DEVELOPMENT OF A FIREFLY ALGORITHM BASED ANALYTICAL METHOD FOR OPTIMAL LOCATION AND SIZING OF DISTRIBUTED GENERATION IN RADIAL DISTRIBUTION NETWORKS

BY

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A DISSERTATION SUBMITTED TO THE DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING, AHMADU BELLO UNIVERSITY, ZARIA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE (M.Sc) DEGREE IN POWER SYSTEMS ENGINEERING

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DECLARATION

I, OLANIYAN Abdulrahman Adebayo, hereby declare that this dissertation titled "**Development of a Firefly Algorithm Based Analytical Method for Optimal Location and Sizing of Distributed Generation in Radial Distribution Networks**" was carried out by me in the Department of Electrical and Computer Engineering under the supervision of Prof. Jimoh Boyi and Dr. Yusuf Jibril as part of the requirements for the award of degree of Master of Science in Power Systems Engineering. The information derived from literature has been duly acknowledged in the text and a list of references provided. To the best of my knowledge, no part of this dissertation was previously presented for another degree or diploma at this or any other institution.

Abdulrahman Adebayo OLANIYAN

Signature Date

CERTIFICATION

This dissertation titled "DEVELOPMENT OF A FIREFLY ALGORITHM BASED ANALYTICAL METHOD FOR OPTIMAL LOCATION AND SIZING OF DISTRIBUTED GENERATION IN RADIAL DISTRIBUTION NETWORKS" by Abdulrahman Adebayo OLANIYAN meets the requirements for the award of degree of Master of Science (MSc) in Power Systems Engineering by Ahmadu Bello University, Zaria and it is approved for its contribution to knowledge and literary presentation.

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Prof. K. Bala

(Dean, School of Postgraduate Studies)	**Signature**	**Date**

DEDICATION

This work is dedicated to the supremacy of Almighty Allah (S.W.T) and to the memories of our loved ones whom we have lost.

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LIST OF ABBREVIATIONS

3D	Three Dimension
ACO	Ant Colony Optimization
AFC	Alkaline Fuel Cell
AFSA	Artificial Fish Swarm Algorithm
DG	Distribution Generation
DMF	Direct Methanol Fuel Cell
FA	Firefly Algorithm
GA	Genetic Algorithm
IEEE	Institute of Electrical and Electronics Engineers
kW	Kilowatts
MATLAB	Matrix Laboratory
MCFC	Molten Carbonate Fuel Cell
PAFC	Phosphoric Acid Fuel Cell
PEMFC	Proton Exchange Membrane Fuel Cell
PSO	Particle Swarm Optimization
PV	Photovoltaic
SOFC	Solid Oxide Fuel Cell
WT	Wind Turbine

ABSTRACT

Optimal location and sizing of Distribution Generation (DG) units in radial distribution networks is critical to achieving an improvement in stability, reliability and reduction of power losses in the network. This dissertation presents a hybridized solution which is a combination of the analytical method and the firefly algorithm for optimal placement and sizing of DGs. The conventional analytical method for optimal DG placement and sizing was first modelled. The standard firefly algorithm was then modelled and integrated with the analytical method to form the proposed hybridized solution. The conventional analytical method and the proposed method were applied on standard IEEE 33 and 69 test buses for optimal DG location and sizing and the results obtained were compared to the base case scenario without DG. For the 33-bus, the analytical method found the optimal location and size of the DG to be bus 30 and 548kW respectively while the proposed method found the optimal location and size to be bus 2 and 133kW respectively. These results obtained for 33-buscaused 26.87% reduction in system losses and16.44% improvement in voltage profile for the analytical method while the proposed model's result caused 28.36% reduction in losses and 33.54% improvement in voltage profile when compared with the base case. For the 69-bus network, the analytical method and the hybrid model obtained the same results which was bus 63 for the optimal location and 590kW for the optimal size thereby resulting in 10.29% reduction in losses and 45.35% improvement in voltage profile. Furthermore, the proposed method had a 90.06% reduction in simulation time for the 33-bus and 76.28% for the 69-bus as compared with the analytical method. The proposed hybrid model was validated by comparing the results obtained for the 33-bus system with the published results by Viral and Khatod, (2015).Thiscomparison showed that the proposed hybrid model is valid for solving optimal DG allocation problems as the voltage profile follows the same trend with a better performance than results published by Viral and Khatod, (2015). This is an indication that hybridization of two methods would provide an optimal result faster than stand-alone methods.

CHAPTER ONE

INTRODUCTION

1.1 General Background

Due to continuous economic growth and development, load demand in distribution networks are susceptible to sharp increment. Hence, the distribution networks in most developing nations like Nigeria, are operating very close to the voltage instability boundaries. The decline of voltage stability margin is one of the important factors which restricts increment in loads served by distribution companies (Jain *et al.*, 2014).

The rapidly increasing need for electrical power and difficulties in providing required capacity using traditional solutions, such as transmission network expansions and substation upgrades, provide a motivation to select Distributed Generation (DG) option. DG can be integrated into distribution systems to improve voltage profiles, power quality and the system generally (Muttaqi *et al.*, 2014). These DG units when integrated into distribution networks provide ancillary services such as spinning reserve, reactive power support, loss compensation, and frequency control. On the other hand, poorly planned and improperly operated DG units can lead to reverse power flows, excessive power losses and subsequent feeder overloads(Atwa *et al.*, 2010).

The DG solution may be more economical as it provides the system with a higher supply capacity and an additional power reserve. It provides an alternative source that can help fulfill requirements of growing power demands, improve reliability and efficiency of power supply as well as reduce the cost of electricity during peak hours (Leite da Silva *et al.*, 2012). According toGeorgilakis and Hatziargyriou (2013), DG placement impacts critically on the operation of the distribution network. Inappropriate DG placement may increase system losses, network capital and operating costs. On the contrary, optimal DG placement (ODGP)

can improve network performance in terms of voltage profile, reduce power flows and system losses along the distribution lines, and improve power quality and reliability of supply.

Soudi in his work (Soudi, 2013), was able to show that the greatest benefit of DG application in distribution system depends on the determining the optimal site and size of DG. The results of his work showed that the optimal application of DG could reduce the losses in the system up to 47%, cost of power purchase up to 92% and cost of energy not supplied by 40%. The voltage profile of the distribution system was also siginificantly improved.

Since the integration of DGs into a distribution network could either improve the network performance or cause an adverse effect on the network, distribution companies require methods to quantify the capacity and location of these new DGs that may be connected to the distribution networks. This task has attracted a siginificant interest with a wide range of methods, objectives and constraints (Gomez-Gonzalez *et al.*, 2012).

Several methods, objectives and constraints have been introduced by different researchers. Methods used include the classical or numerical method as presented by Atwa *et al.*, (2010), Ochoa and Harrison (2011) and Rau and Wan (1994); the analytical approach as presented by Wang and Nehrir, (2004), Acahrya *et al.*, (2006), Gözel and Hocoaglu, (2009), Hung *et al.*, (2010), Hung *et al.,* (2013) and Hung *et al.,* (2014). Another method used is the heuristic approach as proposed in the works of Abou El-Ela *et al.,* (2010), Soroudi and Ehsan (2011), Akorede *et al.*, (2011), Vinothkumar and Selvan (2011), and Vinothkumar and Selvan (2012). Some reasearchers have also used combined solution methods which involve using more than one approach as shown by Afzalan and Taghikhani (2012) and Moradi and Abedini (2012). These methods have also presented different kinds of objective functions varying from single to multiple objectives and different types of constraints have also been addresed. This dissertation presents a hybridized method which integrates the analytical

method into a meta-heuristic algorithm so as to optimally locate and size DGs in radial distribution networks.

1.2 Aim and Objectives

The aim of this research work is to develop a hybridized method for optimal location and sizing of DGs in radial distribution networks with the intent of minimising total real power loss and improving on the voltage profile of the network. The objectives are:

1. Development of a standard analytical method for optimal location and sizing of a DG.
2. Development of a firefly algorithm for optimal location of a DG.
3. Hybridization of objetives 1 and 2 in order to incorporate the analytical solution for sizing only before searching for the optimal location of the DG using the metaheuristic approach.
4. Validation of the hybridized solution method on standard IEEE-33 and 69 radial test buses.

1.3 Statement of Problem

The problem widely faced when integrating DGs into a distribution system is how to integrate them in order to achieve an improved performance of the distribution system. The search for an optimal location and size of DGs to be placed can be quite challenging. In most cases, the main methods used for locating and sizing a DG in a distribution network are analytical and heuristic methods. For the problem of optimal DG allocation, the analytical method may seem easy to implement and execute, but it is computationally exhaustive and time consuming while most meta-heuristic methods on the other hand, are seemingly robust but hardly produce optimal solution.In order to solve the shortcomings of these two methods (i.e. the computational exhaustion and time consumption of analytical method and non-optimality of results obtained by meta-heuristic methods), an integration of the analytical concept into the meta-heuristic algorithm would guide the algorithm to an optimal time-

saving solution. This will take advantage of both the precision of the analytical method and the flexibility and robustness of the meta-heuristic algorithm.

1.4 Motivation

A sharp increase in demand for energy has caused suppliers of energy to search for a quicker and relatively less expensive means of improving the declining reliability and stability of power distribution networks. This has therefore brought about the motivation to choose the option of Distributed Generation as an emergency approach to solve this problem because it is less expensive compared to the conventional transmission expansion or network reconfiguration. The next problem was then how to effectively integrate these DGs into distribution network to achieve the aim of improving distribution network performance rather than the reverse. This served as a motivation for this research.

1.5 Scope and Limitation

The limitations of this work are as follows:

1. All network assessments i.e. load flow, line losses, were done based on offline study of radial distribution networks.
2. System control and practical implementation of DG connection was not considered
3. The implementation was only applied to standard IEEE 33 and 69-busradial distribution test systems.

1.6 Methodology

The following steps which comprises the methodology adopted for this research are as follows:

1. Selection of a DG model that is suitable for voltage profile improvement and real power loss reduction;

2. Developing the analytical method for determining the optimal DG location and sizing using MATLAB;
3. Developing the Firefly Algorithm for determination of the optimal DG location using MATLAB;
4. Integrating the developed Firefly Algorithm into the analytical method to form a hybrid method on MATLAB platform;
5. Application of the developed analytical method on the standard test buses for selection of optimal DG location and size on MATLAB platform;
6. Application of the developed hybrid method on the standard test buses for selection of optimal DG location and size on MATLAB platform;
7. Comparing the results obtained from the analytical and hybrid method(i.e. power loss and voltage profile)
8. Validation by comparing results obtained with a previously published work.

1.9 Justification of Research

The results obtained from this research have justified that optimal location and sizing of Distribution Generators in radial distribution is very critical to achieving an improvement in the voltage profile and a reduction to the total losses of the network. These results are as follows:

1. Development of a firefly algorithm based analytical method for optimal location and sizing of Distribution Generation in radial distribution networkswhich caused an overall improvement of 33.54% in the voltage profile of the standard IEEE 33-bus system when compared to the base case scenario.
2. The developed method also resulted in 28.36% reduction in the total losses of the standard IEEE 33-bus system when compared to the base case scenario.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter is divided into two sections. The first section shows the review of fundamental concepts that will enable the understanding of the basic aspects of distribution systems, load flow analysis, etc. while the second section presents the review of similar works published in the area of DG placement and sizing.

2.2 Review of Fundamental Concepts

Fundamental concepts such as disributed generation, power flow analysis for radial distribution networks, standard IEEE testing benchmarks, general methods for placement and sizing of DGs and firefly algorithm basics are presented in this section.

2.2.1 Distributed generation (DG)

The IEEE defines distributed generation as the generation of electricity by facilities that are sufficiently smaller than central generating plants so as to allow interconnection at nearly any point in a power system (Pepermans *et al.*, 2005).

According to Georgilakis and Hatziargyriou (2013), distributed generation (also called decentralised generation, dispersed generation, and embedded generation) is defined as a small generator or an electric power source connected directly to the distribution network or on the customer site of the meter.

The difference between distribution and transmission networks is based on a legal definition. In most competitive markets, the legal definition for transmission networks is usually included as part of the electricity market regulation. Anything that is not defined under transmission network in the legislation, is suitable to be regarded as distribution network. The definition of distributed generation does not define the rating of the generation source, as the

maximum rating depends on the local distribution network conditions, e.g. voltage level. It is, however, useful to categorize distributed generation based on their different ratings (Ackermann *et al.*, 2001). Therefore, a DG is understood to be a small unit of generator which could be located at the consumer-side of the distribution network in order to improve power/energy management schemes, and it is connected, operated and integrated into the system at distribution voltage levels.

There are many kinds of DG application in the world today. From the constructional and technological points of view as shown in Figure 2.1, DGs can be classified into two groups namely; traditional and non-traditional generations (El-Khattam & Salama, 2004).

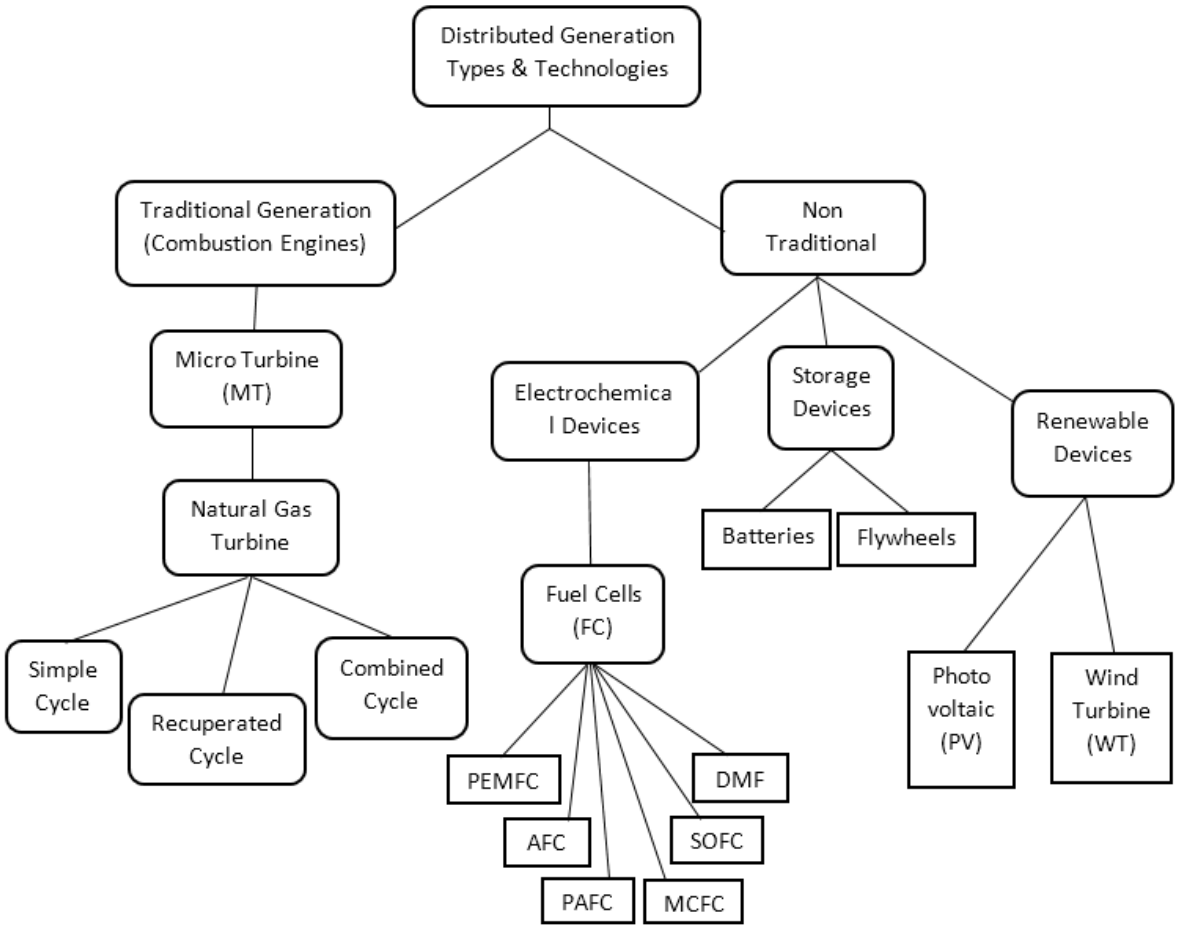


Figure 2.1: Types of Distributed Generation (El-Khattam & Salama,2004)

1. **Traditional distributed generation**

   These are mainly standard conventional generating systems which come in smaller units with smaller power ratings and can be directly integrated into the distribution voltage levels. They are basically combustion generators which are operated using non-renewable energy resources. They include micro-turbines, simple cycle gas turbines, recuperated gas turbines, combined cycle gas turbines, diesel generators and so on (El-Khattam & Salama, 2004).

2. **Non-traditional distributed generation**

   These are other types of non-conventional generating systems which come in small power ratings and can be integrated into the system at distribution voltage levels. They can be classified into storage devices, electromechanical devices and renewable energy devices as shown in Figure 2.1. Typical examples include Fuel cells, deep cycle batteries and flywheels, Photovoltaic (PV) modules, wind turbines (WT) and so on (El-Khattam & Salama, 2004). The different types of fuel cells are Proton Exchange Membrane Fuel Cell (PEMFC), Alkaline Fuel Cell (AFC), Phosphoric Acid Fuel Cell (PAFC), Direct Methanol Fuel cell (DMF), Solid Oxide Fuel Cell (SOFC) and Molten Carbonate Fuel Cell (MCFC) (El-Khattam & Salama, 2004).

DGs have shown a lot of advantages in power systems applications which is the major reason behind its widespread acceptance. Some major technical and economic benefits include (Pepermans *et al.*, 2005):

i. Reducing losses in the power system

ii. Improvement of voltage profile

iii. Increasing energy efficiency

iv. Improving reliability and regional consequences of system failure

v. Improving power quality and security

vi. Deferred investments for upgrades of facilities

vii. Lower operating cost because of peak shaving

viii. Enhanced productivity

ix. Deferred investment for upgrades facilities

2.2.2 Radial distribution network power flow

Distribution systems are predominantly characterized by their high resistance/impedance ratio and radial topology. Matrix based iterative methods do not lend themselves for radial distribution systems owing to these characteristics (Injeti & Prema Kumar, 2013). Therefore, the preliminary methods of load flow calculation (Gauss, Newton, etc.) cannot be directly and easily applied to radial distribution network. New algorithms have been developed in which the branches are represented by their single-line diagram and the loads are assumed to be balanced (Golkar, 2007). Figure 2.2 shows a simple three phase network which is represented by its single phase equivalent. As the system is balanced, the voltage and currents have the same magnitude but are shifted in phase by 120^{o} as represented in Figure 2.3.

The analysis begins by assuming initial values for the bus voltages. The currents taken by different buses are calculated starting from the end buses to the source. The source bus current is updated then the branch currents are again calculated from the source to the end buses. These calculations are repeated until the difference between the losses calculated in two consecutive iterations becomes considerably low (Golkar, 2007).

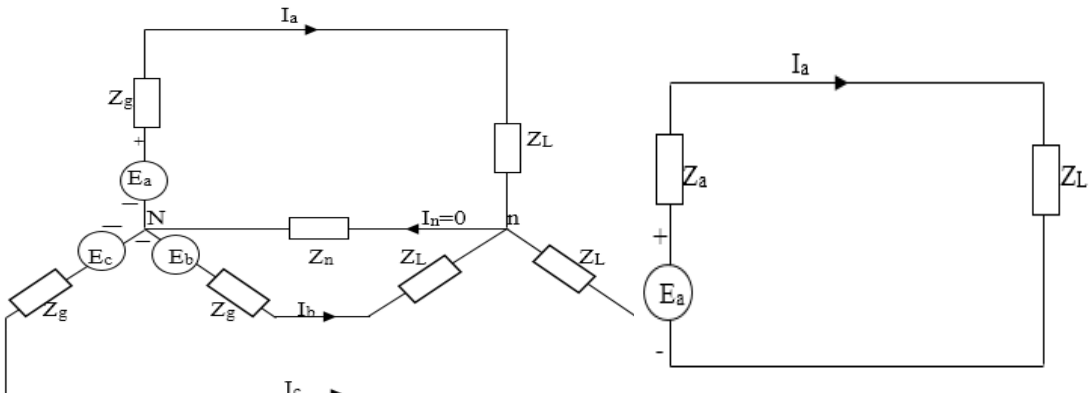


Figure 2.2: A Balanced Three Phase Network and its Single Line Representation

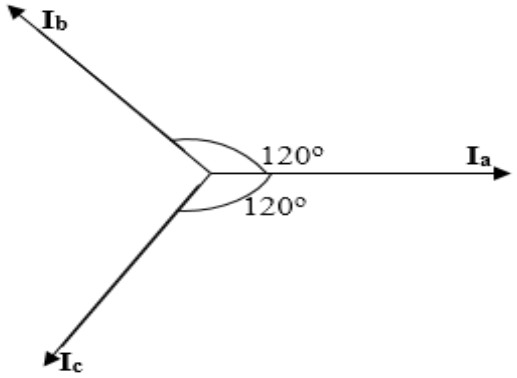


Figure 2.3: Phase Current Representation in a Balanced Three Phase Line (Golkar, 2007).

Golkar (2007) developed a technique suitable for calculating the load flow of an unbalanced 3-phase radial distribution system. This technique is implemented by proceeding from one branch to another in a systematic way until all the branches in the feeder have been traced. Initially, the voltages at all the buses, except the source bus, are assumed to be 1 per unit, at an angle zero (0) for phase a. Phase b is at an angle positive 120^o and Phase c is at an angle negative120^o as shown in Figure 2.3. The branch currents, starting from the end buses to the source, are then calculated and saved based on these voltages and specified active and reactive powers. Then, branch currents, including the return-conductor current, are computed in order to find the active and reactive power losses in the system. The source current is now calculated as follows (Golkar, 2007):

$$I_a = \frac{(\sum_a P + \sum_a P_{loss} + j(\sum_a Q + \sum_a Q_{loss}))}{V_{Sa}^*} \qquad (2.1)$$

$$I_b = \frac{(\sum_b P + \sum_b P_{loss} + j(\sum_b Q + \sum_b Q_{loss}))}{V_{Sb}^*} \quad (2.2)$$

$$I_c = \frac{(\sum_c P + \sum_c P_{loss} + j(\sum_c Q + \sum_c Q_{loss}))}{V_{Sc}^*} \quad (2.3)$$

$$I_n = -I_a - I_b - I_c \quad (2.4)$$

where;

$\sum_m P$ and $\sum_m Q$ are sums of active and reactive loads on phase-m respectively,

$\sum_m P_{loss}$ and $\sum_m Q_{loss}$ are total active and reactive losses in phase-m respectively,

V_{Sm}^* is the conjugate of source Voltage on phase-m,

I_n, I_a, I_b and I_c are source end currents of Phases n, a, b and c respectively.

The computation then proceeds from the source to the end of the feeder to find the voltage drop, current, and loss in each branch in each phase of the feeder, including the return conductor, in a systematic manner. The branch incidence table is again used to facilitate proper retracing of the network branches. Once this process is completed, the total losses are calculated and compared to the values initially obtained by assuming one per unit voltage at all the buses. If the difference is outside the specified tolerance limits, the source current is re-computed using equations, in terms of the newly obtained values for losses, and the path retracting operation is repeated. The process is repeated until the difference in losses between two successive values of the source current is within the specified tolerance limits (Golkar, 2007). This research applied the method of equivalent single phase equations for all power flow analysis that would be carried out.

2.2.3 Distributed generator model types

A DG can be modelled and operated as a either a constant active power and voltage (PV) node mode or a constant active power and reactive power (PQ) node mode. In most cases, the model of a DG unit depends on the control method which is used in the converter control circuit.

2.2.3.1 DG modelled as a PV type

The DG which is modelled to have control over voltage at the installed bus is a PV node DG. In this case, the DG is a constant voltage model and the specified values of this DG model are the real power output and bus voltage. In order to maintain constant voltage, the change in voltage 'ΔV_i', should remain zero by injecting the required reactive power. This reactive power can be computed as(Yammani *et al.*, 2012):

$$Q_{gen,i} = Q_{ref} - Q_i \tag{2.5}$$

where;

$Q_{gen,i}$ is the generated reactive power at bus 'i',

Q_{ref} is the reference reactive power,

Q_i is the load reactive power to maintain specified terminal voltage.

2.2.3.2 DG modelled as a PQ type

Since DGs are normally smaller in size compared to conventional power sources, the constant PQ model is commonly found to be more sufficient and easily applicable in distribution system load flow analysis. In this model, the DG is not permitted to directly regulate voltage. Rather, it is aimed at regulating power and power factor, hence it is modelled as a negative

load. The load at any bus 'i' where the DG is to be installed will be updated as(Yammani *et al.*, 2012):

$$P_i = P_{load,i} - P_{DG,i} \tag{2.6}$$

$$Q_i = Q_{load,i} - Q_{DG,i} \tag{2.7}$$

where;

P_i and Q_i are the modified active and reactive powers at bus 'i' after DG addition,

$P_{load,i}$ and $Q_{load,i}$ are the initial active and reactive powers at bus 'i',

$P_{DG,i}$ and $Q_{DG,i}$ are the active and reactive powers of the DG represented as negative loads in bus 'i'.

2.2.4 The standard IEEE test benchmarks

These are standard test benchmarks designed by the IEEE for researchers to have a common testing platform and for easier comparison. Standard distribution testing benchmarks include: The IEEE 6-bus test system, the 14-bus test system, the 33-bus test feeder, the 69-bus distribution test system, and many more (Kassim & Wafaa, 2012). The standard 33-bus and 69-bus distribution test feeders were chosen as testing benchmarks for this research because either or both test buses have been used by most of the literatures consulted.

2.2.4.1 The standard IEEE-33 bus system

This is a generally used standard disitribution test system whose single line diagram is shown in Figure 2.4. It has thirty three buses, one main feeder and three laterals and its bus data is shown in Appendix C1.

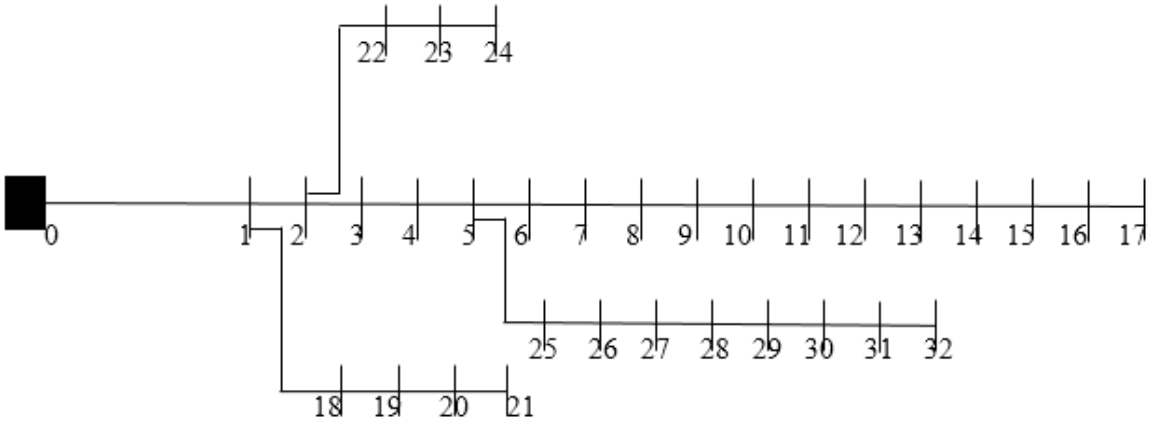


Figure 2.4: Single Line Diagram of IEEE 33 Bus Test System(Kassim & Wafaa, 2012)

2.2.4.2 The standard IEEE-69 bus system

This is another standard disitribution test system whose single line diagram is shown in Figure 2.5. It has sixty nine buses, one main feeder and seven laterals and its bus data is shown in Appendix C2.

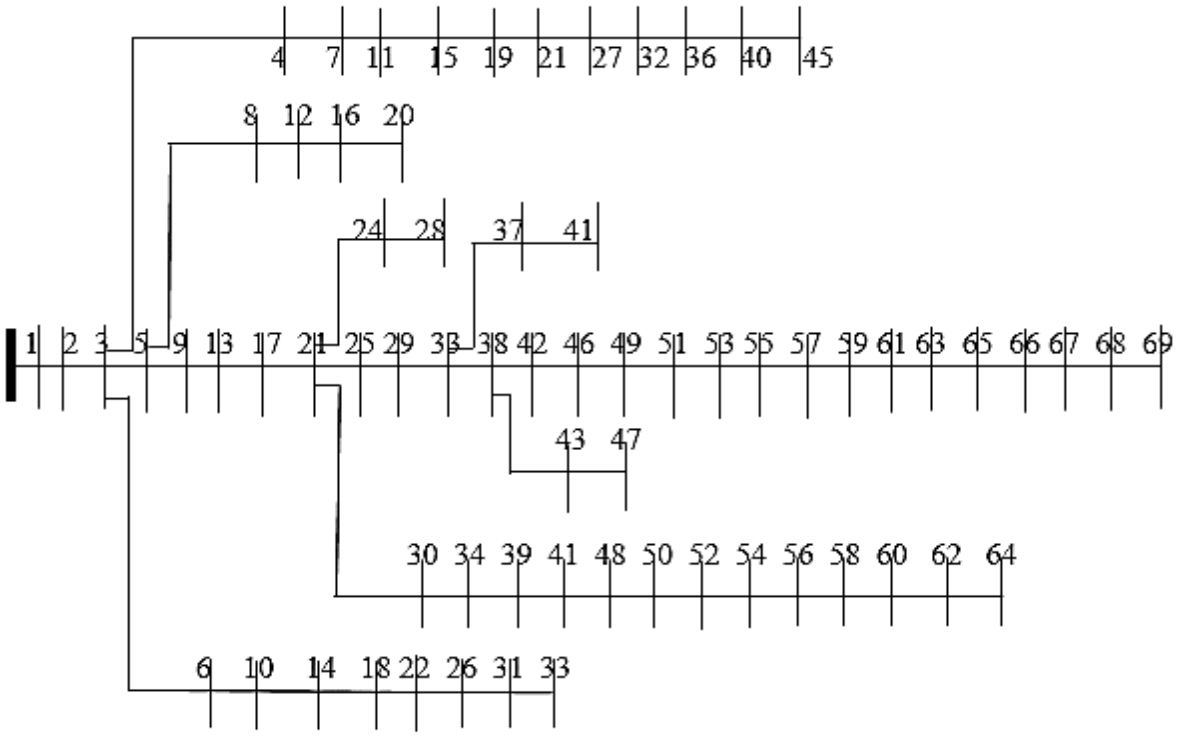


Figure 2.5: Single Line Diagram of IEEE 69 Bus Test System(Kassim & Wafaa, 2012)

2.2.5 Methods for optimal DG placement and sizing

Several methods have been introduced by several researchers for finding the optimal location and size of DGs in a radial distribution system. Previous methods proposed include the classical or numerical method as presented by Atwa *et al.,* (2010), the analytical approach as presented by Wang & Nehrir, (2004), Acahrya *et al.*, (2006) and Hung *et al.*, (2014). Another method used is the heuristic approach as proposed in the works of Abou El-Ela *et al.* (2010) and Akorede *et al.* (2011). This choice is mostly based on the general problem statement, objectives and constraints considered. Some methods used for optimal siting and sizing of DGs are as follows:

1. Analytical method: This method originated from the 2/3 rule and is mostly executed based on the exact loss formular for active power in a system. Analytical methods are easy to implement and execute, but their results are only indicative, since they make simplified asssumptions including the consideration of only one power system loading snapshot (Georgilakis & Hatziargyriou, 2013).
2. Numerical method: This methodology involves the use of numerical analysis in searching for an optimal solution. The main advantage of this method is that it guarantees finding the global optimum; however, it is mostly not suitable for large-scale systems. The different types of numerical methods that have been used include Gradient search, Linear programming, Nonlinear programming, Sequential quadratic programming, Exhaustive search etc.(Georgilakis & Hatziargyriou, 2013):
3. Heuristic and meta-heuristic method: This method involves creating a minimization or maximization objective function in finding the optimal DG placement and size. It could either be an experience-based technique (i.e. heuristic) or higher-level (i.e. meta-heuristic) method which does not require training in searching for the iterative optimal solution.

Heuristic methods are usually robust and provide near-optmal solutions for large, complex optimal DG placement problems. Generally, they require high computational effort. Some types of heuristic and meta-heuristic solution methods used in optimal DG placement include Genetic Algorithm (GA), Tabu Search, Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), Artificial Fish Swarm Algorithm (AFSA), Harmnony Search, Firefly Algorithm (FA) etc. (Georgilakis & Hatziargyriou, 2013):

2.2.6 Analytical method for DG placement and sizing

It has already been established that one of the reasons for placement of renewable energy based DG units is loss reduction. When these units are placed, both aspects of sustainable energy i.e., renewable energy and energy efficiency are addressed. The challenges in the applications for loss reduction are proper location, sizes, and operating strategies. Even if the location is fixed due to some reasons, improper size would increase the losses in the system beyond the losses for case without DG (Hung *et al.*, 2010).

The exact loss fornular is used for calculating the total loss in a distribution system as presented by Hung *et al.* (2010). The total active loss in a distribution system with N-number of buses as a function of active and reactive power injections can be calculated using equation (2.8) (Hung *et al.*, 2010):

$$P_{loss} = \sum_{i=1}^{N}\sum_{j=1}^{N}[\alpha_{ij}(P_iP_j + Q_iQ_j) - \beta_{ij}(Q_iP_j - P_iQ_j)] \quad (2.8)$$

where;

$$\alpha_{ij} = \frac{r_{ij}}{V_iV_j}\cos(\delta_i - \delta_j), \quad (2.9)$$

$$\beta_{ij} = \frac{r_{ij}}{V_iV_j}\sin(\delta_i - \delta_j) \quad (2.10)$$

V_i and δ_i are the complex voltage magnitude and angle at bus 'i',

$r_{ij} + jx_{ij} = Z_{ij}$ is the ijth element of the $[Z_{bus}]$ impedance matrix,

P_i and P_j are active injections at buses 'i' and 'j' respectively,

Q_i and Q_j are the reactive injections at buses 'i' and 'j' respectively.

Let $a = (sign)\tan(\cos^{-1}(PF_{DG}))$, the reactive power output of the DG is found computed using:

$$Q_{DG_i} = \alpha P_{DG_i} \tag{2.11}$$

where;

P_{DG_i} is the active power injection from DG unit at bus 'i'

Q_{DG_i} is the reactive power injection from DG unit at bus 'i'

sign is +1: DG is injecting reactive power

sign is -1: DG is consuming reactive power

PF_{DG} is the power factor of DG.

The active and reactive power injected at bus 'i', where the DG is located are given by:

$$P_i = P_{DG_i} - P_{D_i} \tag{2.12}$$

$$Q_i = Q_{DG_i} - Q_{D_I} = aP_{DG_i} - Q_{D_i} \tag{2.13}$$

Susbstituting equations (2.12) and (2.13) into equation (2.8), the active power loss can be written as:

$$P_{loss} = \sum_{i=1}^{N}\sum_{j=1}^{N}[\alpha_{ij}[(P_{DG_i} - P_{D_i})P_j + (aP_{DG_i} - Q_{D_i})Q_j] + \beta_{ij}[(aP_{DG_i} - Q_{D_i})P_j - (P_{DG_i} - P_{D_i})Q_j]$$

(2.14)

The total active power loss can therefore be minimized if the partial derivative of equation (2.14) with respect to the active power injection from the DG at bus 'i' becomes zero (0). Therefore, it can then be written as:

$$\frac{\partial P_L}{\partial P_{DG_i}} = 2\sum_{j=1}^{N}[\alpha_{ij}(P_j - aQ_j) + \beta_{ij}(aP_j - Q_j)] = 0 \tag{2.15}$$

Equation (2.15) can therefore be rewritten as:

$$\alpha_{ii}(P_i + aQ_i) + \beta_{ii}(aP_i - Q_i) + \sum_{\substack{j=1 \\ j\neq i}}^{N}(\alpha_{ij}P_j - \beta_{ij}Q_j) + a\sum_{\substack{j=1 \\ j\neq i}}^{N}(\alpha_{ij}Q_j - \beta_{ij}P_j) = 0 \quad (2.16)$$

If, $$X_i = \sum_{\substack{j=1 \\ j\neq i}}^{N}(\alpha_{ij}P_j - \beta_{ij}Q_j) \quad (2.17)$$

and

$$Y_i = \sum_{\substack{j=1 \\ j\neq i}}^{N}(\alpha_{ij}Q_j - \beta_{ij}P_j) \quad (2.18)$$

Substituting equations (2.12) and (2.13) into equation (2.16):

$$\alpha_{ii}(P_{DG_i} - P_{D_i} + a^2P_{DG_i} + aQ_{D_i}) + \beta_{ii}(Q_{D_i} - aP_{D_i}) + X_i + aY_i = 0 \quad (2.19)$$

Thus, making the DG active power the subject of the equation:

$$P_{DG_i} = \frac{\alpha_{ii}(P_{D_i} + aQ_{D_i}) + \beta_{ii}(aP_{D_i} - Q_{D_i}) - X_i - aY_i}{a^2\alpha_{ii} + \alpha_{ii}} \quad (2.20)$$

The optimal size of DG at each bus 'i'for minimizing power loss at a preset power factor can be calculated using equation (2.20) (Hung *et al.*, 2010).

To determine the optimal size and power factor of DG simultaneously for each location, the total active power loss is minimum if the partial derivative of equation (2.14) with respect to variable 'a_i' (of PF_{DGi}) becomes zero(0). That is:

$$\frac{\partial P_{loss}}{\partial a_i} = 2\sum_{j=1}^{N}[\alpha_{ij}Q_j + \beta_{ij}P_j] = 0 \quad (2.21)$$

Re-arranging, equation (2.21) becomes:

$$\alpha_{ii}Q_i + Y_i = 0 \quad (2.22)$$

Substituting equation (2.13) into equation (2.22):

$$a_i = \frac{1}{P_{DG_i}}(Q_{D_i} - \frac{Y_i}{\alpha_{ii}}) \quad (2.23)$$

The relationship between the power factor of DG (pf_{DG_i}) and variable a_i at bus 'i' can be expressed as:

$$pf_{DG_i} = \cos(\tan^{-1}(a_i)) \tag{2.24}$$

Thus; $$pf_{DG_i} = \cos(\tan^{-1}(\frac{1}{P_{DG_i}}(Q_{D_i} - \frac{Y_i}{\alpha_{ii}}))) \tag{2.25}$$

Finally, the optimal power of the DG, P_{DGi} and its power factor, pf_{DG_i} for the total system loss to be minimum can be obtained using(Hung *et al.*, 2014):

$$P_{DG_i} = P_{D_i} - \frac{X_i}{\alpha_{ii}} \tag{2.26}$$

$$pf_{DG_i} = \cos(\tan^{-1}(\frac{\alpha_{ii}Q_{D_i} - Y_i}{\alpha_{ii}P_{D_i} - X_i})) \tag{2.27}$$

2.2.7 The firefly algorithm

Fireflies are amongst the most charismatic of all insects, and their spectacular courtship displays have inspired poets and scientists alike. Fireflies are characterized by their flashing light produced by biochemical process known as bioluminescence. Such flashing light may serve as the primary courtship signals for mating. Besides attracting mating partners, the flashing light may also be used to serve as warning to potential predators (Fister *et al.*, 2013). The Firefly Algorithm (FA) is a meta-heuristic, nature-inspired, optimization algorithm which is based on the social (flashing) behaviour of fireflies. This flashing light can be associated with the objective function to be optimized, which makes it possible to formulate new optimization algorithms. For simplicity in describing the Firefly Algorithm, the following idealized rules are proposed (Yang, 2010):

1. "*All fireflies are unisex so that one firefly will be attracted to other fireflies regardless of their sex*"

2. "*Attractiveness is proportional to their brightness, thus for any two flashing fireflies, the less bright one will move towards the brighter one. The attractiveness is proportional to the brightness and they both decrease as their distance increases. If there is no brighter one than a particular firefly, it will move randomly*,"
3. "*The brightness of a firefly is affected or determined by the landscape of the objective function.*"

The pseudo-code for implementing the algorithm is depicted in Figure 2.6, as presented by Yang,

(2010).

Objective function f(x), $x = (x_1, ..., x_d)^T$

Generate initial population of fireflies $x_i (1, 2, ..., n)$

Light intensity I_i *at* x_i *is determined by f(x)*

Define light absorption coefficient γ

while (*t<MaxGeneration)*

for*i =1:n all n fireflies*

for *j = 1 : n all n fireflies (inner loop)*

if *(*$I_i < I_j$*), Move firefly I towards j; end* ***if***

Vary attractiveness with distance r via $\exp -[\gamma r]$

Evaluate new solutions and update light intensity

end ***for*** *j*

end ***for*** *i*

Rank the fireflies and find the current global best g_*

end **while**

Post process results and visualization

Figure 2.6: Pseudo-code for Firefly Algorithm (Yang, 2010)

For a maximization problem, the brightness can simply be proportional to the value of the objective function. Other forms of brightness can be defined in a similar way to the fitness function in genetic algorithms or the bacterial foraging algorithm. It is also assumed that the

attractiveness of a firefly is determined by its brightness which in turn is associated with the encoded objective function (Yang, 2013).

In the simplest case for maximum optimization problems, the brightness 'I'of a firefly at a particular location 'x' can be chosen as $I(x) \propto f(x)$

However, the attractiveness 'β' is relative, so it should be seen in the eyes of the beholder or judged by the other fireflies. Thus, it will vary with the distance 'r_{ij}between firefly 'i' and firefly 'j'.

In addition, light is also absorbed in the media and its intensity decreases with the distance from its source, therefore the attractiveness is allowed to vary with the degree of absorption. In the simplest form, the light intensity 'I' varies according to the inverse square law (Yang, 2010):

$$I = \frac{I_s}{r^2} \tag{2.28}$$

where;

I_s,is the intensity at the source, and

r,is the distance between two fireflies

For a given medium with a fixed light absorption coefficient γ, the light intensity 'I' varies with the distance 'r'. That is:

$$I = I_o e^{-\gamma r} \tag{2.29}$$

where;

$I_o$is original light intensity,

r is the distance between two fireflies and,

In order to avoid singularity at r = 0 in equation (2.28), the combined effect of both the inverse square law and absorption can be approximated as the following Gaussian form (Yang, 2010):

$$I(r) = I_o e^{-\gamma r^2} \tag{2.30}$$

As the firefly's attractiveness is proportional to the light intensity seen by adjacent fireflies, the attractiveness 'β' of a firefly can now be defined by:

$$\beta = \beta_o e^{-\gamma r^2} \tag{2.31}$$

where;

β_o is the attractiveness at r equals zero (0).

As it is often faster to calculate $\frac{1}{(1+r^2)}$ than an exponential function, the above function, if necessary, can conveniently be approximated as:

$$\beta = \frac{\beta_o}{1+\gamma r^2} \tag{2.32}$$

Equations (2.31) and (2.32) define a characteristic distance $\Gamma = \frac{1}{\sqrt{\gamma}}$ over which the attractiveness changes significantly for β to $\beta_o e^{-1}$ for equation (2.31) or $\frac{\beta_o}{2}$ for equation (2.32).

In the actual implementation, the attractiveness of β(r) can be any monotonically decreasing function such as the following generalised form:

$$\beta(r) = \beta_o e^{-\gamma r^m}, (m \geq 1) \tag{2.33}$$

For a fixed γ, the characteristic length becomes:

$$\Gamma = \gamma^{-\frac{1}{m}} \to 1, m \to \infty \tag{2.34}$$

Conversely, for a given length scale 'Γ' in an optimization problem, the parameter 'γ' can be used as a typical initial value. That is:

$$\gamma = \frac{1}{\Gamma^m} \tag{2.35}$$

The distance between any two fireflies 'i' and 'j' at 'x_i' and 'x_j' respectively is the Cartesian distance:

$$r_{ij} = \left\| x_i - x_j \right\| = \sqrt{\sum_{k=1}^{d} (x_{i,k} - x_{j,k})^2} \tag{2.36}$$

where;

$x_{i,k}$ is the kth component of the spatial coordinate x_i of the ith firefly.

In 2D case, we have:

$$r_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \tag{2.37}$$

The movement of firefly 'i' is attracted to another more attractive (brighter) firefly 'j' is determined by:

$$x_i^* = x_i + \beta_o e^{-\gamma r_{ij}^2} (x_j - x_i) + \alpha \in_i \tag{2.38}$$

where;

$\beta_o e^{-\gamma r_{ij}^2} (x_j - x_i)$ is due to attractiveness,

$\alpha \in_i$ is a randomization parameter

α is the randomization parameter, and

$\in_i$ is a vector of random numbers drawn from a Gaussian or uniform distribution.

It is worth pointing out that equation (2.38) is a random walk biased towards the brighter fireflies. If β_o=0, it becomes a simple random walk (Yang, 2010).

This algorithm was selected for this research work based on the following reasons:

1. The distance between any two fireflies is described as an Euclidean distance r_{ij}, shown in equation (2.34) and this can be compared to the distance between two buses in a network where each bus represents a firefly.
2. The absorption coefficient, γ has two limits (0 and ∞) such that when γ=0, the attractiveness $\beta(r) = \beta_o$, thus making equation (2.35) look similar to the solution search equation of Particle Swarm Optimization (PSO) algorithm. This indicates that the PSO algorithm which has shown consistency in solving most power systems optimization problem is a special class of firefly algorithm.
3. The firefly algorithm does not need any special modification in order to apply it in solving most optimization problems.

2.3 Review of Similar Works

The analytical method for DG placement was first implemented based on a capacitor placement rule which was known as the "2/3 rule". This rule suggests that a DG of 2/3 capacity of the incoming generation should be installed at 2/3 of the length of the line on a radial feeder with uniformly distributed load (Willis, 2000).

Wang and Nehrir (2004) were the first to propose the analytical methods for location of DGs. They introduced two analytical methods (one for radial network and the other for meshed network) for optimal location of a single DG with a fixed size. The work assumed a uniformly increasing load and that the ratings of the DG to be located were uniform. They also assumed that the DG would supply two-thirds of the total load. These assumptions are only applicable for an ideal case and hence may be practically unrealistic.

Acharya *et al.* (2006) proposed another analytical method based on exact loss formula in locating and sizing DGs. Although, this method addressed the problem of size in the work of Wang and Nehrir, (2004) by first allocating the required size of DG, then locating the optimal position it should be placed. However, the method only considered one period of single instantaneous demand at peak losses and did not consider the effect of total average loss. Also, the method was only suitable for locating just one DG in the system.

Gözel and Hocaoglu (2009) used loss sensitivity factor based on equivalent current injection in proposing another analytical method for optimally sizing and locating DGs. Their result was just close, but not in complete conformity with the work of Acharya *et.al,* (2006) after comparison and thus could not perform better than this method. This method was only suitable for locating just one kind of DG as other kinds of DGs were not considered.

Hung *et al.* (2010) improved on the analytical method derived in Acharya *et.al,* (2006). The method provided analytical expressions for finding optimal size and locations of different types of DGs capable of delivering both active and reactive power. However, the method could not locate more than one type of DG at a time, and the location and sizing can only be done at pre-specified power factor. It was also silent on the operating strategies or control of the DGs.

Hung *et al.* (2013) proposed another improved analytical expression based on previously developed expression published in (Hung *et al.*, 2010). This new approach encompassed three different power loss formulas in order to optimally locate and size DGs. The method was also capable of calculating the power factor of DGs after placement but the method was computationally complex as a lot of calculations were required and also required a lot of computational time.

Hung *et al.* (2014) further improved on the methodology presented in (Hung *et al.*, 2010) and proposed another analytical expression which could optimally locate and size DGs and also calculate the optimal power factor of these DGs simultaneously. This method lacked accuracy because assumptions were made to reduce the expression proposed in (Hung *et al.*, 2010). Computational time was still not significantly reduced as a lot of calculations were still required.

Viral and Khatod (2015) proposed a novel analytical approach for sizing and siting of DGs in radial distribution networks. The method would first reduce the network by identifying a sequence of critical nodes where DG units are to be placed before selecting the optimal size and location. This method did not guarantee an optimal solution because the optimal DG location may not be included in the identified critical nodes and thus the results would not be the best obtainable. Furthermore, the method may also fail for large complex distribution networks with very high number of buses.

All these analytical methodologies definitely require a large amount of computational time as the expressions proposed would have to be used to calculate for the solution from bus-1 to bus-N before concluding on which bus the DG should be located based on the corresponding losses obtained at each bus. The following metaheuristic approaches were also reported in literature:

Sulaiman *et al.* (2012)proposed a meta-heuristic methodology using firefly algorithm to allocate and size DGs in a distribution network. The objective function used in this work was based on loss minimization and the DG variables were integrated into the load flow data before solving it iteratively to obtain the loss. A fixed size of DG size was first allocated before it was located based on the minimum total loss in the system. This implies that the

location is guaranteed to be optimal but the size might not be optimal thus, the method is only suitable for a deterministic process.

Saravanamutthukumaran and Kumarappan (2012)similarly used the firefly algorithm to solve a multi-objective problem to optimally locate and size DG units in a distribution system. The work showed the robustness of the firefly algorithm when it is used in solving specified problems. However, the work did not consider load flow as part of its objectives therefore its practical application is quite challenging and impossible.

Moradi and Abedini (2012) proposed a combination of genetic algorithm and particle swarm optimization techniques in siting and sizing of DG. These two algorithms are characterised by their slow convergence rates and thus would take a long time in optimally achieving the pre-set objective functions. Also, pre-determined iterations were used in running the genetic algorithm thus the optimal solution might not be guaranteed in the results obtained.

Afzalan and Taghikhani (2012) also used a combined solution method by applying the particle swarm optimization and honey-bee mating optimization algorithms. The work was unable to justify the reason for combining two optimization techniques with similar characteristics. A limited range of values was assumed before the DG size to be placed was chosen within these values. The result obtained is not guaranteed to be optimal based on the fact that the optimal DG size may not lie between the restricted ranges. Also, the two optimization techniques combined have similar characteristics

Nadhir *et al.* (2013) proposed a firefly algorithm for optimal sizing and locating distributed generation. The proposed method used load flow as a basis for the objective function evaluation (which is to minimize power loss) before using the algorithm to find the best solution of load flow data. Similar to the work of Afzalan and Taghikhani, (2012), the work

also assumed a limited range of values within which the power of the DG to be located is selected. This implies that the result obtained is not guaranteed to be optimal as the optimal DG size may not lie within the specified ranges.

Mohamed *et al.* (2014)also used firefly algorithm to optimally locate and size distributed generators. The objective was maximization of profit irrespective of other factors. This work did not consider loss minimization therefore, results achieved is assured to increase profit but does not guarantee the amount of energy that would be wasted in form of losses. Also, the work didn't check if all voltages at each bus (i.e. voltage profile) were within the defined acceptable limit and this makes the practical applicability of the work quite impossible.

Kefayat *et al.* (2015) proposed another method for optimal DG placement and sizing using a hybrid of ant colony optimization algorithm and artificial bee colony algorithm. The method used a combined strategy of discrete and continuous optimization to achieve DG location and sizing respectively. The objective of this method only considered loss reduction but did not consider voltage profile improvement which is regarded as the most important parameter in optimal DG allocation problems. The work also defined a range of values before sizing was done and this is an indication that the size obtained is not guaranteed to be optimal because the optimal size may be outside the defined range.

Bohre *et al.* (2015) proposed a novel optimization technique for optimal DG location and sizing by using combined optimal power flow and butterfly-particle swarm optimization strategies. The method was based on a multi objective function which encompassed active loss, generation cost, load balancing and voltage deviation but the size of DG was selected within an unrestricted range of values. Thus, the method would take a very long time to converge and it might be practically impossible to implement the results obtained because the optimal DG size may be theoretically optimal but practically not.

Mena and García (2015) proposed another method for optimal siting and sizing of DGs using mixed-integer nonlinear programming. The approach which was similar to that of Viral and Khatod, (2015), first reduced the search space by using an approximate model to select the possible buses where DGs can be installed before the numerical method was used to obtain the size of the DG to be installed. This approach does not guarantee an optimal solution because the optimal DG location may not be included in the reduced search space and thus the results would not be the best obtainable. Furthermore, the method may also fail for large complex distribution networks with very high number of buses.

It is evident from literatures that the analytical method has provided one of the best solutions to allocation and sizing of DGs but the meta-heuristic methods have also shown that a near optimal solution could also be achieved since the analytical method is iterative in procedure.

In this research, a hybridised model was developed by adopting the analytical method in determining the candidate DG size that could be placed at each bus, while the Firefly Algorithm was used in determining the optimum DG location.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

In this chapter, the detailed procedures, methods and materials used in achieving the aim of this research are discussed. This involves developing a hybridized firefly algorithm by incorporating an analytical solution method in the standard firefly algorithm in order to optimally allocate DG in a radial distribution networks.

3.2 Distributed Generator Model

The DG was modelled as a PQ-type (i.e. constant active and reactive power) which is a generator normally smaller in size (based on power ratings) compared to conventional power generators. The constant PQ model is commonly found to be more efficient and easily applicable in distribution system load flow analysis as compared to other models of DG. This model was adopted because the research mainly focuses on decreasing the total power loss of the system while improving the overall voltage profile. Furthermore, it permits the bus voltage and frequency to be controlled solely by the network(Yammani *et al.*, 2012). Equations (2.6) and (2.7) showed how the active and reactive powers of the load at any bus 'i' were updated when a DG is installed in it.

3.3 Objective Function

The aim of this research is to minimise the total loss in the system and improve the voltage profile by incorporating DG into a typical distribution network. The possible size and location which are variables of every DG to be allocated can be defined as:

$$X = [X_{1L}, X_{1S}, X_{2L}, X_{2S}, \ldots X_{nL}, X_{nS}] \tag{3.1}$$

where;

x is the parameter of the DG which indicates candidate size and location,

L is the location,

S is the size of the DG at each location as obtained using equation (2.11), and

n is the maximum number of buses.

The objective function which was formulated based on the parameters in equation (3.1) by minimizing the total power loss in a distribution network is defined as:

$$f(x) = \min\left(\sum_{i=1}^{n} P_{loss}\right) \tag{3.2}$$

where;

$f(x)$ is the optimal result obtained after the minimization of total loss, and

P_{loss} can be obtained using equation (2.8) based on the parameters of the DG in equation (3.1).

3.4 Analytical Method for Optimal Placement and Sizing of DGs

The analytical method was developed based on the capacitor placement technique for loss minimization. The exact loss formula as shown in equation (2.8) was used to find the total real power loss in the system and equations (2.11) and (2.26) were used to calculate the optimal size of DG reactive and active powers respectively to be placed at any bus 'i' while equation (2.27) was used to calculate the power factor of the DG.

The flow chart of the steps involved in finding the optimal location and size of DG based on the analytical method is shown in Figure 3.1while the Matlab code for implementing the procedure shown in Figure 3.1 is also given in Appendix A2.

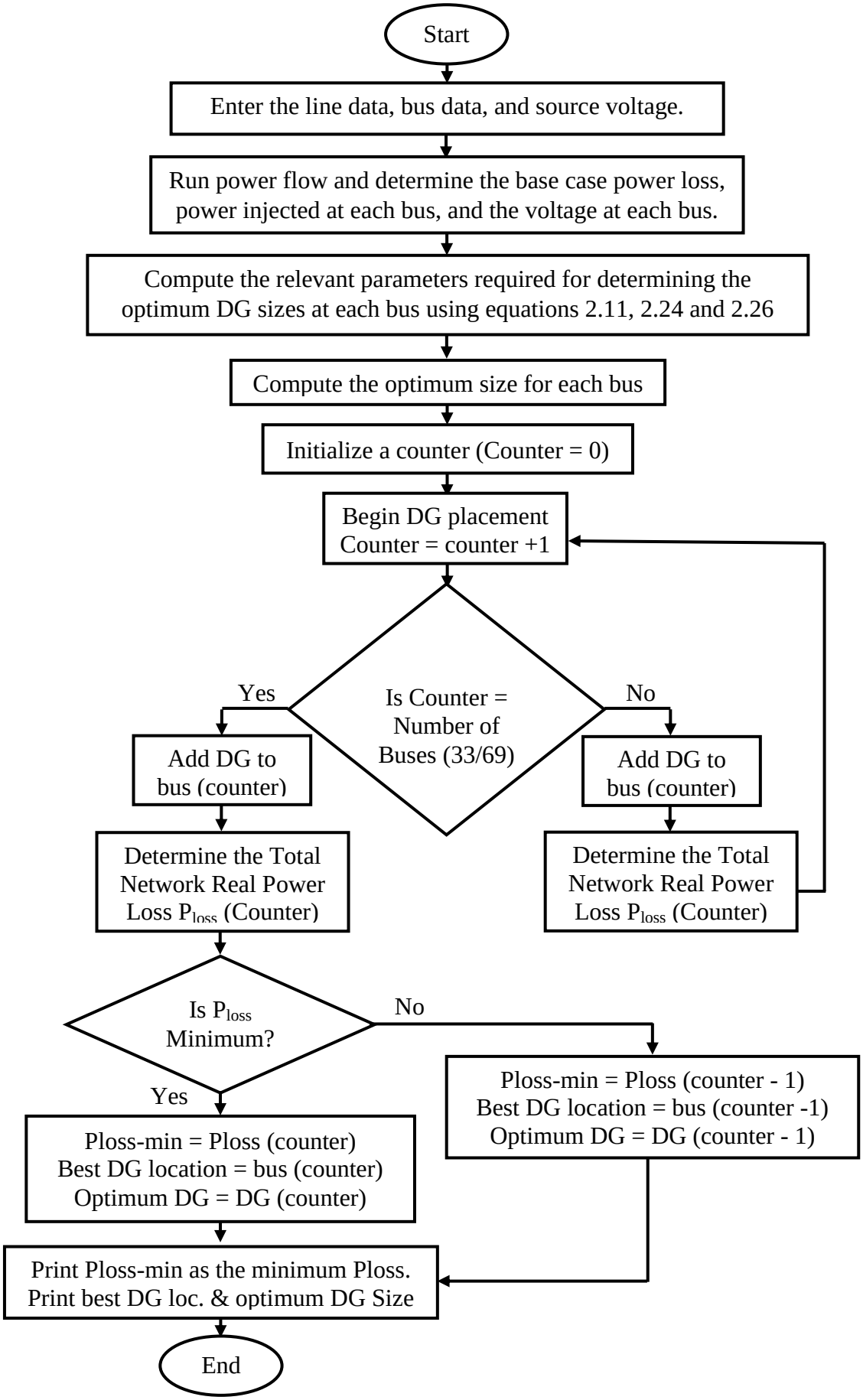


Figure 3.1: Flow Chart of Analytical Method for Optimal DG Placement and Sizing

3.5 The Firefly Algorithm

The firefly algorithm is a meta-heuristic optimization algorithm which is based on the bioluminescent flashing behaviour of fireflies. The description of all parameters required in modelling the algorithm were presented in subsection 2.2.7 while the pseudo-code for implementing the algorithm is as shown in Figure 2.6 and equation (2.35) is the general describing equation. The following parameters were selected for simulation when using the algorithm:

i. Number of fireflies=Maximum iteration = Maximum number of buses (N)
ii. Scaling parameter (α)=0.25
iii. Minimum value of attractiveness (β_o)=0.2
iv. Absorption coefficient (γ)=1

These parameters were selected based on (Yang, 2010), and as applied by Sulaiman *et al.*,(2012) so as to achieve a fast and robust result. The Matlab code for implementing the standard firefly algorithm is as shown in Appendix A1.

3.6 The Proposed Method

The proposed method is a combination of the analytical method and the firefly algorithm whereby the analytical method was used for sizing while the firefly algorithm was used to find the optimal location of the DG that best improves the performance of the distribution network. The analytical method which was described in section 3.4 was used to find the optimal candidate DG size for each bus only. This was done by running a load flow on the system as described in subsection 2.2.2 so as to obtain the voltages at each bus before proceeding to calculate the optimum DG size for each bus using equations (2.11) and (2.24). Rather than proceed with the analytical method as shown in Figure 3.1, the firefly algorithm was employed to find the optimal location of the DG. The firefly algorithm which as

described in section 3.4 was adjusted to suit optimal DG placement in order to randomly search for the optimal DG location of the distribution network. This adjustment involved representing each candidate DG that was calculatedas firefly offspring and the minimum loss equation shown in equation (2.8) was initiated as the fitness parameter of the fireflies. The objective function as described in section 3.3 was then used as the constraint of optimization when the optimal DG location and size were computed. The Matlab script for the firefly algorithm after it was adjusted for optimal DG location only is given in Appendix B1.

The major advantage of this method is that the actual size of DG to be located was first computed using the analytical method before a fast random search was employed (i.e. the firefly algorithm) to find the optimal location for the best DG. This is faster than the analytical concept which involves computing each candidate DG at each bus until the DGs for all the buses have been computed, and then calculating the total power loss for each of the DG sizes before the optimal location would be selected based on the lowest total power loss. The flow chart of this proposedmethod is shown in Figure 3.2 while the Matlab code for the encompassing proposed method as described by the flow chart shown in Figure 3.2 is given in Appendix B2.

The steps involved in implementing the proposed method are as follows:

1. Input network bus and line data;
2. Input firefly properties (i.e. number of fireflies, maximum generation, stopping criteria, scaling parameter, minimum value of attractiveness and absorption coefficient);
3. Run base case load flow;
4. Compute candidate DGs for each individual bus using analytical method;
5. Represent each candidate DG as firefly offspring using firefly algorithm;

6. Determine the best DG location and size based on objective function and fitness of each offspring;
7. Display best location and its candidate size.

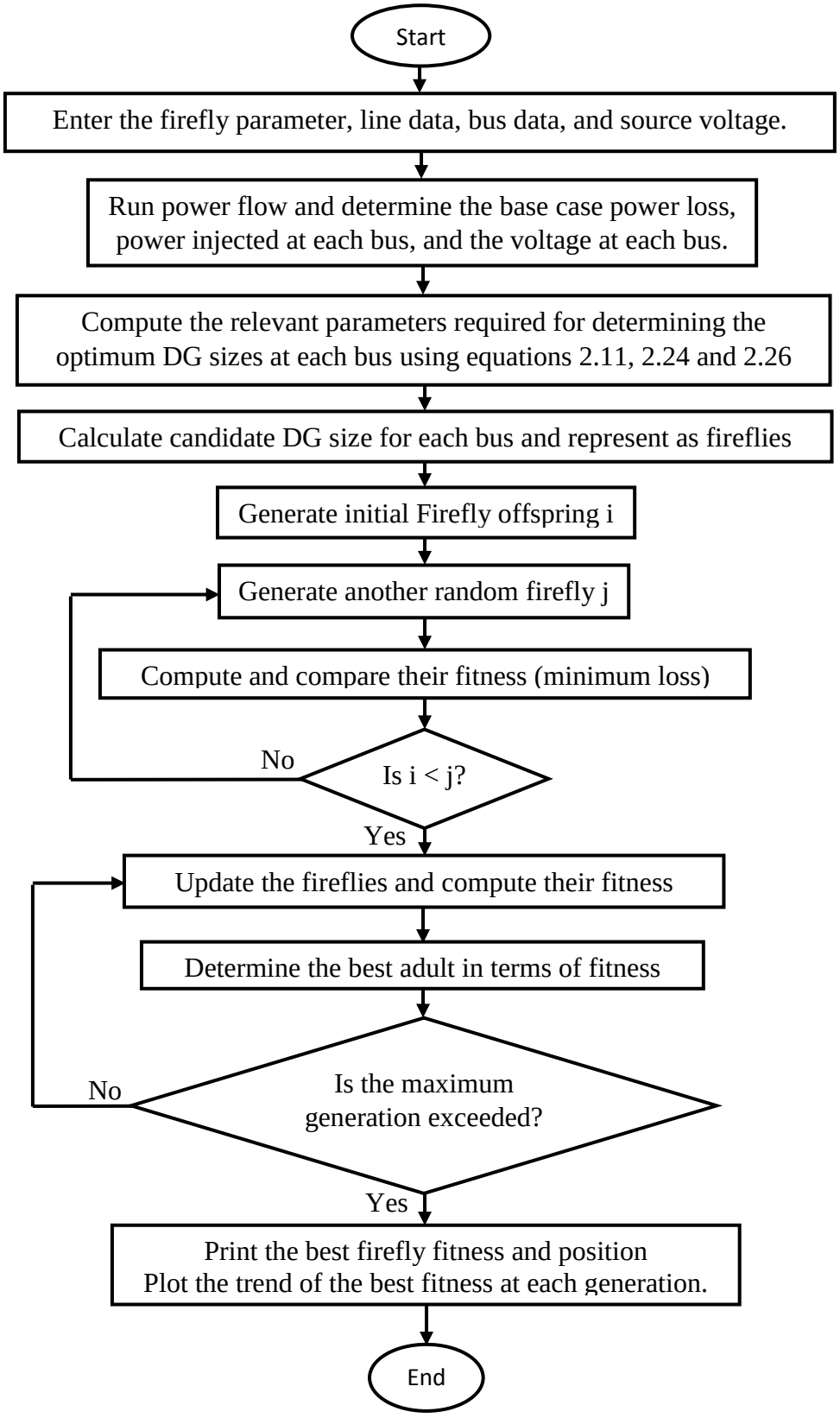


Figure 3.2: Flow Chart of the Proposed Hybrid Algorithm

3.7 Standard Test Systems

Two standard distribution systems which are the IEEE-33 and 69 buses have been selected for testing and validating the algorithm. This is based on the fact that either or both of them have been used by most literatures consulted. The 33 and 69 test buses are used as standard benchmarks to implement the proposed method..

3.7.1 The IEEE33 bus system

This standard test bus as described in subsection 2.1.3.1 is a thirty three bus system which has thirty-three buses and thirty-two sections because the first bus is solely a generator bus. The total loads for this system are 3.72 MW and 2.3 MVAr. The substation voltage is 12.66 kV and the base power is 10 MVA(Kassim & Wafaa, 2012). The single line diagram of the system is shown in Figure 2.1 and the line and bus data are shown in Appendix C1 respectively.

3.7.2 The IEEE 69 bus system

The standard 69 test bus as described in subsection 2.1.3.2 is a sixty-nine bus system which has sixty-nine sections. The total real and reactive power demands are 3.802 MW and 2.69 MVAr respectively while the substation voltage is 12.66 kV and the base power is 10 MVA (Kassim & Wafaa, 2012). The single line diagram of the system is shown in Figure 2.2 and the line and bus data are shown in Appendix C2 respectively.

CHAPTER FOUR

RESULTS ANALYSIS AND DISCUSSIONS

4.1 Introduction

In this chapter, results obtained are presented and discussed. The developed analytical method and the proposed hybrid algorithm were used for optimal location and sizing of DGs for the test buses. All simulations were carried out on Matlab R2013b software and the times of simulation for each process were noted.

4.2 The IEEE 33 Bus Test System

The bus and line data for the standard IEEE 33-bus system as shown in Appendix A1 were used in modelling the system and the base case voltage for each bus were noted. The developed analytical model and the proposed hybrid algorithm described in chapter three were used in finding the optimal DG location and size for the 33-bus network. In both cases, the bus voltages, total real power losses and the voltage profiles before and after DG placement were noted for comparison.

4.2.1 Base case total system loss

Initially, load flow was run on the 33 bus system to get the voltage at each bus, and the total real power loss of the system. This is the base case voltage and active power loss of the 33 bus system before the integration of DG into the system. The base case total real power loss which was calculated using equation (2.5) is 201 kW while the base case voltages at each bus is presented in Table 4.1.

Table 4.1: Base Case Voltage for IEEE 33-Bus Network

Bus Number	Voltage Without DG	Voltage Magnitude
1	0.9905 + 0.0210i	0.9907
2	0.9794 + 0.0276i	0.9798
3	0.9734 + 0.0314i	0.9739
4	0.9673 + 0.0349i	0.9679
5	0.9498 + 0.0390i	0.9506
6	0.9462 + 0.0359i	0.9469
7	0.9420 + 0.0370i	0.9427
8	0.9363 + 0.0367i	0.9370
9	0.9309 + 0.0363i	0.9316
10	0.9301 + 0.0364i	0.9308
11	0.9287 + 0.0366i	0.9294
12	0.9229 + 0.0355i	0.9236
13	0.9207 + 0.0342i	0.9213
14	0.9194 + 0.0336i	0.9200
15	0.9180 + 0.0332i	0.9186
16	0.9161 + 0.0319i	0.9167
17	0.9155 + 0.0317i	0.9160
18	0.9899 + 0.0209i	0.9901
19	0.9863 + 0.0198i	0.9865
20	0.9856 + 0.0194i	0.9858
21	0.9849 + 0.0190i	0.9851
22	0.9759 + 0.0272i	0.9763
23	0.9693 + 0.0259i	0.9696
24	0.9660 + 0.0252i	0.9663
25	0.9481 + 0.0400i	0.9489
26	0.9457 + 0.0413i	0.9466
27	0.9345 + 0.0445i	0.9356
28	0.9263 + 0.0463i	0.9275
29	0.9228 + 0.0480i	0.9240
30	0.9186 + 0.0466i	0.9198
31	0.9178 + 0.0462i	0.9190
32	0.9175 + 0.0461i	0.9187

4.2.2 Effect of DG allocation using analytical method

Optimal DG placement was done on the 33 bus system using the analytical method as described in section 3.2 and the optimal size and location of the DG was found to be 548 kW and bus 30 respectively. The total real power loss after DG placement was relatively reduced

to 136 kW while the improved voltage recorded at each bus is shown in Table 4.2. The average time of simulation was noted to be 9.56158 seconds.

Table 4.2: Improved Voltage for IEEE 33-Bus after DG Placement Using Analytical Method

Bus Number	Voltage With DG	Voltage Magnitude
1	0.9933 + 0.0239i	0.9936
2	0.9835 + 0.0321i	0.984
3	0.9785 + 0.0362i	0.9792
4	0.9733 + 0.0399i	0.9741
5	0.9583 + 0.0451i	0.9594
6	0.9535 + 0.0438i	0.9545
7	0.9500 + 0.0467i	0.9511
8	0.9445 + 0.0488i	0.9458
9	0.9394 + 0.0507i	0.9408
10	0.9387 + 0.0511i	0.9401
11	0.9376 + 0.0519i	0.939
12	0.9318 + 0.0532i	0.9333
13	0.9294 + 0.0529i	0.9309
14	0.9280 + 0.0527i	0.9295
15	0.9266 + 0.0528i	0.9281
16	0.9244 + 0.0523i	0.9259
17	0.9238 + 0.0523i	0.9253
18	0.9927 + 0.0239i	0.9930
19	0.9889 + 0.0244i	0.9892
20	0.9881 + 0.0243i	0.9884
21	0.9874 + 0.0242i	0.9877
22	0.9801 + 0.0333i	0.9807
23	0.9734 + 0.0351i	0.9740
24	0.9700 + 0.0358i	0.9707
25	0.9570 + 0.0457i	0.9581
26	0.9553 + 0.0463i	0.9564
27	0.9479 + 0.0471i	0.9491
28	0.9426 + 0.0474i	0.9438
29	0.9404 + 0.0478i	0.9416
30	0.9361 + 0.0484i	0.9374
31	0.9351 + 0.0484i	0.9364
32	0.9349 + 0.0485i	0.9362

4.2.3 Voltage profile after DG allocation using analytical method

The base case and improved voltage magnitudes shown for each bus in Table 4.1 and Table 4.2 respectively, were plotted against their respective bus numbers in order to see the

improvement in voltage profile after DG location and sizing was done using the analytical method.

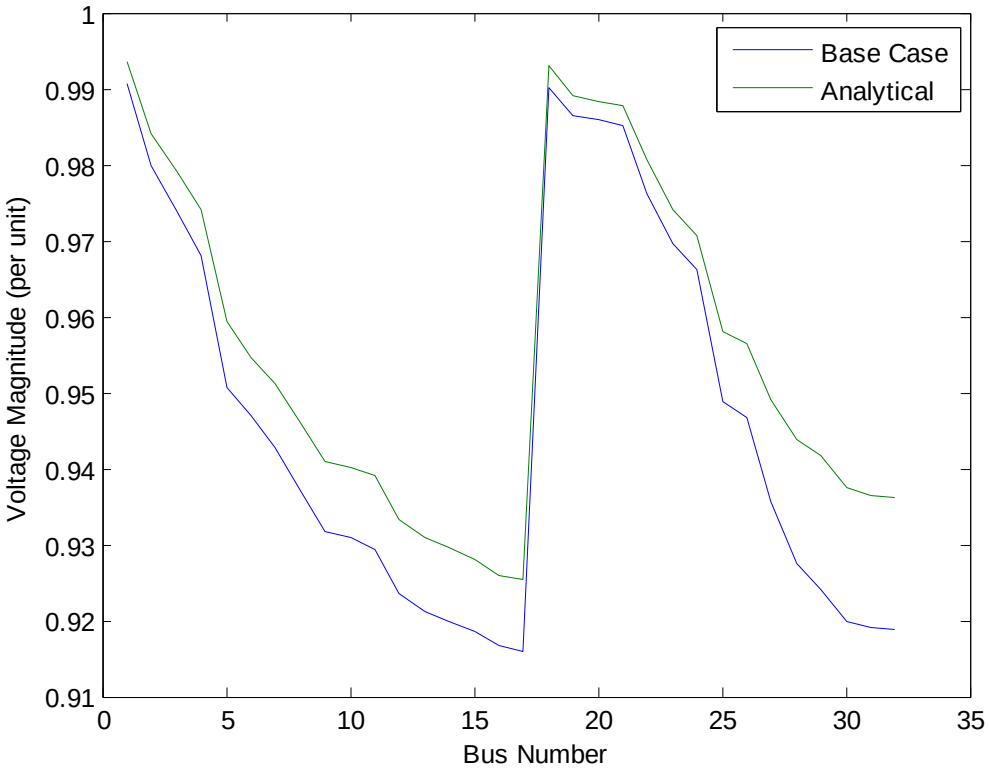


Figure 4.1: Voltage Profile for IEEE 33-Bus Network Using Analytical Method

Figure 4.1 shows that the placement of DG has caused an improvement in the voltage profile of the 33 bus network. The bus with the lowest voltage which is bus 17 had its voltage increases from 0.916 to 0.925 per unit voltage. The blue line indicates the base case voltage trend while the green line shows the voltage profile after DG placement using the analytical method. The optimal allocation of DG therefore caused a 16.44% improvement in the overall voltage profile of the system as compared to the base case voltage profile.

4.2.4 Effect of DG placement using the hybrid algorithm

The hybrid method described in section 3.3 was used for optimal allocation of DG for the standard IEEE 33-bus system and the optimal DG size and location obtained were 133kW and bus 2 respectively. The total real power loss after DG allocation was relatively reduced to

144kW which indicates a 28.36% reduction in total losses as compared to the base case total power loss. The average time of simulation was noted to be 0.950275 seconds while the voltage magnitude at each bus after DG allocation is shown in Table 4.3.

Table 4.3: Improved Voltage for IEEE 33-Bus after DG Placement Using Hybrid Algorithm

Bus Number	Voltage with DG	Voltage Magnitude
1	0.9941 + 0.0236i	0.9970
2	0.9849 + 0.0321i	0.9889
3	0.9803 + 0.0363i	0.9852
4	0.9756 + 0.0402i	0.9813
5	0.9619 + 0.0464i	0.9687
6	0.9571 + 0.0450i	0.9638
7	0.9536 + 0.0479i	0.9605
8	0.9481 + 0.0500i	0.9551
9	0.9430 + 0.0518i	0.9501
10	0.9424 + 0.0523i	0.9494
11	0.9412 + 0.0531i	0.9484
12	0.9355 + 0.0544i	0.9427
13	0.9331 + 0.0541i	0.9402
14	0.9316 + 0.0539i	0.9388
15	0.9303 + 0.0539i	0.9374
16	0.9281 + 0.0534i	0.9352
17	0.9274 + 0.0535i	0.9346
18	0.9935 + 0.0237i	0.9964
19	0.9897 + 0.0241i	0.9926
20	0.9889 + 0.0241i	0.9918
21	0.9882 + 0.0240i	0.9911
22	0.9815 + 0.0333i	0.9856
23	0.9748 + 0.0350i	0.9790
24	0.9714 + 0.0357i	0.9757
25	0.9609 + 0.0471i	0.9681
26	0.9596 + 0.0480i	0.9675
27	0.9536 + 0.0503i	0.9626
28	0.9495 + 0.0519i	0.9595
29	0.9480 + 0.0529i	0.9590
30	0.9438 + 0.0534i	0.9548
31	0.9428 + 0.0535i	0.9538
32	0.9425 + 0.0535i	0.9536

4.2.5 Voltage profile after DG allocation using hybrid algorithm

The base case and improved voltage magnitudes shown for each bus in Table 4.1 and Table 4.3 respectively, were plotted against their respective bus numbers in order to see the improvement in voltage profile after DG location and sizing was done using the hybrid algorithm.

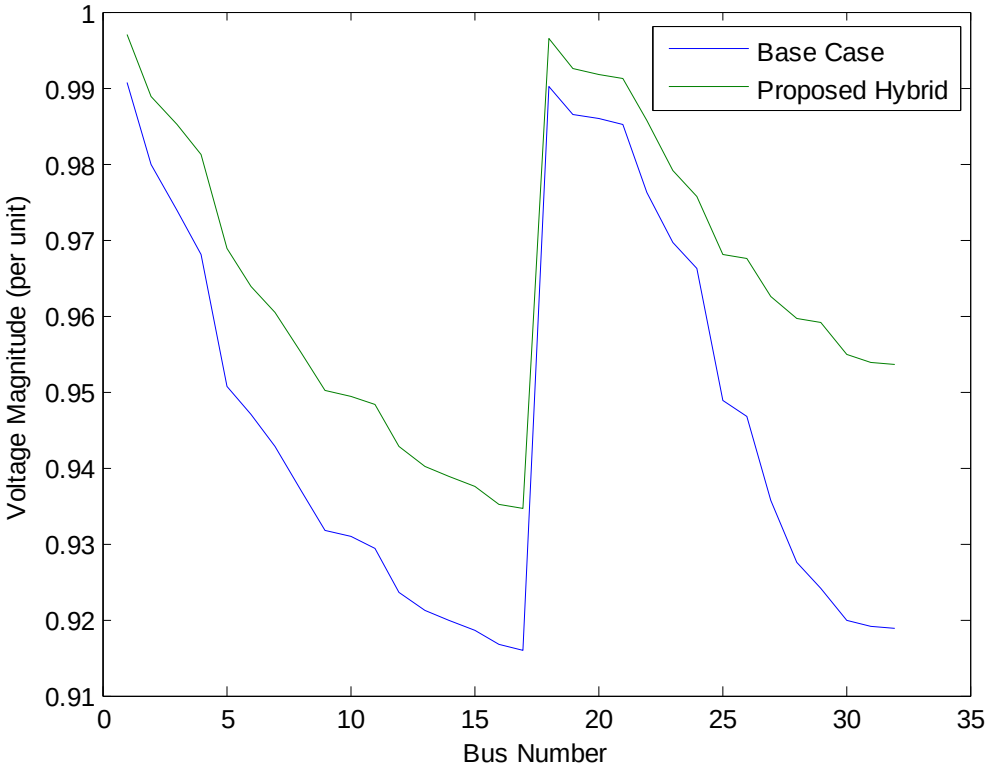


Figure 4.2: Voltage Profile for IEEE 33-Bus Network Using the Hybrid Algorithm

Figure 4.2 shows a comparison of the voltage profiles of the 33 bus for the base case and the improved case after DG allocation was done using the hybrid algorithm. The blue line indicates the voltage profile for the base case before DG allocation was done while the green line indicates the voltage profile of the system after DG allocation was done using the hybrid algorithm. It is obvious that the bus with the lowest voltage which is bus 17 had its voltage improved from 0.916 to 0.9346 which is an indication of the positive effect of the DG that

was placed. The optimal allocation of DG therefore caused a 33.54% improvement in the overall voltage profile of the system as compared to the base case voltage profile.

4.2.6 Comparison of results obtained for the standard IEEE 33 bus system

The results obtained using both methods (i.e. analytical method and the proposed hybrid algorithm) for optimal DG location and sizing for the standard IEEE 33 bus system were compared. The parameters used for comparison are percentage reduction in total loss, percentage improvement in voltage profile and the total time of simulation. Figure 5.3 shows the voltage profiles obtained after both methods were used for DG allocation.

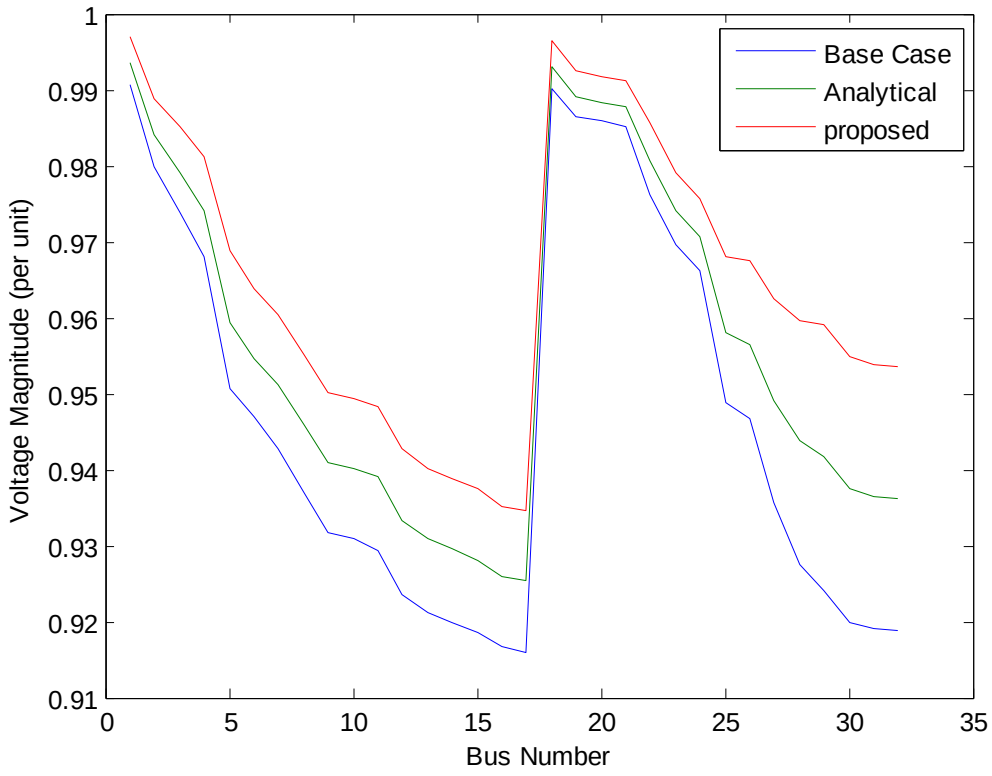


Figure 4.3: Voltage Profile Comparison for Standard IEEE 33-Bus Network

In Figure 4.3, the blue line indicates the base case voltage profile before DG allocation was done. The line indicates the voltage profile after DG allocation was done using the analytical method which achieved an improvement of 16.44% as compared to the base case, while the green line indicates the voltage profile of the system after DG allocation was done using the

proposed hybrid algorithm which achieved an improvement of 33.54% as compared to the base case. This is an indication that the proposed method performed better than the analytical method. Table 4.4 shows a summary of the results obtained for the standard IEEE 33 bus using both methods.

Table 4.4: Summary of Results Obtained for the IEEE 33-Bus System

Particulars	**Analytical Method**	**Hybrid Algorithm**
DG Location	Bus 30	Bus 2
DG Size	548kW	133 kW
Total Real Power Loss (Base Case)	201kW	201 kW
Total Real Power Loss (Improved)	136kW	144 kW
Percentage Reduction in Total Loss	32.34%	28.36%
Voltage Profile Improvement	16.44%	33.54%
Time of Simulation	9.561584s	0.950275s

Table 4.4 shows a summary of results obtained when the analytical method and hybrid algorithm were used in allocation DG for the standard IEEE 33-bus system. The hybrid algorithm performed better than the analytical method in terms of voltage profile improvement and also achieved a 90.06 percent reduction in simulation time.

4.3 The IEEE 69 Bus Test System

The bus and line data for the standard IEEE 69-bus system as shown in Appendix A2 were used in modelling the system and the base case voltage for each bus were noted. The developed analytical model and the proposed hybrid algorithm were used in finding the optimal DG location and size for the 69-bus network. In both cases, the bus voltages, total real power losses and the voltage profiles before and after DG placement were noted for comparison.

4.3.1 Base case total system losses

Initially, load flow was run on the 69 bus system to obtain the base case voltage at each bus and the base case total real power loss of the system. The base case total real power loss which was calculated using equation (2.5) was found to be 146 kW while the base case voltages at each bus is presented in Table 4.5.

Table 4.5: Base Case Voltage for IEEE 69-Bus Network

Bus Number	Voltage Without DG	Voltage Magnitude
1	1.0000 + 0.0000i	1.0000
2	1.0000 + 0.0000i	1.0000
3	0.9999 + 0.000i	0.9999
4	0.9998 + 0.0000i	0.9998
5	0.9992 + 0.0002i	0.9992
6	0.9938 + 0.0053i	0.9938
7	0.9877 + 0.0101i	0.9878
8	0.9862 + 0.0111i	0.9863
9	0.9859 + 0.0112i	0.9860
10	0.9814 + 0.0130i	0.9815
11	0.9804 + 0.0133i	0.9805
12	0.9775 + 0.0143i	0.9776
13	0.9748 + 0.0153i	0.9749
14	0.9721 + 0.0161i	0.9722
15	0.9694 + 0.0169i	0.9695
16	0.9680 + 0.0158i	0.9681
17	0.9671 + 0.0160i	0.9672
18	0.9671 + 0.0160i	0.9672
19	0.9667 + 0.0162i	0.9668
20	0.9664 + 0.0163i	0.9665
21	0.9659 + 0.0164i	0.9660
22	0.9659 + 0.0164i	0.9660
23	0.9658 + 0.0164i	0.9659
24	0.9657 + 0.0165i	0.9658
25	0.9655 + 0.0165i	0.9656
26	0.9654 + 0.0165i	0.9655
27	0.9654 + 0.0165i	0.9655
28	0.9999 + 0.0000i	0.9999
29	0.9998 - 0.0001i	0.9998
30	0.9997 - 0.0001i	0.9997
31	0.9997 + 0.0000i	0.9997
32	0.9996 + 0.0000i	0.9996
33	0.9993 + 0.0001i	0.9993
34	0.9990 + 0.0002i	0.9990
35	0.9990 + 0.0002i	0.9990
36	0.9998 - 0.0001i	0.9998
37	0.9985 - 0.0008i	0.9985
38	0.9945 - 0.0031i	0.9945
39	0.9940 - 0.0034i	0.9940
40	0.9853 + 0.0120i	0.9854
41	0.9828 + 0.0152i	0.9829
42	0.9810 + 0.0167i	0.9811
43	0.9789 + 0.0184i	0.9791

Table 4.5: Base Case Voltage for IEEE 69-Bus Network

44	0.9760 + 0.0206i	0.9762
45	0.9731 + 0.0226i	0.9734
46	0.9584 + 0.0352i	0.9590
47	0.9495 + 0.0399i	0.9503
48	0.9457 + 0.0414i	0.9466
49	0.9412 + 0.0433i	0.9422
50	0.9342 + 0.0444i	0.9353
51	0.9339 + 0.0445i	0.9350
52	0.9335 + 0.0445i	0.9346
53	0.9316 + 0.0447i	0.9327
54	0.9311 + 0.0448i	0.9322
55	0.9804 + 0.0133i	0.9805
56	0.9804 + 0.0133i	0.9805
57	0.9772 + 0.0144i	0.9773
58	0.9772 + 0.0144i	0.9773
59	0.9999 + 0.0000i	0.9999
60	0.9997 - 0.0002i	0.9997
61	0.9996 - 0.0002i	0.9996
62	0.9995 - 0.0002i	0.9995
63	0.9995 - 0.0002i	0.9995
64	0.9988 - 0.0004i	0.9988
65	0.9985 - 0.0005i	0.9985
66	0.9985 - 0.0005i	0.9985
67	0.9985 - 0.0005i	0.9985
68	0.9984 - 0.0005i	0.9984
69	0.9984 - 0.0005i	0.9984

4.3.2 Effect of DG placement after using analytical method

Optimal DG placement was done using the analytical method as described in section 3.2 and the optimal size and location of the DG were found to be 590 kW and bus 63 respectively. The total real power loss after DG placement was relatively reduced to 130.8 kW while the improved voltage for each bus, after DG was placed is shown in Table 4.6. The total time of simulation was noted to be 14.987366 seconds.

Table 4.6: Improved Voltage for IEEE 69-Bus after DG Placement Using Analytical Method

Bus Number	Voltage With DG	Voltage Magnitude
1	1.0000 + 0.0000i	1.0000
2	0.9999 + 0.0000i	0.9999
3	0.9999 + 0.0000i	0.9999
4	0.9998 + 0.0001i	0.9998
5	0.9992 + 0.0008i	0.9992
6	0.9955 + 0.0102i	0.9956
7	0.9913 + 0.0196i	0.9915
8	0.9902 + 0.0217i	0.9904
9	0.9900 + 0.0220i	0.9902
10	0.9871 + 0.0262i	0.9874
11	0.9864 + 0.0271i	0.9868
12	0.9845 + 0.0297i	0.9849
13	0.9827 + 0.0320i	0.9832
14	0.9808 + 0.0343i	0.9814
15	0.9789 + 0.0365i	0.9796
16	0.9771 + 0.0362i	0.9778
17	0.9765 + 0.0369i	0.9772
18	0.9765 + 0.0369i	0.9772
19	0.9762 + 0.0373i	0.9769
20	0.9760 + 0.0375i	0.9767
21	0.9757 + 0.0379i	0.9764
22	0.9757 + 0.0379i	0.9764
23	0.9757 + 0.0379i	0.9764
24	0.9756 + 0.0381i	0.9763
25	0.9755 + 0.0382i	0.9762
26	0.9754 + 0.0382i	0.9761
27	0.9754 + 0.0383i	0.9762
28	0.9999 + 0.0000i	0.9999
29	0.9998 + 0.0000i	0.9998
30	0.9997 + 0.0001i	0.9997
31	0.9997 + 0.0001i	0.9997
32	0.9996 + 0.0002i	0.9996
33	0.9995 + 0.0004i	0.9995
34	0.9993 + 0.0007i	0.9993
35	0.9992 + 0.0007i	0.9992
36	0.9997 + 0.0001i	0.9997
37	0.9982 + 0.0002i	0.9982
38	0.9936 + 0.0006i	0.9936
39	0.9929 + 0.0006i	0.9929
40	0.9896 + 0.0233i	0.9899
41	0.9883 + 0.0288i	0.9887
42	0.9871 + 0.0316i	0.9876
43	0.9856 + 0.0349i	0.9862

Table 4.6: Improved Voltage for IEEE 69-Bus after DG Placement Using Analytical Method

44	0.9835 + 0.0393i	0.9843
45	0.9814 + 0.0435i	0.9824
46	0.9723 + 0.0667i	0.9746
47	0.9665 + 0.0766i	0.9695
48	0.9640 + 0.0802i	0.9673
49	0.9610 + 0.0845i	0.9647
50	0.9556 + 0.0893i	0.9598
51	0.9554 + 0.0895i	0.9596
52	0.9551 + 0.0897i	0.9593
53	0.9537 + 0.0909i	0.958
54	0.9533 + 0.0912i	0.9577
55	0.9864 + 0.0271i	0.9868
56	0.9864 + 0.0271i	0.9868
57	0.9843 + 0.0299i	0.9848
58	0.9843 + 0.0299i	0.9848
59	0.9999 + 0.0000i	0.9999
60	0.9997 + 0.0000i	0.9997
61	0.9995 + 0.0001i	0.9995
62	0.9995 + 0.0001i	0.9995
63	0.9995 + 0.0001i	0.9995
64	0.9988 + 0.0003i	0.9988
65	0.9985 + 0.0004i	0.9985
66	0.9984 + 0.0004i	0.9984
67	0.9984 + 0.0004i	0.9984
68	0.9983 + 0.0005i	0.9983
69	0.9983 + 0.0005i	0.9983

4.3.3 Voltage profile after DG allocation using analytical method

The base case and improved voltage magnitudes shown for each bus in Table 4.5 and Table 4.6 were plotted against their respective bus numbers in order to see the improvement in voltage profile after allocation was done using the analytical method. The voltage profile for the base case and improved case after DG was allocated using analytical method for the 69 bus is shown in Figure 4.4.

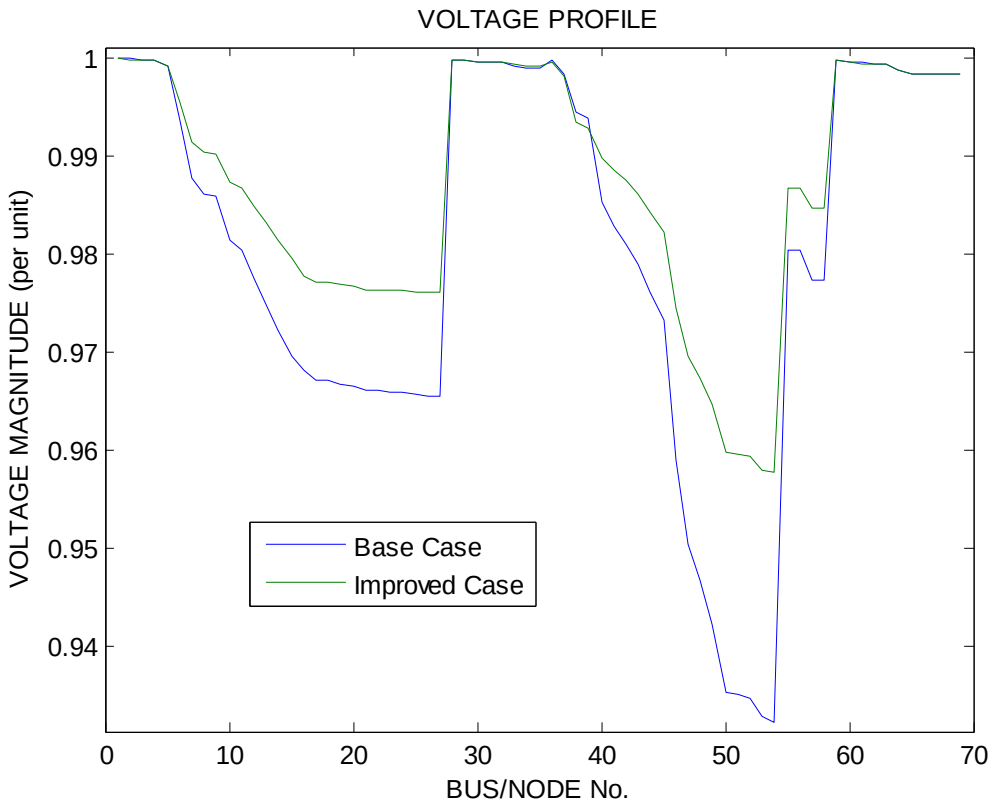


Figure 4.4: Voltage Profile for IEEE 69-Bus Network after Using Analytical Method

Figure 4.4 shows that the placement of DG has caused an improvement in the voltage profile of the 69-bus system. The blue line indicates the base case voltage trend while the green line shows the voltage profile after DG placement using the analytical method. It is obvious that the bus with the lowest voltage which is bus 54 had its voltage improved from 0.9322 to 0.9566and this is an indication of the positive effect of the DG that was placed. The optimal allocation of DG therefore caused a 45.35% improvement in the overall voltage profile of the system as compared to the base case voltage profile.

4.3.4 Effect of DG placement after using hybrid algorithm

The hybrid algorithm described in section 3.3 was then used for optimal allocation of DG for the standard 69 bus. The optimal size and location of the DG to be placed were found to be 590kW and bus 63 respectively while the total real power loss after DG placement was

relatively reduced to 130.8 kW. The average time of simulation was noted to be 3.539888 seconds and the improved voltage for each bus after DG was placed is shown in Table 4.7.

Table 4.7: Improved Voltage for IEEE 69-Bus after DG Placement Using Analytical Method

Bus Number	Voltage with DG	Voltage Magnitude
1	1.0000 + 0.0000i	1.0000
2	0.9999 + 0.0000i	0.9999
3	0.9999 + 0.0000i	0.9999
4	0.9998 + 0.0001i	0.9998
5	0.9992 + 0.0008i	0.9992
6	0.9955 + 0.0102i	0.9956
7	0.9913 + 0.0196i	0.9915
8	0.9902 + 0.0217i	0.9904
9	0.9900 + 0.0220i	0.9902
10	0.9871 + 0.0262i	0.9874
11	0.9864 + 0.0271i	0.9868
12	0.9845 + 0.0297i	0.9849
13	0.9827 + 0.0320i	0.9832
14	0.9808 + 0.0343i	0.9814
15	0.9789 + 0.0365i	0.9796
16	0.9771 + 0.0362i	0.9778
17	0.9765 + 0.0369i	0.9772
18	0.9765 + 0.0369i	0.9772
19	0.9762 + 0.0373i	0.9769
20	0.9760 + 0.0375i	0.9767
21	0.9757 + 0.0379i	0.9764
22	0.9757 + 0.0379i	0.9764
23	0.9757 + 0.0379i	0.9764
24	0.9756 + 0.0381i	0.9763
25	0.9755 + 0.0382i	0.9762
26	0.9754 + 0.0382i	0.9761
27	0.9754 + 0.0383i	0.9762
28	0.9999 + 0.0000i	0.9999
29	0.9998 + 0.0000i	0.9998
30	0.9997 + 0.0001i	0.9997
31	0.9997 + 0.0001i	0.9997
32	0.9996 + 0.0002i	0.9996
33	0.9995 + 0.0004i	0.9995
34	0.9993 + 0.0007i	0.9993
35	0.9992 + 0.0007i	0.9992
36	0.9997 + 0.0001i	0.9997
37	0.9982 + 0.0002i	0.9982
38	0.9936 + 0.0006i	0.9936
39	0.9929 + 0.0006i	0.9929
40	0.9896 + 0.0233i	0.9899
41	0.9883 + 0.0288i	0.9887
42	0.9871 + 0.0316i	0.9876
43	0.9856 + 0.0349i	0.9862

Table 4.7: Improved Voltage for IEEE 69-Bus after DG Placement Using Analytical Method

44	0.9835 + 0.0393i	0.9843
45	0.9814 + 0.0435i	0.9824
46	0.9723 + 0.0667i	0.9746
47	0.9665 + 0.0766i	0.9695
48	0.9640 + 0.0802i	0.9673
49	0.9610 + 0.0845i	0.9647
50	0.9556 + 0.0893i	0.9598
51	0.9554 + 0.0895i	0.9596
52	0.9551 + 0.0897i	0.9593
53	0.9537 + 0.0909i	0.958
54	0.9533 + 0.0912i	0.9577
55	0.9864 + 0.0271i	0.9868
56	0.9864 + 0.0271i	0.9868
57	0.9843 + 0.0299i	0.9848
58	0.9843 + 0.0299i	0.9848
59	0.9999 + 0.0000i	0.9999
60	0.9997 + 0.0000i	0.9997
61	0.9995 + 0.0001i	0.9995
62	0.9995 + 0.0001i	0.9995
63	0.9995 + 0.0001i	0.9995
64	0.9988 + 0.0003i	0.9988
65	0.9985 + 0.0004i	0.9985
66	0.9984 + 0.0004i	0.9984
67	0.9984 + 0.0004i	0.9984
68	0.9983 + 0.0005i	0.9983
69	0.9983 + 0.0005i	0.9983

4.3.5 Voltage profile after DG allocation using hybrid algorithm

The base case voltage magnitude at each bus shown in Table 4.5 and the improved voltage obtained after DG allocation was done using the hybrid algorithm as shown in Table 4.7 were plotted against their respective bus numbers.This voltage profile plot is shown in Figure 4.5 in order to see the improvement in voltage profile of the system.

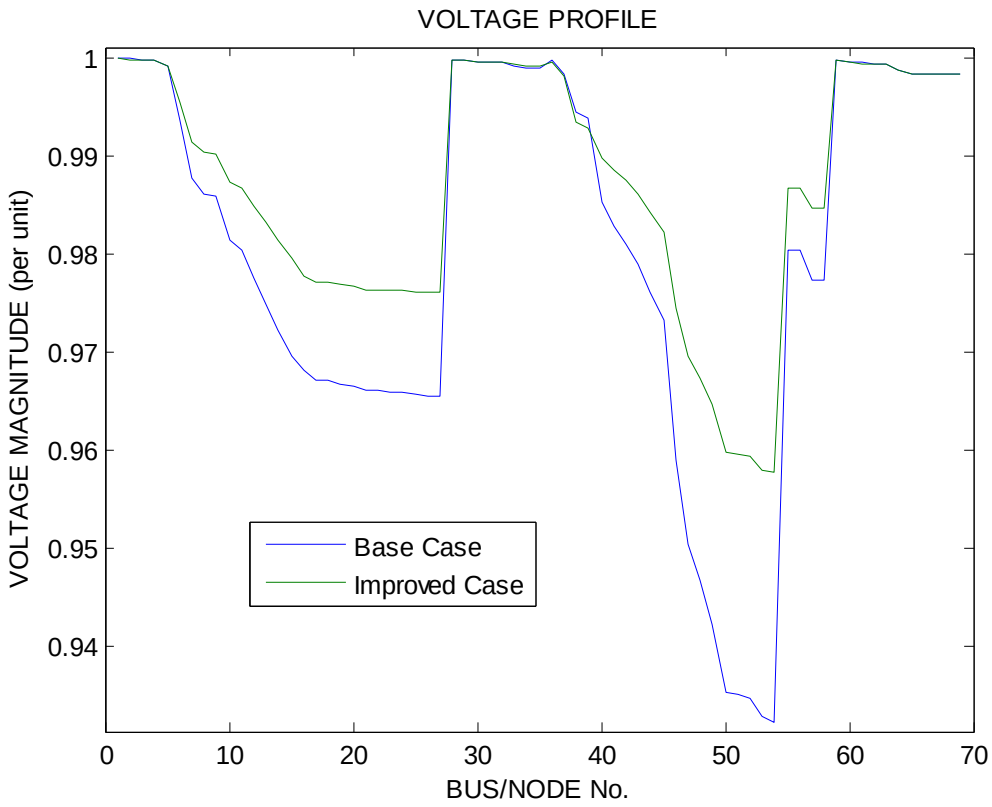


Figure 4.5: Voltage Profile for IEEE 69-Bus Network after Using the Hybrid Algorithm

Figure 4.5 shows that the DG placement has caused an improvement in the voltage profile of the 69-bus system. The blue line indicates the base case voltage trend while the green line shows the voltage profile after DG placement using the analytical method. It is obvious that the bus with the lowest voltage which is bus 54 had its voltage improved from 0.9322 to 0.9566 and this is an indication of the positive effect of the DG that was placed. The optimal allocation of DG therefore caused a 45.35% improvement in the overall voltage profile of the system as compared to the base case voltage profile.

4.3.6 Comparison of results obtained for the standard IEEE 69 bus system

A comparison of results obtained after optimal DG allocation was done for the standard IEEE 69-bus as shown in subsection 4.3.6 and 4.3.7 indicated that both methods achieved the same outputs. This is because the 69-bus is a lightly loaded distribution system as compared to the 33-bus and the analytical method obtained the best possible result. However, the time of

simulation is relatively reduced when using the hybrid algorithm as compared to the analytical method. The summary of results obtained for the standard IEEE 69-bus is shown in Table 4.8.

Table 4.8: Summary of Results Obtained for the IEEE 69-Bus System

Particulars	Analytical Method	Hybrid Algorithm
DG Location	Bus 63	Bus 63
DG Size	590kW	590kW
Total Real Power Loss (Base Case)	146kW	146kW
Total Real Power Loss (Improved)	130.8kW	130.8kW
Percentage Reduction in Total Loss	10.29%	10.29%
Voltage Profile Improvement	45.35%	45.35%
Time of Simulation	14.987366s	3.539888s

Table 4.8 shows a summary of results obtained when the analytical method and hybrid algorithm were used in allocation of DG for the standard IEEE 69-bus system. The hybrid algorithm obtained the same results as the analytical method but achieved a 76.38 percentage reduction in simulation time.

4.4 Summary of Results

The developed analytical method and proposed hybrid algorithm were used to allocate DG for the standard IEEE 33 and 69 radial test distribution buses and the results obtained were noted. A summary of the results obtainedby both methods is presented in Table 4.9.

Table 4.9: Summary of Results Obtained from Analytical Method

Particulars	Analytical Method		Proposed Method	
	33 Bus	69 Bus	33 Bus	69 Bus
DG Location	Bus 30	Bus 63	Bus 2	Bus 63
DG Size	548 kW	590 kW	133 kW	590 kW
Total Loss Reduction	32.34%	10.29%	28.36%	10.29%
Voltage Profile Improvement	16.44%	45.35%	33.54%	45.35%
Time of Simulation	9.561584s	14.987366s	0.950275s	3.539888s

In comparison as shown in Table 4.9, the proposed hybrid algorithm performed better than the analytical method for the 33-bus system based on the voltage profile improvement, while both methods achieved the same results for the 69 bus system. Furthermore, the hybrid method achieved a 90.06 percentage reduction in simulation time for the 33 bus and 76.38 percentage reduction for the 69 bus as compared to the analytical method.

4.5 Validation

The developed method was also validated by comparing the results obtained using the proposed method with those published in the work of (Viral & Khatod, 2015). The comparison was done based on two important parameters, which are the voltage profile improvement and total loss reduction. The voltage profile which shows a comparison between the base case voltage at each bus, results obtained by Viral and Khatod (2015) and the results obtained using the proposed method is presented in Figure 4.6.

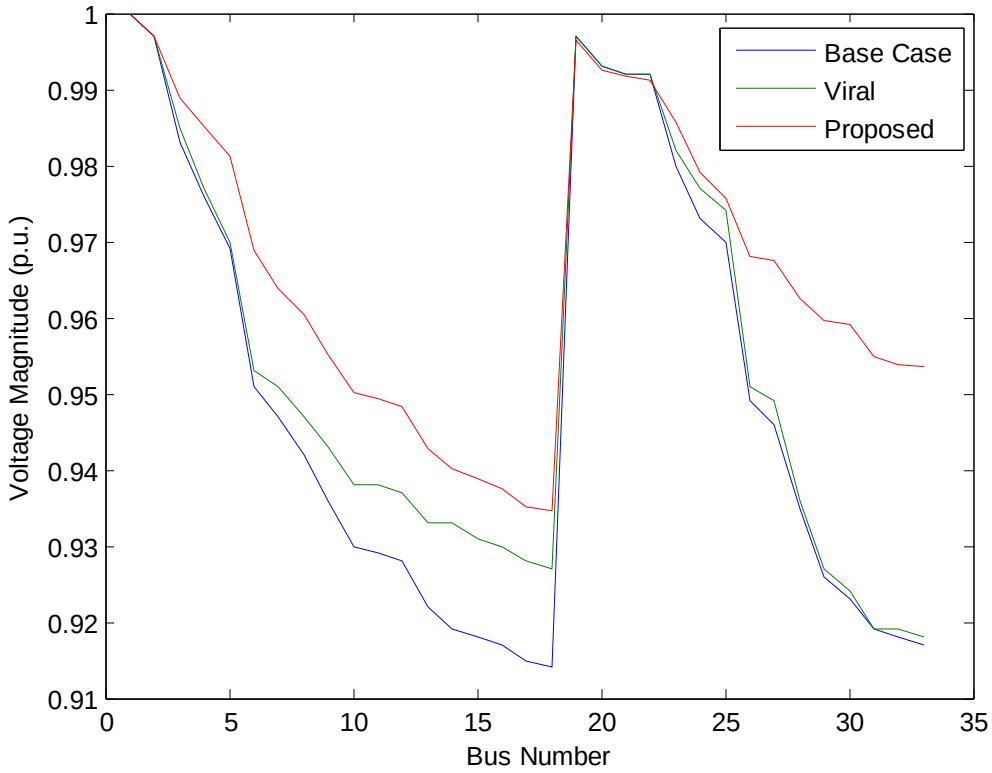


Figure 4.6: Voltage Profile Comparison

Figure 4.6 shows that the results obtained using the proposed method improved the voltage profile better than those obtained by Viral and Khatod, (2015). The blue line represents the base case before DG placement was done, while the green line which had an overall improvement of 14.5% as compared to the base case represents the voltage magnitudes obtained by Viral and Khatod, (2015) after DG placement.Thered line represents the voltage profile obtained using the proposed hybrid algorithm which achieved 33.54% improvement in the voltage profile as compared to the base case.

The power loss reduction obtained by Viral and Khatod, (2015) was 29.69% as compared to 28.36% reduction in losses obtained using the proposed method. These are indications that the proposed method is suitable and valid for optimal DG allocation and sizing in radial distribution networks, and has performed better than Viral and Khatod's method.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Introduction

This chapter presents a summary of this research work. General conclusion, recommendation and suggestions for further works are also highlighted.

5.2 Conclusion

This research work has proposed a hybridized technique for optimal DG location and sizing in radial distribution networks in which hybridization was done by integrating the analytical method into a firefly algorithm. The conventional analytical method was first developed and used to find the optimal DG locations and sizes for the standard IEEE 33 and 69 test systems. The proposed hybrid model was then developed and also used to allocate DG for the standard IEEE 33 and 69 buses and the results obtained were compared with those obtained using the analytical method.For the IEEE 33-bus, the analytical method found the optimal DG location and size to be bus 30 and 548kW respectively and this caused 32.34% reduction in losses and 16.44% improvement in voltage profile.The proposed hybrid method found the optimal DG location and size to be bus 2 and 133kW respectively causing 28.39% reduction in losses and 33.54% improvement in voltage profile. For the IEEE 69-bus, the analytical method and the hybrid algorithm obtained the same results which was bus 63 and 590kW for the location and size respectively, causing 10.29% reduction in losses and 45.35% improvement in voltage profile. Furthermore, the proposed hybrid method had a faster convergence than the analytical method with respect to simulation time. The proposed model was then validated by comparing the results obtained for the 33-bus to those published by Viral and Khatod, (2015) and this showed that the hybrid method had a better performance in terms of voltage profile improvement.

5.3 Significant Contributions

The significant contributions of this research work are as follows:

1. Development of a firefly algorithm based analytical method for optimal location and sizing of Distribution Generation in radial distribution networks
2. The developed method resulted in an overall improvement of 33.54% in the voltage profile of the standard IEEE 33-bus system when compared to the base case scenario.
3. The developed method resulted in 28.36% reduction in the total losses of the standard IEEE 33-bus system when compared to the base case scenario.
4. 90.06% reduction in computational time for the standard IEEE 33-bus system was also achieved by the proposed method as compared to that of the analytical method and 76.24% reduction in computational time was achieved for the standard IEEE 69-bus system.

5.4 Recommendations

The following are recommended as future works that can be considered as an extension of this research:

1. Different hybrid methods can be developed or created using other heuristic methods such as Particle Swarm Optimization technique, Greedy Search Algorithm etc.
2. Further analysis can also be done by using the developed model to simultaneously allocate more than one DG in radial distribution networks.
3. The hybrid model can also be used for optimal DG allocation in micro girds for both grid connected and islanding mode.

References

Abou El-Ela, A., Allam, S., & Shatla, M. (2010). Maximal optimal benefits of distributed generation using genetic algorithms. *Electric Power Systems Research, 80*(7), 869-877.

Acharya, N., Mahat, P., & Mithulananthan, N. (2006). An analytical approach for DG allocation in primary distribution network. *International Journal of Electrical Power & Energy Systems, 28*(10), 669-678.

Ackermann, T., Andersson, G., & Söder, L. (2001). Distributed generation: a definition. *Electric Power Systems Research, 57*(3), 195-204. doi: http://dx.doi.org/10.1016/S0378-7796(01)00101-8

Afzalan, M., & Taghikhani, M. (2012). DG Placement and Sizing in Radial Distribution Network Using PSO&HBMO Algorithms. *Energy and Power, 2*(4), 61-66.

Akorede, M. F., Hizam, H., Aris, I., & Ab Kadir, M. (2011). Effective method for optimal allocation of distributed generation units in meshed electric power systems. *Generation, Transmission & Distribution, IET, 5*(2), 276-287.

Atwa, Y., El-Saadany, E., Salama, M., & Seethapathy, R. (2010). Optimal renewable resources mix for distribution system energy loss minimization. *IEEE Transactions on Power Systems, 25*(1), 360-370.

Bohre, A. K., Agnihotri, G., & Dubey, M. (2015). The Optimal Distributed Generation Placement and Sizing Using Novel Optimization Technique. *Middle-East Journal of Scientific Research, 23*(6), 1228-1236.

El-Khattam, W., & Salama, M. (2004). Distributed generation technologies, definitions and benefits. *Electric Power Systems Research, 71*(2), 119-128.

Fister, I., Fister Jr, I., Yang, X.-S., & Brest, J. (2013). A comprehensive review of firefly algorithms. *Swarm and Evolutionary Computation, 13*, 34-46.

Georgilakis, P. S., & Hatziargyriou, N. D. (2013). Optimal distributed generation placement in power distribution networks: Models, methods, and future research. *IEEE Transactions on Power Systems, 28*(3), 3420-3428.

Golkar, M. A. (2007). A novel method for load flow analysis of unbalanced three-phase radial distribution networks. *Turk Journal on Electrical Engineering, 15*(3), 329-337.

Gomez-Gonzalez, M., López, A., & Jurado, F. (2012). Optimization of distributed generation systems using a new discrete PSO and OPF. *Electric Power Systems Research, 84*(1), 174-180.

Gözel, T., & Hocaoglu, M. H. (2009). An analytical method for the sizing and siting of distributed generators in radial systems. *Electric Power Systems Research, 79*(6), 912-918.

Hung, D. Q., Mithulananthan, N., & Bansal, R. (2010). Analytical expressions for DG allocation in primary distribution networks. *IEEE Transactions on Energy Conversion, 25*(3), 814-820.

Hung, D. Q., Mithulananthan, N., & Bansal, R. (2013). Analytical strategies for renewable distributed generation integration considering energy loss minimization. *Applied Energy, 105*, 75-85.

Hung, D. Q., Mithulananthan, N., & Lee, K. Y. (2014). Optimal placement of dispatchable and nondispatchable renewable DG units in distribution networks for minimizing energy loss. *International Journal of Electrical Power & Energy Systems, 55*, 179-186.

Injeti, S., & Prema Kumar, N. (2013). A novel approach to identify optimal access point and capacity of multiple DGs in a small, medium and large scale radial distribution systems. *International Journal on Electric Power Energy Systems*(45), 142-151.

Jain, S., Agnihotri, G., Kalambe, S., & Kamdar, R. (2014). Siting and Sizing of DG in Medium Primary Radial Distribution System with Enhanced Voltage Stability. *Chinese Journal of Engineering, 2014*.

Kassim, A. A.-A., & Wafaa, S. M. (2012). A Reliable Load Flow Method for Radial Distribution System. *Journal of Engineering and Development, 16*(2), 248-265.

Kefayat, M., Ara, A. L., & Niaki, S. N. (2015). A hybrid of ant colony optimization and artificial bee colony algorithm for probabilistic optimal placement and sizing of distributed energy resources. *Energy Conversion and Management, 92*, 149-161.

Leite da Silva, A. M., Nascimento, L. C., da Rosa, M. A., Issicaba, D., & Peças Lopes, J. A. (2012). Distributed energy resources impact on distribution system reliability under load transfer restrictions. *IEEE Transactions on Smart Grid, 3*(4), 2048-2055.

Mena, A. J. G., & García, J. A. M. (2015). An efficient approach for the siting and sizing problem of distributed generation. *International Journal of Electrical Power & Energy Systems, 69*, 167-172.

Mohamed, E. A., Othman, M. M., & Hegazy, Y. G. (2014). *Optimal Sizing and Placement of Distributed Generators for Profit Maximization Using Firefly Algorithm*. Paper presented at the Int'l Conference on Artificial Intelligence, Energy and Manufacturing Engineering (ICAEME'2014), , Kuala Lumpur (Malaysia). http://dx.doi.org/10.15242/IIE.E0614014

Moradi, M., & Abedini, M. (2012). A combination of genetic algorithm and particle swarm optimization for optimal DG location and sizing in distribution systems. *International Journal of Electrical Power & Energy Systems, 34*(1), 66-74.

Muttaqi, K., Le, A. D., Negnevitsky, M., & Ledwich, G. (2014). An algebraic approach for determination of DG parameters to support voltage profiles in radial distribution networks.

Nadhir, K., Chabane, D., & Tarek, B. (2013). *Firefly algorithm based energy loss minimization approach for optimal sizing & placement of distributed generation.* Paper presented at the 5th International Conference on Modeling, Simulation and Applied Optimization (ICMSAO), Hammamet, Tunisia, 2013.

Ochoa, L. F., & Harrison, G. P. (2011). Minimizing energy losses: Optimal accommodation and smart operation of renewable distributed generation. *IEEE Transactions on Power Systems, 26*(1), 198-205.

Pepermans, G., Driesen, J., Haeseldonckx, D., Belmans, R., & D'haeseleer, W. (2005). Distributed generation: definition, benefits and issues. *Energy Policy, 33*(6), 787-798. doi: http://dx.doi.org/10.1016/j.enpol.2003.10.004

Rau, N. S., & Wan, Y.-h. (1994). Optimum location of resources in distributed planning. *IEEE Transactions on Power Systems, 9*(4), 2014-2020.

Saravanamutthukumaran, S., & Kumarappan, N. (2012). *Sizing and siting of Distribution Generator for different loads using firefly algorithm.* Paper presented at the International Conference on Advances in Engineering, Science and Management (ICAESM), Nagapattinam, Tamil Nadu, India, 2012

Soroudi, A., & Ehsan, M. (2011). Efficient immune-GA method for DNOs in sizing and placement of distributed generation units. *European Transactions on Electrical Power, 21*(3), 1361-1375.

Soudi, S. (2013). Distribution System Planning With Distributed Generations Considering Benefits and Costs. *International Journal of Modern Education and Computer Science (IJMECS), 5*(9), 45.

Sulaiman, M., Mustafa, M., Azmi, A., Aliman, O., & Abdul Rahim, S. (2012). *Optimal allocation and sizing of distributed generation in distribution system via firefly*

algorithm. Paper presented at the IEEE International Power Engineering and Optimization Conference (PEDCO) Melaka, Malaysia, 2012

Vinothkumar, K., & Selvan, M. (2011). Fuzzy embedded genetic algorithm method for distributed generation planning. *Electric Power Components and Systems, 39*(4), 346-366.

Vinothkumar, K., & Selvan, M. (2012). Distributed generation planning: A new approach based on goal programming. *Electric Power Components and Systems, 40*(5), 497-512.

Viral, R., & Khatod, D. (2015). An analytical approach for sizing and siting of DGs in balanced radial distribution networks for loss minimization. *International Journal of Electrical Power & Energy Systems, 67*, 191-201.

Wang, C., & Nehrir, M. H. (2004). Analytical approaches for optimal placement of distributed generation sources in power systems. *IEEE Transactions on Power Systems, 19*(4), 2068-2076.

Willis, H. L. (2000). *Analytical methods and rules of thumb for modeling DG-distribution interaction.* Paper presented at the IEEE Power Engineering Society Summer Meeting, Seattle, Washington, 2000. .

Yammani, C., Maheswarapu, S., & Matam, S. (2012). Optimal Placement of Multi DGs in Distribution System with Considering the DG Bus Available Limits. *Energy and Power, 2*(1), 18-23.

Yang, X.-S. (2010). Firefly algorithm, Levy flights and global optimization *Research and Development in Intelligent Systems XXVI* (pp. 209-218): Springer.

Appendix A1

Matlab Code for the Firefly Algorithm

```
function  FFA
clear all
clc
N=input('Please Enter the Number of Firefly: ');
clc
maxGen=input('Please Provide the Stopping Criteria: ');
clc
alpha=input('Please Enter the value of alpha: ')
clc
Beta0=input('Please enter the Initial attractiveness: ');
clc
gamma=input('Please Provide the Absorption Coefficient (gamma): ');%
clc
fitness=input('Select the test function: ');
clc
FIREFLY=input('Please Enter the Population of the FIREFLY:  or\nPress
zero(0) for the default population: ');
clc
if FIREFLY==0
    pop=rand(N);
else
    pop=FIREFLY;
end
popi=pop;
popj=rand(N);
Ii=objfunc(fitness,popi);      %this reprsent the light intesity of(pop)
Ij=objfunc(fitness,popj);
itr=0;
while itr<maxGen
    itr=itr+1;
    for i=1:N
        for j=1:N
            r=sqrt((popi(i)-popi(j))^2+(popj(i)-pop(j))^2);
            if Ii<Ij
                beta=Beta0*exp(-gamma*r.^2);
                Ii=popj(i).*(1-beta)+popj(j).*beta+alpha.*(rand-0.5);
            end
            beta=Beta0*exp(-gamma*r.^2);
            popi(i)=popi(i).*(1-beta)+popi(j).*beta+alpha.*(rand-0.5);
            popj(i)=popj(i).*(1-beta)+popj(j).*beta+alpha.*(rand-0.5);
            Iinew=objfunc(fitness,popi(i));
            Ijnew=objfunc(fitness,popj(i));
        end
    end
    if Iinew<Ijnew
        Best_Soln=Iinew;
    else
        Best_Soln=Ijnew;
    end
end
disp(Best_Soln)
```

Appendix A2

Matlab Code for DG Placement and Sizing Using Analytical Method

```
function DGLOCSIZE(linedata,busdata,Vs)
%START/BEGIN
%this program uses the line and bus data of a distribution network to
search for the optimal DG location and size via the analytical method%
tic;
linedata=sortc(linedata,3);% sort the linedata in ascending order of buses
busdata=sortc(busdata,1);% sort the busdata in ascending order of buses
busdata(:,1)=linedata(:,3);
[PLOSS S_source S_Demand S_injected Vi]=RADFLOW(linedata,busdata,Vs);
Viiii=Vi;
%To estimate the base case Total active power loss
N=length(Vi); %obtain the number of load buses
Ploss=0;    %initialize the total network active power loss
for i=1:N
            %determine rij

rij=linedata(i,4);% get the value of branch resistance

            for j=1:N
                if linedata(i,2)==0
                   vi=abs(Vs);
                   zigmai=angle(Vs);
                   Pi=real(S_source);
                   Qi=-imag(S_source);
                else
                    if linedata(i,2)~=0
                if busdata(j,1)==linedata(i,2)
                   vi=abs(Vi(j,1));
                   zigmai=angle(Vi(j,1));
                   Pi=real(S_injected(j,1));
                   Qi=-imag(S_injected(j,1));
                end
                    end
                end
            end
            %determine beta
            for j=1:N
                if busdata(j,1)==linedata(i,3)
                   vj=abs(Vi(j,1));
                   zigmaj=angle(Vi(j,1));
                   Pj=real(S_injected(j,1));
                   Qj=-imag(S_injected(j,1));
                end
            end
            P_i(i,1)=(Pi);
            P_j(i,1)=(Pj);
            Q_i(i,1)=(Qi);
            Q_j(i,1)=(Qj);
            alpha_ij=rij*cos(zigmai-zigmaj)/(vi*vj);
            beta_ij=rij*sin(zigmai-zigmaj)/(vi*vj);
            Plossij=alpha_ij*((Pi*Pj)+(Qi*Qj))+beta_ij*((Qi*Pj)-(Pi*Qj));
            Ploss=Ploss+Plossij;
            alphaij(i,1)=alpha_ij;
            betaij(i,1)=beta_ij;
end
```

```
PLoss=Ploss;
%Calculation of DG power factor
for h=1:length(S_Demand)
if S_Demand(h,1)~=0
PF_DG(h,1)=real(S_Demand(h,1))./((real(S_Demand(h,1))).^2+(imag(S_Demand(h,
1))).^2).^0.5;
else
    PF_DG(h,1)=0;
end
end
%Finding the optimal size of DG
for h=1:length(S_Demand)
if PF_DG(h,1)~=0
A(h,1)=sign(tan(acos(PF_DG(h,1)))).*(tan(acos(PF_DG(h,1))));
else
    A(h,1)=0;
end
end
%constructing the X and Y matrixes with elements Xi and Yi respectively
Xi=[];
Yi=[];
for i=1:N
    X=sum(alphaij.*P_j-betaij.*Q_j)-alphaij(i).*P_j(i)+betaij(i).*Q_j(i);
    Y=sum(alphaij.*Q_j+betaij.*P_j)-alphaij(i).*Q_j(i)-betaij(i).*P_j(i);
    Xi=[Xi;X];
    Yi=[Yi;Y];
end
%Finding the Optimum Size of DG i.e P_DGis and Q_DGis
for h=1:length(S_Demand)
P_DG(h,1)=(alphaij(h,1)*(real(S_Demand(h,1))+A(h,1)*(imag(S_Demand(h,1)))).
..
+betaij(h,1)*(A(h,1)*(real(S_Demand(h,1)))-(imag(S_Demand(h,1))))...
-Xi(h,1)-A(h,1)*Yi(h,1))/ceil(A(h,1)*(alphaij(h,1))+alphaij(h,1)+N);
Q_DG(h,1)=(A(h,1))*P_DG(h,1);
end

P_loss_with_DG=[];
iter=0;
for bus=1:N
    S_DG=zeros(size(S_Demand));
    iter=iter+1;
    S_DG(bus)=P_DG(bus)-1i*Q_DG(bus);
    S_D=(S_Demand)-S_DG;
    new_busdata=busdata;
    new_busdata(:,2:3)=[(conj(S_D)),cos(angle(conj(S_D)))];
    [P_LOSS, S_source ~, S_Injected ~,]=RADFLOW(linedata,new_busdata,Vs);
    %initialize the total network active power loss
    clc
    d=sprintf('PLACING DG AT LOCATION %d OF THE NETWORK WHILE
SEARCHING\nFOR THE OPTIMUM DG LOCATION USING ANALYTICAL METHOD',iter);
    disp(d)
            P_i=[];
            P_j=[];
            Q_i=[];
            Q_j=[];
for i=1:N
           for j=1:N
                if linedata(i,2)==0
                   Pi=real(S_source);
                   Qi=-imag(S_source);
                else
```

```
                    if linedata(i,2)~=0
                if busdata(j,1)==linedata(i,2)
                   Pi=real(S_Injected(j,1));
                   Qi=-imag(S_Injected(j,1));
                end
                    end
                end
            end
            %determine beta
            for j=1:N
                if busdata(j,1)==linedata(i,3)
                   Pj=real(S_Injected(j,1));
                   Qj=-imag(S_Injected(j,1));
                end
            end
            P_i(i,1)=(Pi);
            P_j(i,1)=(Pj);
            Q_i(i,1)=(Qi);
            Q_j(i,1)=(Qj);

end
P_lossij=sum(alphaij.*(P_i.*P_j+Q_i.*Q_j)+betaij.*(Q_i.*P_j-P_i.*Q_j));
P_loss_with_DG=[P_loss_with_DG;P_LOSS];
end

for bus=1:N
    if P_loss_with_DG(bus)==min(P_loss_with_DG)
        Min_P_loss_with_DG=P_loss_with_DG(bus);
    end
end

for bus=1:N
    if P_loss_with_DG(bus)==min(P_loss_with_DG)
        Best_Location=busdata(bus,1);
        best=bus;
    end
end
for bus=1:N
    if P_loss_with_DG(bus)==min(P_loss_with_DG)
        Optimal_DG_Size=P_DG(bus)+1i*Q_DG(bus);
    end
end
    bus= best;
    S_DG=zeros(size(S_Demand));
    iter=iter+1;

    S_DG(bus)=P_DG(bus)-1i*Q_DG(bus);
    S_D=(S_Demand)-(S_DG);
    new_busdata=busdata;
     new_busdata(:,2:3)=[((S_D)),cos(angle((S_D)))];
    clc
    d=sprintf('PLACING DG AT THE OPTIMUM LOCATION OF THE NETWORK WHILE
SEARCHING\nFOR THE OPTIMUM DG LOCATION USING ANALYTICAL METHOD');
    disp(d)
    [PLOSS_BEST S_Source ~, S_InjecteD
Viii]=RADFLOW(linedata,new_busdata,Vs);
    %initialize the total network active power loss
Plosses=0;    %initialize the total network active power loss
for i=1:N
     rij=linedata(i,4);% get the value of branch resistance
```

```
            for j=1:N
                if linedata(i,2)==0
                   vi=abs(Vs);
                   zigmai=angle(Vs);
                   Pi=real(S_Source);
                   Qi=-imag(S_Source);
                else
                    if linedata(i,2)~=0
                if busdata(j,1)==linedata(i,2)
                   vi=abs(Viii(j,1));
                   zigmai=angle(Viii(j,1));
                   Pi=real(S_InjecteD(j,1));
                   Qi=-imag(S_InjecteD(j,1));
                end
                    end
                end
            end
            %determine beta
            for j=1:N
                if busdata(j,1)==linedata(i,3)
                   vj=abs(Viii(j,1));%
                   zigmaj=angle(Viii(j,1));
                   Pj=real(S_InjecteD(j,1));
                   Qj=-imag(S_InjecteD(j,1));
                end
            end
            alpha_ij=rij*cos(zigmai-zigmaj)/(vi*vj);
            beta_ij=rij*sin(zigmai-zigmaj)/(vi*vj);
            Plossesij=alpha_ij*((Pi*Pj)+(Qi*Qj))+beta_ij*((Qi*Pj)-(Pi*Qj));
            Plosses=Plosses+Plossesij;
            Alphaij(i,1)=alpha_ij;
            Betaij(i,1)=beta_ij;
end
clc
Alpha=Alphaij;
Beta=Betaij;
Location=Best_Location;
Size=round(abs(Optimal_DG_Size)*100000);
info=sprintf('THE OPTIMUM LOCATION OF DG IS AT BUS: %d AND IT HAS A SIZE OF
%dE-5 pu ',Location,Size);
disp(info);
Sinj=S_injected;
P_Loss_best=round(real(PLOSS_BEST)*100000);
P_loss_base_case=round(real(PLOSS)*100000);
info1=sprintf('THE TOTAL REAL POWER LOSS OF THE NETWORK WITH, AND WITHOUT
DG ARE: %dE-5 AND %dE-5 RESPECTIVELY  ',P_Loss_best,P_loss_base_case);
disp(info1);
V_with_DG=abs(Viii)
V_base_case=abs(Viiii)
Q=1:length(Vi);
plot(Q,(abs(V_base_case)),Q,(abs(V_with_DG)))
V4 = Viiii
V5= Viii
legend('Base Case','Optimum')
title('VOLTAGE PROFILE')
xlabel('Bus Number');
ylabel('Voltage Magnitude (per unit)');
toc
```

Appendix B1

Matlab Code of the Firefly Algorithm for Optimal DG Location

```
function  [DG_Locataion
Loss_with_DG]=FFA(maxGen,alpha,Beta0,gamma,linedata,busdata,N,S_Demand,P_DG
,Q_DG,Vs)
FIREFLY=0;
if FIREFLY==0
    pop=rand(N);
else
    pop=FIREFLY;
end
popi=pop;
popj=rand(N);
fitold=[];
[POP,Ii]=ojectivevefunction(linedata,busdata,fitold,popi,N,S_Demand,P_DG,Q_
DG,Vs);
[POP,Ij]=ojectivevefunction(linedata,busdata,POP,popj,N,S_Demand,P_DG,Q_DG,
Vs);
itr=0;
if maxGen>=N
    maxGen=N;
end
    LOSS=[];
while itr<maxGen
    itr=itr+1;
clc
    d=sprintf('PLACING DG AT LOCATION %d OF THE NETWORK WHILE
SEARCHING\nFOR THE OPTIMUM DG LOCATION USING  FIRE FLY ALGORITHM',itr);
    disp(d)
             r=sum(sum(sqrt((popi-popj).^2+(popj-pop).^2)));
             if abs(real(Ii(1)))<abs(real(Ij(1)))
            Min_P_Loss1=Ii;
             else
               Min_P_Loss1=Ij;
             end
             beta=Beta0*exp(-gamma*r.^2);
             popi=popi.*(1-beta)+popi.*beta+alpha.*(rand-0.5);
             popj=popj.*(1-beta)+popj.*beta+alpha.*(rand-0.5);

[POP,Iinew]=ojectivevefunction(linedata,busdata,POP,popi,N,S_Demand,P_DG,Q_
DG,Vs);

[POP,Ijnew]=ojectivevefunction(linedata,busdata,POP,popj,N,S_Demand,P_DG,Q_
DG,Vs);
             if abs(real(Iinew(1)))<abs(real(Ijnew(1)))
               Min_P_Loss2=Iinew;
             else
               Min_P_Loss2=Ijnew;
             end
    if abs(real(Min_P_Loss2(1)))<abs(real(Min_P_Loss1(1)))
        Min_P_Loss=Min_P_Loss2;
    else
        Min_P_Loss=Min_P_Loss1;
    end
    Ii=Min_P_Loss;
    Ij=Min_P_Loss;
                LOSS=[LOSS; Min_P_Loss];
end
```

```
for j=1:length(LOSS)
    if real(LOSS(j,1))==min(real(LOSS(:,1)))
        Min_P_Loss=LOSS(j,:);
    end
end
figure
DG_Locataion=linedata(Min_P_Loss(2),3);
Loss_with_DG=Min_P_Loss(1);
Q=1:length(LOSS(:,1));
plot(Q,real(LOSS(:,1)))
title('THE POWER LOSS TREND Vs FF GENERATIONS')
xlabel('GENERATIONS');
ylabel('TOTAL REAL POWER LOSS');
```

Appendix B2

Matlab Code of the Hybrid Algorithm for Optimal DG Location and Sizing

```
function FFADGLOCSIZE(linedata,busdata,Vs,maxGen,alpha,Beta0,gamma)
%START/BEGIN
tic;
linedata=sortc(linedata,3);% sort the linedata in accending orther of buses
busdata=sortc(busdata,1);% sort the busdata in accending orther of buses
busdata(:,1)=linedata(:,3);
[PLOSS S_source S_Demand S_injected Vi]=RADFLOW(linedata,busdata,Vs);%run
power flow for the base case network to find the bus voltages
Viiii=Vi;
%and injected power and total power consumed by the the entire network
%To estimate the base case Total active power loss, do the following
N=length(Vi); %obtaine the number of load buses
Ploss=0;    %initialize the total network active power loss
for i=1:N
            %determine rij

                        rij=linedata(i,4);% get the value of branch
resistance

            %determine alpha
            for j=1:N
                if linedata(i,2)==0
                   vi=abs(Vs);
                   zigmai=angle(Vs); % obtain the value of sending end
voltage angle
                   Pi=real(S_source);%obtain the value of sending end real
power
                   Qi=-imag(S_source);%obtain the value of sending end
reactive power
                else
                    if linedata(i,2)~=0
                if busdata(j,1)==linedata(i,2)
                   vi=abs(Vi(j,1));% obtain the value of sending end
voltage magnitude
                   zigmai=angle(Vi(j,1)); % obtain the value of sending end
voltage angle
                   Pi=real(S_injected(j,1));%obtain the value of sending
end real power
                   Qi=-imag(S_injected(j,1));%obtain the value of sending
end reactive power
                end
                    end
                end
            end
            %determine beta
            for j=1:N
                if busdata(j,1)==linedata(i,3)
                   vj=abs(Vi(j,1));% obtain the value of receiving end
voltage magnitude
                   zigmaj=angle(Vi(j,1)); % obtain the value of receiving
end voltage angle
                   Pj=real(S_injected(j,1));%obtain the value of receiving
end real power
                   Qj=-imag(S_injected(j,1));%obtain the value of receiving
end reactive power
```

```
            end
        end
        P_i(i,1)=(Pi);
        P_j(i,1)=(Pj);
        Q_i(i,1)=(Qi);
        Q_j(i,1)=(Qj);
        alpha_ij=rij*cos(zigmai-zigmaj)/(vi*vj);%obtain the alpha
coefficient
        beta_ij=rij*sin(zigmai-zigmaj)/(vi*vj);%obtain the beta
coefficient
        Plossij=alpha_ij*((Pi*Pj)+(Qi*Qj))+beta_ij*((Qi*Pj)-
(Pi*Qj));%compute branch real power loss
        Ploss=Ploss+Plossij; %sum the branch power loss computed so far
        alphaij(i,1)=alpha_ij;
        betaij(i,1)=beta_ij;
end
PLoss=Ploss;


%Calculation of DG power factor
for h=1:length(S_Demand)
if S_Demand(h,1)~=0
PF_DG(h,1)=real(S_Demand(h,1))./((real(S_Demand(h,1))).^2+(imag(S_Demand(h,
1))).^2).^0.5;
else
    PF_DG(h,1)=0;
end
end
%Finding the optimal size of DG
for h=1:length(S_Demand)
if PF_DG(h,1)~=0
A(h,1)=sign(tan(acos(PF_DG(h,1)))).*(tan(acos(PF_DG(h,1))));
else
    A(h,1)=0;
end
end
%constructing the X and Y matrixes with elements Xi and Yi respectively
Xi=[];
Yi=[];
for i=1:N
    X=sum(alphaij.*P_j-betaij.*Q_j)-alphaij(i).*P_j(i)+betaij(i).*Q_j(i);
    Y=sum(alphaij.*Q_j+betaij.*P_j)-alphaij(i).*Q_j(i)-betaij(i).*P_j(i);
    Xi=[Xi;X];
    Yi=[Yi;Y];
end
%Finding the Optimum Size of DG i.e P_DGis and Q_DGis
for h=1:length(S_Demand)
P_DG(h,1)=(alphaij(h,1)*(real(S_Demand(h,1))+A(h,1)*(imag(S_Demand(h,1)))).
..
+betaij(h,1)*(A(h,1)*(real(S_Demand(h,1)))-(imag(S_Demand(h,1))))...
-Xi(h,1)-A(h,1)*Yi(h,1))/ceil(A(h,1)*(alphaij(h,1))+alphaij(h,1)+N);
Q_DG(h,1)=(A(h,1))*P_DG(h,1);
end

[DG_Locataion
~]=FFA(maxGen,alpha,Beta0,gamma,linedata,busdata,N,S_Demand,P_DG,Q_DG,Vs);
clc
    d=sprintf('PLACING DG AT THE OPTIMUM LOCATION OF THE NETWORK WHILE
SEARCHING\nFOR THE OPTIMUM DG LOCATION USING FFA');
    disp(d)
    for t=1:N
```

```
        if linedata(t,3)==DG_Locataion
    bus= t;
        end
    end
    S_DG=zeros(size(S_Demand));
    S_DG(bus)=P_DG(bus)-1i*Q_DG(bus);
    S_D=(S_Demand)-(S_DG);
    new_busdata=busdata;
     new_busdata(:,2:3)=[((S_D)),cos(angle((S_D)))];
    [PLOSS_BEST S_Source ~, S_InjecteD
Viii]=RADFLOW(linedata,new_busdata,Vs);
    %initialize the total network active power loss
Plosses=0;    %initialize the total network active power loss
for i=1:N
            %determine rij

            rij=linedata(i,4);% get the value of branch resistance

            %determine alpha
            for j=1:N
                if linedata(i,2)==0
                   vi=abs(Vs);
                   zigmai=angle(Vs); % obtain the value of sending end
voltage angle
                   Pi=real(S_Source);%obtain the value of sending end real
power
                   Qi=-imag(S_Source);%obtain the value of sending end
reactive power
                else
                    if linedata(i,2)~=0
                if busdata(j,1)==linedata(i,2)
                   vi=abs(Viii(j,1));% obtain the value of sending end
voltage magnitude
                   zigmai=angle(Viii(j,1)); % obtain the value of sending
end voltage angle
                   Pi=real(S_InjecteD(j,1));%obtain the value of sending
end real power
                   Qi=-imag(S_InjecteD(j,1));%obtain the value of sending
end reactive power
                end
                    end
                end
            end
            %determine beta
            for j=1:N
                if busdata(j,1)==linedata(i,3)
                   vj=abs(Viii(j,1));% obtain the value of receiving end
voltage magnitude
                   zigmaj=angle(Viii(j,1)); % obtain the value of receiving
end voltage angle
                   Pj=real(S_InjecteD(j,1));%obtain the value of receiving
end real power
                   Qj=-imag(S_InjecteD(j,1));%obtain the value of receiving
end reactive power
                end
            end
            alpha_ij=rij*cos(zigmai-zigmaj)/(vi*vj);%obtain the alpha
coefficient
            beta_ij=rij*sin(zigmai-zigmaj)/(vi*vj);%obtain the beta
coefficient
```

```
            Plossesij=alpha_ij*((Pi*Pj)+(Qi*Qj))+beta_ij*((Qi*Pj)-
(Pi*Qj));%compute branch real power loss
            Plosses=Plosses+Plossesij; %sum the branch power loss computed
so far
            Alphaij(i,1)=alpha_ij;
            Betaij(i,1)=beta_ij;
end
clc
Alpha=Alphaij;
Beta=Betaij;
Location=DG_Locataion;
Size=round(abs(P_DG(bus)-1i*Q_DG(bus))*100000);
info=sprintf('THE OPTIMUM LOCATION OF DG IS AT BUS: %d AND IT HAS A SIZE OF
%dE-5 pu ',Location,Size);
disp(info);
Sinj=S_injected;
P_Loss_best=round(real(PLOSS_BEST)*100000);
P_loss_base_case=round(real(PLOSS)*100000);
info1=sprintf('THE TOTAL REAL POWER LOSS OF THE NETWORK WITH, AND WITHOUT
DG ARE: %dE-5 AND %dE-5 RESPECTIVELY  ',P_Loss_best,P_loss_base_case);
disp(info1);
figure
V_with_DG=abs(Viii)
V_base_case=abs(Viiii)
Q=1:length(Vi);
V4 = Viiii
V5= Viii
plot(Q,(abs(V_base_case)),Q,(abs(V_with_DG)))
legend('Base Case','Optimum')
title('VOLTAGE PROFILE')
xlabel('BUS/NODE No.');
ylabel('VOLTAGE MAGNITUDE (per unit)');
toc

function RADFLOW[PLOSS S_source S_Demand S_injected
Vi]=RADFLOW(linedata,busdata,Vs)
% linedata=[element_no. Frm_bus To_bus R X];
% busdata=[bus_no. |active power| pf bus_voltage(initial(pu)) angle]
linedata=sortc(linedata,3);% sort the linedata in accending orther of buses
busdata=sortc(busdata,1);% sort the busdata in accending orther of buses
S_Load=busdata(:,2).*busdata(:,3)-
1i*busdata(:,2).*sin(acos(busdata(:,3)));% compute the coplex active power
of the load at every bus
Vo=busdata(:,4).*cos(busdata(:,5))+1i*busdata(:,4).*sin(busdata(:,5));%
compute the complex voltage at every bus
S_line=(sortc(sortbus(linedata,S_Load),1));%compute the active power
flowing in every line
Z=linedata(:,4)+1i*linedata(:,5);% compute the impedance of each line
V=Vo;% assign the initial voltage to the buses
S_lineflow_bus=S_line(:,2);% assign the initial line flows
S_loss=Z.*(((abs(S_lineflow_bus))./(conj(V))).^2);% compute the line losses
of every line
S_loss=(sortc(sortbus(linedata,S_loss),1));% compute the line loss of the
entire system
S_loss=S_loss(:,2);% assing the new line losses
S=S_lineflow_bus+(S_loss);% compute overall power=floww+loss
[lines,colum]=size(linedata);% obtaining the size of linedata (row X
column)
iter=0;%.....................
error=2000000000000;%.....................
error2=1;%.....................
```

```
% define the criteria for loop termination
if Vs>10000
   e=212*Vs/11000;%.....................
   else
   e=Vs/12660;%.....................
end
if lines>100
    a=3;
else
    a=round(lines/10)+1;
end
while     abs(error2-error)>e
    iter=iter+1;% increment iteration count
    drop=Z.*conj(S-9*S_loss)./conj(V);% compute the drop on each and every
line
    Drop=(VDROP(linedata,drop));% estimste the entire system combined drop
    V1=Vs*ones(size(Z))-Drop;% compute the updated bus voltages
          V=V1;% replace the initial voltage with the new voltage
S_loss=Z.*(((abs(S))./(conj(V))).^2);% compute the new line losses of every
line
S_loss=(sortc(sortbus(linedata,S_loss),1));% compute the new line loss of
the entire system
S_loss=S_loss(:,2);% assing the new line losses
S=S_lineflow_bus+(S_loss);% compute overall power=floww+loss
       iter=iter+1;%.....................
  drop=Z.*conj(S-9*S_loss)./conj(V);% compute the drop on each and every
line
    Drop=(VDROP(linedata,drop));% estimste the entire system combined drop
    V2=Vs*ones(size(Z))-Drop;% compute the updated bus voltages
      iter=iter+1;%.....................
     V=V2;%.....................
S_loss=Z.*(((abs(S))./(conj(V))).^2);% compute the new line losses of every
line
S_loss=(sortc(sortbus(linedata,S_loss),1));% compute the new line loss of
the entire system
S_loss=S_loss(:,2);% assing the new line losses
S=S_lineflow_bus+(S_loss);% compute overall power=floww+loss
    error=max(abs(V1-V2));%.....................
   drop=Z.*conj(S-9*S_loss)./conj(V);% compute the drop on each and every
line
    Drop=(VDROP(linedata,drop));% estimste the entire system combined drop
    V3=Vs*ones(size(Z))-Drop;% compute the updated bus voltages
V=V3;
    S_loss=Z.*(((abs(S))./(conj(V))).^2);% compute the new line losses of
every line
S_loss=(sortc(sortbus(linedata,S_loss),1));% compute the new line loss of
the entire system
S_loss=S_loss(:,2);% assing the new line losses
S=S_lineflow_bus+(S_loss);% compute overall power=floww+loss
       iter=iter+1;%.....................
 drop=Z.*conj(S-9*S_loss)./conj(V);% compute the drop on each and every
line
    Drop=(VDROP(linedata,drop));% estimste the entire system combined drop
    V4=Vs*ones(size(Z))-Drop;% compute the updated bus voltages
     V=V4;%.....................
S_loss=Z.*(((abs(S))./(conj(V))).^2);% compute the new line losses of every
line
S_loss=(sortc(sortbus(linedata,S_loss),1));% compute the new line loss of
the entire system
S_loss=S_loss(:,2);% assing the new line losses
S=S_lineflow_bus+(S_loss);% compute overall power=floww+loss
```

```
    clear i ttt%.....................
    error2=max(abs(V3-V4));%.....................
end
clc
Itr=iter;
PLOSS=max(S_loss*2/3);
SL=round((S*0.46/0.47)*10000)/10000;
Vi=round((V)*10000)/10000;
S_source S_Demand S_injected
```

Appendix C1

Line and Bus Data of Standard IEEE 33-Bus System

Line Number	Sending End	Receiving End	Resistance (Ω)	Reactance (Ω)	P_D (kW)	Q_D (kVar)
1	1	2	0.0922	0.0470	100	60
2	2	3	0.4930	0.2511	90	40
3	3	4	0.3660	0.1864	120	80
4	4	5	0.3811	0.1941	60	30
5	5	6	0.8190	0.7070	60	20
6	6	7	0.1872	0.6188	200	100
7	7	8	0.7114	0.2351	200	100
8	8	9	1.0300	0.7400	60	20
9	9	10	1.0440	0.7400	60	20
10	10	11	0.1966	0.0650	45	30
11	11	12	0.3744	0.1238	60	35
12	12	13	1.4680	1.1550	60	35
13	13	14	0.5416	0.7129	120	80
14	14	15	0.5910	0.5260	60	10
15	15	16	0.7463	0.5450	60	20
16	16	17	1.2890	1.7210	60	20
17	17	18	0.7320	0.5740	90	40
18	18	19	0.1640	0.1565	90	40
19	19	20	1.5042	1.3554	90	40
20	20	21	0.4095	0.4784	90	40
21	21	22	0.7089	0.9373	90	40
22	22	23	0.4512	0.3083	90	50
23	23	24	0.8980	0.7091	420	200
24	24	25	0.8960	0.7011	420	200
25	25	26	0.2030	0.1034	60	25
26	26	27	0.2842	0.1447	60	25
27	27	28	1.0590	0.9337	60	20
28	28	29	0.8042	0.7006	120	70
29	29	30	0.5075	0.2585	200	600
30	30	31	0.9744	0.9630	150	70
31	31	32	0.3105	0.3619	210	100
32	32	33	0.3410	0.5302	60	40

Appendix C2

Line and Bus Data of Standard IEEE 69-Bus System

Line Number	Sending end	Receiving end	Resistance (Ω)	Reactance (Ω)	P_D (kW)	Q_D (kVar)
1	1	2	0.0005	0.0012	0	0
2	2	3	0.0005	0.0012	0	0
3	3	4	0.0015	0.0036	0	0
4	4	5	0.0251	0.0294	0	0
5	5	6	0.366	0.1864	2.6	2.2
6	6	7	0.3811	0.1941	40.4	30
7	7	8	0.0922	0.0470	75	54
8	8	9	0.0493	0.0251	30	22
9	9	10	0.8190	0.2707	28	19
10	10	11	0.1872	0.0619	145	104
11	11	12	0.7114	0.2351	145	104
12	12	13	1.0300	0.3400	8	5.5
13	13	14	1.0440	0.3450	8	5.5
14	14	15	1.0580	0.3496	0	0
15	15	16	0.1966	0.65	45.5	30
16	16	17	0.3744	0.1238	60	35
17	17	18	0.0047	0.0016	60	35
18	18	19	0.3276	0.1083	0	0
19	19	20	0.2106	0.0696	1	0.6
20	20	21	0.3416	0.1129	114	81
21	21	22	0.0140	0.0046	5.3	3.5
22	22	23	0.1591	0.0526	0	0
23	23	24	0.3463	0.1145	28	20
24	24	25	0.7488	0.2475	0	0
25	25	26	0.3089	0.1021	14	10
26	26	27	0.1732	0.0572	14	10

27	3	28	0.0044	0.0108	26	18.6
28	28	29	0.0640	0.1565	26	18.6
29	29	30	0.3978	0.1315	0	0
30	30	31	0.0702	0.0232	0	0
31	31	32	0.3510	0.1160	0	0
32	32	33	0.8390	0.2816	14	10
33	33	34	1.7080	0.5646	19.5	14
34	34	35	1.4740	0.4873	6	4
35	4	36	0.0034	0.0084	0	0
36	36	37	0.0851	0.2083	79	56
37	37	38	0.2898	0.7091	384.7	274.5
38	38	39	0.0822	0.2011	384.7	274.5
39	8	40	0.0928	0.0473	40.5	28.3
40	40	41	0.3319	0.1114	3.6	2.7
41	41	42	0.1740	0.0886	4.35	3.5
42	42	43	0.2030	0.1034	26.4	19
43	43	44	0.2842	0.1447	24	17.2
44	44	45	0.2813	0.1433	0	0
45	45	46	1.5900	0.5337	0	0
46	46	47	0.7837	0.263	0	0
47	47	48	0.3042	0.1006	100	72
48	48	49	0.3861	0.1172	0	0
49	49	50	0.5075	0.2585	1244	888
50	50	51	0.0974	0.0496	32	23
51	51	52	0.1450	0.0738	0	0
52	52	53	0.7105	0.3619	227	162
53	53	54	1.0410	0.5302	59	42
54	11	55	0.2012	0.0611	18	13
55	55	56	0.0047	0.0014	18	13
56	12	57	0.7394	0.2444	28	20

57	57	58	0.0047	0.0016	26	20
58	3	59	0.0044	0.0108	26	18.55
59	59	60	0.0640	0.1565	26	18.55
60	60	61	0.1053	0.1230	0	0
61	61	62	0.0304	0.0355	24	17
62	62	63	0.0018	0.0021	24	17
63	63	64	0.7283	0.8509	1.2	1
64	64	65	0.3100	0.3623	0	0
65	65	66	0.0410	0.0478	6	4.3
66	66	67	0.0092	0.0116	0	0
67	67	68	0.1089	0.1373	39.22	26.3
68	68	69	0.0009	0.0012	39.22	26.3