	7	0.110783	0.027057
6	9	0.154057	0.085367
7	8	0.335026	0.081824
9	10	0.599645	0.146454
9	12	0.029569	0.016385
10	11	0.642944	0.157029
12	13	0.053228	0.029495
13	14	0.565461	0.138105
13	18	0.030034	0.016642
14	15	0.141683	0.034604
15	16	0.081098	0.019807
15	17	0.236347	0.057724
18	19	0.184606	0.102294
19	20	0.034882	0.019329
19	23	0.028818	0.015969
20	21	0.068099	0.037735
20	22	0.123485	0.068426
23	24	0.018910	0.010478
24	25	0.125127	0.069336
24	26	0.180368	0.099946
26	27	0.083055	0.046022
26	28	0.022909	0.012695
28	29	0.129269	0.071631
29	30	0.116566	0.064592
29	36	0.110625	0.061300
30	31	0.167909	0.093042

Bus | Plant | Machine | Load | Fixed

From Bus Number	To Bus Number	Line R (pu)	Line X (pu)
30	31	0.167909	0.093042
31	32	0.035012	0.019401
32	33	0.209880	0.051260
32	34	0.283338	0.069201
34	35	0.486189	0.118744
36	37	0.147625	0.036055
36	40	0.024761	0.013721
37	38	0.342168	0.083569
38	39	0.492546	0.120296
40	41	0.099557	0.055167
40	43	0.092261	0.051124
41	42	0.569413	0.139070
43	44	0.092738	0.051388
44	45	0.078664	0.043589
45	46	0.155111	0.037883
45	58	0.047154	0.026129
46	47	0.088985	0.021733
47	48	0.056780	0.013868
48	49	0.052768	0.012888
49	50	0.186367	0.045517
49	54	0.329146	0.080388
50	51	0.331930	0.081068
51	52	0.163795	0.040004
52	53	0.121448	0.029662
54	55	0.146656	0.035818
55	56	0.299997	0.073269
55	57	0.168958	0.041265
58	59	0.145856	0.035623
58	64	0.143383	0.079451
59	60	0.104698	0.025571
59	61	0.788652	0.192615

Bus | Plant | Machine | Load | Fixed

From Bus Number	To Bus Number	Line R (pu)	Line X (pu)
45	58	0.047154	0.026129
46	47	0.088985	0.021733
47	48	0.056780	0.013868
48	49	0.052768	0.012888
49	50	0.186367	0.045517
49	54	0.329146	0.080388
50	51	0.331930	0.081068
51	52	0.163795	0.040004
52	53	0.121448	0.029662
54	55	0.146656	0.035818
55	56	0.299997	0.073269
55	57	0.168958	0.041265
58	59	0.145856	0.035623
58	64	0.143383	0.079451
59	60	0.104698	0.025571
59	61	0.788652	0.192615
61	62	0.414964	0.101348
62	63	0.421961	0.103057
64	65	0.148689	0.082392
64	66	0.055072	0.030516
66	67	0.084370	0.046751
67	68	0.134519	0.074540
67	69	0.015238	0.008444
69	70	0.120316	0.066670
70	71	0.033359	0.018485
71	72	0.049829	0.027612
72	73	0.123054	0.068187
73	74	0.030706	0.017015
73	75	0.054882	0.030411

Bus | Plant | Machine | Load | Fixed

Figure 5.27: Line Data on PSS/E Software- Mallawapitiya Feeder 8

The optimal DG size for Mallawapitiya feeder 8 is obtained as 3.33 MW and 1.596 MVAR from the proposed algorithm and the DG is applied to randomly selected locations and power loss reduction is obtained. The observed percentage values of active power loss reduction and reactive power loss reduction are shown in table 5.9 and table 5.10 respectively. The analyzed results are shown in figure 5.28 and figure 5.29. According to the results, maximum power loss reduction is obtained in same as results from the proposed model and the proposed mathematical model is validated.

Table 5.9: P_{Loss} Reduction Results at PSS/E with Optimal DG- Mallawapitiya

Node	Power from Grid (MW)	Power from DG (MW)	Load (MW)	Power Loss (kW)	Power Loss at Basecase (kW)	Power Loss Reduction %
5	1.241	3.33	4.361	210.27	744.03	71.74
10	1.268	3.33	4.361	237.26	744.03	68.11
15	1.262	3.33	4.361	230.63	744.03	69.00
20	1.143	3.33	4.361	112.01	744.03	84.95
25	1.147	3.33	4.361	116.36	744.03	84.36
30	1.098	3.33	4.361	66.92	744.03	91.01
35	1.217	3.33	4.361	185.74	744.03	75.04
40	1.072	3.33	4.361	41.48	744.03	94.43
41	1.085	3.33	4.361	54.26	744.03	92.71
42	1.158	3.33	4.361	126.65	744.03	82.98
43	1.111	3.33	4.361	80.28	744.03	89.21
44	1.069	3.33	4.361	37.72	744.03	94.93
45	1.057	3.33	4.361	25.97	744.03	96.51
46	1.068	3.33	4.361	36.87	744.03	95.04
47	1.074	3.33	4.361	43.42	744.03	94.16
48	1.080	3.33	4.361	49.07	744.03	93.40
49	1.085	3.33	4.361	54.50	744.03	92.67
50	1.106	3.33	4.361	75.53	744.03	89.85
55	1.142	3.33	4.361	110.92	744.03	85.09
60	1.088	3.33	4.361	56.81	744.03	92.36
65	1.085	3.33	4.361	54.49	744.03	92.68
70	1.084	3.33	4.361	53.18	744.03	92.85
75	1.106	3.33	4.361	74.63	744.03	89.97

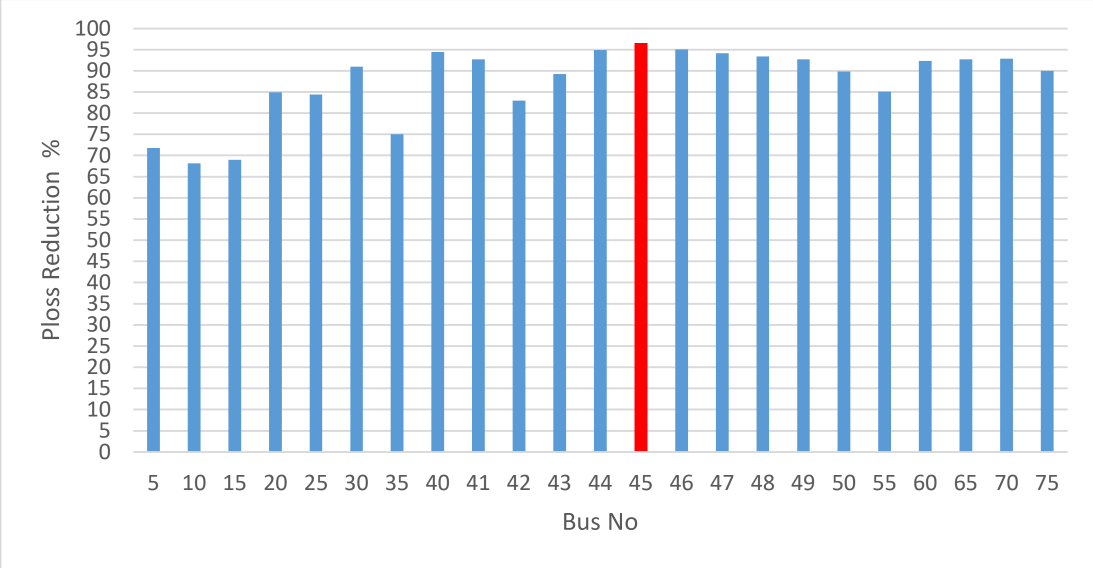


Figure 5.28: P_{Loss} Reduction Results at PSS/E with Optimal DG- Mallawapitiya

Table 5.10: Q_{Loss} Reduction Results at PSS/E with Optimal DG- Mallawapitiya

Node	Power from Grid (MVar)	Power from DG (MVar)	Load (MVar)	Power Loss (kVar)	Power Loss at Basecase (kVar)	Power Loss Reduction %
5	1.222	1.596	2.702	115.13	411.95	72.05
10	1.214	1.596	2.702	107.60	411.95	73.88
45	1.207	1.596	2.702	100.71	411.95	75.55
20	1.167	1.596	2.702	60.74	411.95	85.26
25	1.169	1.596	2.702	63.15	411.95	84.67
30	1.142	1.596	2.702	35.79	411.95	91.31
35	1.179	1.596	2.702	72.17	411.95	82.48
40	1.145	1.596	2.702	21.71	411.95	90.73
41	1.135	1.596	2.702	28.79	411.95	93.01
42	1.153	1.596	2.702	46.58	411.95	88.69
43	1.129	1.596	2.702	22.62	411.95	94.51
44	1.126	1.596	2.702	19.65	411.95	95.23
45	1.120	1.596	2.702	13.84	411.95	96.64
46	1.127	1.596	2.702	20.52	411.95	95.02
47	1.129	1.596	2.702	21.50	411.95	94.48
48	1.129	1.596	2.702	22.90	411.95	94.44
49	1.131	1.596	2.702	24.22	411.95	94.12
50	1.132	1.596	2.702	25.28	411.95	93.86
55	1.140	1.596	2.702	33.98	411.95	91.75
60	1.132	1.596	2.702	21.06	411.95	93.89
65	1.135	1.596	2.702	28.95	411.95	92.97
70	1.132	1.596	2.702	28.22	411.95	93.15
75	1.147	1.596	2.702	40.11	411.95	90.26

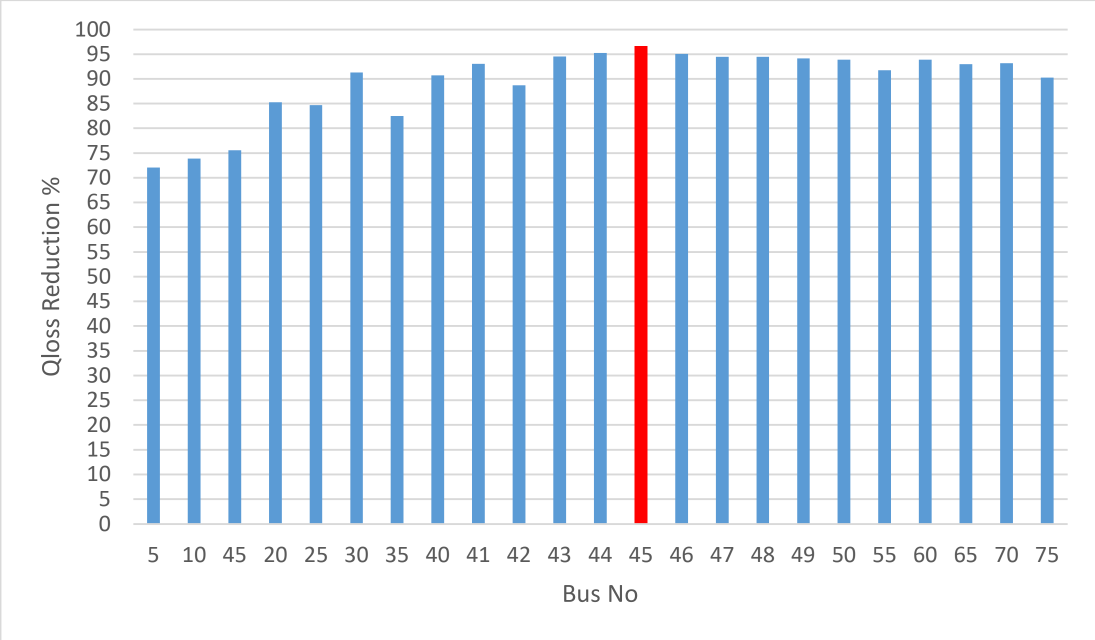


Figure 5.29: Q_{Loss} Reduction Results at PSS/E with Optimal DG- Mallawapitiya

5.3 DG Addition in Distribution System Sri Lanka

DG integration in the Sri Lankan distribution system has increased rapidly. The following two criteria are considered DG planning in the Sri Lankan distribution network.

- Voltage Criteria: Within (+6%) or (-6%) of nominal voltage at the point of supply
- Loading Criteria: Up to max. 80% of the transformer capacity

For DG planning and analysis, the" SynerGEE Electric" software tool is used in CEB. The procedure of DG planning in SynerGEE Electric software is shown in figure 5.30.

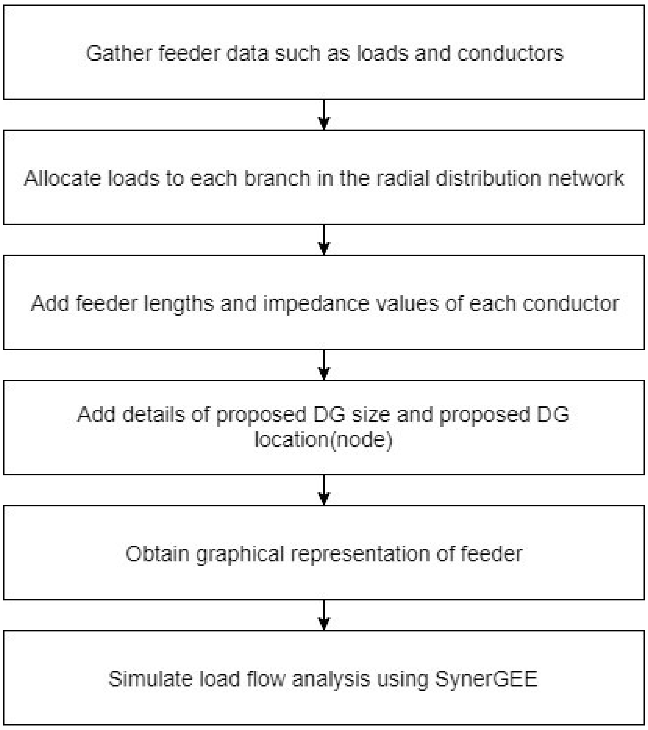


Figure 5.30: Procedure of DG Planning Using SynerGEE Electric Software

A comparison of the proposed model and conventional software is illustrated in table 5.11.

Table 5.11: Comparison of Proposed Model and SynerGEE Electric Software Modeling

Proposed Method	Distribution Modeling Software (SynerGEE)
Can consider multi-objective optimization with ±6% voltage criteria Minimize power loss Minimize DG cost	Mainly consider voltage criteria (Check node voltage with acceptable range ±6%)
Can select the optimal size of DG by given DG limits	Can use predefined DG sizes for analysis
Can select the optimal node (DG location) for DG installation	Can use predefined nodes (DG location) for analysis
Can obtain optimal solution simply	Requires computational time for the optimal solution but slow convergence

6. CONCLUSIONS AND RECOMMONDATIONS

6.1 Conclusion

The research is based on optimal sizing and sitting of DG by minimizing power loss in distribution system with minimum DGs cost. By qualitative and quantitative analysis of available mathematical techniques, Particle Swarm Optimization (PSO) and Newton Raphson (NR) methods are used to develop the proposed mathematical model. Active and reactive power generation limits of DG, bus voltage limits and discrete DG technologies are considered as constraints for the model. The proposed algorithm is developed by MATLAB interface.

The model has been applied to IEEE-30 test bus system by considering type 01 DG(DGs capable of injecting active power only) and type 02 DG(DGs capable of injecting real power and reactive power) with one level loads for different weighting factors. The summary of the test bus system results is listed in table 6.1.

Table 6.1 : Summary of Test Bus System Results

		Active Power Loss Reduction %	Reactive Power Loss Reduction %	Cost Reduction %	Minimum Voltage	Optimal location	Optimal DG Size
Type 01 DG (IEEE 30 Bus System)	Scenario2	31.56		49.95	0.9566	19	23.23 MW
	Scenario 3	30.07		49.96	0.9565	19	20.191 MW
	Scenario 4	24.54		50.07	0.9563	19	13.307 MW
	Scenario 5	32.11		47.05	0.9573	15	32.017 MW
	Scenario 6	11.37		50.17	0.9557	19	5 MW
Type 02 DG (IEEE 30 Bus System)	Scenario 2	33.96	50.97	49.09	0.9645	15	35.091 MW,14.588 MVAR
	Scenario 3	33.02	51.09	48.61	0.9649	15	37.477 MW, 15.24 MVAR
	Scenario 4	33.03	51.17	48.62	0.9649	15	37.444 MW, 15.229 MVAR
	Scenario 5	34.19	48.48	49.12	0.9624	15	32.3 MW, 10.328 MVAR
	Scenario 6	28.15	53.17	48.14	0.9655	15	46.096 MW, 16.434 MVAR
	Scenario 7	14.46	15.41	51.35	0.9739	24	5 MW, 11.248 MVAR

The simulation results are analyzed and validated. It was noted that the newly proposed mathematical model has better results for optimal siting and sizing DG in the test bus system. By the results, the most suitable weighting factors for techno-economical solution in type 1 DG are W_1 =0.7 (The factor for active power loss minimization function) and W_2 = 0.3 (The factor for cost minimization function). And most suitable weighting factors for type 2 DG are, W_1 =0.5 (The factor for active power loss minimization function), W_2 =0.3 (The factor for reactive power loss minimization function) and W_3 = 0.2 (The factor for cost minimization function)

With the successful implementation of the proposed model, this can apply to grid interconnection proposals of DG in the Sri Lankan Distribution system. When applying the model to the actual scenario, it is important to identify DG variation and load variation patterns throughout a day. Two case studies are discussed in this study for type 1 DG at Kalubowila feeder and type 2 DG modeling at Mallawapitiya feeder 8. The summary of the results in case studies is listed in table 6.2.

Table 6.2 : Summary of the Results in Case Studies

		Active Power Loss Reduction %	Reactive Power Loss Reduction%	Cost Reduction %	Minimum Voltage	Optimal location	Optimal DG Size
Kalubowila Feeder	6am – 9am	83.14		44.93	0.9942	52	814.156 kW
	9am-12 noon	83.27		52.98	0.9941	52	445.208 kW
	12noon– 3pm	82.38		53.02	0.9941	52	437.239 kW
	3pm – 6pm	78.68		51.85	0.9934	52	609.463 kW
Mallawapitiya Feeder 8	12mdngt-3am	96.19	96.47	31.76	0.9969	45	3.174 MW, 1.566 MVar
	3am – 6am	96.24	96.52	31.69	0.9968	45	3.239 MW, 1.54 MVar
	6am – 9am	96.27	96.53	31.46	0.9965	45	3.435 MW, 1.608 MVar
	9am-12 noon	96.49	96.66	31.96	0.9968	45	3.333 MW, 1.596 MVar
	12noon– 3pm	96.27	96.54	31.57	0.9967	45	3.325 MW, 1.582 MVar
	3pm – 6pm	96.28	96.51	32.23	0.9966	45	3.368 MW, 1.585 MVar
	6pm–9pm	96.22	96.5	31.44	0.9963	45	3.493 MW, 1.643 MVar
	9pm– 12mdngt	96.23	96.49	31.65	0.9967	45	3.282 , 1.567 MVar

By analyzing power loss and cost reduction results of case studies at different time intervals, it is proposed a 445.208 kW solar plant at bus 52 to Kalubowila feeder with 83.27% power loss reduction and 52.98% cost reduction. Also, it is proposed 3.33 MW and 1.596 MVAR biomass plant at bus 45 to Mallawapitiya feeder with 96.49% active power loss, 96.66% reactive power loss and 31.96% cost reduction. The two feeders are modeled using PSS/E and the proposed algorithm results are validated.

Additionally, it is important to identify most proper environmental conditions for DG locating otherwise need to move DG on nearest node. Table 6.3 illustrates the impact that happens when changing optimal DG to nearest locations in case studies.

Table 6.3: Impact on Changing DGs in Nearest Locations- Case Studies

	Optimal DG Location	Nearest Locations	Deviation of Active Power Loss Reduction %	Deviation of Reactive Power loss Reduction %
Kalubowila Feeder	52	51	1.36%	-
		53	6.11%	-
Mallawapitiya Feeder	45	44	1.58%	1.41%
		46	1.47%	1.62%

Furthermore, it is concluded that the proposed algorithm can apply any distribution feeder to obtain optimal sizing and siting of DGs with the best techno-economical performance at MV distribution feeders in the country.

6.2 Limitations and Assumptions

Limitations and basic assumptions of the proposed model are listed below.

1. Effect of load variation

   Average load data of the particular time intervals are considered for optimal DG planning in actual distribution feeders. And it is assumed load is constant for selected time intervals. According to the load variation data of feeders in different time intervals, the maximum effect of load deviation for DG planning in Kalubowila feeder is ($\pm$3.95%) and Mallawapitiya feeder 8 is ($\pm$2.02%).

2. Cost characteristics of DGs

   It is important to provide accurate cost values for DGs for modeling. But future cost fluctuations are not considered for the model. For solar PV generation in case study 1, capital cost and O & M cost are assumed as 200000 Rs/ kW and 3 Rs/ kWh respectively. For biomass generation in case study 2, capital cost, fuel cost and O & M cost are assumed as 250000 Rs/ kW, 15 Rs/ kWh and 8 Rs/ kWh respectively.

3. System condition

   In this study, only the balanced MV distribution feeder is considered. Also, the model is applied for radial distribution feeder

6.3 Recommendations

Outcomes of the study can apply any MV distribution feeder in the country for optimal sizing and placing of DGs. It is required to follow guidelines below for optimal DG planning for a selected distribution feeder from the proposed mathematical model.

1. Required feeder data (line and load data)
   - Conductor types and lengths of feeder
   - Geological connection of each node
   - Demand data of each node
   - Preconnected DG sizes and location
2. Required DG data
   - DG type (Solar/ Biomass/ wind)
   - DG generation limits
3. Process
   - Apply to the proposed algorithm by changing line and load data of feeder and DG constraints
4. Objective achievement
   - Minimize active and reactive power losses of the distribution system
   - Minimize DG cost
   - Voltage-profile improvement
5. Outputs
   - Optimal DG size (Type 01: DGs capable of injectingP only/ Type 02: DGs capable of injecting both PandQ)
   - Optimal DG location at the feeder

6.4 Future Work

In this study, single DG placement and sizing were introduced and the current cost value of DG was considered. The proposed mathematical algorithm can be further developed as below.

1. Multi-DG planning

The proposed algorithm can be incorporated into multi-DG planning for a distribution feeder by increasing the number of variables in PSO and providing DG variable range.

2. NPV of the cost component

Net present value (NPV) indicates all the costs of installing, fuel, operation and maintenance components of DG through the project lifetime. The objective function of the cost component in the proposed algorithm will be composed of NPV by relevance factors from a proper evaluation of the cost and a lifetime of DGs.

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APPENDIX-A

A.1: Line Data of IEEE-30 Test Bus System

Line		Line Impedance (p.u.)	
From	To	Resistance	Reactance
1	2	0.0192	0.0575
1	3	0.0452	0.1652
2	4	0.057	0.1737
3	4	0.0132	0.0379
2	5	0.0472	0.1983
2	6	0.0581	0.1763
4	6	0.0119	0.0414
5	7	0.046	0.116
6	7	0.0267	0.082
6	8	0.012	0.042
6	9	0	0.208
6	10	0	0.556
9	11	0	0.208
9	10	0	0.11
4	12	0	0.256
12	13	0	0.14
12	14	0.1231	0.2559
12	15	0.0662	0.1304
12	16	0.0945	0.1987
14	15	0.221	0.1997
16	17	0.0524	0.1923
15	18	0.1073	0.2185
18	19	0.0639	0.1292
19	20	0.034	0.068
10	20	0.0936	0.209
10	17	0.0324	0.0845
10	21	0.0348	0.0749
10	22	0.0727	0.1499
21	22	0.0116	0.0236
15	23	0.1	0.202
22	24	0.115	0.179
23	24	0.132	0.27
24	25	0.1885	0.3292
25	26	0.2544	0.38
25	27	0.1093	0.2087
28	27	0	0.396
27	29	0.2198	0.4153
27	30	0.3202	0.6027
29	30	0.2399	0.4533
8	28	0.0636	0.2
6	28	0.0169	0.0599

A.2 : Load Data of IEEE -30 Test Bus System

Bus No	Voltage (pu)	Pgen	Qgen	Pload	Qload	Bus Type
1	1.06	0	0	0	0	Slack Bus
2	1.043	40	50	2.17	1.27	PV Bus
3	1.00	0	0	2.4	1.2	PQ Bus
4	1.06	0	0	3.6	1.6	PQ Bus
5	1.01	0	3.7	3.42	1.9	PV Bus
6	1.00	0	0	0	0	PQ Bus
7	1.00	0	0	2.28	1.09	PQ Bus
8	1.01	0	3.73	3.0	3.0	PV Bus
9	1.00	0	0	0	0	PQ Bus
10	1.00	0	0	5.8	2	PV Bus
11	1.00	0	16.2	0	0	PQ Bus
12	1.00	0	0	1.12	0.75	PQ Bus
13	1.00	0	10.6	0	0	PV Bus
14	1.00	0	0	6.2	1.6	PQ Bus
15	1.00	0	0	8.2	2.5	PQ Bus
16	1.00	0	0	3.5	1.8	PQ Bus
17	1.00	0	0	9	5.8	PQ Bus
18	1.00	0	0	3.2	0.9	PQ Bus
19	1.00	0	0	9.5	3.4	PQ Bus
20	1.00	0	4.3	2.2	0.7	PQ Bus
21	1.00	0	0	1.75	1.12	PQ Bus
22	1.00	0	0	0	0	PQ Bus
23	1.00	0	0	3.2	1.6	PQ Bus
24	1.00	0	0	8.7	6.7	PQ Bus
25	1.00	0	0	0	0	PQ Bus
26	1.00	0	0	3.5	2.3	PQ Bus
27	1.00	0	0	0	0	PQ Bus
28	1.00	0	0	0	0	PQ Bus
29	1.00	0	0	2.4	0.9	PQ Bus
30	1.00	0	0	1.06	0.19	PQ Bus

APPENDIX-B

B.1: Locations and Transformers Details of Kalubowila Feeder

Node	T/F Name	T/F (kVA)	Place	Node	T/F Name	T/F (kVA)	Place
1				36	AZ0515	160	Kolobathanthri Mw 2
2				37	AZ0217	160	EW Perera MW NR Angampitiya Rd
3				38			
4				39			
5	AZ1003	100	Wickramasinghe Place	40	AZ0219	160	Rampart Road
6				41	AZ1047	250	RuIsuru
7	AZ8272	250	Randi Garment	42			
8	AZ0530	160	Ethul Kotte Nr Pertrol Shed	43	AZ0540	160	Angampitiya Road
9	AZ8721	160	Lanka Orix Information Tecnology	44			
10	AZ8702	160	DR Jayasinghe	45	AZ0550	160	RNH Ethul Kotte
11	AZ0202	250	Near Uswatte Mw	46	AZ8299	250	Nigata
12	AZ8903	100	KLS Rajapakse	47			
13				48	AZ8906	400	Prime Lands Ethul Kotte
14	AZ0205	100	Maligawa Rd	49	AZ8915	160	SMS Holdings
15	AZ1041	160	Maligawa Road No 18	50	AZ1009	160	Bangla JN
16	AZ8701	100	Cargills Ceylon Ltd,Ethul Kotte Rd	51			
17	AZ8211	400	Mobitel	52	AZ1038	250	SkyLine
18	AZ8210	630	Ceylon Paper Sacks	53	AZ0520	160	Mission Road
19	AZ0203	160	Near Jyaweera Mw	54	AZ0221	250	Bangla JN
20	AZ0536	100	New Jayaweera Mw	55	AZ0447	160	Beddagana Road
21	AZ8260	100	Graphic System	56	AZ8266	100	Foot Ball Fedaration
22	AZ8907	400	Capital Trust Residenceies	57	AZ8706	250	Solis Reception Hall
23	AZ1008	160	Ethul Kotte	58	AZ8271	160	Keels Super (Bandul)
24	AZ8286	100	TKN Perera	59			
25				60	AZ8707	400	Min. of Envir. & National Resources
26	AZ0215	400	Mahindarama Road 1	61	AZ0517	160	Epitamulla RD
27	AZ1004	160	Mahindarama Road 2	62			
28	AZ0525	160	Ethul Kotte Nr Mati Ambalama	63	AZ0228	250	Epitamulla RD
29	AZ8742	100	Dambadiav Vandana	64	AZ8231	400	National Water Board
30				65	AZ8232	400	National Water Board
31	AZ0539	100	9TH Lane	66	AZ0229	160	Kotte Road Nr Epitamulla
32	AZ1031	400	PRIME Homes	67	AZ1037	160	Dialog Building
33	AZ0542	100	Alakeshwara Road	68			
34				69	AZ0524	100	4th Ln Pita KOT
35	AZ0220	160	Kolobathanthri Mw 1	70			

B.2: Line Data of Kalubowila-Feeder

From	To	Length (m)	R (per km)	R	R pu	X (per km)	X	X pu
1	2	109	0.20457	0.02230	0.018428	0.33056	0.03603	0.029778
2	3	107	0.20457	0.02189	0.018090	0.33056	0.03537	0.029231
3	4	15	0.20457	0.00307	0.002536	0.33056	0.00496	0.004098
4	5	64	0.50498	0.03232	0.026710	0.36253	0.02320	0.019175
4	6	127	0.20457	0.02598	0.021471	0.33056	0.04198	0.034695
6	7	86	0.50498	0.04343	0.035891	0.36253	0.03118	0.025767
7	8	26	0.50498	0.01313	0.010851	0.36253	0.00943	0.007790
8	9	23	0.50498	0.01162	0.009599	0.36253	0.00834	0.006891
9	10	34	0.50498	0.01717	0.014190	0.36253	0.01233	0.010187
6	11	25	0.20457	0.00511	0.004227	0.33056	0.00826	0.006830
11	12	400	0.50498	0.20199	0.166936	0.36253	0.14501	0.119845
11	13	144	0.20457	0.02946	0.024346	0.33056	0.04760	0.039339
13	14	127	0.50498	0.06413	0.053002	0.36253	0.04604	0.038051
14	15	50	0.50498	0.02525	0.020867	0.36253	0.01813	0.014981
13	16	70	0.20457	0.01432	0.011835	0.33056	0.02314	0.019123
16	17	54	0.20457	0.01105	0.009130	0.33056	0.01785	0.014752
17	18	15	0.20457	0.00307	0.002536	0.33056	0.00496	0.004098
18	19	37	0.20457	0.00757	0.006255	0.33056	0.01223	0.010108
19	20	69	0.20457	0.01412	0.011666	0.33056	0.02281	0.018850
20	21	12	0.20457	0.00246	0.002029	0.33056	0.00397	0.003278
21	22	31	0.20457	0.00634	0.005241	0.33056	0.01025	0.008469
22	23	47	0.20457	0.00962	0.007946	0.33056	0.01554	0.012840
23	24	61	0.20457	0.01248	0.010313	0.33056	0.02016	0.016665
24	25	62	0.20457	0.01268	0.010482	0.33056	0.02050	0.016938
25	26	75	0.50498	0.03787	0.031300	0.36253	0.02719	0.022471
26	27	38	0.50498	0.01919	0.015859	0.36253	0.01378	0.011385
25	28	24	0.20457	0.00491	0.004058	0.33056	0.00793	0.006557
28	29	142	0.20457	0.02905	0.024007	0.33056	0.04694	0.038793
29	30	78	0.20457	0.01596	0.013187	0.33056	0.02578	0.021309
30	31	181	0.50498	0.09140	0.075538	0.36253	0.06562	0.054230
30	32	50	0.50498	0.02525	0.020867	0.36253	0.01813	0.014981
32	33	40	0.50498	0.02020	0.016694	0.36253	0.01450	0.011984
30	34	101	0.20457	0.02066	0.017076	0.33056	0.03339	0.027592
34	35	12	0.50498	0.00606	0.005008	0.36253	0.00435	0.003595
35	36	66	0.50498	0.03333	0.027544	0.36253	0.02393	0.019774
34	37	68	0.20457	0.01391	0.011496	0.33056	0.02248	0.018577

37	38	46	0.20457	0.00941	0.007777	0.33056	0.01521	0.012567
38	39	147	0.50498	0.07423	0.061349	0.36253	0.05329	0.044043
39	40	64	0.50498	0.03232	0.026710	0.36253	0.02320	0.019175
39	41	103	0.50498	0.05201	0.042986	0.36253	0.03734	0.030860
38	42	23	0.20457	0.00471	0.003889	0.33056	0.00760	0.006283
42	43	259	0.50498	0.13079	0.108091	0.36253	0.09390	0.077599
42	44	126	0.20457	0.02578	0.021302	0.33056	0.04165	0.034422
44	45	40	0.50498	0.02020	0.016694	0.36253	0.01450	0.011984
44	46	10	0.20457	0.00205	0.001691	0.33056	0.00331	0.002732
46	47	34	0.20457	0.00696	0.005748	0.33056	0.01124	0.009288
47	48	13	0.50498	0.00657	0.005425	0.36253	0.00471	0.003895
48	49	26	0.50498	0.01313	0.010851	0.36253	0.00943	0.007790
47	50	14	0.20457	0.00286	0.002367	0.33056	0.00463	0.003825
50	51	127	0.20457	0.02598	0.021471	0.33056	0.04198	0.034695
51	52	27	0.20457	0.00552	0.004565	0.33056	0.00893	0.007376
52	53	328	0.50498	0.16563	0.136887	0.36253	0.11891	0.098273
52	54	83	0.20457	0.01698	0.014032	0.33056	0.02744	0.022675
54	55	168	0.50498	0.08484	0.070113	0.36253	0.06091	0.050335
55	56	70	0.50498	0.03535	0.029214	0.36253	0.02538	0.020973
54	57	90	0.20457	0.01841	0.015216	0.33056	0.02975	0.024587
57	58	98	0.20457	0.02005	0.016568	0.33056	0.03240	0.026773
58	59	67	0.20457	0.01371	0.011327	0.33056	0.02215	0.018304
59	60	28	0.50498	0.01414	0.011685	0.36253	0.01015	0.008389
60	61	178	0.20457	0.03641	0.030094	0.33056	0.05884	0.048628
61	62	170	0.50498	0.08585	0.070948	0.36253	0.06163	0.050934
62	63	117	0.50498	0.05908	0.048829	0.36253	0.04242	0.035055
62	64	100	0.50498	0.05050	0.041734	0.36253	0.03625	0.029961
64	65	15	0.50498	0.00758	0.006260	0.36253	0.00544	0.004494
59	66	61	0.20457	0.01248	0.010313	0.33056	0.02016	0.016665
66	67	5	0.50498	0.00253	0.002087	0.36253	0.00181	0.001498
66	68	163	0.20457	0.03335	0.027558	0.33056	0.05388	0.044530
68	69	158	0.50498	0.07979	0.065940	0.36253	0.05728	0.047339
68	70	207	0.20457	0.04235	0.034997	0.33056	0.06843	0.056550

B.3: Load Data of Kalubowila Feeder

Node	6am-9am		9 am-12noon		12noon-3pm		3pm-6pm	
	P(kW)	Q (kVAR)	P(kW)	Q (kVAR)	P (kW)	Q (kVAR)	P(kW)	Q (kVAR)
1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	25.263	15.656	11.992	7.431	16.109	9.983	14.426	8.940
6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7	33.792	20.941	53.811	33.347	60.090	37.238	58.770	36.420
8	52.700	32.658	54.846	33.988	64.544	39.998	54.696	33.895
9	16.977	10.521	37.444	23.204	39.747	24.631	36.644	22.708
10	2.202	1.364	7.409	4.591	9.782	6.062	5.568	3.450
11	74.345	46.071	109.135	67.631	110.768	68.643	85.979	53.281
12	22.713	14.075	13.692	8.485	15.284	9.472	16.045	9.943
13	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
14	22.331	13.838	13.467	8.345	13.442	8.330	12.552	7.778
15	35.809	22.191	27.215	16.865	30.152	18.685	35.208	21.819
16	24.731	15.326	39.556	24.513	40.044	24.815	40.293	24.969
17	75.820	46.986	76.840	47.618	77.690	48.144	77.798	48.212
18	1.734	1.075	8.373	5.189	8.859	5.490	5.857	3.629
19	50.782	31.470	74.005	45.861	79.437	49.227	60.666	37.595
20	37.814	23.433	26.888	16.663	30.186	18.706	25.941	16.075
21	15.712	9.736	65.466	40.569	60.050	37.213	36.468	22.599
22	137.806	85.398	117.387	72.745	115.706	71.703	136.868	84.817
23	1.373	0.851	1.364	0.845	1.192	0.739	1.365	0.846
24	9.799	6.072	18.245	11.307	21.433	13.282	19.388	12.015
25	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
26	134.406	83.292	116.559	72.232	114.856	71.176	125.340	77.673
27	21.356	13.234	19.657	12.181	18.806	11.654	20.302	12.581
28	56.937	35.284	67.745	41.982	75.614	46.858	59.509	36.877
29	23.059	14.290	23.907	14.815	24.759	15.343	23.059	14.290
30	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
31	25.263	15.656	14.542	9.012	16.963	10.512	14.426	8.940
32	136.106	84.345	93.607	58.008	105.534	65.400	123.384	76.461
33	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
34	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
35	38.271	23.716	35.721	22.137	34.871	21.609	45.137	27.971
36	25.634	15.886	18.710	11.595	17.861	11.068	21.260	13.175
37	43.023	26.662	66.165	41.003	71.293	44.180	55.804	34.582
38	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
39	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
40	49.507	30.679	34.106	21.136	35.746	22.152	40.821	25.297
41	71.418	44.258	60.361	37.405	66.407	41.152	58.782	36.427
42	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
43	33.409	20.704	26.716	16.556	28.762	17.824	26.303	16.300

44	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
45	7.238	4.486	19.577	12.132	18.857	11.686	15.796	9.789
46	12.784	7.922	30.786	19.078	31.274	19.381	28.996	17.969
47	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
48	136.156	84.376	77.360	47.940	80.769	50.053	76.606	47.473
49	17.981	11.143	35.806	22.189	34.106	21.136	34.860	21.603
50	44.202	27.392	58.226	36.083	63.217	39.176	64.640	40.058
51	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
52	10.328	6.400	20.505	12.707	18.833	11.671	17.129	10.615
53	66.109	40.968	64.699	40.094	64.703	40.097	53.000	32.844
54	61.476	38.097	86.643	53.692	84.302	52.242	69.825	43.270
55	61.328	38.005	35.301	21.876	35.829	22.203	38.429	23.814
56	0.683	0.423	0.679	0.421	0.659	0.408	0.563	0.349
57	25.953	16.083	94.242	58.402	105.627	65.457	49.399	30.612
58	32.174	19.938	57.928	35.898	58.010	35.949	57.729	35.774
59	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
60	112.210	36.872	119.956	39.418	119.108	39.139	102.860	63.742
61	59.606	36.938	42.605	26.403	43.469	26.938	57.835	35.840
62	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
63	72.501	44.929	30.332	18.796	41.142	25.496	44.121	27.342
64	209.187	42.465	201.282	40.860	193.928	39.367	204.111	126.487
65	217.687	44.190	192.840	39.146	210.905	42.814	196.359	121.683
66	66.405	41.151	55.353	34.302	55.381	34.320	64.732	40.114
67	43.216	26.781	43.471	26.939	44.331	27.472	41.759	25.878
68	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
69	23.243	14.404	19.628	12.163	22.171	13.739	21.518	13.335
70	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

APPENDIX-C

C.1: Locations and Transformers Details of Mallawapitiya Feeder 8

Node	T/F Name	T/F (kVA)	Place	Node	T/F Name	T/F (kVA)	Place
1				**39**	4781083	100	Arankele
2				**40**			
3	4813013	400	Clothing (pvt) Ltd	**41**	4811084	100	Kurundugolla
4	4813415	100	Thimbirigasyaya Land Sale	**42**	4811085	100	Boraluwa Hewanegedara
5	4813084	100	Kanduluwa Junction	**43**	4781086	100	Clay prodcut Centre
6				**44**			
7	4813540	100	Karambayaya Watta	**45**	4811087	250	Kumbukgete
8	4813417	100	Godagama	**46**	4811088	100	Kumbukgete Town
9				**47**	4811162	400	Eco Transfer (Pvt) Ltd
10	4812014	160	Aragama	**48**	4811127	100	Koombuwa Kanda
11	4812419	100	Puddukkulama	**49**			
12	4812015	160	Kiribamuna	**50**	4781107	100	Ehetugaswewa
13				**51**	4781092	100	Bannaggama
14	4812558	100	Nelawa Deeyawa	**52**	4781093	100	Isak R/M
15				**53**	4781160	100	Athuruguruthenna
16	4812016	160	Nelawa Hekirilla Village	**54**	4781089	100	Dadapalagamuwa
17	4813474	100	Nelawa	**55**			
18	4812503	100	Wayamba Metal Works	**56**	4185091	100	Waduwawa
19				**57**	4185090	100	Ihalawaduwawa
20				**58**	4215094	100	Kasagala temple
21	4812456	100	Deeyawa	**59**			
22	4812425	100	Wewalagama	**60**	4215095	100	Hettigama Galwewa
23	4812066	100	Manapaha	**61**	4715096	160	Welgala
24				**62**	4215097	100	Nelliya 1
25	4812074	100	Rankirimada	**63**	4225096	100	Nelliya 2
26	4812075	250	Kumbukwewa	**64**			
27	4812149	100	Hipawwa	**65**	4215099	100	Palugahakanda
28	4812170	160	Janapriya Rice Mall	**66**	4215164	100	Mandapola
29				**67**			
30	4811076	100	Kolongolla	**68**			
31	4811078	100	Nikagolla 1	**69**	4215150	100	Ranjith Watta
32				**70**	4215100	160	Doraweruwa
33	4811078	100	Nikagolla 2	**71**	4215145	160	Govijanasewa (near)
34	4811079	100	Kimbulwana Oya (unit 3)	**72**			
35	4821080	100	4 Canel Exit	**73**			
36				**74**	4184126	100	Kadubodagama
37	4811081	100	Thiththarawella	**75**	4184141	1000	Delmo Breeder Ltd
38	4811082	100	Japagama Medalanda				

C.2: Line Data of Mallawapitiya Feeder 8

From	To	Length (km)	R (per km)	R	R pu	X (per km)	X	X pu
1	2	5.141	0.5192	2.66926	0.245111	0.2877	1.47909	0.135821
2	3	0.431	0.5192	0.22394	0.020564	0.2877	0.12409	0.011395
2	4	1.005	0.5192	0.52203	0.047937	0.2877	0.28927	0.026563
2	5	2.165	0.5192	1.12419	0.103232	0.2877	0.62294	0.057203
5	6	0.963	0.5192	0.49992	0.045906	0.2877	0.27702	0.025438
6	7	0.931	1.2963	1.20643	0.110783	0.3166	0.29465	0.027057
7	8	2.814	1.2963	3.64843	0.335026	0.3166	0.89107	0.081824
6	9	3.231	0.5192	1.67769	0.154057	0.2877	0.92964	0.085367
9	10	5.038	1.2963	6.53014	0.599645	0.3166	1.59488	0.146454
10	11	5.401	1.2963	7.00167	0.642944	0.3166	1.71004	0.157029
9	12	0.62	0.5192	0.32200	0.029569	0.2877	0.17843	0.016385
12	13	1.116	0.5192	0.57965	0.053228	0.2877	0.32120	0.029495
13	14	4.75	1.2963	6.15787	0.565461	0.3166	1.50396	0.138105
14	15	1.19	1.2963	1.54292	0.141683	0.3166	0.37683	0.034604
15	16	0.681	1.2963	0.88316	0.081098	0.3166	0.21570	0.019807
15	17	1.986	1.2963	2.57382	0.236347	0.3166	0.62861	0.057724
13	18	0.63	0.5192	0.32707	0.030034	0.2877	0.18124	0.016642
18	19	3.872	0.5192	2.01036	0.184606	0.2877	1.11398	0.102294
19	20	0.732	0.5192	0.37987	0.034882	0.2877	0.21049	0.019329
20	21	1.428	0.5192	0.74160	0.068099	0.2877	0.41094	0.037735
20	22	2.59	0.5192	1.34475	0.123485	0.2877	0.74516	0.068426
19	23	0.604	0.5192	0.31383	0.028818	0.2877	0.17390	0.015969
23	24	0.397	0.5192	0.20592	0.018910	0.2877	0.11411	0.010478
24	25	2.624	0.5192	1.36263	0.125127	0.2877	0.75506	0.069336
24	26	3.783	0.5192	1.96421	0.180368	0.2877	1.08841	0.099946
26	27	1.742	0.5192	0.90447	0.083055	0.2877	0.50119	0.046022
26	28	0.481	0.5192	0.24948	0.022909	0.2877	0.13824	0.012695
28	29	2.711	0.5192	1.40774	0.129269	0.2877	0.78006	0.071631
29	30	2.445	0.5192	1.26941	0.116566	0.2877	0.70341	0.064592
30	31	3.522	0.5192	1.82853	0.167909	0.2877	1.01323	0.093042
31	32	0.734	0.5192	0.38128	0.035012	0.2877	0.21127	0.019401
32	33	1.763	1.2963	2.28559	0.209880	0.3166	0.55822	0.051260
32	34	2.38	1.2963	3.08555	0.283338	0.3166	0.75360	0.069201
34	35	4.084	1.2963	5.29460	0.486189	0.3166	1.29312	0.118744
29	36	2.32	0.5192	1.20471	0.110625	0.2877	0.66756	0.061300
36	37	1.24	1.2963	1.60764	0.147625	0.3166	0.39264	0.036055
37	38	2.874	1.2963	3.72621	0.342168	0.3166	0.91007	0.083569

38	39	4.138	1.2963	5.36383	0.492546	0.3166	1.31003	0.120296
36	40	0.519	0.5192	0.26965	0.024761	0.2877	0.14942	0.013721
40	41	2.088	0.5192	1.08418	0.099557	0.2877	0.60077	0.055167
41	42	4.784	1.2963	6.20091	0.569413	0.3166	1.51447	0.139070
40	43	1.935	0.5192	1.00472	0.092261	0.2877	0.55674	0.051124
43	44	1.945	0.5192	1.00991	0.092738	0.2877	0.55962	0.051388
44	45	1.65	0.5192	0.85665	0.078664	0.2877	0.47469	0.043589
45	46	1.303	1.2963	1.68916	0.155111	0.3166	0.41255	0.037883
46	47	0.748	1.2963	0.96905	0.088985	0.3166	0.23667	0.021733
47	48	0.477	1.2963	0.61833	0.056780	0.3166	0.15102	0.013868
48	49	0.443	1.2963	0.57464	0.052768	0.3166	0.14035	0.012888
49	50	1.566	1.2963	2.02953	0.186367	0.3166	0.49568	0.045517
50	51	2.788	1.2963	3.61472	0.331930	0.3166	0.88284	0.081068
51	52	1.376	1.2963	1.78372	0.163795	0.3166	0.43565	0.040004
52	53	1.02	1.2963	1.32257	0.121448	0.3166	0.32302	0.029662
49	54	2.765	1.2963	3.58440	0.329146	0.3166	0.87543	0.080388
54	55	1.232	1.2963	1.59709	0.146656	0.3166	0.39006	0.035818
55	56	2.52	1.2963	3.26697	0.299997	0.3166	0.79790	0.073269
55	57	1.419	1.2963	1.83995	0.168958	0.3166	0.44938	0.041265
45	58	0.989	0.5192	0.51351	0.047154	0.2877	0.28455	0.026129
58	59	1.225	1.2963	1.58837	0.145856	0.3166	0.38793	0.035623
59	60	0.88	1.2963	1.14016	0.104698	0.3166	0.27847	0.025571
59	61	6.625	1.2963	8.58842	0.788652	0.3166	2.09758	0.192615
61	62	3.486	1.2963	4.51896	0.414964	0.3166	1.10368	0.101348
62	63	3.545	1.2963	4.59516	0.421961	0.3166	1.12229	0.103057
58	64	3.007	0.5192	1.56144	0.143383	0.2877	0.86523	0.079451
64	65	3.119	0.5192	1.61923	0.148689	0.2877	0.89725	0.082392
64	66	1.155	0.5192	0.59973	0.055072	0.2877	0.33232	0.030516
66	67	1.77	0.5192	0.91879	0.084370	0.2877	0.50912	0.046751
67	68	2.821	0.5192	1.46491	0.134519	0.2877	0.81174	0.074540
67	69	0.32	0.5192	0.16594	0.015238	0.2877	0.09195	0.008444
69	70	2.524	0.5192	1.31025	0.120316	0.2877	0.72604	0.066670
70	71	0.7	0.5192	0.36328	0.033359	0.2877	0.20130	0.018485
71	72	1.045	0.5192	0.54264	0.049829	0.2877	0.30069	0.027612
72	73	2.581	0.5192	1.34006	0.123054	0.2877	0.74256	0.068187
73	74	0.644	0.5192	0.33439	0.030706	0.2877	0.18529	0.017015
73	75	1.151	0.5192	0.59766	0.054882	0.2877	0.33118	0.030411

C.3: Load Data of Mallawapitiya Feeder 8

Node	12 mdngt-3.00 a.m		3.00 a.m–6.00 a.m		6.00 a.m–9.00 a.m		9.00 a.m–12.00 nn	
	P(kW)	Q (kVAR)	P(kW)	Q (kVAR)	P(kW)	Q (kVAR)	P(kW)	Q (kVAR)
1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	259.150	160.595	264.170	163.706	310.250	192.262	312.480	193.644
4	68.120	42.214	69.470	43.051	71.480	44.296	65.480	40.578
5	58.710	36.383	59.740	37.021	61.540	38.136	55.870	34.623
6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7	55.470	34.375	57.480	35.620	68.470	42.431	59.710	37.002
8	45.870	28.426	48.120	29.820	58.140	36.029	52.170	32.330
9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10	90.410	56.027	91.450	56.672	101.420	62.850	95.450	59.150
11	43.150	26.740	48.140	29.832	50.140	31.072	46.140	28.593
12	80.560	49.923	81.790	50.685	91.710	56.833	85.710	53.114
13	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
14	39.400	24.416	40.150	24.881	45.180	27.998	40.120	24.862
15	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
16	83.150	51.528	85.410	52.929	89.150	55.246	86.120	53.369
17	51.270	31.772	52.120	32.299	65.180	40.392	59.150	36.655
18	47.150	29.219	49.850	30.892	54.630	33.854	50.140	31.072
19	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
21	52.150	32.317	54.150	33.557	60.180	37.294	59.140	36.649
22	38.450	23.827	37.450	23.208	43.850	27.174	40.150	24.881
23	42.150	26.120	44.520	27.589	50.780	31.468	49.780	30.849
24	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
25	63.210	39.171	65.150	40.373	66.100	40.962	64.230	39.803
26	185.510	114.961	186.470	115.555	192.480	119.280	189.140	117.210
27	48.180	29.857	49.170	30.471	52.150	32.317	51.480	31.902
28	89.120	55.228	91.250	56.548	94.510	58.568	90.450	56.052
29	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
30	63.510	39.357	64.150	39.754	69.150	42.852	66.580	41.260
31	54.210	33.594	53.410	33.098	58.410	36.197	57.100	35.385
32	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
33	49.100	30.427	49.980	30.973	53.140	32.931	50.140	31.072
34	60.140	37.269	61.480	38.099	65.540	40.615	62.040	38.446
35	40.580	25.147	42.020	26.040	45.280	28.060	41.040	25.432
36	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
37	53.710	33.284	54.280	33.637	58.240	36.091	53.150	32.937
38	63.710	39.481	64.870	40.200	68.740	42.598	63.140	39.128
39	42.050	26.058	43.780	27.130	46.100	28.568	45.780	28.370
40	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
41	56.420	34.963	57.410	35.577	59.710	37.002	57.410	35.577
42	66.420	41.160	67.840	42.040	69.470	43.051	67.400	41.768
43	45.980	28.494	48.700	30.179	50.140	31.072	51.010	31.611

44	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
45	181.040	112.190	181.980	112.773	183.040	113.430	182.010	112.792
46	39.450	24.447	40.450	25.067	43.950	27.236	40.950	25.377
47	290.040	179.738	291.010	180.339	301.400	186.778	312.010	193.353
48	43.450	26.926	45.570	28.240	49.180	30.477	47.880	29.671
49	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
50	62.220	38.558	63.100	39.103	65.040	40.305	63.140	39.128
51	52.470	32.516	53.780	33.327	55.980	34.691	53.780	33.327
52	57.210	35.453	58.110	36.011	60.810	37.684	58.810	36.445
53	42.870	26.567	43.170	26.752	45.780	28.370	43.240	26.796
54	38.710	23.989	39.740	24.627	42.040	26.052	40.890	25.340
55	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
56	41.010	25.414	42.010	26.034	44.380	27.502	42.980	26.635
57	51.480	31.902	52.040	32.249	54.780	33.947	53.040	32.869
58	47.380	29.361	48.170	29.851	50.470	31.276	48.730	30.198
59	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
60	70.800	43.875	71.480	44.296	73.150	45.331	72.150	44.711
61	88.720	54.980	89.020	55.166	93.480	57.930	92.010	57.019
62	62.140	38.508	64.930	40.237	66.480	41.198	63.140	39.128
63	53.450	33.123	55.480	34.381	57.150	35.416	54.420	33.724
64	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
65	48.150	29.839	49.120	30.440	53.040	32.869	50.140	31.072
66	57.150	35.416	58.140	36.029	60.140	37.269	59.140	36.649
67	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
68	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
69	60.140	37.269	61.540	38.136	64.780	40.144	62.140	38.508
70	94.140	58.339	95.470	59.163	97.140	60.198	94.280	58.425
71	83.480	51.733	84.750	52.520	86.490	53.598	83.470	51.726
72	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
73	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
74	48.480	30.043	49.780	30.849	52.140	32.311	49.450	30.644
75	500.400	310.098	503.150	311.802	524.150	324.816	525.470	325.634

Node	12.00 nn–3.00 p.m		3.00 p.m–6.00 p.m		6.00 p.m–9.00 p.m		9.00 p.m–12 mdngt	
	P(kW)	Q(kVAR)	P(kW)	Q (kVAR)	P (kW)	Q(kVAR)	P (kW)	Q(kVAR)
1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	315.840	195.726	309.450	191.766	298.450	184.949	260.410	161.376
4	64.780	40.144	68.710	42.580	73.480	45.536	70.410	43.633
5	54.780	33.947	58.740	36.401	63.470	39.332	60.490	37.486
6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7	58.970	36.544	60.710	37.622	69.480	43.057	58.470	36.234
8	51.170	31.710	53.140	32.931	58.450	36.221	49.120	30.440
9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10	93.450	57.911	95.450	59.150	111.780	69.270	100.810	62.472
11	47.120	29.200	49.170	30.471	56.170	34.809	48.170	29.851
12	83.470	51.726	85.410	52.929	91.580	56.752	82.140	50.902
13	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
14	40.210	24.918	43.120	26.721	49.840	30.886	40.170	24.893
15	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
16	84.270	52.222	87.150	54.007	90.170	55.878	87.610	54.292
17	60.120	37.256	60.140	37.269	68.150	42.233	58.150	36.036
18	51.420	31.865	52.730	32.677	59.170	36.668	50.120	31.059
19	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
21	58.140	36.029	59.670	36.977	65.170	40.386	60.450	37.461
22	41.250	25.563	42.580	26.387	45.270	28.054	41.500	25.718
23	48.950	30.334	49.650	30.768	45.180	27.998	42.180	26.139
24	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
25	62.180	38.533	61.250	37.957	68.450	42.418	65.250	40.435
26	186.180	115.376	187.840	116.404	195.480	121.139	189.120	117.198
27	49.710	30.805	50.420	31.245	55.780	34.567	49.560	30.712
28	89.150	55.246	90.150	55.866	97.180	60.222	90.780	56.256
29	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
30	67.150	41.613	68.150	42.233	72.150	44.711	68.400	42.387
31	56.150	34.796	57.140	35.410	60.010	37.188	55.540	34.418
32	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
33	51.260	31.766	52.150	32.317	54.980	34.071	50.210	31.115
34	63.240	39.190	64.010	39.667	67.450	41.799	61.010	37.808
35	42.010	26.034	43.780	27.130	47.350	29.343	42.890	26.579
36	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
37	54.010	33.470	55.010	34.090	60.780	37.665	56.150	34.796
38	64.060	39.698	65.470	40.572	70.140	43.466	66.720	41.346
39	44.050	27.298	45.980	28.494	47.840	29.646	43.780	27.130
40	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
41	57.480	35.620	58.420	36.203	61.870	38.341	57.150	35.416
42	68.010	42.146	68.890	42.691	71.450	44.278	67.480	41.817
43	51.890	32.156	51.070	31.648	47.010	29.132	46.010	28.512
44	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
45	181.010	112.172	182.890	113.337	185.780	115.128	182.980	113.393

46	41.850	25.934	42.800	26.523	46.010	28.512	41.150	25.501
47	312.470	193.638	318.140	197.151	295.040	182.836	293.580	181.932
48	48.540	30.080	48.990	30.359	50.280	31.159	44.040	27.292
49	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
50	62.870	38.961	63.780	39.524	67.070	41.563	63.140	39.128
51	52.740	32.683	53.980	33.451	57.470	35.614	53.720	33.290
52	58.740	36.401	59.040	36.587	63.140	39.128	59.780	37.046
53	42.040	26.052	43.890	27.199	47.850	29.653	43.010	26.653
54	40.720	25.234	41.010	25.414	43.010	26.653	40.420	25.048
55	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
56	42.010	26.034	43.410	26.901	45.040	27.911	43.180	26.759
57	52.140	32.311	53.470	33.135	55.140	34.170	53.140	32.931
58	48.790	30.235	48.990	30.359	52.010	32.231	50.340	31.196
59	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
60	72.480	44.916	71.480	44.296	74.830	46.372	71.480	44.296
61	91.010	56.399	92.890	57.564	95.780	59.355	93.400	57.880
62	63.870	39.580	64.550	40.002	67.480	41.817	63.150	39.134
63	54.250	33.619	55.450	34.362	58.140	36.029	54.180	33.575
64	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
65	50.780	31.468	51.120	31.679	55.020	34.096	53.010	32.850
66	58.470	36.234	59.140	36.649	62.010	38.428	59.140	36.649
67	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
68	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
69	62.870	38.961	63.100	39.103	66.980	41.508	62.890	38.973
70	93.480	57.930	94.820	58.760	98.470	61.022	96.480	59.789
71	82.460	51.100	83.470	51.726	87.640	54.311	85.640	53.071
72	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
73	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
74	50.480	31.282	51.800	32.100	54.150	33.557	51.140	31.691
75	527.150	326.675	522.140	323.570	512.140	317.373	502.140	311.176

APPENDIX-D

D.1: MATLAB Code for Line and Load Data - IEEE-30 Bus System

```
%Bus/ Line data
%Need to change load data and line data according to feeder

%No  Voltage Angle  Pgen    Qgen    Pload   Qload   Gshunt  Bshunt  Type

bus = [...

1   1.0600  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
1.0000   ;
2   1.0430  0.0000 40.0000 50.0000  2.17000 1.27000 0.0000  0.0000
2.0000    ;
3   1.0000  0.0000  0.0000  0.0000  2.4000  1.2000  0.0000  0.0000
3.0000    ;
4   1.0600  0.0000  0.0000  0.0000  3.6000  1.6000  0.0000  0.0000
3.0000    ;
5   1.0100  0.0000  0.0000  3.70000 3.42000 1.90000 0.0000  0.0000
2.0000    ;
6   1.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
3.0000    ;
7   1.0000  0.0000  0.0000  0.0000  2.28000 1.09000 0.0000  0.0000
3.0000    ;
8   1.0100  0.0000  0.0000  3.73000 3.0000  3.0000  0.0000  0.0000
2.0000    ;
9   1.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
3.0000    ;
10  1.0000  0.0000  0.0000  0.0000  5.8000  2.0000  0.0000  0.0000
3.0000    ;
11  1.0000  0.0000  0.0000  16.2000 0.0000  0.0000  0.0000  0.0000
2.0000    ;
12  1.0000  0.0000  0.0000  0.0000  1.12000 0.75000 0.0000  0.0000
3.0000    ;
13  1.0000  0.0000  0.0000  10.6000 0.0000  0.0000  0.0000  0.0000
2.0000    ;
14  1.0000  0.0000  0.0000  0.0000  6.2000  1.6000  0.0000  0.0000
3.0000    ;
15  1.0000  0.0000  0.0000  0.0000  8.2000  2.5000  0.0000  0.0000
3.0000    ;
16  1.0000  0.0000  0.0000  0.0000  3.5000  1.8000  0.0000  0.0000
3.0000    ;
17  1.0000  0.0000  0.0000  0.0000  9.0000  5.8000  0.0000  0.0000
3.0000    ;
18  1.0000  0.0000  0.0000  0.0000  3.2000  0.9000  0.0000  0.0000
3.0000    ;
19  1.0000  0.0000  0.0000  0.0000  9.5000  3.4000  0.0000  0.0000
3.0000    ;
20  1.0000  0.0000  0.0000  4.3000  2.2000  0.7000  0.0000  0.0000
3.0000    ;
21  1.0000  0.0000  0.0000  0.0000  1.75000 1.12000 0.0000  0.0000
3.0000    ;
22  1.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
3.0000    ;
```

```
23  1.0000  0.0000  0.0000  0.0000  3.2000  1.6000  0.0000  0.0000
3.0000    ;
24  1.0000  0.0000  0.0000  0.0000  8.7000  6.7000  0.0000  0.0000
3.0000    ;
25  1.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
3.0000    ;
26  1.0000  0.0000  0.0000  0.0000  3.5000  2.3000  0.0000  0.0000
3.0000    ;
27  1.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
3.0000    ;
28  1.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
3.0000    ;
29  1.0000  0.0000  0.0000  0.0000  2.4000  0.9000  0.0000  0.0000
3.0000    ;
30  1.0000  0.0000  0.0000  0.0000  1.06000 0.19000 0.0000  0.0000
3.0000    ];


%          |  From  |   To    |  R Value |  X Value|     B/2   |  TAP(x)|
%          |  Bus1  |  Bus2   |    pu    |    pu    |      pu   |  TAP     |
   line=[...
                1       2        0.01920     0.0575     0.00         1   ;
                1       3        0.04520     0.1652     0.00         1   ;
                2       4        0.05700     0.1737     0.00         1   ;
                3       4        0.01320     0.0379     0.00         1   ;
                2       5        0.04720     0.1983     0.00         1   ;
                2       6        0.05810     0.1763     0.00         1   ;
                4       6        0.01190     0.0414     0.00         1   ;
                5       7        0.04600     0.1160     0.00         1   ;
                6       7        0.02670     0.0820     0.00         1   ;
                6       8        0.01200     0.0420     0.00         1   ;
                6       9        0.00        0.2080     0.00         1   ;
                6      10        0.00        0.5560     0.00         1   ;
                9      11        0.00        0.2080     0.00         1   ;
                9      10        0.00        0.1100     0.00         1   ;
                4      12        0.00        0.2560     0.00         1   ;
               12      13        0.00        0.1400     0.00         1   ;
               12      14        0.12310     0.2559     0.00         1   ;
               12      15        0.06620     0.1304     0.00         1   ;
               12      16        0.09450     0.1987     0.00         1   ;
               14      15        0.22100     0.1997     0.00         1   ;
               16      17        0.05240     0.1923     0.00         1   ;
               15      18        0.10730     0.2185     0.00         1   ;
               18      19        0.06390     0.1292     0.00         1   ;
               19      20        0.03400     0.0680     0.00         1   ;
               10      20        0.09360     0.209      0.00         1   ;
               10      17        0.03240     0.0845     0.00         1   ;
               10      21        0.03480     0.0749     0.00         1   ;
               10      22        0.07270     0.1499     0.00         1   ;
               21      22        0.01160     0.0236     0.00         1   ;
               15      23        0.10000     0.2020     0.00         1   ;
               22      24        0.11500     0.1790     0.00         1   ;
               23      24        0.13200     0.2700     0.00         1   ;
               24      25        0.18850     0.3292     0.00         1   ;
               25      26        0.25440     0.3800     0.00         1   ;
               25      27        0.10930     0.2087     0.00         1   ;
               28      27        0.00        0.3960     0.00         1   ;
               27      29        0.21980     0.4153     0.00         1   ;
```

```
27      30      0.32020     0.6027     0.00        1   ;
29      30      0.23990     0.4533     0.00        1   ;
 8      28      0.06360     0.2000     0.00        1   ;
 6      28      0.01690     0.0599     0.00        1 ] ;
```

D.2 : MATLAB Codes for Newton-Raphson Load Flow Solution

Build Y-Bus Matrix

```
function [Y] = Y_admi(line,bus,nbuses)
% Build 'Y'BUS
Orden   = zeros  (1  ,  nbuses  );
Y    = zeros  (nbuses)  ;
for     k  =  1  :  nbuses
   orden   (k)  =  k  ;

end
for  p  =   1  : length  (  line  (:  ,  1  )  )  ;
   BusP  =    find  (orden  ==  line  (p  ,  1  ))  ;
   BusQ  =    find  (orden  ==  line  (p  ,  2  ))  ;
   a   =  line  (p  ,  6  )  ; %  Tap  value of  p-th  iteration

   if   a  >  0
   yl  =  (  1  /  (  (  line(p,3)+j*line(p,4))));  % line  admittance
   Ad  =  (  j  *  line  (p,5)  /  2  )  ;  %  line  charging
   Y  (BusP  ,  BusQ)  =    Y(  BusP  ,  BusQ)  -yl  /  a; % non-
diagonal  element
   Y    (  BusQ  ,  Bus  P  )  =  Y   (  BusP  ,  BusQ  )  ;
   Y   (  BusP   ,  BusP  )  =  Y  (  BusP  ,  BusP)+  (  yl / a ) +   (
(  1  /  a  )  *  (  1  /  a-1  )  *  yl  )  +  Ad  ;   %  Equivalent
admittance
   Y   (  BusQ  ,  BusQ  )  =  Y  (BusQ  ,  BusQ  )  +  (  yl  /  a  )   +
(  1  -  1  /  a  )  *  yl  +  Ad  ;  %Equivalent  admittance
   else  %  for  lines
        yl  =  (  1  /  (  (  line  (p  ,  3  )  +  j  *  line  (p  ,  4
))))  ;    %  line    admittance
        Ad  =  (  j  *   line  (  p  ,  5  )  /  2  )  ;    %  line
charging
        Y  (  BusP  ,  BusQ  )  =  Y  (  BusP  ,  BusQ  )  -  yl  ;   %
a   non  diagonal  element
        Y  (  BusQ  ,  BusP  )  =  Y  (  BusP  ,  BusQ  )  ;
        Y  (  BusP  ,  BusP)  =  Y  (BusP  ,  BusP  )  +  yl  ;  %
diagonal   element
        Y  (  BusQ  ,  BusQ  )  =  Y  (  BusQ  ,  BusQ  )  +  yl  ;  %
diagonal   element
        C  =  line  (  p  ,  5  )  ;  %  line  charging  for  the
whole   line
        if   c  >  0
            Y   (  BusP  ,  BusP  )  =  Y  (  BusP  ,  BusP  )  +  Ad  ;
            Y  (BusQ  ,  BusQ  )  =  Y  (  BusQ  ,  BusQ  )  +  Ad  ;
          end
      end
end
```

```
%  Susceptance  and   conductance
For   m    = 1  :  nbuses
   Dir  =  find   (orden  == bus  (  m  , 1  ))  ;
   Y  (  dir  ,  dir  )  =  Y  (  dir  ,  dir  )  +  bus  (m,  8   )  +  j
*  bus  (m  ,  9  )  ;
 end

 end
```

Calculate the Power of at Buses

```
function [  P_cal  ,Q_cal  ]  =  cal_power  (G, B, nodes, Tetha, V)

% Calculate   the   power   except   slack-bus
P_cal  =  zeros  (  nodes  ,  1  )  ;
Q_cal  =  zeros  (nodes  ,  1)  ;
for   k    = 1  :  nodes
   for   m  =   1  :  nodes
      P_cal  (k)    =  P_cal  (k)    +    V  (k)  *  V  (m)  *   ( G
(k,m)  *   cos  (  Tetha  (k)  -  Tetha  (m)  )   +    B  (k, m)*   sin
(  Tetha  (k)   -   Tetha  (m)  )  )  ;
      Q_cal  (k)    =  Q_cal  (k)    +    V  (k)  *   V  (m)  *   (   G
(k,m)  *   sin  (  Tetha  (k)  -  Tetha  (m)  )   -    B  (k,m)  *   cos
(  Tetha  (k)  -    Tetha  (m)  )  )  ;

end

end

end
```

Calculate the Power Mismatches

```
function
[mismatch_PQ]=mismatch_Power(P_neta,Q_neta,P_cal,Q_cal,nodes,PQ,nPQ)
% Calculate   mismatch   of   power
   dP  =  P_neta  -  P_cal  ;
   dQ  =  Q_neta  -  Q_cal  ;
   l  =  1  ;
   mismatch_Q   =  zeros  (  nPQ  ,  1  )   ;  %  Build   mismatchQ
   for   k  =  1  :  nPQ
      n  =  PQ  (  k  )  ;
      mismatch_Q  (l,1)  =  dQ  (  n   )  ;
      l  =  l  +  1   ;

end
   mismatch_P   =  dP  (  2  :  nodes  )  ;   %  Build  mismatchP
   mismatch_PQ  =  [  mismatch_P  ;  mismatch_Q  ]  ;   %  [dP  ;  dQ  ]


end
```

Calculate Elements in the Jacobian Matrix

```
function [J] = Jacobian(G,B,V,Tetha,nodes,PQ,nPQ)

% Build Jacobian matrix
J1 = zeros (nodes - 1 , nodes - 1 );
J2 = zeros (nodes - 1, nPQ ) ;
J3 = zeros (nPQ , nodes - 1 ) ;
J4 = zeros (nPQ , nPQ ) ;

% J1 [ dPk / dTethaj ]
for k = 2 : nodes
    for j = 2 : nodes
        if ( j == k )
        for m = 1 : nodes
            J1 ( k - 1 , j - 1 ) = J1 ( k - 1 , j - 1 )
+ ( V ( k ) * V ( m ) ) * ( -G ( k , m ) * sin (
Tetha ( k ) - Tetha ( m ) ) + B ( k , m ) * cos (
Tetha ( k ) - Tetha ( m ) ) ) ;
          end
            J1 ( k - 1 , j - 1 ) = J1 ( k - 1 , j - 1 )
- ( V ( k ) ^ 2 ) * B ( k , k ) ;
           else
            J1 ( k - 1 , j - 1 ) = V ( k ) * V ( j ) *
( G ( k , j ) * sin ( Tetha ( k ) - Tetha ( j ) ) - B
( k , j ) * cos ( Tetha ( k ) - Tetha ( j ) ) ) ;
          end
      end

end

% J2 [dPk / dV_j]
for k = 2 : nodes
    for j = 1 : nPQ
        m = PQ ( j ) ;
        if ( m == k )
        for m = 1 : nodes
            J2 ( k - 1 , j ) = J2 ( k - 1 , j ) + V (
m ) * ( G ( k , m ) * cos ( Tetha ( k ) - Tetha ( m
) ) + B ( k , m ) * sin ( Tetha ( k ) - Tetha ( m ) )
) ;
           end
            J2 ( k - 1 , j ) = J2 ( k - 1 , j ) + ( V (
k ) ) * G ( k , k ) ;
          else
            J2 ( k - 1 , j ) = V ( k ) * ( G ( k , m )
* cos ( Tetha ( k ) - Tetha ( m ) ) + B ( k , m ) *
sin ( Tetha ( k ) - Tetha ( m ) ) ) ;
           end
      end

end

% J3 [ dQk / dTeth_j ]
for k = 1 : nPQ
    n = PQ (k) ;
    for j = 2 : nodes
```

```
        if  ( j == n )
        for m   = 1 : nodes
            J3 ( k , j - 1 )  = J3 ( k , j - 1 ) + ( V
( n ) * V ( m ) ) * ( G ( n , m ) * cos ( Tetha ( n )
- Tetha ( m ) ) + B ( n , m ) * sin ( Tetha  ( n ) -
Tetha (  m ) ) ) ;
          end
            J3 ( k , j - 1 )  = J3 ( k , j - 1 ) -  ( V (
n )  ^ 2 ) * G ( n , n ) ;
          else
            J3 ( k , j - 1 )  = V ( n ) * V ( j ) * ( - G
( n , j ) *  cos ( Tetha ( n ) - Tetha ( j )  ) -B  ( n
,  j ) * sin ( Tetha ( n ) - Tetha ( j ) ) ) ;
          end
       end
  end


% J4  [ dQk / dV_j  ]
for  k = 1 : nPQ
    n = PQ  ( k ) ;
    for  j = 1 : nPQ
          m = PQ ( j )  ;
        if  ( m == n )
        for  m = 1 : nodes
            J4 ( k , j )  = J4 ( k , j )  + V  ( m ) * (
G ( n , m ) * sin ( Tetha  ( n ) - Tetha ( m ) )  - B
( n , m ) * cos ( Tetha  ( n ) - Tetha ( m ) ) ) ;
        end
            J4 ( k , j ) =  J4 ( k , j ) - V ( n ) * B (
n  , n ) ;
        else
            J4  ( k , j )  = V ( n )  * ( G ( n , m ) *
sin ( Tetha ( n ) - Tetha ( m ) ) - B ( n , m ) * cos
( Tetha ( n ) - Tetha ( m ) ) ) ;
          end
      end
  end

J  = [ J1  J2 ; J3  J4 ] ;
  end
```

<u>Power Flow Solution using NR for Base Case</u>

```
function [V,Theta,Y] = PowerFlowClassical(bus,line)

% Power flow for base case

nbuses=length(bus(:,1));     % Number of buses
[Y] = Y_admi(line,bus,nbuses); % Admittance matrix
V=bus(:,2);     % initial voltage
Theta=bus(:,3); % initial phase

% Net power (Generation - Load)

BMva = 100;              % Base MVA..
```

```
Pg=bus(:,4)/BMva;            %Pg
Pl=bus(:,6)/BMva;
P_neta=Pg-Pl;
Qg=bus(:,5)/BMva;
Ql=bus(:,7)/BMva;
Q_neta=Qg-Ql;

G  =  real  (  Y  )  ;           % conductance matrix
B  =  imag  (  Y  )  ;           % susceptance matrix

%  Types  of  buses
slack=find(bus(:,10)==1);% slack bus
PQ=find(bus(:,10)==3);  % PQ bus
PV=find(bus(:,10)==2);  % PV bus
% Adquiere the total number of buses
nslack  =  length  (slack);   % slack bus
nPQ  =  length  (  PQ  )  ;          %  number  of  PQ  buses
nPV  =  length  (  PV  )  ;          %  number  of  PV  buses
tol_max=10e-7;

%% Newton Raphson Method
Tol=1; %
Ciclos=0;
while (Tol>tol_max)
    [P_cal,Q_cal] = cal_power(G,B,nbuses,Theta,V);
    [mismatch_PQ]
=mismatch_Power(P_neta,Q_neta,P_cal,Q_cal,nbuses,PQ,nPQ);
    % Jacobian Matrix
    [J]=Jacobian(G,B,V,Theta,nbuses,PQ,nPQ);
    mismatch_X=inv(J)*mismatch_PQ;
    dTeth=mismatch_X(1:nbuses-1);
    dV=mismatch_X(nbuses:end);
    %Update V and Tetha
    Theta(2:nbuses)=Theta(2:nbuses)+dTeth;
    for i=1:nPQ
        n=PQ(i);
        V(n)=V(n)+dV(i);
    end
    Tol=max(abs(mismatch_PQ));
    Ciclos=Ciclos+1;
end
end
```

Power Flow Solution with DG

```
function [V,Theta,Y] = PowerFlowClassicalPSO(bus,line,x,run)
%Power flow calculation with DG

nbuses=length(bus(:,1));        % Number of buses
[Y] = Y_admi(line,bus,nbuses); % Admittance matrix
V=bus(:,2); % initial voltage
Theta=bus(:,3); % initial phase

% Net power

% Adding Pdg to the system
BMva = 100;                 % Base MVA..
Pg=bus(:,4)/BMva;            %Pg
```

```
Pl=bus(:,6)/BMva;
Pdg=x(1)/BMva;

for m=1:nbuses
    if m==run
       Pg_old= Pg(m);
       Pg(m)=  Pg_old + Pdg;
    else
        Pg(m)=Pg(m);
    end
end

P_neta=Pg-Pl;

% Adding Qdg to the system
Qg=bus(:,5)/BMva;
Ql=bus(:,7)/BMva;
Qdg=x(2)/BMva;

for m=1:nbuses
    if m==run
       Qg_old= Qg(m);
       Qg(m)=  Qg_old + Qdg;
    else
        Qg(m)=Qg(m);
    end
end

Q_neta=Qg-Ql;

%Get the conductance and suceptance matrix
G   =   real  (  Y  )  ;          %   conductane   matrix
B   =   imag  (  Y  )  ;          %   suceptance   matrix


%   Types   of   buses
Slack  =  find  (  bus  (  :  ,  10  )  ==  1  )  ;  % slack bus
PQ=find(bus(:,10)==3);   % PQ bus
PV=find(bus(:,10)==2);   % PV bus
% Adquiere the total number of buses
nslack=length(slack);    % slack bus

nPQ  =  length  (  PQ  )  ;         % number   of    PQ   buses

nPV  =  length  (  PV  )  ;         % number   of    PV   buses
tol_max=10e-7;          % tolerance of the solution
%% Iterative method Newton Raphson
Tol=1;
Ciclos=0;
while (Tol>tol_max)
    [P_cal,Q_cal] = cal_power(G,B,nbuses,Theta,V);
    [mismatch_PQ]
=mismatch_Power(P_neta,Q_neta,P_cal,Q_cal,nbuses,PQ,nPQ);
    % Jacobian Matrix
    [J]=Jacobian(G,B,V,Theta,nbuses,PQ,nPQ);
    mismatch_X=inv(J)*mismatch_PQ;
    dTeth=mismatch_X(1:nbuses-1);
    dV=mismatch_X(nbuses:end);
```

```
    %Update V and Tetha
    Theta(2:nbuses)=Theta(2:nbuses)+dTeth;
    for i=1:nPQ
        n=PQ(i);
        V(n)=V(n)+dV(i);
    end
    Tol=max(abs(mismatch_PQ));
    Ciclos=Ciclos+1;
end
end
```

D.3: MATLAB Code for Objective Function Generation

```
function [f,OF,Plosses,Qlosses,DgCost] =
ObjectiveFunction(V_n,line_o,Bgen,Theta_n,FromNode,ToNode,PQ,x)

%Build objective function
nbranch=length(line_o(:,1));

for k=1:nbranch

        Zpq(k)=line_o(k,3)+1i*line_o(k,4); % impedance of the line
        Ypq(k)=Zpq(k)^-1;    % admittance of the line
        gpq(k)=real(Ypq(k)); % conductance of the line
        gqp(k)=imag(Ypq(k));

% Active power loss
        Llpq  (  k  )   = gpq(k)  *  ( V_ n  (  FromNode (  k  ))^2 +
V_ n  (  ToNode  (  k  )  )  ^2   -  2  *  V_ n  (FromNode  (  k  )  )  *
V_ n  (  ToNode   ( k  )  )  *  cos  (  Theta_  n (  FromNode  (  k    )
)  -  Theta_ n  (  ToNode  (  k  )  )  )  )   ;
        % Reactive power loss
        Llqq  (  k  )  =  -gqp  ( k )*(V_ n( FromNode( k ))^2 +V_ n
(ToNode ( k )  )^2 -2 * V_ n  (  FromNode  (  k  ) )  *  V_ n ( ToNode
( k ) ) *cos(Theta_n(FromNode(k))-Theta_n(ToNode(k))));

end

Plosses= sum(Llpq);
Qlosses= abs(sum(Llqq));

%Need to select suitable cost function according to type of DG
%Need to modify DG cost for actual cases

% 1. Cost of solar PV DG for IEEE bus system
Cgt = (1.3*( 3985* 25*1000) + 0.01207* x (1)*1000*8*365
+4*1000*(86.2+Plosses*100-x (1)))/(1.3*( 3985* 50*1000) + 0.01207*
50*1000*8*365 +4*1000*(86.2+2.383-50));

% 2. Cost of biomass DG for IEEE bus system
Cgt = (1.3*( 1224* 25*1000) + (0.06481+ 0.0667)* x
(1)*1000*24*365*0.06 +4* 1000*(86.2+Plosses*100-x (1)))/(1*(1.3*(
1224* 50*1000) + (0.06481+0.0667)* 50*1000*24*365*0.06 +4*
1000*(86.2+2.38-50)));
```

```
DgCost= Cgt;

%select one scenario at once

% 1. Objective function for biomass DG  (Scenario #2 selected as
best)
OF=0.7*sum(Llpq) + 0.3*DgCost;    % Scenario #2
OF=0.5*sum(Llpq) + 0.5*DgCost;    % Scenario #3
OF=0.3*sum(Llpq) + 0.7*DgCost;    % Scenario #4
OF=sum(Llpq);                     % Scenario #5
OF= DgCost;                       % Scenario #6

% 2. Objective function for biomass DG  (Scenario #2 selected as
best)
OF=0.5*sum(Llpq) + 0.3*abs(sum(Llqq)) + 0.2*DgCost;    % Scenario #2
OF=0.4*sum(Llpq) + 0.4*abs(sum(Llqq)) + 0.2*DgCost;    % Scenario #3
OF=0.3*sum(Llpq) + 0.3*abs(sum(Llqq)) + 0.4*DgCost;    % Scenario #4
OF=sum(Llpq);                                           % Scenario #5
OF=abs(sum(Llqq));                                      % Scenario #6
OF=DgCost;                                             % Scenario #7



% Fitness Function
KL=1000; % Penalty factor
for k=1:length(PQ)
    % Voltage deviation criteria
    if  V_n (k+length(Bgen))<0.94
        DVL(k)=0.94-V_n(k+length(Bgen));
    end
    if  V_ n  ( k + length (Bgen))>  1.06
        DVL(k)=V_ n( k+  length  (Bgen))  - 1.06;
    end
    if  V_ n  ( k + length ( Bgen ) ) > =0.94
       if   V_ n(k + length (Bgen ) ) < =1.06
            DVL(k)=0;
        end
     end
end
DVLoads=sum(DVL.*DVL);
Z=OF+KL*DVLoads; % Caclulating Fitness Function
f=Z; % Fitness function
end
```

D.4: MATLAB Code for PSO and Load Flow Combination

```
%% Minimize Mulit-Objective function using NR+PSO
clear all; close all; clc


data_30;

bus_o=bus;
line_o=line;
slack=find(bus(:,10)==1);  % Slack bus
PV=find(bus(:,10)==2);     % Generation buses PV
Bgen=vertcat(slack,PV);    % Slack and PV buses
```

```
PQ=find(bus(:,10)==3);     % Load buses


Vmin=0.94;                          % Minimum value of voltage
Vmax=1.06;                          % Maximum value of voltage
n_nodos = length(bus(:,1));          % number of buses of the power
system
nbranch=length(line_o(:,1));
FromNode=line_o(:,1);
ToNode=line_o(:,2);


% Power flow for the base case
% Store V and theta
[V_o,Theta_o,~] = PowerFlowClassical(bus_o,line_o);

for k=1:nbranch

       Zpq(k)=line_o(k,3)+1i*line_o(k,4); % impedance of the line
       Ypq(k)=Zpq(k)^-1; % admittance of the linee
       gpq(k)=real(Ypq(k)); % conductance of the line
       gqp(k)=imag(Ypq(k));
       %power loss of the line
       Llpq(k)=gpq(k)*(V_o(FromNode(k))^2 +V_o(ToNode(k))^2 -
2*V_o(FromNode(k))*V_o(ToNode(k))*cos(Theta_o(FromNode(k))-
Theta_o(ToNode(k))));
       Llqq(k)=-gqp(k)*(V_o(FromNode(k))^2 +V_o(ToNode(k))^2 -
2*V_o(FromNode(k))*V_o(ToNode(k))*cos(Theta_o(FromNode(k))-
Theta_o(ToNode(k))));
end
% Total power lossess for base case
Plosses= sum(Llpq);
Qlosses= sum(Llqq);
fprintf('  Power Loss= %8.8f  %8.8f j', Plosses,Qlosses);

display_1=[bus(:,1) V_o ]; %Display bus voltages at base case
disp(display_1)

% Parameters of the optimization algorithm
%If DG is injecting active power only (solar pv), the algorithm has
one variable and its range

LB= [5 -3.0987];
UB= [50 16.4342];

%PSO parameters values
NVar = 2;                            % variables
pop = 250;                           % population  size
w max  =  0.9  ;                           % inertia  weight
w min  =  0.4  ;                           % inertia  weight
c1  =  2  ;                              % acceleration  factor
c2  =  2  ;                              % acceleration  factor


% Start pso
maxite   =  10  ;   %   max iteration
maxrun   =  n_nodos  ;    %   max   runs
```

```
for  run   = 2  :  maxrun

 run

%  Initialize  pso
for    i  =  1  :  pop
for    j  =  1  :  NVar
x0  (  i , j )  =  unifrnd  (  LB  (  j  )  ,  UB  (  j ) ) ;
end

end
x  =  x0   ;      %  initial  population
v  =  0.1  *  x0   ;    %    initial  velocity


for  i  =  1  :  pop

   [V_ n  ,Theta_ n] = PowerFlowClassicalPSO(bus,line,x0(i,:),run);
   [f0(i,1),
Plosses,Qlosses,DgCost]=ObjectiveFunction(V_n,line_o,Bgen,Theta_n,Fr
omNode,ToNode,PQ,  x0  (  i  ,: ) ) ;

  end

[  fmin0  ,  index0  ]  =  min  (  f 0 ) ;



pbest  =  x0  ;            %  initial  pbest
gbest  =  x0  (  index0  ,  :  )  ;    %  initial  gbest

% End of initializing


% Run pso
ite  =  1  ;

while  ite  <=  maxite

w  =  wmax  -  (  wmax  -  wmin   )  *  ite  /  maxite  ;  %    update
inertial  weight

%   velocity  update

For  i  =  1  :  pop
for  j  =  1  :  NVar
v  (  i  ,  j  )  =  w  *  v  (  i  , j )  +  c1  *  rand ()  *
(pbest(i,j)-x(i,j))...
+  c2  *  rand   ()  *  (  gbest  (  1  , j )  -  x  (  i  ,  j   )  )  ;

end

end

%  pso  position  update
for    i  =  1  :  pop
```

```
for     j  =  1  :  NVar
x  (  I  ,  j)  =  x  (  i , j )  + v  (  i , j )  ;
end
end


%  boundary  violations
for     i  =  1  :  pop
for     j  =  1  :  NVar
if     x  (  i  ,  j  )  <  LB  (  j )
x (  i , j  )  =  LB  (  j  )  ;
elseif   x  (  i  , j )  >  UB  ( j )
x ( i , j )   =  UB  ( j ) ;
end

end
end

%  Evaluate  fitness
for   i  =  1  :  pop
   [V_ n,  Theta_n] = PowerFlowClassicalPSO(bus,line,x(i,:),run);
 [f(i,:),OF,Plosses,Qlosses,DgCost]
=ObjectiveFunction(V_n,line_o,Bgen,Theta_n,FromNode,ToNode,PQ, x ( I
, :  ) ) ;

end

%  Update  pbest  and  fitness
for   i  =  1  :  pop
if   f  (  i  ,  1  )  <  f0  (  i  ,  1 )
   pbest  (  i  ,  :  )  =  x  (  I  ,  :  )  ;
f0  (  i  ,  1  )  =  f  (  i ,  1  )  ;
end
end

[  fmin  ,  index  ]  =  min  (f0)  ;   %  finding  best   particle
ffmin   (   ite  ,  run  )  =  fmin  ;     %  storing  best  fitness
ffite   (  run  )  =  ite  ;          %  storing  iteration  count

%  updating  gbest  and  best  fitness
If   fmin  <  fmin0
gbest  =  pbest  (  index  ,  :  )  ;
fmin0  =  fmin  ;

 end

ite  =  ite  +  1  ;

end

gbest;
[V_ng,Theta_ng] = PowerFlowClassicalPSO(bus,line,gbest,run);
[fvalue,OF,Pls, Qls ,DgCt]
=ObjectiveFunction(V_ng,line_o,Bgen,Theta_ng,FromNode,ToNode,PQ,gbes
t);
```

```
% print results for biomass DG (DG which injecting active and
reactivve power
disp(sprintf('Bus Data: %8g %8.8f %8.8f %8.8f %8.8f %8.4f
%8.4f',index, fvalue, Pls,Qls, DgCt,pbest(index,1),pbest(index,2)));

run=run+1;

end

% End pso main program
disp(sprintf('****************************************************
***'));
```