TRIBHUVAN UNIVERSITY

INSTITUTE OF ENGINEERING

PULCHOWK CAMPUS

DEPARTMENT OF ELECTRICAL ENGINEERING

MASTERS IN POWER SYSTEM ENGINEERING

ROLL No.: 074MSPSE014

OPTIMAL ALLOCATION OF CAPACITORS AND DGS FOR TECHNO-ECONOMIC BENEFITS IN RADIAL DISTRIBUTION SYSTEM

THESIS REPORT

BY

SARU BASTOLA

Thesis Supervisor

Prof. Dr. Nava Raj Karki

February, 2021

COPYRIGHT

Head

Department of Electrical Engineering

Institute of Engineering

Pulchowk Campus, Pulchowk

Lalitpur, Nepal

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. Optimal allocation (i.e. siting and sizing) of Distributed Generation (DG) and Optimal Capacitor Placement are the best ways to strengthen the efficiency of power system. In the present work, a Evaporation-rate based water cycle algorithm has been taken into account to allocate capacitor banks and DGs along the radial distribution network. The objective function is adopted to minify the system power loss, to improve the system voltage profile and finally to carry out for power loss reduction with economic point of view.

Firstly, capacitor placement is applied to standard IEEE buses. In the next stage, Distributed Generations is incorporated in the standard IEEE buses, thirdly capacitor and DGs with unity pf are incorporated simultaneously in the IEEE bus system and finally capacitor and DGs with controllable pf are incorporated simultaneously in the IEEE bus system. Finally, practical distribution feeder (i.e., New Chabahil Feeder and Daachhi Feeder) of Kathmandu valley will be taken to apply the theoretically proven technique to reduce voltage drop and power loss. The overall accuracy and reliability of the approach has been validated and tested on radial distribution systems with differing topologies and of varying sizes and complexities.

The results shown by the proposed approach have been found to outperform the results of existing heuristic algorithms found in the literature for the given problem. The test was performed for four cases. Case I: placement of capacitors only, Case II: Placement of DG only, case III: Placement of DG (unity pf) and capacitors simultaneously, Case IV: Placement of DG (with controllable pf) and capacitors simultaneously taking into consideration for technical objectives only, Case V: Placement of DG (with controllable pf) and capacitors simultaneously taking into consideration for techno-economic objectives. The power loss found with my thesis work is lower than that of with the methodologies in the reference paper. For IEEE 33 bus system, power loss in case I, case II, case III, case IV, and case V was 34.79%, 62.10, 90.23%, 92.04%, and 63.67 % of the base case respectively. Similarly, for IEEE 69 bus system, power loss in case I, case II, case III, case IV, and case V were 35.34%, 69.14%, 94.36%, 96.24%, and 35.53% of the base case respectively the power loss. Moreover, the results for the practical systems (Daachhi feeder and New Chabahil feeder) are supposed to have considerable upgradation in the Nepalese distribution system in the future for

lower power loss and better voltage profile. For Daachhi Feeder, power loss in case I, case II, case III, case IV, and case V was 50.25%, 48.52%, 96.10%, 96.77%, and 70.95% of the base case respectively. Similarly, for New-Chabahil Feeder, power loss in case I, case II, case III, case IV, and case V were 37.46%, 63.54%, 97.10%, 98.23%, and 54% of the base case respectively the power loss

ACKNOWLEDGEMENT

I would like to extend my sincere gratitude to the Department of Electrical Engineering, Pulchowk Campus for providing such a great opportunity to present our thesis project. Most prominently, I would like to thank my supervisor, Prof. Dr. Nava Raj Karki. Without his guidance and supervision this thesis would never have been possible. I am highly thankful to all my friends, seniors and everyone who are directly or indirectly involved in making this thesis succeed. I am grateful to all who provided encouragement to attempt this project.

I would also thank my friends, my Institution and seniors without whose continuous support and advice this project would have been a distant reality. Comments and suggestions from all the teachers and friends were highly encouraged and appreciated. I also like to thank all the faculty member and every person related to the department for their valuable help during the time of the thesis.

Thank You!!

TABLE OF CONTENTS

List of Figures

List of Tables

CHAPTER 1: INTRODUCTION

The power generation capacities around the world are to be expanded at skyrocketing speed to meet out the increased load demand and thereby to avoid power blackouts which have significant economic impact on developing countries. Moreover, the location of electricity generation is far away from the consumer load. This poses huge challenge in electricity transportation over long distance which ultimately leads to more power loss. Solution of above said problems to some extent is achieved by the installation of shunt capacitors and Distributed Generators (DG) close to the load center in the power system network.

The power flows in the distribution line causes high power loss, imposes voltage drop in the lines and also account for poor power factor at the load ends. Reactive power compensation by Capacitor allocation alone can improve the voltage profile and lower the power loss in the system. Cuckoo Search Algorithm has been used as advanced metaheuristic algorithm so as to optimize the cost of power loss improvement with the capacitor allocation in the system. [1] Utilities are facing various problems regarding the power loss and voltage instability due to unbalanced load, sudden fluctuations in the demand side and lack of proper planning. Capacitor placement in the distribution system helps improve the power factor, bus voltage regulation, power and energy loss, increase system capacity in addition to enhance the power quality. In distribution system to improve the voltage regulation we required to minimize reactive power flow through the system. To overcome these difficulties, we place the capacitor in distribution system.

The placement of capacitors in radial distribution systems is also provide power flow control, improving system stability, power factor correction, voltage profile management and losses minimization. The problem associated with capacitor placement is to determine the location of capacitors where power loss is minimum and cost saving is maximum. A number of methods have been proposed to solve capacitors placement problem. Like as combinatorial optimization techniques of genetic algorithm, simulated annealing, Particle swarm optimization have been applied to find the desirable and almost global optimal solution for capacitors placement problem. In this research, Water Cycle Algorithm is used for the optimization since it is supposed to give more exact and simple results compared to another algorithm [2].

Distributed generation units (also called decentralized generation, dispersed generation, and embedded generation) are small generating plants connected directly to the distribution network or on the customer site of the meter. In these recent years, the penetration of renewable and nonrenewable distributed generation (DG) resources is increasing worldwide encouraged by national and international policies aiming to increase the share of renewable energy sources and highly efficient micro-combined heat and power units in order to reduce greenhouse gas emissions and alleviate global warming. DGs also contribute in the application of competitive energy policies, diversification of energy resources, reduction of on-peak operating cost, deferral of network upgrades, lower losses and lower transmission and distribution costs, and potential increase of service quality to the end-customer. DGs are available in modular units, characterized by ease of finding sites for smaller generators, shorter construction times, and lower capital costs [3].

Nowadays, design of micro-grids in power system based on distributed energy resources has become a very important aspect for management of the energy related issues and economic feasibilities. The distribution system is mostly operated as radial because of its cheap and simplicity in operation. An appropriate planning methodology must be carried out for incorporating shunt capacitors and DG units into the distribution network to get the constructive benefits. The installation of these units at non-appropriate places with improper sizing leads to negative consequences such as increase in power loss, Poor system reliability and voltage instability state of the power system network. [4]

The combination of Capacitor and DG sources can mitigate such problems. In this context, the power loss reduction using Capacitor and DG is an important aspect to be taken into account. But such reactive and real power sources are to be optimally placed in the distribution system since improper allocation may give increased system losses posing problems for proper operation of distribution system. Hence choice of correct optimization technique i.e., Evaporation-Based Water Cycle Algorithm used was important in this regard.

1.1 Objectives of the Project

The main objective of this thesis is to study is to minimize the distribution system power loss and cost and improve voltage profile in IEEE buses and practical feeders of Nepal.

1.2 Scope

The basic scopes of this thesis are:

- Study the penetration of DGs and CBs to enhance the technical and economic issues of distribution systems.
- Three technical objectives are satisfied that are: power loss reduction, voltage profile improvement, and stability index enhancement
- Two economic issues are considered as minimizing the costs of generated power and CBs.
- Providing a controllable power factor strategy of DG for flexible operation of distribution systems.

1.3 Outline of thesis

This thesis is organized in six chapters. Chapter 1 deals with the basic concept of distribution system loss reduction techniques. The chapter deals with the discussion related to collaboration of DG and capacitor so as to reduce the system loss. Brief review of literature review on loss reduction techniques is presented in Chapter 2. The overall methodology, basic configuration and features of Evaporation-Rate Based Water Cycle Algorithm is presented in chapter 3. Chapter 4 deals with the system consideration, tools and software used in this thesis works. Chapter 5 presents the results and discussion of the study and conclusion is discussed in chapter 6.

1.4 Problem Statement

Nepalese distribution system is currently having huge amount of technical and non-technical losses. Even though, various researches have been done in the field of loss reduction, Nepalese system is not having any amendments in this field. This is the major problem that needs to be addressed as soon as possible. I hope this project to be done in the certain part of Nepalese distribution system will provide some accurate results and provide us with the idea for the selection of the location and size of the capacitors and Distributed Generation (DGs). Moreover, capacitor sizing and placement problem is an important task for planning studies in distribution networks. This impact on voltage regulation as well. The problem regarding DGs is that they are very costly. Hence it is very important to do some research on the optimal placement of DGs in the system so as to reduce the loss, improve the voltage profile, and so on. Nepal Electricity Authority (NEA) has released its guidelines at April, 2016 for interconnection of photovoltaic to distribution network. On February 2018, Ministry of Energy released standard procedure for connection of alternative energy to 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.

Because of the guidelines of MOE and NEA to incorporate alternative sources to the system, it can be said that incorporating DG in the distribution system is not the choice for Nepalese System, but it is the compulsion. Hence, it is very necessary to study the impact of DG addition to the system power loss (both active and reactive power) and the power factor. The DGs IPPs mostly targets for the DG which produce the real power but not the reactive power because of cost and loss constraints for them. But it can be analyzed that addition of only active power to the system without reactive power disrupts the power balance. As a result, system power factor turns to be very poor. Hence, capacitor allocation in the DG incorporated system is only the option to improve the system power factor. Following these ICIMOD- Khumaltar (92 kW) and CIAA- Tangal (514 kW) are already installed and ready for integration in the distribution network while NMB Bank- Babarmahal (50kW) is due for PPA with NEA. They are to be connected to the national grid now or later. Hence, sufficient research is to be done for the optimal location of them so as to reduce the cost and the power loss.

CHAPTER 2: REVIEW OF LITERATURE

2.1 Introduction:

In the paper [1] a cuckoo search optimisation-based approach has been developed to allocate static shunt capacitors along radial distribution networks. The objective function is adopted to minify the system operating cost at different loading conditions and to improve the system voltage profile. In addition to find the optimal location and values of the fixed and switched capacitors in distribution networks with different loading levels using the proposed algorithm. Higher potential buses for capacitor placement are initially identified using power loss index. However, that method has proven less than satisfactory as power loss indices may not always indicate the appropriate placement. At that moment, the proposed approach identifies optimal sizing and placement and takes the final decision for optimum location within the number of buses nominated with minimum number of effective locations and with lesser injected VARs. The overall accuracy and reliability of the approach have been validated and tested on radial distribution systems with differing topologies and of varying sizes and complexities. The results shown by the proposed approach have been found to outperform the results of existing heuristic algorithms.

Integration of distributed generation units (DGs) and capacitor banks (CBs) in distribution systems aim to enhance the system performance. The paper [2] proposes water cycle algorithm (ER-WCA) for optimal placement and sizing of DGs and CBs. The proposed method aims to achieve technical, economic, and environmental benefits. Different objective functions: minimizing power losses, voltage deviation, total electrical energy cost, total emissions produced by generation sources and improving the voltage stability index are considered. Simulations are carried out on three distribution systems, namely IEEE33-bus, 69-bus test systems, and East Delta network, as a real part of Egyptian system. Research article [3] has mentioned that the integration of distributed generation (DG) units in power distribution networks has become increasingly important in recent years. The aim of the optimal DG placement (ODGP) is to provide the best locations and sizes of DGs to optimize electrical distribution network operation and planning taking into account DG capacity constraints. Several models and methods have been suggested for the solution of the ODGP problem.

The planning problem of simultaneous DG and capacitor bank placement in distribution network was investigated from the local DISCO's viewpoint based on minimum total cost over the planning period considering several economic and technical factors and modeling the customers' load types and the feeder's failure rate in [4] . After optimal DG and capacitor placement, the system energy loss and risk level over the planning period were decreased noticeably, and also voltage profiles of all the system buses at different load levels were improved. It was proven that considering different feeder's failure rate models in the simultaneous DG and capacitor placement planning problem can notably affect the simulation results.

Steady increase in energy demand on distribution system due to natural growth of a service territory or through stimulation of energy market is a big challenge to planning engineers so that the system is adaptable without violating service quality. Load growth on system results into either extra expenditure made towards the addition of new substation or expanding the existing substation capacity. Due to power system deregulation and environmental concerns as well as technological advancements, the Disco (Distribution Company) planners are forced to investigate expansion planning through alternatives such as distributed generation (DG). Incorporation of distributed generation is an important aspect in distribution system in view of loss reduction, reduction in operating costs and improvement in voltage profile. It was estimated that distribution systems cause a loss of about 5–13% of the total power generated. The cost due to energy losses is a major part of the electricity bill. Restructuring in power systems encourage the penetration of more and more DG at distribution level [5].

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. Optimal allocation (i.e. siting and sizing) of Distributed Generation (DG) is one of the best ways to strengthen the efficiency of power system among capacitor placement and 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. In this paper a comprehensive study is carried out for optimum DG placement considering minimization of power/energy losses, enhancement of voltage stability, and improvement of voltage profile. An attempt has been made to summarize the existing approaches and present a detailed discussion which can help the energy planners in deciding which objective and planning factors need more attention for optimum DG allocation for a given location or in a given scenario. [6]

In [7] , authors present a novel approach based on cuckoo search (CS) which is applied for optimal distributed generation (DG) allocation to improve voltage profile and reduce power loss of the distribution network. The voltage profile which is the main criterion for power quality improvement is indicated by two indices: voltage deviations from the target value which must be minimized and voltage variations from the initial network without DG which must be maximized. The CS was inspired by the obligate brood parasitism of some cuckoo species by putting their eggs in the nests of other species. Some host birds can engage direct contest with the infringing cuckoos. For example, if a host bird detects the eggs are not their own, it will either throw these alien eggs away. The CS has been compared with other evolutionary algorithms such as genetic algorithm (GA) and particle swarm optimization (PSO) and different cases have been investigated for indicating the applicability of the proposed algorithm. The results indicate the better performance of CS compared with other methods due to the fewer parameters which must be well tuned in this method. In addition, in this method the convergence rate is not sensitive to the parameters used, so the fine adjustment is not needed for any given problems.

In [8] , authors proposed the pioneering attempts to minimize power losses in radial distribution networks and facilitates an enhancement in bus voltage profile by determining optimal locations, optimally sized distributed generators and shunt capacitors by hybrid Harmony Search Algorithm approach. The procedure travels to examine the robustness of the proposed hybrid approach on 33 and 119 node test systems and the result outcomes are compared with the other techniques existing in the literature. The simulation results reveal the efficiency of the proposed hybrid algorithm in obtaining optimal solution for simultaneous placement of distributed generators and shunt capacitors in distribution networks.

In paper [9] work has been carried out to find out the optimal siting and sizing of distributed generation in the radial distribution system, considering precise model for DG's and in this work has presented a new approach for optimum simultaneous distributed generation (DG) Units and capacitors placement and sizing on the basis of voltage stability index for improvement in voltage profile. The optimal locations of distributed power sources has been identified by means of voltage stability index of the bus and optimal rating of the DG source are determined by using Genetic Algorithm (GA). The results in [10] shows that in active distribution systems the benefits and undesirable effects obtained by the installation or existence of DG and CB are directly related to the locations of these devices in the network and their operation modes. Thus, paper presents a methodology for the simultaneous CB and DG allocation, taking into account the presence of stochastic DG. The system's operational state is susceptible to DG operation, causing a large voltage variation. The results presented show that the proposed methodology is very efficient in finding the buses where CB and DG are to be allocated, as well as the control scheme of the switched CB and DG dispatches, considering physical and operational constraints. Paper [11] presents the novelty of the water cycle algorithm for solving the optimization problems in the least possible time and in the most accurate way.

2.2 Why Distributed Generation?

In the last decade, technological innovations and a changing economic and regulatory environment have resulted in a renewed interest for distributed generation. This is confirmed by the IEA (2002), who lists five major factors that contribute to this evolution, i.e. developments in distributed generation technologies, constraints on the construction of new transmission lines, increased customer demand for highly reliable electricity, the electricity market liberalization and concerns about climate change .We feel that these five factors can be further reduced to two major driving forces, i.e. electricity market liberalization and environmental concerns. The developments in distribution technologies have been around for a long time, but were as such not capable of pushing the "economy as scale" out of the system. We doubt that distributed generation is capable of postponing, and certainly not of avoiding, the development of new transmission lines: at the minimum the grid has to be available as backup supply. The third element, being reliability, is at this moment not an issue in the interconnected European high voltage system, although this may change rapidly in the following years.

There is the increased interest by electricity suppliers in distributed generation because they see it as a tool that can help them to fill in niches in a liberalized market. In such a market, customers will look for the electricity service best suited for them. Different customers attach different weights to features of electricity supply, and distributed generation technologies can help electricity suppliers to supply to the electricity customers the type of electricity service they prefer. In short, distributed generation allows players in the electricity sector to respond in a flexible way to changing market conditions.

To conclude, importance of DGs can be written as:

- Optimal DG allocation secures distribution system from unwanted events and allows the operator to run the system in islanding mode [6].
- 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.
- 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), therefore benefiting the environment.
- Highly efficient combined heat and power plants, and backup and peak-load systems are providing increasing capacity. In addition, it enables the use of waste heat, improving overall system efficiency.
- 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 [11].

2.3 Types of Distributed Generation:

The different types of traditional and nontraditional DGs are classified and described in [12] from the constructional, technological, size, and power time duration pint of view. The DGs may also be grouped into four major types based on terminal characteristics in terms of real and reactive power delivering capability as described in [13].

The four major types are considered for comparative studies which are described as follows:

Type 1: This type DG is capable of delivering only active power such as photovoltaic, micro turbines, fuel cells, which are integrated to the main grid with the help of converters/inverters. However, according to current situation and grid codes the photovoltaic can and in sometimes are required to provide reactive power as well.

Type 2: DG capable of delivering both active and reactive power. DG units based on synchronous machines (cogeneration, gas turbine, etc.) come under this type.

Type 3: DG capable of delivering only reactive power. Synchronous compensators such as gas turbines are the example of this type and operate at zero power factors.

Type 4: DG capable of delivering active power but consuming reactive power. Mainly induction generators, which are used in wind farms, come under this category. However, doubly fed induction generator (DFIG) systems may consume or produce reactive power i.e., operates similar to synchronous generator. In this paper, the analysis of T1, T2, T3, and T4 for optimal size and location is done on the basis of terminal characteristic of basic DGs in terms of their power delivering capability.

In this thesis work, type 1 and type 2 DGs are taken into consideration.

2.4 Voltage Stability Index of Radial Distribution Networks:

With the increased loading and exploitation of the existing power structure, the probability of occurrence of voltage collapse are significantly greater than before and the identification of the nodes which prone to the voltage fluctuations have attracted more attention for the transmission and as well as the distribution systems. For operating a power system in a safe and secure manner, all insecure operating states must be identified well in advance to facilitate corrective measures to overcome the threat of possible voltage collapse. 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.

Mathematical model of the stability index

For a distribution line model, the quadratic equation which is mostly used for the calculation of the line sending end voltages in load flow analysis can be written in general form as in reference paper [14]:

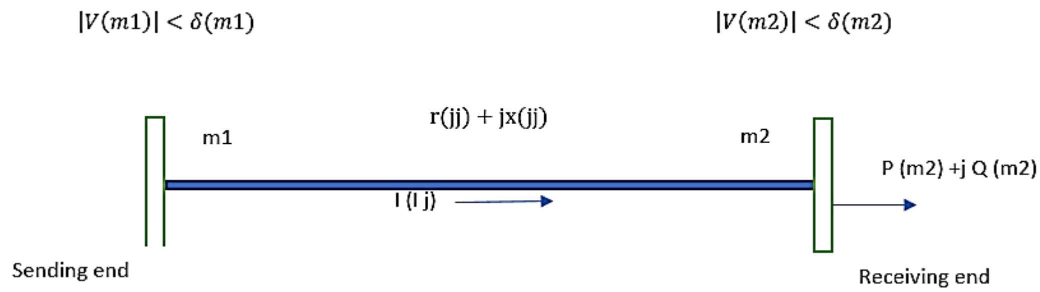


Figure 1: Figure showing the sending end and receiving end buses.

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

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

$I(ij)= \frac{P(m2)\text{-}jQ(m2)}{V^{*}(m2)}$……………………..……. (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 eq. (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 eqns. (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)* ≥ *0*. The node at which the value of

the stability index is minimum, is more sensitive to the voltage collapse.

2.5 Evaporation-Rate Based Water Cycle Algorithm

The ER-WCA is based on the observation of water cycle process and how rivers and streams flow into downhill towards the sea in nature. It was first introduced by authors [11] for solving engineering optimization problems starting with Water Cycle Algorithm. They showed that the ER-WCA is more able to find a wider range of solutions compared with the GA and PSO. ER-WCA [15] begins with an initial population similar to other metaheuristic algorithms, this initial population called the raindrops (RD). The values of the problem-controlled variables *xi* (PG*i*, QG*i*, *Q*CB total, and placement of DG and CB) can be formed as an array called "RD" for single solution. This array can be defined as follows:

RD = [x1, x2, x3, . . . , xN] ……………….. (15)

RP matrix contains random solutions in iteration #1 as

$$RP=\{x_k^j : j=1:N_{pop} \text{ and } k=1:N_{var}\} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (16)$$

Then, a number of good streams (i.e. fitness function values close to the current best record) are chosen as rivers, while the other streams flow into the rivers and sea.

$$ff_i=f\left(x_1^i, x_2^i, x_3^i, \ldots\ldots, x_{Nvar}^i\right),\ i=1,2,3,\ldots\ldots,N_{pop} \ldots\ldots\ldots\ldots\ldots\ldots \quad (17)$$

Where, N_{pop} and N are population size and the number of design variables, respectively. Each of the decision variable values ($x_1, x_2, \ldots, x_N$) can be represented as floating point number (real values) or as a predefined set for continuous and discrete problems, respectively. The cost of a stream is obtained by the evaluation of cost function (fitness function).

At the first step, N_{pop} streams are created. A number of N_{sr} from the best individuals (minimum values) are selected as a sea and rivers. The stream which has the minimum value among others is considered as the sea. In fact, N_{sr} is the summation of number of rivers (which is defined by user) and a single sea. The rest of the population (i.e., streams flow into the rivers or may directly flow to the sea) are considered as streams.

Depending on magnitude of flow, each river absorbs water from streams. The amount of water entering a river and/or the sea, hence, varies from stream to stream. In addition, rivers flow to the sea which is the most downhill location. The designated streams for each rivers and sea are calculated. The best RD is selected to be the sea, number of good RD is chosen to be the rivers and the remainder RD are assumed to be streams that flow to the sea or the rivers. Equation below calculates the streams that flow to a sea or a river depending on the flow intensity as

$$NS_n=\mathrm{round}\left\{\left|\frac{ff_n}{\sum_{i=1}^{N_{sr}} ff_i}\right| * N_{pop}\right\},\ n=1,2,3,\ldots,N_{sr} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (18)$$

Where, NS_n is the number of streams which flow to the specific rivers and sea. As it happens in nature, streams are created from the raindrops and join each other to generate new rivers. Some stream may even flow directly to the sea. All rivers and streams end up in the sea that corresponds to the current best solution.

A stream flows to the river along the path between them using a random distance (x). The same concept is applied for flowing rivers to the sea, so the new position for the streams and rivers can be *given as*

$$X_{stream}^{i+1}=X_{stream}^{i}+rand*U*\left(X_{river}^{i}-X_{stream}^{i}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. \quad (19)$$

$$X_{river}^{i+1}=X_{river}^{i}+rand*U*\left(X_{sea}^{i}-X_{river}^{i}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (20)$$

Where, $1 < U < 2$ and the best value for U may be chosen as 2 and *rand* is an uniformly distributed random number between zero and one. Equations above are for streams which flow into the sea and their corresponding rivers, respectively. If the solution given by a stream is better than its connecting river, the positions of river and stream are exchanged (i.e., the stream becomes a river and the river becomes a stream). A similar exchange can be performed for a river and the sea.

The evaporation process operator also is introduced to avoid premature (immature) convergence to local optima (exploitation phase) .Basically, evaporation causes sea water to evaporate as rivers/streams flow into the sea. This leads to new precipitations. Therefore, we have to check if the river/stream is sufficiently close to the sea to make the evaporation process occur. For that purpose, the following criterion is utilized for evaporation condition.

$$|Xi\ sea-Xi\ river|<dmax,\ i=1,2,3,\ldots\ldots,Nsr-1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (21)$$

After each evaporation process, the value of dmax is as

di+1 max=dimax-(dimax/ max iteration)………………………………… (22)

Where, i is an iteration index.

In ER-WCA, some Rivers having low flow because of lesser Streams pouring into them have lower potential to become the Sea, so they evaporate. The evaporation rate (ER) for Rivers is calculated using:

$$ER=\frac{Sum(NS_n)}{N_{sr}-1}*rand,\ n=2.....Nsr \qquad (23)$$

A large value for d_{max} prevents extra searches and small values encourage the search intensity near the sea. Therefore, d_{max} controls the search intensity near the sea (i.e., best obtained solution). The value of d_{max} adaptively decreases. d_{max} is a small number close to zero. After evaporation, the raining process is applied and new streams are formed in the different locations. Hence, in the new generated sub-population, the best stream will act as a new river and other streams move toward their new river. This condition will also apply for streams that directly flow to the sea.

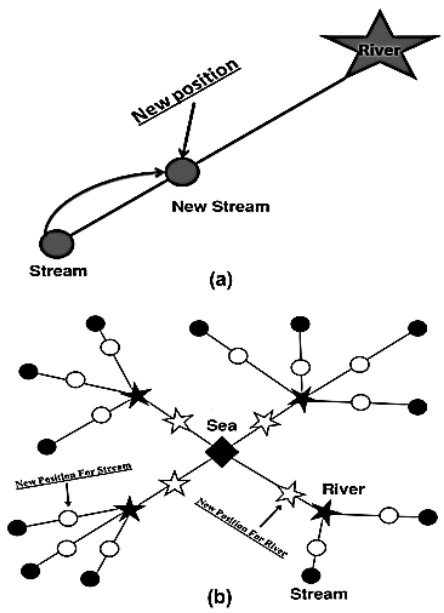
Similarly, the best newly formed stream is considered as a river flowing to the sea. The rest of new streams are assumed to flow into the rivers or may directly flow into the sea. The following equation is used only for the streams which directly flow to the sea. It encourages the creation of streams which directly flow to the sea in order to improve the exploration near the sea (the optimum solution) in the feasible region for constrained problems.

$$X_{new}^{stream}=Xsea+\sqrt{\mu}*rand(1,Nvar) \qquad (24)$$

where μ is a coefficient which shows the range of searching region near the sea, *rand* is the normally distributed random number. The larger μ increases the possibility to exit from feasible region. The smaller μ leads the algorithm to search in smaller region near the sea. Its suitable value is set to 0.1. Indeed, term $\sqrt{\mu}$ represents the standard deviation. The generated individuals with variance μ are distributed around the best obtained optimum point (sea). Therefore, the evaporation operator is responsible for the exploration phase in the ER-WCA.

It should be noted that higher flow Rivers have lower evaporation rate and lower flow Rivers have higher evaporation rate. Also, there are two evaporations in each cycle in ER-WCA – first of Rivers/Streams when reaching the Sea; second of Rivers having lower flow because of lesser streams pouring into those rivers. In short, ER-WCA has an ability to effectively search for the best solution in the global space.

The development of the ER-WCA optimization process is illustrated by Figure below where circles, stars, and the diamond correspond to streams, rivers, and sea, respectively. The white (empty) shapes denote the new positions taken by streams and rivers.



Parameters of ER-WCA:

i) **Number of Population:** The number of population decides how many solutions are generated in one iterations i.e. raindrops in case of ER-WCA. It is better to have as many number of population as possible, but to reduce the computation time, a suitable value should be chosen. In this thesis work, number of population of 100 is chosen.

ii) **Upper Boundary and Lower Boundary:** Upper and lower boundary decide the boundary limits for the solution generated by ER-WCA. For example, the lower boundary limit for capacitor placement and DG placement is 1 and the upper boundary limit is the identification number given to the last bus of the system. Similarly, the power factor assigned to DGs has lower boundary of 0 and upper boundary of 1.

iii) **Number of Rivers and Streams:** In this thesis work, number of rivers and streams was chosen to be 4. In general, that value of 2 to 10 gave satisfactory results and the solution converged easily.

CHAPTER 3: METHODOLOGY

The developed algorithm is first tested over the IEEE standard bus system so as to validate the results as given in the reference papers. Then, the computer program will be manipulated so as to achieve the accurate results in the distribution system of urban area.

The basic stages that carried out are as follows:

1. Objective function and the constraints for the project are evaluated.
2. Code was developed for the optimal allocation of capacitors only based on Evaporation-Rate Based water cycle algorithm for IEEE 33, IEEE 69 bus system based on only technical objective function.
3. Code was developed for the optimal allocation of DGs only based on Evaporation-Rate Based water cycle algorithm for IEEE 33 and IEEE 69 bus system based on only technical objective function.
4. Code was developed for the simultaneous optimal allocation of capacitors and DGs (with unity pf) based on Evaporation-Rate Based water cycle algorithm for IEEE 33 and IEEE 69 bus system based on only technical objective function.
5. Code was developed for the simultaneous optimal allocation of capacitors and DGs (with controllable pf) based on Evaporation-Rate Based water cycle algorithm for IEEE 33 and IEEE 69 bus system based on only technical objective function.
6. Code was developed for the simultaneous optimal allocation of capacitors and DGs (with controllable pf) based on Evaporation-Rate Based water cycle algorithm for IEEE 33 and IEEE 69 bus system based on techno-economic objective function.
7. The results were analyzed so as to use the code in the practical system (i.e. New Chabahil feeder and Daachhi Feeder) of Nepal.

The following procedures are to be followed so as to develop the metaheuristic algorithm (ER-WCA).

Step 1: Loading distribution system data and defining the power limits of DGs and CBs in the system.

Step 2: Identifying the ER-WCA parameters.

Step 3: Randomly initialize the set of RD (solution).

Step 4: Checking the system constrains for each solution.

Step 5: Determining the fitness function of each RD.

Step 6: Determining the best solution in the rain drops.

Step 7: Generating the new set of solutions.

Step 8: Repeating steps from 4–7 until stopping criteria or maximum iteration is satisfied.

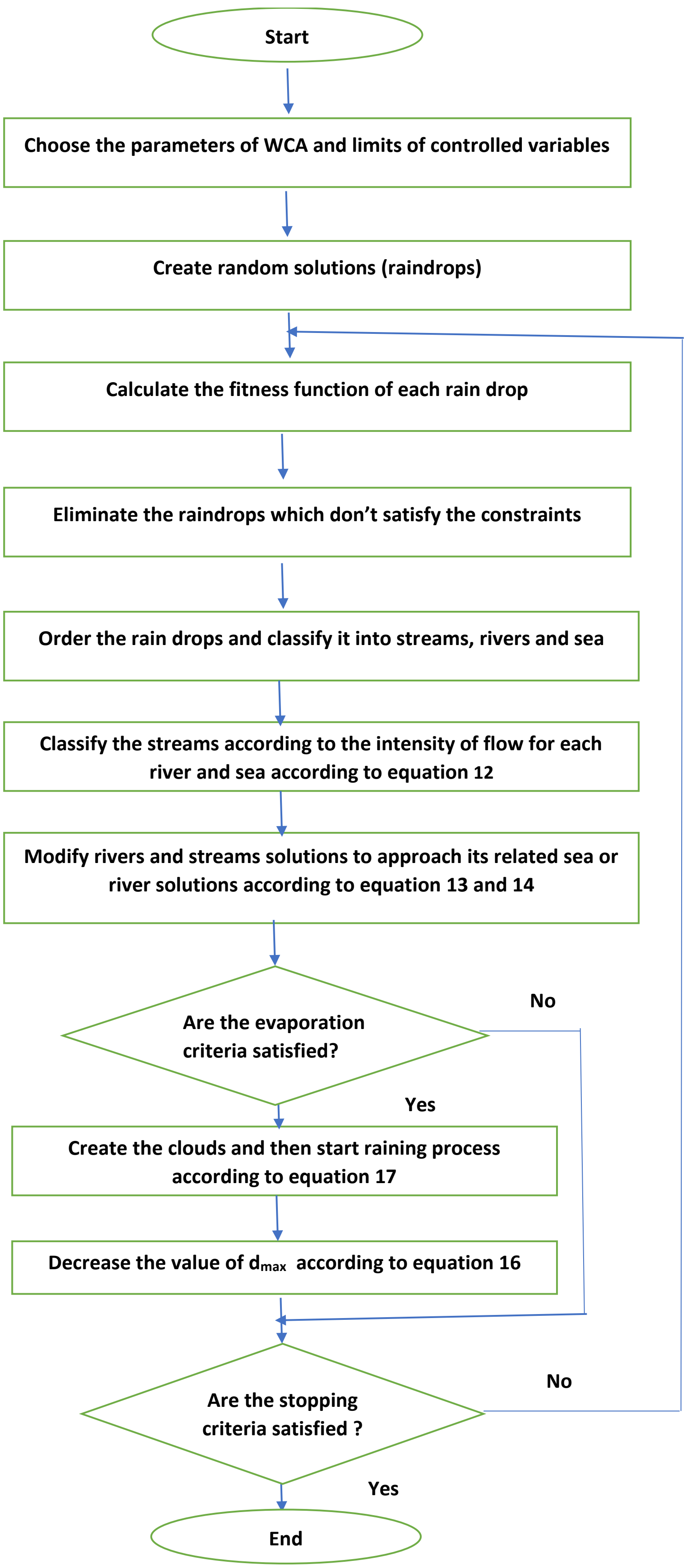


Figure 2: Flowchart for Evaporation-Rate Based Water Cycle Algorithm- based optimization problem.

3.1 Cases Studied:

For the proper analysis, four operational cases were studied using ER-WCA. It helps to understand the adequacy of the proposed algorithm over other algorithms.

Case 1: Power loss minimization (f1) by optimal placement of Capacitors only.
OF = minimize (f1)

The Streams contain *2n* number of Raindrops, *n* being the number of Capacitors to be inserted into the network. First *n* Raindrops store the bus location of Capacitors, and the second *n* Raindrops store the kVar size of those Capacitors.

Case 2*:* Power loss minimization (f1) by allocating DGs that operate at unity PF.

OF = minimize (f1)

The Streams contain *2n* number of Raindrops, *n* being the number of DGs to be inserted into the network. First *n* Raindrops store the bus location of DGs, and the second *n* Raindrops store the MW size of those DGs.

Case 3*:* Power loss minimization (f1) by allocating the combination of CBs, and DGs operating at unity pf.

OF = minimize (f1)

The Streams contain *2m+2n* number of Raindrops, *m* being the number of Capacitors, and *n* being the number of DGs to be inserted into the network. First *m* Raindrops store the bus location of Capacitors, next *m* Raindrops store the kVar size of Capacitors, next *n* Raindrops store bus location of DGs, and the next *n* Raindrops store the MW size of those DGs.

Case 4*:* Power loss minimization (f1), voltage profile improvement (f2), and minimum VSI enhancement (f3) by allocating the combination of CBs, and DGs with adjustable power factor.

OF = minimize (w1*f1 + w2*f2 + w3*f3)   where, w1, w2, and w3 are weighing factors of f1, f2, and f3 respectively.

In this analysis, w1, w2, and w3 are taken as 0.5, 0.25, and 0.25 respectively. The Streams contain *2m+3n* number of Raindrops, *m* being the number of Capacitors, and *n* being the number of DGs to be inserted into the network. First *m* Raindrops store the bus location of Capacitors, next *m* Raindrops store the kVar size of Capacitors, next *n* Raindrops store bus location of DGs, the next *n* Raindrops store the MW size of DGs, and the last *n* Raindrops store the operating power factor of those DGs. In this research work, maximum of three Capacitor banks, and three DGs were incorporated in the distribution network.

***Case 5**:* Power loss minimization (f1), and cost minimization (f4) by allocating the combination of CBs, and DGs with adjustable power factor.

OF = minimize (w1*f1 + w2*f2) where, w1, w2 are weighing factors of f1, and f4 respectively.

In this analysis, w1, and w4 are taken as 0.75, and 0.25 respectively. The Streams contain *2m+3n* number of Raindrops, *m* being the number of Capacitors, and *n* being the number of DGs to be inserted into the network. First *m* Raindrops store the bus location of Capacitors, next *m* Raindrops store the kVar size of Capacitors, next *n* Raindrops store bus location of DGs, the next *n* Raindrops store the MW size of DGs, and the last *n* Raindrops store the operating power factor of those DGs. In this research work, maximum of three Capacitor banks, and three DGs were incorporated in the distribution network.

3.2 Problem Formulation:

The objective functions (OFs), equality and inequality constraints are introduced for optimal placement and sizing of DGs and CBs in distribution systems as follows:

A. <u>Objective Function</u>

1) Technical Objective Function

The proposed method aims to achieve three types of technical OFs:

a) **Power Loss OF**: The first one aims to minimize the distribution power losses (f1) that can be expressed as:

$f_1(x)= \min \sum_{i=1}^{nL} R_i*|I_i|^2$……………. (25)

b) **Voltage Profile OF**: The second technical OF aims to improve the voltage profile and preserve better voltage profile.

$f_2(x)=\min \sum_{i=0}^{N} \left(\frac{v_i-v_i^{spec}}{v_i^{max}-v_i^{min}}\right)^2$…………….. (26)

c) **Voltage Stability Index (VSI):** The third OF (*f*3) for voltage stability index (VSI) is:

$f_3(x)=\min \left(\frac{1}{VSI(m2)}\right)$……………………… (27)

Where, 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)|}

2) **Economic Objective Function**

The economical OF (f4) aims to minimize the power generation costs that can be calculated given as:

$f_4(x)=\min(C_{DG_i}+C_{sub}+C_{CB})$…………………….. (28)

At first, for DG,

$C_{DG_i}=\sum_{i=1}^{N_{DG}} (a+b*P_{DG_i})$…………………………… (29)

$a=\frac{\text{capital cost}\left(\frac{\$}{kW}\right)*\text{capacity}(kW)*G_r}{\text{lifetime(year)}*8760*LF}$………………… (30)

Where, G_r = annual rate of benefit

LF = DG loading factor

P_{DG_i} =Energy generated by DG.

$\eta=\frac{G_r}{\text{lifetime(year)}*8760*LF}$=1.3 (constant) taken from the reference paper [16] ……………………….. (31)

b=O &M cost $\left(\frac{\$}{kWh}\right)$+fuel cost$\left(\frac{\$}{kwh}\right)$ ……………………………………………… (32)

$C_{sub}=\sum_{i=1}^{N_{DG}}(P_{sub}*Pr_{sub})$……………………………………………… (33)

Where, P_{sub} =active power production at substation

Pr_{sub} = cost of power generated at substation (taken 0.44 \$/kWh from reference [17]

C=cost of electrical energy generation by each source

Similarly, for capacitor,

$C_{CB}=\frac{\sum_{i=1}^{NC}(e_i+C_{ci}*Q_{ci})}{\text{life time}*8760}$…………………………………………………………… (34)

Where, $\frac{1}{\text{lifetime}*8760}$ acts as depreciation rate over its lifetime period.

e_i = fixed VAR source installation cost at bus i taken equal to 1000 from paper [18]

C_{ci}=corresponding purchase cost taken equal to 30,000 \$/MVar from paper [18]

Q_{ci}=reactive power of existing VAR sources installed at bus i

N_C=reactive compensator bus

B. <u>Constraints</u>:

Equality Constraints: The constraints for power balance requirements:

$\sum_{i=1}^{NG} PG_i-P_L=P_d$……………………………………… (35)

$\sum_{i=1}^{NG} QG_i-Q_L=Q_d$……………………….…………... (36)

Inequality Constraints: Maximum admissible generated power from DGs/CBs should not exceed to permissible limitations of the distribution systems.

1) Generation Operating limits

$PG_i^{min}\leq PG_i\leq PG_i^{max}$……………………………………. (37)

$QG_i^{min}\leq QG_i\leq QG_i^{max}$………………………………….. (38)

2) Installed Capacitor limits

$$Q_{CB}^{total} < Q_d \text{……} \quad (39)$$

3) Bus Voltage Limits

$$0.95 \le V_i \le 1.05,\ i=1,2,3,\ldots n \text{ bus} \quad (40)$$

4) DG power factor limit

$$0.8 \le PF \le 1 \quad (41)$$

3.3 Basic Stages:

Stage 1: At first, the objective function and the constraints for the problem was set. In this case, objective function had been set in accordance to our requirement. This thesis focused on loss minimization, voltage profile improvement and voltage stability of the system. Objective functions were set according to the cases as mentioned previously.

Stage 2: In this stage, objective function was tested with the base case. Base case is the condition without the addition of capacitor and DGs. Power loss, minimum voltage for the initial case was determined.

Stage 3: In this stage, capacitors were incorporated to the test system (i.e. IEEE 33 bus system and IEEE 69 bus system). Three capacitors were placed in the different buses of those system. Power loss, minimum voltage for the initial case was determined and checked across the reference paper results.

Stage 4: In this stage, DGs were incorporated to the test system (i.e. IEEE 33 bus system and IEEE 69 bus system). Three DGs were placed in the different buses of those system. Power loss, minimum voltage for the initial case was determined and checked across the reference paper results.

Stage 5: In this stage, capacitors and DGs (with unity pf) were incorporated to the test system (i.e. IEEE 33 bus system and IEEE 69 bus system). Three DGs and three capacitors were placed in the different buses of those system. Power loss, minimum voltage for the initial case was determined and checked across the reference paper results.

Stage 6: In this stage, capacitors and DGs (with controllable pf) were incorporated to the test system (i.e. IEEE 33 bus system and IEEE 69 bus system). Three DGs and three capacitors were placed in the different buses of those system. Power loss, minimum voltage for the initial case was determined and checked across the reference paper results.

Stage 7: In this stage, capacitors and DGs (with unity pf) were incorporated to the test system (i.e. IEEE 33 bus system and IEEE 69 bus system). Three DGs and three capacitors were placed in the different buses of those system. Power loss minimization and cost minimization are incorporated objective function. Hence techno-economic objective function has been tested in this stage.

Stage 8 (**Data collection and GIS plotting**): Data was collected for the practical system of Nepal. Daachhi and New Chabahil feeder under Baneshwor Distribution Centre were found worth testing for capacitor and DG placement since these feeders are longer than other feeders and seem to have more losses in comparison to others under that Distribution Centre. Data was collected with the help of employees in that distribution Centre. Transformer location and size were plotted in the GIS mapping and length of the line was achieved from Q-GIS software.

Stage 8: All the process from Stage 1- Stage 7 were repeated for these two practical feeders until the fruitful results were achieved.

CHAPTER 4: SYSTEM UNDER CONSIDERATION, TOOLS AND SOFTWARE

4.1 System under Consideration:

The proposed ER-WCA was applied to four distribution systems. First, the tests were carried out on IEEE 33-bus distribution system, and IEEE 69-bus distribution system. Then, the discussed approach was applied to improve the performance of Daachhi feeder, and New-Chabahil feeder of Kathmandu, Nepal. The total active power loss for the four distribution systems in the beginning without any reinforcement was: 202.67 kW, 225 kW, 193.913 kW, and 197.026 kW.

IEEE 33- bus distribution system:

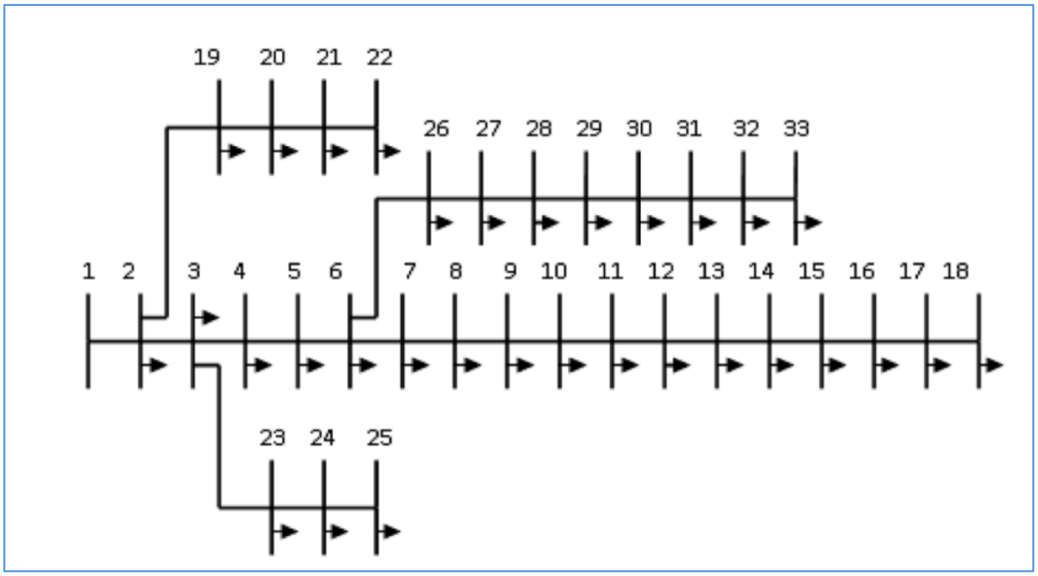


Figure 3: IEEE 33-bus test distribution system

IEEE 69- bus distribution system:

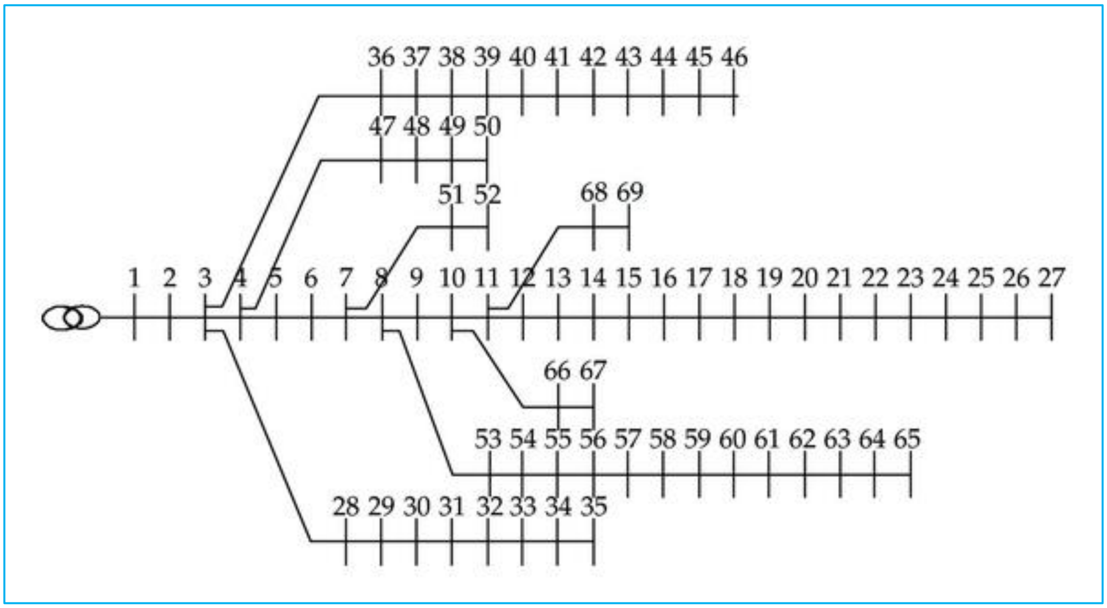


Figure 4: IEEE 69 bus test distribution system

Practical Nepalese System: Daachhi Feeder

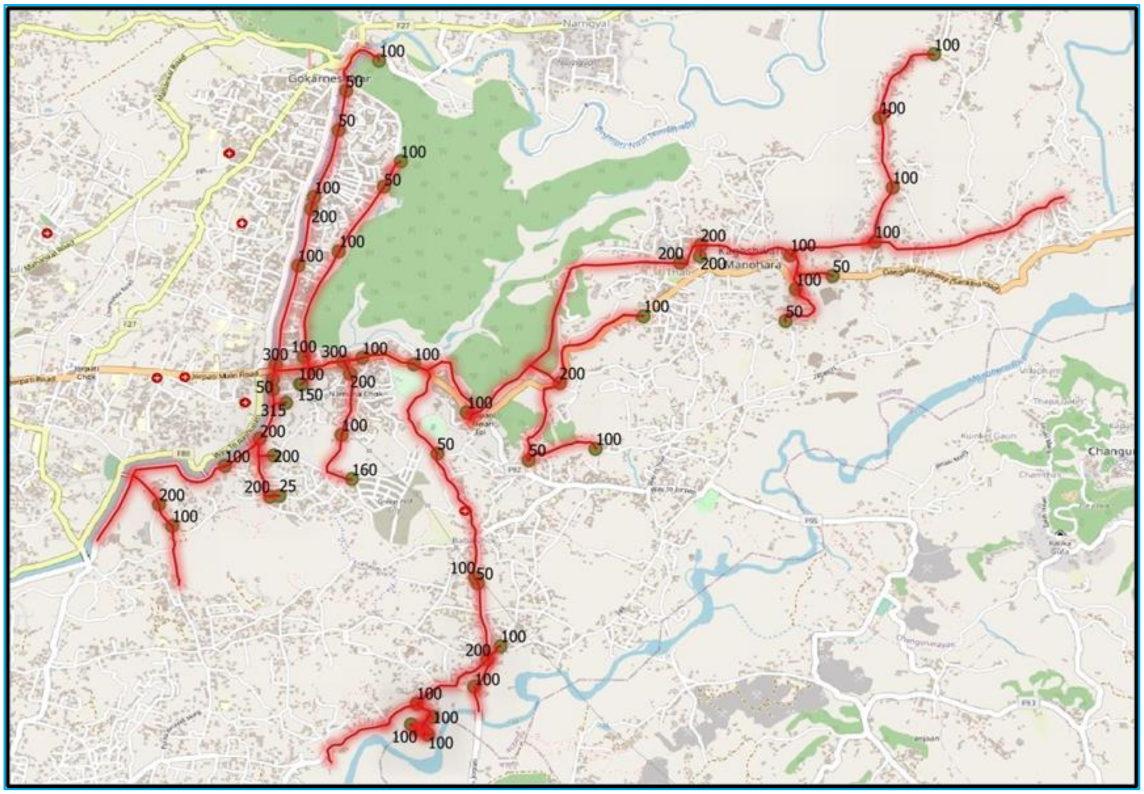


Figure 5: Daachhi feeder of Nepalese Distribution System.

Practical Nepalese System: New Chabahil Feeder

Figure 6: New Chabahil Feeder of Nepalese Distribution System

4.2 Software and Tools Used:

MATLAB was used for coding purpose so as to develop the program for calculating the power loss. MATLAB is an abbreviation of 'matrix laboratory'. It is a multi-paradigm programming language and numerical computing environment which was developed by MathWorks. It allows plotting of functions and data, matrix manipulations, implementation of algorithm, creation of user interfaces, etc. MATPOWER tool associated with MATLAB software is used for the load flow analysis. MATPOWER is a package of M-files for solving power flow, continuation power flow and optimal power flow problems using MATLAB. 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. As MATPOWER has its inbuilt database system for IEEE test system, it gives very accurate results. Moreover, for the practical system also the results are more accurate as MATPOWER considers numerical values with their higher significant values. Hence, load flow has been easier and more accurate using MATPOWER tool.

Q-GIS was used for plotting the map for two different feeders of Nepal. QGIS functions as geographic information system (GIS) software, allowing users to analyze and edit spatial information, in addition to composing and exporting graphical maps. Gary Sherman began development of Quantum GIS in early 2002, and it became an incubator project of the Open-Source Geospatial Foundation in 2007. Version 1.0 was released in January 2009. In 2013, along with release of version 2.0 the name was officially changed from *Quantum GIS* to *QGIS* to avoid confusion as both names had been used in parallel. All the required data was found using this software after locating the distribution transformers along with their capacity associated with those feeders.

CHAPTER 5: RESULTS AND DISCUSSION

To make the program as interactive as possible, it has been set to consult the user for the number of capacitors and DG to be placed, maximum capacity of DG and capacitor, minimum source power factor that should be maintained, feeder to be taken, number of iterations, base voltages and the cases to be checked. This can be presented as follows:

```
*********************** START OF THE PROGRAM ****************************
--------------------------------------------------------------------------
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
**************************************************************************
Consider the following options:
--------------------------------

[1] ENTER 1 for PLACEMENT AND SIZING OF CAPACITOR BANKS.
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
[2] ENTER 2 for PLACEMENT and SIZING OF DGs.
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
[3] ENTER 3 for OPTIMAL PLACEMENT AND SIZING COMBINATION OF CBs/DGs
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
[4] ENTER 4 for MULTIOBJECTIVE OPTIMAL PLACEMENT AND SIZING OF CBs/DGs.
             (DGs are operated with controllable PF,)
            three Technical Objectives are considered.)
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
[5] ENTER 5 for MULTIOBJECTIVE OPTIMAL PLACEMENT AND SIZING OF CBs/DGs.
             (DGs are operated with controllable PF,
         Technical and Economic Objectives are optimized.)
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

Enter the value:  1
---------------------------------------------------------------------
---------------------------------------------------------------------
How many Iterations? (Minimum of 200 recommended):   300
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

Consider the following options:
--------------------------------
--------------------------------
(a) Enter 1 for IEEE 33 Bus system
```

```
How many Iterations? (Minimum of 200 recommended):   300
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

Consider the following options:
--------------------------------
--------------------------------
(a) Enter 1 for IEEE 33 Bus system
(b) Enter 2 for IEEE 69 Bus system
(c) Enter any other number for importing an MS-Excel file with Customized Bus system

Enter your choice:   1
-------------------------------------------------------------
How many Capacitor Banks? (Default is 3.): 3
Maximum capacity of Capacitor Bank in kVAR ? (Default is 1000.): 1500
Minimum Bus Voltage at any Bus (in per unit) ? (Default is 0.90 pu.):
No input was given. Default value 0.90 per unit was taken.
Minimum Source Power Factor ? (Default is 0.20 pu.):
No input was given. Default value 0.20 was taken.


=====================================================================
Created initial population and formed sea, rivers, and streams
Sea Formed
Rivers Formed
Streams Formed
Designated streams to rivers and sea
```

Figure 7: Options given to user in the computer program

5.1 For 33 Bus System:

Summary of the results obtained for the 33-bus system is illustrated as follows:

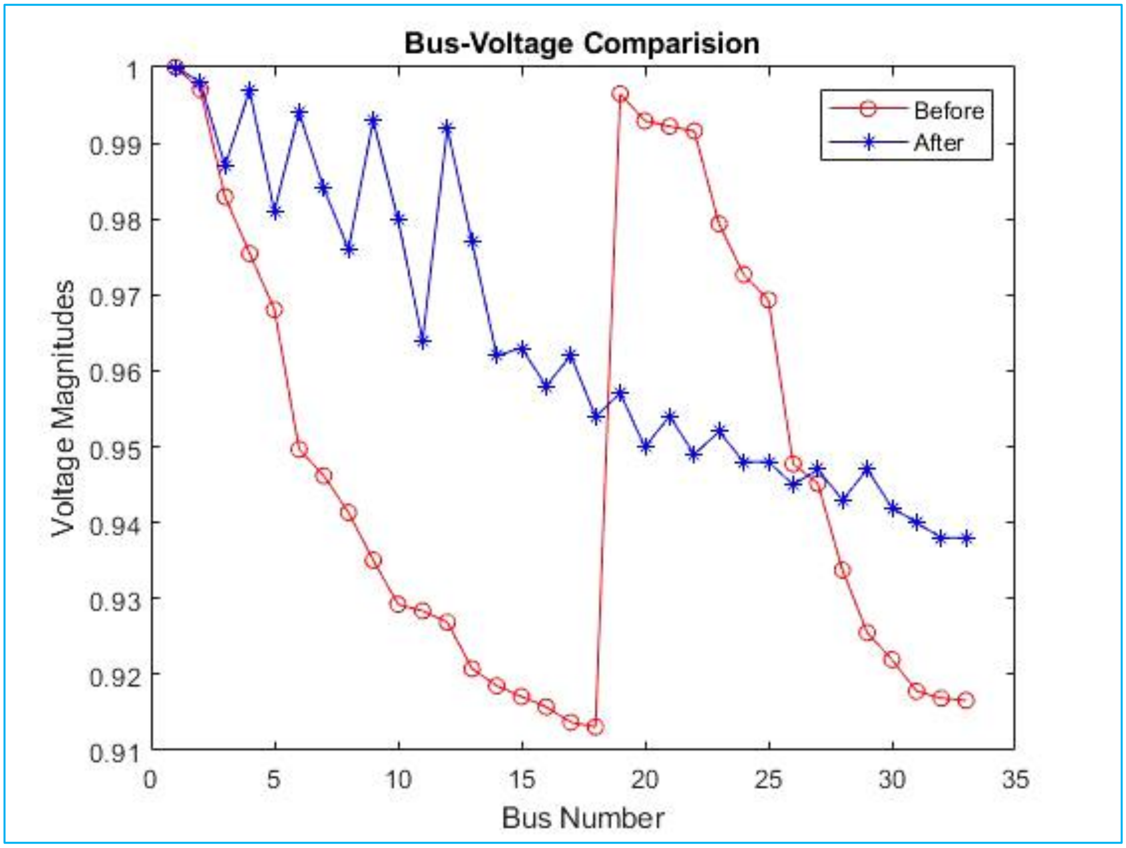


Figure 8: Case I- Bus voltage profile before and after capacitor allocations to the system

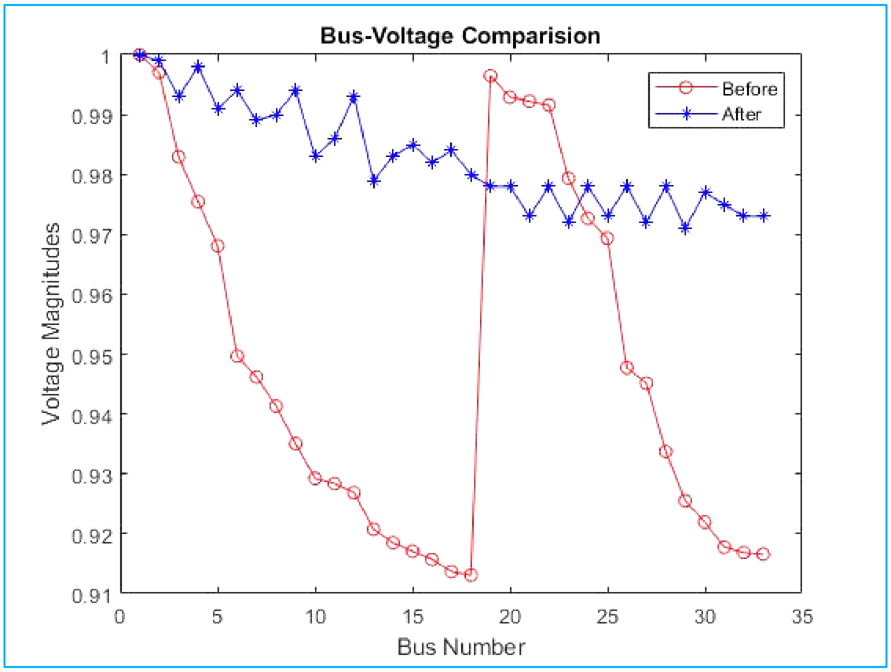


Figure 9: Case II- Bus voltage profile before and after DG allocation to the system

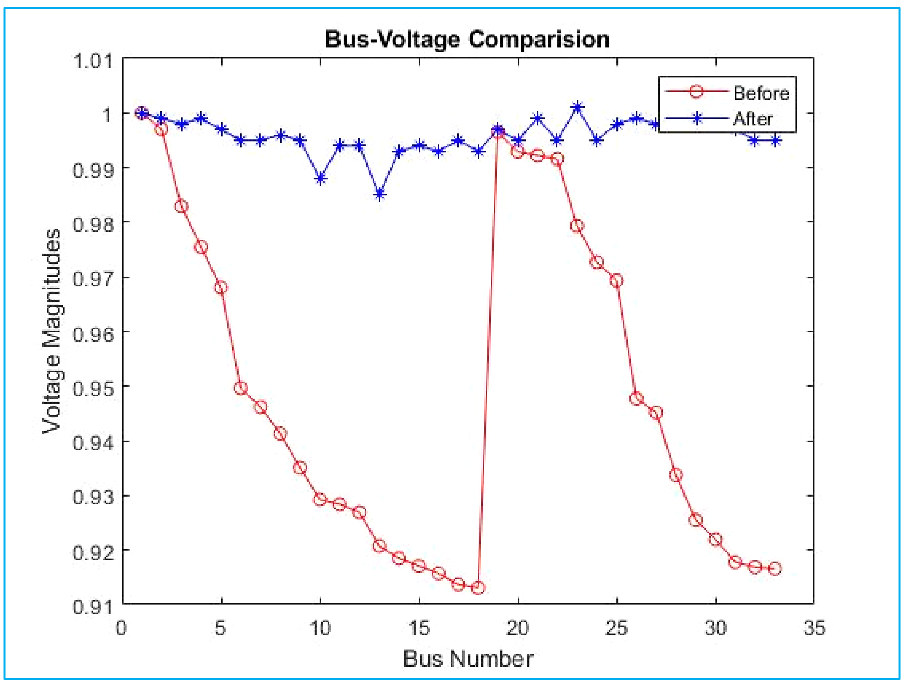


Figure 10: Case III- Bus voltage profile before and after simultaneous placement of capacitors and DG (unity pf)

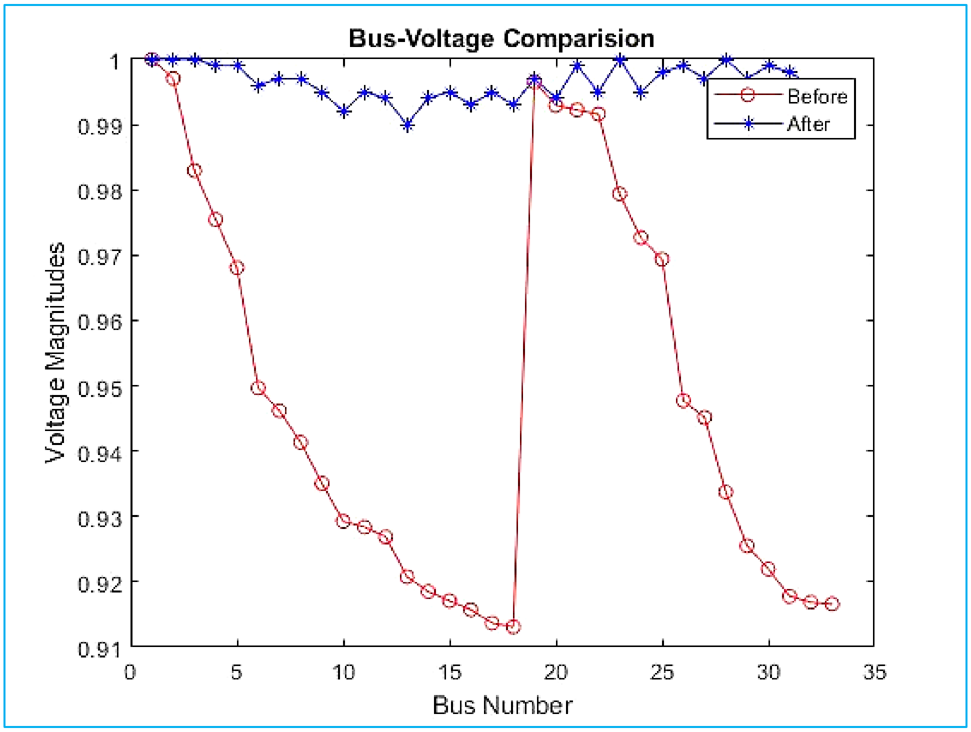


Figure 11: Case IV- Bus voltage profile before and after simultaneous placement of capacitors and DG (controllable pf)-for only technical objective function

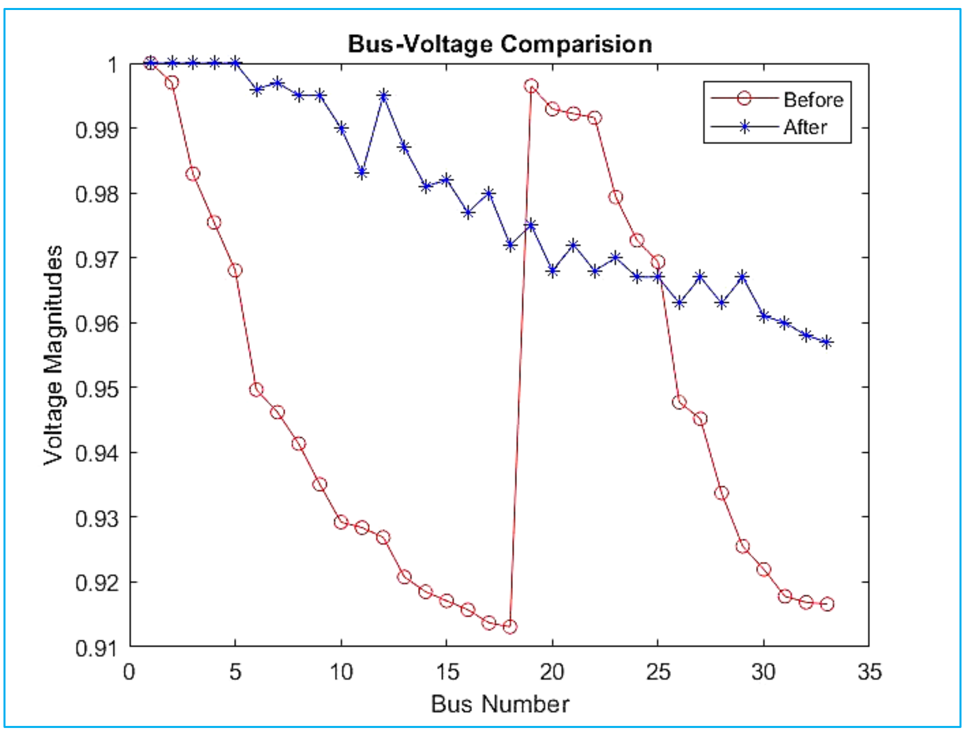


Figure 12:Case V- Bus voltage profile before and after simultaneous placement of capacitors and DG (controllable pf)-for techno-economic objective function

Table 1:Summary of results of IEEE 33 bus system

IEEE 33 BUS SYSTEM	ACHIEVED RESULTS	REFERENCE PAPERS RESULTS	
Case I (only capacitors)	**ER-WCA**	**BFOA**	**PSO**
Minimum voltage	0.938 (32)	0.9361	0.92 (18)
Active Power loss (KW)	132.173	144.04	132.48
Reactive Power loss (KVar)	88.331		
Loss reduction (%)	34.79	31.72	34.63
Placement	0.378 (13),0.544 (24), 1.036 (30)	0.3496 (18), 0.8206 (30), 0.2773 (33)	0.9 (2), 0.45 (7), 0.45(31), 0.3 (15), 0.45 (29)
Case II (only DGs)	**ER- WCA**	**BFOA**	**FWA**
Minimum voltage	0.971 (29)	0.9645	0.968
Active Power loss (KW)	76.807	98.3	88.68
Reactive Power loss (KVar)	53.014		
Loss reduction (%)	62.10	53.41	56.25
Placement	0.604 (14), 1.228 (6), 0.686 (31)	0.6335 (17), 0.0908 (18), 0.9470 (33)	0.589 (14), 0.189 (18), 1.014(32)
Case III (Capacitors and DGs with unity pf simultaneously)	**ER- WCA**	**BFOA**	**GA**
Minimum voltage	0.985 (13)	0.9783	0.971
Active Power loss (KW)	19.799	41.41	71.25
Reactive Power loss (KVar)	15.499		
Loss reduction (%)	90.23	80.37	64.85
Placement capacitor	0.194 (32), 0.393 (13), 0.869 (30)	0.1632 (18), 0.5410 (30), 0.3384 (33)	0.3 (15), 0.3 (18), 0.3 (29), 0.6 (30), 0.3(31)
Placement DG	0.728 (14), 1.486 (3), 1.01 (30)	0.5424 (17), 0.1604 (18), 0.8955 (33)	0.25 (16), 0.25 (22), 0.5 (30)
IEEE 33 BUS SYSTEM	**ACHIEVED RESULTS**	**IEEE 33 BUS SYSTEM**	**ACHIEVED RESULTS**
Case IV (Capacitors and DGs with controllable pf simultaneously) for only technical objectives	**ER-WCA**	**Case V (Capacitors and DGs with controllable pf simultaneously) for techno-economic objectives**	**ER-WCA**
Minimum voltage	0.990 (13)	Minimum voltage	0.957 (33)
Active Power loss (KW)	16.126	Active Power loss (KW)	73.64
Reactive Power loss	13.169	Reactive Power loss	57.933
Loss reduction (%)	92.04	Loss reduction (%)	63.67
Placement capacitor (MVAR)	0.194 (32), 0.333 (25), 0.708 (30)	Placement capacitor (MVAR)	0.333 (14), 0.827 (30), 0.161 (33)
Placement DG (MW)	0.796 (14), 1.712 (3), 0.999 (30)	Placement DG (MW)	0.524 (2), 1.31 (3), 2.229 (4)
power factor of DGs	0.905, 0.961, 0.995	power factor of DGs	0.906, 0.915, 0.989

Discussion on Results for 33 bus system:

i) **Case I:** This is the case for only capacitor placement. The real power loss, reactive power loss, loss reduction percentage and minimum voltage that was obtained are 132.173kW, 88.331 KVar, 34.79%, and 0.938 p.u. whereas in the reference papers results using Bacterial Foraging Optimization Algorithm (BFOA) [19] they were 144.04 kW, 31.72%, and 0.9361 p.u respectively and using Particle Swarm Optimization Algorithm (PSO) [20] they were 132.48 kW, 34.63%, and 0.92 p.u respectively. The result obtained shows the optimal value for CB location are at bus 13 with CB capacity of 378 KVar, bus 24 with capacitor capacity of 544KVar, and bus 30 with capacitor capacity as 1036 KVar. Whereas, result that is in the reference papers are given as in the table 1. From these results, it can be analyzed that power losses, power factor and minimum voltage are nearly as that of reference paper. Hence, results are satisfactory with respect to the reference paper.

ii) **Case II:** This is the case for only DG placement. The real power loss, reactive power loss, loss reduction percentage and minimum voltage that was obtained are 76.807 kW, 53.014 KVar, 62.10 %, and 0.971 p.u. whereas in the reference paper [19] using BFOA they were 98.3kW, 53.41%, and 0.9645 p.u respectively and using Fireworks Algorithm (FWA) [21] , they were 88.68 kW, 56.25%, and 0.968 p.u respectively. The result obtained shows the optimal value for DG location are at bus 14 with DG capacity of 604kW, bus 6 with DG capacity of 1228 kW, bus 31 with DG capacity as 686 kW. It gives total of 2518kW. Whereas, result that is in the reference paper for DG placement are shown in the table. From these results, it can be analyzed that power losses has decreased and minimum voltage have increased than that of reference paper. Hence, results have improved from the program that has been used for the thesis.

iii) **Case III:** This is the case for capacitor and DG (unity pf) placement. The real power loss, reactive power loss, loss reduction percentage, and minimum voltage that was obtained are 19.799 kW, 15.499 KVar, 90.23%, and 0.985 p.u. whereas in the reference paper using BFOA [19]they were 41.41 kW, 80.37 %, and 0.9783 p.u respectively and using Genetic Algorithm (GA) [22], results were 71.25 kW, 64.85%, and 0.971 p.u respectively. The result obtained shows the optimal value for capacitor location are at bus 32 with capacity 194 KVar, bus 13 with capacity 393 KVar, bus 30 with capacity 869 KVar and DG location are at bus 14 with DG capacity of 728kW, bus 3 with DG capacity of 1486 kW, bus 30 with DG capacity as 1010 kW.

Whereas, result that is in the reference paper are given as in the table. Results can be analyzed as the power losses got decreased significantly with the program used.

iv) **Case IV:** This is the case for capacitor and DG (controllable pf) placement taking into consideration only technical objectives. The real power loss, reactive power loss, loss reduction percentage, and minimum voltage that was obtained are 16.126 kW, 13.169 KVar, 92.04%, 0.990 p.u. respectively. The result obtained shows the optimal value for capacitor location are at bus 32 with capacity 194 KVar, bus 25 with capacity 333 KVar, bus 30 with capacity 708 KVar and DG location are at bus 14 with DG capacity of 796 kW (0.905 pf), bus 3 with DG capacity of 1712 kW (0.961 pf), bus 30 with DG capacity as 999 kW (0.995 pf).

v) **Case V:** This is the case for capacitor and DG (controllable pf) placement taking into consideration techno-economic objectives. The real power loss, reactive power loss, loss reduction percentage, and minimum voltage that was obtained are 73.64 kW, 57.933 KVar, 63.67%, 0.957 p.u. respectively. The result obtained shows the optimal value for capacitor location are at bus 14 with capacity 333 KVar, bus 30 with capacity 827 KVar, bus 33 with capacity 161 KVar and DG location are at bus 2 with DG capacity of 524 kW (0.906 pf), bus 3 with DG capacity of 1310 kW (0.915 pf), bus 4 with DG capacity as 2229 kW (0.989 pf).

5.2 For 69 Bus System:

Summary of the results obtained for the 69-bus system is illustrated as follows:

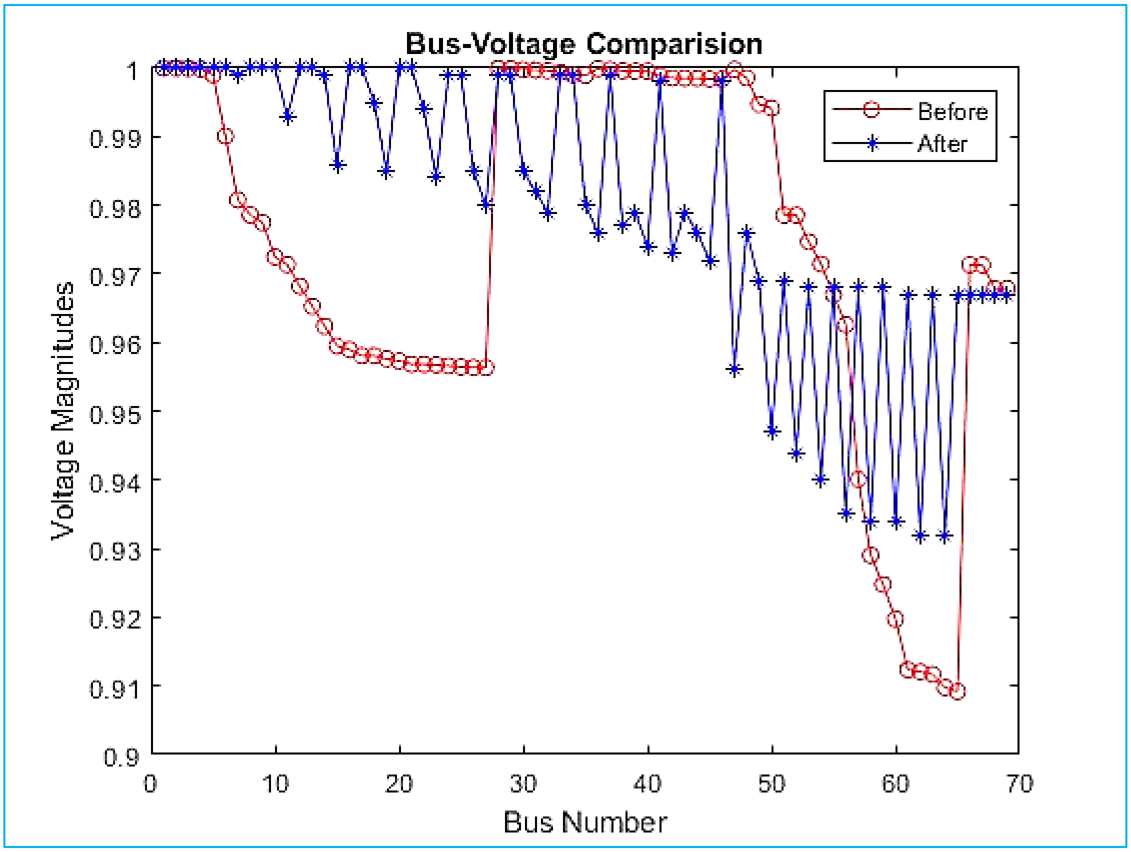


Figure 13: Case I- Bus voltage profile before and after allocation of capacitors to the system

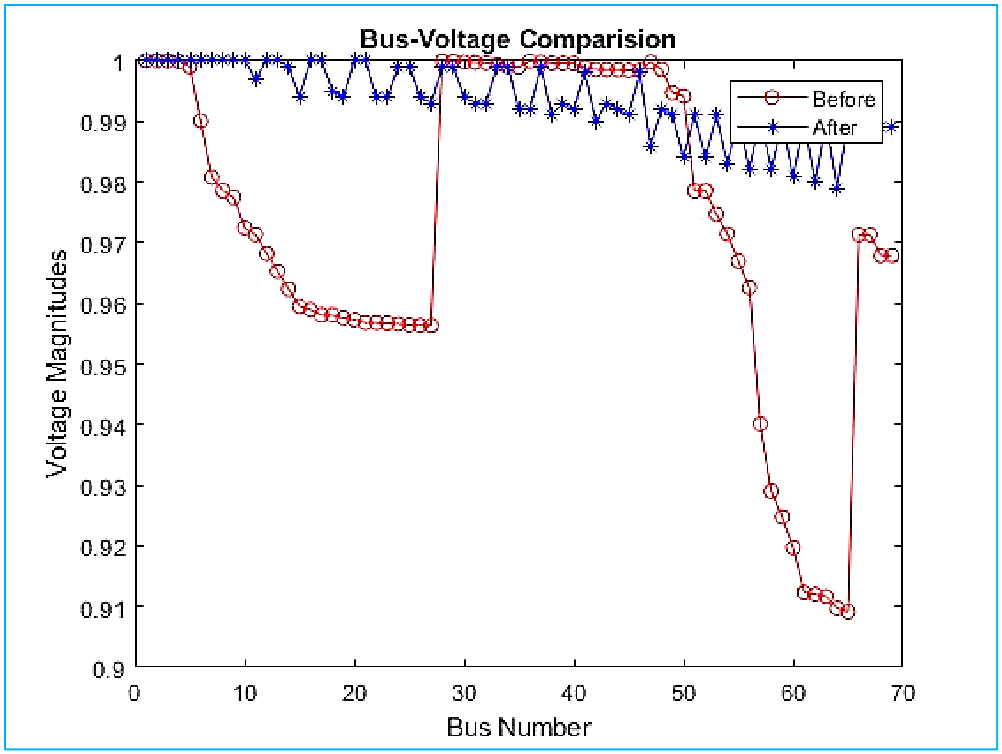


Figure 14: Case II- Bus voltage profile before and after allocation of DGs only

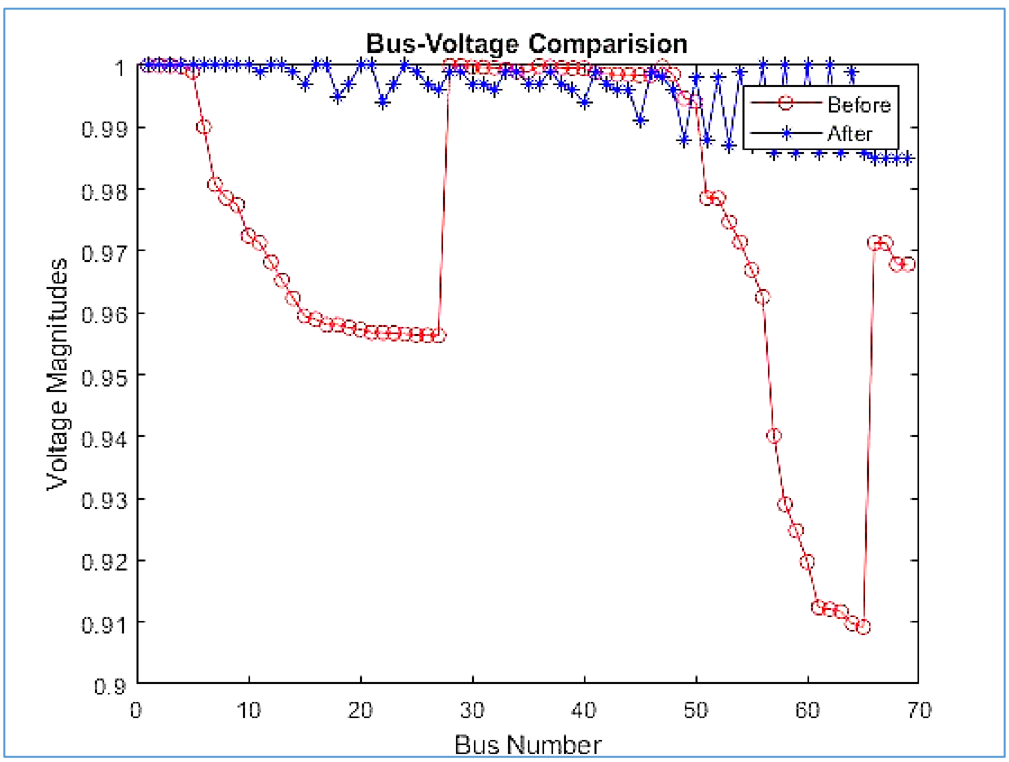


Figure 15: Case III- Bus voltage profile before and after simultaneous placement of capacitors and DG (unity pf)

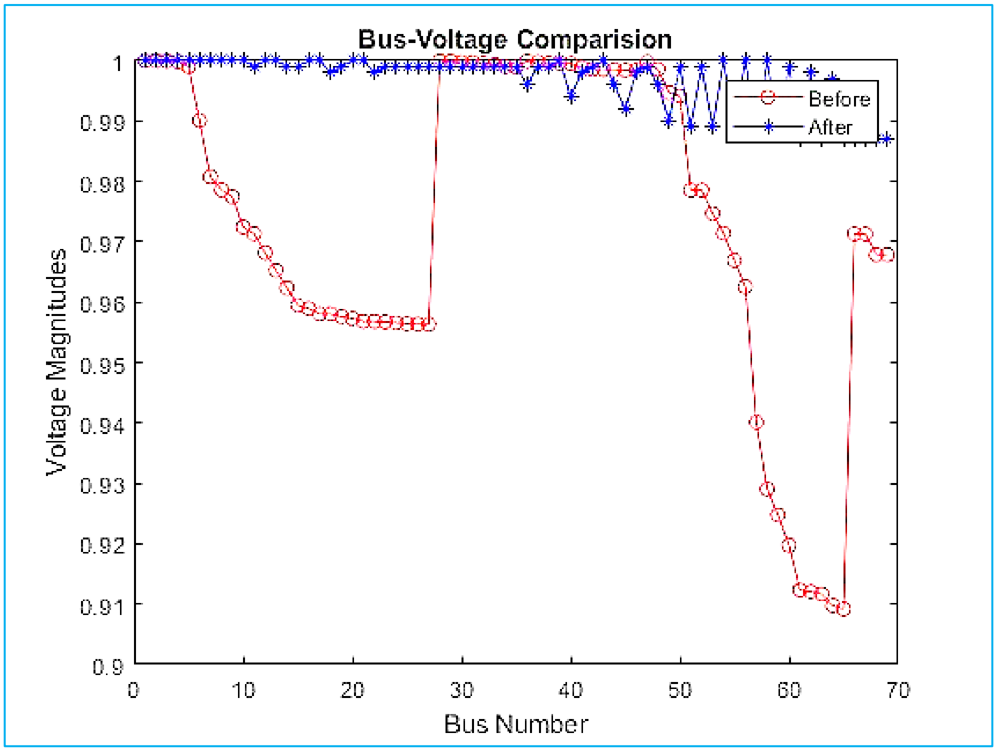


Figure 16: Bus voltage profile before and after simultaneous placement of capacitors and DG (controllable pf)-for only technical objective function

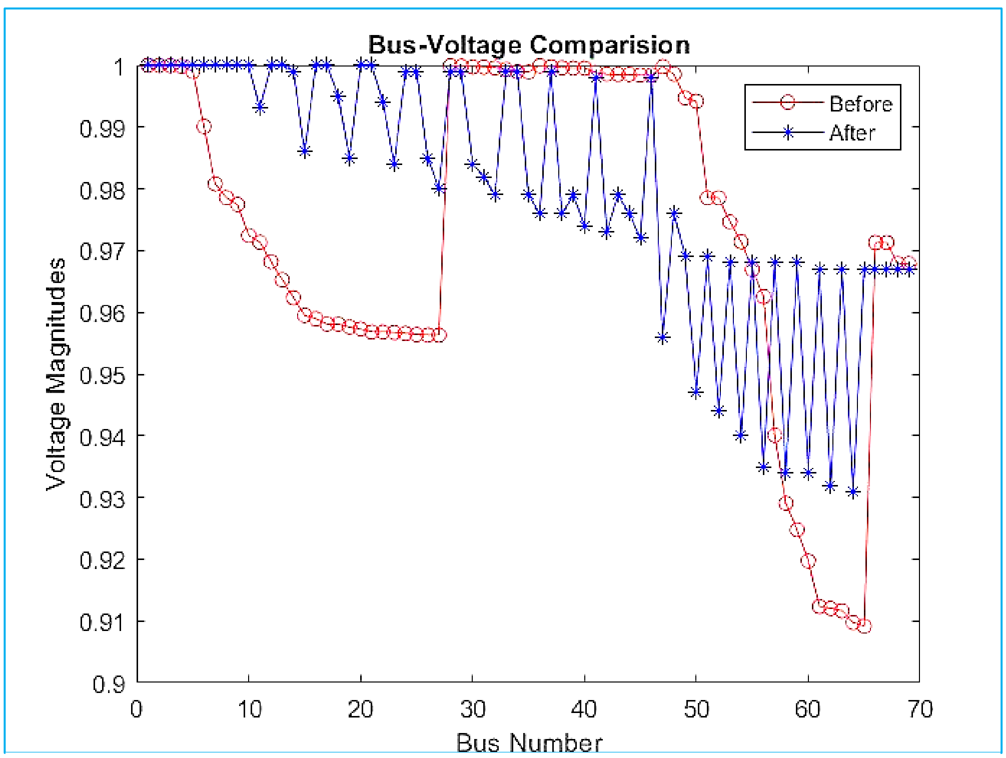


Figure 17: Case V- Bus voltage profile before and after simultaneous placement of capacitors and DG (controllable pf)-for techno-economic objective function

Table 2: <u>Summary of results for IEEE 69 Bus</u>

IEEE 69 BUS SYSTEM	**ACHIEVED RESULTS**	**REFERENCE PAPERS RESULTS**	
Case I (only capacitors)	**ER-WCA**	**GSA**	**PSO**
Minimum voltage	0.932 (62)	0.952	0.934
Active Power loss (KW)	145.49	145.9	152.48
Reactive Power loss (Kvar)	67.798		
Loss reduction %	35.34	35.16	32.23
Placement capacitor (MVAr)	0.425 (53), 0.312 (18), 1.205 (61)	0.15 (26), 0.15 (13), 1.050 (15)	1.015 (59), 0.241(61), 0.365 (65)
Case II (only DGs)	**ER-WCA**	**CVSI**	**GA**
Minimum voltage	0.979 (64)	0.968 (27)	0.969
Active Power loss (KW)	69.428	83.18	88.5
Reactive Power loss (Kvar)	34.962		
Loss reduction %	69.14	63.03	60.67
Placement DG (MW)	1.719 (61), 0.526 (11), 0.380 (18)	1.895 (61)	1.9471
Case III (Capacitors and DGs with unity pf simultaneously)	**ER-WCA**	**DICA**	
Minimum voltage	0.985 (66)	0.979	
Active Power loss (KW)	12.681	17.2	
Reactive Power loss (Kvar)	10.012		
Loss reduction (%)	94.36	92.36	
Placement capacitor (MVAr)	0.023 (34), 1.5 (36), 1.298 (61)	0.35 (11), 0.25 (20)	
Placement DG (MW)	0.380 (64), 1.309 (61), 0.795 (12)	2.25	
IEEE 33 BUS SYSTEM	**ACHIEVED RESULTS**	**IEEE 33 BUS SYSTEM**	**ACHIEVED RESULTS**
Case IV (Capacitors and DGs with controllable pf simultaneously) for only technical objectives	**ER-WCA**	**Case V (Capacitors and DGs with controllable pf simultaneously) for techno-economic objectives**	**ER-WCA**
Minimum voltage	0.987 (61)	Minimum voltage	0.931 (64)
Active Power loss (KW)	8.455	Active Power loss (KW)	145.066
Reactive Power loss (Kvar)	6.501	Reactive Power loss (Kvar)	67.249
Loss reduction (%)	96.24	Loss reduction (%)	35.53
Placement capacitor (MVar)	0.568 (49), 0.267 (18)	Placement capacitor (MVAR)	1.237 (61), 0.337 (66), 0.266 (18)
Placement DG (MW)	0.864 (66), 1.244 (2), 2.073 (61)	Placement DG (MW)	2.281 (2), 2.066 (3), 2.281 (4)
Power factor of DGs	0.932, 1, 0.815	Power factor of DGs	1, 0.945, 0.959

Discussion on Results for 69 bus system:

i) **Case I:** This is the case for only capacitor placement. The real power loss, reactive power loss, loss reduction percentage and minimum voltage that was obtained are 145.49kW, 67.798 KVar, 35.34 %, and 0.932 p.u. whereas in the reference papers results using Gravitational Search Algorithm (GSA) [23] they were 145.9 kW, 35.61%, and 0.952 p.u respectively and using Particle Swarm Optimization Algorithm (PSO) [24] they were 152.48 kW, 32.23%, and 0.934 p.u respectively. The result obtained shows the optimal value for CB location are at bus 53 with CB capacity of 425 KVar, bus 18 with capacitor capacity of 312 KVar, and bus 61 with capacitor capacity as 1205 KVar. Whereas, result that is in the reference papers are given as in the table 2. From these results, it can be analyzed that power losses, power factor and minimum voltage are nearly as that of reference paper. Hence, results are satisfactory with respect to the reference paper.

ii) **Case II:** This is the case for only DG placement. The real power loss, reactive power loss, loss reduction percentage and minimum voltage that was obtained are 69.428 kW, 34.962 KVar, 69.14 %, and 0.979 p.u. whereas in the reference paper using Combined Voltage Stability Index (CVSI) [25] they were 83.18 kW, 63 %, and 0.968 p.u respectively and using GA [26], they were 88.5 kW, 60.67 %, and 0.969 p.u respectively. The result obtained shows the optimal value for DG location are at bus 61 with DG capacity of 1719 kW, bus 11 with DG capacity of 526 kW, bus 18 with DG capacity as 380 kW. Whereas, result that is in the reference paper for DG placement are shown in the table 2. From these results, it can be analyzed that power losses have decreased and minimum voltage have increased than that of reference paper. Hence, results have improved from the program that has been used for the thesis.

iii) **Case III:** This is the case for capacitor and DG (unity pf) placement. The real power loss, reactive power loss, loss reduction percentage, and minimum voltage that was obtained are 12.681 kW, 10.012 KVar, 94.36 %, and 0.985 p.u. whereas in the reference paper using Discrete Imperialistic Competition Algorithm (DICA) [27] they were 17.2 kW, 92.36 %, and 0.979 p.u respectively. The result obtained shows the optimal value for capacitor location are at bus 34 with capacity 23 KVar, bus 36 with capacity 1500 KVar, bus 61 with capacity 1298 KVar and DG location are at bus 64 with DG capacity of 380 kW, bus 61 with DG capacity of 1309 kW , bus 12 with DG capacity as 795 kW .Whereas, result that is in the reference paper are given as in the table 2. Results can be analyzed as the power losses got decreased significantly with the program used.

iv) **Case IV:** This is the case for capacitor and DG (controllable pf) placement taking into consideration only technical objective function. The real power loss, reactive power loss, loss reduction percentage, and minimum voltage that was obtained are 8.455 kW, 6.501 KVar, 96.24%, 0.987 p.u. The allocation of capacitors is at bus 49, and bus 18 with capacity 568 KVar, and 267 KVar respectively and DG allocations at bus 66, bus 2, bus 61 with capacity 864 KW, 1244 KW and 2073 KW respectively. Hence, the results that were achieved have lower power loss, higher power factor and minimum voltage. The location of DGs and capacitor are given on the table.

v) **Case V:** This is the case for capacitor and DG (controllable pf) placement taking into consideration techno-economic objectives. The real power loss, reactive power loss, loss reduction percentage, and minimum voltage that was obtained are 145.066 kW, 67.249 KVar, 35.53 %, 0.931 p.u. respectively. The result obtained shows the optimal value for capacitor location are at bus 61 with capacity 1237 KVar, bus 66 with capacity 337 KVar, bus 18 with capacity 266 KVar and DG location are at bus 2 with DG capacity of 2281 kW (1 pf), bus 3 with DG capacity of 2066 kW (0.945 pf), bus 4 with DG capacity as 2281 kW (0.959 pf).

5.3 For Daachhi Feeder:

Summary of the results obtained for the Daachhi Feeder is illustrated as follows:

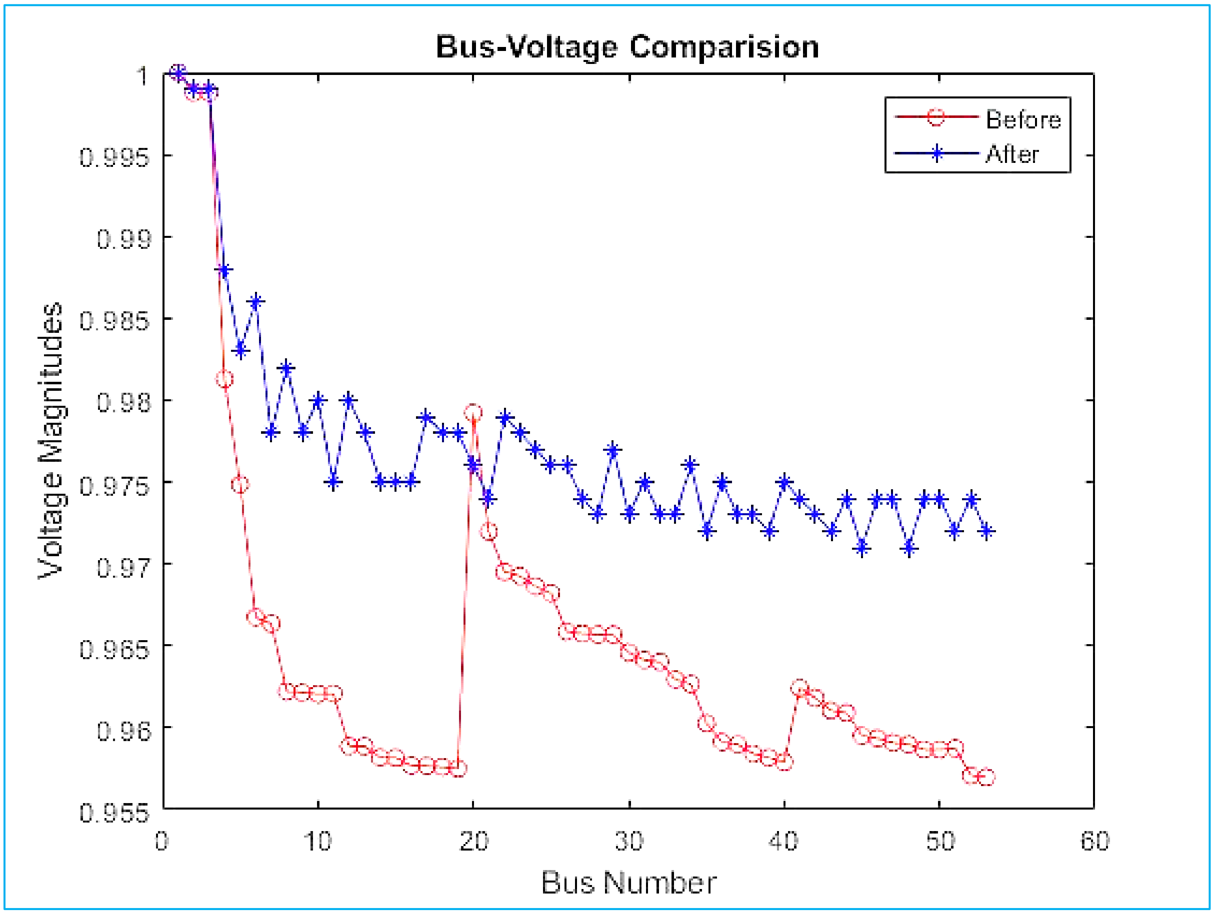


Figure 19: Voltage profile before and after allocation of capacitors

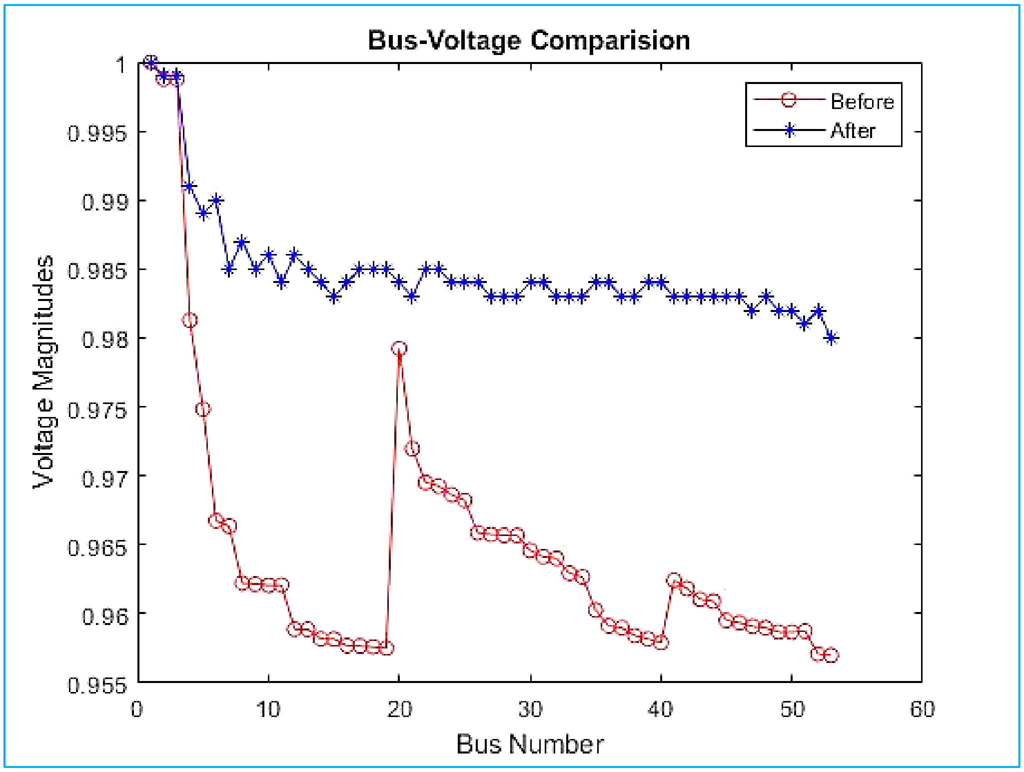


Figure 20: Case II- Bus voltage profile before and after allocation of DGs only

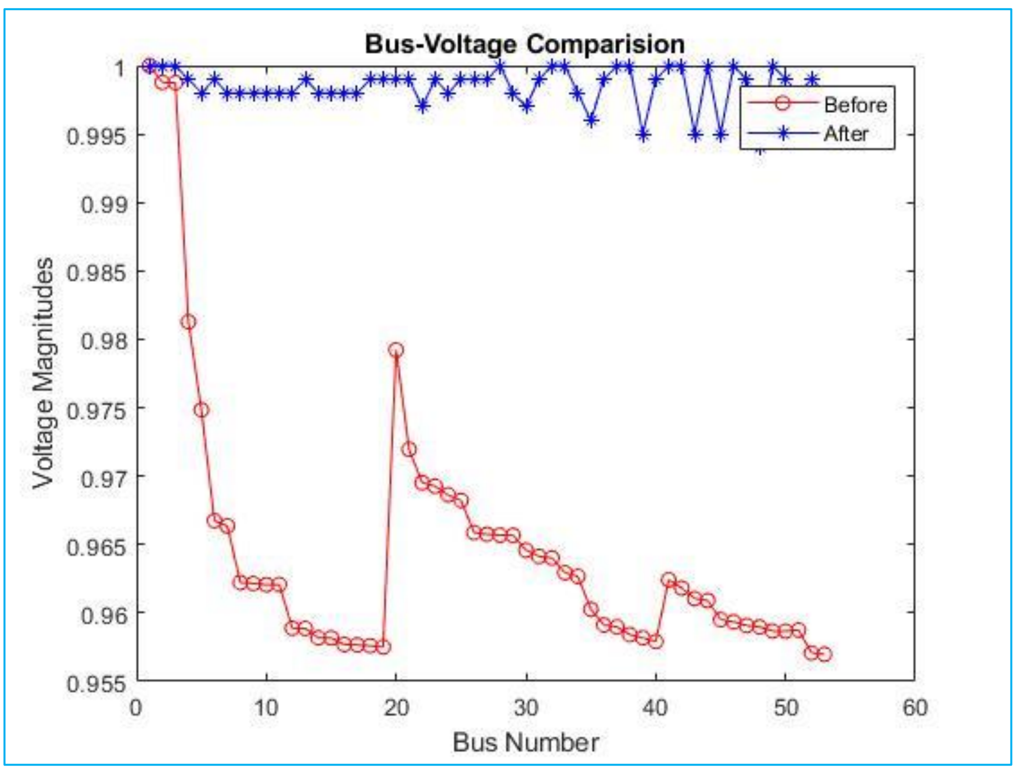


Figure 21: Case III- Bus voltage profile before and after simultaneous placement of capacitors and DG (unity pf)

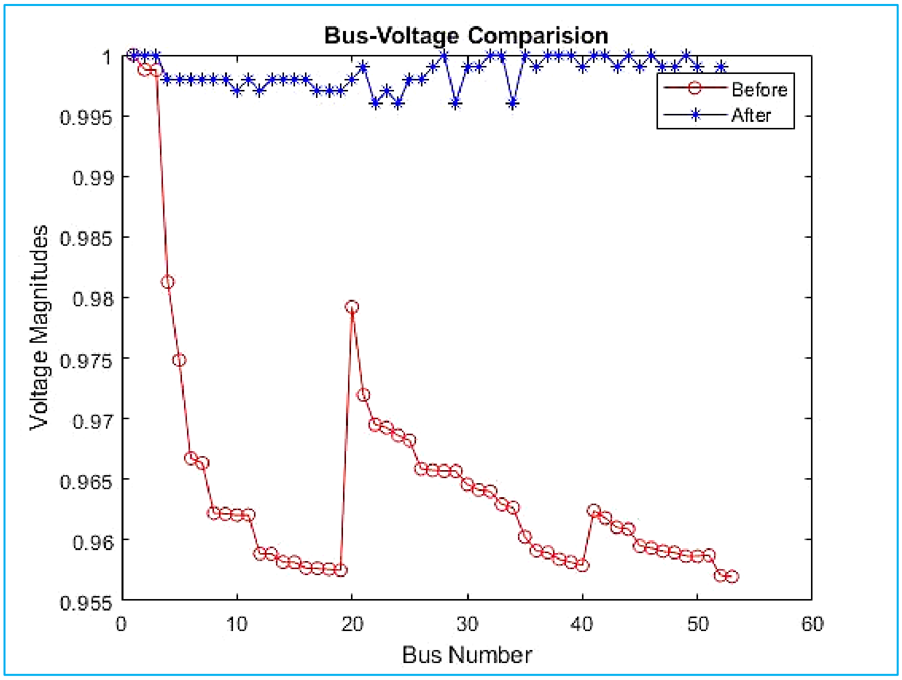


Figure 22: Case IV- Bus voltage profile before and after simultaneous placement of capacitors and DG (controllable pf)-for only technical objective function

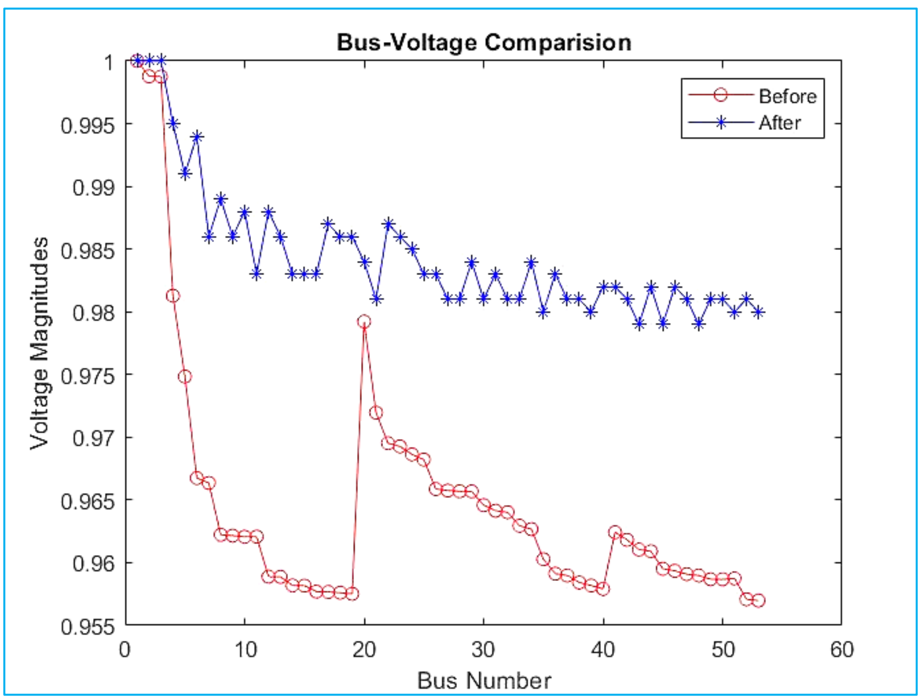


Figure 23: Case V- Bus voltage profile before and after simultaneous placement of capacitors and DG (controllable pf)-for techno-economic objective function

Table 3: <u>Summary of the results of New-Chabahil Feeder and Daachhi Feeder of Kathmandu valley</u>

Cases	Results for New - Chabahil Feeder	Results for Daachhi Feeder
Case I (only capacitors)	**ER-WCA**	**ER-WCA**
Minimum voltage	0.971 (50)	0.971 (39)
Active Power loss (KW)	121.282	98.028
loss reduction %	37.46%	50.25%
Placement capacitor (MVAr)	1.277 (30), 1.195 (12), 1.5 (42)	1.161 (46), 1.038 (16), 1.5 (26)
Case II (only DGs)	**ER-WCA**	**ER-WCA**
Minimum voltage	0.978 (52)	0.980 (53)
Active Power loss (KW)	70.706	101.434
loss reduction %	63.54%	48.52%
Placement DG (MW)	0.925 (33), 0.948 (27), 2.868 (21)	1.643 (43), 0.985 (16), 0.537 (36)
Case III (Capacitors and DGs with unity pf simultaneously)	**ER-WCA**	**ER-WCA**
Minimum voltage	0.998 (7)	0.994 (48)
Active Power loss (KW)	5.628	7.676
Loss reduction (%)	97.10%	96.10%
Placement capacitor (MVAr)	1.026 (40), 1.5 (42), 0.792 (33)	0.982 (46), 1.5 (33), 1.05 (16)
Placement DG (MW)	1.512 (44), 1.7 (17), 1.75 (30)	1.074 (46), 1.54 (26), 1.01 (16)
Case IV (Capacitors and DGs with controllable pf simultaneously) for only technical objective function	**ER-WCA**	**ER-WCA**
Minimum voltage	0.998 (50)	0.996 (22)
Active Power loss (KW)	3.439	6.357
Loss reduction (%)	98.23%	96.77%
Placement capacitor (MVAR)	0.452 (27), 0.461 (19), 0.559 (47)	0.577 (41), 0.419 (8), 0.896 (22)
Placement DG (MW)	1.411 (12) ,1.699 (30), 2.531 (22)	1.757 (45) ,1.269 (16), 0.828 (36)
Power factor	0.878, 0.864, 0.945	0.87, 0.84, 0.85
Case V (Capacitors and DGs with controllable pf simultaneously) for techno-economic objectives	**ER-WCA**	**ER-WCA**
Minimum voltage	0.976 (50)	0.979 (43)
Active Power loss (KW)	91.154	57.244
Reactive Power Loss (KVar)	91.685	30.933
Loss reduction (%)	54%	70.95%
Placement capacitor (MVAR)	0.578 (47), 1.499 (42), 1.272 (30)	1.007 (16), 1.101 (46), 1.5 (26)
Placement DG (MW)	0.554 (2), 3.322 (4), 1.994 (3)	0.388 (3) ,1.406 (2), 2.331 (4)
Power factor	1, 0.988, 0.97	0.8, 1, 0.996

Discussion on Results for Daachhi Feeder:

i) **Case I:** This is the case for only capacitor placement. The real power loss, reactive power loss, loss reduction percentage, and minimum voltage that was obtained are 98.028 kW, 52.971 KVar, 50.25%, and 0.971 p.u. The capacitor placement and sizes are given as in the table. From these results, it can be analyzed that power loss reduction, and minimum voltage are improved than that of base case tremendously.

ii) **Case II:** This is the case for only DG placement. The real power loss, reactive power loss, loss reduction percentage, and minimum voltage that was obtained are 101.434 kW, 54.812 KVar, 48.52%, and 0.980 p.u. The DG placement and sizes are given as in the table. The power loss, and minimum voltages are improved than that of base case tremendously.

iii) **Case III:** This is the case for capacitor and DG (unity pf) placement. The real power loss, reactive power loss, loss reduction percentage, and minimum voltage that was obtained are 7.676 kW, 4.148 KVar, 96.10%, and 0.994 p.u. Hence, the results that were achieved have lower power loss, higher power factor and minimum voltage than that of base case. The location of DGs and capacitor are given on the table 3.

iv) **Case IV:** This is the case for capacitor and DG (controllable pf) placement taking into consideration only technical objectives. The real power loss, reactive power loss, loss reduction percentage, and minimum voltage that was obtained are 6.357 kW, 3.435KVar, 96.77 %, and 0.996 p.u. Hence, the results that were achieved have lower power loss, higher power factor and minimum voltage than that of the base case. The location of DGs and capacitor are given on the table 3.

v) **Case V:** This is the case for capacitor and DG (controllable pf) placement taking into consideration techno-economic objectives. The real power loss, reactive power loss, loss reduction percentage, and minimum voltage that was obtained are 57.244 kW, 30.933 KVar, 70.95 %, and 0.979 p.u. Hence, the results that were achieved have lower power loss, higher power factor and minimum voltage than that of the base case. The location of DGs and capacitor are given on the table 3.

5.4 For New-Chabahil Feeder:

Summary of the results obtained for the New-Chabahil Feeder is illustrated as follows:

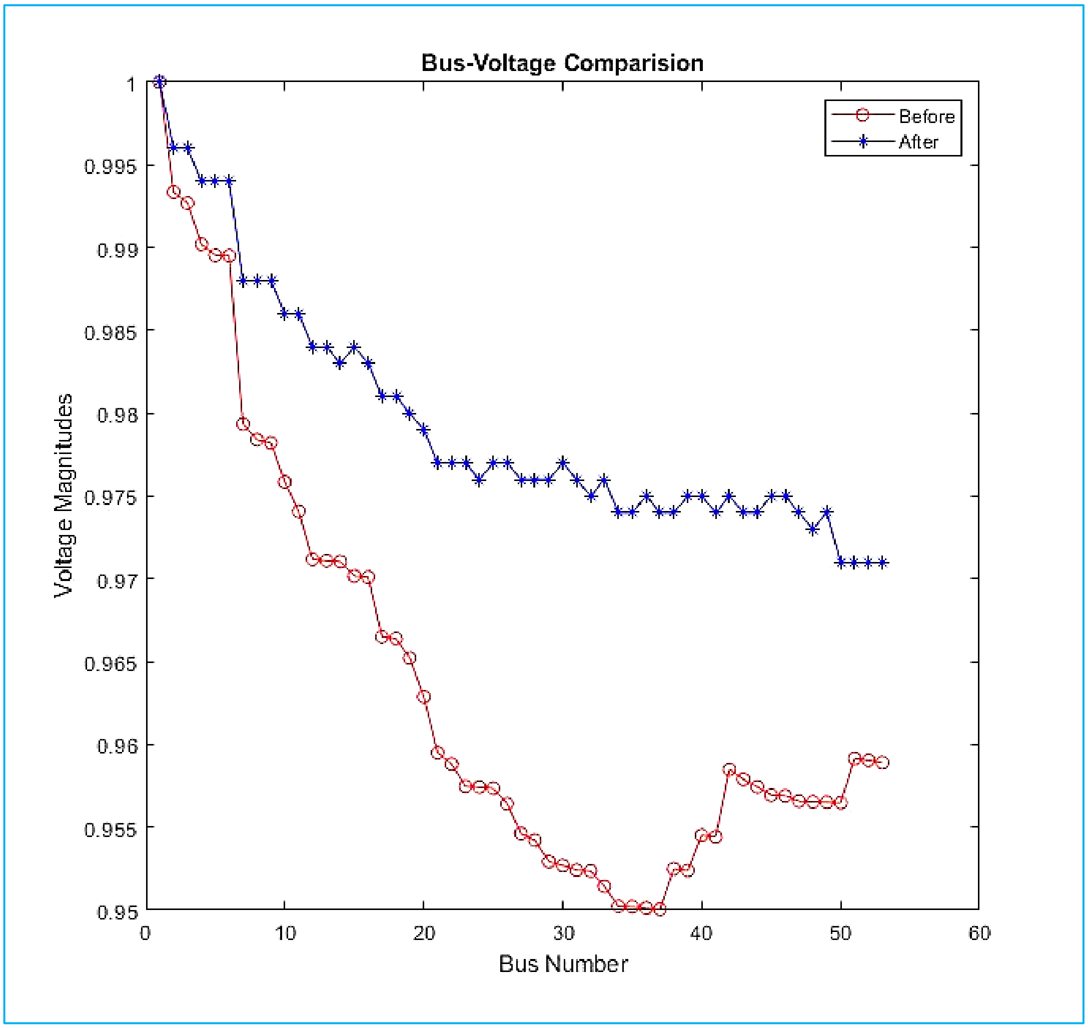


Figure 24: Voltage profile before and after allocation of capacitors

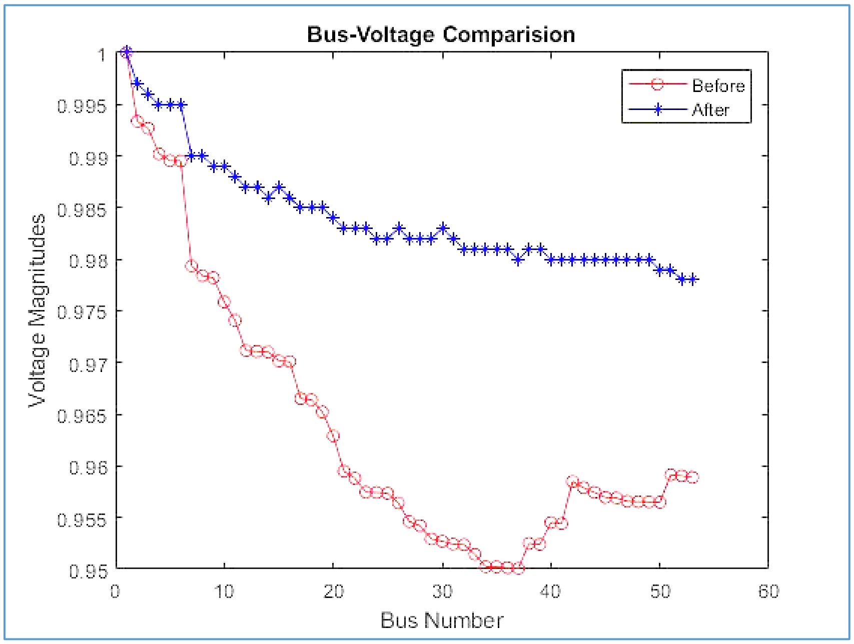


Figure 26: Case II-Bus voltage Profile before and after allocation of DGs

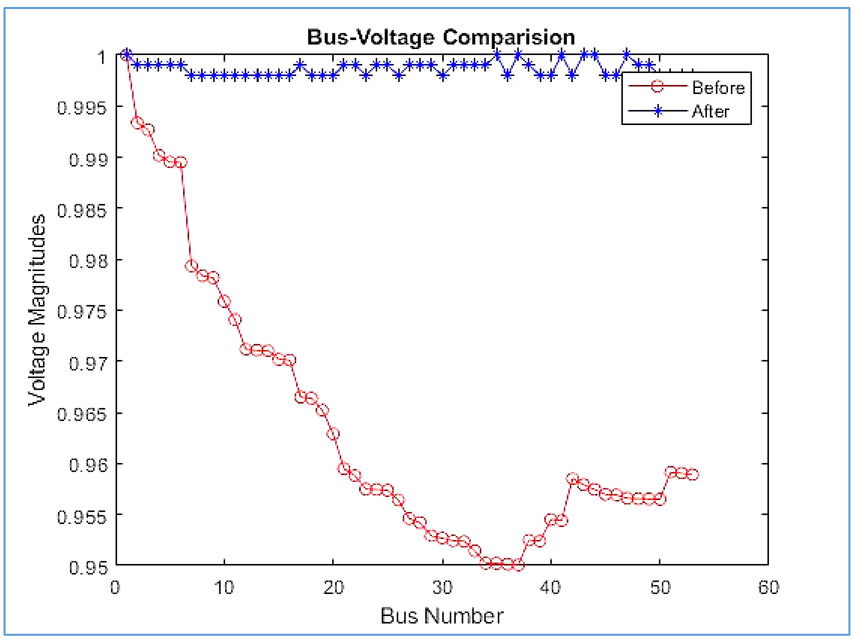


Figure 25: Case III- Bus voltage profile before and after simultaneous placement of capacitors and DG (unity pf)

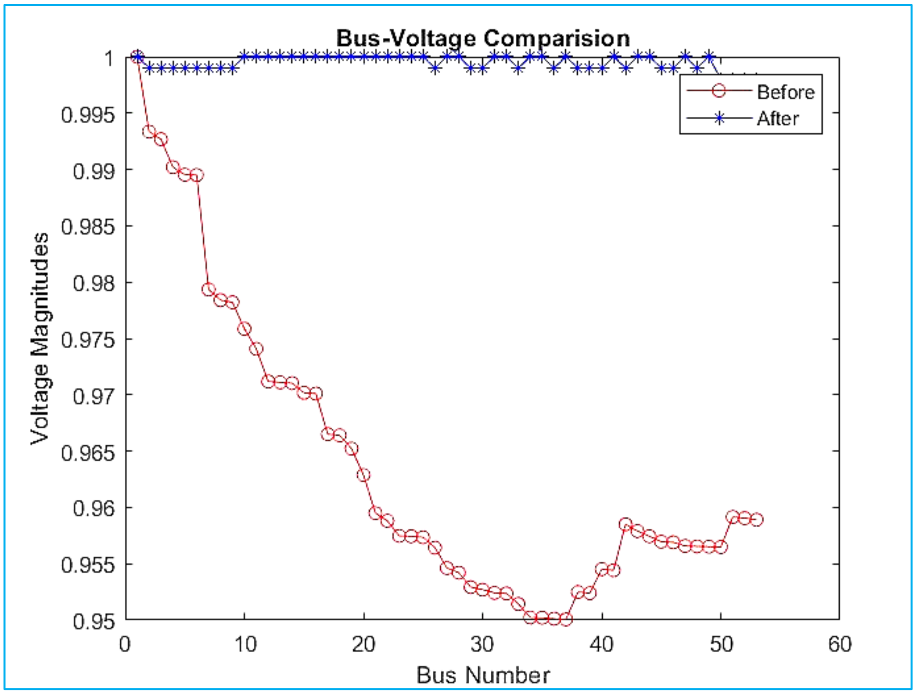


Figure 28: Bus voltage profile before and after simultaneous placement of capacitors and DG (controllable pf)-for only technical objective function

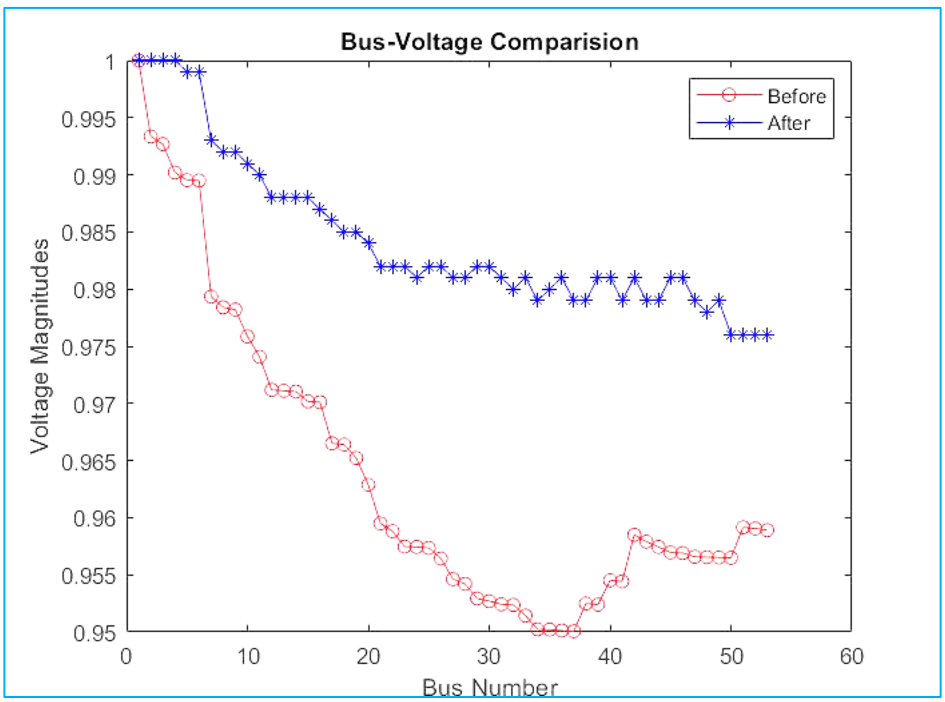


Figure 27: Case V- Bus voltage profile before and after simultaneous placement of capacitors and DG (controllable pf)-for techno-economic objective function

<u>Discussion on Results for New Chabahil Feeder:</u>

i) **Case I:** This is the case for only capacitor placement. The real power loss, reactive power loss, loss reduction percentage, and minimum voltage that was obtained are 121.282 kW, 121.99 KVar, 37.46%, 0.971 p.u. The capacitor placement and sizes are given as in the table. From these results, it can be analyzed that power losses and minimum voltage are improved than that of base case tremendously. The location of DGs and capacitor are given on the table 3.

ii) **Case II:** The real power loss, reactive power loss, loss reduction percentage, and minimum voltage that was obtained are 70.706 kW, 54.812 KVar, 63.54%, 0.978 p.u. The DG placement and sizes are given as in the table. The power loss, and minimum voltages are improved than that of base case tremendously. The location of DGs and capacitor are given on the table 3.

iii) **Case III:** This is the case for capacitor and DG (unity pf) placement. The real power loss, reactive power loss, loss reduction percentage, and minimum voltage that was obtained are 5.628 kW, 5.661 KVar, 97.10 %, 0.998 p.u. Hence, the results that were achieved have lower power loss, and minimum voltage than that of base case. The location of DGs and capacitor are given on the table 3.

iv) **Case IV:** This is the case for capacitor and DG (controllable pf) placement taking into consideration only technical objectives. The real power loss, reactive power loss, loss reduction percentage, and minimum voltage that was obtained are 3.439 kW, 3.459 KVar, 98.23 %, 0.998 p.u. Hence, the results that were achieved have lower power loss, and minimum voltage than that of the base case. The location of DGs and capacitor are given on the table 3.

v) **Case V:** This is the case for capacitor and DG (controllable pf) placement taking into consideration for techno-economic objectives. The real power loss, reactive power loss, loss reduction percentage, and minimum voltage that was obtained are 91.154 kW, 91.685 KVar, 54 %, 0.976 p.u. Hence, the results that were achieved have lower power loss, and minimum voltage than that of the base case. The location of DGs and capacitor are given on the table 3.

CHAPTER 6: CONCLUSION AND FUTURE WORKS

6.1 Conclusion

In this thesis work, optimal allocation of capacitors and DGs was implemented using Evaporation Rate based Water Cycle Algorithm (ER-WCA). To meet the objectives, a computer program was developed in MATLAB software using MATPOWER toolbox. This research analyzed the results of the five cases namely allocating capacitors only (Case I), allocating DGs only (Case II), allocating capacitors and DGs (unity pf) simultaneously (Case III), allocating capacitors and DGs (controllable pf) for technical objectives only (Case IV), and allocating capacitors and DGs (controllable pf) for techno-economic benefits (Case V). The power loss minimization, voltage profile improvement, voltage stability enhancement and cost reduction have been achieved with the help of the allocations. The results obtained in this thesis work using ER-WCA were better than the results found in the reference papers.

For IEEE 33 bus system, power loss in case I, case II, case III, case IV, and case V was 34.79%, 62.10, 90.23%, 92.04%, and 63.67 % of the base case respectively. Similarly, for IEEE 69 bus system, power loss in case I, case II, case III, case IV, and case V were 35.34%, 69.14%, 94.36%, 96.24%, and 35.53% of the base case respectively.

The method discussed in this thesis work was applied to two practical systems of Kathmandu valley (Daachhi feeder and New Chabahil feeder) which needed upgradation for reducing power loss and improving voltage profile. For Daachhi Feeder, power loss in case I, case II, case III, case IV, and case V was 50.25%, 48.52%, 96.10%, 96.77%, and 70.95% of the base case respectively. Similarly, for New-Chabahil Feeder, power loss in case I, case II, case III, case IV, and case V were 37.46%, 63.54%, 97.10%, 98.23%, and 54% of the base case respectively the power loss.

In conclusion, the active and reactive power losses were reduced and voltage drop was minimized for different standard IEEE bus systems and two practical distribution systems of Nepal. Thus, this thesis work has addressed the technical and economic criteria for capacitor and DG placement. Hence, objectives of this thesis work have been effectuated.

6.2 Future works

This research can be further extended to meet the limitations that are realized while carrying out this thesis. This thesis only presents the idea for the possible best allocation of capacitors considering the system always run at the full load. But, the load in the system is not always constant. Hence, for such variable load, other type of compensator like static VAR compensator can be placed in the future research.

The optimization of optimal allocation of DGs and capacitors can be done using other optimization techniques and may make the comparison with the result of the above ER-WCA technique based on other features like time elapsed for the best outputs.

Since this thesis considered only Type 1 and Type 2 DGs, in further works other DGs like Type 3 and Type 4 DGs can be considered.

REFERENCES

[1] A. El-Fergany and A. Abdelaziz, "Capacitor allocations in radial distribution network using cuckoo search algorithm," *IET Generation, Transmission and Distribution*, vol. 8 no.2, pp. 223-232, 2014.

[2] A. El-Ela, E. Sehiemy and A. Abbas, "Optimal Placement and sizing of Distributed Generation and Capacitor Banks in the Distribution Systems Using Water Cycle Algorithm," *IEEE systems Journal*, vol. 12 no. 4, pp. 3629-3696, 2018.

[3] P. Georgilakis and N. Hatziargyriou, "Optimal Distributed Generation Placement in Power Distribution Networks: Models, Methods, and Future Research," *IEEE transactions on power Systems* , vol. 28, no. 3, pp. 3420-3428, Aug 2013.

[4] M. Rahmani-Andebili, "Simultaneous Placement of DG and Capacitor in distribution Network," *Electric Power System Research*, vol. 131, pp. 1-10, 2016.

[5] K. Mistry and R. Roy, "Enhancement of loading capacity of distribution system throgh distributed generator placement considering techno-economic benefits with load growth," *International Journal of Electrical Power and Energy Systems* , vol. 54, pp. 505-515, 2014.

[6] U. Sultana, A. Khairuddin, M. Aman, A. Mokhtar and N. Zareen, "A review of optimium Dg placement based on minimization of power losses and voltage stability enhancement of distribution system.," *Renewable and sustainable Energy Reviews* , vol. 63, pp. 363-378, 2016.

[7] Z. Moravei and A. Akhlaghi, "A novel approach based on cuckoo Search for DG allocation in distribution network," *International journal of electrical Power and Energy Systems* , vol. 44, no. 1, pp. 672-679, 2013.

[8] K. Muthukumar and S. Jayalalitha, "Optimal placement and sizing of Distributed generators and shunt capacitors for power loss minimization in radial distribution networks using hybrid heuristic search optimization technique," *International journal of Electrical Power and Energy Systems* , vol. 78, pp. 299-319, 2016.

[9] P. T. Ananthapadmanabha, S. D.n and B. , "Optimal Allocation of Combined DG and Capacitor Units for Voltage Stability Enhancement," *Procedia Technology* , vol. 21, pp. 216-223, 2015.

[10] B. Pereira , G. R. Martins, J. Contreras and J. R. S. Mantovani, "Optimal Distributed Generation and Reactive Power Allocation in Electrical Distribution Systems," *IEEE Transactions on Sustainable Energy* , vol. 7, no. 3, pp. 975-984, 2016.

[11] A. Bayod-Rujula, "Future development of electricity systems with distributed generation," *Energy*, vol. 34, no. 3, pp. 377-383, 2019.

[12] E. Khattam W and S. M. M. A, "Distributed Generation Technologies , Definitions and Benefits .," *Electric Power System Research* , vol. 71, no. 2, pp. 119-128, 2004.

[13] H. D. Q, M. N and B. R.C, "Analytical expression for DG allocation in primary distribution network," *IEEE Transaction in Energy Conversion* , vol. 25, no. 3, pp. 814-820, 2010.

[14] G. Murthy , S. Sivanagaraju, S. Satyanarayana and B. Rao, "Volatge Stability Enhancement of Distribution System Using Network Reconfihuration Of Presence of DG," *Distributed Generation and Alternative Energy Journal* , vol. 30, no. 4, pp. 37-54, 2015.

[15] A. Sadollah, H. Eskandar, A. Bahreinineja and J. H. Kim, "Water cycle algorithm with evaporation rate for solving constrained and unconstrained optimization problems," *Applied Soft Computing* , vol. 30, pp. 58-71, 2015.

[16] H. Doagou-mojarrad, G. Gharehpetian, H. Rastegar and J. Olamaei, "Optimal placement and sizing of DG (distributed generation) units in distribution networks by novel hybrid evolutionary algorithm," *Energy*, pp. 1-10, 2013.

[17] M. kefayat, A. Lashkar Ara and S. Nabavi niaki, "A hybrid of ant colony optimization and artificial bee colony algorithm for probabilistic optimal placement and sizing of distributed energy sources," *Energy conversion and management*, vol. 92, pp. 149-161, 2015.

[18] a. mohammed shaheed, R. A. EL-Sehiemy and S. M. Farrag, "Adequate Planning of Shunt Power Capacitors Involving Transformer Capacity Release Benefit," *IEEE system Journal*, pp. 1932-8184, 2015.

[19] A. Mohamed Imran and M. Kowsalya , "Optimal Distributed Generation and Capacitor Placement in Power distribution networks for power loss minimization," 2014.

[20] A. Askarzadeh, "Capacitor Placement in distribution systems for power loss reduction and voltage improvement : a new methodology," *IET Generation, Transmission, and Distribution* , vol. 10, no. 14, pp. 3631-3638, 2016.

[21] A. Mohammed Imran , M. Kowsalya and D. Kothari, "A novel integration technique for optimal network reconfiguration and distributed generation placement in power distribution networks," *Electrical Power and Energy Systems*, vol. 63, pp. 461-472, 2014.

[22] A. Saonerkar and B. Bagde, "Optimized DG Placement in radial distribution system with reconfiguration and capacitor placement using Genetic Algorithm," *Ramanathapuram*, 2014.

[23] Y. Mohamed Shuaib, M. Surya Kalavathi and C. Christober Asir Rajan , "Optimal capacitor placement in radial distribution system using Gravitational Search Algorithm," *Electrical Power and Energy Systems*, vol. 64, pp. 384-397, 2015.

[24] K. Prakash and M. Sydulu, "Particle Swarm Optimization based capacitor placement on radial distribution system," 2007.

[25] A. Gantayet and S. Mohanty, "An analytical approach for optimal placement and sizing of distributed generation based on a combined voltage stability index," 2015.

[26] K. Nara, A. Shiose, M. Kitagawa and T. Ishihara, "Implementation of genetic algorithm for distribution system loss minimum reconfiguration," *IEEE transactions on power system*, vol. 7, pp. 1044-1051, 1992.

[27] A. Mahari , "Optimal DG and Capacitor allocation in distribution systems using DICA," *Journal of Engineering Science and Technology* , vol. 9, no. 5, pp. 641-656, 2014.

APPENDIX A

Result Windows

1. RESULT WINDOWS FOR IEEE 33-BUS SYSTEM

   a) Case II: Placement and sizing of Capacitors

```
********************************************************************
********************************************************************
--------------------------------------------------------------------
--------------     CALCULATIONS COMPLETED      ---------------------
--------------------------------------------------------------------
--------------------------------------------------------------------
********************************************************************
********************************************************************
YOU CHOSE PLACEMENT AND SIZING OF CAPACITOR BANKS.
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

Location of Capacitors is at Buses: 30  13  24

Size of Capacitors is:  1036.6656      378.68528       544.2116 kVar each.
Bus Voltages are:
                        Bus No.      ||     Voltage (pu)
                    -----------------------------------
                         1                          1
                         2                      0.998
                         3                      0.987
                         4                      0.997
                         5                      0.981
                         6                      0.994
                         7                      0.984
                         8                      0.976
                         9                      0.993
                        10                       0.98
                        11                      0.964
                        12                      0.992
                        13                      0.977
                        14                      0.962
                        15                      0.963
                        16                      0.958
```

17	0.962
18	0.954
19	0.957
20	0.95
21	0.954
22	0.949
23	0.952
24	0.948
25	0.948
26	0.945
27	0.947
28	0.943
29	0.947
30	0.942
31	0.94
32	0.938
33	0.938

```
Minimum bus voltage is 0.938 pu at 32 bus.
Power Losses are:
-------------------
Active Power Loss = 132.173 kW.
Reactive Power Loss = 88.331 kVar.
Power Factor = 0.99
```

```
OBJECTIVE FUNCTION for the best solution = 132.173.


The best solution was found in Iteration No. 153.

For Base case:
---------------
Minimum bus voltage was 0.913 pu at 18 bus.
Active power loss was 202.677 kW.
Reactive power loss was 135.141 kVar.
Power Factor was 0.849
```

b) <u>Case II: Placement and sizing of DGs</u>

```
--------------      CALCULATIONS COMPLETED      ---------------------
---------------------------------------------------------------------
---------------------------------------------------------------------
*********************************************************************
*********************************************************************
YOU CHOSE PLACEMENT and SIZING OF DGs.
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~


The size of DGs is: 0.60391      1.2287     0.68635   MW each.


The locations of DGs is at Buses:   14   6   31
Bus Voltages are:
                       Bus No.      ||    Voltage (pu)
                     -----------------------------------
                         1                          1
                         2                      0.999
                         3                      0.993
                         4                      0.998
                         5                      0.991
                         6                      0.994
                         7                      0.989
                         8                       0.99
                         9                      0.994
                        10                      0.983
                        11                      0.986
                        12                      0.993
                        13                      0.979
                        14                      0.983
                        15                      0.985
                        16                      0.982
```

```
                        17                      0.984
                        18                       0.98
                        19                      0.978
                        20                      0.978
                        21                      0.973
                        22                      0.978
                        23                      0.972
                        24                      0.978
                        25                      0.973
                        26                      0.978
                        27                      0.972
                        28                      0.978
                        29                      0.971
                        30                      0.977
                        31                      0.975
                        32                      0.973
                        33                      0.973

Minimum bus voltage is 0.971 pu at 29 bus.
Power Losses are:
-------------------
Active Power Loss = 76.807 kW.
Reactive Power Loss = 53.014 kVar.
Power Factor = 0.48

OBJECTIVE FUNCTION for the best solution = 76.807.


The best solution was found in Iteration No. 186.
```

c) <u>Case III: Simultaneous placement of capacitors and DGs (unity pf)</u>

```
--------------      CALCULATIONS COMPLETED      ---------------------
---------------------------------------------------------------------
---------------------------------------------------------------------
*********************************************************************
*********************************************************************
YOU CHOSE OPTIMAL PLACEMENT AND SIZING COMBINATION OF CBs/DGs
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

Location of capacitors is at Buses: 32  13  30
Size of capacitors is:  194.1242       393.299      869.1957  kVar each.

The size of DGs is: 0.72868       1.486      1.0107  MW each
The locations of DGs is at Buses:   14  3   30

Bus Voltages are:
                        Bus No.     ||    Voltage (pu)
                    -----------------------------------
                         1                          1
                         2                      0.999
                         3                      0.998
                         4                      0.999
                         5                      0.997
                         6                      0.995
                         7                      0.995
                         8                      0.996
                         9                      0.995
                        10                      0.988
                        11                      0.994
                        12                      0.994
                        13                      0.985
                        14                      0.993
                        15                      0.994
                        16                      0.993
                        17                      0.995
                        18                      0.993
                        19                      0.997
                        20                      0.995
                        21                      0.999
                        22                      0.995
                        23                      1.001
                        24                      0.995
                        25                      0.998
                        26                      0.999
                        27                      0.998
                        28                          1
                        29                      0.998
                        30                      0.998
                        31                      0.997
                        32                      0.995
                        33                      0.995

Minimum bus voltage is 0.985 pu at 13 bus.
Power Losses are:
------------------
Active Power Loss = 19.799 kW.
Reactive Power Loss = 15.499 kVar.
Power Factor = 0.51

OBJECTIVE FUNCTION for the best solution = 19.799.


The best solution was found in Iteration No. 252.
```

d) <u>Case IV: Simultaneous placement of capacitors and DGs (Controllable pf) –only technical objective function</u>

```
--------------     CALCULATIONS COMPLETED     ---------------------
--------------------------------------------------------------------
--------------------------------------------------------------------
********************************************************************
********************************************************************
  YOU CHOSE MULTIOBJECTIVE OPTIMAL PLACEMENT AND SIZING OF CBs/DGs.
             (DGs are operated with controllable PF,)
            three Technical Objectives are considered.)
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

Location of capacitors is at Buses: 32  25  30
Size of capacitors is:  194.4903       333.864      701.7887  kVar each.

The size of DGs is: 0.79629      1.7124      1.0003  MW each
The optimal pf for the DGs is:  0.90583     0.96131     0.99518  each
The locations of DGs is at Buses:   14  3   30

Bus Voltages are:
```

Bus No.	Voltage (pu)
1	1
2	1
3	1
4	0.999
5	0.999
6	0.996
7	0.997
8	0.997
9	0.995
10	0.992
11	0.995
12	0.994
13	0.99
14	0.994
15	0.995
16	0.993
17	0.995
18	0.993
19	0.997
20	0.994
21	0.999
22	0.995
23	1
24	0.995
25	0.998
26	0.999
27	0.997
28	1
29	0.997
30	0.999
31	0.998
32	0.996
33	0.995

```
Minimum bus voltage is 0.990 pu at 13 bus.
Power Losses are:
------------------
Active Power Loss = 16.126 kW.
Reactive Power Loss = 13.169 kVar.
Power Factor = 0.90

OBJECTIVE FUNCTION for the best solution = 8.086.
```

e) <u>Case V: Simultaneous placement of capacitors and DGs (Controllable pf) – techno-Economic objective function</u>

```
**********************************************************************
----------------------------------------------------------------------
--------------     CALCULATIONS COMPLETED      ---------------------
----------------------------------------------------------------------
----------------------------------------------------------------------
**********************************************************************
**********************************************************************
  YOU CHOSE MULTIOBJECTIVE OPTIMAL PLACEMENT AND SIZING OF CBs/DGs.
             (DGs are operated with controllable PF,
         Technical and Economic Objectives are optimized.)

Location of capacitors is at Buses: 14   30   33
Size of capacitors is:  333.991      827.3612      161.7665  kVar each.

The size of DGs is: 0.52419        1.31       2.229  MW each

The optimal pf for the DGs is:  0.90622     0.91594     0.98916  each

The locations of DGs is at Buses:   2   3   4
Bus Voltages are:
                        Bus No.     ||    Voltage (pu)
                    -----------------------------------
                         1                         1
                         2                         1
                         3                         1
                         4                         1
                         5                         1
                         6                     0.996
                         7                     0.997
                         8                     0.995
                         9                     0.995
                        10                      0.99
                        11                     0.983
                        12                     0.995
                        13                     0.987
                        14                     0.981
                        15                     0.982
                        16                     0.977
                        17                      0.98
                        18                     0.972
                        19                     0.975
                        20                     0.968
                        21                     0.972
                        22                     0.968
                        23                      0.97
                        24                     0.967
                        25                     0.967
                        26                     0.963
                        27                     0.967
                        28                     0.963
                        29                     0.967
                        30                     0.961
                        31                      0.96
                        32                     0.958
                        33                     0.957

Minimum bus voltage is 0.957 pu at 33 bus.
Power Losses are:
-------------------
Active Power Loss = 73.640 kW.
Reactive Power Loss = 57.933 kVar.
Power Factor = 0.92
```

2. RESULT WINDOWS FOR IEEE 69-BUS SYSTEM

a) Case I: Placement and sizing of capacitor banks:

```
------------------------------------------------------------------------
--------------      CALCULATIONS COMPLETED      ---------------------
------------------------------------------------------------------------
------------------------------------------------------------------------
************************************************************************
************************************************************************
YOU CHOSE PLACEMENT AND SIZING OF CAPACITOR BANKS.
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

Location of Capacitors is at Buses: 53   18   61

Size of Capacitors is:  425.45467      312.31705      1205.7686 kVar each.
Bus Voltages are:
```

Bus No.	Voltage (pu)
1	1
2	1
3	1
4	1
5	1
6	1
7	0.999
8	1
9	1
10	1
11	0.993
12	1
13	1
14	0.999
15	0.986
16	1
17	1
18	0.995
19	0.985
20	1
21	1
22	0.994
23	0.984
24	0.999
25	0.999
26	0.985
27	0.98
28	0.999
29	0.999
30	0.985
31	0.982
32	0.979
33	0.999
34	0.999
35	0.98
36	0.976
37	0.999
38	0.977
39	0.979
40	0.974
41	0.998
42	0.973
43	0.979
44	0.976
45	0.972
46	0.998
47	0.956
48	0.976
49	0.969
50	0.947
51	0.969
52	0.944
53	0.968
54	0.94
55	0.968
56	0.935
57	0.968
58	0.934
59	0.968
60	0.934
61	0.967
62	0.932
63	0.967
64	0.932
65	0.967
66	0.967
67	0.967
68	0.967
69	0.967

```
Minimum bus voltage is 0.932 pu at 62 bus.
Power Losses are:
--------------------
Active Power Loss = 145.490 kW.
Reactive Power Loss = 67.798 kVar.
Power Factor = 0.98
```

```
OBJECTIVE FUNCTION for the best solution = 145.490.


The best solution was found in Iteration No. 299.

For Base case:
---------------
Minimum bus voltage was 0.909 pu at 65 bus.
Active power loss was 225.001 kW.
Reactive power loss was 102.165 kVar.
Power Factor was 0.821
```

b) <u>Case II: Placement and sizing of DGs</u>**:**

```
--------------      CALCULATIONS COMPLETED      ---------------------
---------------------------------------------------------------------
---------------------------------------------------------------------
*********************************************************************
*********************************************************************
YOU CHOSE PLACEMENT and SIZING OF DGs.
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~


The size of DGs is: 1.719     0.52697     0.38021  MW each.


The locations of DGs is at Buses:   61  11  18
Bus Voltages are:
```

Bus No.	Voltage (pu)
1	1
2	1
3	1
4	1
5	1
6	1
7	1
8	1
9	1
10	1
11	0.997
12	1
13	1
14	0.999
15	0.994
16	1
17	1
18	0.995
19	0.994
20	1
21	1
22	0.994
23	0.994
24	0.999
25	0.999
26	0.994
27	0.993
28	0.999
29	0.999
30	0.994
31	0.993
32	0.993
33	0.999
34	0.999
35	0.992
36	0.992
37	0.999
38	0.991
39	0.993
40	0.992
41	0.998
42	0.99
43	0.993
44	0.992
45	0.991
46	0.998
47	0.986
48	0.992
49	0.991
50	0.984
51	0.991
52	0.984
53	0.991
54	0.983
55	0.991
56	0.982
57	0.991
58	0.982
59	0.99
60	0.981
61	0.99
62	0.98
63	0.99
64	0.979
65	0.99
66	0.99
67	0.99
68	0.989
69	0.989

```
Minimum bus voltage is 0.979 pu at 64 bus.
Power Losses are:
-------------------
Active Power Loss = 69.428 kW.
Reactive Power Loss = 34.962 kVar.
Power Factor = 0.42

OBJECTIVE FUNCTION for the best solution = 69.428.
```

c) <u>Case III: Simultaneous placement of capacitors and DGs (unity pf)</u>

```
--------------      CALCULATIONS COMPLETED      ---------------------
---------------------------------------------------------------------
---------------------------------------------------------------------
*********************************************************************
*********************************************************************
YOU CHOSE OPTIMAL PLACEMENT AND SIZING COMBINATION OF CBs/DGs
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

Location of capacitors is at Buses: 34  36  61
Size of capacitors is:  23.399699          1500      1298.2018  kVar each.

The size of DGs is: 0.38021      1.3097      0.7946  MW each
The locations of DGs is at Buses:   64  61  12

Bus Voltages are:
```

Bus No.	Voltage (pu)
1	1
2	1
3	1
4	1
5	1
6	1
7	1
8	1
9	1
10	1
11	0.999
12	1
13	1
14	0.999
15	0.997
16	1
17	1
18	0.995
19	0.997
20	1
21	1
22	0.994
23	0.997
24	1
25	0.999
26	0.997
27	0.996
28	0.999
29	0.999
30	0.997
31	0.997
32	0.996
33	0.999
34	0.999
35	0.997
36	0.997
37	0.999
38	0.997
39	0.996
40	0.994
41	0.999
42	0.997
43	0.996
44	0.996
45	0.991
46	0.999
47	0.998
48	0.996
49	0.988
50	0.998
51	0.988
52	0.998
53	0.987
54	0.999
55	0.987
56	1
57	0.986
58	1
59	0.986
60	1
61	0.986
62	1
63	0.986
64	0.999
65	0.986
66	0.985
67	0.985
68	0.985
69	0.985

```
Minimum bus voltage is 0.985 pu at 66 bus.
Power Losses are:
------------------
Active Power Loss = 12.681 kW.
Reactive Power Loss = 10.012 kVar.
Power Factor = 1.00

OBJECTIVE FUNCTION for the best solution = 12.681.
```

d) Case IV: Simultaneous placement of capacitors and DGs (Controllable pf) –only technical objective function

```
--------------     CALCULATIONS COMPLETED     ---------------------
-------------------------------------------------------------------
-------------------------------------------------------------------
*******************************************************************
*******************************************************************
  YOU CHOSE MULTIOBJECTIVE OPTIMAL PLACEMENT AND SIZING OF CBs/DGs.
            (DGs are operated with controllable PF,)
           three Technical Objectives are considered.)
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

Location of capacitors is at Buses: 49   2   18
Size of capacitors is:  568.6273           0      267.4907   kVar each.

The size of DGs is: 0.86376       1.244      2.0731  MW each
The optimal pf for the DGs is:  0.93232           1      0.81498   each
The locations of DGs is at Buses:   66   2   61

Bus Voltages are:
                        Bus No.     ||    Voltage (pu)
                      ----------------------------------
                         1                         1
                         2                         1
                         3                         1
                         4                         1
                         5                         1
                         6                         1
                         7                         1
                         8                         1
                         9                         1
                        10                         1
                        11                     0.999
                        12                         1
                        13                         1
                        14                     0.999
                        15                     0.999
                        16                         1
                        17                         1
                        18                     0.998
                        19                     0.999
                        20                         1
                        21                         1
                        22                     0.998
                        23                     0.999
                        24                     0.999
                        25                     0.999
                        26                     0.999
                        27                     0.999
                        28                     0.999
                        29                     0.999
                        30                     0.999
                        31                     0.999
                        32                     0.999
                        33                     0.999
                        34                     0.999
                        35                     0.999
                        36                     0.996
                        37                     0.999
                        38                     0.999
                        39                         1
                        40                     0.994
                        41                     0.998
                        42                     0.999
                        43                         1
                        44                     0.996
                        45                     0.992
                        46                     0.998
                        47                     0.999
                        48                     0.996
                        49                      0.99
                        50                     0.999
                        51                     0.989
                        52                     0.999
                        53                     0.989
                        54                         1
                        55                     0.989
                        56                         1
                        57                     0.988
                        58                         1
                        59                     0.988
                        60                     0.999
                        61                     0.987
                        62                     0.998
                        63                     0.987
                        64                     0.997
                        65                     0.987
                        66                     0.987
                        67                     0.987
                        68                     0.987
                        69                     0.987

Minimum bus voltage is 0.987 pu at 61 bus.
Power Losses are:
------------------
Active Power Loss = 8.455 kW.
Reactive Power Loss = 6.501 kVar.
Power Factor = 0.20

OBJECTIVE FUNCTION for the best solution = 4.284.
```

e) Case V: Simultaneous placement of capacitors and DGs (Controllable pf) –techno-Economic objective function

```
*********************************************************************
*********************************************************************
---------------------------------------------------------------------
--------------     CALCULATIONS COMPLETED      ---------------------
---------------------------------------------------------------------
---------------------------------------------------------------------
*********************************************************************
*********************************************************************
  YOU CHOSE MULTIOBJECTIVE OPTIMAL PLACEMENT AND SIZING OF CBs/DGs.
             (DGs are operated with controllable PF,
         Technical and Economic Objectives are optimized.)

Location of capacitors is at Buses: 61   66   18
Size of capacitors is:  1237.0914      337.93661      266.02235  kVar each.

The size of DGs is: 2.2813      2.0695      2.2813  MW each

The optimal pf for the DGs is:  1     0.94526     0.95985  each

The locations of DGs is at Buses:   2   3   4
Bus Voltages are:
```

Bus No.	Voltage (pu)
1	1
2	1
3	1
4	1
5	1
6	1
7	1
8	1
9	1
10	1
11	0.993
12	1
13	1
14	0.999
15	0.986
16	1
17	1
18	0.995
19	0.985
20	1
21	1
22	0.994
23	0.984
24	0.999
25	0.999
26	0.985
27	0.98
28	0.999
29	0.999
30	0.984
31	0.982
32	0.979
33	0.999
34	0.999
35	0.979
36	0.976
37	0.999
38	0.976
39	0.979
40	0.974
41	0.998
42	0.973
43	0.979
44	0.976
45	0.972
46	0.998
47	0.956
48	0.976
49	0.969
50	0.947
51	0.969
52	0.944
53	0.968
54	0.94
55	0.968
56	0.935
57	0.968
58	0.934
59	0.968
60	0.934
61	0.967
62	0.932
63	0.967
64	0.931
65	0.967
66	0.967
67	0.967
68	0.967
69	0.967

```
Minimum bus voltage is 0.931 pu at 64 bus.
Power Losses are:
------------------
Active Power Loss = 145.066 kW.
Reactive Power Loss = 67.249 kVar.
Power Factor = 0.99
```

3. RESULT WINDOWS FOR DAACHHI FEEDER

a) Case I: Placement and sizing of capacitor banks:

```
--------------      CALCULATIONS COMPLETED      ---------------------
---------------------------------------------------------------------
---------------------------------------------------------------------
*********************************************************************
*********************************************************************
YOU CHOSE PLACEMENT AND SIZING OF CAPACITOR BANKS.
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

Location of Capacitors is at Buses: 46  16  26

Size of Capacitors is:  1161.2052     1038.2371          1500 kVar each.
Bus Voltages are:
```

Bus No.	Voltage (pu)
1	1
2	0.999
3	0.999
4	0.988
5	0.983
6	0.986
7	0.978
8	0.982
9	0.978
10	0.98
11	0.975
12	0.98
13	0.978
14	0.975
15	0.975
16	0.975
17	0.979
18	0.978
19	0.978
20	0.976
21	0.974
22	0.979
23	0.978
24	0.977
25	0.976
26	0.976
27	0.974
28	0.973
29	0.977
30	0.973
31	0.975
32	0.973
33	0.973
34	0.976
35	0.972
36	0.975
37	0.973
38	0.973
39	0.972
40	0.975
41	0.974
42	0.973
43	0.972
44	0.974
45	0.971
46	0.974
47	0.974
48	0.971
49	0.974
50	0.974
51	0.972
52	0.974
53	0.972

```
Minimum bus voltage is 0.971 pu at 45 bus.
Power Losses are:
-------------------
Active Power Loss = 98.028 kW.
Reactive Power Loss = 52.971 kVar.
Power Factor = 1.00

OBJECTIVE FUNCTION for the best solution = 98.028.


The best solution was found in Iteration No. 65.

For Base case:
---------------
Minimum bus voltage was 0.957 pu at 53 bus.
Active power loss was 197.026 kW.
Reactive power loss was 106.467 kVar.
Power Factor was 0.708
```

b) Case II: Placement and sizing of DGs:

```
--------------      CALCULATIONS COMPLETED      ---------------------
--------------------------------------------------------------------
--------------------------------------------------------------------
********************************************************************
********************************************************************
YOU CHOSE PLACEMENT and SIZING OF DGs.
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~


The size of DGs is: 1.6431      0.9851     0.53795  MW each.


The locations of DGs is at Buses:   43  16  36
Bus Voltages are:
```

Bus No.	Voltage (pu)
1	1
2	0.999
3	0.999
4	0.991
5	0.989
6	0.99
7	0.985
8	0.987
9	0.985
10	0.986
11	0.984
12	0.986
13	0.985
14	0.984
15	0.983
16	0.984
17	0.985
18	0.985
19	0.985
20	0.984
21	0.983
22	0.985
23	0.985
24	0.984
25	0.984
26	0.984
27	0.983
28	0.983
29	0.983
30	0.984
31	0.984
32	0.983
33	0.983
34	0.983
35	0.984
36	0.984
37	0.983
38	0.983
39	0.984
40	0.984
41	0.983
42	0.983
43	0.983
44	0.983
45	0.983
46	0.983
47	0.982
48	0.983
49	0.982
50	0.982
51	0.981
52	0.982
53	0.98

```
Minimum bus voltage is 0.980 pu at 53 bus.
Power Losses are:
-------------------
Active Power Loss = 101.434 kW.
Reactive Power Loss = 54.812 kVar.
Power Factor = 0.20

OBJECTIVE FUNCTION for the best solution = 101.434.


The best solution was found in Iteration No. 232.

For Base case:
---------------
Minimum bus voltage was 0.957 pu at 53 bus.
Active power loss was 197.026 kW.
Reactive power loss was 106.467 kVar.
Power Factor was 0.708
```

c) Case III: Simultaneous placement of capacitors and DGs (unity pf)

```
--------------     CALCULATIONS COMPLETED      ---------------------
---------------------------------------------------------------------
---------------------------------------------------------------------
*********************************************************************
*********************************************************************
YOU CHOSE OPTIMAL PLACEMENT AND SIZING COMBINATION OF CBs/DGs
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

Location of capacitors is at Buses: 46  33  16
Size of capacitors is:  982.68679          1500      1055.4264  kVar each.

The size of DGs is: 1.0746      1.5477      1.0051  MW each
The locations of DGs is at Buses:   46  26  16

Bus Voltages are:
                        Bus No.     ||    Voltage (pu)
                    -----------------------------------
                          1                         1
                          2                         1
                          3                         1
                          4                     0.999
                          5                     0.998
                          6                     0.999
                          7                     0.998
                          8                     0.998
                          9                     0.998
                         10                     0.998
                         11                     0.998
                         12                     0.998
                         13                     0.999
                         14                     0.998
                         15                     0.998
```

```
    16                      0.998
    17                      0.998
    18                      0.999
    19                      0.999
    20                      0.999
    21                      0.999
    22                      0.997
    23                      0.999
    24                      0.998
    25                      0.999
    26                      0.999
    27                      0.999
    28                          1
    29                      0.998
    30                      0.997
    31                      0.999
    32                          1
    33                          1
    34                      0.998
    35                      0.996
    36                      0.999
    37                          1
    38                          1
    39                      0.995
    40                      0.999
    41                          1
    42                          1
    43                      0.995
    44                          1
    45                      0.995
    46                          1
    47                      0.999
```

```
                          48                      0.994
                          49                          1
                          50                      0.999
                          51                      0.998
                          52                      0.999
                          53                      0.998

Minimum bus voltage is 0.994 pu at 48 bus.
Power Losses are:
------------------
Active Power Loss = 7.676 kW.
Reactive Power Loss = 4.148 kVar.
Power Factor = 0.53

OBJECTIVE FUNCTION for the best solution = 7.676.


The best solution was found in Iteration No. 173.

For Base case:
---------------
Minimum bus voltage was 0.957 pu at 53 bus.
Active power loss was 197.026 kW.
Reactive power loss was 106.467 kVar.
Power Factor was 0.708
```

d) <u>Case IV: Simultaneous placement of capacitors and DGs (Controllable pf) –only technical objective function:</u>

```
--------------      CALCULATIONS COMPLETED      ---------------------
---------------------------------------------------------------------
---------------------------------------------------------------------
*********************************************************************
*********************************************************************
  YOU CHOSE MULTIOBJECTIVE OPTIMAL PLACEMENT AND SIZING OF CBs/DGs.
            (DGs are operated with controllable PF,)
           three Technical Objectives are considered.)
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

Location of capacitors is at Buses: 41   8   22
Size of capacitors is:  577.1019      419.6478      896.3094  kVar each.

The size of DGs is: 1.7579      1.2692     0.82898  MW each
The optimal pf for the DGs is:  0.87986     0.84019     0.85296  each
The locations of DGs is at Buses:   45  16  36

Bus Voltages are:
```

Bus No.	Voltage (pu)
1	1
2	1
3	1
4	0.998
5	0.998
6	0.998
7	0.998
8	0.998
9	0.998
10	0.997
11	0.998
12	0.997
13	0.998
14	0.998
15	0.998
16	0.998
17	0.997
18	0.997
19	0.997
20	0.998
21	0.999
22	0.996
23	0.997
24	0.996
25	0.998
26	0.998
27	0.999
28	1
29	0.996
30	0.999
31	0.999
32	1
33	1
34	0.996
35	1
36	0.999
37	1
38	1
39	1
40	0.999
41	1
42	1
43	0.999
44	1
45	0.999
46	1
47	0.999
48	0.999
49	1
50	0.999
51	0.998
52	0.999
53	0.998

```
Minimum bus voltage is 0.996 pu at 22 bus.
Power Losses are:
------------------
Active Power Loss = 6.357 kW.
Reactive Power Loss = 3.435 kVar.
Power Factor = 0.98

OBJECTIVE FUNCTION for the best solution = 3.188.


The best solution was found in Iteration No. 300.

For Base case:
---------------
Minimum bus voltage was 0.957 pu at 53 bus.
Active power loss was 197.026 kW.
Reactive power loss was 106.467 kVar.
Power Factor was 0.708
```

e) Case V: Simultaneous placement of capacitors and DGs (Controllable pf) –techno-Economic objective function:

```
*********************************************************************
---------------------------------------------------------------------
--------------     CALCULATIONS COMPLETED      ---------------------
---------------------------------------------------------------------
---------------------------------------------------------------------
*********************************************************************
*********************************************************************
  YOU CHOSE MULTIOBJECTIVE OPTIMAL PLACEMENT AND SIZING OF CBs/DGs.
             (DGs are operated with controllable PF,
         Technical and Economic Objectives are optimized.)

Location of capacitors is at Buses: 16  46  26
Size of capacitors is:  1007.9304      1101.3668          1500  kVar each.

The size of DGs is: 0.3885      1.4065       2.331  MW each

The optimal pf for the DGs is:  0.80015          1      0.99625  each

The locations of DGs is at Buses:   3   2   4
Bus Voltages are:
                        Bus No.     ||    Voltage (pu)
                    -----------------------------------
                         1                        1
                         2                        1
                         3                        1
                         4                    0.995
                         5                    0.991
                         6                    0.994
                         7                    0.986
                         8                    0.989
                         9                    0.986
                        10                    0.988
                        11                    0.983
                        12                    0.988
                        13                    0.986
```

```
14                       0.983
15                       0.983
16                       0.983
17                       0.987
18                       0.986
19                       0.986
20                       0.984
21                       0.981
22                       0.987
23                       0.986
24                       0.985
25                       0.983
26                       0.983
27                       0.981
28                       0.981
29                       0.984
30                       0.981
31                       0.983
32                       0.981
33                       0.981
34                       0.984
35                        0.98
36                       0.983
37                       0.981
38                       0.981
39                        0.98
40                       0.982
41                       0.982
42                       0.981
43                       0.979
44                       0.982
45                       0.979
46                       0.982
47                       0.981
48                       0.979
```

```
                        49                       0.981
                        50                       0.981
                        51                        0.98
                        52                       0.981
                        53                        0.98

Minimum bus voltage is 0.979 pu at 43 bus.
Power Losses are:
------------------
Active Power Loss = 57.244 kW.
Reactive Power Loss = 30.933 kVar.
Power Factor = 0.89

OBJECTIVE FUNCTION for the best solution = 11894067.844.


The best solution was found in Iteration No. 124.

For Base case:
---------------
Minimum bus voltage was 0.957 pu at 53 bus.
Active power loss was 197.026 kW.
Reactive power loss was 106.467 kVar.
Power Factor was 0.708
```

4. RESULT WINDOWS FOR NEW-CHABAHIL FEEDER

a) Case I: Placement and sizing of capacitor banks:

```
--------------     CALCULATIONS COMPLETED     ---------------------
--------------------------------------------------------------------
--------------------------------------------------------------------
********************************************************************
********************************************************************
YOU CHOSE PLACEMENT AND SIZING OF CAPACITOR BANKS.
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

Location of Capacitors is at Buses: 30   12   42

Size of Capacitors is:  1277.5048      1195.5072          1500 kVar each.
Bus Voltages are:
                       Bus No.     ||    Voltage (pu)
                    -----------------------------------
                        1                          1
                        2                      0.996
                        3                      0.996
                        4                      0.994
                        5                      0.994
                        6                      0.994
                        7                      0.988
                        8                      0.988
                        9                      0.988
                       10                      0.986
                       11                      0.986
                       12                      0.984
                       13                      0.984
                       14                      0.983
                       15                      0.984
                       16                      0.983
                       17                      0.981
                       18                      0.981
                       19                       0.98
                       20                      0.979
                       21                      0.977
                       22                      0.977
                       23                      0.977
                       24                      0.976
                       25                      0.977
                       26                      0.977
                       27                      0.976
                       28                      0.976
                       29                      0.976
                       30                      0.977
                       31                      0.976
                       32                      0.975
                       33                      0.976
                       34                      0.974
                       35                      0.974
                       36                      0.975
                       37                      0.974
                       38                      0.974
                       39                      0.975
                       40                      0.975
                       41                      0.974
                       42                      0.975
                       43                      0.974
                       44                      0.974
                       45                      0.975
                       46                      0.975
                       47                      0.974
                       48                      0.973
                       49                      0.974
                       50                      0.971
                       51                      0.971
                       52                      0.971
                       53                      0.971

Minimum bus voltage is 0.971 pu at 50 bus.
Power Losses are:
-------------------
Active Power Loss = 121.282 kW.
Reactive Power Loss = 121.990 kVar.
Power Factor = 1.00

OBJECTIVE FUNCTION for the best solution = 121.282.


The best solution was found in Iteration No. 83.

For Base case:
---------------
Minimum bus voltage was 0.950 pu at 37 bus.
Active power loss was 193.913 kW.
Reactive power loss was 195.043 kVar.
Power Factor was 0.797
```

b) Case II: Placement and sizing of DGs:

```
--------------      CALCULATIONS COMPLETED      ---------------------
---------------------------------------------------------------------
---------------------------------------------------------------------
*********************************************************************
*********************************************************************
YOU CHOSE PLACEMENT and SIZING OF DGs.
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~


The size of DGs is: 0.92508     0.94829      2.8687   MW each.


The locations of DGs is at Buses:   33   27   21
Bus Voltages are:
```

Bus No.	Voltage (pu)
1	1
2	0.997
3	0.996
4	0.995
5	0.995
6	0.995
7	0.99
8	0.99
9	0.989
10	0.989
11	0.988
12	0.987
13	0.987
14	0.986
15	0.987
16	0.986
17	0.985
18	0.985
19	0.985
20	0.984
21	0.983
22	0.983
23	0.983
24	0.982
25	0.982
26	0.983
27	0.982
28	0.982
29	0.982
30	0.983
31	0.982
32	0.981
33	0.981
34	0.981
35	0.981
36	0.981
37	0.98
38	0.981
39	0.981
40	0.98
41	0.98
42	0.98
43	0.98
44	0.98
45	0.98
46	0.98
47	0.98
48	0.98
49	0.98
50	0.979
51	0.979
52	0.978
53	0.978

```
Minimum bus voltage is 0.978 pu at 52 bus.
Power Losses are:
--------------------
Active Power Loss = 70.706 kW.
Reactive Power Loss = 71.118 kVar.
Power Factor = 0.20

OBJECTIVE FUNCTION for the best solution = 70.706.


The best solution was found in Iteration No. 300.

For Base case:
----------------
Minimum bus voltage was 0.950 pu at 37 bus.
Active power loss was 193.913 kW.
Reactive power loss was 195.043 kVar.
Power Factor was 0.797
```

c) Case III: Simultaneous placement of capacitors and DGs (unity pf)

```
--------------     CALCULATIONS COMPLETED     ---------------------
--------------------------------------------------------------------
--------------------------------------------------------------------
********************************************************************
********************************************************************
YOU CHOSE OPTIMAL PLACEMENT AND SIZING COMBINATION OF CBs/DGs
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

Location of capacitors is at Buses: 40  42  33
Size of capacitors is:  1026.644         1500      792.03612  kVar each

The size of DGs is: 1.5126      1.7003      1.7495  MW each
The locations of DGs is at Buses:   44  17  30

Bus Voltages are:
```

Bus No.	Voltage (pu)
1	1
2	0.999
3	0.999
4	0.999
5	0.999
6	0.999
7	0.998
8	0.998
9	0.998
10	0.998
11	0.998
12	0.998
13	0.998
14	0.998
15	0.998
16	0.998
17	0.999
18	0.998
19	0.998
20	0.998
21	0.999
22	0.999
23	0.998
24	0.999
25	0.999
26	0.998
27	0.999
28	0.999
29	0.999
30	0.998
31	0.999
32	0.999
33	0.999
34	0.999
35	1
36	0.998
37	1
38	0.999
39	0.998
40	0.998
41	1
42	0.998
43	1
44	1
45	0.998
46	0.998
47	1
48	0.999
49	0.999
50	0.998
51	0.998
52	0.998
53	0.998

```
Minimum bus voltage is 0.998 pu at 7 bus.
Power Losses are:
------------------
Active Power Loss = 5.628 kW.
Reactive Power Loss = 5.661 kVar.
Power Factor = 0.57

OBJECTIVE FUNCTION for the best solution = 5.628.


The best solution was found in Iteration No. 299.

For Base case:
---------------
Minimum bus voltage was 0.950 pu at 37 bus.
Active power loss was 193.913 kW.
Reactive power loss was 195.043 kVar.
Power Factor was 0.797
```

d) Case IV: Simultaneous placement of capacitors and DGs (Controllable pf) –only technical objective function:

```
--------------     CALCULATIONS COMPLETED      ---------------------
--------------------------------------------------------------------
--------------------------------------------------------------------
********************************************************************
********************************************************************
  YOU CHOSE MULTIOBJECTIVE OPTIMAL PLACEMENT AND SIZING OF CBs/DGs.
             (DGs are operated with controllable PF,)
            three Technical Objectives are considered.)
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

Location of capacitors is at Buses: 27  19  47
Size of capacitors is:  452.8213      461.5512      559.8596  kVar each.

The size of DGs is: 1.4112      1.6995      2.5331  MW each
The optimal pf for the DGs is:  0.87886     0.86414     0.94511  each
The locations of DGs is at Buses:   12  31  22

Bus Voltages are:
                        Bus No.     ||    Voltage (pu)
                    -----------------------------------
                         1                         1
                         2                    0.999
                         3                    0.999
                         4                    0.999
                         5                    0.999
                         6                    0.999
                         7                    0.999
                         8                    0.999
                         9                    0.999
                        10                         1
                        11                         1
                        12                         1
                        13                         1
                        14                         1
                        15                         1
                        16                         1
                        17                         1
                        18                         1
                        19                         1
                        20                         1
                        21                         1
                        22                         1
                        23                         1
                        24                         1
                        25                         1
                        26                     0.999
                        27                         1
                        28                         1
                        29                     0.999
                        30                     0.999
                        31                         1
                        32                         1
                        33                     0.999
                        34                         1
                        35                         1
                        36                     0.999
                        37                         1
                        38                     0.999
                        39                     0.999
                        40                     0.999
                        41                         1
                        42                     0.999
                        43                         1
                        44                         1
                        45                     0.999
                        46                     0.999
                        47                         1
                        48                     0.999
                        49                         1
                        50                     0.998
                        51                     0.998
                        52                     0.998
                        53                     0.998

Minimum bus voltage is 0.998 pu at 50 bus.
Power Losses are:
------------------
Active Power Loss = 3.439 kW.
Reactive Power Loss = 3.459 kVar.
Power Factor = 0.80

OBJECTIVE FUNCTION for the best solution = 1.725.


The best solution was found in Iteration No. 300.

For Base case:
---------------
Minimum bus voltage was 0.950 pu at 37 bus.
Active power loss was 193.913 kW.
Reactive power loss was 195.043 kVar.
Power Factor was 0.797
```

e) <u>Case V: Simultaneous placement of capacitors and DGs (Controllable pf) –techno-Economic objective function:</u>

```
***********************************************************************
***********************************************************************
-----------------------------------------------------------------------
--------------     CALCULATIONS COMPLETED     ---------------------
-----------------------------------------------------------------------
-----------------------------------------------------------------------
***********************************************************************
***********************************************************************
  YOU CHOSE MULTIOBJECTIVE OPTIMAL PLACEMENT AND SIZING OF CBs/DGs.
             (DGs are operated with controllable PF,
        Technical and Economic Objectives are optimized.)

Location of capacitors is at Buses: 47  42  30
Size of capacitors is:  578.08877      1499.9999      1272.5425  kVar each.

The size of DGs is: 0.5536      3.3216      1.9938  MW each

The optimal pf for the DGs is:  1     0.98882     0.97005  each

The locations of DGs is at Buses:   2   4   3
Bus Voltages are:
```

Bus No.	Voltage (pu)
1	1
2	1
3	1
4	1
5	0.999
6	0.999
7	0.993
8	0.992
9	0.992
10	0.991
11	0.99
12	0.988
13	0.988
14	0.988
15	0.988
16	0.987
17	0.986
18	0.985
19	0.985
20	0.984
21	0.982
22	0.982
23	0.982
24	0.981
25	0.982
26	0.982
27	0.981
28	0.981
29	0.982
30	0.982
31	0.981
32	0.98
33	0.981
34	0.979
35	0.98
36	0.981
37	0.979
38	0.979
39	0.981
40	0.981
41	0.979
42	0.981
43	0.979
44	0.979
45	0.981
46	0.981
47	0.979
48	0.978
49	0.979
50	0.976
51	0.976
52	0.976
53	0.976

```
Minimum bus voltage is 0.976 pu at 50 bus.
Power Losses are:
------------------
Active Power Loss = 91.154 kW.
Reactive Power Loss = 91.685 kVar.
Power Factor = 0.86

OBJECTIVE FUNCTION for the best solution = 11894093.261.


The best solution was found in Iteration No. 195.

For Base case:
---------------
Minimum bus voltage was 0.950 pu at 37 bus.
Active power loss was 193.913 kW.
Reactive power loss was 195.043 kVar.
Power Factor was 0.797
```

APPENDIX B

System Data

IEEE test system:

IEEE 33 Bus System						
Bus data			Branch Data			
Bus No.	Pload (MW)	Qload (MW)	From Bus	To Bus	R (Ohms)	X (Ohms)
1	0	0	1	2	0.0922	0.047
2	100	60	2	3	0.493	0.2511
3	90	40	3	4	0.366	0.1864
4	120	80	4	5	0.3811	0.1941
5	60	30	5	6	0.819	0.707
6	60	20	6	7	0.1872	0.6188
7	200	100	7	8	0.7114	0.2351
8	200	100	8	9	1.03	0.74
9	60	20	9	10	1.044	0.74
10	60	20	10	11	0.1966	0.065
11	45	30	11	12	0.3744	0.1238
12	60	35	12	13	1.468	1.155
13	60	35	13	14	0.5416	0.7129
14	120	80	14	15	0.591	0.526
15	60	10	15	16	0.7463	0.545
16	60	20	16	17	1.289	1.721
17	60	20	17	18	0.732	0.574
18	90	40	2	19	0.164	0.1565
19	90	40	19	20	1.5042	1.3554
20	90	40	20	21	0.4095	0.4784
21	90	40	21	22	0.7089	0.9373
22	90	40	3	23	0.4512	0.3083
23	90	50	23	24	0.898	0.7091
24	420	200	24	25	0.896	0.7011
25	420	200	6	26	0.203	0.1034
26	60	25	26	27	0.2842	0.1447
27	60	25	27	28	1.059	0.9337
28	60	20	28	29	0.8042	0.7006
29	120	70	29	30	0.5075	0.2585
30	200	600	30	31	0.9744	0.963
31	150	70	31	32	0.3105	0.3619
32	210	100	32	33	0.341	0.5302
33	60	40				

IEEE 69-Bus System						
Bus Data			Branch Data			
Bus No.	Pload (MW)	Qload (MW)	From Bus	To Bus	R (Ohms)	X (Ohms)
1	0	0	1	2	0.0000312	7.487E-05
2	0	0	2	3	0.0000312	7.487E-05
3	0	0	3	4	9.359E-05	0.0002246
4	0	0	4	5	0.0015661	0.0018343
5	0	0	5	6	0.0228357	0.01163
6	0.0026	0.0022	6	7	0.0237778	0.0121104
7	0.0404	0.03	7	8	0.0057526	0.0029325
8	0.75	0.054	8	9	0.003076	0.0015661
9	0.03	0.022	9	10	0.5109948	0.0168897
10	0.028	0.019	10	11	0.1167988	0.0038621
11	0.145	0.104	11	12	0.4438605	0.0146685
12	0.145	0.104	12	13	0.0642643	0.0212135
13	0.008	0.0055	13	14	0.0651378	0.0215254
14	0.008	0.0055	14	15	0.0660113	0.0218124
15	0	0	15	16	0.0122664	0.0040555
16	0.0455	0.03	16	17	0.0233598	0.0077242
17	0.06	0.035	17	18	0.0002932	9.983E-05
18	0.06	0.035	18	19	0.0204398	0.0067571
19	0	0	19	20	0.0131399	0.0043425
20	0.001	0.0006	20	21	0.0213133	0.0070441
21	0.114	0.081	21	22	0.0008735	0.000287
22	0.0053	0.0035	22	23	0.0099267	0.0032819
23	0	0	23	24	0.0216065	0.0071439
24	0.028	0.02	24	25	0.0467195	0.0154422
25	0	0	25	26	0.0192731	0.0063703
26	0.014	0.01	26	27	0.0108064	0.0035689
27	0.014	0.01	3	28	0.0002745	0.0006738
28	0.026	0.0186	28	29	0.0039931	0.0097644
29	0.026	0.0186	29	30	0.0248198	0.0082046
30	0	0	30	31	0.00438	0.0014475
31	0	0	31	32	0.0218998	0.0072375
32	0	0	32	33	0.0523473	0.001757
33	0.014	0.001	33	34	0.1065664	0.0352268
34	0.0195	0.014	34	35	0.9196659	0.0304039
35	0.006	0.004	3	36	0.0002745	0.0006738
36	0.026	0.0186	36	37	0.0039931	0.0097644

37	0.026	0.0186	37	38	0.0065699	0.0076743
38	0	0	38	39	0.0018967	0.0022149
39	0.024	0.017	39	40	0.0001123	0.000131
40	0.024	0.017	40	41	0.0454405	0.0530898
41	0.0012	0.001	41	42	0.0193417	0.0226048
42	0	0	42	43	0.0025581	0.0029824
43	0.006	0.0043	43	44	0.000574	0.0007238
44	0	0	44	45	0.0067946	0.0085665
45	0.0392	0.0263	45	46	5.615E-05	7.487E-05
46	0.392	0.0263	4	47	0.0002121	0.0005241
47	0	0	47	48	0.0053096	0.0129964
48	0.079	0.0564	48	49	0.0180814	0.0442425
49	0.3847	0.2745	49	50	0.0051287	0.0125471
50	0.3847	0.2745	8	51	0.00579	0.0029512
51	0.0405	0.0283	51	52	0.0207081	0.0069505
52	0.0036	0.0027	9	53	0.0108563	0.005528
53	0.0043	0.0035	53	54	0.0126657	0.0064514
54	0.0264	0.019	54	55	0.017732	0.0090282
55	0.024	0.0172	55	56	0.017551	0.0089409
56	0	0	56	57	0.0992041	0.0332989
57	0	0	57	58	0.048897	0.0164092
58	0	0	58	59	0.0189798	0.0062767
59	0.1	0.072	59	60	0.0240898	0.0073124
60	0	0	60	61	0.0316642	0.0161285
61	1.244	0.888	61	62	0.006077	0.0030947
62	0.032	0.023	62	63	0.0090469	0.0046046
63	0	0	63	64	0.0443299	0.0225799
64	0.227	0.162	64	65	0.0649506	0.0330805
65	0.059	0.042	11	66	0.0125534	0.0038122
66	0.018	0.013	66	67	0.0002932	8.735E-05
67	0.018	0.013	12	68	0.046133	0.0512487
68	0.028	0.02	68	69	0.0002932	9.983E-05
69	0.028	0.02				

Practical Distribution feeders:

Daachhi Feeder						
Bus Data			Branch Data			
Bus No.	Pload (MW)	Qload (MW)	From Bus	To Bus	R (Ohms)	X (Ohms)
1	0	0	1	2	0.0236024	0.012754
2	0	0	2	3	0.0214567	0.011594
3	0.07	0.07141428	2	4	0.3433071	0.185512
4	0	0	4	5	0.4298491	0.232276
5	0.035	0.03570714	5	6	0.557874	0.301457
6	0.07	0.07141428	6	7	0.0286089	0.015459
7	0.035	0.03570714	7	8	0.3154134	0.170439
8	0	0	8	9	0.0693766	0.037489
9	0.07	0.07141428	8	10	0.1695079	0.091596
10	0.07	0.07141428	8	11	0.012874	0.006957
11	0.14	0.14282857	11	12	0.3404462	0.183966
12	0	0	12	13	0.0121588	0.00657
13	0.07	0.07141428	12	14	0.0829659	0.044832
14	0	0	14	15	0.0135892	0.007343
15	0.07	0.07141428	14	16	0.0650853	0.03517
16	0.14	0.14282857	16	17	0.0336155	0.018165
17	0.07	0.07141428	16	18	0.019311	0.010435
18	0.14	0.14282857	18	19	0.032185	0.017392
19	0.21	0.21424285	4	20	0.0572178	0.030919
20	0.07	0.07141428	20	21	0.2074147	0.11208
21	0.07	0.07141428	21	22	0.0715223	0.038648
22	0.21	0.21424285	22	23	0.0600787	0.032465
23	0.14	0.14282857	23	24	0.2646325	0.142999
24	0.07	0.07141428	24	25	0.278937	0.150728
25	0.112	0.11426285	22	26	0.1351772	0.073045
26	0	0	26	27	0.0851115	0.045991
27	0.105	0.10712143	26	28	0.0550722	0.029759
28	0	0	28	29	0.0121588	0.00657
29	0.07	0.07141428	28	30	0.4741929	0.256238
30	0.07	0.07141428	30	31	0.3204199	0.173144
31	0.035	0.03570714	31	32	0.1301706	0.07034
32	0.07	0.07141428	26	33	0.1308858	0.070726
33	0	0	33	34	0.032185	0.017392
34	0.21	0.21424285	34	35	0.4277034	0.231117
35	0.07	0.07141428	35	36	0.2446063	0.132177

36	0.14	0.14282857	36	37	0.0522113	0.028213
37	0.07	0.07141428	37	38	0.2996785	0.161936
38	0.035	0.03570714	38	39	0.1680774	0.090823
39	0.035	0.03570714	39	40	0.291811	0.157685
40	0.07	0.07141428	33	41	0.0371916	0.020097
41	0.035	0.03570714	41	42	0.0450591	0.024348
42	0.07	0.07141428	42	43	0.0615092	0.033238
43	0	0	43	44	0.0464895	0.025121
44	0.2205	0.224955	43	45	0.1594948	0.086186
45	0.14	0.14282857	45	46	0.0214567	0.011594
46	0	0	46	47	0.067231	0.036329
47	0	0	47	48	0.0565026	0.030532
48	0.14	0.14282857	47	49	0.1909646	0.103191
49	0.14	0.14282857	49	50	0.038622	0.02087
50	0.0175	0.01785357	46	51	0.1594948	0.086186
51	0.07	0.07141428	51	52	0.5936352	0.320781
52	0.14	0.14282857	52	53	0.105853	0.057199
53	0.07	0.07141428				

New-Chabahil Feeder						
Bus Data			Branch Data			
Bus No.	Pload (MW)	Qload (MW)	From Bus	To Bus	R (Ohms)	X (Ohms)
1	0	0	1	2	0.079576	0.08004
2	0.128	0.096	2	3	0.008232	0.00828
3	0.08	0.06	3	4	0.03087	0.03105
4	0.16	0.12	4	5	0.008575	0.008625
5	0	0	5	6	0.018179	0.018285
6	0.08	0.06	5	7	0.132398	0.13317
7	0.16	0.12	7	8	0.012691	0.012765
8	0	0	8	9	0.08232	0.0828
9	0.16	0.12	8	10	0.035329	0.035535
10	0.08	0.06	10	11	0.025039	0.025185
11	0.08	0.06	11	12	0.041503	0.041745
12	0	0	12	13	0.016807	0.016905
13	0.16	0.12	13	14	0.025039	0.025185
14	0.16	0.12	12	15	0.015435	0.015525
15	0	0	15	16	0.060368	0.06072
16	0.08	0.06	15	17	0.057624	0.05796
17	0	0	17	18	0.043561	0.043815
18	0.16	0.12	17	19	0.020923	0.021045
19	0.24	0.18	19	20	0.040474	0.04071
20	0.24	0.18	20	21	0.062426	0.06279
21	0	0	21	22	0.014749	0.014835
22	0	0	22	23	0.045962	0.04623
23	0	0	23	24	0.032585	0.032775
24	0.04	0.03	24	25	0.127596	0.12834
25	0.04	0.03	23	26	0.037387	0.037605
26	0.24	0.18	26	27	0.074088	0.07452
27	0	0	27	28	0.019894	0.02001
28	0.16	0.12	28	29	0.069972	0.07038
29	0.16	0.12	29	30	0.014749	0.014835
30	0	0	30	31	0.022981	0.023115
31	0	0	31	32	0.019894	0.02001
32	0.16	0.12	31	33	0.100842	0.10143
33	0.2	0.15	33	34	0.178703	0.179745
34	0.2	0.15	34	35	0.009947	0.010005

35	0.08	0.06	35	36	0.068257	0.068655
36	0.08	0.06	34	37	0.14063	0.14145
37	0.08	0.06	30	38	0.056595	0.056925
38	0.16	0.12	38	39	0.083349	0.083835
39	0.08	0.06	27	40	0.027783	0.027945
40	0.16	0.12	40	41	0.082663	0.083145
41	0.08	0.06	22	42	0.018522	0.01863
42	0.16	0.12	42	43	0.040817	0.041055
43	0.16	0.12	43	44	0.037387	0.037605
44	0.2	0.15	44	45	0.053165	0.053475
45	0	0	45	46	0.04116	0.0414
46	0.08	0.06	45	47	0.046305	0.046575
47	0.288	0.216	47	48	0.010633	0.010695
48	0.08	0.06	48	49	0.021952	0.02208
49	0.08	0.06	48	50	0.047677	0.047955
50	0.08	0.06	21	51	0.043561	0.043815
51	0.2	0.15	51	52	0.021952	0.02208
52	0.16	0.12	52	53	0.059339	0.059685
53	0.16	0.12				