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POWER LOSS MINIMIZATION AND VOLTAGE PROFILE IMPROVEMENT IN TRANSMISSION NETWORKS USING A NETWORK MODIFICATION ALGORITHM

By

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July 2022

As the candidate's supervisor, I agree to the submission of this dissertation.

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DECLARATION

This dissertation is my original work, and all sources have been properly cited or referenced, I hereby declare. Additionally, this work hasn't been partially or completely published before for another degree at another university.

This research was duly supervised by Dr Kabeya Musasa and Mr Moketjema C Leoaneka at the Durban University of Technology.

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12 July 2022

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DEDICATION

To the cherished memory of my father and my grandmother, Nkosinathi Ntombela and Madlamini Ntombela, I dedicate this master's dissertation.

ACKNOWLEDGEMENT

My sincere gratitude goes to Dr. Musasa Kabeya and Clarence Moketjema, my dissertation supervisors, for their support useful advices and ongoing monitoring of my progress during the dissertation work, thank you for everything you have done and for believing in me.

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God bless us all

ABSTRACT

A number of algorithms that aim to reduce power system losses and improve voltage profiles by optimizing distributed generator (DG) location and size have already been proposed, but they are still subject to several limitations. Hence, new algorithms can be developed or existing ones can be improved so that this important issue can be addressed much more appropriately and effectively. In their formulations, the majority of algorithms focused only on real power loss minimization. Power systems operate with reactive power controller installed at various locations, which are essential to their operation. Therefore, the effect of reactive power control must be taken into consideration when optimizing DG allocation for voltage profile improvement. State-of-the-art optimization algorithms can be used to improve the effectiveness of the existing one in taking into account the effect of reactive power control. This study proposed a modification methodology based on a hybrid optimization algorithm, consisting of a combination of the genetic algorithm (GA) and the improved particle swam optimization (IPSO) algorithm m for minimizing active power loss and maintaining the voltage magnitude at about 1 p.u. The buses at which DGs should be injected were identified based on optimal real power loss and reactive power limit. When applying the proposed optimization algorithm for DGs allocation in power systems, the search space or number of iterations was reduced, increasing its convergence rate. The proposed modification methodology was tested in an IEEE-30 bus electrical network system with DGs allocations and the simulations were conducted using MATLAB software. The hybrid GA and IPSO (HGAIPSO) method has less iterations and is more effective at solving optimization issues than other optimization algorithms like GA, PSO, and IPSO. An IEEE-30 bus network system with DGs allocations was used to evaluate the effectiveness of the proposed HGAIPSO, and the test results were compared to those from alternative techniques (i.e. GA, PSO and IPSO). The outcomes of the simulation demonstrate that the suggested HGAIPSO can be an effective and promising optimization technique for issues with transmission network modification. IEEE-30 bus test system with DGs included at various locations, Type 1, Type 2, and Type 3 DGs allocation, respectively, showed decreases in overall real power loss of 40.7040%, 36.2403%, and 42.9406%. For the IEEE-30 bus, the highest bus voltage profiles are up to 1.01pu.

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ABBREVIATIONS

CSF-Combined Sensitivity Factors

ANN-Artificial Neuron Network

DG-Distributed Generator

DGs-Distributed Generators

DISCO-Transmission Company

LLRI-Line Loss Reduction Index

HGAIPSO-Hybrid Genetic Algorithm Improved Particle Swarm Optimization

LSF-Loss Sensitivity Factor method

IPSO-Improved Particle Swarm Optimization

ORPF-Optimal Reactive Power Flow

PLI-Power Loss Index

PLRI-Real Power Loss Reduction Index

PSO-Particle Swarm Optimization

QLRI-Reactive power control Reduction Index

FLA-Fuzzy Logic Algorithm

GA-Genetic Algorithm

T&D-Transmission and Distribution

BRTN-Best Radial Transmission Network

TSTATCOM-Transmission-Static Compensator

RCGAA- Real-Coded Genetic Algorithm

NBPSO-Novel Binary Particle Swarm Optimization

DPSO-Discrete Particle Swarm Optimization

THD-Total Harmonic Distortion

PDIP-Primal Dual Interior Point

VSI-Voltage Sensitivity Indexes

IPP-Independent Power Producer

CHAPTER ONE: INTRODUCTION AND BACKGROUND TO THE STUDY

1.1 Introduction

All living things on the planet require energy to survive. Energy cannot be generated or destroyed, but it can be changed into several forms. Modern life-styles have become even more important, because a speedier life means faster communication, manufacturing processes and transportation [1]. The electric power sector is one of the world's major consumer markets. The electrical power system desperately needs non-conventional alternative generating due to the increase in demand. Studies [1] indicate that the transmission level wastes about 13% of the total electricity generated. The financial stability and general effectiveness of transmission utilities are directly impacted by these not insignificant losses. In addition, each of these elements increases the demand for energy.

The power transmission network has always had to deal with changes in load demand, which has resulted in voltage oscillations outside the boundaries limit of variations at different buses and power losses. As a result, the proper placement and scale of distributed generation (DG) are required to improve the voltage profile and reduce electrical power losses. According to research, global consumption is predicted to expand at a 1.6 percent yearly rate between now and 2025. Consequently, Distributed Generation (DG), also known as alternative energy systems, is likely to play a larger role in the future of power systems [2]. Due to their overall favorable impacts on power networks, DG units are now becoming more frequently used in electrical transmission networks. For smart grid technology, DG systems constitute the backbone of smart electrical networks. These DG systems can also increase system dependability by acting as a backup generator for some customers in the event of electricity outages.

There are two categories of DG technologies: those that use fossil fuels and renewable energy sources. Examples of DGs using fossil fuels are internal combustion engines, combustion turbines, and fuel cells. Wind turbines, solar, biomass, geothermal, small hydro and other renewable energy source-based DGs are examples of renewable energy sources. It is crucial to assess the technological implications of DG in electricity networks [3]. However, the technical impact of DG on electricity networks is extremely important and time-consuming to assess. The fact is that the installation of DG units in power systems is not a straightforward decision. [4].

1.2 Context, Background and Motivation

More than 6 000 MW of generation capacity has been added to the capacity of the existing power systems in African nations as a result of the use of renewable energy resources, primarily the wind, solar, biomass, and small hydro that are components of DG systems. Through private sector investment, the Independent Power Producer (IPP) approach seeks to add more megawatts to the power system. For the purchase of coal projects from IPPs, approximately 2 500 MW have been allocated [6]. While the Grand Inga Project, which aims to secure 2,500 MW, is still under construction, South Africa and the DRC have already signed an energy deal. A legal framework for collaboration between the two nations is provided by the 2014 agreement.

Early in the 1990s, many nations implemented open energy markets, opening the door for new competitors to enter the market. Additionally, the market for power was liberalized as a result of the addition of new electrical production. Environmentally speaking, a number of conventional generator types emit carbon dioxide, which might have an impact on the heavily debated global warming. Switching from generation based on fossil fuels like coal, gas, and oil to renewable energy sources like solar and wind would be necessary to reduce emissions. Governments have therefore implemented incentives to encourage IPPs to employ renewable energy sources as a substitute for conventional energy sources [6].

Operators of power systems must create a balance between supply and demand because electricity cannot be successfully stored and must be used immediately. The redial design of transmission networks with the inclusion of DGs was not taken into consideration when developing the power system [5]. Due to this, it is essential to involve the DGs in the placement and sizing of DGs in order to meet the system's technical and economic needs. The best DG allocation and sizing strategies have significant applications in this situation [7].

1.3 Problem Statement

The use of optimization methods for electrical transmission network modification and the deployment of DGs has produced impressive results for reducing power loss and improving voltage profiles. The optimization method used in this research project for electrical transmission network modification is the HGAIPSO, which is an artificial intelligence-based approach that selectively locates the optimal location for a particle [8]. The problems in this study entail determining the optimal size or rating of DGs to be injected in the power system at specific nodes and to also find the optimal allocation of DGs in the power system for reactive power control and power loss minimization. Details of the GA, PSO and IPSO algorithms can be found in literature. Therefore, the use of a hybrid method, i.e. the combination of GA and IPSO, is applied in this study to search for optimal buses in the power system at which DGs could be injected to minimize the overall power losses and to maintain the voltage magnitude at about 1pu [9].

The HGAIPSO method inherits the positive characteristics of the GA and IPSO algorithms whilst avoiding their negative characteristics. The algorithm's search space is minimized, which shortens the iteration period, by identifying the chosen buses for DG allocation based on real and reactive power flow and power loss sensitivity parameters. The problem statement has two main parts, namely:

- Determining the candidate bus in the power system at which DGs should be allocated based on the load flow, reactive power control limit and power loss sensitivity factors; and
- For DGs placement and sizing, the load flow problem, including constraints, is solved using a hybrid approach that combines both GA and IPSO. A sample electrical transmission network, i.e. IEEE-30-bus test system, is used to evaluate the performance of the proposed algorithm.

1.4 Research aims and objectives

This research project presents an improved optimization method for electrical power network modification applications. Constraints like real power loss minimization, reactive power limit, and voltage amplitude stability are taken into account during the algorithm's iteration phase. Other aims of the study include:

- To develop the HGAIPSO algorithm, which is a combination of GA and IPSO algorithms, for optimal allocation of DGs in electrical transmission networks.
- To develop a multi-objective function that incorporates the real power loss reduction index (PLRI), the reactive power control reduction index (QCRI), and the voltage profile improvement index (VPII).
- To reduce power losses and improve voltage profiles by optimal sizing and placement of DGs; and
- To evaluate the proposed HGAIPSO method in contrast to the current GA, PSO, and IPSO algorithm. For testing, an IEEE-30 bus electrical network with DGs allocation at various buses was used.

1.5 Research Questions

Answers to the following questions are provided by performing an analysis of the sample electrical power network with DG allocation:

- By considering the real power losses and voltage profile as index for analysis, what would be the performance of a power system with and without the optimal allocation and sizing of DGs?
- What are the advantages of using the HGAIPSO method compared to the GA, PSO and IPSO methods in power system modification?

1.6 Contributions of the study

Various parties will benefit directly or indirectly from this research. The transmission companies will benefit directly from this research work for the following reasons:

- As a result of this research work, transmission companies and Independent Power Producers (IPP) will have the ability to reduce real power loss in their networks. Taking advantage of this reduction will help them to avoid penalties and compensations, thus improving their profit margins;
- During this work, Independent Power Producers (IPP) will be able to integrate small-scale renewable energy sources more easily and more reliably into their networks. Due to the switch to green energy in the power production industry, this is very important; and
- This study's findings will have a significant impact on others as well. Customers, for instance, will benefit from this since they will feel confident using steady voltage profiles to operate their machines.

1.7 Dissertation structure

The dissertation research is arranged into six chapters. The introduction is the first chapter. General transmission systems are discussed in this section. This chapter also addresses how to minimize system power losses and improve voltage profiles.

Chapter Two reviews the literature and identifies the gaps in existing research. The problem that this research aims to solve is stated clearly in this chapter.

Chapter Three discusses various methods of solving the problem using different formulations. It presents a formulation of sensitivity factors combined. This chapter presents a multi-objective function and a set of operational constraints. The methods chosen for this investigation are selection, crossovers and mutations. Throughout this chapter, the proposed algorithm and flow-chart are described in detail.

In Chapter Four, tables and graphs represent the results obtained. This chapter also discusses the results obtained in detail.

A conclusion to the entire study is provided in Chapter Four. This chapter also mentions the work and recommendations made to carry on with this investigation.

1.8 List of publications

1) M. Ntombela, K. Musasa and C. M. Leoaneka. *2022.* "Review of Optimization Techniques for Power Network Reconfiguration". *30th Southern African Universities Power Engineering Conference (SAUPEC)*, 2022, pp. 1-6, doi: 10.1109/SAUPEC55179.2022.9730628.

2) M. Ntombela, K. Musasa and C. M. Leoaneka "Power Loss Minimization and Voltage Profile Improvement by DG Sizing and Placement", 2022 IEEE PES/IAS Power Africa, Kigali, Rwanda, 2022, PP.1-5, doi: 10.1109/PowerAfrica53997.2022.9905254.

3) Ntombela, M. ; Musasa, K. ; Leoaneka, MC. Power Loss Minimization and Voltage Profile Improvement by System Modification, DG sizing and Placement. Computation 2022, 10, 180. https. //doi/10.3390/computation10100180.

4) M. Ntombela, K. Musasa and C. M. Leoaneka. 2023. "Artificial Intelligence Hybrid Algorithm for System Reconfiguration to Reduce Power Losses in The Distribution System". Accepted and presented at the ICONIC2022 that was held at Ravenala Attitude Hotel in Mauritius on the 8th and 9th December 2022.

5) M. Ntombela, K. Musasa and C. M. Leoaneka. 2023. "Optimal Positioning and Sizing of Distributed Generation to Reconfigure Power Network Using Wind Power DG". Accepted and presented at the 2023 SAUPEC Conference, Johannesburg, South Africa, January 24-26, 2023.

6) M. Ntombela, K. Musasa and C. M. Leoaneka. 2022. “Optimal Positioning and Sizing of Distributed Generation to Reconfigure Power Network Using Artificial Intelligent Algorithm”. Accepted and presented at the 2023 SAUPEC Conference, Johannesburg, South Africa, January 24-26, 2023.

1.9 Summary

Introduction, objectives, scope of the project, and the dissertation's outline were all provided in Chapter one. A review of Distributed Generation and related technologies will be presented in the following chapter.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

In this chapter, state-of-the-art artificial intelligent algorithms for voltage profile optimization and power loss minimization in transmission networks are reviewed. This includes the fuzzy logic, artificial neural network, GA, PSO and the IPSO algorithms.

2.2 Generality of Distributed Generation

In Figure 2.1, the plot of a typical power loss versus DG size for a particular transmission network is depicted. It shows that as the DG size increases in power rating at a specific bus, the losses become minimal. If the size of the DG is increased further, one is likely to see power losses also increase. Therefore, in order to minimize the overall losses, DGs must be optimally allocated in transmission networks.

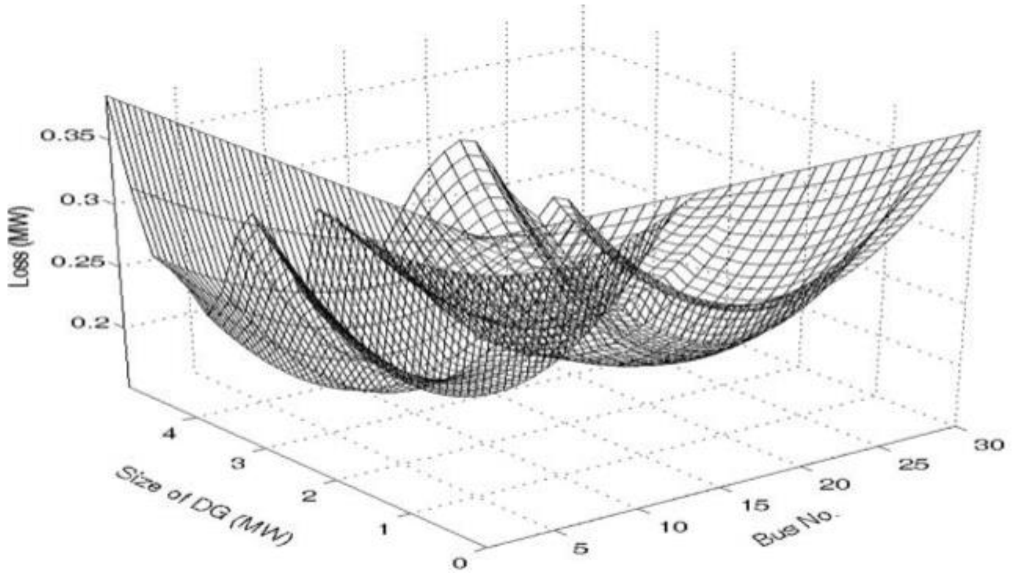


Figure 2-1: Effect of the DG's size and location on system loss.

From the characteristics in Figure 2.1, it is not appropriate to inject a large DG into the electrical transmission system [10]. It should be of size such that it can be consumed within the transmission sub-station boundary at most. Moreover, it will be difficult to utilize a high-capacity DG for exporting power beyond the sub-station (reversing power flow through the sub-station), since it will result in very high losses. Therefore, in choosing the size of the DG, it will be important to consider the size of the electrical transmission system, including the size of the load (MW). Losses are greater with larger DG capacities because the transmission system is originally built to optimise power flow from the source end (sub-station) to the load and subsequently reduce conductor diameters from the sub-station to the consumer point. Using high capacity DGs without a strengthening of the system therefore results in an excessive flow of power through small conductors and consequently higher losses [11].

2.3 Type of Electrical Networks

To provide low voltage electric current to consumer loads, the electrical power transmission system was introduced. Radial and ring transmission networks are among the two types of transmission networks. The radial transmission system shown in Figure 2.2, which has separated feeders that each come from a single sub-station [12]. The ring transmission system, showed in Figure 2.3, has feeders arranged in a ring shape that terminates back at the supply sub-station. This network modification is carried out at the radial transmission network as one of the requirements.

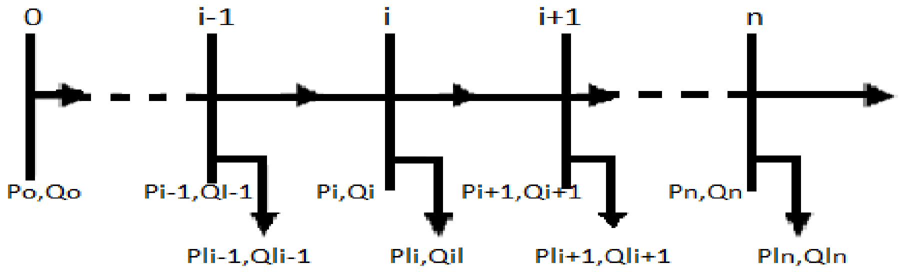


Figure 2-2: The line diagram for the Radial system

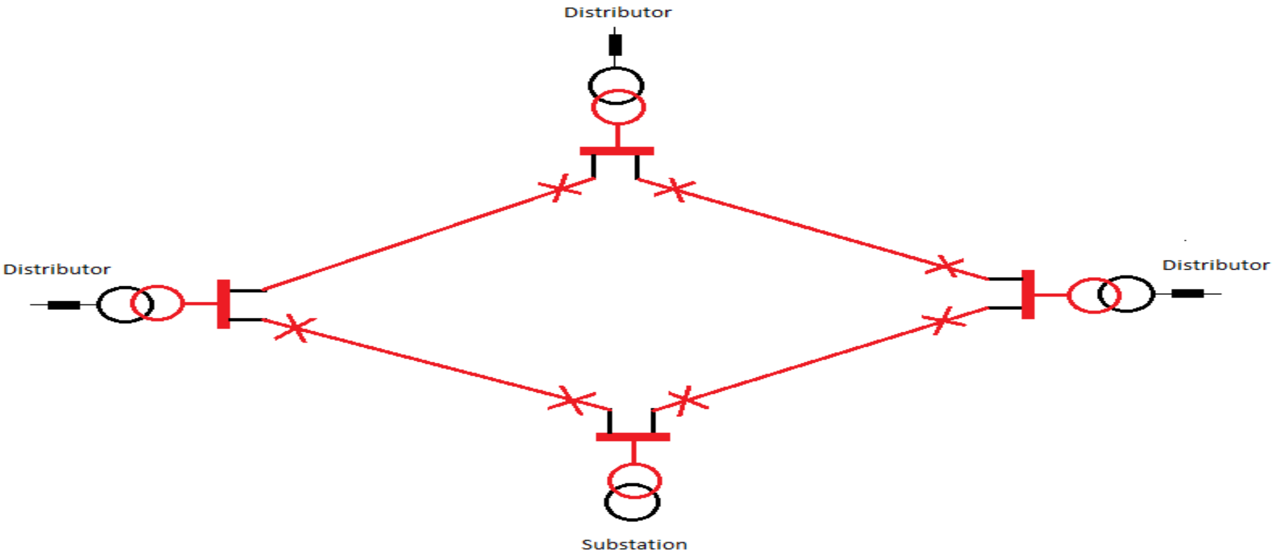


Figure 2-3: The line diagram for the Ring system

2.4 Fuzzy Logic Algorithm

Fuzzy logic, as illustrated in the flow diagram in Figure 2.4, has been used for reactive power control with the goal of optimizing the voltage profile of the power system for many years. To establish the relationships between voltage and the regulating capability of the installed controlling device, the voltage and controlling variables are transformed into fuzzy sets. On the basis of local control for buses with unacceptable voltage and overall control for buses with a poor voltage profile, the control variables are chosen. They can be applied to anything, including small circuits and huge mainframes. Additionally, since most of the data utilized in power system analysis are approximations and assumptions, they can be used to improve the efficiency of the systems [13].

Advantages of a Fuzzy Logic Algorithm:

- It is everlasting and reliable;
- It can be easily documented; and
- It can be easily transferred or reproduced.

Disadvantage of a Fuzzy Logic Algorithm:

- Unable to learn or adapt to new problems or situations.

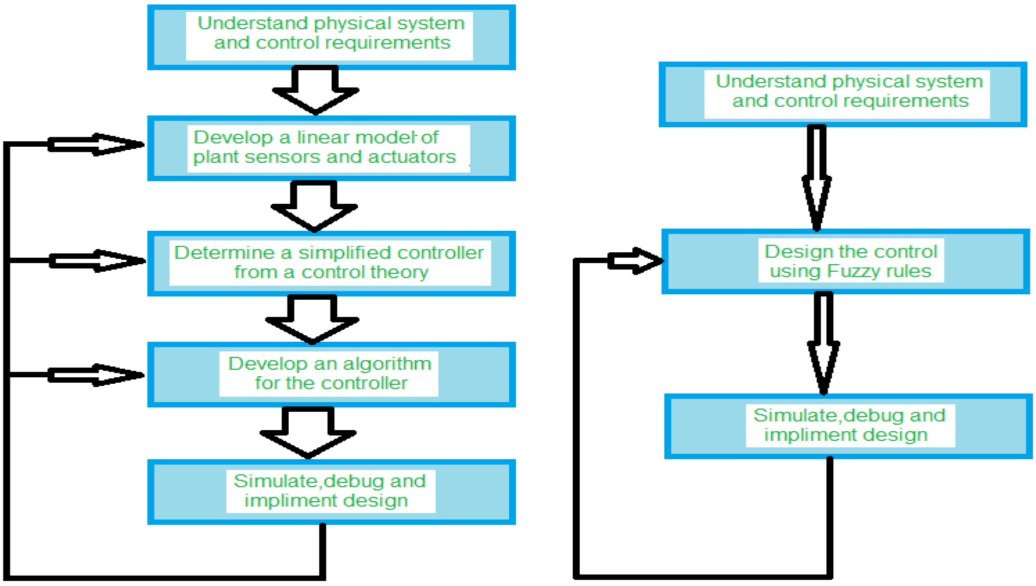


Figure 2-4: Fuzzy Logic Algorithm flow diagram

In [14], Aman and Jasmon proposed a new method for the placement of DGs in radial systems that employs Fuzzy Logic algorithms (FLA) in order to reduce real power losses and improve voltage profiles. The FLA algorithm takes a shorter time to compute than GA and PSO because it is simple by design. In [15], using the Fuzzy Logic Algorithm (FLA) to maximize the system voltage profile and reduce line losses, Ali Khan, Ghosh and Ghoshal proposed an approach to allocate and size DGs in networks. Utilizing voltage profile improvement indexes (VPII) and line loss reduction indexes (LLRI), the benefits of employing DG were evaluated.

2.5 Artificial Neural Network (ANN)

These are biologically inspired systems that use a network of neurons to translate a collection of inputs into a set of outputs. Each neuron can create one output depending on the inputs it receives. A basic neuron can be thought of as a processor that can perform a straightforward non-linear operation on its inputs to produce a single output. As demonstrated in Figure 2.5, a computer that can solve problems of pattern classification in the actual world can be built using knowledge of how neurons function and the pattern of their connections. They can be categorized as follows based on their structural characteristics, such as the quantity of layers and topology, connection pattern, and repeating. [16].

- Input Layers: The nodes units that can distribute data and information to other units but cannot process data or information themselves.
- Hidden Layers: The nodes are invisible, immediately obvious hidden units. Their responsibility is to give the networks the ability to map or categorize the non-linear issues.
- Output Layer: The nodes are output units that are capable of encoding potential values that could be assigned to the case being examined.

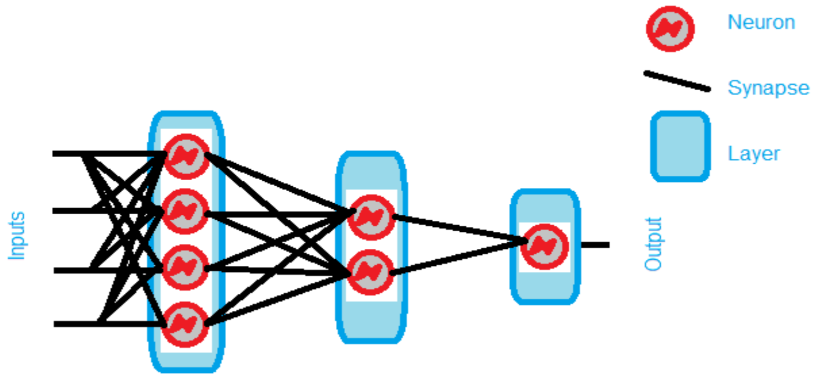


Figure 2-5: Architecture of a feed-forward ANN

Artificial Neutral Networks have the following benefits:

- Fast processing; and
- No specific knowledge of the power system is required.

Drawbacks of Artificial Neutral Networks

- Large dimensionality; and
- The fact that even with irrational input data, results can always be produced.

In [17], the methodology proposed by Heydari, Hosseini and. Gholamian can solve the optimal capacitor allocation problem in practical transmission networks using an ANN algorithm. It proposed that the Best Radial Network (BRDN) is determined by the Artificial Neuron Network (ANN) algorithm. This algorithm finds the best location, size and number of capacitors [18]. Padma, Sinarami and Veera used the ANN algorithm to optimize the placement and sizing of DGs for capacity improvement and loss reduction. There was a forward-backward sweep in the power flow pattern. In order to account for the consequences of uncertainty in the allocation and sizing problem for the transmission-static compensator (TSTATCOM), a novel stochastic framework based on a probabilistic load flow was proposed in order to explore the search space globally and take into account the uncertainty brought on by the forecast error of the loads and a new optimization approach based on Artificial Neuron Networks (ANN) has also been presented [19].

2.6 GA algorithm

In [20], Auglt, Hooshmand and Ataei mentioned that the size and location of the DG units were determined by Genetic Algorithms (GA). Cost function-based approaches provide the best solution, but they are computationally intensive and have a slow convergence. They have addressed the problem in terms of costs, but cost function calculations may lead to uncertainty on the exact size of DG units at suitable locations. In [21], Rahmat-Allah Hooshmand employed a Real-Coded Genetic Algorithm (RCGA) to address the issue of where to arrange capacitor banks in unbalanced distributed systems with mesh/radial designs. For reducing losses and controlling voltages of transmission systems, fixed and switched capacitors were optimally used.

In [22], based on RCGA (real coded genetic algorithm), Jalilzadeh, Galvani, Hosseinian and Razavi developed a method of finding the optimal values for fixed and switched capacitors in transmission networks. Various types of capacitors available on the market were used to model the loads at different load levels. To solve for the optimal capacitor rate, this study used the RCGA method. In a study based on genetic algorithms in [23], Boyerahmadi, and Poor examined voltage profiles in transmission systems. Reactive power injection was used to facilitate the improvement of voltage profiles in end busses that are far from slack buses. To determine optimum reactive power injection values, the genetic algorithm was used. The method resulted in an improved voltage profile and a decrease in losses.

In [24], according to Carpinelli. DGs can be optimally located in radial transmission networks if they are located with the lowest minimum system losses. The problem was formulated as an optimization problem with the objective of eliminating real power loss while complying to equality and inequality constraints. Based on how responsive active power loss is to real power injection through DG, the location was chosen. The researchers demonstrated the benefit increases, as more locations are located within certain areas beyond which it is not economically feasible. Only active power loss was considered in this formula.

In [25], a study by Hajizadeh on shunt capacitor placement and distributed generation plants, the authors examined the effect of genetic algorithms on the radial systems' decrease of power loss and voltage profile. In their study, they found that locating distributed generation plants and capacitors at the best location leads to voltage profiles with lower losses. A transmission plant located near the load is the best location for shunt capacitors.

In GA, the population successive generations adapt to the environment by mimicking the biological processes that occur in an ecosystem. The principle of Evolutionary Adaptation was modeled by genetic algorithms, unconstrained optimization methods. The Genetic Algorithm uses natural selection and evolution to start solving an optimization problem with an objective function f(x), where $x = x_1, x_2, x_3 \ldots, x_n$ Optimization parameters in N-dimensions. The basic unit of the GA are genes and chromosomes. As GA standard optimization parameters are encoded in binary code string [26], the GA gene represents a binary code. Genes are combined together to make chromosomes.

One of the greatest approaches for parameter search is GA. The following are some ways that GA is different from traditional optimization and search techniques.

- Rather than being parameterized in GA, parameters are typically coded;
- This method searches over a population of points rather than a single point by relying just on objective functions in place of additional information like derivatives.; and
- By eliminating the use of derivatives, only objective functions are used instead.

GA offers several advantages, namely:

- The gradient of the response surface does not understand;
- They may be applied to a wide range of optimization issues since they are not subject to local optimum trapping;
- A vast set of solutions are scanned quickly;
- The end solution is not affected by bad proposals since they are simply discarded; and
- Since it chooses its own behavior based on internal principles, the algorithm does not need to be familiar with the rules controlling the problem.

2.7 GA Parameters choice

For GA to converge rapidly, it is essential to select appropriate parameters. In the absence of any guidelines, there is a mechanism developed to determine these parameters in the method. The following are GA parameters [27]:

2.7.1 Initial population

Normally, the GA operates on an N-chromosome population. A random number is assigned to the first number in this population. This means that each vector represents one possible search solution. There are typically 2 to 2.5 times as many genes as there are in N populations.

2.7.2 Scaling

Sometimes, an objective function needs to be scaled into a fitness function by means of a scaling operator (a pre-processor). By preventing premature convergence in the early stages of evolution, and speeding up convergence at the later stages, it works to prevent premature convergence.

2.7.3 Criteria for termination

Following the calculation of fitness, the termination criterion needs to be determined. Several methods are used to determine this. Amongst them are the following:

- After a certain amount of accuracy is achieved; and
- There has been a pre-defined finite number of generations reached. A winner is declared and the problem solved based on the best match amongst the population.

2.7.4 Selection

Using this operator, chromosome fitness values are used to select good chromosomes and the resulting mating pool produced. There are a number of ways to accomplish this, but Roulette Wheel Selection is the most common. Roulette wheels are biased according to the fitness of each candidate solution. There are M strings in the population, so the wheel is spun M times. By performing this operation, the measure that is calculated reflects the fitness of candidates from the previous generation.

2.7.5 Mutation and Crossover

Most crossovers and mutations on based on user preferences. Amongst them is the crossover operator. Chromosomes are mated in pairs and the mated pairs crossed over with a probability Pcross to generate candidate offspring. In general, there is a probability between 0.6 and 1.0 of parental chromosome crossover. The candidate offspring have some of their genes inverted with a probability of Pmut. In the GA, this operation is called mutation. As a result, a new population is generated. The mutation operator ensures that there is diversity within the population to prevent premature convergence. Usually, 0.01 or 0.1 is used to calculate the probability of mutation.

2.7.6 Elitism

Whenever the best number in the newly generated population is less than that in the old population, when a population is created, the poorest chromosome is replaced by the best chromosome in the previous population. This ensures that the algorithm's convergence is achieved. Elite parent preservation is referred to as ‘elitism’.

2.7.7 Implementation of GA steps

GA is when the population represents candidate solutions due to n chromosomes. Each chromosome represents a real value vector with m dimensions, where m is the quantity of variables that were optimized. Figure 2.6 shows the GA flowchart used to resolve engineering challenges. The stages for implementing a Genetic Algorithm are used to generate the flowchart [27].

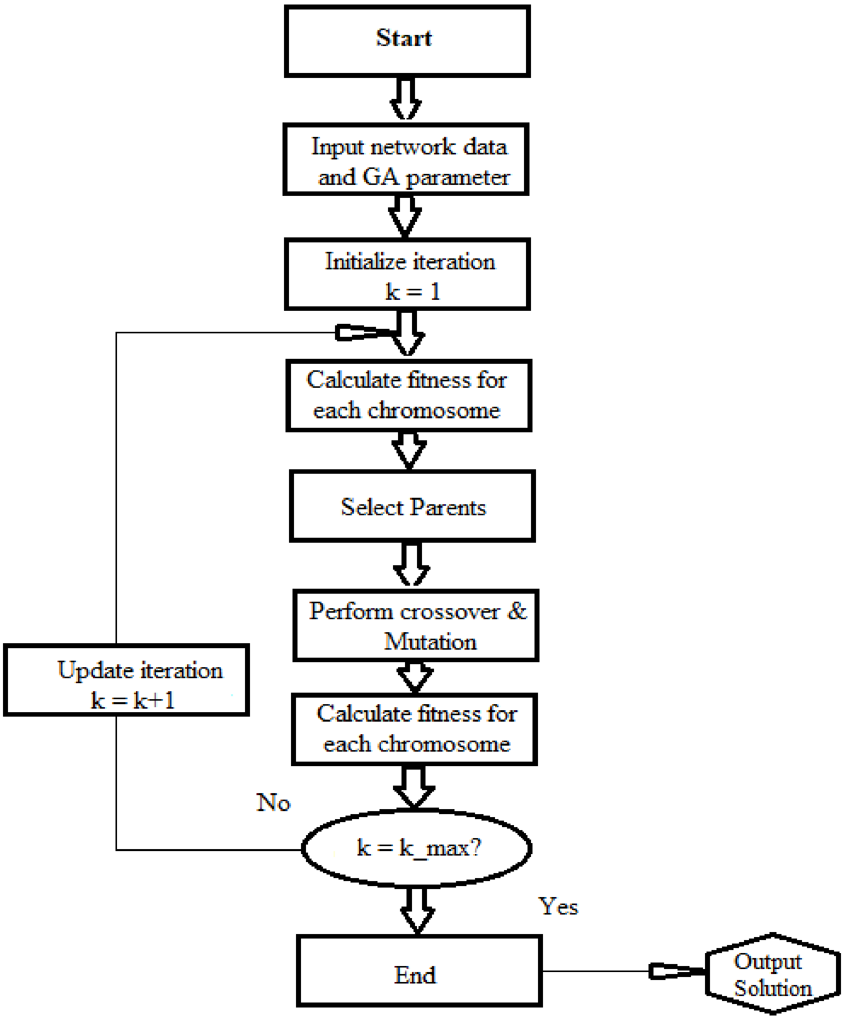


Figure 2-6: Steps for the implementation of a Genetic Algorithm

2.8 PSO algorithm

In [28], it is suggested by Hajizadeh and Hajizadeh that transmission planning be done PSO-based. They created a multi-objective framework for the best sizing and positioning of distributed generation assets in transmission systems, reducing the costs of power loss. Based on a PSO and weight approach, a best compromise is achieved between these two costs using the implemented technique. In [29], a study by Zou and Agalgaonkar, shunt capacitors and DG units were employed to establish voltage support zones in transmission networks. This method reduces the search space by identifying the target voltage zones numerically and analytically. By strategically positioning DG units and shunt capacitors using PSO for overall voltage support and power loss reduction, it is suggested to reduce the investment cost for these components.

In [30], a methodology has been proposed by Ziari et al. for the optimal allocation of capacitors and sizing capacitors for minimizing transmission line losses and improving voltage profiles. The results showed that the proposed methodology was more accurate and robust compared to genetic algorithms and non-linear programming. In [31], according to Khanjanzadeh et al., the role of the location and capacity of a DG in enhancing stable voltage in radial distributed systems via PSO could be determined and the results of the PSO algorithm compared to the GA algorithm in terms of accuracy and convergence. PSO was found to be more accurate and faster to convergence than GA method in terms of response and convergence speed.

Using a PSO-based technique, in [32], Varesi proposed optimizing DG unit allocation in the power system to reduce power losses and improve voltage profiles. To choose the ideal combination of DG unit types, sizes, and locations, the load flow algorithm and PSO were appropriately integrated. The researcher only considered two types of DG units. According to Mohammed and Nasab in [33], a multi-objective PSO approach was used to optimize DG size and placement. The research employed a hybrid objective function with two components, the first of which was the Power Loss Reduction Index and the second of which was the Reliability Improvement Index. Only acting power losses were taken into account in the study.

In [34], using a Novel Binnary Particle Swarm Optimization (NBPSO) technique, Mancer, Mahdad and Srairi presented an improved total voltage profile by incorporating the optimal placement of shunt capacitors with constraints in power transmission systems. The NBPSO method determined the optimal capacitor sizing and locations by using the near global optimization approach. Shunt capacitors were incorporated into the sizing and placement of capacitors. In [35], a new study by Mehdi Nafar used discrete particle swarm optimization (DPSO) to optimize the transmission system voltage profile and to reduce total harmonic distortion (THD) in a distributed generation and capacitor system. Their objective function contained a component that prevented harmonic resonance between the reactance of the capacitor and the reactance of the system. Voltage limit, voltage, number/size of capacitors, and generator limitations were among the restrictions. The suggested technique was tested using a modified version of the IEEE 33-bus test system.

In [36], Hajforoosh and Seyed M employed Particle Swarm Optimization to reduce the price of active losses, DG investment and running expenses, and emission costs. They identified flaws in the GA and PSO approaches. These two approaches frequently become stuck in local optimum solutions. This basically means that the approaches' output may not always yield the best outcomes. The challenge was addressed utilizing sophisticated artificial intelligence techniques.

PSO is an optimization technique that draws its initial inspiration from the social behavior of fish schools and flocks of birds, as the steps shown Figure 2.7. The PSO algorithm creates a population of particles that positioned randomly throughout the search space. Particles represent solutions to the problem and have fitness values. It optimized based on its fitness. Eventually, particles will move towards the optimal position as they will have experienced their best position and the best solution. An updated velocity of particles was based on three factors, namely its past velocity; its best position to date; and the best position the entire swarm has reached in the past [37].

2.9 Parameter choices of PSO

Particle Velocity

The limit imposes restrictions on the present velocity. The parameter indicates the resolution, or fitness, achieved by defining which regions between the present position and the target position will be searched. As a result, particles move in larger steps and might miss good solutions if it is very high. Conversely, if is too low, particles move around long distances before reaching desired solutions. There is a risk that their exploration is insufficient and thus they are captured in local minimum solutions [38].

2.9.1 Weighting Coefficients

In the stochastic acceleration formula, for high values, the target region approached shortly, or passed over. In the meantime, low values permit particles to wander farther from the target zone before being drawn back. As the number of iterations increases, it is possible to adopt parameters within the range [1, 2], but in many applications there are often constants. The study controls the rate at which other particles are influenced by their memories and the typical values of their memories [39].

2.9.2 Inertia Weight

By choosing an inertia weight that is appropriate for each exploration, a balance is achieved between global and local explorations. Exploration and exploitation balanced by the choice of the inertia weight. Typically, the optimization process starts with a large inertia weight and gradually reduces it throughout [40].

2.9.3 Termination criterion

In the following iterations of the initial phase, there are several updates and evaluations until a stopping condition is reached. There are generally two types of stopping condition: a predefined maximum number of iterations or a maximum level of precision.

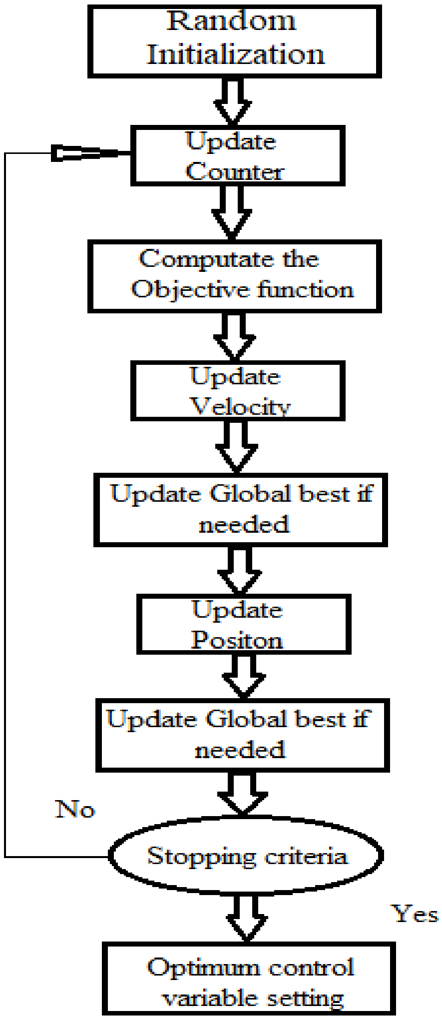


Figure 2-7: Flow chart of a Particle Swarm Optimization algorithm

2.10 IPSO algorithm

In [41], the IPSO (IPSO) referred to by Ziari and Platt used optimal scheduling of DG and capacitor banks to minimize the reliability and line loss costs, as well as the investment cost associated with electricity networks. They used crossover and mutation operators in their research to reduce the likelihood of catching in the local minima by limiting power loss, maintaining the voltage profile, and keeping the stability margin, they solely took into account genuine power losses while simulating IPSOs... In [42], Jain, Singh and Srivastava developed a method for optimizing the placing and sizing of multiple DGs using IPSO. The researchers found that the method performed better compared to other classical and analytical methods for the placement of a single DG.

In [43], the IPSO-based method proposed by Umapathi Reddy et al. is an application to loss reduction in unbalanced radial transmission systems. Their study presented an efficient algorithm for determining where, what kind, and what size of capacitor bank to install in unbalanced radial systems. In addition, a selected bus identification method was described for determining optimal capacitor placement locations using power loss indices (PLI) analysis. In unbalanced radial systems, the researcher used the IPSO approach to determine the optimal capacitor bank sizing. In [44], a power loss reduction model was implemented by Jamian et al. to size DGs and reduce power losses by selecting the survival particles that will remain in the next iteration.

There are n particles in the population of the IPSO algorithm, each representing a candidate solution. m is the number of optimized parameters for each particle, and each particle is an m dimensional real value vector. These parameters represent dimensions of the problem space. There are several steps in the process of IPSO. Moreover, the IPSO algorithm needs to be adapted to each type of optimization problem that it must solve. Figure 2.7 shows how a specially personalized IPSO algorithm works to solve engineering optimization problems [45].

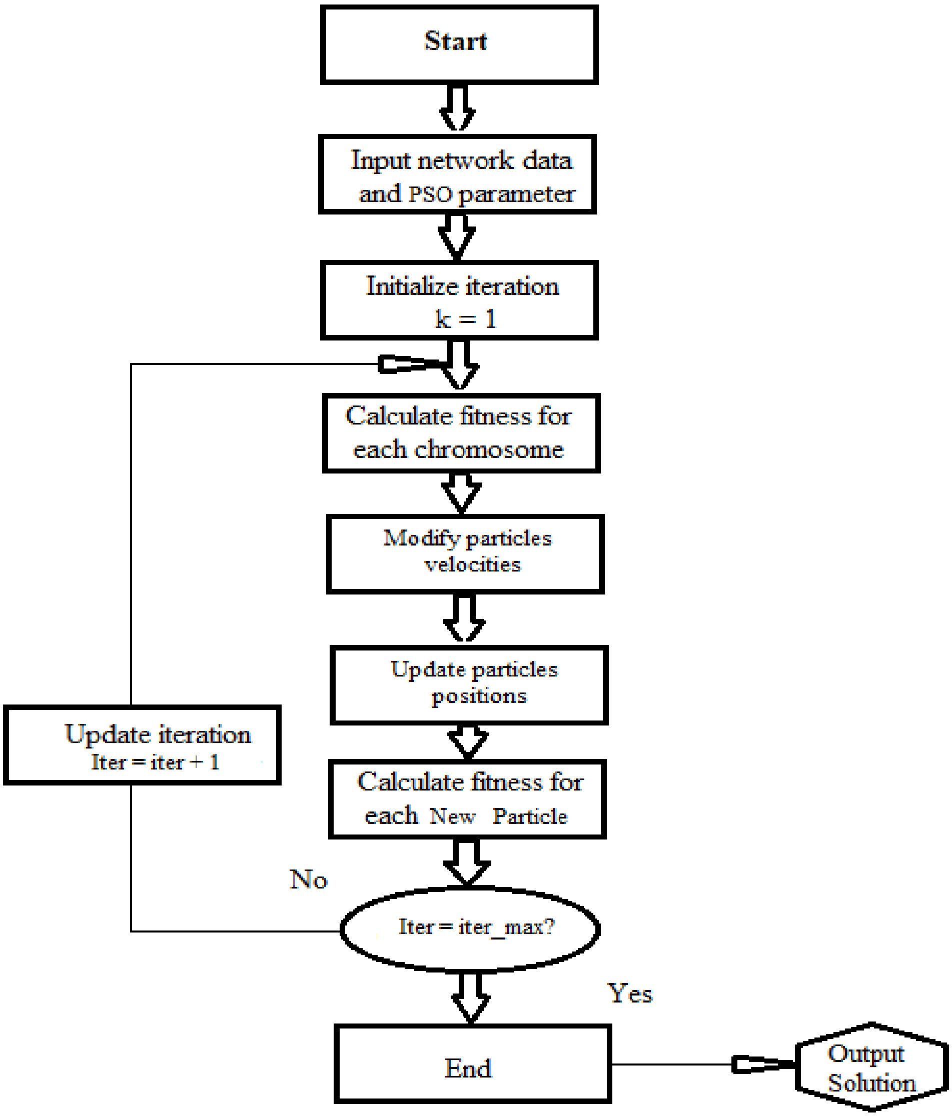


Figure 2-8: Flowchart showing steps for IPSO algorithmII.9.

Analytical Methods

In [46], Graham *et al*. presented a linearization of the original non-linear equation around the initial operating point and revealed a Loss Sensitivity Factor method (LSF). This reduces the amount of solution space for the non-linear equation. A DG unit optimal placement was determined solely by the load profile of the distributed loads in order to minimize total losses. They ranked the nodes according to the size of the DG unit that was incrementally raised at all buses based on the loss calculations. The highest ranked nodes are chosen for the placement of DG units. In [47], EI-hattam and Salma developed new indices for voltage profile improvement comprising two quadratic terms. A new index was developed to select the optimal location for generating real and reactive power using the Primal-Dual Interior-Point (PDIP) method. In order to use the voltage profile in an optimization process, the models treated it in a quadratic form.

In [48], Iyer, Ray and Ramakumar presented a new approach to control and optimized the reactive power of feeders and sub-stations. In order to better regulate voltage and reduce power losses, the proposed method used an agent objecting model to determine the optimal location, placement and control scheme for capacitor banks by means of trial-and-error interactions within the power system. The proposed methodology improved by using a sensitivity analysis. In [49], a study by Issicaba, Bettiol, Coelho and Alcantara analyzed how voltage control strategies worked in networks with DGs. Multiple voltage control strategies which integrated existing voltage control devices and reactive power compensators with varying levels of integration were proposed by these researchers. The results of his study indicated that a coordinated control approach, participating transmission and generation plants are the most effective control strategy and may be a good way to manage the voltage network against the penetration of DGs.

In [50], considering voltage regulation constraints, Su proposed two models based on optimization for computing the allowed penetration level. Models indicate that on-load transformers that change taps on-load include a switch function, as well as the effect of outages caused by distributed generators. To solve problems with a large number of DGs, it was necessary to develop efficient algorithms. In [51], Huang, Gan, Xia, Kobayashi and Xu proposed two optimization models to obtain the optimal positions for DGs and capacitor banks so that transmission systems can maintain better voltage profiles. An innovative mathematical representation for voltage profile optimization was developed first in order to formulate the optimal DG placement problem as a modified optimal power flow problem. Next, the researchers modeled and solved the optimal capacitor placement problem. The IEEE-41 bus transmission system was used to test both models, which are radial systems. Based on their research, it was found that the strategic placement of DG units was important in improving the voltage profile of the transmission system as the optimum configuration of capacitor banks.

In [52], Naik, Khatod and Sharma presented a simple technique for reducing real power losses, improving voltage profiles and releasing capacity at sub-stations. This study analyzed voltage sensitivity indexes (VSI) and power flows using the forward-backward sweep method to come up with the proposed method. Unlike other sweeping algorithms, the forward-backward sweep algorithm had low memory demands, is computationally efficient and has robust convergence characteristics. In [53], in order to minimize real power loss as much as feasible, the article by

Sirish, Srihara Rao, and Ramachandra Murthy employed a KVS-Direct Search algorithm to identify the ideal sizes, locations, and types of static capacitors for the 69-bus radial transmission system. By searching for every location a specific capacitor or DG could be located in the system, the algorithm can reduce active power loss to the maximum. The consideration of standard capacitor and DG sizes that are available on the market, (i.e., discrete capacitor and DG sizes) are taken into account when choosing capacitor size and DG size.

In [54], Karayat, Srihara Rao, Kenguva and Ramachandra Murthy proposed the use of a Modified KVS - Direct Search Algorithm in order to calculate the optimal size and placement of Type B-Remote Generators (DGs) in radial transmission systems in order to achieve the maximum reduction in real power losses. A particular size of capacitor or DG was searched for at every possible location in the system, and then placed at the bus, which minimizes active power loss as much as possible. In [55], using the Direct Search Algorithm (DSA), Ramachandra Murthy, Karayat and Das have proposed a new algorithm for determining the optimal sizes for Static Capacitors and Type-3 Distributed Generators (DGs) as well as their optimal locations in radial transmission systems, thereby reducing the loss of power as much as possible. The method designed an algorithm that searched the entire system for capacitors or detectors of a specific size and placed them at the bus point that provided the maximum reduction in active power loss. As standard sizes of capacitors and DGs were available, they were chosen as the optimal sizes. There was consideration given to discrete capacitor and DG sizes.

In [56], a study by Mahmud, Hossain, Pota and Nasiruzzaman documented a method for compensating the reactive power in transmission networks with DG. Based on the worst-case scenario of the network, they presented voltage control. The reactive power of the compensators had to regulate in order to keep the voltage profile within specified limits. Reactive power compensation provided the desired voltage according to simulation results. In [57], Ashwani Kumar and Wenzhong Gao propose that a multi-objective optimization technique can be used to find the best location for DGs in deregulated energy markets with the aim of improving the voltage profile while lowering line losses. Utilizing power flow and loss sensitivity factors in combination, this approach was used to identify the best zone and optimize the solution by minimizing line losses and optimizing the voltage improvement. Reactive power control was not taken into account in this optimization.

In [58], Le and Kashem propose a method to improve voltage by substituting active power for reactive power depending on the voltage sensitivity of lines. A placement index for DG based on the thevenin equivalent of the network and system voltage was designed to reduce loss, load on the line, and the need for reactive power in the transmission networks for optimum voltage improvement in a transmission feeder. In [59], Gradients and second order techniques have been employed by Rau and Wan. Using a theoretically based 2/3 rule and assuming a steady supply and uniform load transmission, they next analyzed loss minimization.

2.11 Summary

In this chapter, DG technologies and their advantages were discussed. Power loss reduction and voltage profile improvement can be achieved by using the types of DG placement algorithms as discussed above. Optimum location and sizing of DGs can be done using different types of artificial algorithms such as the Fuzzy Logic Algorithm (FLA), Artificial Neural Network (ANN), Genetic Algorithm (GA), Particle Swarm Optimization Algorithm (PSO) and Improved Particle Swarm Optimization Algorithm (IPSO). The next chapter elucidates the research methodology adapted in this study.

CHAPTER THREE: METHODOLOGY

3.1 Introduction

This chapter provides a description of the network, i.e. the IEEE-30 bus electrical network, for testing and analysis. The types of DGs to be considered for analysis are discussed and the HGAIPSO algorithm is also developed in this chapter. Chapter Three also shows the formulation of the multi-objective function and the system sensitivity factors.

3.2 IEEE-30 bus electrical network

The American Electric Power System is represented in part by the IEEE-30 Bus Test Case (in the Midwestern US). In reality, the model places these buses at either 132 or 33 kV. The IEEE-30 bus test case does not have line limits. Figure 3.1 shows the line diagram of the test system, whilst Tables 3.1, 3.2 and 3.3 show the bus load injection, reactive power limit and line parameters of the IEEE-30 bus test system respectively.

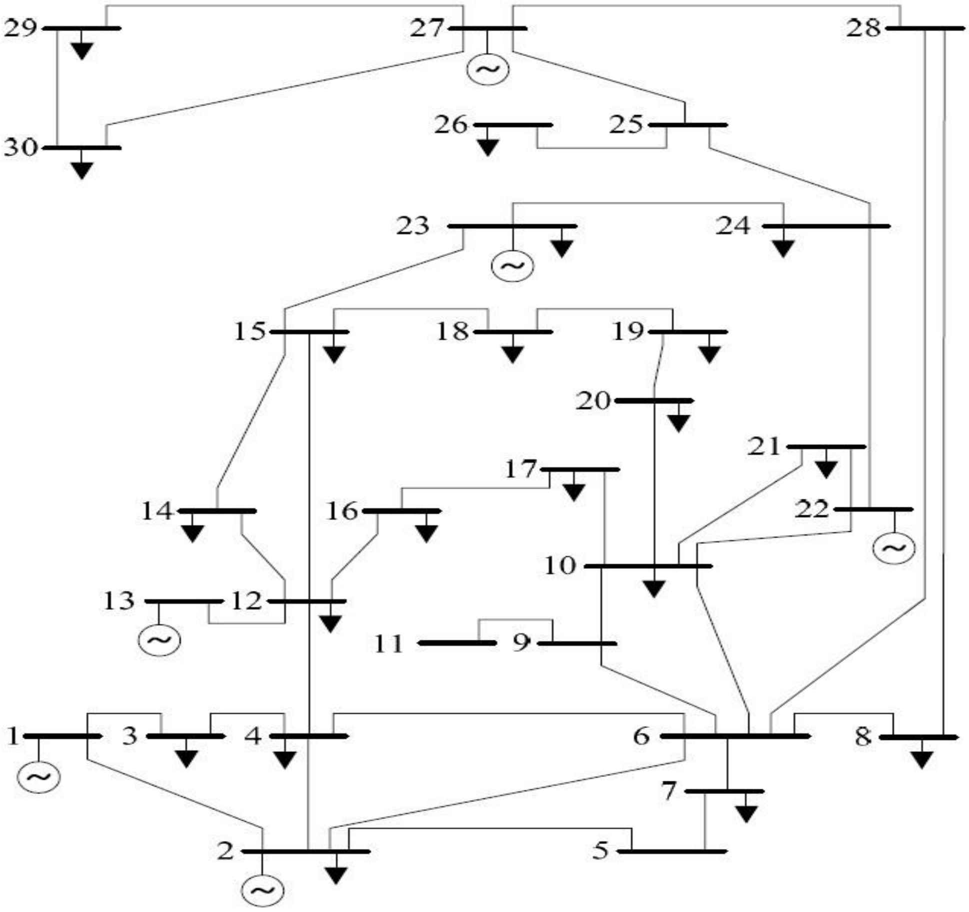
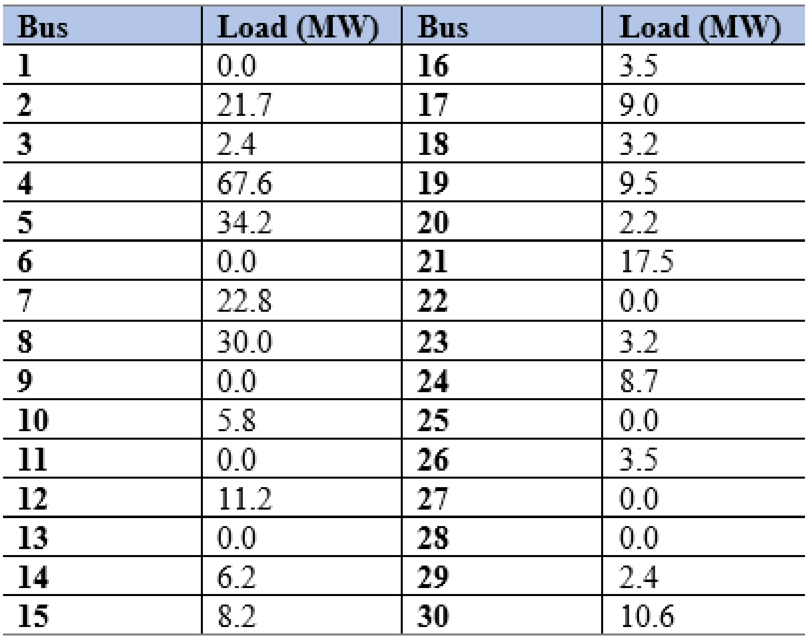


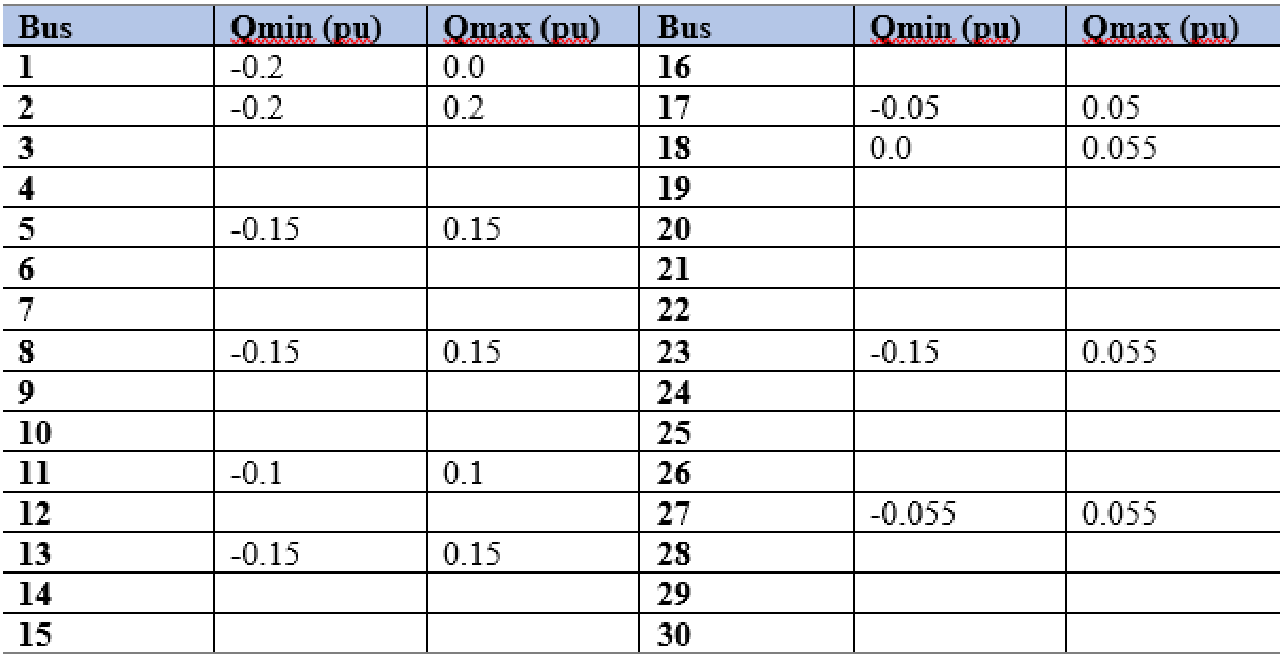
Figure 3-1: IEEE-30 bus test system

Table 3-1: Bus Load Injection Bus for the IEEE 30-bus test system



Bus	Load (MW)	Bus	Load (MW)
1	0.0	**16**	3.5
2	21.7	**17**	9.0
3	2.4	**18**	3.2
4	67.6	**19**	9.5
5	34.2	**20**	2.2
6	0.0	**21**	17.5
7	22.8	**22**	0.0
8	30.0	**23**	3.2
9	0.0	**24**	8.7
10	5.8	**25**	0.0
11	0.0	**26**	3.5
12	11.2	**27**	0.0
13	0.0	**28**	0.0
14	6.2	**29**	2.4
15	8.2	**30**	10.6

Table 3-2: Reactive Power Limit for the IEEE 30-bus test system



Bus	Qmin (pu)	Qmax (pu)	Bus	Qmin (pu)	Qmax (pu)
1	-0.2	0.0	**16**		
2	-0.2	0.2	**17**	-0.05	0.05
3			**18**	0.0	0.055
4			**19**		
5	-0.15	0.15	**20**		
6			**21**		
7			**22**		
8	-0.15	0.15	**23**	-0.15	0.055
9			**24**		
10			**25**		
11	-0.1	0.1	**26**		
12			**27**	-0.055	0.055
13	-0.15	0.15	**28**		
14			**29**		
15			**30**		

Table 3-3: Line Parameters for the IEEE 30-bus test system

Line	From Bus	To Bus	R(p.u)	X(p.u)	Tap Ratio	Rating(pu)
1	1	2	0.00192	0.0575		0.300
2	1	3	0.0452	0.1852	0.9610	0.300
3	2	4	0.0570	0.1737	0.9560	0.300
4	3	4	0.0132	0.4845		0.300
5	2	5	0.0472	0.5215		0.300
6	2	6	0.0581	0.4521		0.300
7	4	6	0.0119	0.4152		0.300
8	5	7	0.0460	0.5560		0.300
9	6	7	0.0267	0.1737		0.300
10	6	8	0.0120	0.0379		0.300
11	6	9	0.0000	0.1983		0.300
12	6	10	0.0000	0.1763		0.300
13	9	11	0.0000	0.0414	0.9700	0.300
14	9	10	0.0000	0.1160	0.9650	0.650
15	4	12	0.0000	0.0820	0.9635	0.650
16	12	13	0.0000	0.0420		0.320
17	12	14	0.1231	0.2080		0.320
18	12	15	0.0662	0.2560		0.320
19	12	16	0.0945	0.1304		0.320
20	14	15	0.2210	0.1987		0.160
21	16	17	0.0824	0.1997		0.160
22	15	18	0.1070	0.1932		0.160
23	17	19	0.0936	0.2185	0.9590	0.160
24	18	20	0.0324	0.1292		0.320
25	19	20	0.0348	0.0680		0.300
26	10	17	0.0727	0.2090	0.9850	0.300
27	10	21	0.0116	0.0749		0.300
28	10	22	0.0116	0.1499		0.160
29	10	22	0.1000	0.0236		0.300
30	21	23	0.1150	0.2020		0.160
31	15	24	0.1320	0.1790		0.300
32	22	24	0.1885	0.2700		0.300
33	23	25	0.2544	0.3292	0.9655	0.300
34	24	26	0.1093	0.3800		0.300
35	25	27	0.0000	0.2087		0.300
36	25	27	0.2198	0.3960		0.300
37	28	29	0.3202	0.4153	0.9810	0.300
38	27	30	0.0636	0.6027		0.300
39	29	30	0.0169	0.4533		0.300
40	8	28	0.0120	0.2000	0.9530	0.300
41	6	28	0.0485	0.0599		0.300

3.3 Types and number of DG used

Using the assumption that DGs are functioning under any one of the three situations described below, this research aims to optimize the location and size of three different types of DGs.:

- Case 1; A DG that injects active power only, referred to as Type A, which is Photovoltaic Power. The number of DGs to be used will be determined by the proposed algorithm and one will be placed per selected bus.
- Case 2; A DG that injects both active and reactive power, referred to as Type B, which is Wind Power. The number of DGs to be used will be determined by the proposed algorithm and one will be placed per selected bus.
- Case 3; A DG that injects active power and absorbs reactive power, referred to as Type C, which is Hydro Power. The number of DGs to be used will be determined by the proposed algorithm and one will be placed per selected bus.

3.4 Development of the HGAIPSO algorithm

The proposed method is the hybrid of GA and Improved Particle Swarm Optimization IPSO to allocate DG optimally. The DG is located within the chosen buses on the transmission system with the intention of lowering power system losses and improving the voltage profile. Based on parameters affecting power flow and power loss sensitivity, the buses used for the DG location are chosen. [60]. The proposed algorithm (HGAIPSO) is able to select quickly by reducing the number of iterations. Based on sensitivity factors, the location of the DG is determined by HGAIPSO.

IPSO receives some GA output containing DG locations and DG sizes for various solutions. This GA output was then used as the initial particle set by IPSO. This helps IPSO reach convergence faster. Optimal solutions are derived from Genetic Algorithms through IPSO. The following diagram, Figure 3.2, is the implementation steps showing how DG units in the transmission system optimally allocated using HGAIPSO [61]:

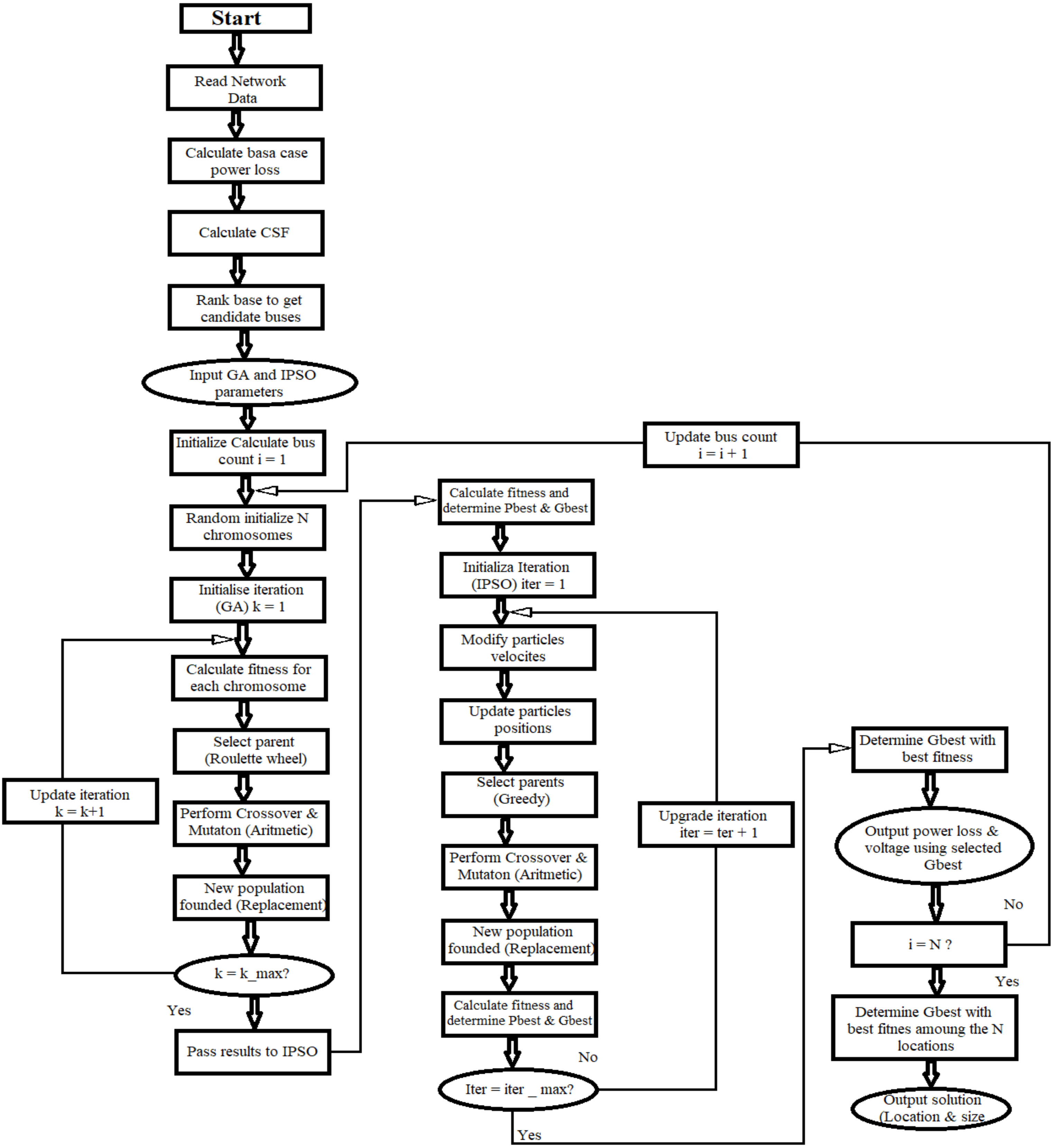


Figure 3-2: Flowchart showing the detailed steps of the proposed algorithm

3.5 Multi-objective function and Sensitivity Factors

3.5.1 System Power Flow Sensitivity Factors

When a certain quantity of power is injected into any one of the system's buses, for example, bus i and bus j, change in the amount of power flowing in a distribution or transmission line between those two buses is particularly determined by the system flow sensitivity. The injection of complex power by a source into a system bus, say a power system bus i^{th}, is described as follows [62]

J_i^* is injected into the bus by the source current.

Source current is given by:

$$J_i = \sum_{j=1}^{n} Y_i V_{J;\,=1,2,\ldots.n} \tag{3-1}$$

Alternatively, the following is the outcome of using equation 3.3 as a substitute in the complex conjugate equation of power injection:

$$P_i - jQ_i \ \ = \sum_{j=1}^{n} Y_i V_{J;\,=1,2,\ldots.n} \tag{3-2}$$

One gets the following equation when combining the real and imaginary parts:

$$P_i = R_e\{V_i * \sum_{j=1}^{n} Y_i V_J\} \tag{3-3}$$

$$Q_i = -\mathrm{Im}\{V_i * \sum_{j=1}^{n} Y_i V_J\} \tag{3-4}$$

Polar form V_i and Y_{ij} are expressed as:

$$V_i = |V_i| e^{j\delta i} \tag{3-5}$$

$$Y_i = |Y_i| e^{j\delta i} \tag{3-6}$$

The actual and reactive powers are expressed in general by the polar representations given:

$$P_i = |V_i| \sum_{j=1}^{n} \left|Y_{ij}\right| \cos\left(\theta_{ij} + \delta_{ij}\right); i = 1,2,\ldots,n \tag{3-7}$$

$$Q_i = -|V_i| \sum_{j=1}^{n} \left|Y_{ij}\right| \sin\left(\theta_{ij} + \delta_{ij}\right); i = 1,2,\ldots,n \tag{3-8}$$

3.5.2 Change in Real Power Flow Analysis

When two buses, bus I and bus j, are connected by line k, the real power flow is expressed as:

$$P_{ij} = V_iV_jY_{ij}\ \cos(\theta_{ij} + \delta_{ij}) - V_i^*V_{ji}\cos(\theta_{ij}) \tag{3-9}$$

Where: V_i and V_j, are respectively, the voltage magnitudes at buses I and j. and δ_i and δ_j are the voltage angles at buses *i* and *j* respectively.

Y_{ij} is the Magnitude of element of the Y_{BUS} matrix and θ_{ij} is the angle of the ij^{th}element of the Y_{BUS} matrix.

The real power flow sensitivity is expressed mathematically as:

$$\begin{bmatrix}\frac{\Delta P_{ij}}{\Delta P_n}\\ \frac{\Delta P_{ij}}{\Delta Q_n}\end{bmatrix} \tag{3-10}$$

Using Taylor series approximation and ignoring higher order terms, the change is represented as:

$$\Delta P_{ij} = \frac{\partial P_{ij}}{\partial \delta_i}\Delta Q_i + \frac{\partial P_{ij}}{\partial \delta_j}\Delta Q_j + \frac{\partial P_{ij}}{\partial \delta_i}\Delta V_i + \frac{\partial P_{ij}}{\partial \delta_j}\Delta V_i \tag{3-11}$$

Using the partial derivatives of the real power flow with respect to ∂ and V, the coefficients in the above equation are obtained as follows:

$$\frac{\partial P_{ij}}{\partial \delta_i} = V_iV_jY_{ij}\ \sin(\theta_{ij} + \delta_{ij}) \tag{3-12}$$

$$\frac{\partial P_{ij}}{\partial \delta_i} = -V_iV_jY_{ij}\ \sin(\theta_{ij} + \delta_{ij}) \tag{3-13}$$

$$\frac{\partial P_{ij}}{\partial V_i} = V_jY_{ij}\ \cos(\theta_{ij} + \delta_{ij}) - 2V_jY_{ij}\cos(\theta_{ij}) \tag{3-14}$$

$$\frac{\partial P_{ij}}{\partial V_j} = V_j Y_{ij}\ \cos\left(\theta_{ij} + \delta_{ij}\right) \tag{3-15}$$

3.5.3 Change in Reactive Power Flow Analysis

When two buses, bus I and bus j, are connected by line k, reactive power flow is expressed as:

$$Q_{ij} = -V_i V_j Y_{ij}\ \sin\left(\theta_{ij} + \delta_{ij}\right) + V_i^2 Y_{ji} \sin\left(\theta_{ij}\right) - \frac{V_i^2 Y_{sh}}{2} \tag{3-16}$$

Where: V_i and V_j, are respectively, the voltage magnitudes at buses I and j. and δ_i and δ_j are the voltage angles at buses *i* and *j* respectively.

Y_{ij} is the Magnitude of element of the Y_{BUS} matrix and θ_{ij} is the angle of the ij^{th}element of the Y_{BUS} matrix.

The reactive power flow sensitivity is expressed mathematically as:

$$\begin{bmatrix} \frac{\Delta Q_{ij}}{\Delta P_n} \\ \frac{\Delta Q_{ij}}{\Delta Q_n} \end{bmatrix} \tag{3-17}$$

Using Taylor series approximation and ignoring higher order terms, the change is represented as:

$$\Delta Q_{ij} = \frac{\partial Q_{ij}}{\partial \delta_i}\Delta\delta_i + \frac{\partial Q_{ij}}{\partial \delta_j}\Delta\delta_j + \frac{\partial Q_{ij}}{\partial v_i}\Delta V_i + \frac{\partial Q_{ij}}{\partial v_j}\Delta V_i \tag{3-18}$$

Using the partial derivatives of the real power flow with respect to ∂ and V, the coefficients in the above equation are obtained as follows:

$$\frac{\partial Q_{ij}}{\partial \delta_i} = V_i V_j Y_{ij}\ \cos\left(\theta_{ij} + \delta_{ij}\right) \tag{3-19}$$

$$\frac{\partial Q_{ij}}{\partial \delta_i} = -V_i V_j Y_{ij}\ \cos\left(\theta_{ij} + \delta_{ij}\right) \tag{3-20}$$

$$\frac{\partial Q_{ij}}{\partial V_i} = -V_j Y_{ij} \sin\left(\theta_{ij} + \delta_{ij}\right) + 2V_i^2 Y_{ji} \cos\left(\theta_{ij}\right) - V_i^2 Y_{sh} \tag{3-21}$$

$$\frac{\partial Q_{ij}}{\partial V_i} = -V_j Y_{ij} \sin\left(\theta_{ij} + \delta_{ij}\right) \tag{3-22}$$

Real power flow sensitivity factors measure the change in real power flow over distribution or transmission lines connected between buses-i and bus-j as a result of changing active power injected at any other bus-n. In comparison to reactive power flow sensitivity factors, which measure the change in reactive power flow over distribution or transmission lines connected between buses-i and bus-j as a result of changing reactive power injected at any other bus, real power flow sensitivity factors measure the change in real power flow over distribution or transmission lines connected between buses. Equation 3.24 for line flow changes are given as matrices. [63].

$$\begin{vmatrix} \Delta P_{ij} \\ \Delta Q_{ij} \end{vmatrix} = \begin{vmatrix} \frac{\partial P_{ij}}{\partial \delta} & \frac{\partial P_{ij}}{\partial \mathrm{V}} \\ \frac{\partial Q_{ij}}{\partial \delta} & \frac{\partial Q_{ij}}{\partial \mathrm{V}} \end{vmatrix} \begin{vmatrix} \Delta \delta \\ \Delta \mathrm{V} \end{vmatrix} \tag{3-23}$$

Using the Newton Raphson approach, the variables Δδ and ΔV may be extracted from the load flow solution as shown below:

Jacobian matrix of the full N-R load expressed as;

$$\begin{vmatrix} \Delta \mathrm{P} \\ \Delta \mathrm{Q} \end{vmatrix} = |J| \begin{vmatrix} \Delta \delta \\ \Delta \mathrm{V} \end{vmatrix} = \begin{vmatrix} J_{11} & J_{12} \\ J_{21} & J_{22} \end{vmatrix}^{-1} \begin{vmatrix} \Delta \delta \\ \Delta \mathrm{V} \end{vmatrix} \tag{3-24}$$

Thus, the variables ΔP and ΔQ were obtained from this equation as follows:

$$\begin{vmatrix} \Delta \mathrm{P} \\ \Delta \mathrm{Q} \end{vmatrix} = |J|^{-1} \begin{vmatrix} \Delta \delta \\ \Delta \mathrm{V} \end{vmatrix} = \begin{vmatrix} J_{11} & J_{12} \\ J_{21} & J_{22} \end{vmatrix}^{-1} \begin{vmatrix} \Delta \mathrm{P} \\ \Delta \mathrm{Q} \end{vmatrix} \tag{3-25}$$

Once the derived equation is substituted for the variables ΔP and ΔQ in the equation for the change in line flows, the following results:

$$\begin{vmatrix}\Delta P_{ij}\\ \Delta Q_{ij}\end{vmatrix} = \begin{vmatrix}\frac{\partial P_{ij}}{\partial \delta} & \frac{\partial P_{ij}}{\partial \mathrm{V}}\\ \frac{\partial Q_{ij}}{\partial \delta} & \frac{\partial Q_{ij}}{\partial \mathrm{V}}\end{vmatrix} |J|^{-1} \begin{vmatrix}\Delta \mathrm{P}\\ \Delta \mathrm{Q}\end{vmatrix} \tag{3-26}$$

The equation 3.28, provides the change in power in both real and reactive terms, can be used to compute both the reactive and real power flow sensitivity factors. Following is a representation of the actual power flow sensitivity factors: [64]:

$$\begin{bmatrix}\frac{\delta P_{ij}}{\delta P_n}\\ \frac{\delta P_{ij}}{\delta Q_n}\end{bmatrix} = \begin{vmatrix}F_{P-P}\\ F_{P-Q}\end{vmatrix} = |J^T|^{-1} \begin{bmatrix}\frac{\delta P_{ij}}{\partial \delta}\\ \frac{\delta P_{ij}}{\partial \mathrm{V}}\end{bmatrix} \tag{3-27}$$

The following is a representation of the reactive power flow sensitivity factors:

$$\begin{bmatrix}\frac{\delta Q_{ij}}{\delta P_n}\\ \frac{\delta Q_{ij}}{\delta Q_n}\end{bmatrix} = \begin{vmatrix}F_{Q-P}\\ F_{Q-Q}\end{vmatrix} = |J^T|^{-1} \begin{bmatrix}\frac{\delta Q_{ij}}{\partial \delta}\\ \frac{\delta Q_{ij}}{\partial \mathrm{V}}\end{bmatrix} \tag{3-28}$$

Where

J = The Jacobian matrix of power flow and the superscript T denotes the transpose;

$F_{(P-P)}$ = The real power flow sensitivity related to the real power injection;

$F_{(P-Q)}$ = The active flow sensitivity related to the reactive power injection;

$F_{(Q-P)}$ = The reactive power flow sensitivity related to the active power injection; and

$F_{(Q-Q)}$ = The reactive power flow sensitivity related to the reactive power injection.

The four sensitivities in this instance are column vectors with dimensions equal to the number of system buses.

3.5.4 System Power Loss Sensitivity Factors

A real and reactive power control Sensitivity factor is calculated from figure 3.3 [65].

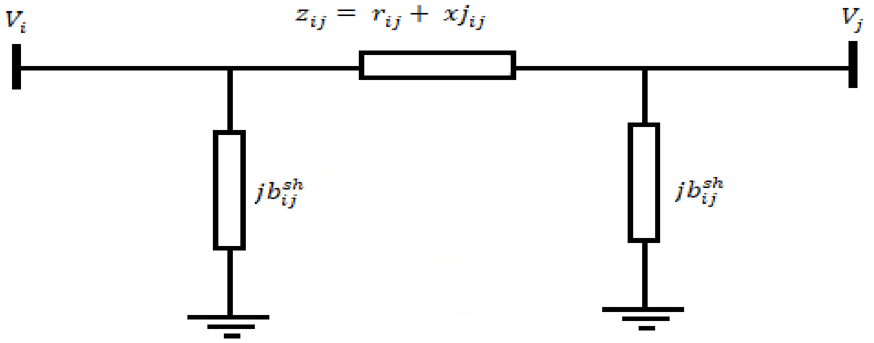


Figure 3-3: Circuit diagram of a line lumped model

3.5.5 Change in Real Power Loss Analysis

The line lumped model's active power loss, as demonstrated in the line-(pie) circuit, is given by

$$P_{L(ij)} \; = g_{ij} \left[V_i^2 + V_i^2 - 2V_i^2 Y_{ji} \cos(\delta_{ij})\right] \tag{3-29}$$

Consequently, the circuit's overall active power loss is stated as

$$P_{L(total)} \; = \sum_{j=1}^{nL} \left[g_{ij} \left(V_i^2 + V_i^2 - 2V_i^2 Y_{ji} \cos(\delta_{ij})\right)\right] \tag{3-30}$$

Where:

nL stands for the number of lines in the network;

g_ig is the conductance of line g and I,

V_i is the nodal voltage of bus I

V_ j is the nodal voltage of bus j, and

δ_ij is the difference in phase angle between buses I and j.

The real power flow sensitivity is expressed mathematically as:

$$\begin{bmatrix} \dfrac{\Delta P_{L(ij)}}{\Delta P_n} \\ \dfrac{\Delta P_{L(ij)}}{\Delta Q_n} \end{bmatrix} \tag{3-31}$$

Using Taylor series approximation and ignoring higher order terms, the change is represented as:

$$\Delta P_{L(ij)} = \frac{\partial P_{L(ij)}}{\partial \delta_i}\Delta\delta_i + \frac{\partial P_{L(ij)}}{\partial \delta_j}\Delta\delta_j + \frac{\partial P_{L(ij)}}{\partial v_i}\Delta V_i + \frac{\partial P_{L(ij)}}{\partial v_j}\Delta V_i \qquad (3\text{-}32)$$

Using the partial derivatives of the real power flow with respect to ∂ and V, the coefficients in the above equation are obtained as follows:

$$\frac{\partial P_{L(ij)}}{\partial \delta_i} = 2g_{ij}2V_iV_i \sin\left(\delta_{ij}\right) \qquad (3\text{-}33)$$

$$\frac{\partial P_{L(ij)}}{\partial \delta_i} = -2g_{ij}2V_iV_i \sin\left(\delta_{ij}\right) \qquad (3\text{-}34)$$

$$\frac{\partial P_{L(ij)}}{\partial \delta_i} = g_{ij}\left[2V_i - 2V_j \cos\left(\delta_{ij}\right)\right] \qquad (3\text{-}35)$$

$$\frac{\partial P_{L(ij)}}{\partial \delta_i} = g_{ij}\left[2V_j - 2V_i \cos\left(\delta_{ij}\right)\right] \qquad (3\text{-}36)$$

Where:

nL stands for the number of lines in the network;

g_ig is the conductance of line g and I,

V_i is the nodal voltage of bus I

V_ j is the nodal voltage of bus j; and

δ_ij is the difference in phase angle between buses I and j.

3.5.6 Change in Reactive Power Flow Analysis

If second and higher order terms are ignored, and Taylor series approximation is used, the change in real line flow is expressed as:

$$\Delta Q_{L(ij)} = \frac{\partial Q_{L(ij)}}{\partial \delta_i}\Delta\delta_i + \frac{\partial Q_{L(ij)}}{\partial \delta_j}\Delta\delta_j + \frac{\partial Q_{L(ij)}}{\partial v_i}\Delta V_i + \frac{\partial Q_{L(ij)}}{\partial v_j}\Delta V_i \tag{3-37}$$

Using the partial derivatives of the real power flow with respect to ∂ and V, the coefficients in the above equation are obtained as follows:

$$\frac{\partial Q_{L(ij)}}{\partial \delta_i} = -2g_{ij}2V_iV_i\sin(\delta_{ij}) \tag{3-38}$$

$$\frac{\partial Q_{L(ij)}}{\partial \delta_i} = 2g_{ij}2V_iV_i\sin(\delta_{ij}) \tag{3-39}$$

$$\frac{\partial Q_{L(ij)}}{\partial \delta_i} = -2b_{ij}^{sh}V_i - b_{ij}\left(2V_i - 2V_j\cos(\delta_{ij})\right) \tag{3-40}$$

$$\frac{\partial Q_{L(ij)}}{\partial \delta_j} = -2b_{ij}^{sh}V_j - b_{ij}\left(2V_j - 2V_i\cos(\delta_{ij})\right) \tag{3-41}$$

Where:

b_ij = nodal voltage of bus I

v_i is the nodal voltage of bus j

b_{ij}^{sh} is the conductance of the line g and I?

δ_ij is the difference between buses I and j in the phase angle.

nL stands for the number of lines in the network.

3.5.7 Formulating the Power Loss Sensitivity Factors

When determining the real power flow sensitivity factors, one considers how the active power injected at any other bus-n affects the real power flow along distribution or transmission lines connected between bus-i and bus-j. Reactive power flow sensitivity factors allow one to quantify how reactive power flows through distribution or transmission lines connecting buses I and j change in response to changes in reactive power injected at any other bus. The matrix form of the equations used to represent changes in line flow [66,67] is:

$$\begin{vmatrix}\Delta P_{Lij}\\ \Delta Q_{Lij}\end{vmatrix} = \begin{vmatrix}\frac{\partial P_{Lij}}{\partial\delta} & \frac{\partial P_{Lij}}{\partial \mathrm{V}}\\ \frac{\partial Q_{Lij}}{\partial\delta} & \frac{\partial Q_{Lij}}{\partial \mathrm{V}}\end{vmatrix}\begin{vmatrix}\Delta\delta\\ \Delta \mathrm{V}\end{vmatrix} \tag{3-42}$$

Using the Newton Raphson approach, the variables Δδ and ΔV may be extracted from the load flow solution as shown below:

Jacobian matrix of the full N-R load expressed as;

$$\begin{vmatrix}\Delta \mathrm{P}\\ \Delta \mathrm{Q}\end{vmatrix} = |J|\begin{vmatrix}\Delta\delta\\ \Delta \mathrm{V}\end{vmatrix} = \begin{vmatrix}J_{11} & J_{12}\\ J_{21} & J_{22}\end{vmatrix}\begin{vmatrix}\Delta\delta\\ \Delta \mathrm{V}\end{vmatrix} \tag{3-43}$$

Thus, the variables ΔP and ΔQ were obtained from this equation as follows:

$$\begin{vmatrix}\Delta\delta\\ \Delta \mathrm{V}\end{vmatrix} = |J|^{-1}\begin{vmatrix}\Delta \mathrm{P}\\ \Delta \mathrm{Q}\end{vmatrix} = \begin{vmatrix}J_{11} & J_{12}\\ J_{21} & J_{22}\end{vmatrix}^{-1}\begin{vmatrix}\Delta \mathrm{P}\\ \Delta \mathrm{Q}\end{vmatrix} \tag{3-44}$$

Once the derived equation is substituted for the variables ΔP and ΔQ in the equation for the change in line flows, the following results:

$$\begin{vmatrix}\Delta P_{L(ij)}\\ \Delta Q_{L(ij)}\end{vmatrix} = \begin{vmatrix}\frac{\partial P_{L(ij)}}{\partial\delta} & \frac{\partial P_{L(ij)}}{\partial \mathrm{V}}\\ \frac{\partial Q_{L(ij)}}{\partial\delta} & \frac{\partial Q_{L(ij)}}{\partial \mathrm{V}}\end{vmatrix}|J|^{-1}\begin{vmatrix}\Delta \mathrm{P}\\ \Delta \mathrm{Q}\end{vmatrix} \tag{3-45}$$

The equation 3.47, provides the change in power in both real and reactive terms, can be used to compute both the reactive and real power flow sensitivity factors. Following is a representation of the actual power flow sensitivity factors [68]:

$$\begin{bmatrix}\frac{\delta P_{L(ij)}}{\delta P_n}\\ \frac{\delta P_{L(ij)}}{\delta Q_n}\end{bmatrix} = \begin{vmatrix}S_{P-P}\\ S_{P-Q}\end{vmatrix} = |J^T|^{-1}\begin{bmatrix}\frac{\delta P_{L(ij)}}{\partial\delta}\\ \frac{\delta P_{L(ij)}}{\partial \mathrm{V}}\end{bmatrix} \tag{3-46}$$

The following is a representation of the reactive power flow sensitivity factors:

$$\begin{bmatrix} \frac{\delta Q_{L(ij)}}{\delta P_n} \\ \frac{\delta Q_{L(ij)}}{\delta Q_n} \end{bmatrix} = \begin{vmatrix} S_{Q-P} \\ S_{Q-Q} \end{vmatrix} = |J^T|^{-1} \begin{bmatrix} \frac{\delta Q_{L(ij)}}{\partial \delta} \\ \frac{\delta Q_{L(ij)}}{\partial \mathrm{V}} \end{bmatrix} \tag{3-47}$$

Where

J = The Jacobian matrix of power flow and the superscript T denotes the transpose;

F $_{(P-P)}$ = The real power flow sensitivity related to the real power injection;

F $_{(P-Q)}$ = The active flow sensitivity related to the reactive power injection;

F $_{(Q-P)}$ = The reactive power flow sensitivity related to the active power injection; and

F $_{(Q-Q)}$ = The reactive power flow sensitivity related to the reactive power injection.

The four sensitivities in this instance are column vectors with dimensions equal to the number of system buses.

3.5.8 Objective Function Parameters

With regard to DG size and location planning with load models, the multi-objective index considers each of the following indexes and gives weight to each one [69]:

3.5.8.1 Real Power Loss Reduction Index

To minimize power loss, DGs are typically sized and positioned. When a DG is installed at bus I, power loss is reduced, as measured by the Real Power Loss Reduction Index. As shown below, the Real Power Loss Reduction Index (PLRI) is computed:

$$PLRI = \frac{P_{L(base)} - P_{L(DG)}}{P_{L(base)}} \tag{3-48}$$

The active power loss before installing a DG is denoted by $P_{L(base)}$, and the actual power loss following DG installation is denoted by $P_{L(DG)}$.

3.5.8.2 Reactive power control Reduction Index

An objective function is calculated to determine the reduction in reactive power lost when DGs are installed on bus i. The reduction in reactive power control is quantified by the Reactive Power Control Reduction Index. The Reactive power control Reduction Index (QLRI) is calculated as follows [70]:

$$QLRI = \frac{Q_{L(base)} - Q_{L(DG)}}{Q_{L(base)}} \tag{3-49}$$

$Q_{L(base)}$: Reactive power control before DG installation

$Q_{L(DG)}$: Reactive power control after installation of DG

3.5.9 Multi-objective Function Formulation

The multi-objective function was formulated to satisfy the electrical requirements for the transmission network, and it was reduced based on numerous operational constraints. The Multi-Objective Function for DG Size and Location Determined by the Formula is the foundation for the Performance-based Calculation of Distributed Systems [71]:

$$\text{MOF}= W_1\text{PLRI}+ W_2\text{QLRI}+ W_3\text{VPII} \tag{3-50}$$

W_1, W_2 and W_3 are the weights attached to each factor.

All the weighted impacts should sum to one. This means that each impact has the same weight.

$$|W_1|+|W_2| +|W_3|= 1 \tag{3-51}$$

Each impact index weighs the DG penetration in accordance with its importance based on the corresponding impact indices and the required analysis based on the corresponding impact indices.

3.5.10 Load balance constraint

According to the following load regulations, every bus should be able to carry its load:

$$P_{gni} - P_{dni} = - V_{ni} \sum_{j=1}^{N} Y_{nj} Y_{nj} \cos\left(\delta_{nj} - \delta_{nj} - \theta_{nj}\right) = 0 \tag{3-52}$$

$$Q_{gni} - Q_{dni} = -V_{ni} \sum_{j=1}^{N} Y_{nj} Y_{nj} \cos(\delta_{nj} - \delta_{nj} - \theta_{nj}) = 0 \qquad (3\text{-}53)$$

3.5.11 Power Generation Limit

This upper and lower real and reactive power generation limits also apply to generators and other reactive sources.

$$P_{gi}^{min} \leq P_{gi} \leq P_{gi}^{max}, i = 1,2, \ldots Ng \qquad (3\text{-}54)$$

$$Q_{gi}^{min} \leq Q_{gi} \leq Q_{gi}^{max}, i = 1,2, \ldots Ng \qquad (3\text{-}55)$$

P_{gi}^{min} and P_{gi}^{max} are the real power generation limits, both minimum and maximum; and

Q_{gi}^{min} and Q_{gi}^{max} are the reactive power generation's minimum and maximum limitations.

3.5.12 Voltage limit

The magnitude limits for upper and lower voltages, as well as at bus-i, are included. In actual practice, the generator voltage will be equal to the load or bus voltage and some values related to the line impedance and the power flowing along the line. It is important to maintain a standard voltage on each line [72].

$$V_i^{min} \leq V_i \leq V_i^{max}, i = 1,2, \ldots Ng \qquad (3\text{-}56)$$

Where: V_i^{min} and V_i^{max} are the minimum and maximum voltage limits.

3.5.13 DG Power Generation Limit

Upper and lower limits on their real and reactive power production must be satisfied by transmission generators (DGs) linked at bus-i [73].

$$P_{DGi}^{min} \leq P_{DGi} \leq P_{DGi}^{min}, i = 1,2, \ldots Ng \qquad (3\text{-}57)$$

$$Q_{DGi}^{min} \leq Q_{DGi} \leq Q_{DGi}^{min}, i = 1,2, \ldots Ng \qquad (3\text{-}58)$$

P_{DGi}^{min} and P_{DGi}^{min} are the minimum and maximum real power generation limits of the distributed generators.

Q_{DGi}^{min} and P_{DGi}^{min} are the minimum and maximum reactive power generation limits of the distributed generators.

3.6 Choosing Weights values for the Multi-Objective Function

Depending on the designer's concerns, different weights in a particular multi-objective function are assigned. Because it can lower operating costs overall and improve the effectiveness of the power network, this research project places a greater emphasis on real power loss reduction [74]. The other two elements, however, are as crucial. In light of this, a research of the impact of weights on fitness was conducted to identify the ideal weight-combination to use in order to develop the multi-objective function. The weight values in this study are restricted to positive values and are:

- W_1 was between 0.6 and 0.8; and
- W_2 and W_3 were restricted between 0.1 and 0.3.

This was done to ensure that the multi-objective function takes into account all three indices while also ensuring that the real power loss reduction index, as previously said, receives a lot of attention. All of the effects of weight values and fitness are shown in Table 3.4. [75].

It's also crucial to remember that each situation requires that the condition |W1 |+|W2 |+ |W3 |=1 be met.

Table 3-4: The Effects of Weights on Fitness

Weight 1 (W1)	Weight 2 (W2)	Weight 3 (W3)	Best Fitness
0.5	0.1	0.4	0.909
0.5	0.2	0.3	0.910
0.5	0.3	0.2	0.909
0.5	0.4	0.1	0.910
0.6	0.1	0.3	0.910
0.6	0.2	0.2	0.909
0.6	0.3	0.1	0.909
0.7	0.1	0.2	0.91
0.7	0.2	0.1	0.910
0.8	0.1	0.1	0.909

The combination of weights selected, which is the one that provided the minimal best fitness, is shown in Table 3.1. The multi-objective function was given by and the weights selected were W1=0.6, W2=0.2, and W3=0.2:

$$MOF \ = 0.6PLRI + 0.2QLRI + 0.2\,VPII \tag{3-59}$$

The base case reactive power regulated, calculated using the Newton Raphson method, was determined to be 68.8881 MVAR. The number of DGs to be placed and sized properly in order to achieve fair comparison was equal to the number of DGs in the comparison work, that is:

- The real power limitation for Type A, B and C DGs is 0MW - 12MW;
- For Type B and C DGs, the reactive power limitation is 0MVar - 3MVAR; and
- For Type C, the reactive power limitation is -3MVar - 0MVAR.

The buses having a combined sensitivity factor more than 0.80 are considered to be the selected buses based on the total sensitivity factors of all the buses. The combined sensitivity factors of all the buses are studied as given in Table 3.5 in order to establish the optimum location, size, and number of the DGs.

Table 3-5: Combined Sensitivity Factor, Fitness and optimal DG sizes for selected buses

Selected Bus	**Combined Sensitivity Factor (CSF)**	**Type A DG**		**Type B DG**		**Type C DG**	
		Fitness	**DG Size (MW)**	**Fitness**	**DG Size (MW)**	**Fitness**	**DG Size (MW)**
10	0.878	0.917	11.980	0.917	12+j2.690	0.917	11.982-j0
11	0.923	0.919	11.981	0.919	11.8514+j2.99	0.919	11.840-j2.116
15	0.835	0.916	11.505	0.915	12+j2.515	0.916	12-j1.439
17	0.873	0.917	11.505	0.916	12+j2.456	0.917	11.639-j0.0601
18	1.020	0.913	11.998	0.912	11.9865+j3	0.914	11.987-j2.998
19	1.095	0.911	11.709	0.910	11.7872+j2.960	0.911	12-j0.488
20	1.063	0.913	11.587	0.912	11.7311+j2.889	0.913	11.663-j0.380
21	0.997	0.912	11.339	0.911	12+j5.81	0.912	11.94-j0.504
22	1.055	0.916	11.987	0.916	12+j2.759	0.916	11.990-j0
23	0.990	0.912	11.710	0.911	11.7548+j3	0.912	12-j0.088
24	1.034	0.912	11.995	0.911	12+j1.370	0.912	11.917-j0.069
25	0.874	0.917	11.523	0.915	11.9782+j3	0.916	10.641-j0.57
26	1.006	0.922	11.824	0.919	11.9763+j1.511	0.921	11.889-j0
30	0.811	0.909	11.706	0.908	11.8308+j1.581	0.919	11.365-j0.580

3.7 Summary

A hybrid optimization method, which is the HGAIPSO form power losses minimization, was analyzed in this chapter, and their implementation steps were discussed. System power flow and system power loss sensitivities were developed in this chapter in order to obtain the combined sensitivity factors. Additionally, the multi-objective function used to calculate fitness for solutions during optimization and how to choose weights for multi-objective function were shown in the chapter.

CHAPTER FOUR: RESULT ANALYSIS AND DISCUSSION

4.1 Introduction

A performance analysis of the proposed method is done in this chapter. Moreover, the comparative analysis of the proposed HGAIPSO algorithm with the existing one, i.e., the GA, PSO and IPSO, is discussed. An IEEE-30 bus electrical network with DGs allocation at various bus has been used for testing.

4.2 Testing/and simulations of the electrical network modification using the GA algorithm

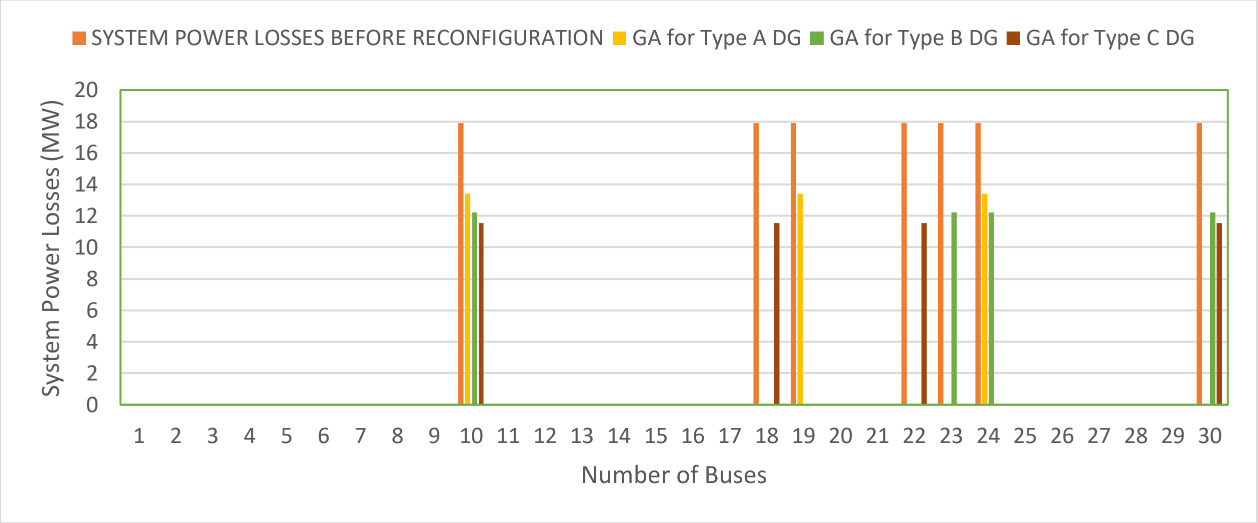


Figure 4-1: Simulation results for the power loss reduction of DGs using GA

4.3 Testing/and simulations of the electrical network modification using the PSO algorithm

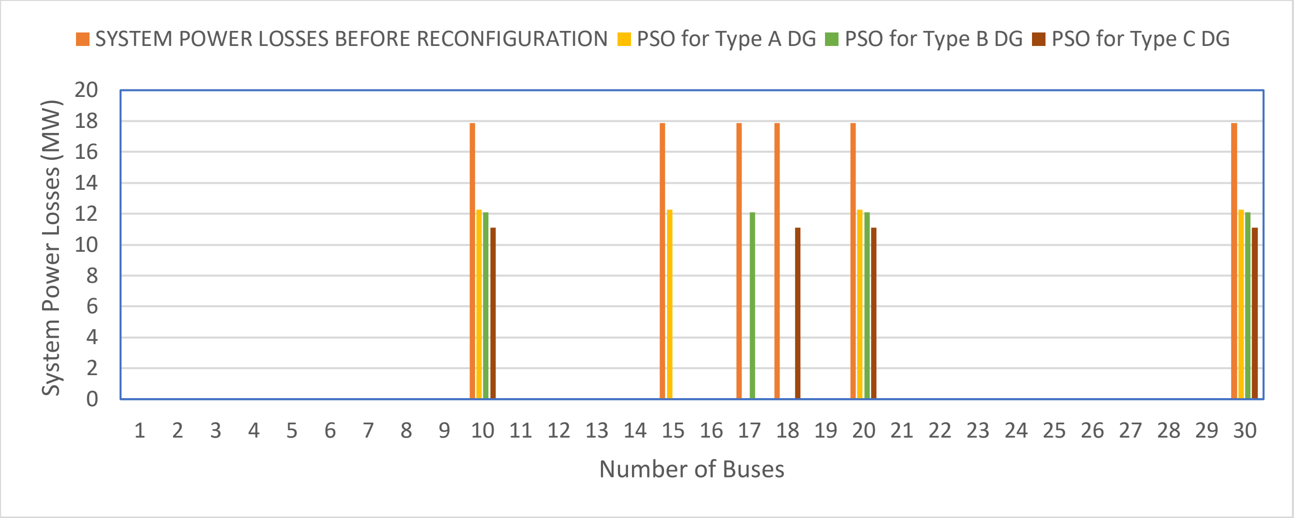


Figure 4-2: Simulation results for the power loss reduction of DGs using PSO

4.4 Testing/and simulations of the electrical network modification using the IPSO algorithm

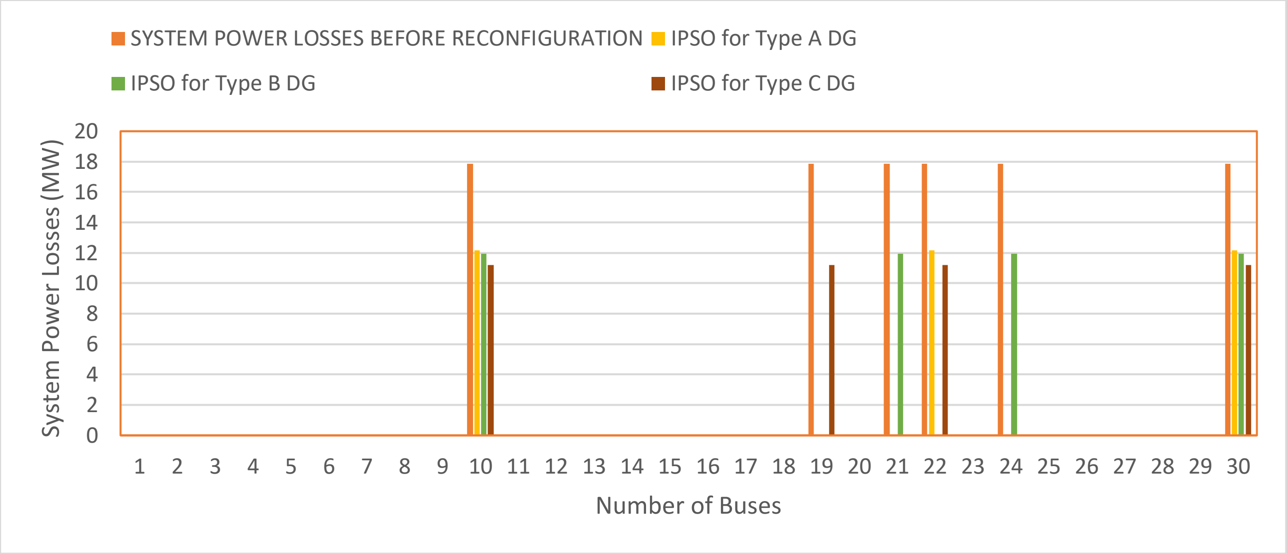


Figure 4-3: Simulation results for the voltage profile improvement of DGs using IPSO

4.5 Testing/and simulations of the electrical network modification using the HGAIPSO algorithm

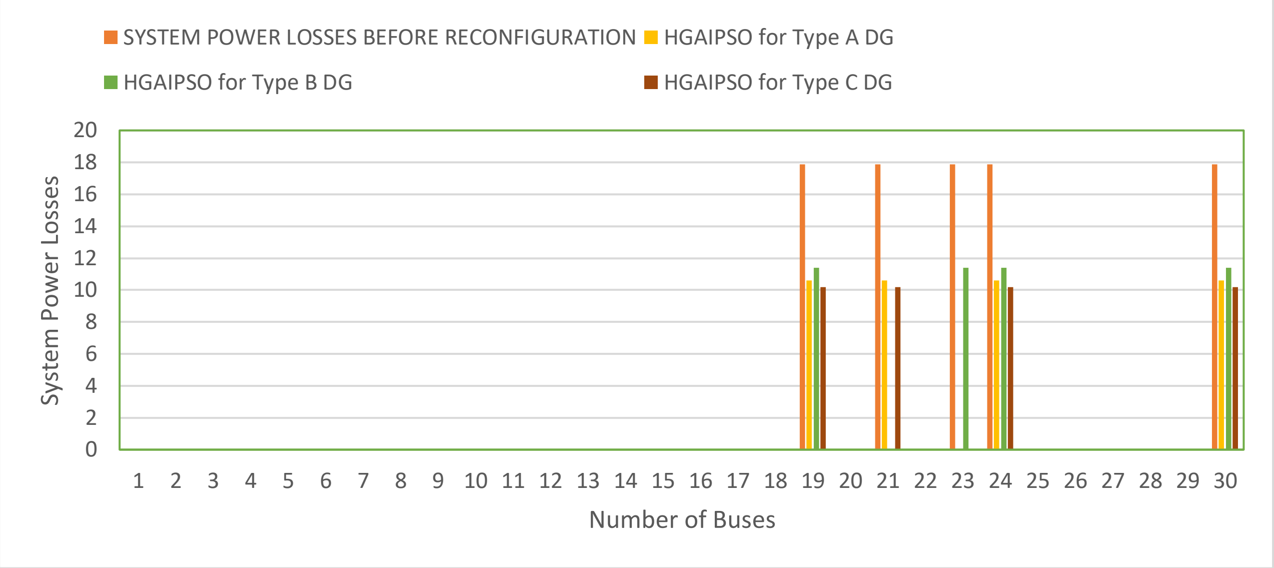


Figure 4-4: Simulation results for the power loss reduction of DGs using HGAIPSO

4.6 Comparative analysis and discussion

4.6.1 Case 1: Type A DG

Based on the columns in Table 4.1 that represent fitness and DG size, four optimal locations for the DGs of type A and their corresponding optimal sizes were selected. The minimal fitness values and corresponding DG sizes were allocated at these locations. The four most effective locations, together with their optimum DG sizes, are as follows.:

- The DG size of bus number 19 is 11.7099MW;
- The DG size of bus number 21 is 11.9937MW;
- The DG size of bus number 24 is 11.9960MW; and
- The DG size of bus number 30 is 11.7061MW.

Table 4-1: A comparison of Results obtained using Type A DG

Method	Bus Number	DG Size	Power Losses		Power Loss Reduction		%Power Loss Reduction	
		MW	MW	MVar	MW	MVar	%MW	%MVar
Power Loss without DG			17.8798					
GA	10	11.472	13.3919	-	4.4879	-	25.1002	-
	10	11.904						
	19	11.052						
	24	11.772						
PSO	10	11.694	12.2622	-	5.6176	-	31.4187	-
	15	11.394						
	20	11.378						
	30	10.577						
IPSO	10	11.625	12.1851	-	5.6947	-	31.8499	-
	10	11.956						
	22	11.995						
	30	11.986						
HGAIPSO	19	11.7099	10.6020	-	6.2778	-	40.7040	-31.2150
	21	11.9937						
	24	11.9960						
	30	11.7061						

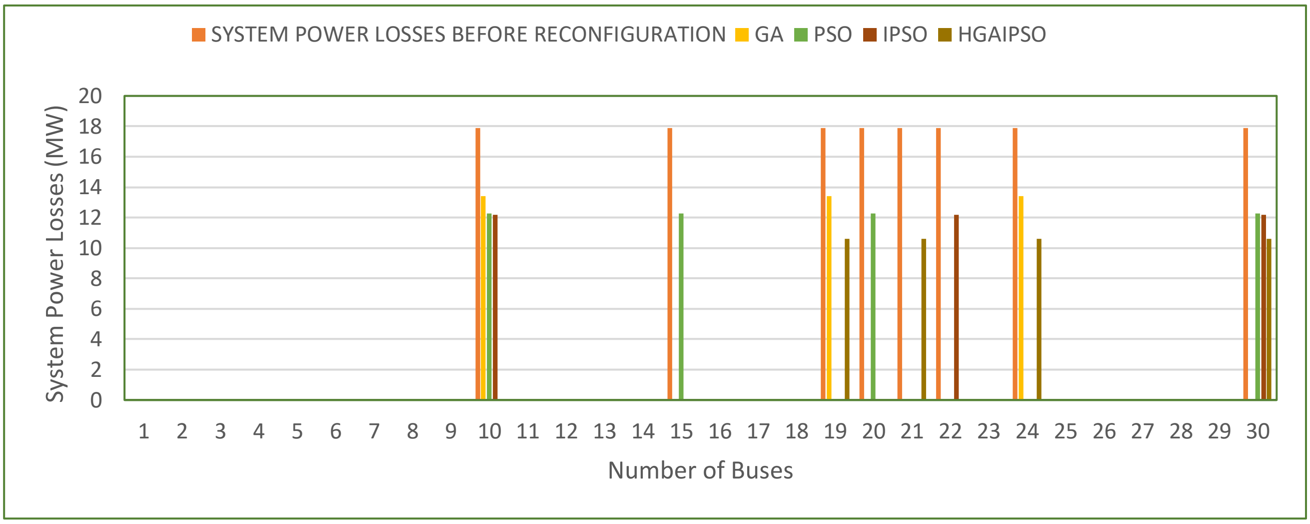


Figure 4-5: Comparison of Results for power loss obtained using Type A DG

From Table 4.1 and Figure 4.5 for Type A DG, it is clear that the HGAIPSO method reduced real power loss the most when compared with all other methods- GA with 25.1002 % compared to PSO with 31.4187% and IPSO with 31.8499%. The proposed method reduced real power loss by 40.7040%. When compared to results from other techniques, the HGAIPSO method DG derived from the suggested method shows good results with DG allocations for loss reduction. Thus, the HGAIPSO method is superior to the GA, PSO and IPSO methods when determining the optimum location and size for a Type A DG with the objective of reducing power losses within the electrical transmission system.

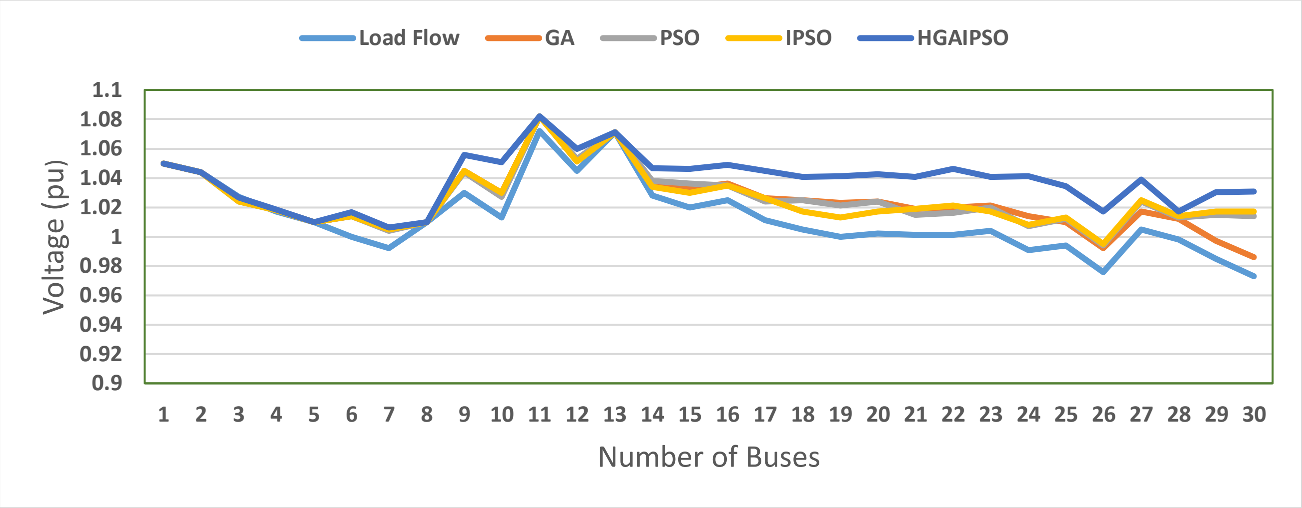


Figure 4-6: Bus voltage results for profile comparison using Type A DG

According to GA, PSO, IPSO, and HGAIPSO, the optimally positioned and sized DGs compare favorably with those without them in Table 4.2 and Figure 4.6. Even though the voltages in an IEEE-30 bus system are between 0.95 pu and 1.1 pu, which is within acceptable ranges, a DG can still influence the voltage stability of the system. This can be seen in Table 4.2, whereby the inclusion of DGs does not result in voltage levels to be outside of the acceptable limits. It is evident that all the bus voltages were within a range of 0.95pu to 1.1pu. The HGAIPSO method improved the voltage levels of the bus that had voltages below 1.0 pu to at least 1.01pu, and no voltage exceeded the acceptable limit.

Table 4-2: Comparison of Bus Voltage using Type A DG

	Voltage Without DGs (pu)	Voltage With Type A DG (pu)			
Number of Buses	**Load Flow**	**GA**	**PSO**	**IPSO**	**HGAIPSO**
1	1.050	1.050	1.050	1.050	1.050
2	1.044	1.044	1.044	1.044	1.044
3	1.027	1.026	1.024	1.024	1.026
4	1.017	1.018	1.018	1.018	1.018
5	1.010	1.010	1.010	1.010	1.010
6	1.010	1.014	1.014	1.014	1.016
7	0.992	1.005	1.004	1.005	1.006
8	1.012	1.012	1.012	1.012	1.012
9	1.030	1.045	1.044	1.045	1.055
10	1.013	1.03	1.027	1.035	1.050
11	1.072	1.082	1.082	1.082	1.082
12	1.045	1.052	1.053	1.051	1.059
13	1.071	1.071	1.071	1.071	1.071
14	1.028	1.036	1.038	1.034	1.046
15	1.020	1.033	1.036	1.033	1.046
16	1.025	1.036	1.035	1.035	1.049
17	1.011	1.026	1.024	1.026	1.044
18	1.005	1.025	1.025	1.017	1.040
19	1.023	1.023	1.021	1.013	1.041
20	1.002	1.024	1.024	1.017	1.042
21	1.001	1.019	1.015	1.019	1.040
22	1.001	1.02	1.016	1.021	1.046
23	1.004	1.021	1.02	1.017	1.040
24	0.991	1.014	1.007	1.008	1.041
25	0.994	1.01	1.012	1.013	1.034
26	0.976	0.992	0.994	0.995	1.017
27	1.005	1.017	1.024	1.025	1.038
28	0.998	1.012	1.013	1.014	1.017
29	0.985	0.997	1.015	1.017	1.030
30	0.973	0.986	1.014	1.017	1.030

4.6.2 Case 2: Type B DG

Based on the columns in Table 4.3 that represent fitness and DG size, four optimal locations for the DGs of Type B and their corresponding optimal sizes were selected. The minimal fitness values and corresponding DG sizes were allocated at these locations. The four most effective locations, together with their optimum DG sizes, are as follows:

- Bus number 19 with a DG which is generating 11.7872MW and 2.9609MVar;
- Bus number 23 with a DG which is generating 11.7548MW and 3.0002MVar;
- Bus number 24 with a DG which is generating 12.0001 MW and 1.3702MVar; and
- Bus number 30 with a DG which is generating 11.8308MW and 1.5817MVar.

Table 4-3: Comparison of Bus Voltage using Type B DG

Method	Bus Number	DG Size	Power Losses		Power Loss Reduction		%Power Loss Reduction	
		MW	**MW**	**MVar**	**MW**	**MVar**	**%MW**	**%MVar**
Power Loss without DG			17.8798					
GA	10	11.35+j1.22	12.2260	-	5.6538	-	31.5890	-
	23	11.47+j1.17						
	24	11.92+j2.04						
	30	11.816+j1.468						
PSO	10	11.474+j2.159	12.1060	-	5.7738	-	32.2923	-
	17	11.981+j0.919						
	20	11.67+j2.309						
	30	11.349+j3						
IPSO	10	11.83+j0.001	11.9500	-	5.9298	-	33.1648	-
	21	11.433+j3						
	24	11.739+j3						
	30	11.995+j0.001						
HGAIPSO	19	11.7872+j2.9609	11.4001	-	6.4797	-	36.2403	
	23	11.7548+j3.0002						
	24	12+j1.3702						
	30	11.8308+j1.5817						

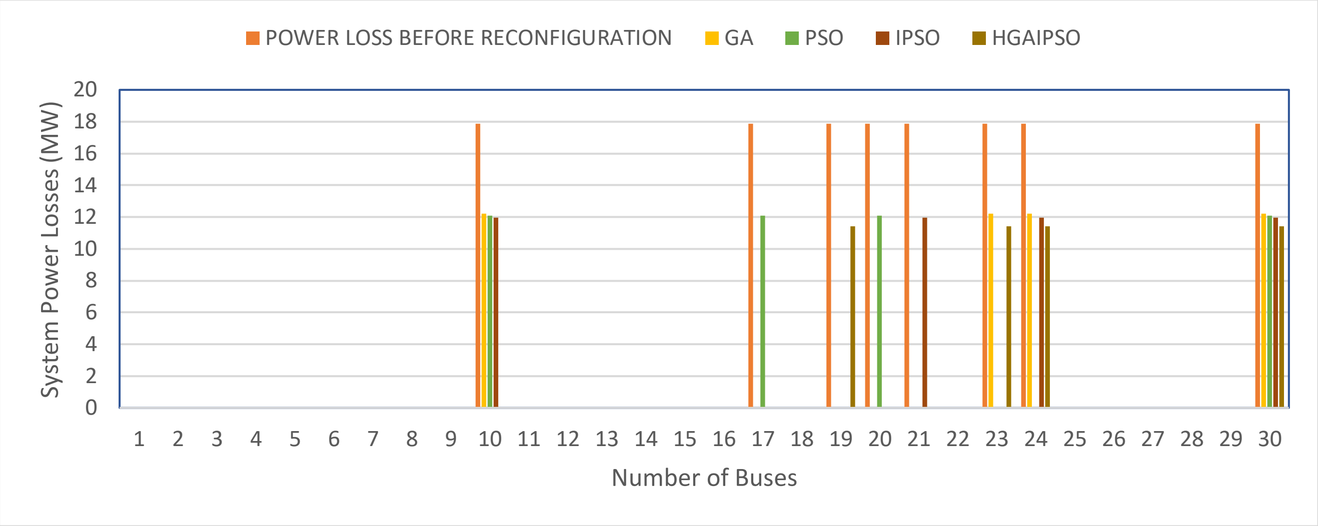


Figure 4-7: A comparison of Results for power loss obtained using Type B DG

According to Table 3.4 and Figure 4.7, using the HGAIPSO method to optimize the location and size of this type of DG results in a 36.2403% reduction in real power losses. As compared to GA, PSO and IPSO, the proposed method shows a higher percentage. the GA shows a reduction of 31.5890%; PSO shows a reduction of 32.2923%; and IPSO shows a reduction of 33.1648% . It is also comparable to the sizes determined using the other techniques that were chosen for the DGs sizing and allocation for power loss minimization.

Voltage Profile

An analysis of the voltage profile of the IEEE-30 bus system was performed after the placement and sizing of the Type B DGs were optimized. Below is a table showing the results of the bus voltage levels under this condition. A comparison is also given in the table between this case and the one without DGs, and with DGs placed and sized using other methods. This comparison was also done using a bar chart, as shown in Figure 5.8 below.

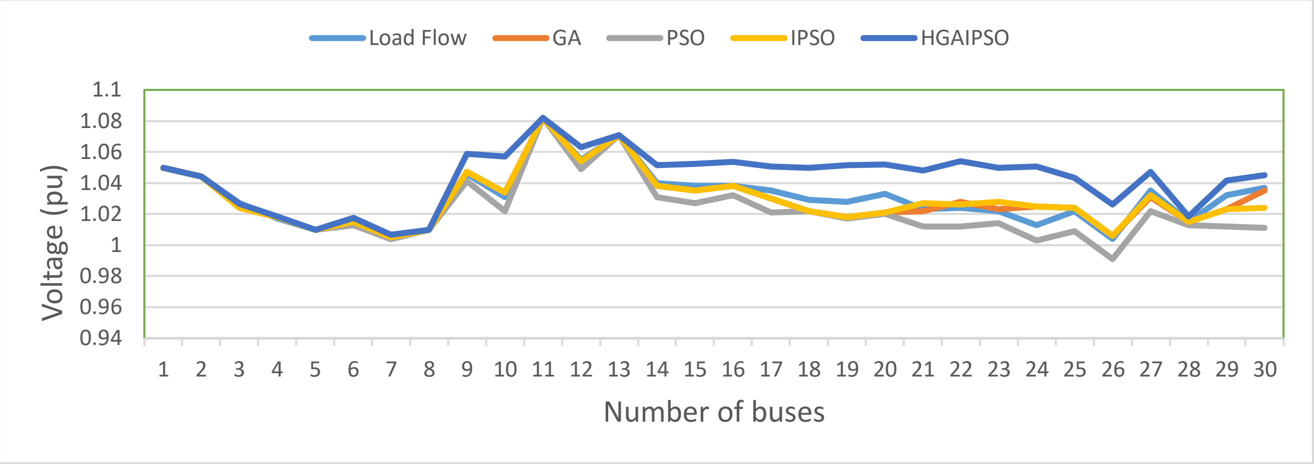


Figure 4-8: Bus voltage profile comparison using Type B DG

The voltages for the cases with and without DGs are compared in Table 4.4 along with their ideal placement and sizing based on GA, PSO, IPSO, and HGAIPSO. Even when the voltages in an IEEE-30 bus system are within the allowed range, namely 0.95 pu to 1.1 pu, a DG might still have an impact on the voltage stability of the system. Figure 4.8 and Table 4.4 both show this. The addition of DGs does not cause voltage levels to exceed permissible thresholds. It is evident that all the bus voltages were within a range of 0.95pu to 1.1pu. Thus, the HGAIPSO method improved the voltage levels of the bus that had voltages, and no voltage exceeded the acceptable limit.

Table 4-4: Comparison of Bus Voltage using Type B DG

	Voltage Without DGs (pu)	Voltage With Type B DG (pu)			
Number of Buses	**Load Flow**	**GA**	**PSO**	**IPSO**	**HGAIPSO**
1	1.050	1.050	1.050	1.050	1.050
2	1.044	1.044	1.044	1.044	1.044
3	1.027	1.026	1.024	1.024	1.026
4	1.017	1.018	1.018	1.018	1.018
5	1.010	1.010	1.010	1.010	1.010
6	1.014	1.015	1.013	1.015	1.017
7	1.005	1.005	1.004	1.005	1.067
8	1.010	1.010	1.010	1.010	1.010
9	1.046	1.047	1.041	1.047	1.058
10	1.031	1.034	1.022	1.034	1.056
11	1.082	1.082	1.082	1.082	1.082
12	1.055	1.054	1.049	1.054	1.061
13	1.071	1.071	1.071	1.071	1.071
14	1.04	1.038	1.031	1.038	1.051
15	1.038	1.035	1.027	1.035	1.052
16	1.038	1.038	1.032	1.038	1.053
17	1.035	1.030	1.021	1.030	1.050
18	1.029	1.022	1.022	1.022	1.049
19	1.028	1.018	1.017	1.018	1.051
20	1.033	1.021	1.020	1.021	1.052
21	1.023	1.027	1.012	1.027	1.048
22	1.024	1.028	1.012	1.028	1.053
23	1.022	1.027	1.014	1.027	1.049
24	1.013	1.025	1.003	1.025	1.050
25	1.022	1.024	1.009	1.024	1.043
26	1.004	1.006	0.991	1.006	1.026
27	1.035	1.031	1.022	1.031	1.047
28	1.015	1.015	1.013	1.015	1.018
29	1.032	1.023	1.012	1.023	1.041
30	1.037	1.024	1.011	1.024	1.045

4.6.3 Case 3: Type C DG

Based on the columns in Table 4.5 that represent fitness and DG size, four optimal locations for the DGs of Type B and their corresponding optimal sizes were selected. The minimal fitness values and corresponding DG sizes were allocated at these locations. The four most effective locations, together with their optimum DG sizes, are as follows:

- Bus number 19 with a DG generating 12.0010MW and absorbing 0.4882MVar;
- Bus number 24 with a DG generating 11.9470MW and absorbing 0.5042MVar;
- Bus number 21 with a DG generating 11.9179MW and absorbing 0.0692MVar; and
- Bus number 30 with a DG generating 11.3651MW and absorbing 0.5807MVar.

Table 4.5 shows the comparison of the results of the power losses as a function of the different methods. When compared to GA, PSO and IPSO, the HGAIPSO method shows the greatest reduction in power loss, which is 42.9406. The proposed method performed better than GA which is 35.6967%; PSO which is 37.8874%; and IPSO which is 37.3041%.

Table 4-5: A comparison of Results obtained using Type C DG

Method	**Bus Number**	**DG Size**	**Power Losses**		**Power Loss Reduction**		**%Power Loss Reduction**	
		MW	**MW**	**MVar**	**MW**	**MVar**	**%MW**	**%MVar**
Power Loss without DG			17.8798					
GA	10	9.0384-j0.0882	11.5265	-	6.3533	-	35.6967	-
	18	11.1120-j0.7150						
	22	11.7480-j0.5891						
	30	10.0081-j0.4870						
PSO	10	11.885-j0.7970	11.1056	-	6.7742	-	37.8874	-
	18	10.8811-j0.3215						
	20	11.5631-j0.8990						
	30	11.5310-j0.3831						
IPSO	10	12.0215-j0.5260	11.2099	-	6.6699	-	37.3041	-
	19	10.8610-j0.3002						
	22	11.9170-j0.8370						
	30	11.9560-j0.5260						
HGAIPSO	19	12.0010-j0.4882	10.2021		7.6777	-	42.9406	22.36547
	21	11.9470-j0.5042						
	24	11.9179-j0.0692						
	30	11.3651-j0.5807						

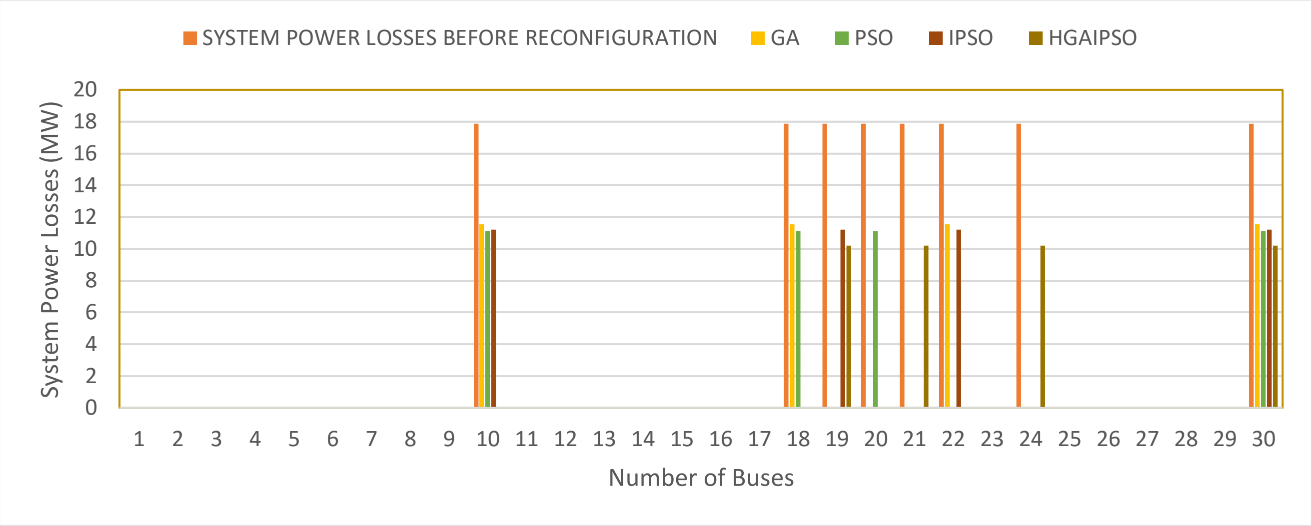


Figure 4-9: A comparison of Results for power loss obtained using Type C DG

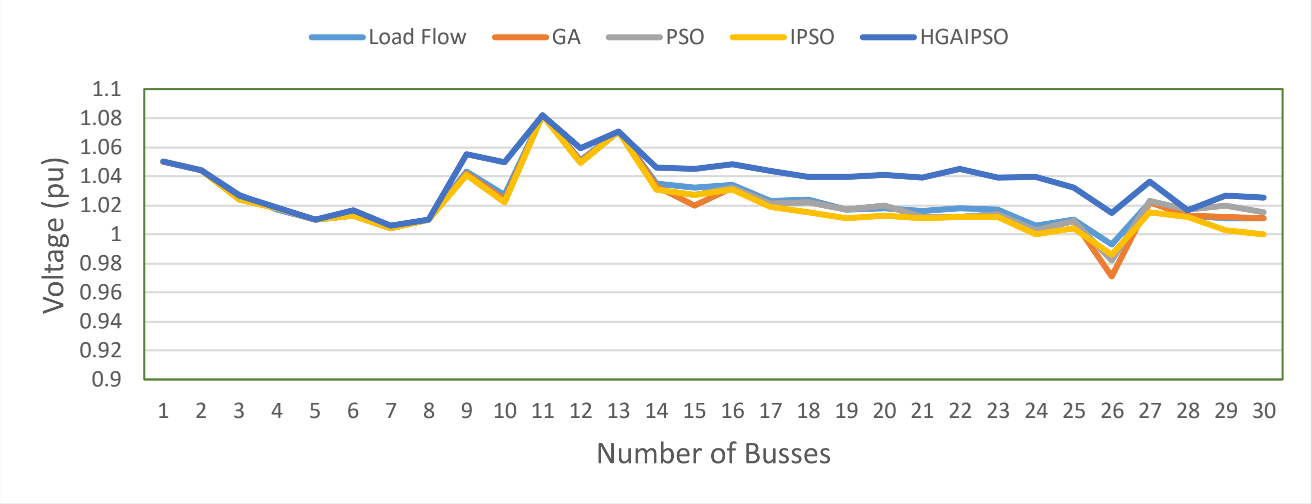


Figure 4-10: Bus voltage profile comparison using Type C DG

The results from Table 4.6 clearly show that the use of the HGAIPSO method significantly lowers the bus voltage, which means the inclusion of the DGs by optimizing their placement and sizing. Based on the optimization of the Type C DG location and size, it was possible to achieve a lower bus voltage level of 1.01pu from 0.973pu. This means that the highest value was maintained at 1.095pu. Therefore, based on these data, the bus voltage profile has improved.

Table 4-6: Comparison of Bus Voltage using Type C DG

	Voltage Without DGs (pu)	Voltage With Type C DG (pu)			
Number of Buses	**Load Flow**	**GA**	**PSO**	**IPSO**	**HGAIPSO**
1	1.05	1.05	1.05	1.05	1.05
2	1.044	1.044	1.044	1.044	1.044
3	1.027	1.026	1.024	1.024	1.0267
4	1.017	1.018	1.018	1.018	1.0184
5	1.01	1.01	1.01	1.01	1.01
6	1.013	1.013	1.013	1.013	1.0164
7	1.004	1.004	1.004	1.004	1.006
8	1.01	1.01	1.01	1.01	1.01
9	1.043	1.042	1.041	1.041	1.0551
10	1.027	1.024	1.022	1.022	1.0495
11	1.082	1.082	1.082	1.082	1.082
12	1.051	1.05	1.049	1.049	1.0594
13	1.071	1.071	1.071	1.071	1.071
14	1.035	1.033	1.031	1.031	1.046
15	1.032	1.03	1.027	1.027	1.0451
16	1.034	1.032	1.032	1.031	1.0483
17	1.023	1.021	1.021	1.019	1.0439
18	1.024	1.022	1.022	1.015	1.0396
19	1.017	1.017	1.017	1.011	1.0394
20	1.018	1.02	1.02	1.013	1.0411
21	1.016	1.012	1.012	1.011	1.0392
22	1.018	1.012	1.012	1.012	1.0449
23	1.017	1.014	1.014	1.012	1.0392
24	1.006	1.003	1.003	1.004	1.0394
25	1.01	1.009	1.009	1.004	1.0323
26	0.993	0.991	0.991	0.986	1.0148
27	1.022	1.022	1.022	1.015	1.0363
28	1.013	1.013	1.013	1.012	1.0166
29	1.011	1.012	1.014	1.020	1.0265
30	1.011	1.015	1.017	1.025	1.0950

4.7 Summary

Under three different load conditions, this chapter presented the results of three scenarios that consider the nature of DGs for the optimal allocation of DGs in the IEEE-30-bus system using HGAIPSO. This chapter presented results comparisons, discussions about the approaches used, the power loss resulting from each case, as well as improvements in voltage profiles. The final chapter follows, drawing conclusions and making recommendations for future research.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

By optimizing the location and size of DGs, the problem of power losses in systems was solved because power losses are reduced and voltage profiles are improved. This study presented a hybridized algorithm (HGAIPSO) to reduce system power losses and improve voltage profiles. Combining the sensitivity factors and tests on the IEEE-30 bus test system was effective in reducing the number of iterations for algorithms. Fourteen buses were chosen as the best DG locations for the IEEE-30 bus test system. Comparing the HGAIPSO method to the GA, PSO and IPSO methods in all three types of DGs using the IEEE-30 bus shows that it can be reduced. According to Type A, Type B and Type C DGs, real power losses were reduced by 40.7040%, 36.2403% and 42.9406% respectively. Each of the three cases produced the highest bus voltage of 1.01pu, which shows that the voltage profile is generally improved.

The IEEE-30 bus test system's losses are decreased and the voltage profile can be improved as a result of HGAIPSO, proving that this method is more effective at optimizing this parameter than GA, PSO, and IPSO. In studying the impact of transmission generation on power loss and voltage profile using the HGAIPSO algorithm, it clearly demonstrated that there was a reduction in system power losses as distributed generators were introduced to the power system up to an optimal number. In addition, it was also observed that the voltage profile would be having a different way that would result in the worsening of bus voltages within the acceptable range upon further DG introduction from the optimal number. The research objectives were met successfully and the HGAIPSO optimization algorithm implemented in this study was demonstrated to be more effective than GA, PSO and IPSO for optimum locating and sizing of DGs in the power transmission system to minimize losses.

5.2 Recommendations for future work

- Power transmission companies can use this method whenever it is necessary to integrate DG into the power transmission network because the loading of the network cannot be stopped, including other aspects of the power system, like stability, improves the Multi-Objective function;
- Code for this project was programmed in Matlab and long iteration times were observed. Thus, further efforts need to try reducing these delays; and

- Engineers in charge of planning should carefully consider any adverse effects of DG that can be eliminated with the best allocation of DG.

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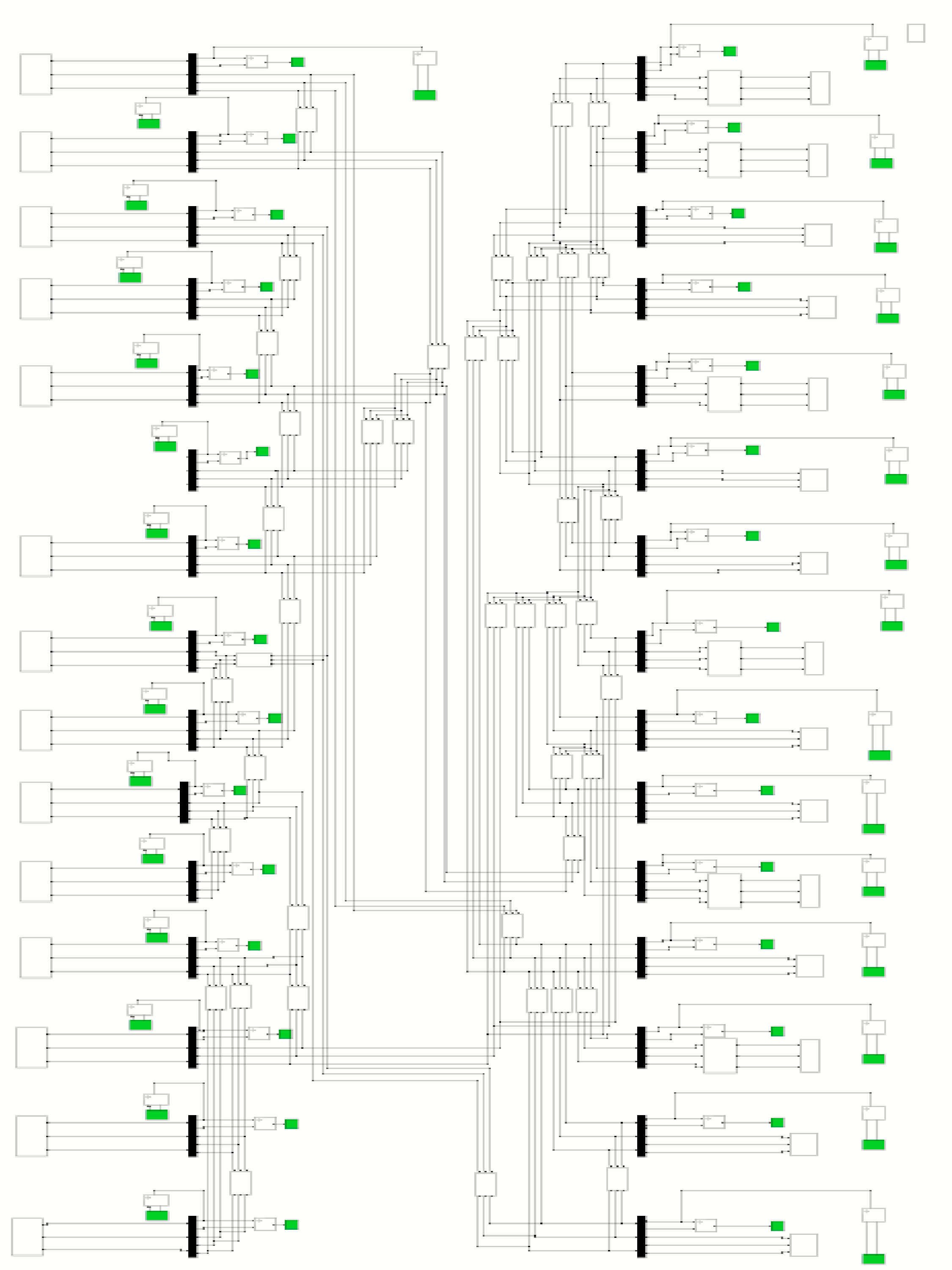
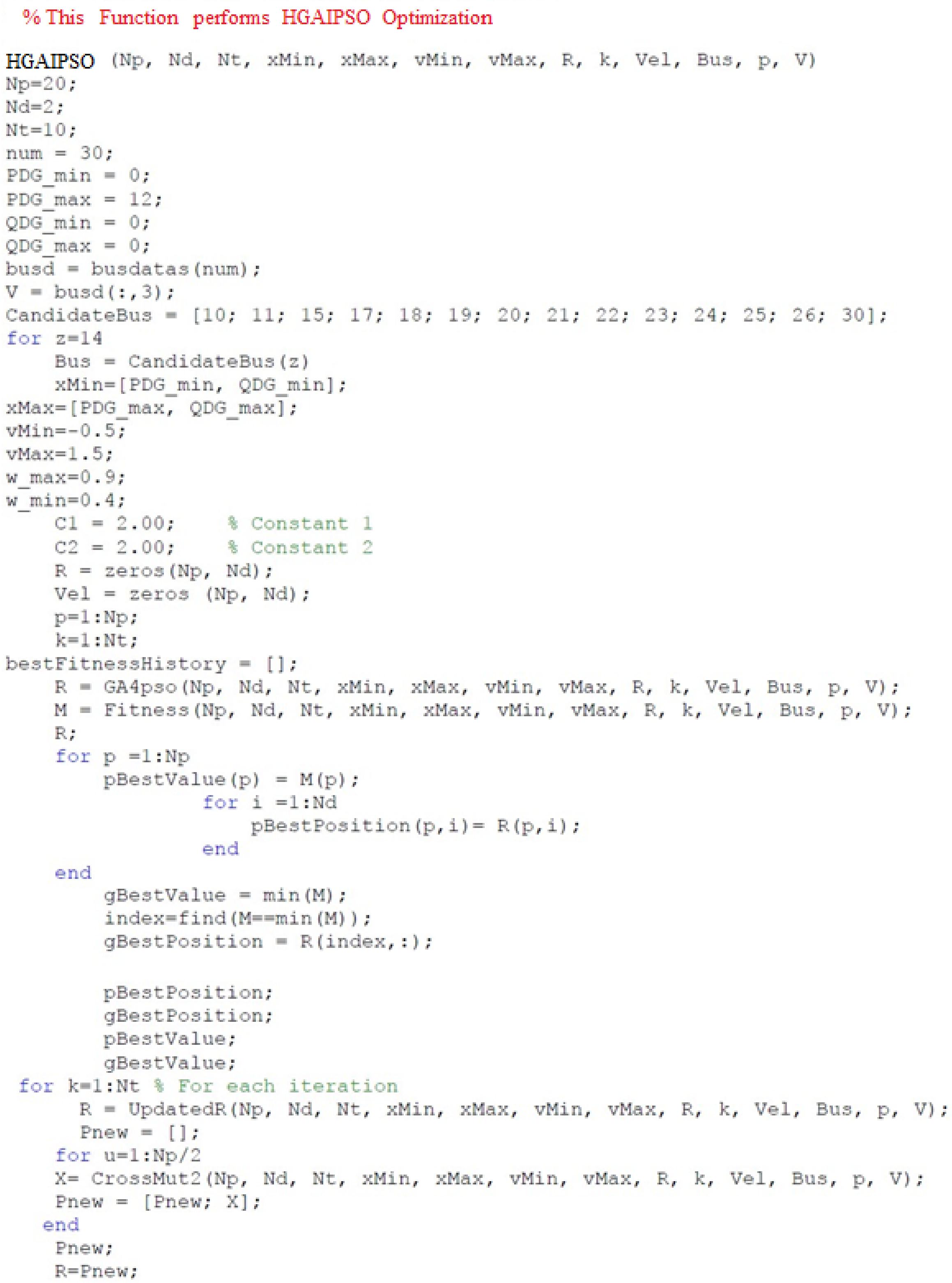
APPENDICES

Appendix A: Matlab IEEE-30 bus test system



Appendix B: Matlab code for the proposed algorithm



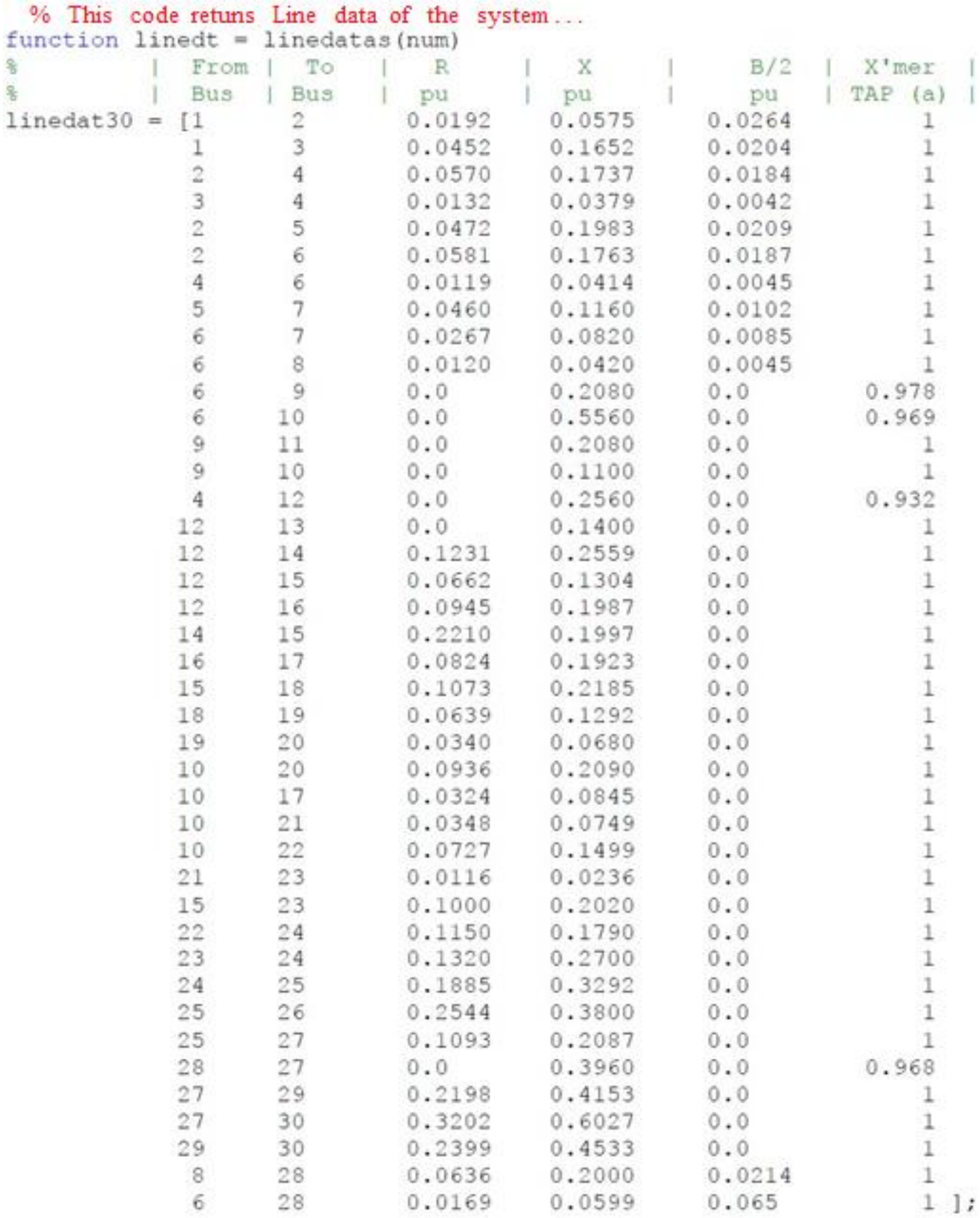
```
 % This  Function  performs  HGAIPSO  Optimization

HGAIPSO (Np, Nd, Nt, xMin, xMax, vMin, vMax, R, k, Vel, Bus, p, V)
Np=20;
Nd=2;
Nt=10;
num = 30;
PDG_min = 0;
PDG_max = 12;
QDG_min = 0;
QDG_max = 0;
busd = busdatas(num);
V = busd(:,3);
CandidateBus = [10; 11; 15; 17; 18; 19; 20; 21; 22; 23; 24; 25; 26; 30];
for z=14
    Bus = CandidateBus(z)
    xMin=[PDG_min, QDG_min];
xMax=[PDG_max, QDG_max];
vMin=-0.5;
vMax=1.5;
w_max=0.9;
w_min=0.4;
    C1 = 2.00;    % Constant 1
    C2 = 2.00;    % Constant 2
    R = zeros(Np, Nd);
    Vel = zeros (Np, Nd);
    p=1:Np;
    k=1:Nt;
bestFitnessHistory = [];
    R = GA4pso(Np, Nd, Nt, xMin, xMax, vMin, vMax, R, k, Vel, Bus, p, V);
    M = Fitness(Np, Nd, Nt, xMin, xMax, vMin, vMax, R, k, Vel, Bus, p, V);
    R;
    for p =1:Np
        pBestValue(p)  = M(p);
                for i =1:Nd
                    pBestPosition(p,i)= R(p,i);
                end
    end
        gBestValue = min(M);
        index=find(M==min(M));
        gBestPosition = R(index,:);

        pBestPosition;
        gBestPosition;
        pBestValue;
        gBestValue;
 for k=1:Nt % For each iteration
      R = UpdatedR(Np, Nd, Nt, xMin, xMax, vMin, vMax, R, k, Vel, Bus, p, V);
      Pnew = [];
    for u=1:Np/2
    X= CrossMut2(Np, Nd, Nt, xMin, xMax, vMin, vMax, R, k, Vel, Bus, p, V);
    Pnew = [Pnew; X];
   end
    Pnew;
    R=Pnew;
```

```
    for p=1:Np
      for i=1:Nd
       % Correct any errors
       if R(p,i) > xMax(1,i)
          R(p,i) = xMax(1,i);
       elseif  R(p,i) < xMin(1,i)
                R(p,i) = xMin(1,i);
       end
       end
    end
         % Evaluate Fitness
     M = Fitness(Np, Nd, Nt, xMin, xMax, vMin, vMax, R, k, Vel, Bus, p, V);
        R;
        for p=1:Np
            %Check if it is a personal best
            %If it is, record the value and the position
            if M(p) < pBestValue(p)
                pBestValue(p) = M(p);
                for i=1:Nd
                    pBestPosition(p,i) = R(p,i);
                end
            end
            % Check if it is a global best
            % If it is, record the value and the position
            if M(p) < gBestValue
                gBestValue = M(p);
                for i=1:Nd
                    gBestPosition(i) = R(p,i);
                end
            end
        end
        bestFitnessHistory(k) = gBestValue;
       % Calculate Velocity
        w = w_max-((w_max-w_min)/Nt)*k; % evaluate w
        for p=1:Np
            for i=1:Nd
  Vel(p,i)  =w * Vel(p,i)+ rand * C1 * (pBestPosition(p,i)-R(p,i)) + rand *
C2 * (gBestPosition(i) - R(p,i));
                if Vel(p,i) > vMax
                    Vel(p,i) = vMax;
                elseif  Vel(p,i) < vMin
                    Vel(p,i) = vMin;
                end
            end
        end
        Vel;
        gBestPosition=gBestPosition(1,:);
        gBestValue;
        k=k+1;
 end
        pBestPosition;
        gBestPosition
        pBestValue;
        gBestValue
    z=z+1;
end
end
```

Appendix C: Matlab Bus Load Injection Bus for IEEE-30 bus test system



```
 % This code retuns Line data of the system...
function linedt = linedatas(num)
%           | From |  To    |   R      |   X      |     B/2   |  X'mer   |
%           | Bus  | Bus    |  pu      |  pu      |     pu    | TAP (a)  |
linedat30 = [1        2        0.0192     0.0575      0.0264        1
             1        3        0.0452     0.1652      0.0204        1
             2        4        0.0570     0.1737      0.0184        1
             3        4        0.0132     0.0379      0.0042        1
             2        5        0.0472     0.1983      0.0209        1
             2        6        0.0581     0.1763      0.0187        1
             4        6        0.0119     0.0414      0.0045        1
             5        7        0.0460     0.1160      0.0102        1
             6        7        0.0267     0.0820      0.0085        1
             6        8        0.0120     0.0420      0.0045        1
             6        9        0.0        0.2080      0.0       0.978
             6       10        0.0        0.5560      0.0       0.969
             9       11        0.0        0.2080      0.0           1
             9       10        0.0        0.1100      0.0           1
             4       12        0.0        0.2560      0.0       0.932
            12       13        0.0        0.1400      0.0           1
            12       14        0.1231     0.2559      0.0           1
            12       15        0.0662     0.1304      0.0           1
            12       16        0.0945     0.1987      0.0           1
            14       15        0.2210     0.1997      0.0           1
            16       17        0.0824     0.1923      0.0           1
            15       18        0.1073     0.2185      0.0           1
            18       19        0.0639     0.1292      0.0           1
            19       20        0.0340     0.0680      0.0           1
            10       20        0.0936     0.2090      0.0           1
            10       17        0.0324     0.0845      0.0           1
            10       21        0.0348     0.0749      0.0           1
            10       22        0.0727     0.1499      0.0           1
            21       23        0.0116     0.0236      0.0           1
            15       23        0.1000     0.2020      0.0           1
            22       24        0.1150     0.1790      0.0           1
            23       24        0.1320     0.2700      0.0           1
            24       25        0.1885     0.3292      0.0           1
            25       26        0.2544     0.3800      0.0           1
            25       27        0.1093     0.2087      0.0           1
            28       27        0.0        0.3960      0.0       0.968
            27       29        0.2198     0.4153      0.0           1
            27       30        0.3202     0.6027      0.0           1
            29       30        0.2399     0.4533      0.0           1
             8       28        0.0636     0.2000      0.0214        1
             6       28        0.0169     0.0599      0.065         1 ];
```