TRIBHUVAN UNIVERSITY
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DEPARTMENT OF ELECTRICAL ENGINEERING
MASTER OF SCIENCE IN POWER SYSTEM ENGINEERING

ROLL NO.: 074MSPSE017

SMART RECONFIGURATION OF DISTRIBUTION NETWORKS HANDLING DG PENETRATION FOR POWER LOSS MINIMIZATION AND VOLTAGE PROFILE IMPROVEMENT

THESIS REPORT

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February, 2021

ABSTRACT

Power loss minimization and voltage stability improvement are important areas of power systems due to existing transmission line contingency, financial loss of utility and power system blackouts. Distribution network reconfiguration (DNR) can significantly reduce power losses, improve the voltage profile, and increase the power quality. DNR studies require implementation of the power flow analysis and complex optimization procedures capable of handling large combinatorial problems. In addition, optimal allocation (i.e. siting, sizing, and operating power factor) of Distributed Generation (DG) is one of the best ways to strengthen the efficiency of power system along with network reconfiguration. Power system operators and researchers put forward their efforts to solve the distribution system problem related to power loss, energy loss, voltage profile, and voltage stability based on optimal DG allocation. Furthermore, optimal DG allocation secures distribution system from unwanted events and allows the operator to run the system in islanding mode.

The size of the distribution network influences the type of the optimization method to be applied. In particular, straight forward approaches can be computationally expensive or even prohibitive whereas heuristic or metaheuristic approaches can yield acceptable results with less computation cost. In the problems like DNR, there is extensive search procedure involved in finding the optimum solution. In addition, the solution improves in various stages of search procedure and in each iteration. In the optimization problems like the one in this thesis work, large number of variables have to be optimized. Distribution network reconfiguration and placement of DGs involves fourteen variables when five disconnecting switches and three DGs are considered – five for the disconnecting switches, three variables for the placement of DGs, three variables for the sizing of DGs, and three variables for the optimum power factor of DGs. Only the most efficient algorithms are able to find the optimum solution in minimum iteration and minimum time. Artificial Bee Colony (ABC) algorithm has been used in this thesis work as it is very easy to implement and efficient in finding optimum solution when compared to other popular metaheuristic algorithms like Genetic Algorithm, and Particle Swarm Optimization Algorithm.

Firstly, the bus voltage profile, and power loss was determined for the system taken into consideration *(Base Case)*. Then, distribution network reconfiguration was implemented in standard IEEE buses *(Case I)*. In the next step, DGs were incorporated in the standard IEEE buses and reconfiguration was designed. In that analysis, initially only the case of DG installation was analyzed *(Case II)*. Afterwards, the case of DG installation after reconfiguration was taken *(Case III)*. Then, the case of reconfiguration after DG installation was studied *(Case IV)*. Finally, the case of simultaneous reconfiguration after DG installation was analyzed *(Case V)*.

First, IEEE 33 Bus System was considered and the base case power loss for the system was 202.67 kW. For the *Case I*, the power loss reduced by 30.93%. When considering DGs capable of injecting active power only, the power loss was reduced by 59.16%, 71.24%, 68.81%, and 71.49% respectively for *Case II, Case III, Case IV,* and *Case V* respectively. The minimum bus voltage improved significantly and was at least 0.951 pu for *Case II, Case III, Case IV, and Case V*. When considering DGs capable of injecting both active power and reactive power, the power loss was reduced by 86.86%, 89.29%, 91.60%, and 92.93% for *Case II, Case III, Case IV,* and *Case V* respectively. The minimum bus voltage also improved significantly and was at least 0.966 pu for *Case II, Case III, Case IV, and Case V*.

In the next step, IEEE 69 Bus System was considered and the base case power loss for the system was 225 kW. For the *Case I*, the power loss reduced by 56.17%. When considering DGs capable of injecting active power only, the power loss was reduced by 66.93%, 83.21%, 80.92%, and 83.52% respectively for *Case II, Case III, Case IV,* and *Case V* respectively. The minimum bus voltage improved significantly and was at least 0.978 pu for *Case II, Case III, Case IV, and Case V*. When considering DGs capable of injecting both active power and reactive power, the power loss was reduced by 95.16%, 95.96%, 96.56%, and 97.45% for *Case II, Case III, Case IV,* and *Case V* respectively. The minimum bus voltage also improved significantly and was at least 0.987 pu for *Case II, Case III, Case IV, and Case V*.

Finally, Daachhi feeder of Kathmandu valley was taken as a subject to apply the theoretically proven technique of reconfiguration and DG incorporation to optimize voltage profile and power loss. The base case power loss for the system was 197.026 kW. For the *Case I*, the power loss reduced by 5.30%. When considering DGs capable of injecting active power only, the power loss

was reduced by 40.17%, 51.18%, 41.94%, and 51.43% respectively for *Case II, Case III, Case IV*, and *Case V* respectively. The minimum bus voltage improved significantly and was at least 0.968 pu for *Case II, Case III, Case IV, and Case V*. When considering DGs capable of injecting both active power and reactive power, the power loss was reduced by 76.30%, 91.89%, 76.57%, and 92.71% for *Case II, Case III, Case IV*, and *Case V* respectively. The minimum bus voltage also improved significantly and was at least 0.973 pu for *Case II*, *Case III*, *Case IV, and Case V*. Overall findings showed that performing simultaneous distribution network reconfiguration and allocation of DGs yielded best results in reducing system loss and improving bus voltage profile, which is in-line with objectives of this thesis work.

ACKNOWLEDGEMENTS

The successful completion of this thesis work would not have been possible without the guidance and support of many people and I am extremely grateful to have got this all along the way of my thesis work. I would like to offer my thankfulness to my thesis supervisor Prof. Dr. Nava Raj Karki for his invaluable guidance, support, and encouragement throughout this thesis work and research process. I am grateful for his mentorship and friendly guidance not only during this thesis, but also throughout the master's program.

I would like to express my sincere appreciation to all teachers and staff of Department of Electrical Engineering, Pulchowk Campus. In addition, I would like to express my gratitude to Engineer Saru Bastola of Baneshwor Distribution Centre, Nepal Electricity Authority for her support during field visits and data collection of Daachhi feeder.

Last but not the least, I would like to acknowledge my family and friends who have made a contribution directly or indirectly to complete this thesis work.

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CHAPTER I: INTRODUCTION

1.1 Introduction

Utilities in the developing and under-developed countries face capital shortage for generation and transmission system amid disproportionate load growth. Efficiency of the power system depends on the performance of the transmission and distribution network. Higher the power losses of the transmission and distribution systems, lower is the efficiency of the power system. Power losses account for financial loss of the utilities - lower the losses, higher the revenue. For utilities facing lack of capital, effective and smart utilization of existing infrastructure with minimal improvements brings two important benefits – first, it delays the capital requirement to reinforce the existing system; second, it generates additional revenue which can serve as a part of capital requirement to reinforce the existing system. Meanwhile, after deregulation and privatization of the power system, another common problem observed in distribution systems is the lack of reactive power sources in the system [1]. Barring installation of reactive power sources exclusively to cater reactive power load, reactive power generated by distributed generators can reduce the reactive power supplied from the grid.

Network reconfiguration is the process of changing the topology by altering the open/closed status of switches, so as to find a radial operating structure that minimizes the losses and improves the voltage stability while satisfying the operating constraints. Distribution network reconfiguration (DNR) is the best methodology that can reduce power loss and improve power quality for the efficient operation of power distribution systems using existing resources. Radial distribution networks often feature sectionalizing switches and tie switches mainly used for fault isolation, power supply recovery, and system reconfiguration. These switches allow for reconfiguring the topology of the network, with the objectives being reduction of power losses, load balancing, and voltage profile improvement and increasing reliability of the system [2]. A network reconfiguration is a complex non-linear combinatorial problem as the solution is a large combination search space of open switches. The complexity increases with increase in network size. It is why, artificial intelligence and meta-heuristic optimization techniques are efficient to solve such problems as compared to analytical methods.

On the other hand, introduction of the smart grid, and the liberalization of energy markets has allowed interconnection Distributed Generations at distribution end. The DGs are mainly of renewable energy type, dominated by solar and wind power plants. Distribution companies try to minimize real losses in order to obtain profit rather than paying a penalty. Therefore, a host of research publications has proposed numerous methods for active power loss minimization of distribution systems. To maintain voltage profile of the system within a given minimum level, sufficient reactive power support is needed, which in turn also raises the stability and reliability of the system. In such a situation, it is imperative to introduce a variety of innovative technologies for optimal utilization of existing resources and resolution of reported issues to meet the target of load demand with power quality and in a cost-effective way [1]. One of the latest ways to handle these issues in economical and reasonable time is the optimal allocation of distributed generation in power systems. In a power system composed of distributed energy resources, much smaller amounts of energy are produced by numerous small, modular energy conversion units, which are often located close to the point of end use. Both demand and distribution generation are directly connected to the distribution network. Besides, DG units, local responsive demands, and storage systems can be operated stand alone or integrated into the electricity grid [3]. Combination of multiple methodologies such as distribution reconfiguration and optimal allocation of DGs have been proposed to increase the benefits; however, the practical complexity of implementing such combination of methodologies increases significantly.

1.2 Problem Statement

The performance of distribution system becomes inefficient due to the reduction in voltage magnitude and increase in distribution losses. Since the distribution power system is the final stage of the distribution process from the source to the individual customer, it has seemed to contribute the greatest amount of power loss which finally results into the instability of the system. Many researchers have been focusing on power loss minimization in the distribution system by using various methods.

In the context of Nepal, it is not a necessity but a compulsion to integrate DGs if they are willing to integrate in the existing network. Nepal Electricity Authority (NEA) has released its guidelines in April, 2016 for interconnection of photovoltaic to distribution network. In February 2018, Ministry of Energy released standard procedure for connection of alternative energy to the existing grid. According to the guideline, energy producers willing to sell energy for solar capacity above 500 watts may apply to NEA for interconnection through net metering. Following these: CIAA- Tangal (514 kW), ICIMOD- Khumaltar (92 kW) are already installed and ready for integration in the distribution network while NMB Bank- Babarmahal (50kW) is due for PPA with NEA. NEA has already integrated 600 kW solar plant installed at Dhobighat under Kathmandu Upatyaka Khanepani Limited (KUKL), 100 kW solar plant installed at NEA Training Center, and 60 kW solar installed at Bir Hospital in the distribution network.

Among the various methods of loss minimization, the recent method used is reconfiguration Distribution Network Reconfiguration capable of handling Distributed Generation penetration has been proposed in this thesis work. Distribution Network Reconfiguration alters the present connection of branches between the buses and proposes a new configuration of connection which gives the shortest path between the source and the load, resulting minimum power loss. And, proper allocation of Distributed Generations facilitates as on-site supplier of active power and reactive power to the loads. That way, all the demand power doesn’t have to travel from the grid to the load, resulting minimum power loss. This thesis work shall give optimum reconfiguration of the distribution network along with proper siting, sizing, and operating power factor of DGs if there are new ones to come. Even if there are existing DGs, the outcome of this thesis will propose optimum reconfiguration of the network to minimize power loss and improve voltage profile.

1.3 Objectives of the Project

The objective of this thesis is to study simultaneous network reconfiguration, and optimum allocation (placement, sizing & operating power factor) of distributed generations so as to minimize power loss and optimize voltage profile using Artificial Bee Colony (ABC) algorithm-based computer program.

1.4 Scope

At the end of this work, a software/program is developed that can take the inputs of any number of buses of a practical distribution system. That way, smaller to larger, both sorts of systems can be reconfigured using the outputs given at the end of this work.

In addition, the effect of incorporation of distribution generations can be seen along with distribution network reconfiguration. Also, whether the distribution generation should be introduced or not for the purpose of reducing power loss and voltage drop can be analyzed. Or, whether the network reconfiguration is needed or not can be analyzed when distributed generations are added.

1.5 Outline of the Report

This thesis report is organized in six chapters. Chapter I deals with the basic concept of need for distribution network reconfiguration, and distributed generations. It emphasizes on the optimum use of existing infrastructures to reduce power loss and optimize voltage profile.

Chapter II reviews the past works conducted in similar subjects that of this thesis work by various authors in the past. It highlights how and when the reconfiguration problem was considered to solve power loss and voltage drop issues, and how incorporation of DGs assisted the same.

In Chapter III, overall methodology followed to fulfil the objective of this thesis work is explained. It explains the algorithm adopted in this thesis work and the cases considered. It also explains how the search space for optimization was increased using shortlisting criteria of candidate buses for DG installation.

In Chapter IV, systems under consideration, and software and tools used are explained. It shows the single line diagram and the bus/branch data of the systems considered. It also explains about the software and tools used for this thesis work.

Chapter V presents results and discussion of results for various scenarios considered in this thesis work. First, it compares the results obtained in this thesis work against the results in the reference papers. Later, it demonstrates the method used in this thesis work to improve the power loss and voltage profile of a practical distribution system of Kathmandu, Nepal.

Finally, Chapter VI concludes the study conducted for various systems under consideration under various scenarios. It shows that the objectives of this thesis work are fulfilled.

CHAPTER II: REVIEW OF LITERATURE

2.1 Introduction

The distribution network transfers the electrical energy directly from the intermediate transformer substations to consumers. Electric distribution systems are becoming large and complex leading to higher system losses and poor voltage regulation. In general, almost 10–13% of the total power generated is lost as I^2R losses at the distribution level, which in turn, causes increase in the cost of energy and poor voltage profile along the distribution feeder. Therefore, it becomes important to improve the reliability of the power transmission in distribution networks. While the transmission networks are often operated with loops or radial structures, the distribution networks are always operated radially. By operating in radial configuration, short-circuit current is reduced significantly. The restoration of the network from faults is implemented through the closing/cutting manipulations of electrical switch pairs located on the loops, consequently. Therefore, there are many switches on the distribution network.

Distribution network reconfiguration (DNR) is the process of varying the topological arrangement of distribution feeders by changing the open/closed status of sectionalizing and tie switches while respecting system constraints upon satisfying the operator’s objectives. DG units are small generating plants connected directly to the distribution network or on the customer site of the meter. The number of DG units installed in the distribution system has been increasing significantly, and their technical, economical, and environmental impacts on power system are being analyzed. The most critical factors that influence the technical and economic impacts are type, size, and location of DG units in power system.

The most common methods used for voltage stability enhancement and power loss reduction in power distribution systems are network reconfiguration and DG placement. The configuration of the network, placement and size of DG units should be optimal to maximize the benefits and reduce their impact on the power system. Thus, the optimal integration between these two problems becomes a significant and complex problem. The results in [4] proves that the simultaneous reconfiguration with DG allocation give better results out of all other combinations with or without DGs.

Many researchers solved the network reconfiguration problems using different methods for the last two decades [1]. Authors in [5] proposed a pioneering solution to solve the network reconfiguration problem for loss minimization using a branch and bound-type optimization technique. Later on, several optimization algorithms have been developed for loss minimization and/or voltage profile improvement. Authors in [6] used a discrete artificial bee colony algorithm to find the maximum loadable point by optimizing the distribution network, and also used continuation power flow along with graph theory to compute power flow. In [7], authors solved the reconfiguration problem assuming a series fault at a bus using Bacterial Foraging Optimization Algorithm (BFOA). Authors in [8] proposed modified honey bee mating optimization algorithm to investigate the network reconfiguration problem with the consideration effect of the renewable energy sources. In the very latest researches, a new non-revisiting genetic algorithm had been proposed for solving the reconfiguration problem [9].

DG units are small generating plants connected directly to the distribution network or on the customer site of the meter. DGs has many advantages over centralized power generation including reduction in power losses, improved voltage profile, system stability improvement, pollutant emission reduction and relieving transmission and distribution system congestion. After deregulation of power system, many power companies are investing in small-scale renewable energy resources such as wind, photo-voltaic cells, micro turbines, small hydro turbines, etc. to meet the active power demand (MW) as well as to earn a profit [1].

In distribution systems, DG can provide benefits for the consumers as well as for the utilities, especially in sites where the central generation is impracticable or where there are deficiencies in the transmission system. In this context, the utility obligation of providing access to distribution network for independent producers to install DG units confronts with the need of controlling the network and guaranteeing appropriate security and reliability levels. The expected benefits of distributed energy sources are:

- Increased penetration of RES and other DG will help security of supply by reducing energy imports and building a diverse energy portfolio.

- Wide-scale use of RES will reduce fossil fuel consumption and greenhouse gas emissions as well as noxious emissions such as oxides of Sulphur and nitrogen (SOx/NOx), thereby benefiting the environment in a power system dominated by the thermal power generation.
- DG helps bypass ‘‘congestion’’ in existing transmission grids. DG could serve as a substitute for investments in transmission and distribution capacity. DG can postpone the need for new infrastructure. Because of opportunities for integration in buildings, PV development often occurs in the same location as demand. In such cases, if production output is concurrent with demand—such as demand for air-conditioning in hot regions—network reinforcement may be unnecessary while generation remains in the same order of magnitude as demand. Moreover, normal development of the grid in response to growing demand may also be postponed or even avoided as DG has the net effect of decreasing demand in that area.
- On-site production reduces the amount of power that must be transmitted from centralized plant, and avoids resulting transmission losses and distribution losses as well as the transmission and distribution costs.
- DG can provide network support or ancillary services. The connection of distributed generators to networks generally leads to a rise in voltage in the network. In areas where voltage support is difficult, installation of a distributed generator may improve quality of supply [3].

The number of DG units installed in the distribution system has been increasing significantly, and their technical, economical, and environmental impacts on power system are being analyzed. The most critical factors that influence the technical and economic impacts are type, size, and location of DG units in power system. Authors in [10] and [11] presented an analytical and improved analytical expression for finding the optimal location and size of DG units for reducing power loss along with methodologies for identifying the optimal location. Authors in [12] proposed Particle Swarm Optimization (PSO) based technique to solve the optimal placement of different types of DGs for power loss minimization. In [13], the authors used Fireworks Algorithm (FWA) to solve the network reconfiguration problem combined with placement and sizing of DGs.

All the above researches focused only on the optimization of either distribution network or the DG placement. However, the objective was to minimize the power loss and/or to improve the voltage stability, network reconfiguration usually did not take the DG units into consideration and vice versa. To benefit the whole distribution network effectively, it is necessary to integrate both the network reconfiguration and DG placement problems. The novelty of this thesis is that it uses recently developed Artificial Bee Colony (ABC) algorithm for solving the distribution system network reconfiguration together with DG placement for the problem of power loss minimization and voltage stability enhancement.

2.2 The Distribution Power System

Power flow calculation is an essential numerical (often nonlinear) analysis needed when making power systems studies. The practical application of proposed methods on the improvement of the power distribution network (e.g. power loss reduction, increase in reliability levels, voltage profile improvement) typically require many power flow analysis algorithms runs. The power flow methodologies applied to distribution systems will have to adapt to the nature of the distribution network, in strict terms, they will be demanded to include single phase and three phase unbalanced system analysis, as well as the influence of distributed generation interconnection. In Distribution system reconfiguration, the objectives are to minimize power losses and enhance voltage profile, consequently, power flow analysis becomes an essential procedure to be performed in order to obtain steady state electrical characteristics of the distribution system as consequence of reconfiguration. Often, power flow analysis methodology applied to transmission systems is mainly comprised by the Gauss-Seidel, Newton-Raphson (NR) and its decoupled version. These power flow methods are typically used assuming a balanced system, consequently using a single-phase representation of a three-phase system. Due to the particular characteristics of distribution systems (i.e. unbalanced loads, radial topology, often un-transposed lines, distributed generation, etc.) the assumptions made in the analysis of transmission systems fail to be extrapolated to the distribution system. Thereupon, a power flow method considering three phase unbalanced networks must be considered for its application in distribution systems. The forward/backward methods (a popular power flow method applied to distribution systems) are capable of performing power flow analysis assuming unbalanced phase systems, however, it is limited to radial networks and does not have the ability to consider the influence of distributed generation, given in both, phase frame and sequence frame references. On the other hand, Newton based methods typically can deal with any topology type (i.e. radial, weakly meshed and meshed) and can consider the influence of distributed generation, in both, phase frame and sequence frame references. The main attribution to the success of the modified Newton method in distribution systems is the representation of the Jacobian matrix which is created based on the nature of the network topology. MATPOWER toolbox was used in this thesis work to compute power flows for various configuration of open/closed switches. The injection of various DGs of various capacities at various locations can easily be incorporated in power flow studies in MATPOWER. Distribution reconfiguration for power loss reduction is implemented based on a radial network.

2.3 Distribution Network Reconfiguration and Optimal Distributed Generation Allocation

The electric power distribution network is an elemental component of the power distribution system. It deserves particular attention for the most significant challenges, both design- and operational-wise, emerge at this level. One particular area of interest for power engineers working on distribution systems is finding feasible solutions for power loss reduction; power losses in distribution systems can account for up to 70 percent of the total power losses, consequently increasing the operational costs of the system. Introduction of the smart grid (SG) concept that aims at supporting the transition into a safe, efficient and sustainable power system, requires the use of computational intelligence methods to meet the aforementioned objectives. Distribution network reconfiguration (DNR) has been shown to be a feasible approach, often involving computational intelligence algorithms to optimize power delivery by reducing power losses, balancing loads, increasing power quality and improve reliability. The radial distribution systems often feature sectionalizing switches and tie switches mainly used for fault isolation, power supply recovery and system reconfiguration. The radial network topology analysis may be a complex task by itself. Due to a large number of possible network architectures (increasing exponentially with the size of the system), as well as multi-modal nature of the problem (i.e., the presence of many local optima), DNR is a highly complex combinatorial problem. Its practical solution requires implementation of efficient optimization algorithms with global search capability. Optimization algorithms applied to distribution network reconfiguration can be divided in two groups, Heuristic and Stochastic Methods, both with particular advantages and disadvantages. Merlin and Back [5] were the first to propose an algorithm for distribution system reconfiguration; their method was a based-on branch exchange search with all tie lines initially closed thus creating a arbitrarily meshed system; subsequent switch opening was continued until radial configuration was achieved. Similarly, in [14] a method was proposed where the network was initially meshed, switches were ranked based on current carrying magnitude, the top-ranked switch was opened and the power flow calculation was carried out. The process was repeated until system was radial. The branch exchange was performed wherever a loop had been identified. Configuration with lower power losses was kept. In [15], a generalized approach has been proposed in which the tie line with the highest voltage difference is closed and the neighboring branch is opened in the loop formed, leading to reduction of power losses. Another heuristic method applied to DNR is the Optimal Flow Pattern. Here, similarly to branch exchange, all tie lines are closed thus forming a weakly meshed network. Loads at corresponding connection busses are converted into currents, and only the real part of the complex impedance of the branches is taken into consideration. Once Kirchhoff current and voltage law is satisfied, the optimal load flow pattern is reached, at this point, the switch carrying the lowest current value is opened at each corresponding loop, thus making the system radial again. This method is typically fast and can be done in multi-feeder networks.

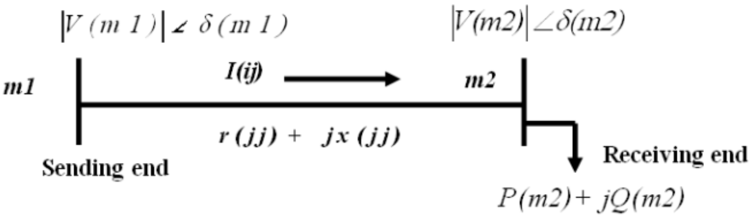
Distribution network reconfiguration is proven to enhance the operational characteristics of distribution systems (i.e. power loss minimization, voltage profile improvement, reliability increase, cost reduction, etc.). Other methods in addition to DNR have been considered for further enhancement of system operational characteristics. One of the techniques is optimal allocation of DG sources. Power generation at the distribution level from DG sources has recently increased significantly, mainly attributed to the liberalization of the energy market and the development of renewable energy technology. Some of the sources of DG generation are often, solar photovoltaics (PV), wind, biomass, mini hydro and/or a combination of sources, typically under 10 MW capacity [16]. Although DG sources interconnection to the distribution system may bring benefits for the system, the location and size of DG sources is to be considered. Excess DG generation or misplacement may increase power losses, reduce voltage profile and reduce reliability of the system. Thereupon, optimal sizing and location of DG sources should be considered to maintain a reliable system under operational standards. Although several methods are reported in the literature applied to DNR and optimal allocation of DG (i.e. Artificial Intelligence and Heuristics), meta-heuristics are often applied due to their capability of dealing with the multi-modal nature of the given problem. Meta- heuristic algorithms implement learning strategies and innovative strategies for an efficient search, the former being of great advantage due the large search space accompanied by large scale distribution networks. Several optimization methods have been proposed for solving the optimal DG allocation problem. In [17], a Particle Swarm Optimization (PSO) algorithm has been applied to the optimum sitting and sizing of two DGs on a 13-bus network, however, the basis for selecting the optimum location of DG is not provided. In [18], the authors determine optimal location of DG based on the Power Loss Index (PLI) and sizing is performed using the GA taking into account three objective functions, power loss reduction, voltage profile improvement and voltage stability index (VSI). In [19], the authors determine candidate buses for DG allocation based on the loss sensitivity (LSF) and voltage sensitivity factors (VSF); the optimum DG size is then determined with a hybrid PSOGSA optimization algorithm. Although DNR and optimal allocation of DG can be performed individually, their benefits can be further enhanced when performed collectively. In [13], DNR and optimum sitting and sizing of DG based on the fireworks algorithm (FWA) under three different loading scenarios has been proposed. The buses with the lowest VSI are selected as candidate buses followed by optimal DG sizing determined by the FWA; when both methods are executed simultaneously, the losses are reduced by up to 84 percent. In [20], the authors applied GA to a 16-bus network taking as objective minimization of power costs; here, all buses were candidate for DG placement and DG sizes were generated randomly. Although all methods mentioned above solve the reconfiguration and optimal DG allocation problem, no scenario of a practical distribution system is considered, which is essential for measuring quality of results obtained by the algorithm. Also, all of the cases, only standard IEEE buses are considered which does not permit conclusive assessment of the proposed methodologies in terms of their prospective performance when applied to more realistic cases.

2.4 Voltage Stability Index of Radial Distribution Networks

Voltage stability of a distribution system is one of the keen interests of industry and research sectors around the world. When a power system approaches the voltage stability limit, the voltage of some buses reduces rapidly for small increments in load and the controls or operators may not be able to prevent the voltage decay. In some cases, the response of controls or operators may aggravate the situation and the ultimate result is voltage collapse. So, engineers need a fast and accurate voltage stability index (VSI) to help them monitoring the system condition. Nowadays, a proper analysis of the voltage stability problem has become one of the major concerns in distribution power system operation and planning studies.

Due to considerable costs, the DGs must be allocated suitably with optimal size to improve the system performance such as to reduce the system loss, improve the voltage profile while maintaining the system stability. The problem of DG planning has recently received much attention by power system researchers. Selecting the best places for installing DG units and their preferable sizes in large distribution systems is a complex combinatorial optimization problem.

VSI is a new steady state voltage stability index for identifying the node, which identifies the most sensitive buses to voltage collapse [21]. Figure below shows the electrical equivalent of radial distribution system.



From the figure above, the following equation can be written:

$$I(ij)=\frac{V(m1)-V(m2)}{r(jj)+jx(jj)} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$I(ij)=\frac{P(m2)-jQ(m2)}{V^{*}(m2)} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where,

jj = branch number,

m1 = sending end node,

m2 = receiving end node,

I(ij) = current of branch ij,

V(m1) = voltage of node *m1*,

V(m2) = voltage of node *m2*,

P(m2) = total real power load fed through node *m2*,

Q(m2) = total reactive power load fed through node *m2*.

Equating (1) and (2),

$[V(m1)<\theta_{m1} - V(m2)< \theta_{m2}][V(m2)< -\theta_{m2}] = [P(m2) - jQ(m2)][r(jj) - jx(jj)]$ ………………. (3)

Equating real and imaginary parts of (3), we get

$V(m1)*V(m2)\cos(\theta_{m1}- \theta_{m2}) - V(m2)^2 = P(m2)*r(jj) + Q(m2)*x(jj)$ ………………. (4)

$X(jj)*P(m2) - r(jj)*Q(m2) = V(m1)*V(m2)\sin(\theta_{m1}- \theta_{m2})$ ………………. (5)

In radial distribution systems, voltage angles are negligible. So $(\theta_{m1}- \theta_{m2}) \approx 0$, and (4) and (5) become

$V(m1)*V(m2) - V(m2)^2 = P(m2)*r(jj) + Q(m2)*x(jj)$ ………………. (6)

$x(jj) = r(jj)*Q(m2)/ P(m2)$ ………………. (7)

From (6) and (7),

$|V(m2)|^4 - b(jj)|V(m2)|^2 +c(jj)=0$ ………………. (8)

where,

$b(jj) = \{|V(m1)|^2 - 2P(m2)\, r(jj) - 2Q(m2)x(jj)\}$ ………………. (9)

$c(jj) = \{|P^2 (m2)| +Q^2(m2)\}\{r^2(jj)+ x^2(jj)\}$ ………………. (10)

The solution of (2) is unique. That is,

$|V(m2)| = 0.707\, [b(jj)+ \{b^2(jj) - 4\, c(jj)\}^{0.5}]^{0.5}$ ………………. (11)

$b^2(jj) - 4\, c(jj)\geq 0$ ………………. (12)

From (9), (10) and (11) we get

$\{|V(m1)|^2 - 2P(m2)\, r(jj) - 2Q(m2)\, x(jj)\}^2 - 4\, \{P^2(m2) +Q^2(m2)\}\{ r^2(jj) +x^2(jj)\} \geq 0$

After simplification, we get

$\{|V(m1)|^4\} - 4\{ P(m2)\, x(jj)-Q(m2)r(jj)\}^2 - 4\{P(m2)r(jj)+Q(m2)x(jj)\}|\, V(m1)| \geq 0$ ………………. (13)

Let,

$VSI(m2) = \{|V(m1)|^4\} - 4\{ P(m2)\ x(jj)-Q(m2)r(jj)\}^2 - 4\{P(m2)r(jj)+Q(m2)x(jj)\}|\ V(m1)|$ ………………. (14)

where,

VSI(m2) = Voltage Stability Index of node m2.

For stable operation of the radial distribution networks, $VSI(m2) \geq 0$. The node at which the value of the stability index is minimum, is more sensitive to the voltage collapse.

2.5 Artificial Bee Colony Algorithm

Bee swarms exhibit many intelligent behaviors in their tasks such as nest site building, marriage, foraging, navigation and task selection. There is an efficient task selection mechanism in a bee swarm that can be adaptively changed by the state of the hive and the environment. Foraging is another crucial task for bees. Forage selection depends on recruitment for and abandonment of food sources. There are three types of bees associated with the foraging task with respect to their selection mechanisms. Employed bees fly onto the sources which they are exploiting; onlooker bees choose the sources by watching the dances performed by employed bees, and scouts choose sources randomly by means of some internal motivation or possible external clue. The exchange of information among bees is the most important occurrence in the formation of the collective knowledge. The most important part of the hive in terms of exchanging information is the dancing area. Communication among bees related to the quality of food sources takes place in the dancing area. Various dances are performed on the dancing area, such as waggle, round, tremble depending on the distance of the discovered source.

In a real bee colony, some tasks are performed by specialized individuals. These specialized bees try to maximize the nectar amount stored in the hive using efficient division of labor and self-organization. The Artificial Bee Colony (ABC) algorithm, proposed by Karaboga in 2005 for real-parameter optimization, is a recently introduced optimization algorithm which simulates the foraging behavior of a bee colony [22]. The minimal model of swarm-intelligent forage selection in a honey bee colony which the ABC algorithm simulates consists of three kinds of bees: employed bees, onlooker bees and Scout bees. Half of the colony consists of employed bees, and the other half includes onlooker bees. Employed bees are responsible for exploiting the nectar sources explored before and giving information to the waiting bees (onlooker bees) in the hive about the quality of the food source sites which they are exploiting. Onlooker bees wait in the hive and decide on a food source to exploit based on the information shared by the employed bees. Scouts either randomly search the environment in order to find a new food source depending on an internal motivation or based on possible external clues.

Using the analogy between emergent intelligence in foraging of bees and the ABC algorithm, the units of the basic ABC algorithm can be explained as follows:

2.5.1 Producing initial food source sites

If the search space is considered to be the environment of the hive that contains the food source sites, the algorithm starts with randomly producing food source sites that correspond to the solutions in the search space. Initial food sources are produced randomly within the range of the boundaries of the parameters.

$x_{ij} = x_j^{min} + rand(0,1) * (x_j^{max} - x_j^{min}),$

where $i = 1...SN$, $j = 1...D$.

SN is the number of food sources and *D* is the number of optimization parameters. In addition, counters which store the numbers of trials of solutions are reset to 0 in this phase.

After initialization, the population of the food sources (solutions) is subjected to repeat cycles of the search processes of the employed bees, the onlooker bees and the scout bees. Termination criteria for the ABC algorithm might be reaching a maximum cycle number (MCN) or meeting an error tolerance (ε).

2.5.2 Sending employed bees to the food source sites

As mentioned earlier, each employed bee is associated with only one food source site. Hence, the number of food source sites is equal to the number of employed bees. An employed bee produces a modification on the position of the food source (solution) in her memory depending on local information (visual information) and finds a neighboring food source, and then evaluates its quality. In ABC, finding a neighboring food source is defined by:

$v_{ij} = x_{ij} + \phi_{ij} * (x_{ij} - x_{kj})$

Within the neighborhood of every food source site represented by $\boldsymbol{x_{ij}}$, a food source $\boldsymbol{v_{ij}}$ is determined by changing one parameter of $\boldsymbol{x_{ij}}$. In above equation, $\boldsymbol{j}$ is a random integer in the range [1, *D*] and k € {1,2,. . .*SN*} is a randomly chosen index that has to be different from $\boldsymbol{i}$, $\boldsymbol{\phi_{ij}}$is a uniformly distributed real random number in the range [-1,1].

As the difference between the parameters of the x_{ij} and x_{kj} decreases, the perturbation on the position $x_{i,j}$ decreases. Thus, as the search approaches to the optimal solution in the search space, the step length is adaptively reduced.

If a parameter value produced by this operation exceeds its predetermined boundaries, the parameter can be set to an acceptable value. In this work, the value of the parameter exceeding its boundary is set to its boundaries. If $x_i > x_i^{max}$; then $x_i = x_i^{max}$; If $x_i < x_i^{min}$ then $x_i = x_i^{min}$.

After producing v_i within the boundaries, a fitness value for a minimization problem can be assigned to the solution v_i by:

$$fitness_i = \begin{cases} 1/(1+f_i), & if\ f_i \geq 0 \\ 1 + abs(f_i), & if\ f_i < 0 \end{cases}$$

where f_i is the cost value of the solution v_i. For maximization problems, the cost function can be directly used as a fitness function. A greedy selection is applied between x_i and v_i; then the better one is selected depending on fitness values representing the nectar amount of the food sources at x_i and v_i. If the source at v_i is superior to that of xi in terms of profitability, the employed bee memorizes the new position and forgets the old one. Otherwise the previous position is kept in memory. If x_i cannot be improved, its counter holding the number of trials is incremented by 1, otherwise, the counter is reset to 0.

2.5.3 Calculating probability values involved in probabilistic selection

After all employed bees complete their searches, they share their information related to the nectar amounts and the positions of their sources with the onlooker bees on the dance area. This is the multiple interaction feature of the artificial bees of ABC. An onlooker bee evaluates the nectar information taken from all employed bees and chooses a food source site with a probability related to its nectar amount. This probabilistic selection depends on the fitness values of the solutions in the population. A fitness-based selection scheme might be a roulette wheel, ranking based, stochastic universal sampling, tournament selection or another selection scheme. In basic ABC, roulette wheel selection scheme in which each slice is proportional in size to the fitness value is employed, as expressed below:

$$p_i = \frac{\text{fitness}_i}{\sum_{i=1}^{SN} \text{fitness}_i}.$$

In this probabilistic selection scheme, as the nectar amount of food sources (the fitness of solutions) increases, the number of onlookers visiting them increases, too. This is the positive feedback feature of ABC.

2.5.4 Food source site selection by onlookers based on the information provided by employed bees

In the ABC algorithm, a random real number within the range [0, 1] is generated for each source. If the probability value (*pi*) associated with that source is greater than this random number then the onlooker bee produces a modification on the position of this food source site as in the case of the employed bee. After the source is evaluated, greedy selection is applied and the onlooker bee either memorizes the new position by forgetting the old one or keeps the old one. If solution $\boldsymbol{x_i}$ cannot be improved, its counter holding trials is incremented by 1, otherwise, the counter is reset to 0. This process is repeated until all onlookers are distributed onto food source sites.

2.5.5 Abandonment criteria: Limit and scout production

In a cycle, after all employed bees and onlooker bees complete their searches, the algorithm checks to see if there is any exhausted source to be abandoned. In order to decide if a source is to be abandoned, the counters which have been updated during search are used. If the value of the counter is greater than the control parameter of the ABC algorithm, known as the '*limit*', then the source associated with this counter is assumed to be exhausted and is abandoned. The food source abandoned by its bee is replaced with a new food source discovered by the scout, which represents the negative feedback mechanism and fluctuation property in the self-organization of ABC. This is simulated by producing a site position randomly and replacing it with the abandoned one. If assumed that the abandoned source is $\boldsymbol{x_i}$, then the scout randomly discovers a new food source to be replaced with $\boldsymbol{x_i}$. In basic ABC, it is assumed that only one source can be exhausted in each cycle, and only one employed bee can be a scout. If more than one counter exceeds the '*limit*' value, one of the maximum ones might be chosen programmatically [23].

All these units and interactions between them are shown as a flowchart below:

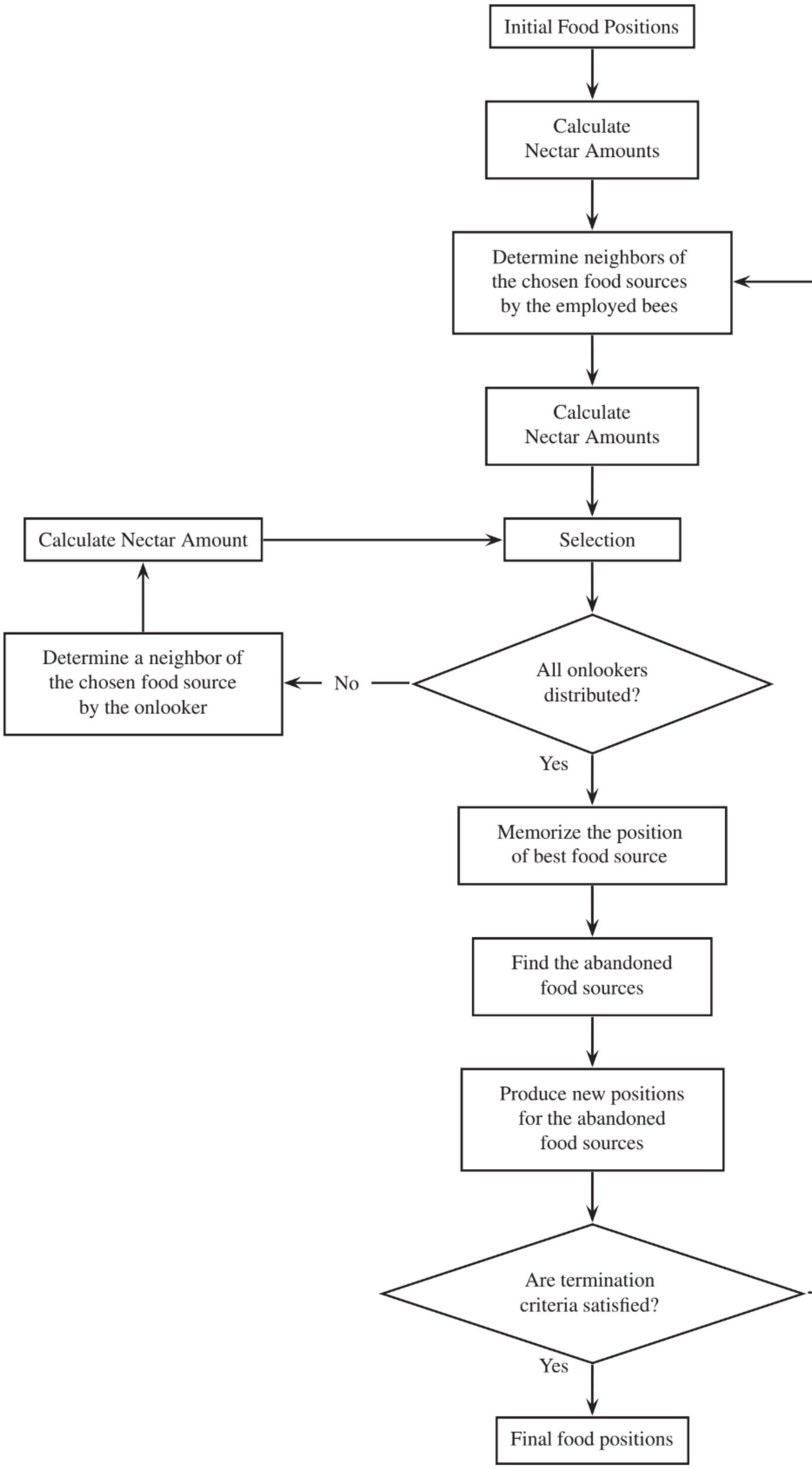


Figure 1: Flowchart of ABC algorithm

CHAPTER III: METHODOLOGY

In this chapter, the overall procedure of performing DNR, and optimization of sizing, placement, and operating power factor of DGs are explained.

3.1 Power Distribution System Modeling

In this work, MATPOWER toolbox of MATLAB was utilized to carry out power flow simulations of the standard IEEE test distribution systems. The test distribution systems were modeled as power lines and loads in MATPOWER. Initially, n_{br} number of branch data was supplied in n_{br} number of rows. An additional oSw number of branch data for tie-lines (open branches) was fed in the next oSw number of rows along with original branch data. Branch data included branch resistance and branch reactance. Bus data for n_{bus} number of buses was also fed to the computer program. Bus data included bus number, active power load and reactive power load at the bus. It is to be noted that $n_{bus} = (n_{br} + 1)$ in a radial network.

To demonstrate the performance and effectiveness of Artificial Bee Colony (ABC) algorithm from small-scale to large-scale distribution networks, it has been be applied to standard IEEE test systems. However, the computer program was designed in such a way that it can accept data of any radial distribution network, how large or small may it be.

The developed computer program was applied to Daachhi feeder of Kathmandu. The size and GPS location of each distribution transformer was collected along with the routing of the HT lines. All those data were used to plot the feeder in QGIS. The line length was extracted from the QGIS. The limitation of this approach is that the line length doesn’t consider the sag of the conductor. And, the load power factor was taken from the substation where the feeder originated.

3.2 Short-listing of the candidate buses for installation of DGs

Voltage Stability Index (VSI) that identifies the most sensitive bus is be used to determine the candidate bus locations for DG installation in the system, as explained in the Literature Review.

$$\mathrm{VSI}(k+1) = |V_k|^4 - 4.0(P_{k+1,eff}X_k - Q_{k+1,eff}R_k)^2 \\ - 4.0(P_{k+1,eff}R_k + Q_{k+1,eff}X_k)|V_k|^2$$

The estimation of these candidate buses initially helps in reducing the search space significantly for the optimization technique.

A new approach of short-listing the candidate buses for installation of DGs has been applied. In various literatures, the first ‘n’ number of buses with lowest values of VSI are directly selected for the installation of DGs. However, that approach sidelines the opportunity to try other buses for installing DGs. To handle that issue, computer program developed for this thesis work has been designed to shortlist first $\boldsymbol{n_c}$ number of candidate buses based on VSI values, the lowest value for $\boldsymbol{n_c}$ shall not be less than the number of DGs to be installed and the largest value for $\boldsymbol{n_c}$ shall not be more than the number of buses in the radial network. For example, ten buses can be shortlisted as candidate buses for the installation of three DGs against only three bus as proposed in various literatures.

3.3 Cases of Analysis

Six cases of analysis have been carried out. The description of various cases is given below:

Base Case:

Evaluation of the objective function for the base case i.e. without network reconfiguration and without insertion of DGs: The network configuration scenario for the base case has been fed into MATLAB computer program. The base case is the condition when all the tie-lines are in open condition. The computer program gives the base case voltage profile and base case power loss. The improvements to be achieved in later stages of analysis has been compared with that of the base case.

Case I:

Distribution network reconfiguration of the existing network and evaluation of the objective function for the reconfigured network: This is the first part of analysis where only the reconfiguration has been done of the existing network by considering the given tie-lines, which were in open condition for the base case. The computer program optimizes the voltage profile and power loss.

Case II:

No reconfiguration of the network and performing only the insertion of DGs: In this analysis, only the DGs are placed in the candidate buses, candidate buses being identified from VSI method. Tie-lines are open in this stage of analysis. The computer program optimizes the size, location, and power factor of DGs to optimize voltage profile and power loss.

Case III:

First insertion of DGs in the existing network and then performing the network reconfiguration: This is the third case of analysis where the tie-lines are kept open and optimization of DGs parameters is done. The shortlisting of locations for installation of DGs is done using VSI method. The computer program gives optimum size, location and power factor of DGs. By considering the given size, location and power factor of DGs, the computer program performs network reconfiguration. The computer program then gives optimized voltage profile and power loss at the end of reconfiguration.

Case IV:

First reconfiguring the existing network and then performing insertion of DGs: In fourth case of analysis, the network reconfiguration is performed where tie-lines can be switched on or off. After finding out the best configuration, the computer program optimizes the size, location and power factor of DGs. The shortlisting of locations for installation of DGs is done using VSI method. At the end of the computer program, optimal voltage profile and power loss is given.

Case V:

Simultaneous reconfiguration of the network and addition of DGs: This is the last stage of analysis and it holds the core objective of this thesis work. All the branches can be turned open or closed, along with the tie-lines. Then, there is certain number of DGs willing to be connected in the given distribution network. Now, the computer program performs simultaneous network reconfiguration, and sizing & placement of DGs along with optimization of operating power factor of DGs. At the end of the computer program, optimum configuration of the network is given along with sizing, placement and optimal operating power factor of DGs. That solution is the best one to optimize voltage profile and power loss.

3.4 Problem Formulation

The Objective Function for the solution is to: $\text{Minimize } F = \min.\left(\left(\frac{P^{R}_{T,\text{Loss}} + P^{DG}_{T,\text{Loss}}}{P_{T,\text{Loss}}}\right) + \Delta V_D\right)$

Subjected to the following operating constraints.
Power conservation limits:

$$P_{ss} = \sum_{k=2}^{n} P_{Lk} + \sum_{k=1}^{nb} P_{\text{Loss}}(k, k+1) - \sum_{k=1}^{nd} P_{DG,k}$$

Voltage deviation limits:

$$|V_1 - V_k| \leqslant \Delta V_{\max}$$

Distribution line capacity limits:

$$|S_k| \leqslant |S_{k,\max}|$$

Distributed generation capacity limits:

$$P^{\min}_{\text{TDG}} \leqslant P_{\text{TDG}} \leqslant P^{\max}_{\text{TDG}}$$

where $P^{min}_{TDG} = 0.1 * \sum_{k=2}^{n} P_{Lk}$ and $P^{\max}_{\text{TDG}} = 0.6 * \sum_{k=2}^{n} P_{Lk}$

$P^{R}_{T,Loss}$ = Total power loss of the system after reconfiguration
$P^{DG}_{T,Loss}$ = Total power loss of the system with DGs
$P_{T,Loss}$ = Total power loss of the system (base case)
P_{Lk} = Real power load at bus k
$P_{Loss(k,k+1)}$ = Real power loss in the line connecting buses k and k+1
$P_{DG,k}$ = Real power supplied by DG at node k
Pss = Power supplied by the substation
V_k = Voltage magnitude at bus k
ΔV_{max} = Maximum voltage drop limit between buses 1 (substation) and k
S_k = Apparent power flowing in the line section between buses k and k+1
$S_{k,max}$ = Maximum power flow capacity limit of line section between buses k and k+1
P^{min}_{TDG} = Minimum total real power generation limit
P_{TDG} = Total real power supplied by DG in the system
P^{max}_{TDG} = Maximum total real power generation limit
ΔV_D = max{(V1-Vk)/V1} where k=1, 2,….,n

3.5 Solution Variables supplied to ABC algorithm

For six cases of analysis, as explained in the section 4.3, different sets of variables were supplied to the ABC algorithm:

Base Case:

Evaluation of the objective function for the base case i.e. without network reconfiguration and without insertion of DGs: For the base case, no optimization had to be done. So, only the base case voltage profile, power loss, branch currents and source power factor were calculated.

Case I:

Distribution network reconfiguration of the existing network and evaluation of the objective function for the reconfigured network: The number of variables equaled the number of open branches in the radial network. Those open lines are also called tie-lines or the lines out-of-service.

The optimal solution would be that set of open branches for which the value of objective function would be minimum.

Case II:

No reconfiguration of the network and performing only the insertion of DGs: The number of variables is equal to three times the number of DGs. If ***n*** is the number of DGs, then first ***n*** corresponds to the size of DGs in MW, next ***n*** corresponds to the bus location of DGs, and the last ***n*** corresponds to the power factor that the DGs operate. For the optimal solution, the ***3n*** is the number of variables corresponding to DG size, location and power factor should give the minimum value of objective function.

Case III: First insertion of DGs in the existing network and then performing the network reconfiguration: Firstly, the parameters related to DGs had to be optimized. So, the number of variables would be ***3n***, if ***n*** is the number of DGs. Then, first ***n*** corresponds to the size of DGs in MW, next ***n*** corresponds to the bus location of DGs, and the last ***n*** corresponds to the power factor that the DGs operate. Secondly, the optimum configuration of the branches had to be done. So, the DG parameters from the first part was taken and that was used while performing the reconfiguration. Here, the number of variables was ***oSw***, where ***oSw*** is the number of open branches. At the end of this analysis, the best configuration of the network was found where the insertion of DGs was already done.

Case IV:

First reconfiguring the existing network and then performing insertion of DGs: Firstly, the reconfiguration problem had to be solved. So, the number of variables was ***oSw***, where ***oSw*** is the number of open branches. Now, using that configuration of the network, DGs had to be added in the system. If ***n*** is the number of DGs, then first ***n*** corresponds to the size of DGs in MW, next ***n*** corresponds to the bus location of DGs, and the last ***n*** corresponds to the power factor that the DGs operate. For the optimal solution, the ***3n*** is the number of variables corresponding to DG size, location and power factor. At the end of the analysis, the best parameters of DGs (size, location, and power factor) were found for the network where network reconfiguration was already done.

Case V:

Simultaneous reconfiguration of the network and addition of DGs: In this stage of analysis, the number of variables is ***(oSw + 3n)***, where ***oSw*** is the number of open branches, and ***n*** is the number of DGs. The first oSw number of variables give the set of open branches in the network. The next ***n*** variables give the size of DGs, the next ***n*** variables give the location of DGs, and the last ***n*** variables give the operating power factor of DGs. The best solution would be that set of ***(oSw + 3n)*** variables which gives the least value of the objective function.

3.6 Steps in ABC algorithm

Initialization: The first phase in ABC is initialization of parameters (Colony Size, Limit for scout bees, and maximum number of cycles) and set up an initial population randomly using:

$$p_{ij} = LB_j + rand \times (UB_j - LB_j)$$

where $i = 1, 2, \ldots, (Colonysize/2)$ and $j = 1, 2 \ldots, D$. Here, D represent dimension of problem. $\boldsymbol{p_{ij}}$ denotes location of i^{th} solution in j^{th} dimension. LB_j and UB_j denotes lower and upper boundary values of search region correspondingly. *rand* is a randomly selected value in the range [0, 1].

Employed Bee Phase: This phase tries to detect superior quality solutions in proximity of current solutions. If the quality of fresh solution is enhanced than present solution, the position is updated. The position of employed bee updated using:

$$V_{ij} = p_{ij} + \overbrace{\phi_{ij} \times (p_{ij} - p_{kj})}^{s}$$

where $\varphi_{ij} \in [-1, 1]$ is an arbitrary number, $k \in 1, 2, \ldots (Colonysize/2)$ is a haphazardly identified index such that $k \neq i$. In this equation, s denotes step size of position update equation. A larger step size leads to skipping of actual solution and convergence rate may degrade if step size is very small.

Onlooker Bee Phase: The selection of a food source depends on their probability of selection. The probability is computed using fitness of solution with the help of:

$$Prob_i = \frac{fitness_i}{\sum_{i=1}^{colonysize/2} Fitness_i}$$

Scout Bee Phase: An employed bee become a scout bee when the solution value not updated till the predefined threshold limit. This scout bee engenders new solution instead of rejected solution using:

$$p_{ij} = LB_j + rand \times (UB_j - LB_j)$$

Parameters of ABC algorithm:

i. **Number of Population:** This is an important parameter in ABC algorithm as it determines how many solution sets are generated and tried in one iteration to optimize for the best objective function. The Number of Population should be decided by considering the problem dimension and the complexity of the problem. In general, it should be around 50, as a general rule of thumb.

ii. **Limit:** The parameter Limit is very important in rejecting the given solution set. It signifies how many times a given solution is given the opportunity to be better before it is rejected. For this thesis, the value of *limit* was varied from 2 to 5 to find the best solution. In general, it was observed that if *limit* = 2, then the solution converged very fast but sometimes it missed the global optima. If its value was increased gradually, the number of iterations for convergence increased but the algorithm found the global optima.

iii. **Upper Bound and Lower Bound:** These parameters decide the lowest bound and the highest bound of each solution of the given solution vector. The lower bound and upper bound for the open set of branches (for reconfiguration) was *1* and the *number of branches* in radial configuration respectively. For the size of DGs, the lowest bound was 10% of the total active power load of the network and the highest bound was 60% pf the total active power load of the network. The lowest bound for the location of DGs was 1 and the highest bound was the number of buses in the network. The lowest bound for the power factor of operation of DGs was 0.7 and the highest bound was 1.

3.7 Checking Radial Topology

Radial topology was checked for all the trial solutions found by ABC algorithm. The solutions were deemed infeasible when the solution violated any of the constraint. Prior to checking any of the constraint, the trial solution was checked whether it maintained radial topology or not. If not, that solution was rejected and the algorithm checked for another solution.

Step 1: Initialize a connected matrix of the loop distribution network A(b,b) with b is the number of buses of the network system. Each entry in matrix A is defined as follows:

A(i,j) = 1 and A(j,i) = 1 if node i is connected to node j.

A(i,j) = 0 and A(j,i) = 0 if node i is not connected to node j

Initialize a set of power buses S = [feeder$_1$, feeder$_2$,. . .,feeder$_k$], with k is the number of feeders in the network system.

Step 2: Read the trial solution. This is a set of tie-switches, which need to check and modify A(i,j) = 0 and A(j,i) = 0 if the switch on the branch from node i to node j is a tie-switch.

Step 3: Evaluate all load nodes as follows:

If node n R S and A(m,n) = 1, with m = 1, 2,. . .,length(S) and n = k + 1, k + 2,. . .,b then the node n is moved to S, S = S + [node n] and A(m,n) = 0, A(n,m) = 0.

Step 4: If matrix A is a zero matrix and length of array S is equal to the number of buses then the trial solution is a radial network configuration.

Following flowchart shows the procedure adopted to check radial topology for any set of open branches.

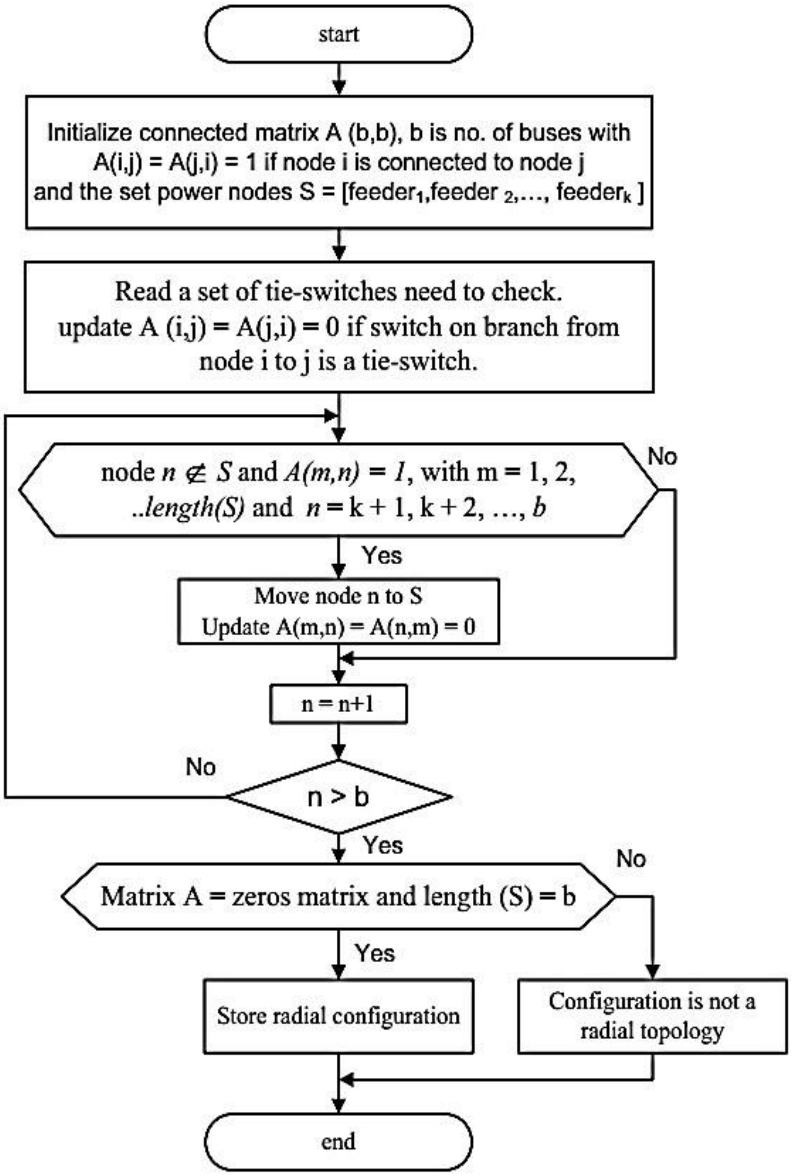
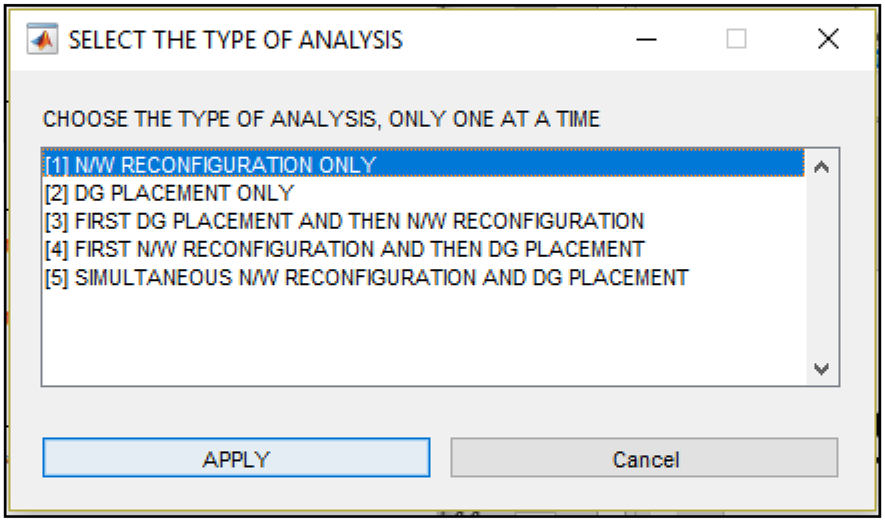


Figure 2: Flowchart for checking radial topology

To fulfil the objectives of this thesis work, a computer program was developed in MATLAB using MATPOWER toolbox. Following are the salient features of the computer program:

i. It asks the user what analysis to perform among a set of choices, as shown in figure below:

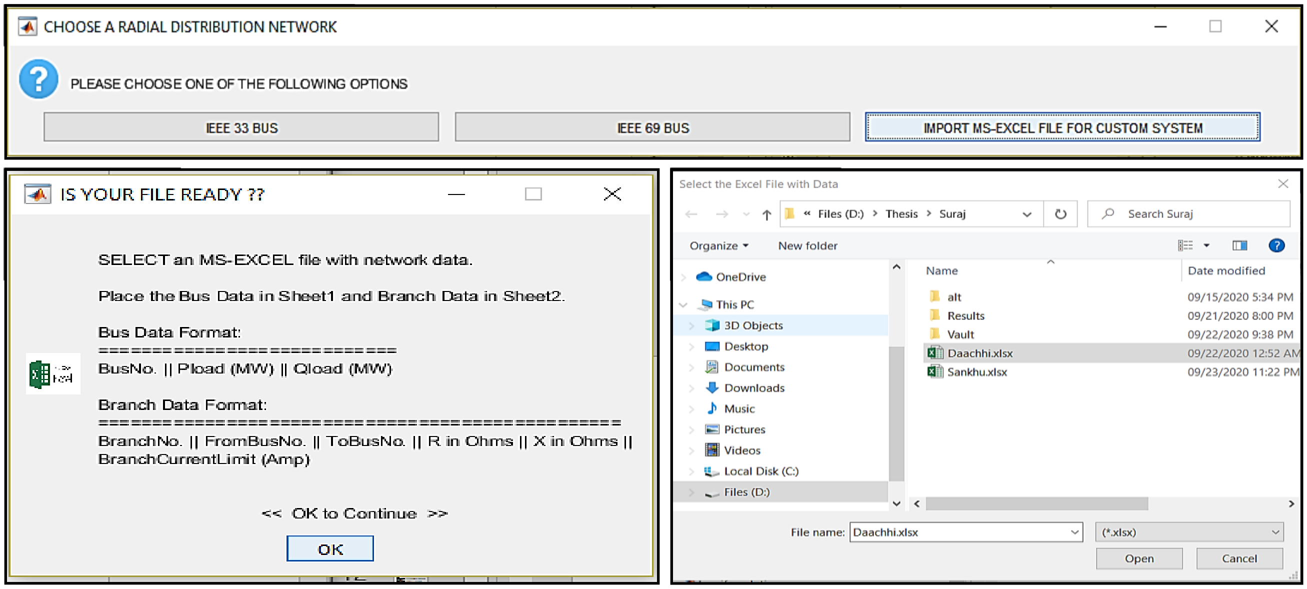

SELECT THE TYPE OF ANALYSIS

CHOOSE THE TYPE OF ANALYSIS, ONLY ONE AT A TIME

[1] N/W RECONFIGURATION ONLY
[2] DG PLACEMENT ONLY
[3] FIRST DG PLACEMENT AND THEN N/W RECONFIGURATION
[4] FIRST N/W RECONFIGURATION AND THEN DG PLACEMENT
[5] SIMULTANEOUS N/W RECONFIGURATION AND DG PLACEMENT

Figure 3: Choices for type of analysis

ii. It asks user whether to perform analysis on standard buses or to import custom data of any radial network. The branch data of tie-lines shall be on the bottom rows where the branch data lies.


CHOOSE A RADIAL DISTRIBUTION NETWORK

PLEASE CHOOSE ONE OF THE FOLLOWING OPTIONS

IS YOUR FILE READY ??

SELECT an MS-EXCEL file with network data.

Place the Bus Data in Sheet1 and Branch Data in Sheet2.

Bus Data Format:
============================
BusNo. || Pload (MW) || Qload (MW)

Branch Data Format:
==
BranchNo. || FromBusNo. || ToBusNo. || R in Ohms || X in Ohms || BranchCurrentLimit (Amp)

<< OK to Continue >>

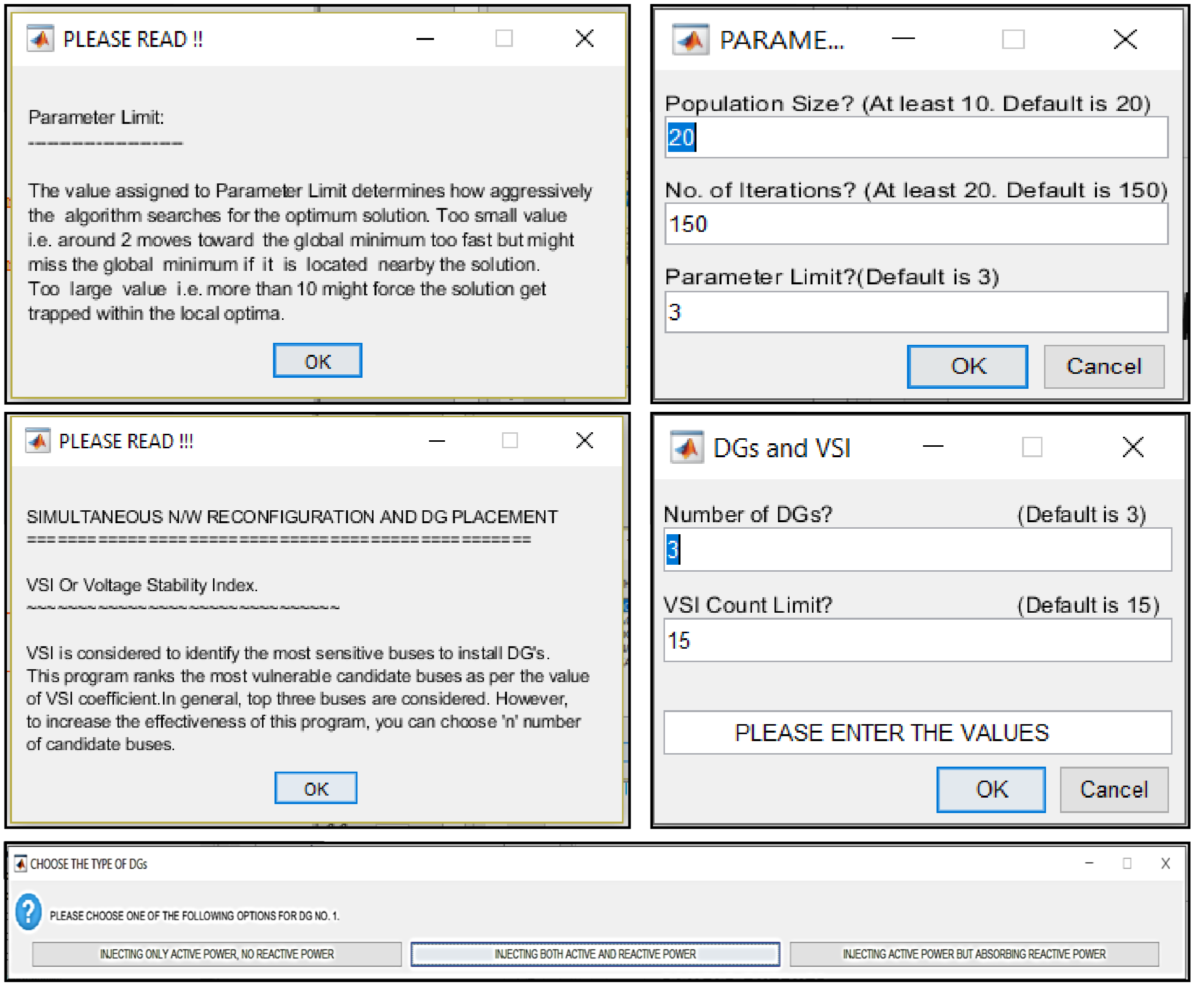
Select the Excel File with Data

Name	Date modified
alt	09/15/2020 5:34 PM
Results	09/21/2020 8:00 PM
Vault	09/22/2020 9:38 PM
Daachhi.xlsx	09/22/2020 12:52 AM
Sankhu.xlsx	09/23/2020 11:22 PM

File name: Daachhi.xlsx
(*.xlsx)

Figure 4: Options to choose data set

iii. The computer program asks user for the Population Size, Number of Iterations, Parameter Limit, Number of DGs, and number of shortlisted buses for DG installations (VSI count limit).



Parameter Limit:

The value assigned to Parameter Limit determines how aggressively the algorithm searches for the optimum solution. Too small value i.e. around 2 moves toward the global minimum too fast but might miss the global minimum if it is located nearby the solution. Too large value i.e. more than 10 might force the solution get trapped within the local optima.

Population Size? (At least 10. Default is 20)
20

No. of Iterations? (At least 20. Default is 150)
150

Parameter Limit?(Default is 3)
3

SIMULTANEOUS N/W RECONFIGURATION AND DG PLACEMENT
==

VSI Or Voltage Stability Index.
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

VSI is considered to identify the most sensitive buses to install DG's. This program ranks the most vulnerable candidate buses as per the value of VSI coefficient.In general, top three buses are considered. However, to increase the effectiveness of this program, you can choose 'n' number of candidate buses.

Number of DGs? (Default is 3)
3

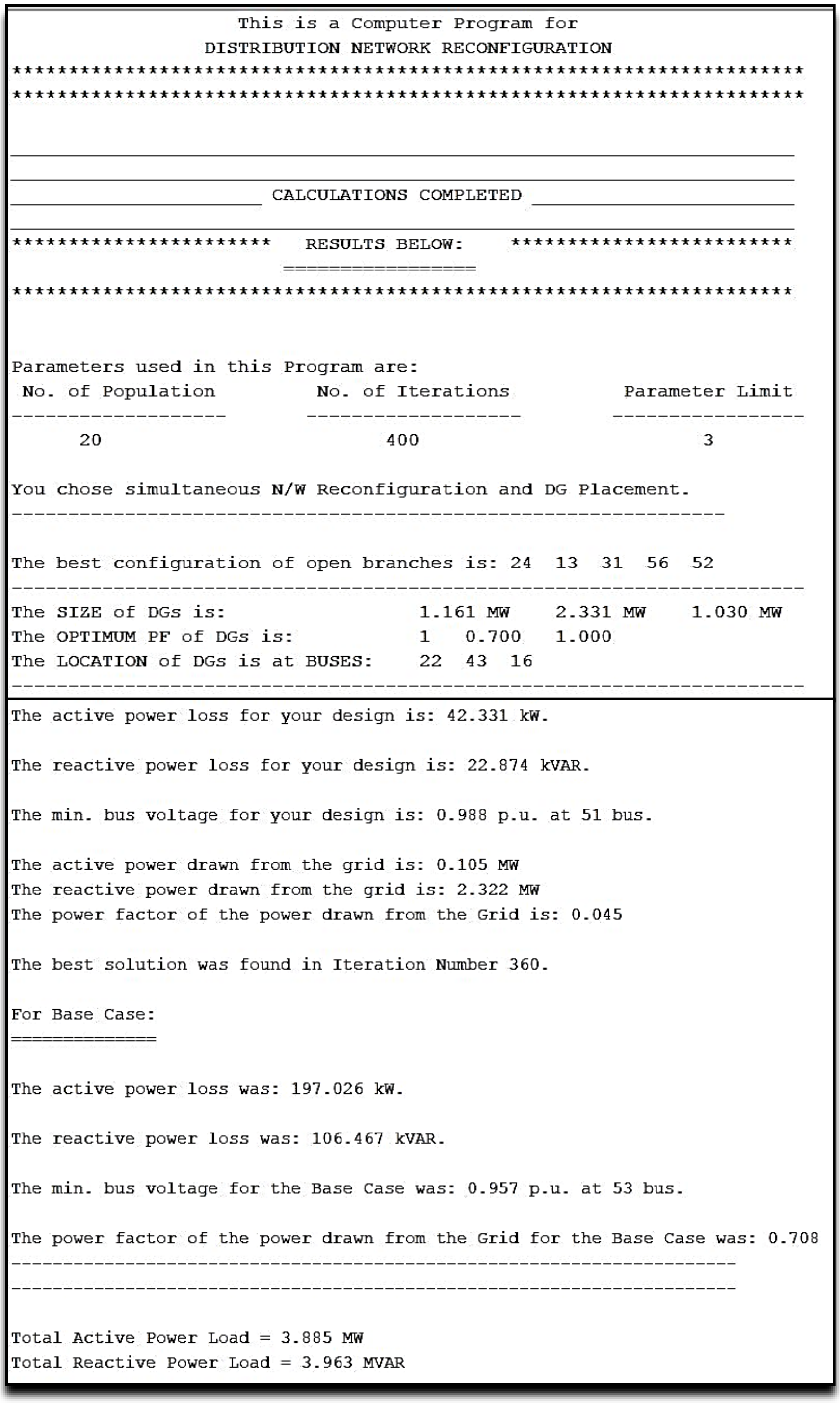
VSI Count Limit? (Default is 15)
15

PLEASE ENTER THE VALUES

PLEASE CHOOSE ONE OF THE FOLLOWING OPTIONS FOR DG NO. 1.

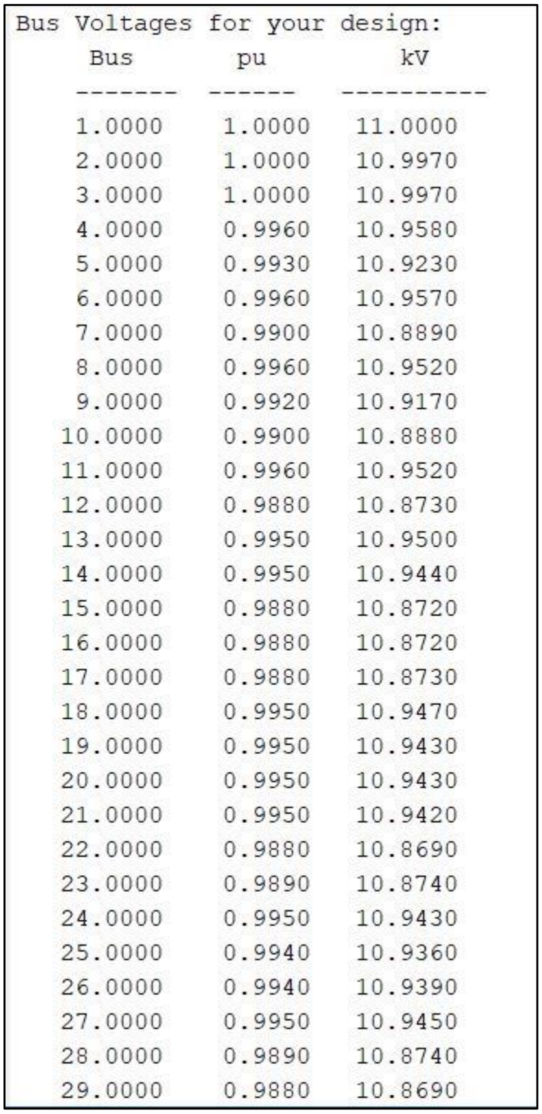
Figure 5: Windows for user inputs

iv. The result of the computer program includes the optimal configuration of the network, the size, location, and operating power factor of DGs, the voltage profile of the network (in kV and per unit), branch currents, active power loss, reactive power loss, active/reactive power drawn/injected into the grid, and power factor of the power drawn from the grid.
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~



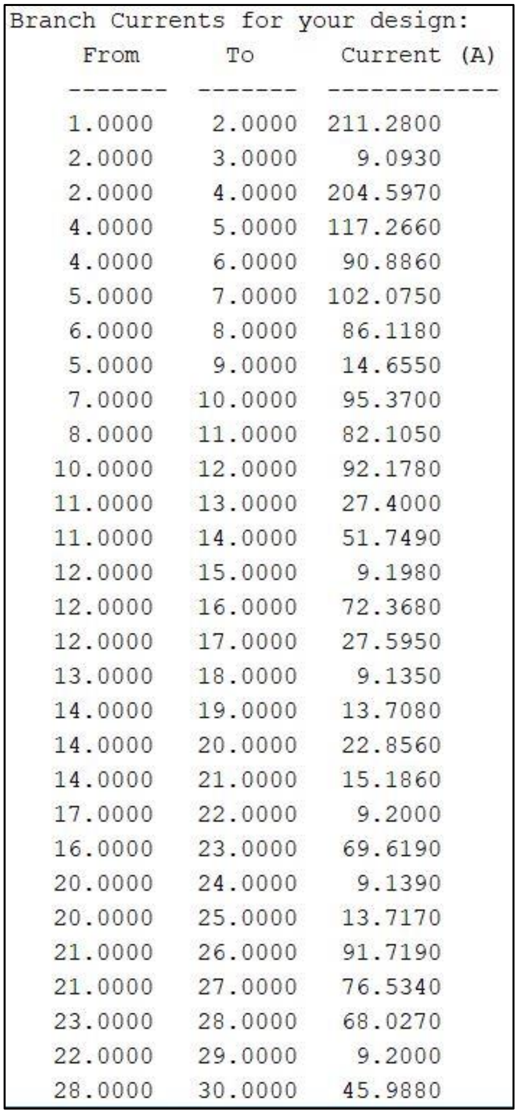
```
                    This is a Computer Program for
                 DISTRIBUTION NETWORK RECONFIGURATION
**********************************************************************
**********************************************************************


_____________________________________________________________________
_____________________________________________________________________
______________________ CALCULATIONS COMPLETED _______________________
_____________________________________________________________________
***********************   RESULTS BELOW:    *************************
                        =================
*********************************************************************


Parameters used in this Program are:
 No. of Population         No. of Iterations          Parameter Limit
-------------------       -------------------        -----------------

      20                        400                          3

You chose simultaneous N/W Reconfiguration and DG Placement.
---------------------------------------------------------------

The best configuration of open branches is: 24  13  31  56  52
----------------------------------------------------------------------
The SIZE of DGs is:                  1.161 MW    2.331 MW    1.030 MW
The OPTIMUM PF of DGs is:            1   0.700   1.000
The LOCATION of DGs is at BUSES:     22  43  16
----------------------------------------------------------------------
The active power loss for your design is: 42.331 kW.

The reactive power loss for your design is: 22.874 kVAR.

The min. bus voltage for your design is: 0.988 p.u. at 51 bus.

The active power drawn from the grid is: 0.105 MW
The reactive power drawn from the grid is: 2.322 MW
The power factor of the power drawn from the Grid is: 0.045

The best solution was found in Iteration Number 360.

For Base Case:
==============


The active power loss was: 197.026 kW.

The reactive power loss was: 106.467 kVAR.

The min. bus voltage for the Base Case was: 0.957 p.u. at 53 bus.

The power factor of the power drawn from the Grid for the Base Case was: 0.708
----------------------------------------------------------------------
----------------------------------------------------------------------


Total Active Power Load = 3.885 MW
Total Reactive Power Load = 3.963 MVAR
```

Figure 6: Result format



```
Bus Voltages for your design:
     Bus        pu          kV
   -------   ------   ----------
    1.0000    1.0000   11.0000
    2.0000    1.0000   10.9970
    3.0000    1.0000   10.9970
    4.0000    0.9960   10.9580
    5.0000    0.9930   10.9230
    6.0000    0.9960   10.9570
    7.0000    0.9900   10.8890
    8.0000    0.9960   10.9520
    9.0000    0.9920   10.9170
   10.0000    0.9900   10.8880
   11.0000    0.9960   10.9520
   12.0000    0.9880   10.8730
   13.0000    0.9950   10.9500
   14.0000    0.9950   10.9440
   15.0000    0.9880   10.8720
   16.0000    0.9880   10.8720
   17.0000    0.9880   10.8730
   18.0000    0.9950   10.9470
   19.0000    0.9950   10.9430
   20.0000    0.9950   10.9430
   21.0000    0.9950   10.9420
   22.0000    0.9880   10.8690
   23.0000    0.9890   10.8740
   24.0000    0.9950   10.9430
   25.0000    0.9940   10.9360
   26.0000    0.9940   10.9390
   27.0000    0.9950   10.9450
   28.0000    0.9890   10.8740
   29.0000    0.9880   10.8690
```

Figure 8: Voltage Profile (numbers) format



```
Branch Currents for your design:
     From       To       Current (A)
   -------   -------   ------------
    1.0000    2.0000   211.2800
    2.0000    3.0000     9.0930
    2.0000    4.0000   204.5970
    4.0000    5.0000   117.2660
    4.0000    6.0000    90.8860
    5.0000    7.0000   102.0750
    6.0000    8.0000    86.1180
    5.0000    9.0000    14.6550
    7.0000   10.0000    95.3700
    8.0000   11.0000    82.1050
   10.0000   12.0000    92.1780
   11.0000   13.0000    27.4000
   11.0000   14.0000    51.7490
   12.0000   15.0000     9.1980
   12.0000   16.0000    72.3680
   12.0000   17.0000    27.5950
   13.0000   18.0000     9.1350
   14.0000   19.0000    13.7080
   14.0000   20.0000    22.8560
   14.0000   21.0000    15.1860
   17.0000   22.0000     9.2000
   16.0000   23.0000    69.6190
   20.0000   24.0000     9.1390
   20.0000   25.0000    13.7170
   21.0000   26.0000    91.7190
   21.0000   27.0000    76.5340
   23.0000   28.0000    68.0270
   22.0000   29.0000     9.2000
   28.0000   30.0000    45.9880
```

Figure 7: Branch Current format

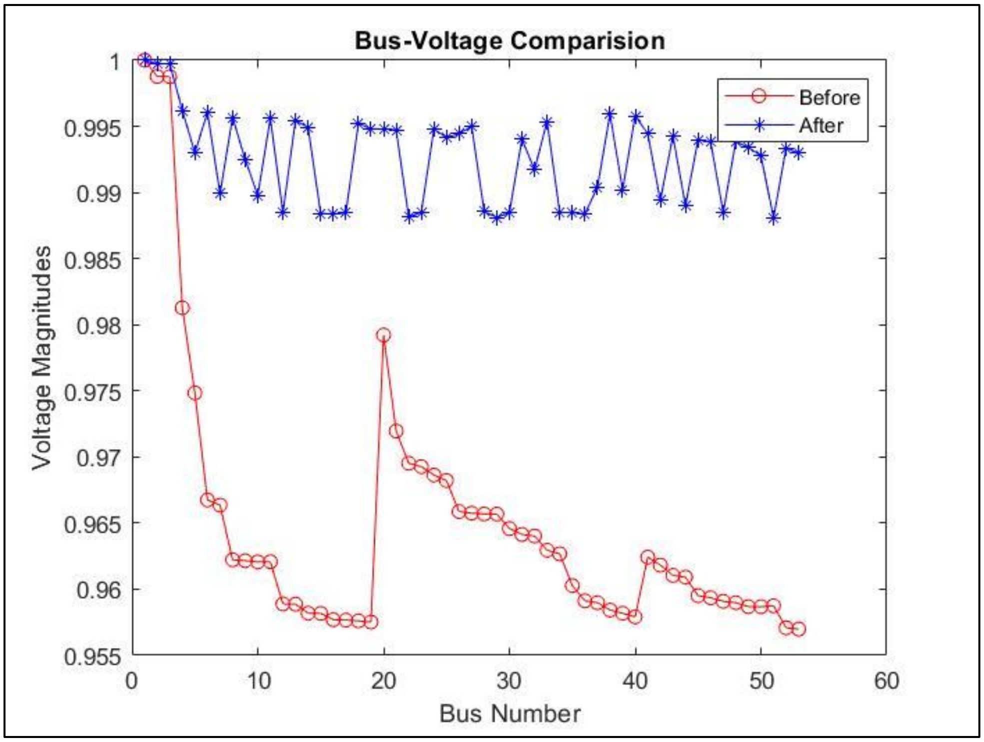


Figure 9: Voltage Profile Comparison (Before and After) format

CHAPTER IV: SYSTEM UNDER CONSIDERATION, SOFTWARE AND TOOLS

4.1 Systems under consideration

To examine the effectiveness of methodology proposed in this thesis work, the results were compared with that of the reference papers for IEEE 33 Bus system, and IEEE 69 Bus system.

Each system has extra set of branches, also called tie-lines, between some buses, which are open initially. For IEEE 33 Bus system, there are five tie-lines, and there are same number of tie-lines for IEEE 69 Bus system.

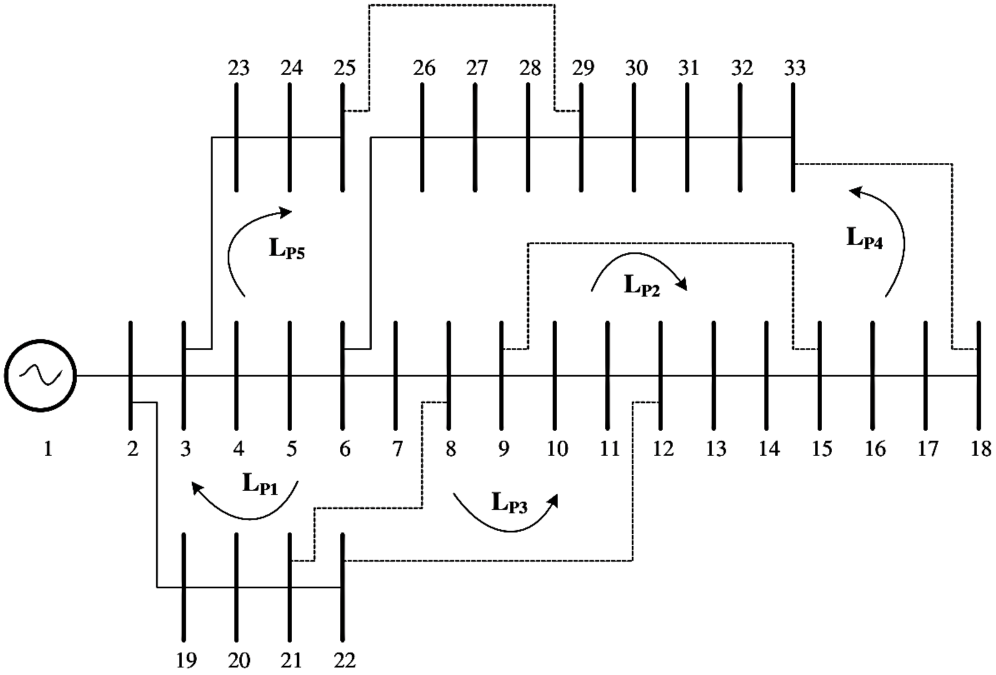


Figure 10: IEEE 33 Bus Test System

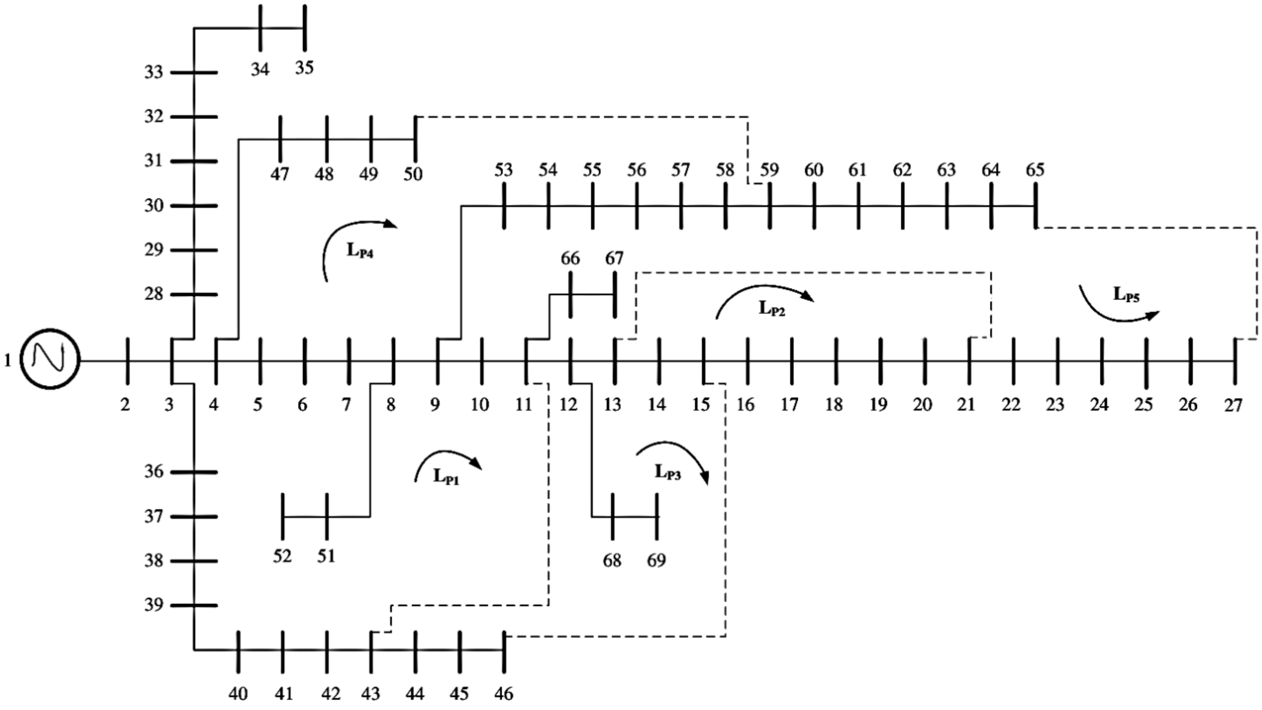


Figure 11: IEEE 69 Bus Test System

Table 1 shows the system data for IEEE 33-Bus system.

Table 1: System data for 33-bus radial distribution network (‘’ denotes a tie-line)*

Branch No.	Sending Bus	Receiving Bus	Resistance (Ohm)	Reactance (Ohm)	Nominal Load at Receiving Bus	
					P (kW)	Q (kVAR)
1	1	2	0.0922	0.047	100	60
2	2	3	0.493	0.2511	90	40
3	3	4	0.366	0.1864	120	80
4	4	5	0.3811	0.1941	60	30
5	5	6	0.819	0.707	60	20
6	6	7	0.1872	0.6188	200	100
7	7	8	0.7114	0.2351	200	100
8	8	9	1.03	0.74	60	20
9	9	10	1.044	0.74	60	20
10	10	11	0.1966	0.065	45	30
11	11	12	0.3744	0.1298	60	35
12	12	13	1.468	1.155	60	35
13	13	14	0.5416	0.7129	120	80
14	14	15	0.591	0.526	60	10
15	15	16	0.7463	0.545	60	20
16	16	17	1.289	1.721	60	20
17	17	18	0.732	0.574	90	40
18	2	19	0.164	0.1565	90	40
19	19	20	1.5042	1.3554	90	40
20	20	21	0.4095	0.4784	90	40
21	21	22	0.7089	0.9373	90	40
22	3	23	0.4512	0.3083	90	50
23	23	24	0.898	0.7091	420	200

24	24	25	0.896	0.7011	420	200
25	6	26	0.203	0.1034	60	25
26	26	27	0.2842	0.1447	60	25
27	27	28	1.059	0.9337	60	20
28	28	29	0.8042	0.7006	120	70
29	29	30	0.5075	0.2585	200	600
30	30	31	0.9744	0.963	150	70
31	31	32	0.3105	0.3619	210	100
32	32	33	0.341	0.5302	60	40
33	21	8	2.0000	2.0000	-	-
34	9	15	2.0000	2.0000	-	-
35	12	22	2.0000	2.0000	-	-
36	18	33	0.5000	0.5000	-	-
37	25	29	0.5000	0.5000	-	-

Table 2 shows the system data for IEEE 69-Bus system.

Table 2: System data for 69-bus radial distribution network (‘*’ denotes a tie-line)

Branch No.	**Sending Bus**	**Receiving Bus**	**Resistance (Ohm)**	**Reactance (Ohm)**	**Nominal Load at Receiving Bus**	
					P (kW)	**Q (kVAR)**
1	1	2	0.0005	0.0012	0	0
2	2	3	0.0005	0.0012	0	0
3	3	4	0.0015	0.0036	0	0
4	4	5	0.0251	0.0294	0	0
5	5	6	0.366	0.1864	2.6	2.2

6	6	7	0.3811	0.1941	40.4	30
7	7	8	0.0922	0.047	75	54
8	8	9	0.0493	0.0251	30	22
9	9	10	0.819	0.2707	28	19
10	10	11	0.1872	0.0619	145	104
11	11	12	0.7114	0.2351	145	104
12	12	13	1.03	0.34	8	5
13	13	14	1.044	0.345	8	5.5
14	14	15	1.058	0.3496	0	0
15	15	16	0.1966	0.065	45.5	30
16	16	17	0.3744	0.1238	60	35
17	17	18	0.0047	0.0016	60	35
18	18	19	0.3276	0.1083	0	0
19	19	20	0.2106	0.069	1	0.6
20	20	21	0.3416	0.1129	114	81
21	21	22	0.014	0.0046	5	3.5
22	22	23	0.1591	0.0526	0	0
23	23	24	0.3463	0.1145	28	20
24	24	25	0.7488	0.2475	0	0
25	25	26	0.3089	0.1021	14	10
26	26	27	0.1732	0.0572	14	10
27	3	28	0.0044	0.0108	26	18.6
28	28	29	0.064	0.1565	26	18.6
29	29	30	0.3978	0.1315	0	0
30	30	31	0.0702	0.0232	0	0
31	31	32	0.351	0.116	0	0
32	32	33	0.839	0.2816	14	10
33	33	34	1.708	0.5646	9.5	14
34	34	35	1.474	0.4873	6	4

35	3	36	0.0044	0.0108	26	18.55
36	36	37	0.064	0.1565	26	18.55
37	37	38	0.1053	0.123	0	0
38	38	39	0.0304	0.0355	24	17
39	39	40	0.0018	0.0021	24	17
40	40	41	0.7283	0.8509	1.2	1
41	41	42	0.31	0.3623	0	0
42	42	43	0.041	0.0478	6	4.3
43	43	44	0.0092	0.0116	0	0
44	44	45	0.1089	0.1373	39.22	26.3
45	45	46	0.0009	0.0012	39.22	26.3
46	4	47	0.0034	0.0084	0	0
47	47	48	0.0851	0.2083	79	56.4
48	48	49	0.2898	0.7091	384.7	274.5
49	49	50	0.0822	0.2011	384.7	274.5
50	8	51	0.0928	0.0473	40.5	28.3
51	51	52	0.3319	0.1114	3.6	2.7
52	52	53	0.174	0.0886	4.35	3.5
53	53	54	0.203	0.1034	26.4	19
54	54	55	0.2842	0.1447	24	17.2
55	55	56	0.2813	0.1433	0	0
56	56	57	1.59	0.5337	0	0
57	57	58	0.7837	0.263	0	0
58	58	59	0.3042	0.1006	100	72
59	59	60	0.3861	0.1172	0	0
60	60	61	0.5075	0.2585	1244	888
61	61	62	0.0974	0.0496	32	23
62	62	63	0.145	0.0738	0	0
63	63	64	0.7105	0.3619	227	162

64	64	65	1.041	0.5302	59	42
65	11	66	0.2012	0.0611	18	13
66	66	67	0.0047	0.0014	18	13
67	12	68	0.7394	0.2444	28	20
68	68	69	0.0047	0.0016	28	20
69*	11	43	0.5	0.5	-	-
70*	13	21	0.5	0.5	-	-
71*	15	46	1	1	-	-
72*	50	59	2	2	-	-
73*	27	65	1	1	-	-

After proving the effectiveness of the proposed algorithm, the methodology was applied to a practical distribution system, Daachhi feeder, of Kathmandu, Nepal. Daachhi feeder originates from Chabahil substation situated in Chabahil, Kathmandu. The feeder is under the control of Baneshwor Distribution Center, Nepal Electricity Authority. Required branch data, and load data was collected for the feeder and plotted in QGIS. Bus numbers and branch numbers were assigned. Later, the data was entered in MS-Excel in the format mentioned in Chaper III.

Figure 12 shows the GIS plot, and Table 3 has the system data for Daachhi feeder.

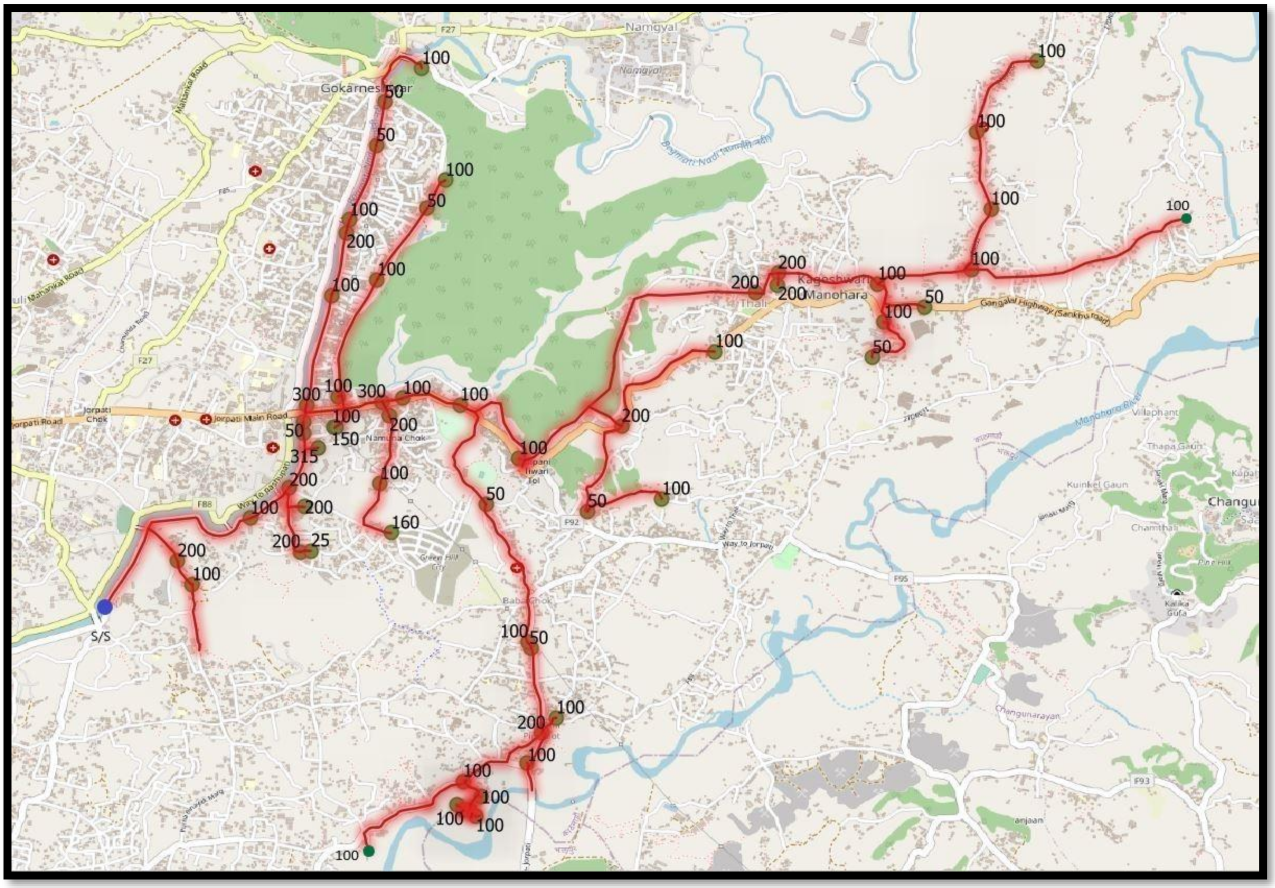


Figure 12: GIS Plot of Daachhi Feeder

Figure 13 shows the single line diagram of the Daachhi feeder.

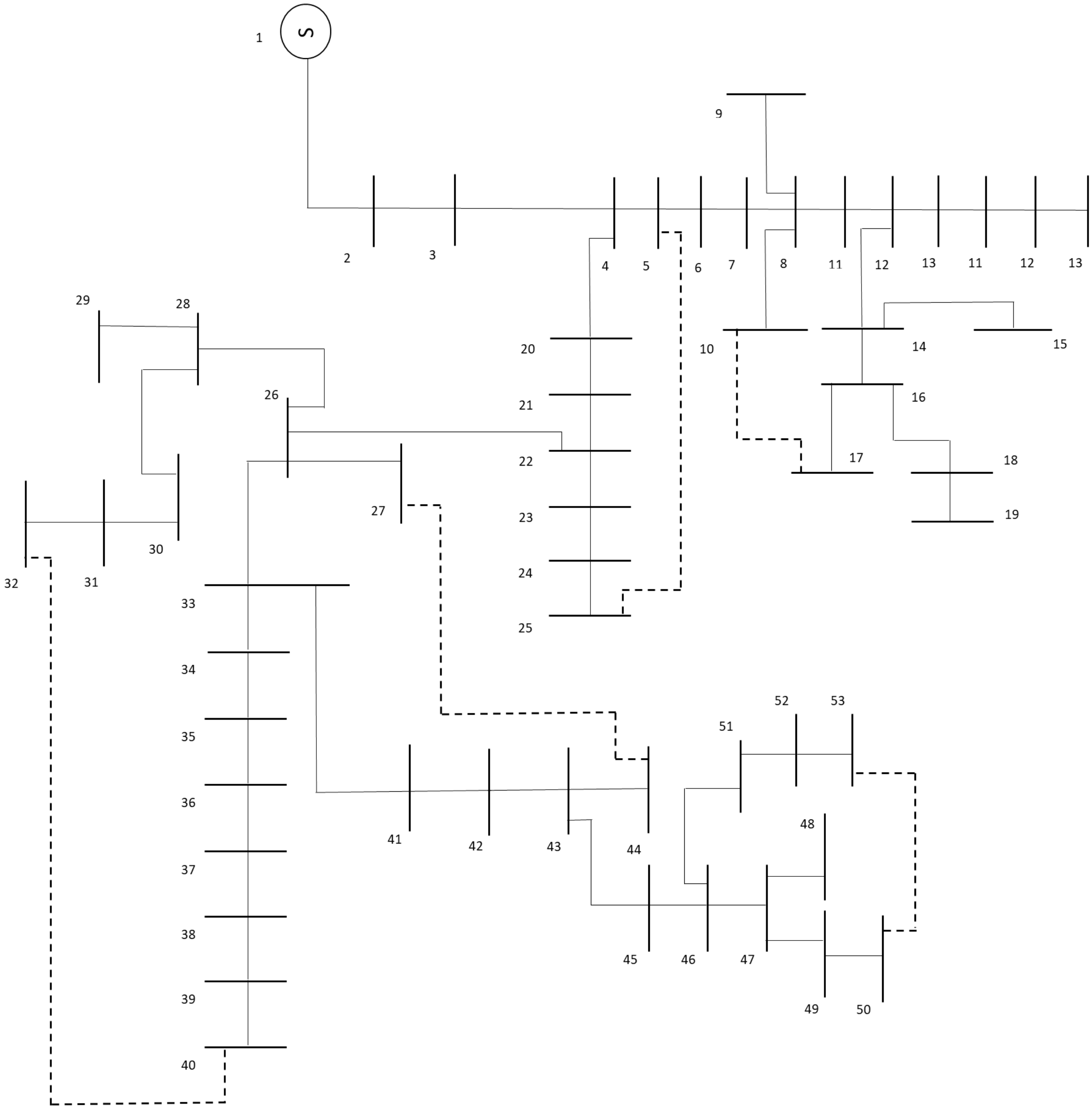


Figure 13: SLD of Daachhi feeder

Table 3: System data for distribution network of Daachhi feeder of Kathmandu valley (‘’ denotes a tie-line)*

Branch No.	Sending Bus	Receiving Bus	Length (m)	Resistance (Ohm)	Reactance (Ohm)	Power Demand	
						P (MW)	Q (MVAR)
1	1	2	33	0.023602	0.012754	0	0
2	2	3	30	0.021457	0.011594	0.07	0.071414
3	2	4	480	0.343307	0.185512	0	0
4	4	5	601	0.429849	0.232276	0.035	0.035707
5	5	6	780	0.557874	0.301457	0.07	0.071414
6	6	7	40	0.028609	0.015459	0.035	0.035707
7	7	8	441	0.315413	0.170439	0	0
8	8	9	97	0.069377	0.037489	0.07	0.071414
9	8	10	237	0.169508	0.091596	0.07	0.071414
10	8	11	18	0.012874	0.006957	0.14	0.142829
11	11	12	476	0.340446	0.183966	0	0
12	12	13	17	0.012159	0.00657	0.07	0.071414
13	12	14	116	0.082966	0.044832	0	0
14	14	15	19	0.013589	0.007343	0.07	0.071414
15	14	16	91	0.065085	0.03517	0.14	0.142829
16	16	17	47	0.033615	0.018165	0.07	0.071414
17	16	18	27	0.019311	0.010435	0.14	0.142829
18	18	19	45	0.032185	0.017392	0.21	0.214243
19	4	20	80	0.057218	0.030919	0.07	0.071414
20	20	21	290	0.207415	0.11208	0.07	0.071414
21	21	22	100	0.071522	0.038648	0.21	0.214243
22	22	23	84	0.060079	0.032465	0.14	0.142829
23	23	24	370	0.264633	0.142999	0.07	0.071414

24	24	25	390	0.278937	0.150728	0.112	0.114263
25	22	26	189	0.135177	0.073045	0	0
26	26	27	119	0.085112	0.045991	0.105	0.107121
27	26	28	77	0.055072	0.029759	0	0
28	28	29	17	0.012159	0.00657	0.07	0.071414
29	28	30	663	0.474193	0.256238	0.07	0.071414
30	30	31	448	0.32042	0.173144	0.035	0.035707
31	31	32	182	0.130171	0.07034	0.07	0.071414
32	26	33	183	0.130886	0.070726	0	0
33	33	34	45	0.032185	0.017392	0.21	0.214243
34	34	35	598	0.427703	0.231117	0.07	0.071414
35	35	36	342	0.244606	0.132177	0.14	0.142829
36	36	37	73	0.052211	0.028213	0.07	0.071414
37	37	38	419	0.299678	0.161936	0.035	0.035707
38	38	39	235	0.168077	0.090823	0.035	0.035707
39	39	40	408	0.291811	0.157685	0.07	0.071414
40	33	41	52	0.037192	0.020097	0.035	0.035707
41	41	42	63	0.045059	0.024348	0.07	0.071414
42	42	43	86	0.061509	0.033238	0	0
43	43	44	65	0.04649	0.025121	0.2205	0.224955
44	43	45	223	0.159495	0.086186	0.14	0.142829
45	45	46	30	0.021457	0.011594	0	0
46	46	47	94	0.067231	0.036329	0	0
47	47	48	79	0.056503	0.030532	0.14	0.142829
48	47	49	267	0.190965	0.103191	0.14	0.142829
49	49	50	54	0.038622	0.02087	0.0175	0.017854
50	46	51	223	0.159495	0.086186	0.07	0.071414
51	51	52	830	0.593635	0.320781	0.14	0.142829
52	52	53	148	0.105853	0.057199	0.07	0.071414

53*	10	17	382	0.273215	0.147636	-	-
54*	5	25	484	0.346168	0.187058	-	-
55*	50	53	595	0.425558	0.229957	-	-
56*	27	44	65	0.04649	0.025121	-	-
57*	32	40	610	0.436286	0.235755	-	-

4.2 Software and Tools Used

MATLAB’s programming environment was the software used in this thesis. MATLAB stands for "Matrix Laboratory" is a proprietary multi-paradigm programming language and numerical computing environment developed by MathWorks. MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages. Common usage of the MATLAB application involves using the "Command Window" as an interactive mathematical shell or executing text files containing MATLAB code.

As this thesis work involves numerous power flow computations in one iteration, a time-efficient way to compute power flow results is required. MATPOWER is a package of MATLAB M-files for solving power flow and optimal power flow problems. It is intended as a simulation tool for researchers and educators that is easy to use and modify. MATPOWER is designed to give the best performance possible while keeping the code simple to understand and modify. MATPOWER was initially developed by Ray D. Zimmerman, Carlos E. MurilloS´anchez and Deqiang Gan at Cornell University under the direction of Robert J. Thomas.

CHAPTER V: RESULTS AND DISCUSSIONS

This chapter presents the results achieved in this thesis work. Firstly, the results were first compared against those in the reference paper [13]. In various literatures related to distribution network reconfiguration and installation of DGs, provision of specifying the nature of DGs have not been considered. In those works, the DGs were assumed to have injected active power only i.e. operating at unity power factor. In practice, there are following types of DGs:

- DGs injecting active power only,
- DGs injecting both active and reactive power,
- DGs injecting active power but absorbing reactive power.

This thesis work has taken the incorporation of DGs in the given distribution network one notch further and studies the effect of having different types of DGs. Taking that improvement into consideration, the developed computer program was run with exactly same inputs as in the reference paper 13 except specifying that one of the DGs injects active power only, another one injecting both active power and reactive power, and the last DG injecting active power but absorbing reactive power. The lower limit of power factor was taken to be 0.8.

5.1 For IEEE 33 Bus System

Base Case: For the base case, the result for the power loss achieved in this thesis work (202.67 kW) is exactly same with what given in reference paper 13. It shows that the network parameters considered in both scenarios are exactly same.

Case I: For the network reconfiguration only case, the configuration for the network recommended in the reference paper 13 exactly matches with that achieved in this thesis work (7-14-9-32-28). Hence, the power loss (139.978 kW) and minimum voltage (0.913 pu at 18th bus) match in both the cases. Until this case, there is not much significance on the choice of optimization algorithm.

Case II: For the DG Installation only case, the results achieved in this thesis work using ABC algorithm is superior to that given in the reference paper 13. The power loss and min. bus voltage achieved in this thesis work is 82.769 kW and 0.9413 pu (32nd bus) against 88.68 kW and 0.968 pu (30th bus) in the reference paper 13. All the DGs were considered to inject active power only. When

DGs were considered to inject both active power and reactive power (pf limited to 0.8 lagging), the power loss and min. bus voltage achieved in this thesis work is 26.639 kW and 0.966 pu (33^{rd} bus).

Case III: For the DG installation after network reconfiguration case, the results achieved in this thesis work using ABC algorithm is superior to that given in the reference paper 13. The power loss and min. bus voltage achieved in this thesis work is 58.283 kW and 0.976 pu (31^{st} bus) against 83.91 kW and 0.9612 pu (30^{th} bus) in the reference paper 13. All the DGs were considered to inject active power only. When DGs were considered to inject both active power and reactive power (pf limited to 0.8 lagging), the power loss and min. bus voltage achieved in this thesis work is 21.704 kW and 0.989 pu (31^{st} bus).

Case IV: For the network reconfiguration after DG installation case, the results achieved in this thesis work using ABC algorithm is superior to that given in the reference paper 13. The power loss and min. bus voltage achieved in this thesis work is 63.217 kW and 0.975 pu (22^{nd} bus) against 68.28 kW and 0.9712 pu (29th bus) in the reference paper 13. All the DGs were considered to inject active power only. When DGs were considered to inject both active power and reactive power (pf limited to 0.8 lagging), the power loss and min. bus voltage achieved in this thesis work is 17.030 kW and 0.993 pu (18^{th} bus).

Case V: For the simultaneous network reconfiguration and DG installation case, the results achieved in this thesis work using ABC algorithm is superior to that given in the reference paper 13. The power loss and min. bus voltage achieved in this thesis work is 57.776 kW and 0.974 pu (33^{rd} bus) against 67.11 kW and 0.9713 pu (14^{th} bus) in the reference paper 13. All the DGs were considered to inject active power only. When DGs were considered to inject both active power and reactive power (pf limited to 0.8 lagging), the power loss and min. bus voltage achieved in this thesis work is 14.324 kW and 0.994 pu (12^{th} bus).

Following table summarizes and compares the results for IEEE 33 Bus System:

Table 4: Results comparison for IEEE 33 Bus System

For IEEE 33 Bus	**Using FWA [13], DGs inject P only**	**Results found, DGs inject P only**	**Results found, DGs inject both P and Q**
Base Case (no reconfiguration and no inclusion of DGs)			
Open Branches	33-34-35-36-37	33-34-35-36-37	33-34-35-36-37
Vmin (pu)	0.913 (18)	0.913 (18)	0.913 (18)
Ploss (kW)	202.67	202.67	202.67
Only Reconfiguration (Case I), independent of presence of DGs			
Open Branches	7-14-9-32-28	7-14-9-32-28	
Vmin (pu)	0.941 (32)	0.941 (32)	
Ploss (kW)	139.98 **(less by 30.93%)**	139.98 **(less by 30.93%)**	
Only DG Installation (Case II)			
Open Branches	33-34-35-36-37	33-34-35-36-37	33-34-35-36-37
Vmin (pu)	0.968 (30)	0.951 (33)	0.966 (33)
Ploss (kW)	88.68 **(less by 56.24%)**	82.77 **(less by 59.16%)**	26.64 **(less by 86.86%)**
DG cap. (MW), loc., and operating pf	0.590 (14), 0.190 (18), 1.010 (32)	0.677 (31), 1.629 (26), 0.817 (25)	1.132 (30) at 0.800 pf, 0.890 (25) at 0.902 pf, 1.645 (26) at 0.822 pf
DG Installation after Reconfiguration (Case III)			
Open Branches	7-14-9-32-28	7-14-9-32-28	7-14-9-32-28
Vmin (pu)	0.961 (30)	0.976 (31)	0.989 (31)
Ploss (kW)	83.91**(less by 58.60%)**	58.28 **(less by 71.24%)**	21.70 **(less by 89.29%)**
DG cap. (MW), loc., and operating pf	0.600 (32), 0.310 (33), 0.160 (18)	1.551 (29), 0.509 (17), 1.454 (10)	0.639 (13) at 0.923 pf, 2.030 (25) at 0.839 pf, 0.610 (16) at 0.973 pf
Reconfiguration after DG Installation (Case IV)			
Open Branches	7-34-9-32-28	30-11-14-33-28	15-33-3-13-37
Vmin (pu)	0.971 (29)	0.975 (22)	0.993 (18)
Ploss (kW)	68.28 **(less by 66.31%)**	63.22 **(less by 68.81%)**	17.03 **(less by 91.60%)**
DG cap. (MW), loc., and operating pf	0.590 (14), 0.190 (18), 1.020 (32)	1.010 (24), 0.673 (31), 1.583 (26)	1.132 (30) at 0.800 pf, 0.890 (25) at 0.902 pf, 1.645 (26) at 0.822 pf
Simultaneous Reconfiguration & DG Installation (Case V)			
Open Branches	7-14-11-32-28	9-28-17-33-34	12-8-33-28-36

For IEEE 33 Bus	Using FWA [13], DGs inject P only	Results found, DGs inject P only	Results found, DGs inject both P and Q
Vmin (pu)	0.971 (14)	0.974 (33)	0.994 (12)
Ploss (kW)	67.11 **(less by 66.89%)**	57.776 **(less by 71.49%)**	14.324 **(less by 92.93%)**
DG cap. (MW), loc., and operating pf	0.54 (32), 0.62 (29), 0.53 (18)	0.599 (13), 0.885 (26), 1.512 (30)	0.744 (13) at 0.896 pf, 0.913 (26) at 0.887 pf, 1.736 (30) at 0.800 pf

5.2 For IEEE 69 Bus System

Base Case: For the base case, the result for the power loss achieved in this thesis work (225 kW) is exactly same with what given in reference paper 13. It shows that the network parameters considered in both scenarios are exactly same.

Case I: For the network reconfiguration only case, the configuration for the network recommended in the reference paper 13 exactly matches with that achieved in this thesis work (69-70-14-56-61). Hence, the power loss (98.611 kW) and minimum voltage (0.949 pu at 61st bus) match in both the cases. Until this case, there is not much significance on the choice of optimization algorithm.

Case II: For the DG Installation only case, the results achieved in this thesis work using ABC algorithm is superior to that given in the reference paper 13. The power loss and min. bus voltage achieved in this thesis work is 74.404 kW and 0.981 pu (64th bus) against 77.85 kW and 0.974 pu (62nd bus) in the reference paper 13. All the DGs were considered to inject active power only. All the DGs were considered to inject active power only. When DGs were considered to inject both active power and reactive power (pf limited to 0.8 lagging), the power loss and min. bus voltage achieved in this thesis work is 10.892 kW and 0.987 pu (69th bus).

Case III: For the DG installation after network reconfiguration case, the results achieved in this thesis work using ABC algorithm is superior to that given in the reference paper 13. The power loss and min. bus voltage achieved in this thesis work is 37.772 kW and 0.984 pu (40th bus) against 43.88 kW and 0.972 pu (61st bus) in the reference paper 13. All the DGs were considered to inject active power only. When DGs were considered to inject both active power and reactive power (pf limited to 0.8

lagging), the power loss and min. bus voltage achieved in this thesis work is 9.084 kW and 0.987 pu (69th bus).

Case IV: For the network reconfiguration after DG installation case, the results achieved in this thesis work using ABC algorithm is superior to that given in the reference paper 13. The power loss and min. bus voltage achieved in this thesis work is 42.92 kW and 0.978 pu (55th bus) against 39.69 kW and 0.9763 pu (61st bus) in the reference paper 13. All the DGs were considered to inject active power only. When DGs were considered to inject both active power and reactive power (pf limited to 0.8 lagging), the power loss and min. bus voltage achieved in this thesis work is 7.745 kW and 0.997 pu (64th bus).

Case V: For the simultaneous network reconfiguration and DG installation case, the results achieved in this thesis work using ABC algorithm is superior to that given in the reference paper 13. The power loss and min. bus voltage achieved in this thesis work is 37.075 kW and 0.981 pu (65th bus) against 39.25 kW and 0.98 pu (61st bus) in the reference paper 13. All the DGs were considered to inject active power only. When DGs were considered to inject both active power and reactive power (pf limited to 0.8 lagging), the power loss and min. bus voltage achieved in this thesis work is 5.74 kW and 0.995 pu (57th bus).

Following table summarizes and compares the results for IEEE 69 bus system:

Table 5: Results comparison for IEEE 69 Bus System

For IEEE 69 Bus	**Using FWA [13], DGs inject P only**	**Results found, DGs inject P only**	**Results found, DGs inject both P and Q**
Base Case (no reconfiguration and no inclusion of DGs)			
Open Branches	69-70-71-72-74	69-70-71-72-73	69-70-71-72-73
Vmin (pu)	0.913 (18)	0.913 (18)	0.913 (18)
Ploss (kW)	225	225	225
Only Reconfiguration (Case I), independent of presence of DGs			
Open Branches	69-70-14-56-61	69-14-61-56-70	
Vmin (pu)	0.950 (61)	0.950 (61)	
Ploss (kW)	98.60 **(less by 56.18%)**	98.61 **(less by 56.17%)**	
Only DG Installation (Case II)			

Open Branches	69-70-71-72-73	69-70-71-72-73	69-70-71-72-73
Vmin (pu)	0.974 (62)	0.981 (64)	0.987 (69)
Ploss (kW)	77.85 **(less by 65.40%)**	74.40 **(less by 66.93%)**	10.89 **(less by 95.16%)**
DG cap. (MW), loc., and operating pf	0.410 (65), 1.20 (61), 0.230 (27)	0.384 (68), 1.738 (62), 0.548 (67)	0.884 (50) at 0.814 pf, 0.862 (68) at 0.838 pf, 2.083 (62) at 0.814 pf
DG Installation after Reconfiguration (Case III)			
Open Branches	69-70-14-56-61	69-61-14-70-56	69-61-14-70-56
Vmin (pu)	0.972 (61)	0.984 (40)	0.987 (69)
Ploss (kW)	43.88 **(less by 80.50%)**	37.77 **(less by 83.21%)**	9.08 **(less by 95.96%)**
DG cap. (MW), loc., and operating pf	1.000 (61), 0.220 (62), 0.140 (64)	1.538 (61), 0.651 (66), 0.770 (26)	0.780 (20) at 0.800 pf, 0.503 (66) at 0.912 pf, 1.755 (61) at 0.863 pf
Reconfiguration after DG Installation (Case IV)			
Open Branches	69-70-12-58-61	55-10-64-17-71	10-25-14-17-53
Vmin (pu)	0.976 (61)	0.978 (55)	0.997 (64)
Ploss (kW)	39.69 **(less by 82.36%)**	42.92 **(less by 80.92%)**	7.75 **(less by 96.56%)**
DG cap. (MW), loc., and operating pf	0.410 (65), 1.200 (61), 0.230 (27)	1.738 (62), 0.548 (67), 0.384 (68)	0.884 (50) at 0.814 pf, 0.862 (68) at 0.838 pf, 2.083 (62) at 0.814 pf
Simultaneous Reconfiguration & DG Installation (Case V)			
Open Branches	69-70-13-55-63	69-62-13-70-53	12-69-13-63-56
Vmin (pu)	0.980 (61)	0.981 (50)	0.995 (57)
Ploss (kW)	39.25 **(less by 82.56%)**	37.08 **(less by 83.52%)**	5.74 **(less by 97.45%)**
DG cap. (MW), loc., and operating pf	1.130 (61), 0.280 (62), 0.420 (65)	1.588 (61), 0.491 (65), 0.458 (66)	0.585 (66) at 0.813 pf, 1.779 (61) at 0.813 pf, 0.624 (65) at 0.817 pf

From the above analysis, it has been verified that the algorithm developed for this thesis work has superior performance when compared against older methods specified in various literatures. As per the scope of this thesis, the computer program was applied to 11 kV Daachhi feeder of Kathmandu valley.

5.3 For Daachhi Feeder of Kathmandu

For Daachhi feeder of Kathmandu, five tie-lines and insertion of three DGs were considered. Also, two different scenarios were tested – first, three different types of DGs were considered; second, all three DGs were assumed to inject both active power and reactive power. Lower limit of operating power factor of DGs was limited to being not less than 0.8. Following table shows the outputs and compares it against the base case.

Table 6: Results comparison for Daachhi feeder of Kathmandu when considering three different types of DGs

For Daachhi feeder	Results found, DGs inject P only	Results found, DGs inject both P and Q
Base Case (no reconfiguration and no inclusion of DGs)		
Open Branches	53-54-55-56-57	53-54-55-56-57
Vmin (pu)	0.957 (53)	0.957 (53)
Ploss (kW)	197.026	197.026
Only Reconfiguration (Case I), independent of presence of DGs		
Open Branches	42-15-22-38-52	
Vmin (pu)	0.949 (61)	
Ploss (kW)	186.593 **(less by 5.30%)**	
Only DG Installation (Case II)		
Open Branches	53-54-55-56-57	53-54-55-56-57
Vmin (pu)	0.968 (42)	0.973 (42)
Ploss (kW)	117.882 **(less by 40.17%)**	46.692 **(less by 76.30%)**
DG cap. (MW), loc., and operating pf	1.121 (45), 0.493 (37), 1.494 (28)	1.671 (33) at 0.800 pf, 1.498 (28) at 0.800 pf, 1.179 (45) at 0.800 pf
DG Installation after Reconfiguration (Case III)		
Open Branches	52-42-15-22-38	52-42-15-22-38
Vmin (pu)	0.984 (39)	0.995 (13)
Ploss (kW)	96.184 **(less by 51.18%)**	15.971 **(less by 91.89%)**
DG cap. (MW), loc., and operating pf	1.322 (8), 1.208 (34), 1.250 (45)	1.551 (41) at 0.851 pf, 1.678 (11) at 0.800 pf, 1.687 (45) at 0.800 pf
Reconfiguration after DG Installation (Case IV)		
Open Branches	15-42-52-39-24	20-39-55-15-42
Vmin (pu)	0.968 (39)	0.977 (35)

Ploss (kW)	114.403 **(less by 41.94%)**	46.169 **(less by 76.57%)**
DG cap. (MW), loc., and operating pf	1.113 (45), 0.493 (37), 1.499 (28)	1.663 (45) at 0.800 pf, 1.396 (37) at 0.800 pf, 1.254 (28) at 0.800 pf
Simultaneous Reconfiguration & DG Installation (Case V)		
Open Branches	23-42-52-15-38	22-13-31-56-55
Vmin (pu)	0.985 (47)	0.994 (13)
Ploss (kW)	95.703 **(less by 51.43%)**	14.372 **(less by 92.71%)**
DG cap. (MW), loc., and operating pf	1.446 (33), 1.138 (45), 1.124 (16)	2.331 (42) at 0.800 pf, 0.868 (36) at 0.800 pf, 1.649 (17) at 0.800 pf

Above table shows that a gradual improvement in power loss was observed when the distribution network of Daachhi feeder goes through only reconfiguration, only DG installation, reconfiguration after DG installation, DG installation after reconfiguration, and simultaneous reconfiguration and DG installation respectively when the DGs were considered to inject active power only. Same pattern in loss reduction was observed when the DGs were considered to inject both active power and reactive power. However, greater reduction in power loss was observed when DGs injected both active power and reactive power instead of just active power. For the simultaneous network reconfiguration and DG installation case, power loss reduced by 51.43% and 92.71% respectively when DGs injected active power only, and when DGs injected both active power and reactive power.

CHAPTER VI: CONCLUSION

This thesis work focused on efficient reconfiguration of distribution network while optimizing the size, location and optimum operating power factor of DGs. Artificial Bee Colony (ABC) algorithm was used as the optimization algorithm for fulfilling the objectives of the project. An interactive computer program was developed in MATLAB using MATPOWER toolbox. The program takes a variety of inputs from the user and takes those inputs as parameters for the optimization process. The program optimizes the configuration of branches, sizes, locations and operating power factor of DGs in such a way that the program suggests a design that would give the best voltage profile and least power loss.

To summarize, adopting the algorithm and procedures stated in this thesis work, better results were found for IEEE 33 Bus system and IEEE 69 Bus systems. For IEEE 33 Bus System, power loss was better than the Base Case by 30.93% for Case I i.e. when performing network reconfiguration only. Similarly, power loss was better than the Base Case by 59.16%, 71.24%, 68.81%, and 71.49% respectively for Case II, Case III, Case IV, and Case V, when considering DGs could inject active power only. When considering that DGs could inject both active power and reactive power, power loss was better than the Base Case by 86.86%, 89.29%, 91.60%, and 92.93% for Case II, Case III, Case IV, and Case V respectively.

For IEEE 69 Bus System, power loss was better than the Base Case by 56.17% for Case I i.e. when performing network reconfiguration only. Similarly, power loss was better than the Base Case by 66.93%, 83.21%, 80.92%, and 83.52% respectively for Case II, Case III, Case IV, and Case V, when considering DGs could inject active power only. When considering that DGs could inject both active power and reactive power, power loss was better than the Base Case by 95.16%, 95.96%, 96.56%, and 97.45% for Case II, Case III, Case IV, and Case V respectively.

When the methods adopted in this thesis work were applied to 11 kV Daachhi feeder distribution system of Kathmandu valley, power loss was reduced by 5.30% when performing network reconfiguration only. Similarly, power loss was better than the Base Case by 40.17%, 51.18%, 41.94%, and 51.43% respectively for Case II, Case III, Case IV, and Case V, when considering DGs could inject active power only. When considering that DGs could inject both active power and reactive power, power loss was better than the Base Case by 76.30%, 91.89%, 76.57%, and 92.71% for Case II, Case III, Case IV, and Case V respectively.

In conclusion, the method proposed in this thesis work to allow DGs to inject reactive power into the network along with active power while performing network reconfiguration improved the efficiency and performance of the distribution system by reducing the power loss and improving the voltage profile. Hence, the objective of this thesis work has been accomplished.

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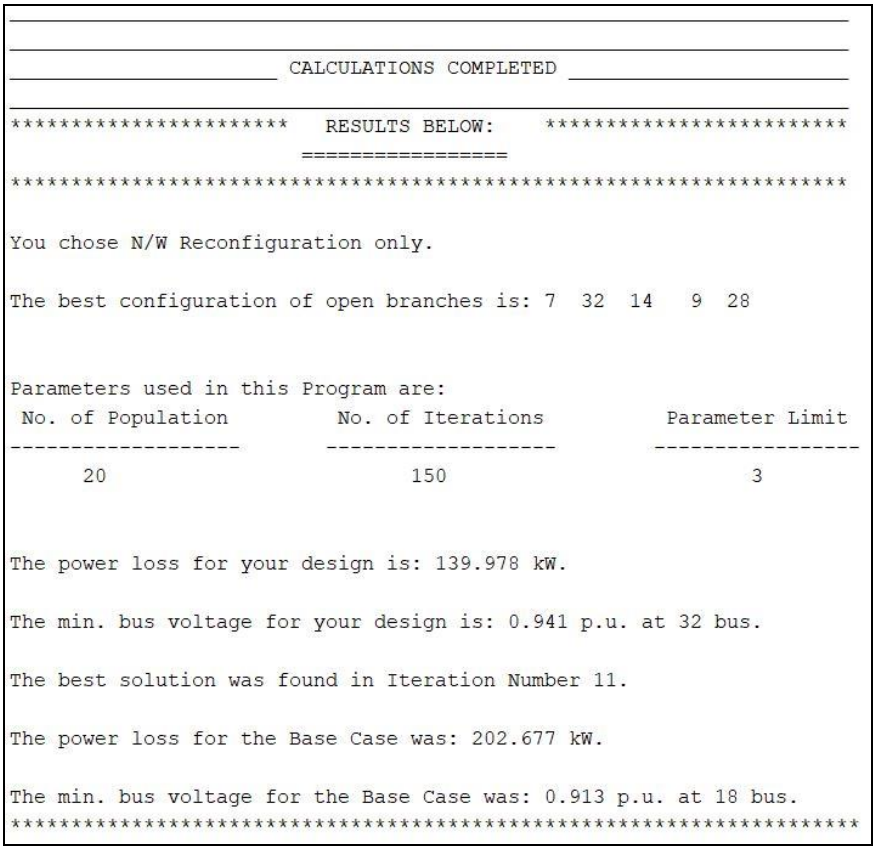
Appendix-1: <u>Results for IEEE 33 Bus System</u>



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______________________________________________________________________
______________________________________________________________________
______________________ CALCULATIONS COMPLETED _______________________
______________________________________________________________________
***********************   RESULTS BELOW:    *************************
                        =================
**********************************************************************

You chose N/W Reconfiguration only.

The best configuration of open branches is: 7  32  14   9  28


Parameters used in this Program are:
 No. of Population         No. of Iterations         Parameter Limit
-------------------       -------------------       -----------------
      20                         150                           3


The power loss for your design is: 139.978 kW.

The min. bus voltage for your design is: 0.941 p.u. at 32 bus.

The best solution was found in Iteration Number 11.

The power loss for the Base Case was: 202.677 kW.

The min. bus voltage for the Base Case was: 0.913 p.u. at 18 bus.
***********************************************************************
```

Figure 14: Result window for N/W Reconfiguration only for IEEE 33 Bus System when considering all DGs inject active power only

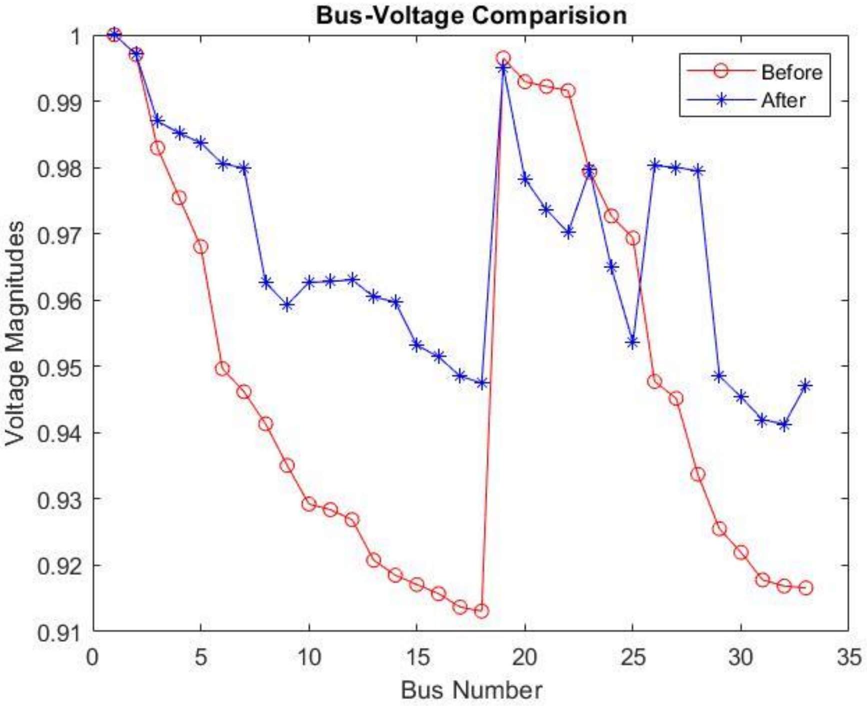
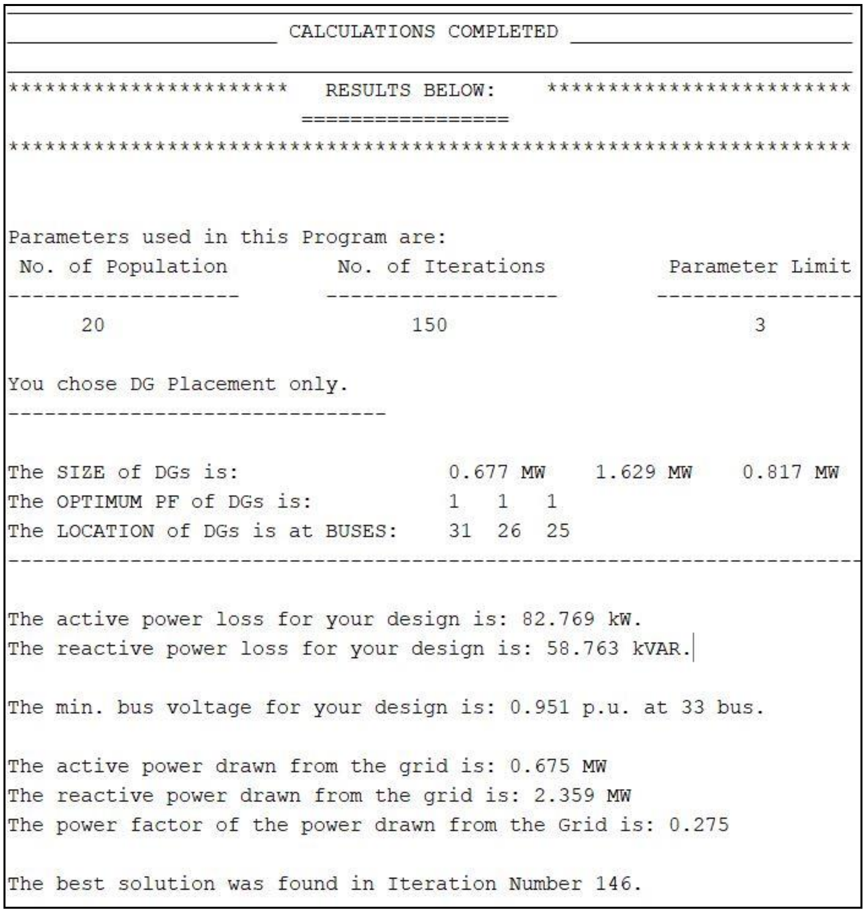


Figure 15: Bus Voltage Profile for N/W Reconfiguration only for IEEE 33 Bus System when considering all DGs inject active power only



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_______________________ CALCULATIONS COMPLETED _______________________________
________________________________________________________________________________
***********************   RESULTS BELOW:    *************************
                          =================
********************************************************************



Parameters used in this Program are:
 No. of Population        No. of Iterations         Parameter Limit
-------------------      -------------------       ----------------
      20                          150                          3

You chose DG Placement only.
-------------------------------

The SIZE of DGs is:                 0.677 MW    1.629 MW    0.817 MW
The OPTIMUM PF of DGs is:           1   1   1
The LOCATION of DGs is at BUSES:    31  26  25
-----------------------------------------------------------------------

The active power loss for your design is: 82.769 kW.
The reactive power loss for your design is: 58.763 kVAR.

The min. bus voltage for your design is: 0.951 p.u. at 33 bus.

The active power drawn from the grid is: 0.675 MW
The reactive power drawn from the grid is: 2.359 MW
The power factor of the power drawn from the Grid is: 0.275

The best solution was found in Iteration Number 146.
```

Figure 16: Result window for DG Placement only for IEEE 33 Bus System when considering all DGs inject active power only

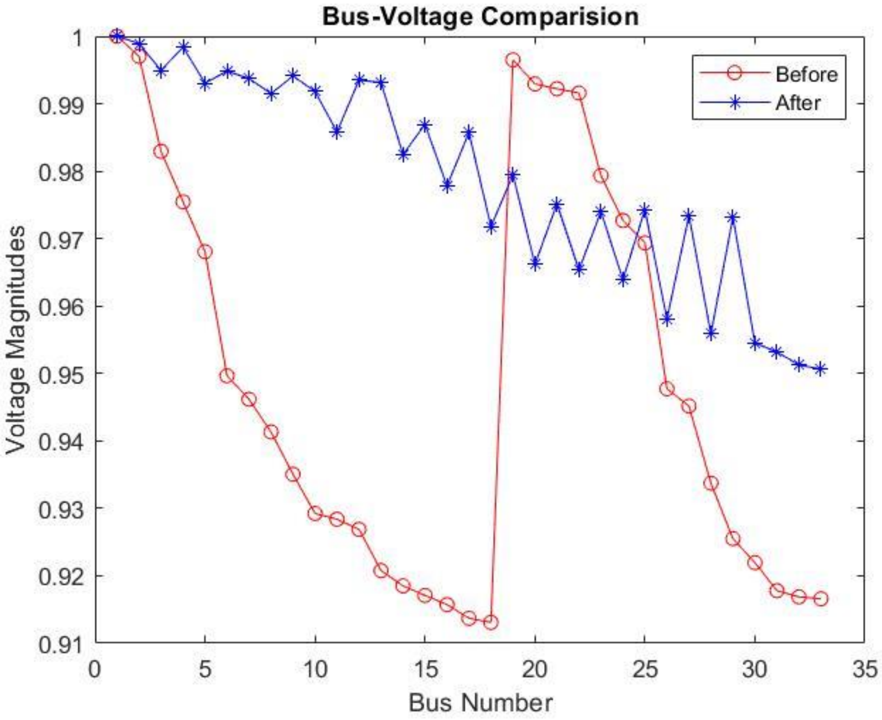
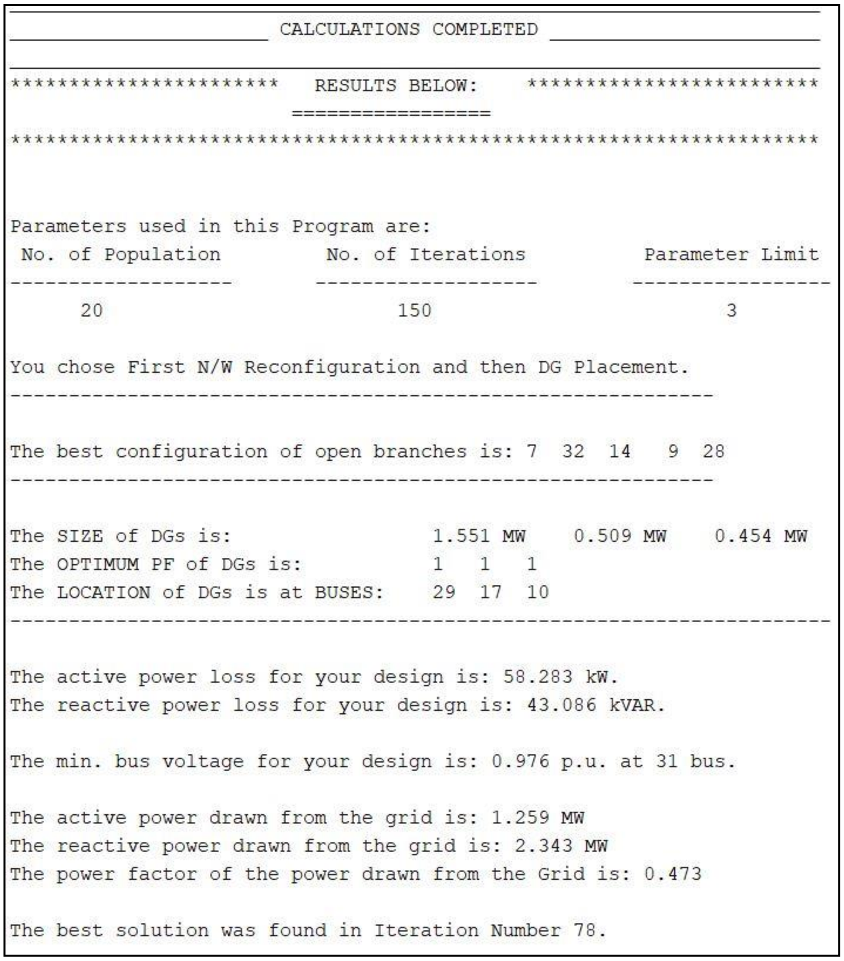


Figure 17: Bus Voltage Profile for DG Placement only for IEEE 33 Bus System when considering all DGs inject active power only



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______________________ CALCULATIONS COMPLETED _______________________

_____________________________________________________________________
***********************   RESULTS BELOW:    *************************
                        =================
*********************************************************************



Parameters used in this Program are:
 No. of Population         No. of Iterations          Parameter Limit
-------------------       -------------------        -----------------

      20                          150                           3

You chose First N/W Reconfiguration and then DG Placement.
------------------------------------------------------------

The best configuration of open branches is: 7  32  14   9  28
------------------------------------------------------------

The SIZE of DGs is:                1.551 MW    0.509 MW    0.454 MW
The OPTIMUM PF of DGs is:          1   1   1
The LOCATION of DGs is at BUSES:    29  17  10
----------------------------------------------------------------------

The active power loss for your design is: 58.283 kW.
The reactive power loss for your design is: 43.086 kVAR.

The min. bus voltage for your design is: 0.976 p.u. at 31 bus.

The active power drawn from the grid is: 1.259 MW
The reactive power drawn from the grid is: 2.343 MW
The power factor of the power drawn from the Grid is: 0.473

The best solution was found in Iteration Number 78.
```

Figure 18: Result window for First N/W Reconfiguration and then DG Placement for IEEE 33 Bus System when considering all DGs inject active power only

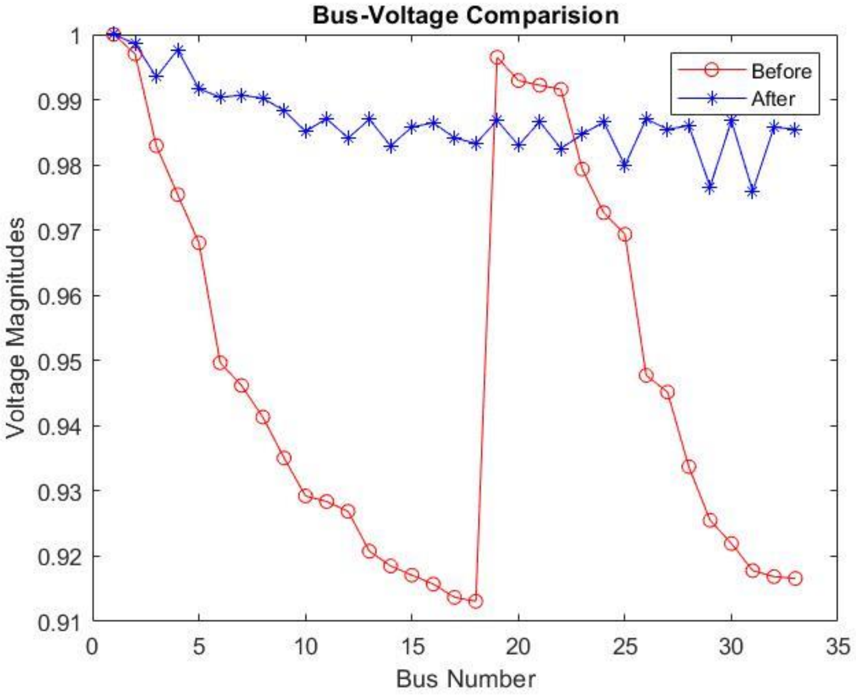
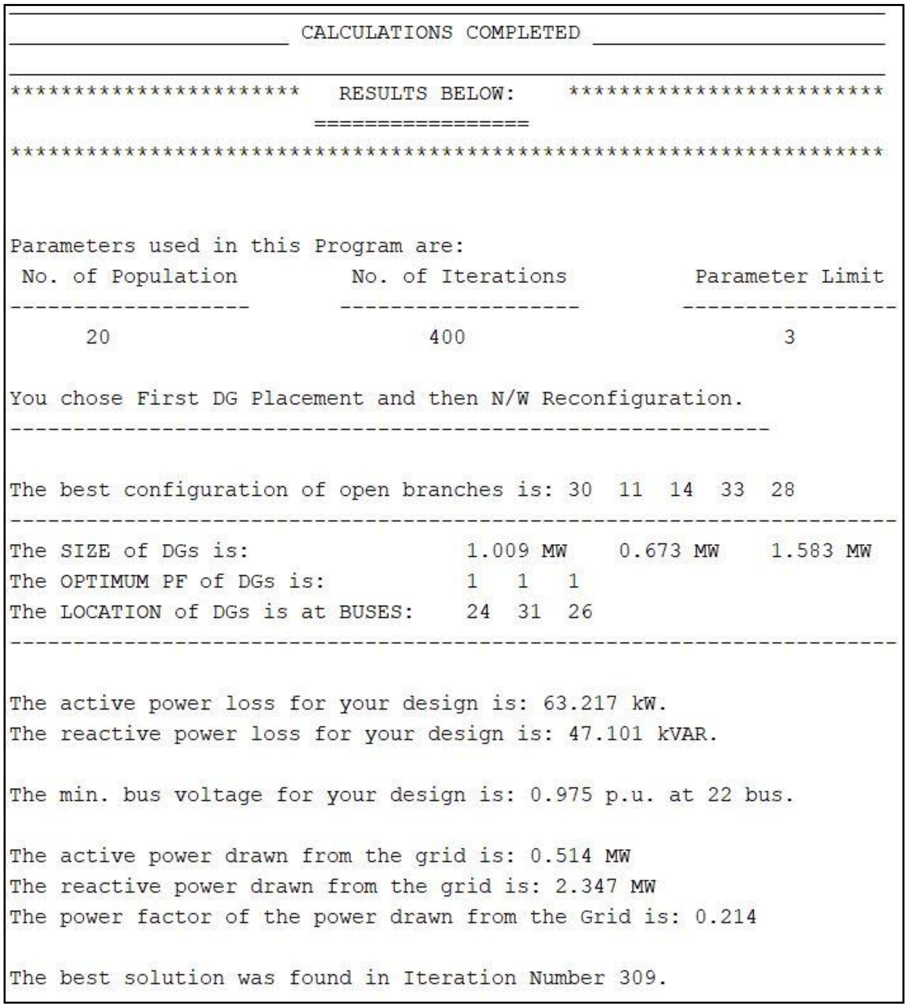


Figure 19: Bus Voltage Profile Result for First N/W Reconfiguration and then DG Placement for IEEE 33 Bus System when considering all DGs inject active power only



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______________________________________________________________________
______________________ CALCULATIONS COMPLETED ________________________
______________________________________________________________________
***********************   RESULTS BELOW:   *************************
                        =================
*********************************************************************



Parameters used in this Program are:
 No. of Population         No. of Iterations          Parameter Limit
-------------------       -------------------        -----------------

      20                         400                          3

You chose First DG Placement and then N/W Reconfiguration.
------------------------------------------------------------


The best configuration of open branches is: 30  11  14  33  28
----------------------------------------------------------------------
The SIZE of DGs is:                1.009 MW    0.673 MW    1.583 MW
The OPTIMUM PF of DGs is:          1   1   1
The LOCATION of DGs is at BUSES:   24  31  26
----------------------------------------------------------------------


The active power loss for your design is: 63.217 kW.
The reactive power loss for your design is: 47.101 kVAR.

The min. bus voltage for your design is: 0.975 p.u. at 22 bus.

The active power drawn from the grid is: 0.514 MW
The reactive power drawn from the grid is: 2.347 MW
The power factor of the power drawn from the Grid is: 0.214

The best solution was found in Iteration Number 309.
```

Figure 20: Result window for First DG Placement and then N/W Reconfiguration for IEEE 33 Bus System when considering all DGs inject active power only

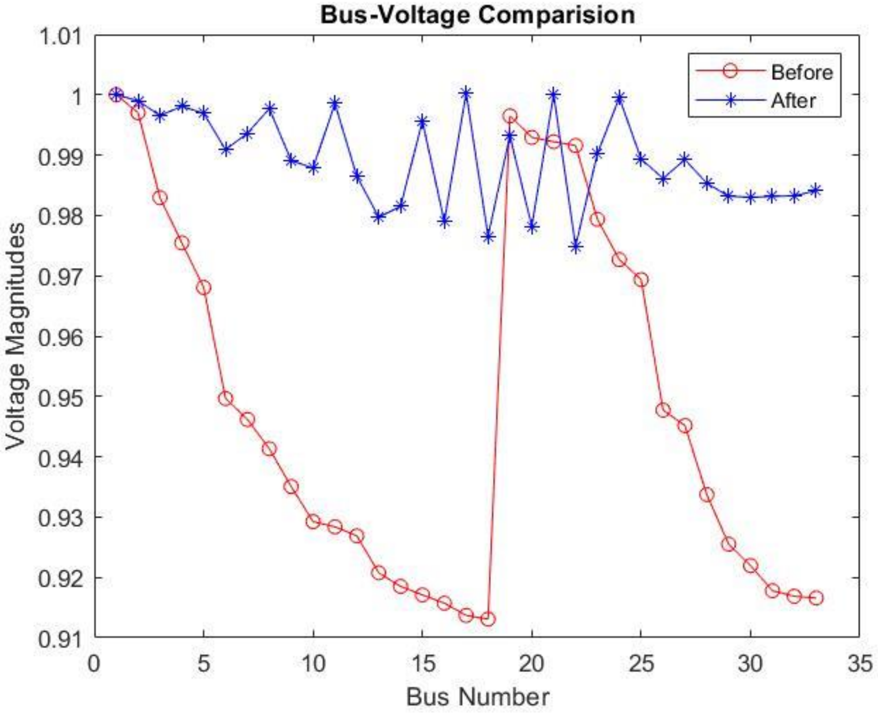
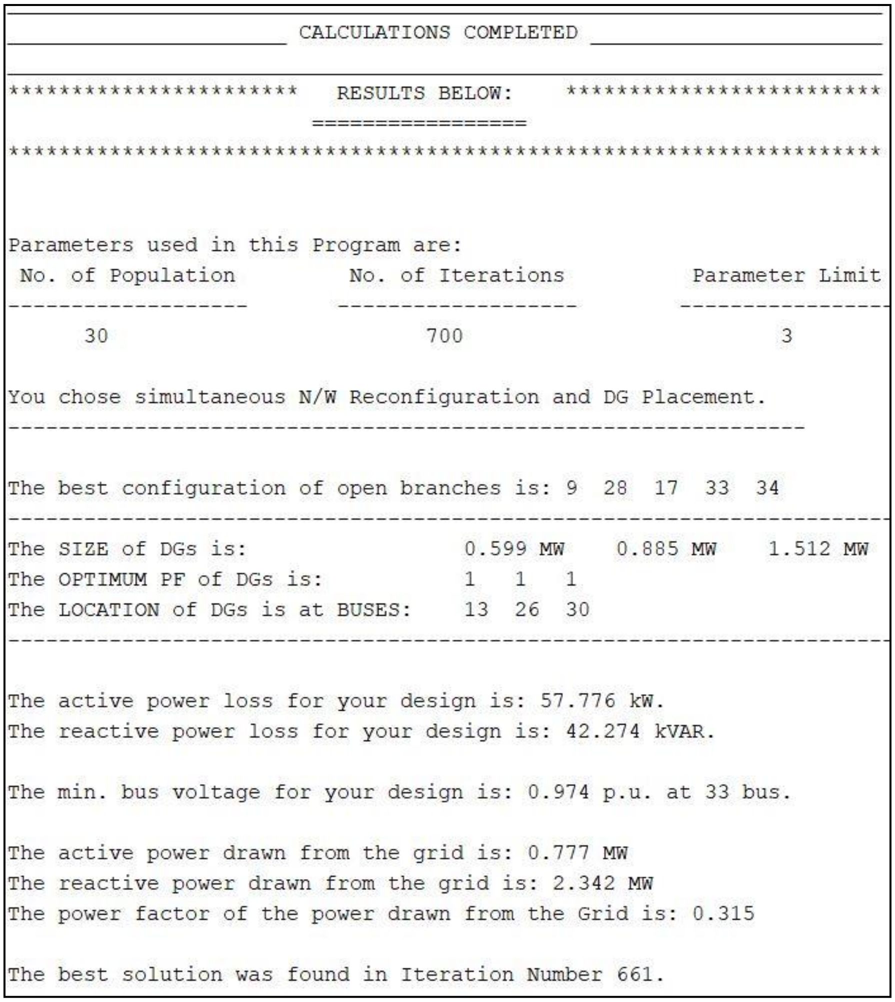


Figure 21: Bus Voltage Profile for First DG Placement and then N/W Reconfiguration for IEEE 33 Bus System when considering all DGs inject active power only



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______________________________________________________________________
______________________ CALCULATIONS COMPLETED ________________________
______________________________________________________________________
***********************   RESULTS BELOW:   *************************
                        =================
*********************************************************************



Parameters used in this Program are:
 No. of Population        No. of Iterations         Parameter Limit
-------------------      -------------------       ----------------
      30                         700                          3

You chose simultaneous N/W Reconfiguration and DG Placement.
---------------------------------------------------------------

The best configuration of open branches is: 9  28  17  33  34
----------------------------------------------------------------------
The SIZE of DGs is:                0.599 MW    0.885 MW    1.512 MW
The OPTIMUM PF of DGs is:          1   1   1
The LOCATION of DGs is at BUSES:   13  26  30
----------------------------------------------------------------------

The active power loss for your design is: 57.776 kW.
The reactive power loss for your design is: 42.274 kVAR.

The min. bus voltage for your design is: 0.974 p.u. at 33 bus.

The active power drawn from the grid is: 0.777 MW
The reactive power drawn from the grid is: 2.342 MW
The power factor of the power drawn from the Grid is: 0.315

The best solution was found in Iteration Number 661.
```

Figure 22: Result window for Simultaneous N/W Reconfiguration and DG Placement for IEEE 33 Bus System when considering all DGs inject active power only

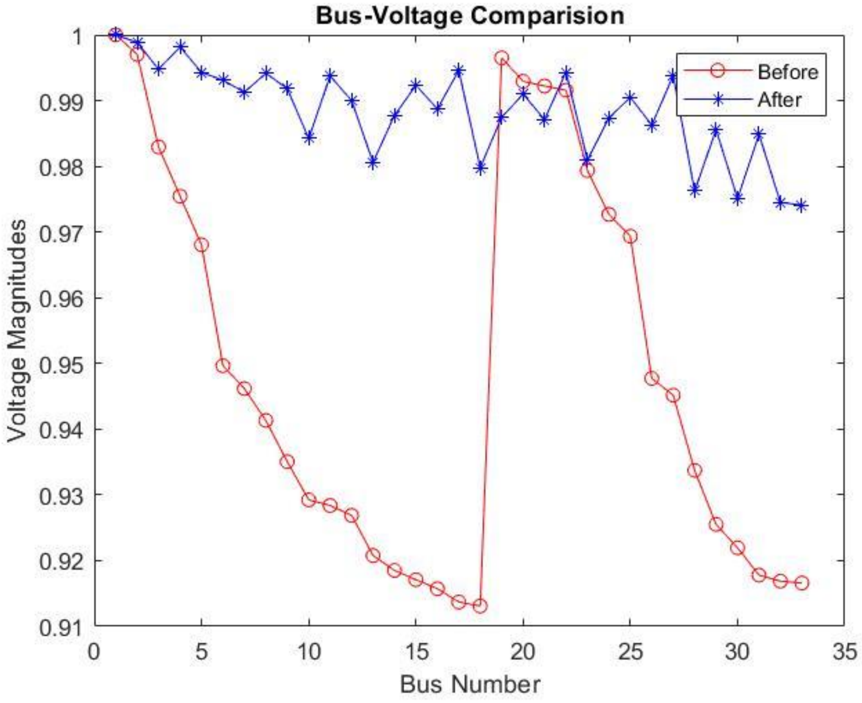
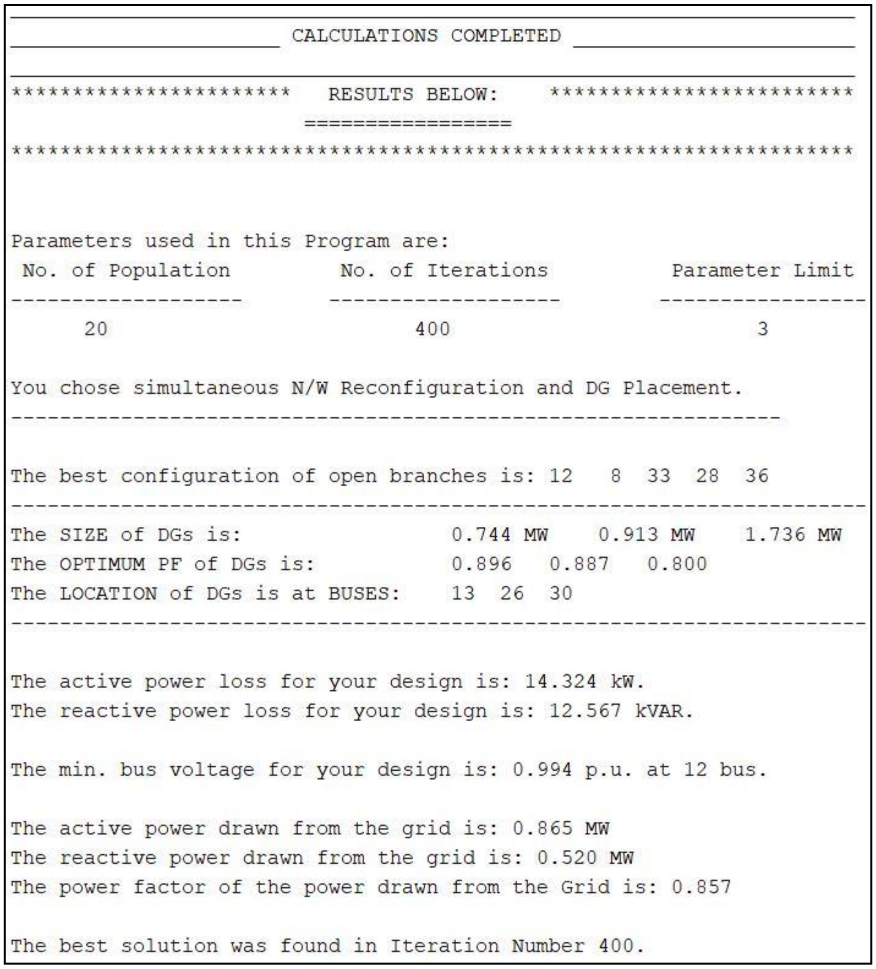


Figure 23: Bus Voltage Profile for Simultaneous N/W Reconfiguration and DG Placement for IEEE 33 Bus System when considering all DGs inject active power only



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_____________________________________________________________________
______________________ CALCULATIONS COMPLETED _______________________

_____________________________________________________________________
***********************   RESULTS BELOW:    *************************
                         =================
*********************************************************************



Parameters used in this Program are:
 No. of Population         No. of Iterations         Parameter Limit
-------------------       -------------------       -----------------

      20                        400                            3

You chose simultaneous N/W Reconfiguration and DG Placement.
---------------------------------------------------------------

The best configuration of open branches is: 12   8  33  28  36
----------------------------------------------------------------------
The SIZE of DGs is:                 0.744 MW    0.913 MW    1.736 MW
The OPTIMUM PF of DGs is:           0.896   0.887   0.800
The LOCATION of DGs is at BUSES:    13  26  30
----------------------------------------------------------------------


The active power loss for your design is: 14.324 kW.
The reactive power loss for your design is: 12.567 kVAR.

The min. bus voltage for your design is: 0.994 p.u. at 12 bus.

The active power drawn from the grid is: 0.865 MW
The reactive power drawn from the grid is: 0.520 MW
The power factor of the power drawn from the Grid is: 0.857

The best solution was found in Iteration Number 400.
```

Figure 24: Result window for Simultaneous N/W Reconfiguration and DG Placement for IEEE 33 Bus System when considering all DGs inject both active and reactive power

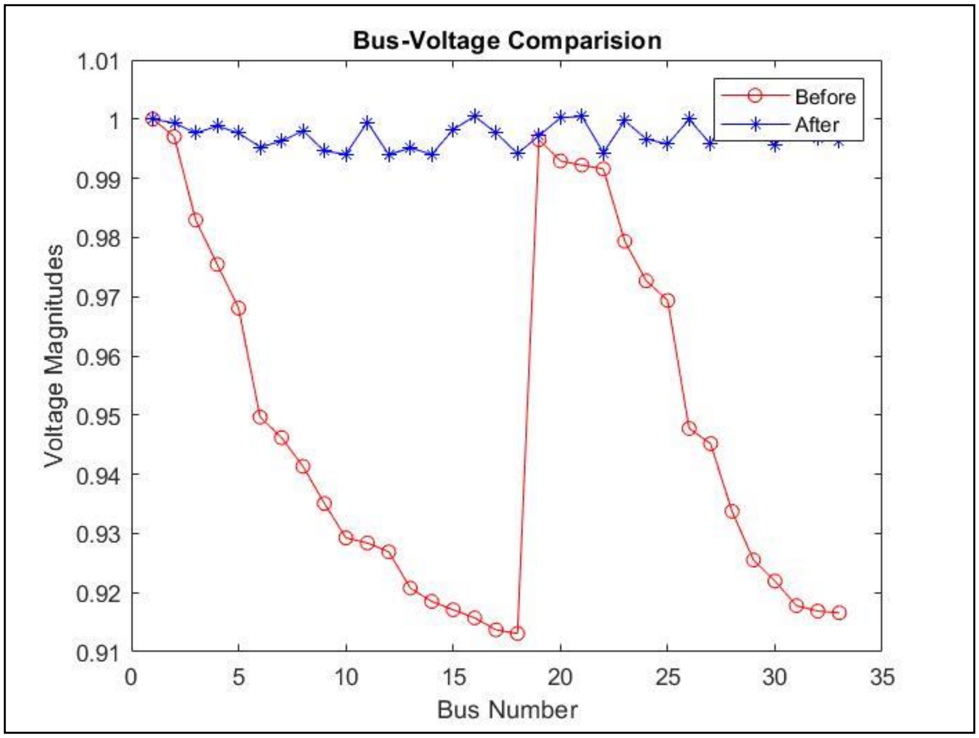
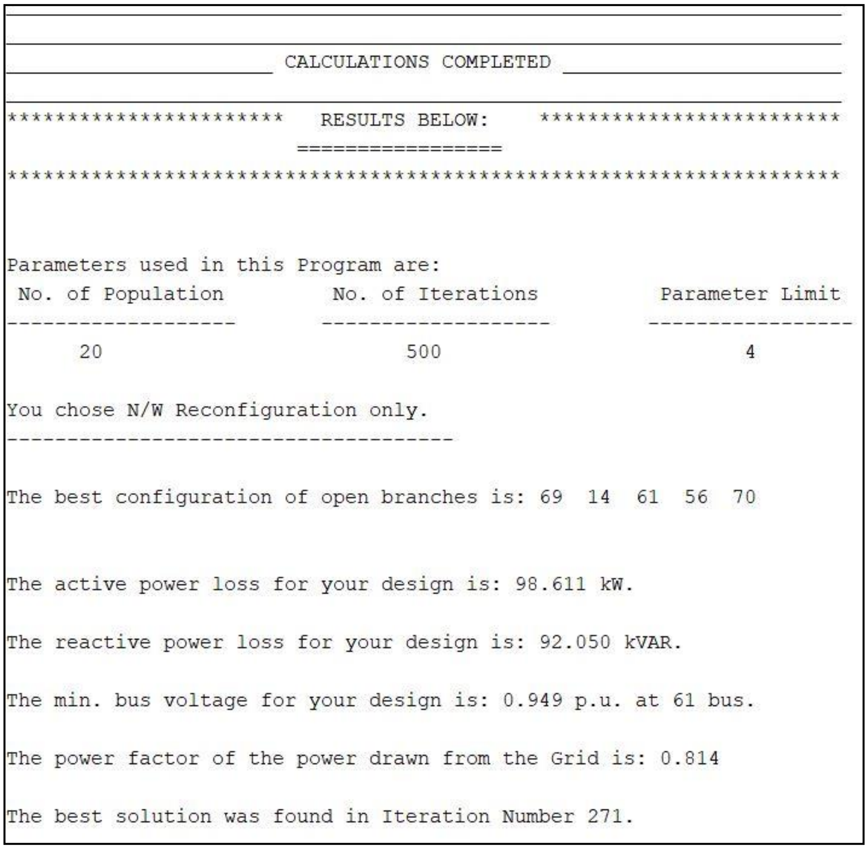


Figure 25: Voltage Profile for Simultaneous N/W Reconfiguration and DG Placement for IEEE 33 Bus System when considering all DGs inject both active and reactive power

Appendix-2: Results for IEEE 69 Bus System



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______________________ CALCULATIONS COMPLETED _______________________

***********************   RESULTS BELOW:    *************************
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**********************************************************************



Parameters used in this Program are:
 No. of Population         No. of Iterations          Parameter Limit
-------------------       -------------------        -----------------
      20                          500                         4

You chose N/W Reconfiguration only.
-------------------------------------

The best configuration of open branches is: 69  14  61  56  70


The active power loss for your design is: 98.611 kW.

The reactive power loss for your design is: 92.050 kVAR.

The min. bus voltage for your design is: 0.949 p.u. at 61 bus.

The power factor of the power drawn from the Grid is: 0.814

The best solution was found in Iteration Number 271.
```

Figure 26: Result window for N/W Reconfiguration only for IEEE 69 Bus System when considering all DGs inject active power only

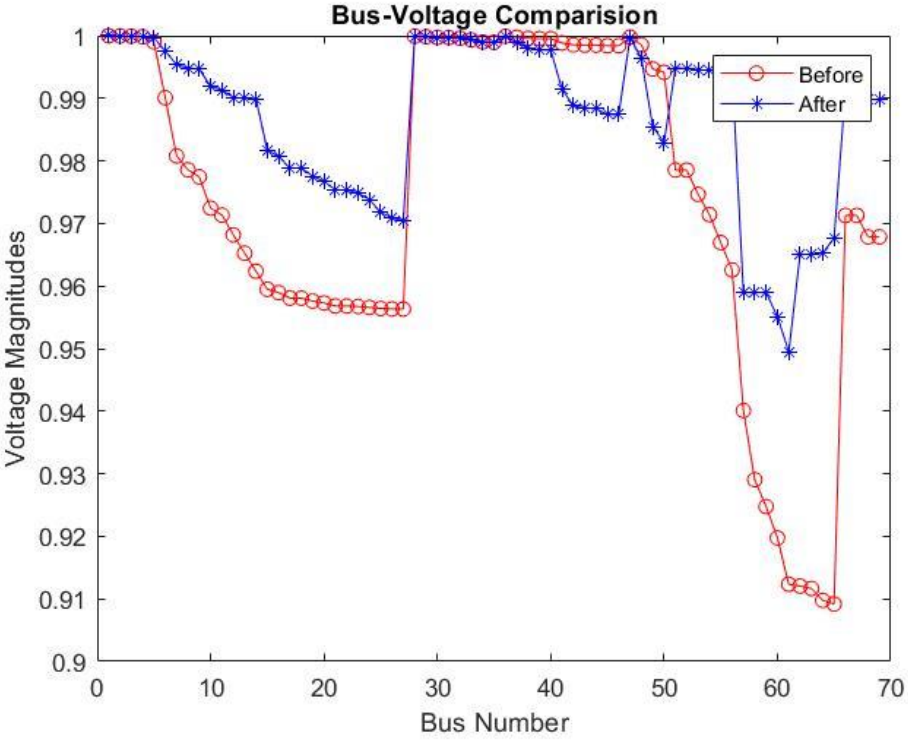
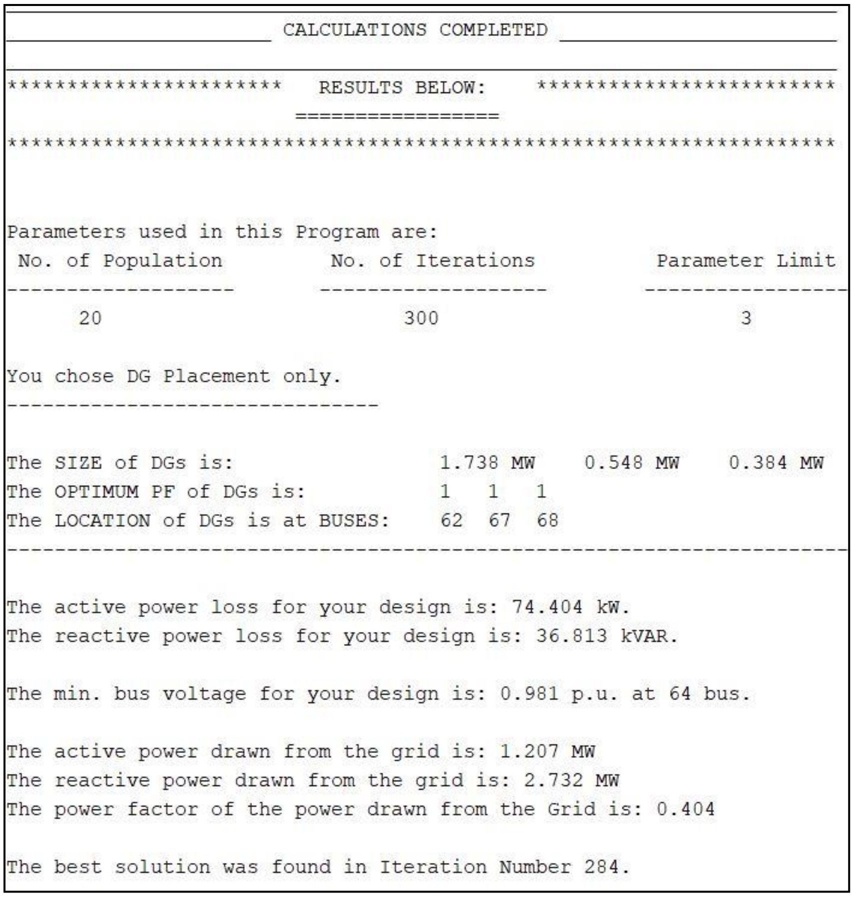


Figure 27: Bus Voltage Profile for N/W Reconfiguration only for IEEE 69 Bus System when considering all DGs inject active power only



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______________________ CALCULATIONS COMPLETED _______________________

***********************   RESULTS BELOW:    *************************
                        =================
*********************************************************************



Parameters used in this Program are:
 No. of Population         No. of Iterations          Parameter Limit
-------------------       -------------------        -----------------
     20                         300                          3

You chose DG Placement only.
-------------------------------


The SIZE of DGs is:                 1.738 MW    0.548 MW    0.384 MW
The OPTIMUM PF of DGs is:           1   1   1
The LOCATION of DGs is at BUSES:    62  67  68
----------------------------------------------------------------------

The active power loss for your design is: 74.404 kW.
The reactive power loss for your design is: 36.813 kVAR.

The min. bus voltage for your design is: 0.981 p.u. at 64 bus.

The active power drawn from the grid is: 1.207 MW
The reactive power drawn from the grid is: 2.732 MW
The power factor of the power drawn from the Grid is: 0.404

The best solution was found in Iteration Number 284.
```

Figure 28: Result window for DG Placement only for IEEE 69 Bus System when considering all DGs inject active power only

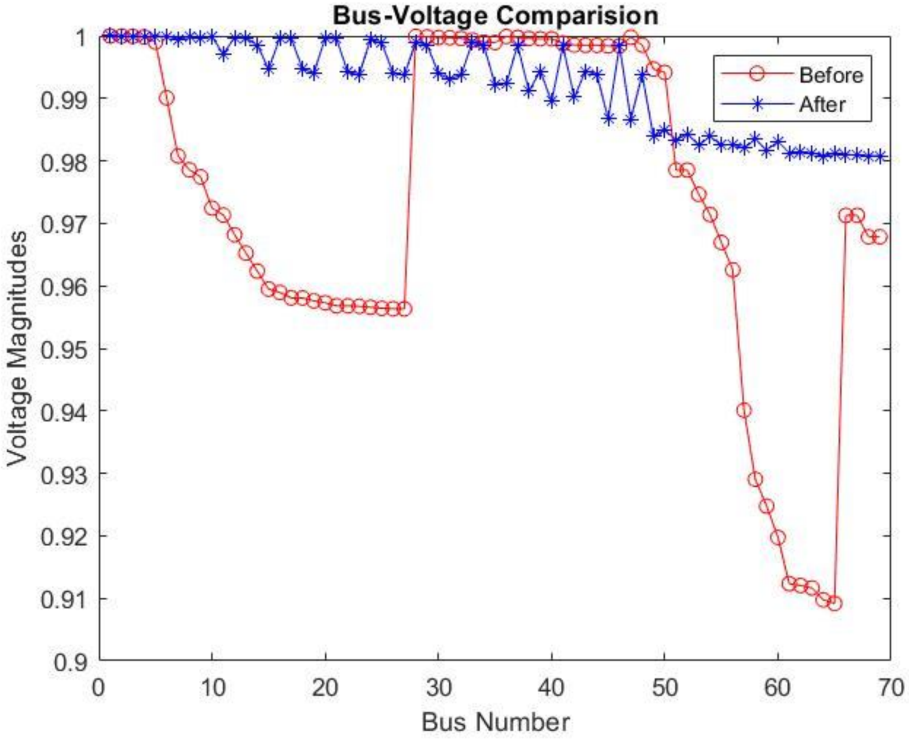
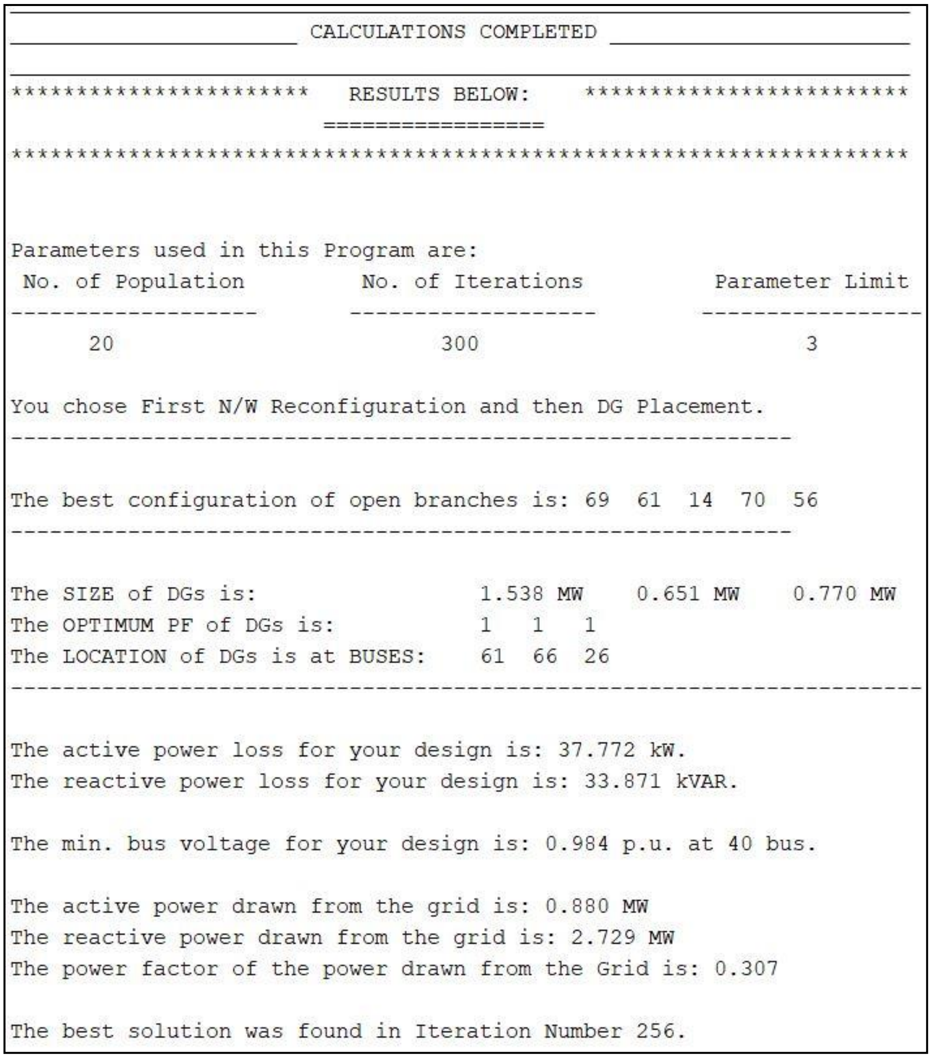


Figure 29: Bus Voltage Profile for DG Placement only for IEEE 69 Bus System when considering all DGs inject active power only



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_____________________________________________________________________
______________________ CALCULATIONS COMPLETED _______________________

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***********************   RESULTS BELOW:    *************************
                        =================
*********************************************************************


Parameters used in this Program are:
 No. of Population        No. of Iterations         Parameter Limit
-------------------      -------------------       -----------------

      20                       300                          3

You chose First N/W Reconfiguration and then DG Placement.
------------------------------------------------------------

The best configuration of open branches is: 69  61  14  70  56
------------------------------------------------------------


The SIZE of DGs is:                1.538 MW    0.651 MW    0.770 MW
The OPTIMUM PF of DGs is:          1   1   1
The LOCATION of DGs is at BUSES:   61  66  26
----------------------------------------------------------------------

The active power loss for your design is: 37.772 kW.
The reactive power loss for your design is: 33.871 kVAR.

The min. bus voltage for your design is: 0.984 p.u. at 40 bus.

The active power drawn from the grid is: 0.880 MW
The reactive power drawn from the grid is: 2.729 MW
The power factor of the power drawn from the Grid is: 0.307

The best solution was found in Iteration Number 256.
```

Figure 30: Result window for First N/W Reconfiguration and DG Placement for IEEE 69 Bus System when considering all DGs inject active power only

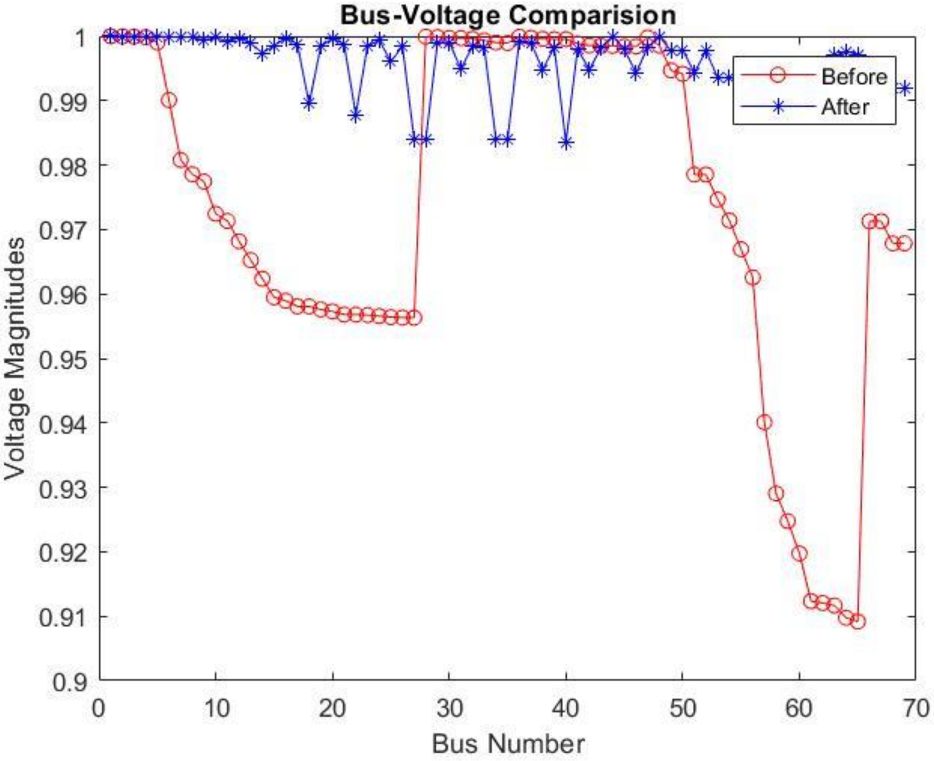
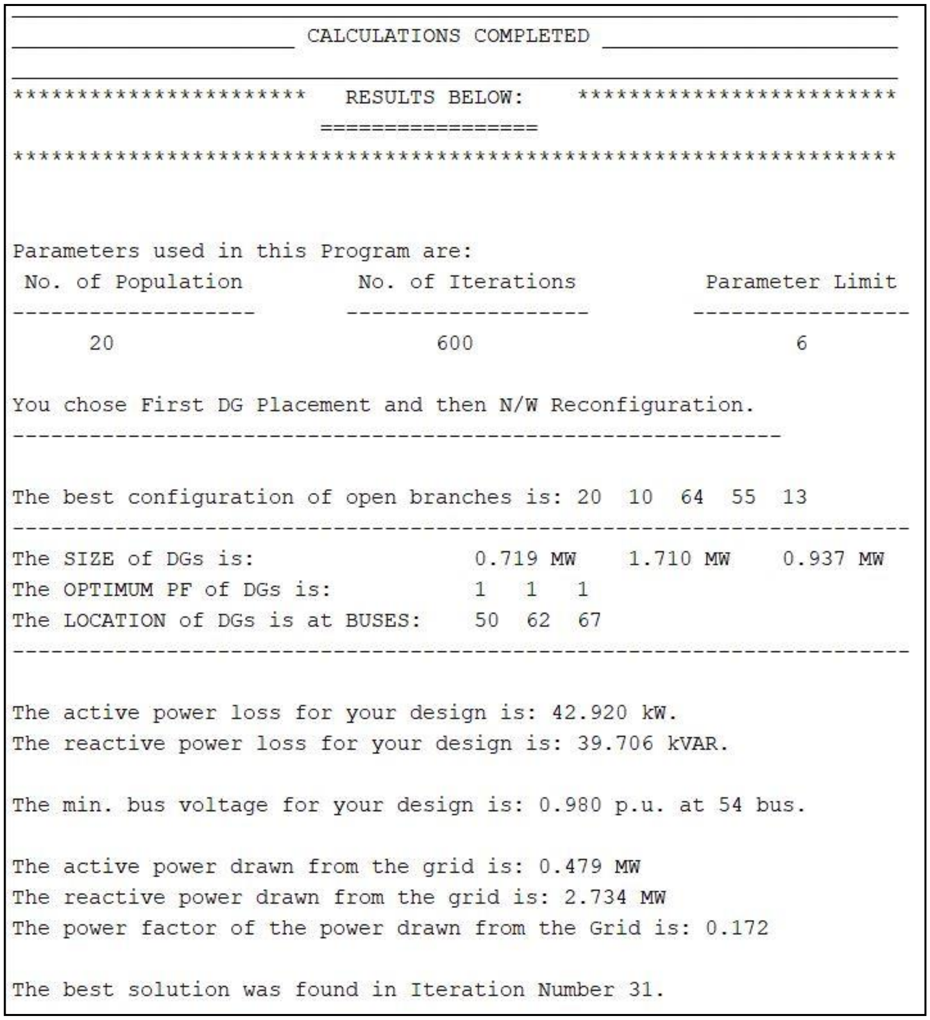


Figure 31: Bus Voltage Profile for First N/W Reconfiguration and DG Placement for IEEE 69 Bus System when considering all DGs inject active power only



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______________________ CALCULATIONS COMPLETED _______________________
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***********************   RESULTS BELOW:    *************************
                         =================
*********************************************************************



Parameters used in this Program are:
 No. of Population        No. of Iterations         Parameter Limit
-------------------      -------------------       -----------------

      20                          600                          6

You chose First DG Placement and then N/W Reconfiguration.
------------------------------------------------------------


The best configuration of open branches is: 20  10  64  55  13
----------------------------------------------------------------------
The SIZE of DGs is:                 0.719 MW    1.710 MW    0.937 MW
The OPTIMUM PF of DGs is:           1   1   1
The LOCATION of DGs is at BUSES:    50  62  67
----------------------------------------------------------------------


The active power loss for your design is: 42.920 kW.
The reactive power loss for your design is: 39.706 kVAR.

The min. bus voltage for your design is: 0.980 p.u. at 54 bus.

The active power drawn from the grid is: 0.479 MW
The reactive power drawn from the grid is: 2.734 MW
The power factor of the power drawn from the Grid is: 0.172

The best solution was found in Iteration Number 31.
```

Figure 32: Result window for First DG Placement and then N/W Reconfiguration for IEEE 69 Bus System when considering all DGs inject active power only

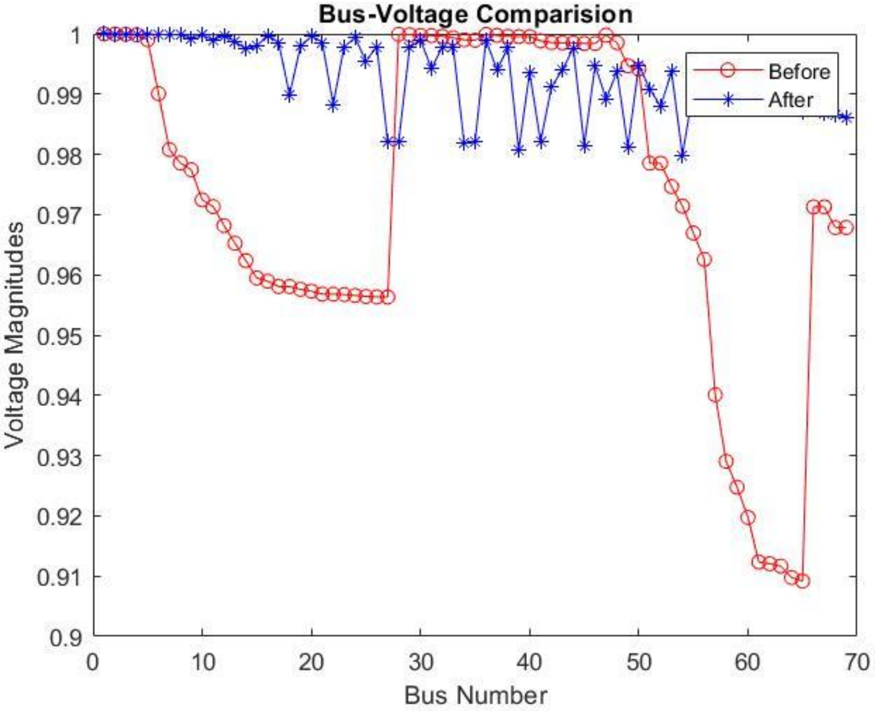
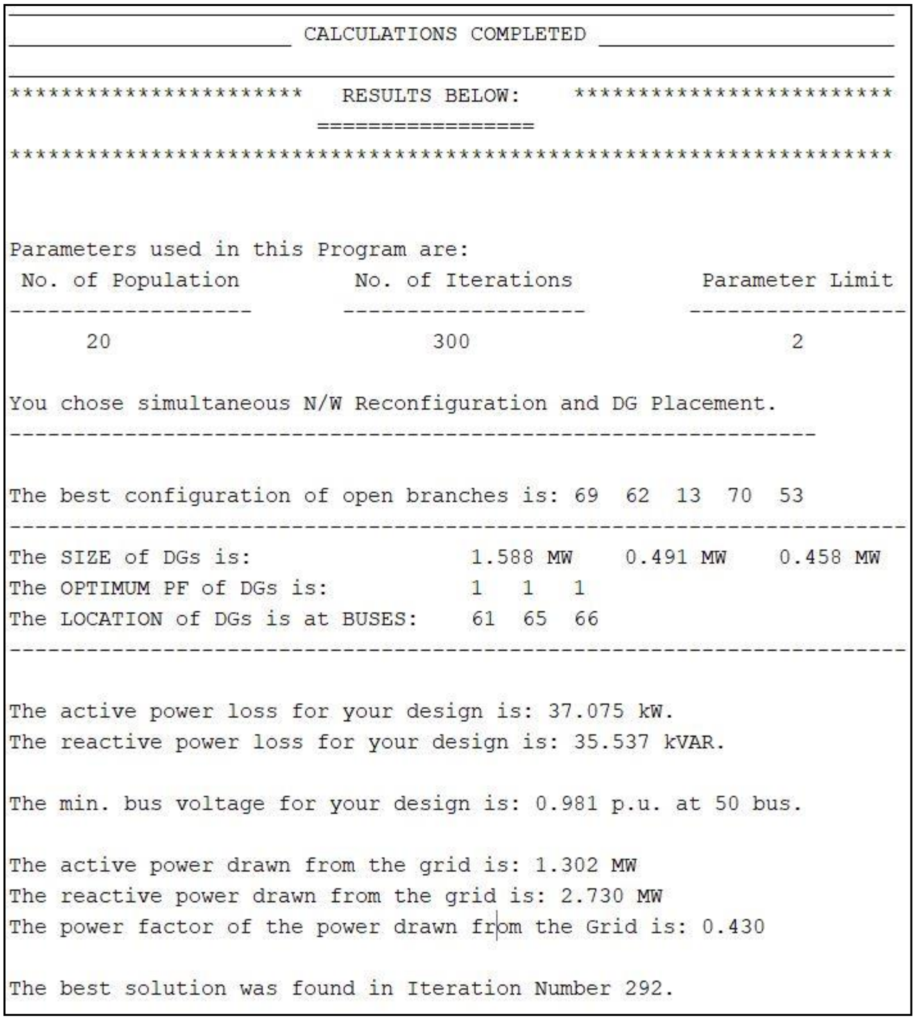


Figure 33: Bus Voltage Profile for First DG Placement and then N/W Reconfiguration for IEEE 69 Bus System when considering all DGs inject active power only



```
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______________________ CALCULATIONS COMPLETED _______________________
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***********************   RESULTS BELOW:    *************************
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Parameters used in this Program are:
 No. of Population        No. of Iterations         Parameter Limit
-------------------      -------------------       -----------------

      20                         300                         2

You chose simultaneous N/W Reconfiguration and DG Placement.
---------------------------------------------------------------

The best configuration of open branches is: 69  62  13  70  53
----------------------------------------------------------------------
The SIZE of DGs is:                1.588 MW    0.491 MW    0.458 MW
The OPTIMUM PF of DGs is:          1   1   1
The LOCATION of DGs is at BUSES:   61  65  66
----------------------------------------------------------------------

The active power loss for your design is: 37.075 kW.
The reactive power loss for your design is: 35.537 kVAR.

The min. bus voltage for your design is: 0.981 p.u. at 50 bus.

The active power drawn from the grid is: 1.302 MW
The reactive power drawn from the grid is: 2.730 MW
The power factor of the power drawn from the Grid is: 0.430

The best solution was found in Iteration Number 292.
```

Figure 34: Result window for Simultaneous N/W Reconfiguration and DG Placement for IEEE 69 Bus System when considering all DGs inject active power only

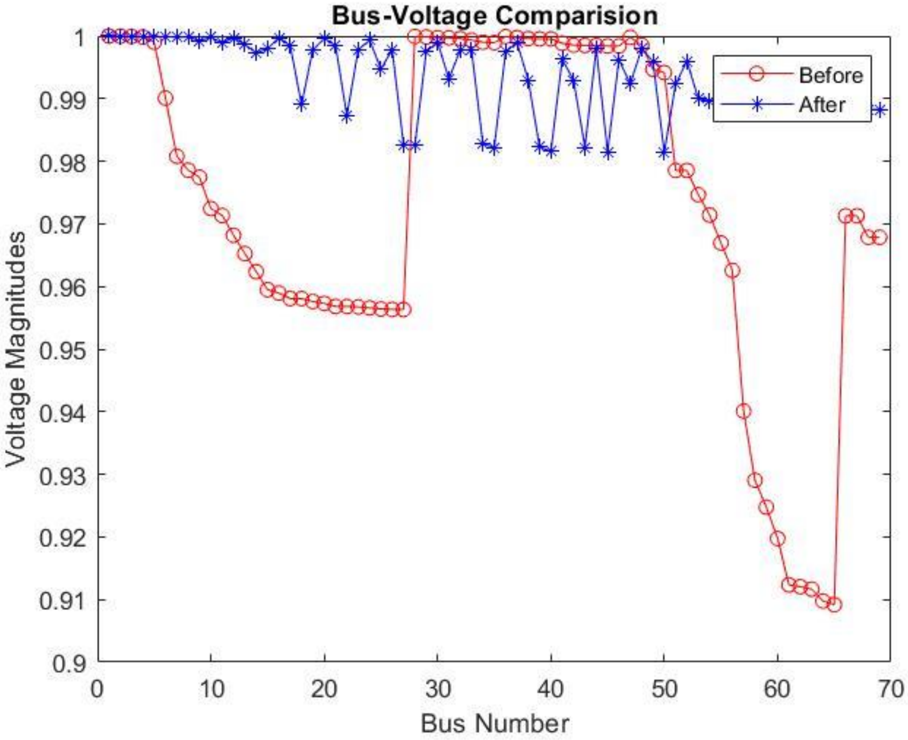
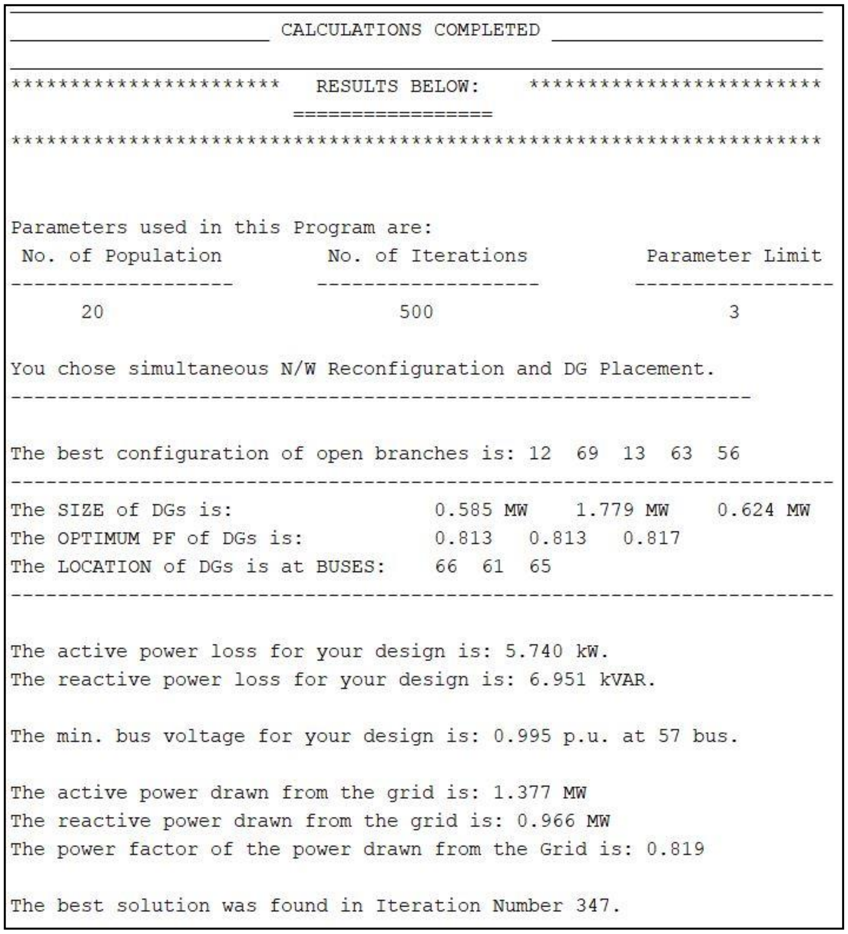


Figure 35: Bus Voltage Profile for Simultaneous N/W Reconfiguration and DG Placement for IEEE 69 Bus System when considering all DGs inject active power only



```
______________________ CALCULATIONS COMPLETED _______________________

_____________________________________________________________________
***********************   RESULTS BELOW:    *************************
                        =================
*********************************************************************



Parameters used in this Program are:
 No. of Population         No. of Iterations          Parameter Limit
-------------------       -------------------       -----------------

      20                          500                           3

You chose simultaneous N/W Reconfiguration and DG Placement.
---------------------------------------------------------------

The best configuration of open branches is: 12  69  13  63  56
----------------------------------------------------------------------
The SIZE of DGs is:                 0.585 MW    1.779 MW    0.624 MW
The OPTIMUM PF of DGs is:           0.813   0.813   0.817
The LOCATION of DGs is at BUSES:    66  61  65
----------------------------------------------------------------------


The active power loss for your design is: 5.740 kW.
The reactive power loss for your design is: 6.951 kVAR.

The min. bus voltage for your design is: 0.995 p.u. at 57 bus.

The active power drawn from the grid is: 1.377 MW
The reactive power drawn from the grid is: 0.966 MW
The power factor of the power drawn from the Grid is: 0.819

The best solution was found in Iteration Number 347.
```

Figure 36: Result window for Simultaneous N/W Reconfiguration and DG Placement for IEEE 69 Bus System when considering all DGs inject both active and reactive power

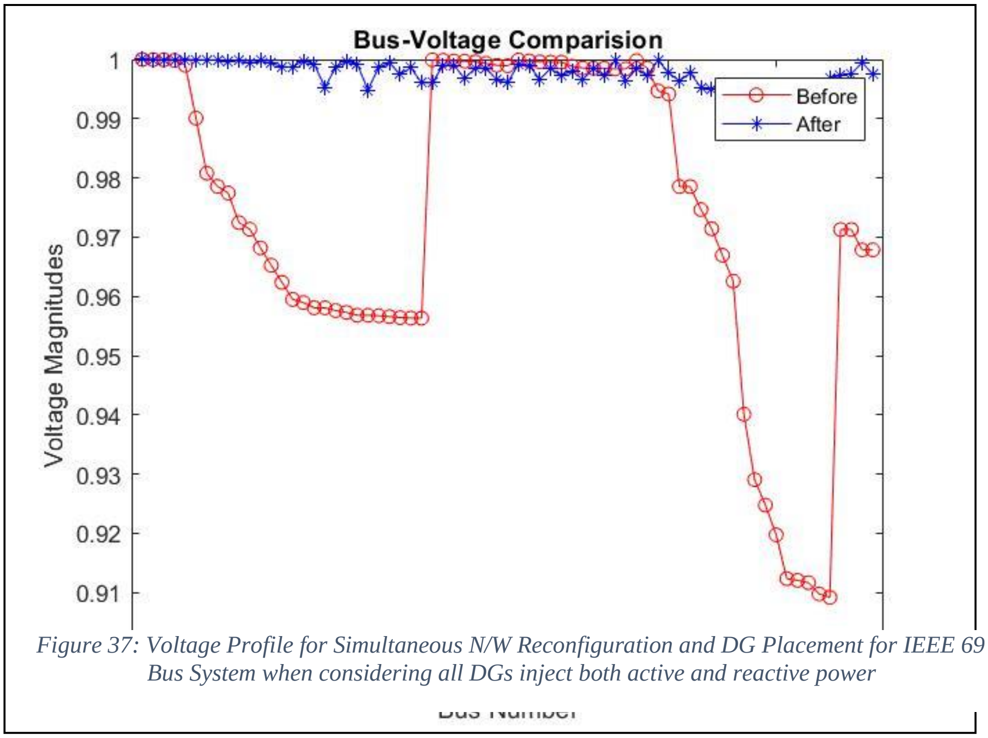
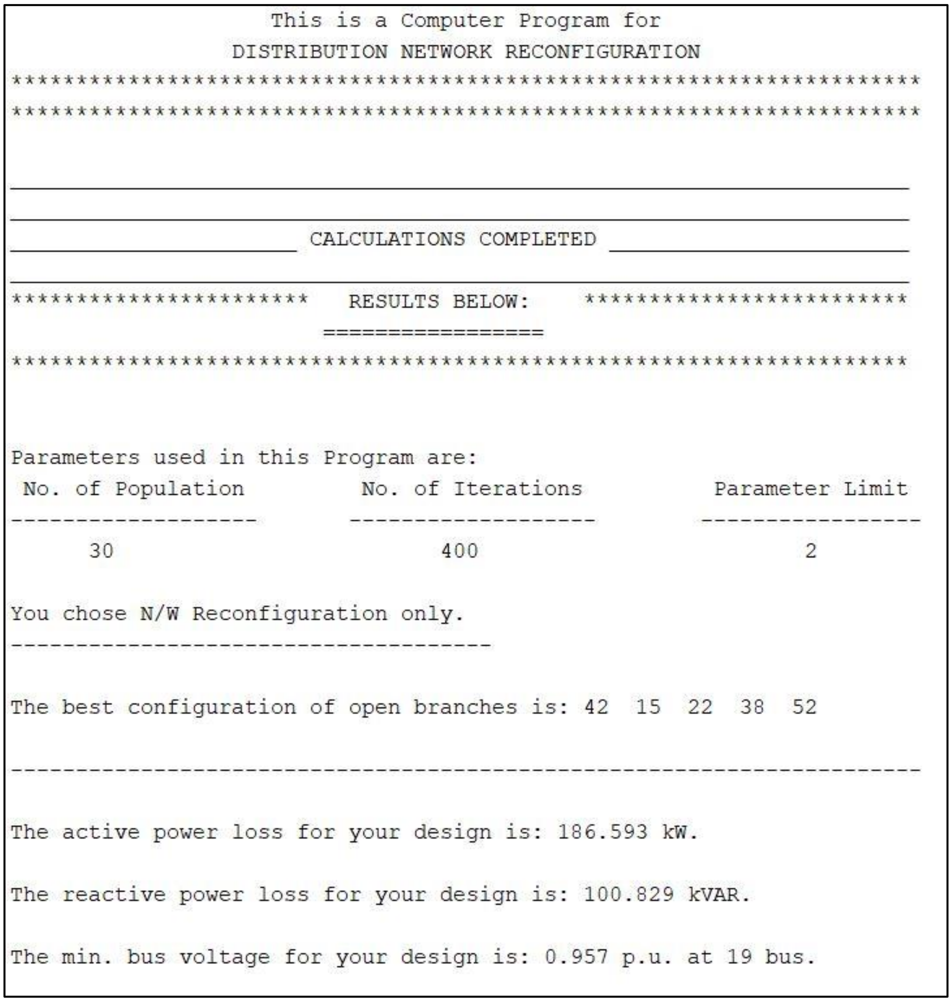


Figure 37: Voltage Profile for Simultaneous N/W Reconfiguration and DG Placement for IEEE 69 Bus System when considering all DGs inject both active and reactive power

Appendix-3: <u>Results for Daachhi Feeder</u>



```
                    This is a Computer Program for
                 DISTRIBUTION NETWORK RECONFIGURATION
**********************************************************************
**********************************************************************


_____________________________________________________________________
_____________________________________________________________________
______________________ CALCULATIONS COMPLETED _______________________
_____________________________________________________________________
***********************   RESULTS BELOW:    *************************
                        =================
*********************************************************************



Parameters used in this Program are:
 No. of Population         No. of Iterations         Parameter Limit
-------------------       -------------------       -----------------
      30                          400                          2

You chose N/W Reconfiguration only.
-------------------------------------

The best configuration of open branches is: 42  15  22  38  52

----------------------------------------------------------------------

The active power loss for your design is: 186.593 kW.

The reactive power loss for your design is: 100.829 kVAR.

The min. bus voltage for your design is: 0.957 p.u. at 19 bus.
```

Figure 38: Result window for N/W Reconfiguration only for Daachhi feeder

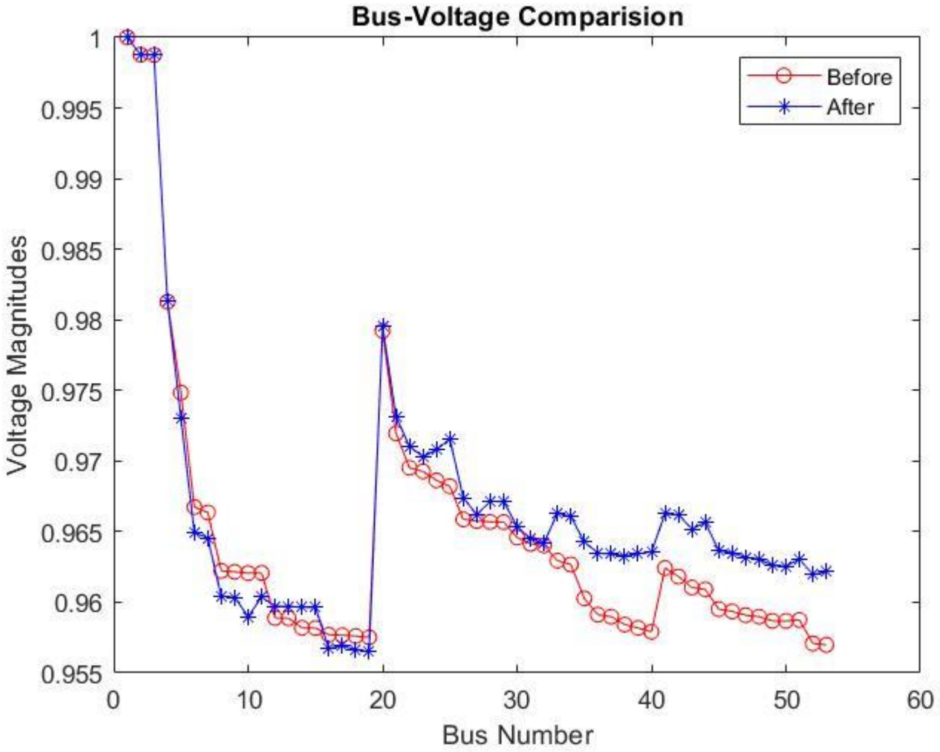
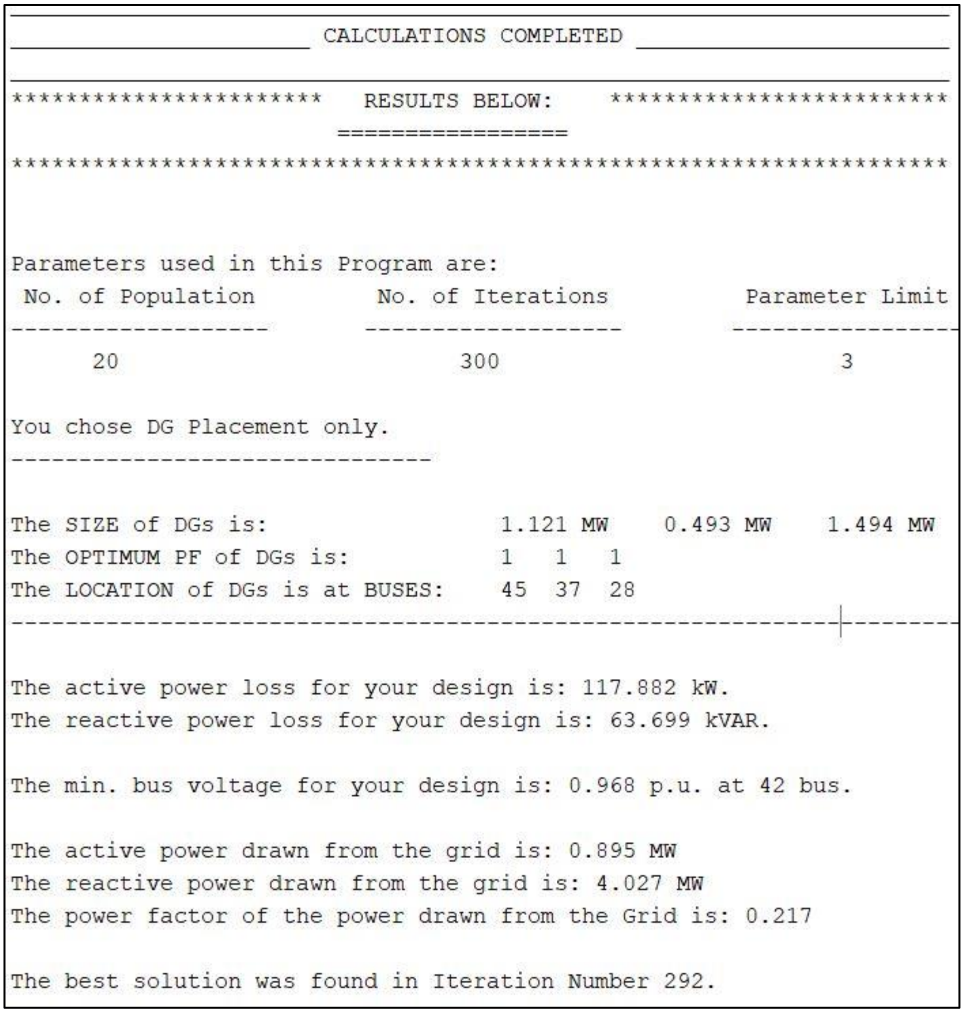


Figure 39: Bus Voltage Profile for N/W Reconfiguration only for Daachhi feeder



```
______________________________________________________________________
______________________ CALCULATIONS COMPLETED ________________________
______________________________________________________________________
***********************   RESULTS BELOW:    **************************
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**********************************************************************



Parameters used in this Program are:
 No. of Population        No. of Iterations         Parameter Limit
-------------------      -------------------       ----------------
      20                         300                        3

You chose DG Placement only.
-------------------------------


The SIZE of DGs is:                 1.121 MW    0.493 MW    1.494 MW
The OPTIMUM PF of DGs is:           1   1   1
The LOCATION of DGs is at BUSES:    45  37  28
---------------------------------------------------------------------------


The active power loss for your design is: 117.882 kW.
The reactive power loss for your design is: 63.699 kVAR.

The min. bus voltage for your design is: 0.968 p.u. at 42 bus.

The active power drawn from the grid is: 0.895 MW
The reactive power drawn from the grid is: 4.027 MW
The power factor of the power drawn from the Grid is: 0.217

The best solution was found in Iteration Number 292.
```

Figure 40: Result window for DG placement only for Daachhi feeder when DGs inject active power only

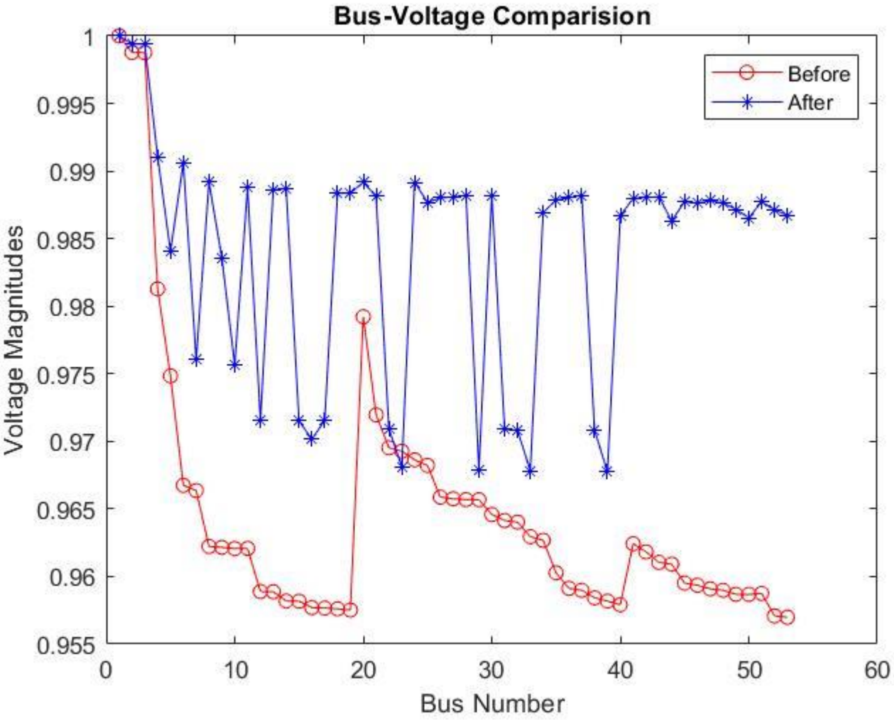
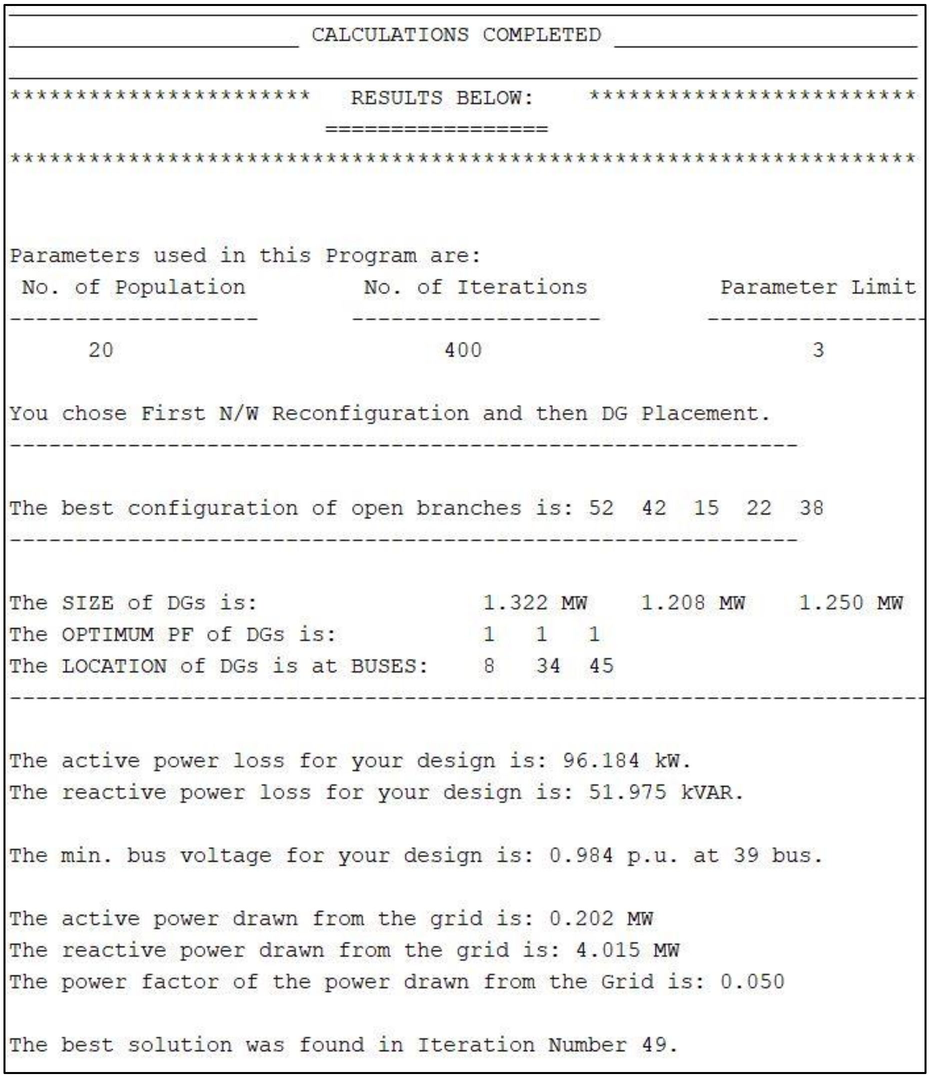


Figure 41: Bus Voltage Profile for DG placement only for Daachhi feeder when DGs inject active power only



```
_____________________________________________________________________
______________________ CALCULATIONS COMPLETED _______________________

_____________________________________________________________________
***********************   RESULTS BELOW:   **************************
                        =================
*********************************************************************



Parameters used in this Program are:
 No. of Population        No. of Iterations         Parameter Limit
-------------------       -------------------       -----------------

      20                         400                          3

You chose First N/W Reconfiguration and then DG Placement.
------------------------------------------------------------

The best configuration of open branches is: 52  42  15  22  38
------------------------------------------------------------

The SIZE of DGs is:                 1.322 MW    1.208 MW    1.250 MW
The OPTIMUM PF of DGs is:           1   1   1
The LOCATION of DGs is at BUSES:    8   34  45
---------------------------------------------------------------------

The active power loss for your design is: 96.184 kW.
The reactive power loss for your design is: 51.975 kVAR.

The min. bus voltage for your design is: 0.984 p.u. at 39 bus.

The active power drawn from the grid is: 0.202 MW
The reactive power drawn from the grid is: 4.015 MW
The power factor of the power drawn from the Grid is: 0.050

The best solution was found in Iteration Number 49.
```

Figure 42: Result window for First N/W Reconfiguration and then DG Placement for Daachhi feeder when DGs inject active power only

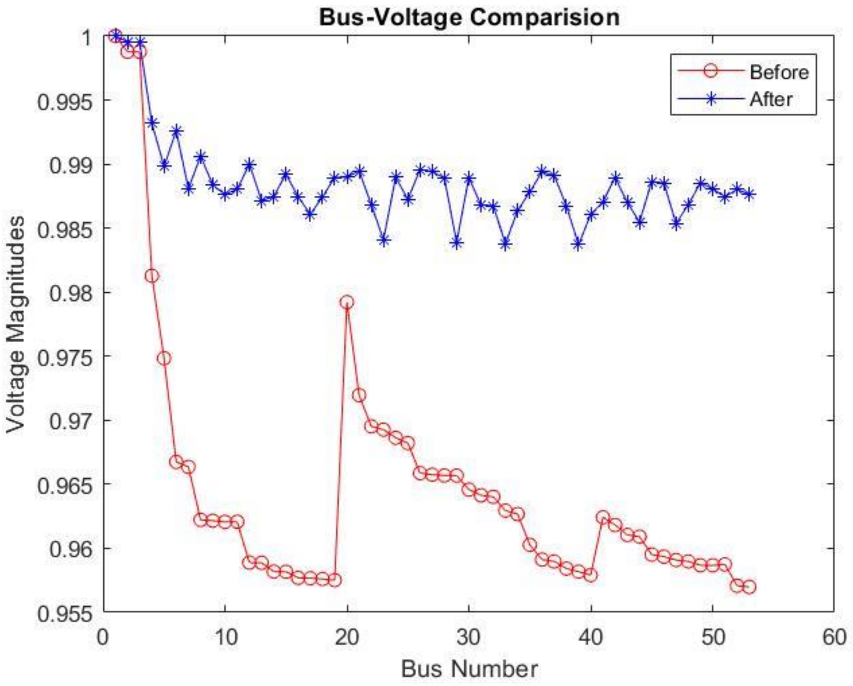
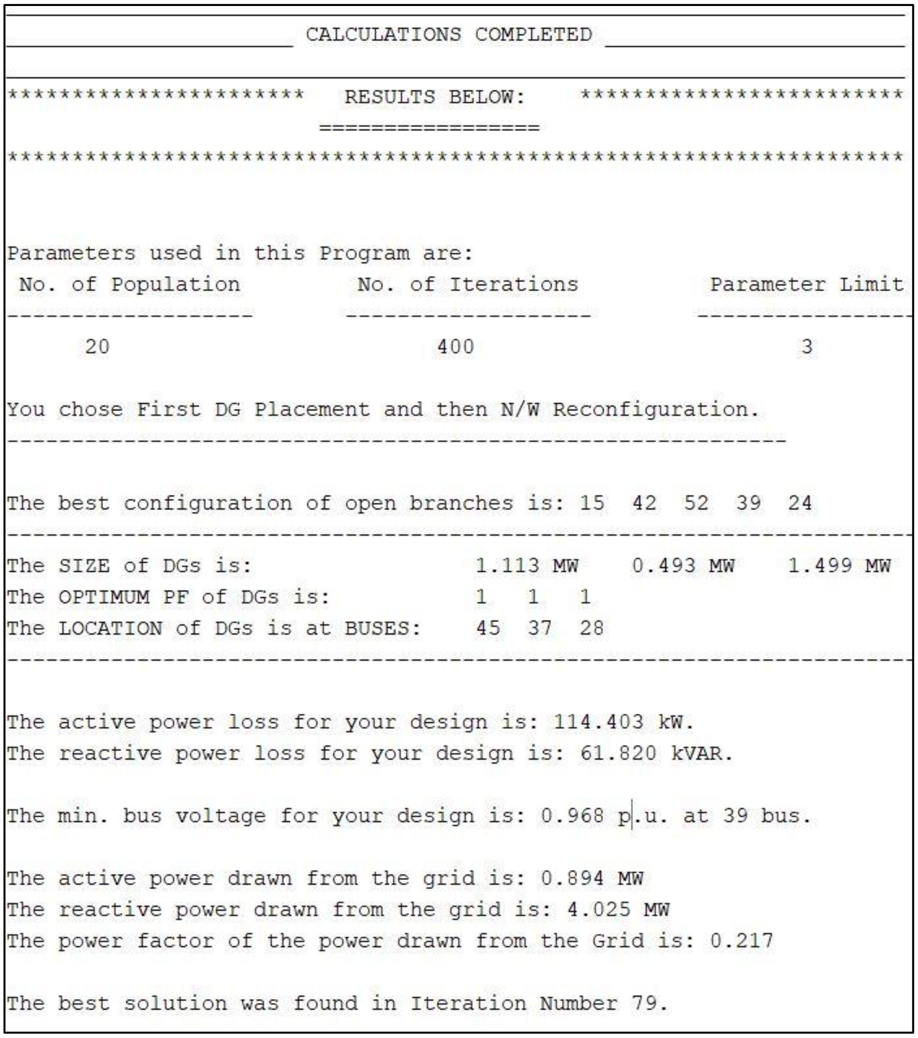


Figure 43: Bus Voltage Profile for First N/W Reconfiguration and then DG Placement for Daachhi feeder when DGs inject active power only



```
_____________________________________________________________________
______________________ CALCULATIONS COMPLETED _______________________
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***********************   RESULTS BELOW:    *************************
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*********************************************************************



Parameters used in this Program are:
 No. of Population        No. of Iterations         Parameter Limit
-------------------       -------------------       -----------------

      20                        400                          3

You chose First DG Placement and then N/W Reconfiguration.
------------------------------------------------------------

The best configuration of open branches is: 15  42  52  39  24
---------------------------------------------------------------------
The SIZE of DGs is:                1.113 MW    0.493 MW    1.499 MW
The OPTIMUM PF of DGs is:          1   1   1
The LOCATION of DGs is at BUSES:    45  37  28
---------------------------------------------------------------------

The active power loss for your design is: 114.403 kW.
The reactive power loss for your design is: 61.820 kVAR.

The min. bus voltage for your design is: 0.968 p.u. at 39 bus.

The active power drawn from the grid is: 0.894 MW
The reactive power drawn from the grid is: 4.025 MW
The power factor of the power drawn from the Grid is: 0.217

The best solution was found in Iteration Number 79.
```

Figure 44: Result window for First DG Placement and then N/W Reconfiguration for Daachhi feeder when DGs inject active power only

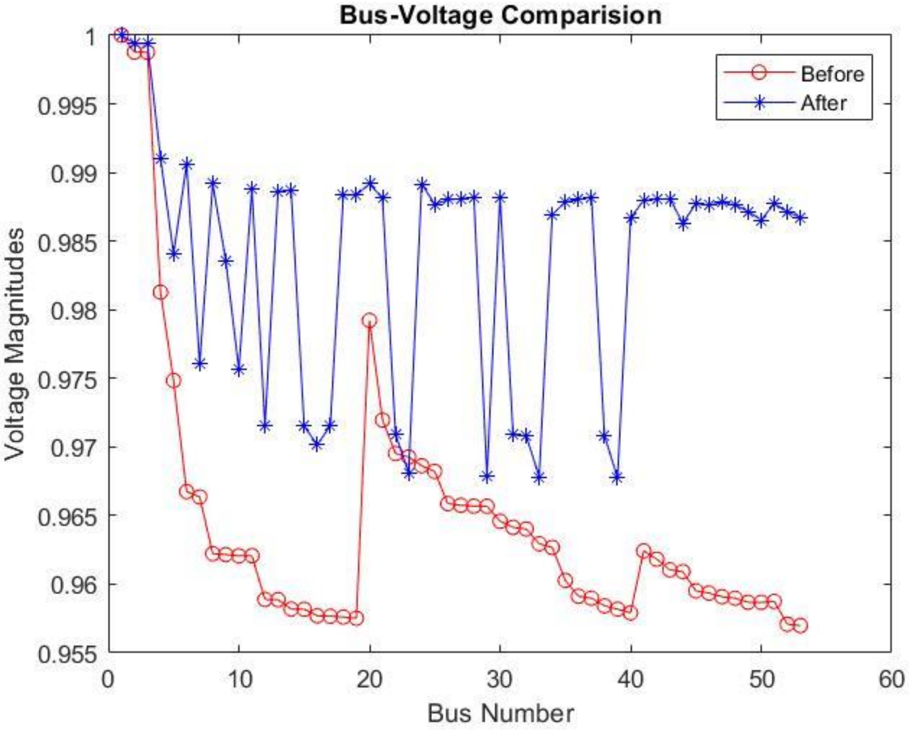
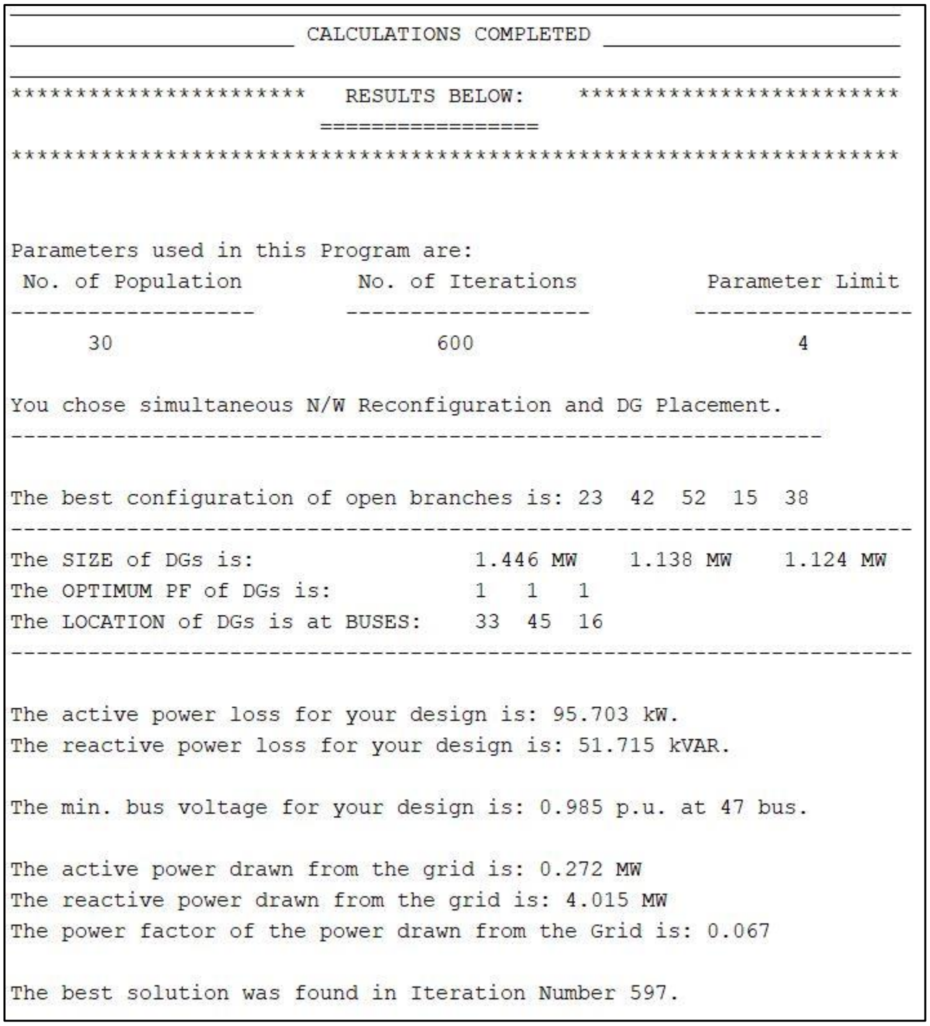


Figure 45: Bus Voltage Profile for First DG Placement and then N/W Reconfiguration for Daachhi feeder when DGs inject active power only



```
______________________ CALCULATIONS COMPLETED _______________________
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***********************   RESULTS BELOW:    *************************
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**********************************************************************



Parameters used in this Program are:
 No. of Population         No. of Iterations         Parameter Limit
-------------------       -------------------       -----------------

      30                        600                           4

You chose simultaneous N/W Reconfiguration and DG Placement.
---------------------------------------------------------------

The best configuration of open branches is: 23  42  52  15  38
----------------------------------------------------------------------
The SIZE of DGs is:                 1.446 MW    1.138 MW    1.124 MW
The OPTIMUM PF of DGs is:           1   1   1
The LOCATION of DGs is at BUSES:    33  45  16
----------------------------------------------------------------------


The active power loss for your design is: 95.703 kW.
The reactive power loss for your design is: 51.715 kVAR.

The min. bus voltage for your design is: 0.985 p.u. at 47 bus.

The active power drawn from the grid is: 0.272 MW
The reactive power drawn from the grid is: 4.015 MW
The power factor of the power drawn from the Grid is: 0.067

The best solution was found in Iteration Number 597.
```

Figure 46: Result window for Simultaneous N/W Reconfiguration and DG placement for Daachhi feeder when DGs inject active power only

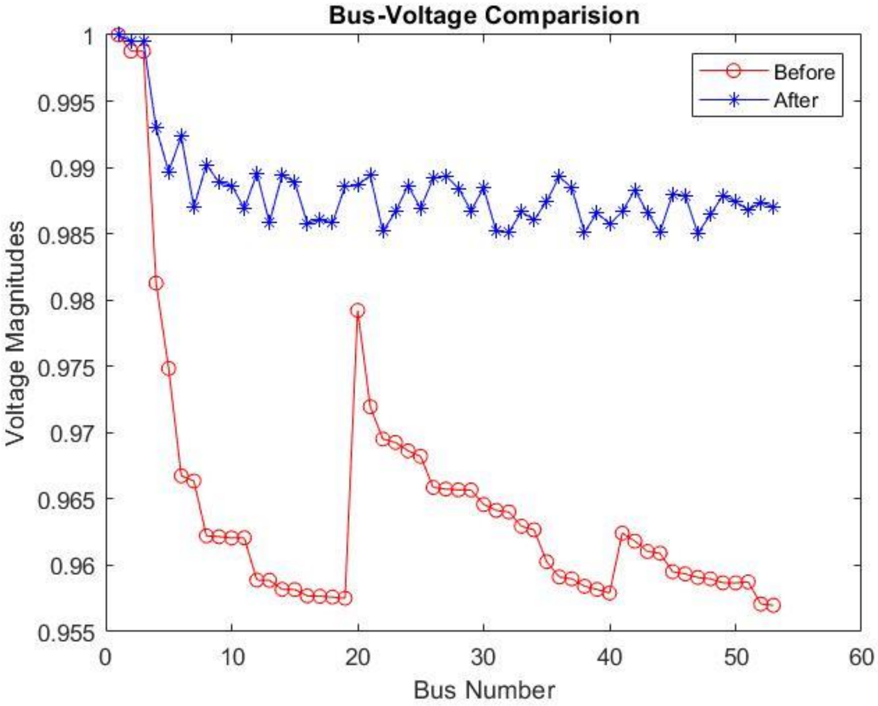
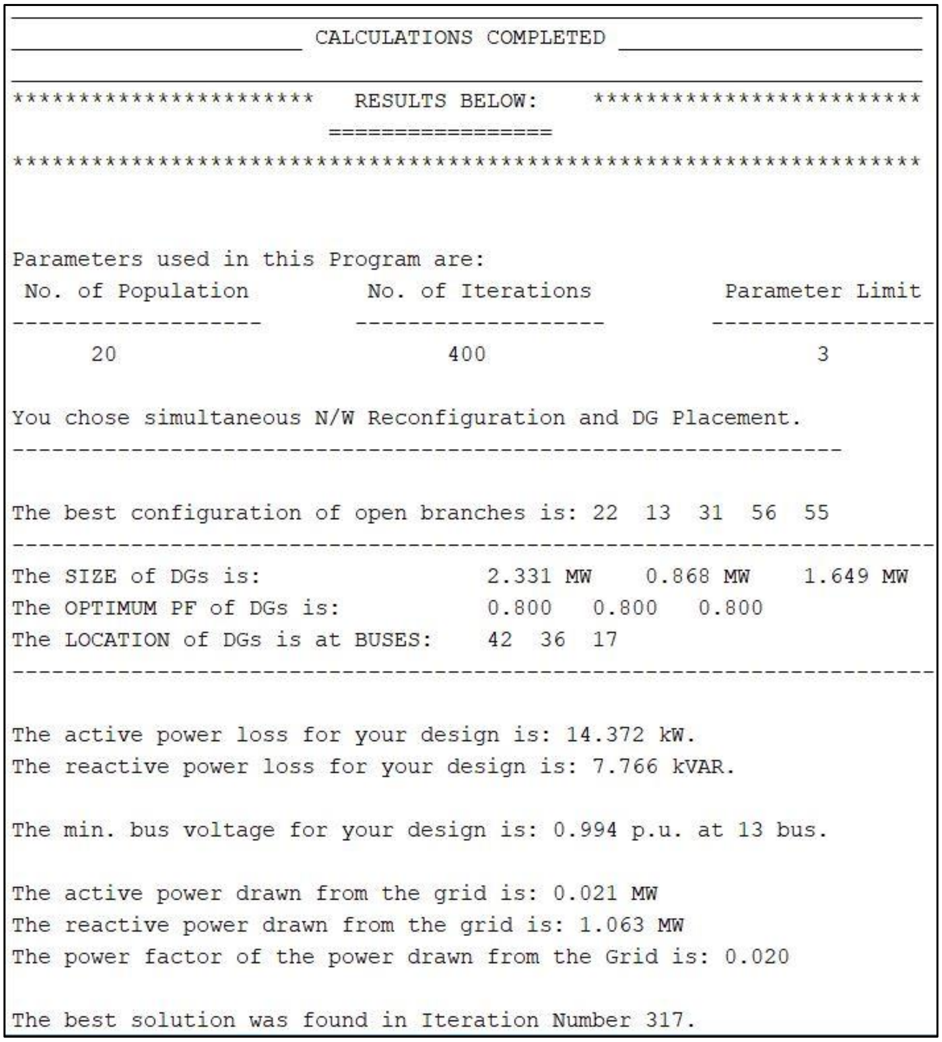


Figure 47: Bus Voltage Profile for Simultaneous N/W Reconfiguration and DG placement for Daachhi feeder when DGs inject active power only



```
______________________ CALCULATIONS COMPLETED ________________________

______________________________________________________________________
***********************   RESULTS BELOW:   *************************
                          =================
********************************************************************



Parameters used in this Program are:
 No. of Population        No. of Iterations        Parameter Limit
-------------------      -------------------      -----------------

      20                         400                       3

You chose simultaneous N/W Reconfiguration and DG Placement.
---------------------------------------------------------------

The best configuration of open branches is: 22  13  31  56  55
----------------------------------------------------------------------
The SIZE of DGs is:                2.331 MW    0.868 MW    1.649 MW
The OPTIMUM PF of DGs is:          0.800   0.800   0.800
The LOCATION of DGs is at BUSES:    42  36  17
----------------------------------------------------------------------


The active power loss for your design is: 14.372 kW.
The reactive power loss for your design is: 7.766 kVAR.

The min. bus voltage for your design is: 0.994 p.u. at 13 bus.

The active power drawn from the grid is: 0.021 MW
The reactive power drawn from the grid is: 1.063 MW
The power factor of the power drawn from the Grid is: 0.020

The best solution was found in Iteration Number 317.
```

Figure 48: Result window for Simultaneous N/W Reconfiguration and DG placement for Daachhi feeder when DGs inject both active power and reactive power

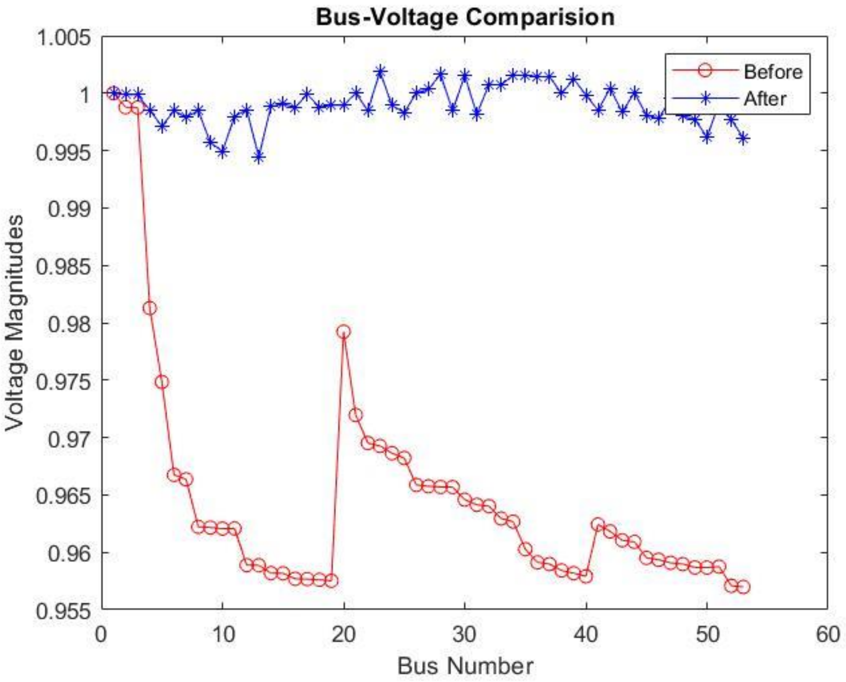


Figure 49: Bus Voltage Profile for Simultaneous N/W Reconfiguration and DG placement for Daachhi feeder when DGs inject both active power and reactive power