TRIBHUVAN UNIVERSITY

INSTITUTE OF ENGINEERING

PULCHOWK CAMPUS

Thesis No.: 073/MSPS/704

Analyzing the Effectiveness of Distributed Generation and Capacitor Banks in Distribution Systems Using Water Cycle Algorithms

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073MSPS704

THESIS REPORT

SUBMITTED TO

THE DEPARTMENT OF ELECTRICAL ENGINEERING IN PARTIAL

FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF

SCIENCE IN POWER SYSTEM ENGINEERING

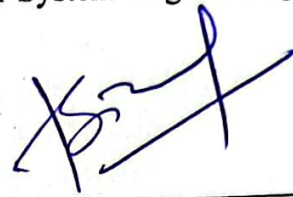DEPARTMENT OF ELECTRICAL ENGINEERING LALITPUR, NEPAL

July 2023

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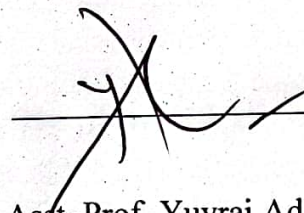
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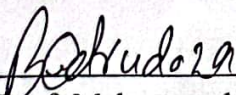
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ABSTRACT

Minimizing power losses and enhancing voltage stability are critical objectives in power systems due to their impact on transmission line contingencies, financial losses for utilities, and the risk of power system blackouts. One effective strategy to improve power system efficiency is the optimal allocation of Distributed Generation (DGs) and capacitor banks (CBs), considering factors such as sizing and operating power factor. Power system operators and researchers are dedicated to addressing distribution system challenges related to power loss, energy loss, voltage profile, and voltage stability by optimizing the placement of DGs and CBs. This optimization not only ensures the security of the distribution system but also enables its operation in islanding mode. To enhance the performance of distribution systems, this thesis proposes the integration of DGs and CBs using a water cycle algorithm (WCA) for optimal placement and sizing. The proposed method aims to achieve technical and economic benefits by considering various objective functions, including power loss minimization, voltage deviation, total electrical energy cost, and improvement in the voltage stability index. The WCA algorithm mimics the flow of water from streams to rivers and from rivers to the sea. Through simulations conducted on three distribution systems, namely the IEEE 33-bus, 69-bus test systems, and the Sankhu feeder network, which is part of INPS, the performance of the proposed methodology is evaluated. The simulation results demonstrate the superiority of the WCA algorithm compared to other optimization algorithms in terms of flexibility and efficiency. The proposed approach exhibits notable improvements in economic benefits, making it a promising solution for optimizing DG and CB placement in distribution systems.

Furthermore, the study highlights the advantages of utilizing Distributed generation along with controllable PF over Distributed generation along with fixed PF, as it allows for more flexible operation. The analysis considers five operational cases to evaluate the proposed methodology. These include the base case, capacitor allocation and sizing (Case I), DG allocation and sizing (Case II), simultaneous placement and sizing of DGs and CBs with unity power factor (Case III), allocation and sizing of DGs and CBs with adjustable power factor for technical objectives (Case IV), and allocation and sizing for techno-economic objectives (Case V). The results of the analysis on the IEEE 33-bus system demonstrate that the proposed methodology leads to a reduction in power loss of 34.79% (Case I), 62.10% (Case II), 90.23% (Case III), 92.04% (Case IV), and 63.67% (Case V) compared to the base case. Additionally, the minimum bus voltage significantly improves across all cases. Similar trends are observed for the IEEE 69-bus system and the Sankhu feeder network, with substantial reductions in power loss and significant improvements in the minimum bus voltage achieved through the proposed methodology. Overall, the findings of this thesis work emphasize the effectiveness of simultaneous allocation and sizing of DGs and CBs in reducing system losses and improving bus voltage profiles, aligning with the objectives of the research.

ACKNOWLEDGEMENTS

LIST OF ABBREVIATIONS

DGs: Distributed generations

CBs: Capacitor banks

VSI: Voltage stability index

WCA: Water cycle algorithm

INPS: Integrated Nepal power system

N_{DG}:   Number of DG units

nL: Number of branches

PF: Power factor of DG units

P_L and Q_L: Active power loss and reactive power loss, respectively

P_d and Q_d: Active Load demand and reactive Load demand, respectively

LF: Load factor of DGs

N_{sr}:   Number of rivers and sea.

BFOA: Bacterial Foraging Optimization Algorithm.

GA: Genetic Algorithm.

PSO: Particle Swarm Optimization.

FWA: Fireworks Algorithm.

GSA: Gravitational Search Algorithm.

CVSI: Conditional Value of Sample Information.

DICA: Discrete Imperialist Competitive Algorithm

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CHAPTER ONE

INTRODUCTION

1.1 Background

The integration of capacitor banks and distributed generations in distribution networks has become increasingly important to meet the growing demand for electrical power while ensuring a reliable and efficient distribution system. DG units offer additional power capacity and contribute to voltage regulation, while CBs help reduce system losses and improve power factor. However, determining the optimal allocation and sizing of CBs and DGs elements is a complex problem due to the nonlinear and non-convex nature of the optimization process. In recent years, various optimization algorithms such as genetic algorithms, particle swarm optimization, and differential evolution have been proposed to address this challenge [1] [2].

Generation and transmission systems in developing and under-developed countries often face capital shortages, particularly when dealing with disproportionate load growth. The efficiency of the power system heavily relies on the performance of the transmission and distribution network. It is crucial to minimize power losses in these systems as it directly affects the financial stability of utilities. By making effective use of existing infrastructure with minimal improvements, utilities can delay the need for expensive system reinforcements and generate additional revenue. Moreover, a common issue in distribution systems, especially after deregulation and privatization, is the absence of reactive power sources. However, distributed generators can help mitigate this problem by reducing the reactive power supplied from the grid [4] [9].

Power flow in distribution lines leads to high power losses, voltage drops, and poor power factor at load endpoints. Optimal allocation of capacitors alone or in combination with DG sources can mitigate these problems, aiming to achieve both technical and economic benefits. The significance of DGs includes securing the distribution system, enabling islanding mode operation, postponing the need for new infrastructure, reducing transmission and distribution losses, improving voltage support, and enhancing supply quality. However, DGs primarily focus on generating real power rather than reactive power due to cost and loss constraints. This results in poor system power factor, which can be improved through capacitor allocation in DG-incorporated systems. It is crucial to optimally place both reactive and real power sources in the distribution system to avoid increased losses and ensure proper operation [7] [10].

In Nepal, where hydropower is the primary source of electricity generation, optimizing the placement and sizing of DGs and capacitor banks is particularly important due to the intermittent nature of hydropower and the geographical challenges faced by the distribution network. Implementing an optimal approach using the water cycle algorithm (WCA) can bring several benefits, such as improved system reliability, reduced energy losses, and enhanced voltage stability. This optimization is particularly relevant in rural areas of Nepal, where the distribution network is weaker and more susceptible to voltage fluctuations and power outages.

1.2 Problem Statement:

Since most DGs tend to operate at a power factor close to unity, they supply more active power than reactive power. Additionally, power drawn from the grid contains more active power than reactive power. This situation decreases the grid power factor, which in turn decreases the effectiveness of the generation and transmission network. Therefore, it is necessary to install capacitor banks to improve the system power factor. There is a need to find the best combination of location and size of capacitor banks in the distribution network in the presence of DGs

In Nepal, integrating distributed generation (DG) into the existing network is not just a necessity but a compulsion. The Nepal Electricity Authority (NEA) has released guidelines and procedures to facilitate the interconnection of photovoltaic systems to the distribution network. These guidelines were issued in April 2016, and in February 2018, the Ministry of Energy also established a standard procedure for connecting alternative energy sources to the grid. According to the guidelines, energy producers who wish to sell energy from solar capacity exceeding 500 watts can apply to NEA for interconnection using net metering. As a result, several DG installations have already been implemented or are in the process of being integrated into the distribution network in Nepal. For instance, CIAA-Tangal with a capacity of 514 kW and ICIMOD-Khumaltar with a capacity of 92 kW are already installed and ready for integration. NMB Bank-Babarmahal, with a capacity of 50 kW, is awaiting a power purchase agreement (PPA) with NEA. Furthermore, NEA has successfully integrated a 600 kW solar plant at Dhobighat under the Kathmandu Upatyaka Khanepani Limited (KUKL), a 100 kW solar plant at the NEA Training Center, and a 60 kW solar plant at Bir Hospital. These initiatives reflect the commitment of NEA and the government of Nepal to promote the integration of DG into the distribution network, enabling the utilization of renewable energy sources and contributing to a more sustainable and reliable power system.

Among the various method of loss minimization, the method used optimal allocation and sizing of DGs and CBs using the WCA has been implemented in this thesis work. This thesis work shall give an optimum allocation of DGs and CBs along with their sizing, resulting in minimum power loss and improved voltage profile.

1.3 Scope of the Study

- The examination of the integration of CBs and DGs to improve the technical along with economic aspects of distribution system.
- Three technical objectives are achieved, namely: enhancement of voltage profile, reduction of active and reactive power losses and improvement of voltage stability index.
- Two economic considerations are taken into account, which involve minimizing the expenses associated with generated power and CBs.
- Providing a controllable power factor strategy of DG for flexible operation of distribution systems.

1.4 Objectives

- To minimize the distribution system power loss and improve the voltage profile in distribution systems using the Water Cycle Algorithm.

1.5 Outline of the report:

The following is an outline of the thesis report:

Chapter I: Introduction: Introduction to the need for distributed generations and capacitor banks and the Importance of optimizing DGs and CBs to reduce power loss and optimize voltage profile

Chapter II: Literature Review: Past works conducted by various authors on similar subjects and discussion on how and when DGs and CBs placement and sizing problems were considered to solve power loss and voltage drop issues

Chapter III: Methodology: Explanation of the overall methodology followed to fulfill the objective of this thesis work and the algorithm adopted in this thesis work and the cases considered and an explanation of how the WCA for optimization for DGs and CBs installation and sizing.

Chapter IV: Systems and Tools: Explanation of the systems under consideration and introduction to the software and tools used for this thesis work. Presentation of the single line diagram and the bus/branch data of the systems considered.

Chapter V: Results and Discussion: The results obtained in this thesis work is compared against the results in the reference papers and Demonstration of the method used in this thesis work to improve the power loss and voltage profile of a practical distribution system of Kathmandu Valley, Nepal and Discussion of the results for various scenarios considered in this research thesis work.

Chapter VI: Conclusion: Summary of the study conducted for various systems under consideration under various scenarios and Discussion on how the objectives of this thesis work are fulfilled.

CHAPTER TWO

LITERATURE REVIEW

2.1 General

The distribution network transfers the electrical energy directly from the intermediate transformer substations to consumers. Electric distribution systems are becoming large and complex leading to higher system losses and poor voltage regulation. In general, almost 10–13% of the total power generated is lost as I^2R losses at the distribution level, which in turn, causes an increase in the cost of energy and poor voltage profile along the distribution feeder. Therefore, it becomes important to improve the reliability of power transmission in distribution networks. While the transmission networks are often operated with loops or radial structures, the distribution networks are always operated radially [3]. By operating in a radial configuration, short-circuit current is reduced significantly. The restoration of the network from faults is implemented through the closing/cutting manipulations of electrical switch pairs located on the loops, consequently. Therefore, there are many switches on the distribution network.

Allocation and sizing of Distributed Generators (DGs) refer to the process of determining the optimal location and capacity of DGs in a power system. DGs are small-scale power generation units that can be connected to the distribution network to provide electricity at the point of use. The allocation of DGs involves identifying the locations in the power system where they should be installed. This is typically done by analyzing the load demand, the existing network topology, and the available renewable energy sources. Once the optimal locations for DGs have been identified, the sizing of the DGs is determined. This involves calculating the appropriate capacity of the DGs to converge the local electricity demand while minimizing the cost of installation and operation. The sizing of the DGs is influenced by various factors, including the load profile, the availability of renewable energy sources, the operating conditions, and the economic considerations.

The strategic allocation and sizing of Distributed Generators (DGs) play a vital role in the planning and design of contemporary power systems. These processes enable the enhancement of power system reliability, efficiency, and environmental sustainability by carefully determining the optimal locations and sizes of DG installations. [11]

The allocation and sizing of capacitor banks (CBs) in an electrical power system is an important task to improve power factor, reduce reactive power, and increase overall system efficiency. Here are the key steps involved in allocating and sizing capacitor banks:

Power Factor Correction Study: Conduct a power factor correction study to determine the PF of the systems as well as identify that areas with low PF. This study involves measuring the power factor at various points in the system and analyzing the data to identify the equipment or areas causing low power factor.

Load Analysis: Conduct a detailed load analysis to determine the magnitude and nature of the reactive power demand in the system. Reactive power is the power that

is not converted to useful work and is responsible for a low power factor. The load analysis should include information such as the type of loads (inductive or capacitive), their operating characteristics, and their usage patterns.

Capacitor Bank Sizing: Once the areas with low power factor and high reactive power demand are identified, the next step is to size the capacitor banks accordingly. The sizing of capacitor banks depends on the magnitude of the reactive power demand and the desired power factor improvement. Capacitors are rated in kVAR (kilo-volt-ampere reactive) and their size should be selected based on the amount of reactive power that needs to be compensated. A general rule of thumb is to install capacitor banks with a total KVar rating that is approximately 70-80% of the measured reactive power demand.

Location of Capacitor Banks: After sizing the capacitor banks, the next step is to determine the optimal locations for their installation. Capacitor banks should be strategically located in the system to maximize their effectiveness in compensating for reactive power. The optimal locations are usually near the loads or equipment that are responsible for the reactive power demand. This can be determined based on the results of the power factor correction study and load analysis.

Control and Switching: Capacitor banks can be controlled and switched in various ways to optimize their performance. For example, automatic controllers can be used to switch capacitor banks in and out of service based on real-time measurements of the system's power factor or reactive power demand. Additionally, switching devices such as circuit breakers or contactors should be used to connect and disconnect the capacitor banks from the system as needed.

Safety Considerations: Proper safety measures should be followed during the allocation and sizing of capacitor banks. Capacitors store energy and can pose a safety risk if not handled properly. It is important to follow applicable safety standards and guidelines, such as those provided by the National Electrical Code (NEC) and the manufacturer's instructions when working with capacitor banks.

Monitoring and Maintenance: Once the capacitor banks are installed and commissioned, it is important to regularly monitor their performance and conduct maintenance activities as needed. This may include periodic inspections, checking for signs of deterioration or damage, and testing the capacitor banks to ensure they are operating within their specified parameters.

In conclusion, the allocation and sizing of capacitor banks in an electrical power system require a thorough power factor correction study, load analysis, proper sizing of capacitors, strategic placement of capacitor banks, control and switching mechanisms, safety considerations, and ongoing monitoring and maintenance. Consulting with a qualified electrical engineer or power system expert is recommended to ensure accurate allocation and sizing of capacitor banks for a given power system. Always follow applicable safety standards and guidelines when working with electrical systems. It is important to comply with local codes and regulations and work with qualified professionals when making decisions regarding capacitor bank allocation and sizing. Properly sized and allocated capacitor banks can

help improve power factors, reduce reactive power demand, and increase the efficiency of an electrical power system. However, improper allocation and sizing of capacitor banks can lead to operational issues. [12]

The following is a brief literature review of some of the notable studies in this area:

In [1], a research paper introduces an optimization-based approach using the cuckoo search algorithm to allocate static shunt capacitors in radial distribution networks. The objective is to minimize the system operating cost under various loading conditions and improve the voltage profile.

In [2], another paper proposes the utilization of a water cycle algorithm (WCA) for optimal placement and sizing of Distributed Generators (DGs) and capacitor banks (CBs). The aim of this method is to achieve technical and environmental benefits in distribution systems.

In [7], researchers present a novel approach based on the cuckoo search algorithm to optimize the allocation of DGs in distribution networks. The objective is to improve the voltage profile and reduce power losses.

In [8], the authors introduce a pioneering approach that minimizes power losses and enhances bus voltage profile in radial distribution networks. This is achieved by determining the optimal locations and sizes of distributed generators and shunt capacitors using a hybrid Harmony Search Algorithm.

The optimal locations of distributed power sources and their sizing are determined in [9] using the voltage stability index of the bus and the Genetic Algorithm (GA).

Overall, the literature suggests that different optimization algorithms are effective techniques for the placement and sizing of distributed generation and capacitor banks in distribution systems. These approaches significantly enhance the performance of the distribution system and facilitate the integration of renewable energy sources, leading to a more reliable, efficient, and sustainable power system.

2.2 The Distribution Power System:

Power flow calculation is an essential numerical analysis technique used in power systems studies to improve power distribution networks. It aims to reduce power losses, enhance reliability, and improve voltage profiles. Achieving these objectives often requires multiple iterations of power flow analysis algorithms. However, when applying power flow methodologies to distribution systems, it is crucial to adapt them to the unique characteristics of these networks. This adaptation includes incorporating single-phase and three-phase unbalanced system analysis and considering the impact of distributed generation interconnection. In transmission systems, commonly used power flow analysis methods such as Gauss-Seidel and Newton-Raphson assume a balanced system and utilize a single-phase representation of a three-phase system. However, these assumptions and methods cannot be directly applied to distribution systems due to their distinct features, including unbalanced loads, radial topology, un-transposed lines, and the presence of distributed generation. As a result, power flow methods for distribution systems need to consider three-phase unbalanced networks.

Forward/backward methods are popular power flow techniques employed in distribution systems as they can handle unbalanced phase systems. However, they are limited to radial networks and cannot account for the influence of distributed generation in both the phase frame and sequence frame references. On the other hand, Newton-based methods can handle various network topologies (radial, weakly meshed, and meshed) and consider the impact of distributed generation in both the phase frame and sequence frame references. The modified Newton method has proven successful in distribution systems, with its key factor being the tailored representation of the Jacobian matrix based on the network topology. By carefully adapting power flow analysis methods to the characteristics of distribution systems, it becomes possible to improve their performance, optimize the placement and sizing of DGs and CBs, minimize power losses, and enhance voltage profiles. MATPOWER toolbox was used in this thesis work to compute power flows for various configurations of open/closed switches. The injection of various DGs of various capacities at various locations can easily be incorporated into power flow studies in MATPOWER.

The power distribution system is responsible for delivering electricity from power generation sources to end-users or consumers. It is a complex network of infrastructure, equipment, and technology that is designed to ensure a reliable and efficient supply of electricity to meet the demands of modern society. At its core, the power distribution system is composed of three main components: power generation, transmission, and distribution. Power generation involves the conversion of various energy sources into electricity, such as coal, natural gas, nuclear, hydroelectric, solar, and wind. Transmission involves the movement of high-voltage electricity over long distances through high-voltage transmission lines to substations, where it is stepped down to lower voltages for distribution. Distribution involves the final stage of delivering electricity to homes, businesses, and other end-users through low-voltage distribution lines and transformers. The power distribution system also includes a range of equipment and infrastructure, such as transformers, switches, circuit breakers, and other protective devices that help to regulate the flow of electricity and prevent power outages or other disruptions. These components work together to ensure a safe and reliable supply of electricity to end-users, while also maintaining the overall stability and reliability of the electrical grid.

One of the key challenges facing the power distribution system is the need to balance the growing demand for electricity with the need to maintain a stable and reliable electrical grid. This requires the deployment of advanced technologies and strategies to manage the flow of electricity, such as demand response programs, energy storage systems, and smart grid technologies that enable the grid to respond to changing conditions and optimize the distribution of electricity. Another key challenge facing the power distribution system is the need to transition to cleaner and more sustainable energy sources, such as solar, wind, and other renewable sources of energy. This requires significant investments in new infrastructure and technology, as well as a coordinated effort among stakeholders to support the development and deployment of renewable energy sources and the integration of these sources into the existing power distribution system. In addition to these challenges, the power distribution system

must also meet a range of regulatory and environmental requirements, such as compliance with emissions standards, land-use regulations, and other environmental regulations. These requirements often involve significant costs and require careful planning and management to ensure that the power distribution system can continue to meet the needs of society while also protecting the environment and public health.

In conclusion, the power distribution system is a critical component of modern society that is responsible for delivering a reliable and efficient supply of electricity to homes, businesses, and other end-users. It is a complex network of infrastructure, equipment, and technology that must balance the demands of consumers with the need to maintain a stable and reliable electrical grid. As the energy landscape continues to evolve, the power distribution system will face new challenges and opportunities, requiring ongoing investments in technology, infrastructure, and regulatory compliance to ensure that it can continue to meet the needs of society in a safe and sustainable manner.

2.3 Voltage Stability of radial distribution system:

Voltage stability is a crucial aspect of power system operation, as it affects the ability of the power distribution network to maintain a steady and reliable supply of electricity. Voltage instability can result in voltage sags, dips, and even complete blackouts, leading to significant disruptions and economic losses. Voltage Stability Index (VSI) is an important parameter used to assess the voltage stability of radial distribution networks. Radial distribution networks are the most common type of power distribution networks used for delivering electricity from the substation to consumers. These networks consist of a single power source at the substation and several branches that deliver power to different loads. As the electricity flows through the network, the voltage levels drop due to line losses and voltage drop. The voltage drop along the network determines the voltage level at each load, which can affect the voltage stability of the entire network.

The voltage Stability Index (VSI) is a parameter that is used to evaluate the voltage stability of radial distribution networks. The VSI is calculated based on the voltage deviation from the nominal voltage level at each bus in the network, and it provides an indication of the degree of voltage stability in the network. A higher VSI value indicates a lower level of voltage stability, while a lower VSI value indicates a higher level of voltage stability. The VSI value is calculated using various algorithms and methods, including the Fast Voltage Stability Index (FVSI), the Modal Analysis Voltage Stability Index (MAVSI), and the Line Stability Index (LSI). The FVSI method calculates the VSI using a fast algorithm that analyzes the real and reactive power flows in the network. The MAVSI method analyzes the eigenvalues of the network matrix to determine the VSI. The LSI method calculates the VSI based on the voltage drop along each line in the network. The VSI is a useful parameter for assessing the voltage stability of radial distribution networks, as it can help identify potential voltage stability problems before they cause disruptions or blackouts. By monitoring the VSI values, utilities can take proactive measures to maintain the voltage stability of the network, such as adjusting voltage regulators, increasing

reactive power compensation, or even adding new feeders or transformers to the network.

Figure below shows the electrical equivalent of radial distribution system.
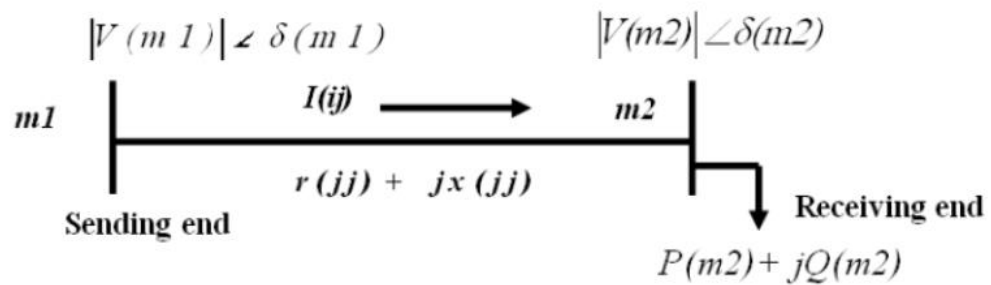
From the above figure, the following equation can be written:

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

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

Where,
jj = branch number, m2 = receiving end node,
m1 = sending end node,
I(ij) = current of branch ij, V (m2) = voltage of node m2,
V(m1) = voltage of node m1,
Q(m2) = total reactive power load fed through node m2, P (m2) = total real power load fed through node m2,

Equating (1) and (2)

[V(m1)<θm1 − V(m2)< θm2][V(m2)< -θm2] = [P(m2) − jQ(m2)][r(jj) − jx(jj)]
…………… (3)

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

V(m1)*V(m2)cos(θm1- θm2) − 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(θm1- θm2) ………………. (5)

In radial distribution systems, voltage angles are negligible. So (θm1- θm2) ≈ 0, and (4) and (5) become

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

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

From (6) and (7),

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

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

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

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

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

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

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

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

After simplification, we get

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

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

The Voltage Stability Index (VSI) of node m2 is a measure of the voltage stability in radial distribution networks. In order to ensure stable operation of these networks, the VSI of node m2 should be greater than or equal to zero. The node with the lowest value of the stability index is considered more susceptible to voltage collapse, indicating its heightened sensitivity to voltage stability issues.

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CHAPTER THREE

METHODOLOGY

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This chapter explains the overall procedure of performing strategic placement and sizing of CBs and DGs using the Water cycle algorithm (WCA).

3.1 Problem Formulation:

Objective Function

The proposed method strives to attain two categories of objectives: technical objectives and economic objectives.

1. Technical OF: In this segment, the focus is on the three key technical objectives. The first objective focuses on minimizing distribution power losses (f_1), which can be mathematically expressed as follows:

$$f_1(x) = min \sum_{i=1}^{nL} R_i * I_i^2 \dots\dots\dots\dots\dots\dots (1)$$

The second technical objective aims to enhance the voltage profile and maintain a more stable voltage level. This objective can be described using the following function (f_2):

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

Voltage stability is a crucial indicator of system performance. The third objective (f_3) focuses on the voltage stability index (VSI) and can be described as follows:

$$f_3(\text{x}) = min \left(\frac{1}{VSI(m_2)}\right) \dots\dots\dots\dots\dots\dots\dots\dots\dots. (3)$$

Where VSI (m_2) is the voltage stability index at node 2.

$$VSI(m_2) = ABS \left(|V(m_1)|^4 - 4 * [P(m_2) * X_{ij} - Q(m_2) * R_{ij}]^2 \right.$$
$$\left. - [P(m_2) * R_{ij} + Q(m_2) * X_{ij}] * |V(m_1)|^2\right) \dots\dots\dots\dots\dots. (4)$$

For the stable operation of radial distribution networks, VSI (m_2) $\geq$ 0. The node at which the value of the stability index is minimum is more sensitive to voltage collapse.

1. Economic OF: The economics OF (f_4) focus to optimize the power generation costs that can be calculated as

$$f_4(x) = min \sum_{i=1}^{N_{DG}} (C_{DGi} + C_{sub} + C_{CB}) \dots\dots\dots\dots\dots\dots\dots\dots. (5)$$

At first, for DG,

$$C_{DGi} = \sum_{i=1}^{N_{DG}} (a + b * PG_i) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. (6)$$

Where,

$$a = \frac{\left(Capital\ cost\left(\frac{\$}{KW}\right)*Capacity(KW)*Gr\right)}{lifetime(year)*8760*LF}\ (\$) \dots \dots \dots \dots \dots \dots \dots \dots (7)$$

where,

Gr= Annual rates of benefit

LF= DG loading factors.

PG_i= Energy generated by DG.

Ŋ= Gr/(llifetimeyear)*8760*LF)= 1.3(constant)

b = Operation & Maintenance cost($/kW.h)+ fuel cost($/kW.h)…….(8)

$$C_{sub} = \sum_{i=1}^{N_{DG}} P_{sub} * Pr_{sub} \dots \dots \dots \dots \dots \dots \dots \dots \dots (9)$$

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

Pr_{sub}= cost of power generated at the substation (taken 0.044$/kWh)

C_{sub}= cost of electrical energy generation by each source

Similarly, for capacitor

$$C_{CB} = \frac{\sum_{i=1}^{N_C}(e_i + C_{ci} * Q_{ci})}{8760 * life\ time} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots (10)$$

Where, $\frac{1}{life\ time*8760}$ acts as the depreciation rate over lifetime period

e_i= fixed VAR source installation cost at bus i have taken equal to 1000

C_{ci}= corresponding purchase cost is taken equal to 30,000 $/MVar

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

N_C= reactive compensator bus

Constraints:

Equality constraints: The constraints for power balance requirements:

$$\sum_{i=1}^{N_G} PG_i - P_L = P_d \qquad \sum_{i=1}^{N_G} QG_i - Q_L = Q_d \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots (11)$$

Inequality constraints: It is crucial to ensure that the power generated from DGs/CBs does not surpass the allowable limitations of the distribution systems. Adhering to the generation operation limits is essential to maintain a permissible level of power generation within the distribution systems.

$$PG_i^{min} \le PG_i \le PG_i^{max} \dots \dots \dots \dots \dots \dots \dots \dots (12)$$

Install capacitor limits

$$Q_{CBs}^{Total} < Q_d \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots (13)$$

Bus voltage limits

$0.95 \le V_i \le 1.05$, i= 1,2,3,4….n bus……………(14)

DG power factor limits

$0.8 \le PF \le 1$ …………………………………(15).

 [2]

3.2 Cases Studied:

For the proper analysis, five operational cases were studied using Water Cycle Algorithm. It helps to understand the adequacy of the proposed algorithm over other algorithms.

- Case 1: Power loss minimization (f_1) by optimal placement of Capacitors only.
  OF= minimize (f_1) ………………………………….(16)

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 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 (f_1) …………………………………..(17)

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 second n Raindrops store the MW size of those DGs.

- Case 3: Power loss minimization (f_1) by allocating the combination of CBs, and DGs operating at unity pf.

OF= minimize (f_1) ……………………………………….(18)

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 the bus location of DGs, and next n Raindrops store the MW size of those DGs.

- Case 4: Power loss minimization (f_1), voltage profile improvement (f_2), and minimum VSI enhancement (f_3) by allocating the combination of CBs, and DGs with adjustable power factor.

OF= minimize (w_1 *f_1+ w_2*f_2 + w_3*f_3)…………………………………….(19)
Where, w_1, w_2, and w_3 are weighing factors of f_1, f_2, and f_3 respectively.

In this analysis, w_1, w_2, and w_3 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, a maximum of three Capacitor banks, and three DGs were incorporated into the distribution network.

- Case 5: Power loss minimization (f_1), and cost minimization (f_4) by allocating the combination of CBs, and DGs with adjustable power factor.

OF= minimize (w_1 *f_1+ w_4*f_4)…………………………………….(20)

Where, w_1, w_4 are weighing factors of f_1, and f_4 respectively.

In this analysis, w_1, and w_4 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, a maximum of three Capacitor banks, and three DGs were incorporated into the distribution network. [2]

3.3 Water Cycle Algorithm:
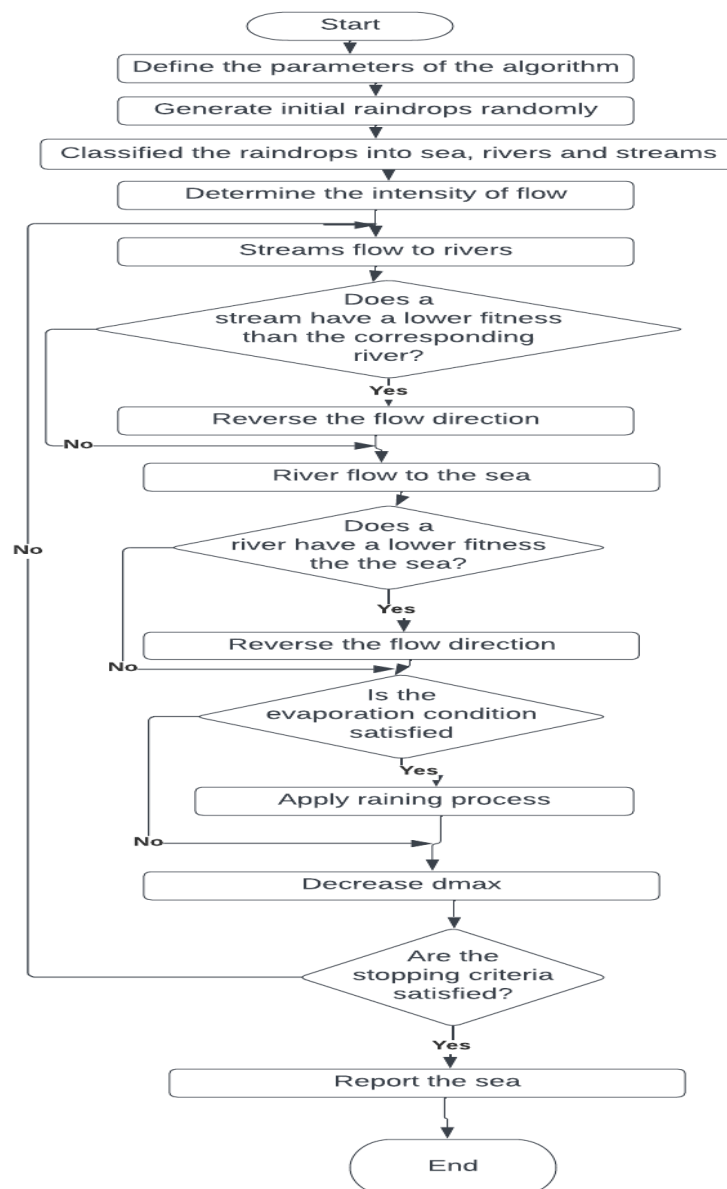
Fig.1 Flowchart of the proposed method

Fig.1 shows the flowchart of proposed method for evaluating the allocation and sizing implementing Water Cycle Algorithm as follows.

The ER-WCA algorithm involves the following steps:

Step 1. Determine the initial values for WCA parameters, including Nsr, dmax, Npop, and the maximum number of iterations.

Step 2. Create an initial population randomly and form streams, rivers, and seas.

Step 3. Evaluate the cost function for each stream, considering minimization problems.

Step 4. Calculate the flow intensity for rivers and the sea.

Step 5. Allow streams to flow into the rivers and sea.

Step 6. Exchange the position of a river or sea with a stream that produces the best solution.

Step 7. Allow the rivers to flow into the sea.

Step 8. Exchange their positions if a river finds a better solution than the sea.

Step 9. Calculate the evaporation rate (ER).

Step 10. Use pseudo-code S3 to check the evaporation conditions between streams and rivers and calculate their new positions.

Step 11. Check the evaporation conditions between the sea and streams/rivers by pseudocode S1 and S2 and calculate their new positions.

Step 12. Reduce the value of dmax.

Step 13. Check the stopping condition. If the criterion is met, the algorithm stops; otherwise, return to Step 5.

Detailed steps in WCA:

WCA, short for Water Cycle Algorithm, is a metaheuristic optimization algorithm inspired by the natural water cycle process. The algorithm begins by initializing an initial population called raindrops (RD), similar to other metaheuristic algorithms.

The values of the problem-controlled variables x_i (PG_i, QG_i, Q_{CB}^{total}, and placement of DG and CB) can be formed as an array called "RD" for a single solution. This array can be defined as follows:

$$RD = [x_1, x_2, x_3 \dots \dots \dots \dots x_N] \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots (21)$$

Each set of solutions is referred to as a Stream, and the Stream with the best fitness is selected as the Sea. A fixed number of Streams with better fitness values are designated as Rivers. The allocation of Streams to Rivers and the Sea is determined by the intensity of flow (NS_n)

$$NS_n = round\left\{\left|\frac{ff_n}{\sum_{i=1}^{N_{sr}} ff_i}\right| * N_{pop}\right\} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (22)$$

Where,

NS_n is the number of Streams that flow into specific Rivers and the Sea,

N_{pop} is the total number of Streams considered,

N_{sr} is the combined number of Sea and Rivers

The fitness of any stream is given by:

$$ff_i = f\left(x_1^i, x_2^i, x_3^i, \dots\dots\dots\dots x_{Nvar}^i\right) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (23)$$

i= 1,2,3,….N_{pop}

The fitness of each Stream is determined by evaluating the objective function, which depends on the problem variables. The Streams flow into the Rivers, and the Rivers flow into the Sea using randomly generated distances as shown below:

$$X_{stream}^{i+1} = X_{stream}^i + rand * U * \left(X_{river}^i - X_{stream}^i\right) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (24)$$

$$X_{river}^{i+1} = X_{river}^i + rand * U * \left(X_{sea}^i - X_{river}^i\right) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (25)$$

Where $1< U < 2$ and the best value of U is chosen as 2 and rand is a uniformly distributed random number between 0 and 1.

If the fitness of a Stream is better than the associated River, their roles are exchanged. The same rule applies to the Rivers and the Sea. To prevent being trapped in local optima, evaporation is introduced into the algorithm. Rivers and Streams are checked for proximity to the Sea, and if they are too close, evaporation occurs using:

$$|X_{sea}^i - X_{river}^i| < d_{max} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (26), \text{i= 1,2,3……}, N_{sr}\text{-1}$$

$$|X_{sea}^i - X_{stream}^i| < d_{max} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (27), \text{i= 1,2,3……}, N_{s,}$$

Where d_{max} is a very small value close to zero.

After the evaporation process, the raining process is applied. This process generates new Streams based on the Sea or the Sea with some random variation. The raining process after evaporation of Streams generates new Streams by adding a random value within the search range near the Sea using:

$$X_{new\ stream}^{i+1} = LB + rand * (UB - LB) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (28)$$

Where LB and UB are lower and upper boundaries respectively

And, the raining process after the evaporation of Streams generates new Streams using:

$$X_{new,stream} = X_{sea} + sqrt(\mu) * rand(1, N_{var}) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (29)$$

Where, μ is a coefficient (taken as 0.1) showing the search range in the regions near the sea (a larger value can move the search away from the optima and a lower value

may confine the search in a small area), and the rand is the normally distributed random number from 0 to 1.

The algorithm iteratively updates the value of d_{max}, which controls the proximity for evaporation. At the end of each evaporation process, d_{max} is updated based on a predefined formula.

$$d_{max}^{i+1} = d_{max}^i - \left(d_{max}^i / max. iteration\right) \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots (30)$$

In ER-WCA, Rivers with lower flow evaporate more frequently due to the limited number of Streams pouring into them. The evaporation rate for Rivers is calculated based on the number of Streams allocated to each River. Higher-flow Rivers have lower evaporation rates, while lower-flow Rivers have higher evaporation rates. The evaporation rate (ER) for Rivers is calculated using:

$$ER = \frac{SUM(NS_n)}{N_{sr}-1} * rand \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots (31), \quad n=2,\dots, N_{sr}$$

ER-WCA performs two evaporation processes in each cycle: one when Rivers/Streams reach the Sea, and another for Rivers with lower flow. This dual evaporation strategy allows for effective search in the global solution space. In summary, ER-WCA is an optimization algorithm that mimics the water cycle process. It employs various mechanisms such as flowing, evaporation, and raining to explore the search space and find the best solution for the given optimization problem. [2] [Modified WCA algorithm book]

CHAPTER FOUR

SYSTEM TO BE CONSIDERED, TOOLS AND SOFTWARE

4.1 System to be considered:

In this thesis, we consider three types of test systems for the optimal placement and sizing of CBs and DGs for different case studied. IEEE 33-bus test system, IEEE 69-bus test system and the Sankhu feeder of INPS as a real system are three different test system.

(i) IEEE 33-bus system:

The IEEE 33 bus system is a widely used test case in power systems research and education. It is a simplified model of a distribution network that consists of 33 buses, including 32 loads and one generator. The system has a base voltage of 12.66 KV and a base MVA is 100. It is designed to represent a balanced three-phase system and includes different kinds of loads, such as constant impedance, constant current, and constant power. The IEEE 33 bus system has become a standard benchmark for testing new algorithms, control strategies, and optimization techniques in power systems analysis and operation. The data used in this research of the system is attached in **Appendix 1**.

IEEE-33 bus system is a radial distribution system (RDS) with a total load of 3.72 MW, 2.3 MVar, 33 buses, and 32 branches as shown in Fig 1 below
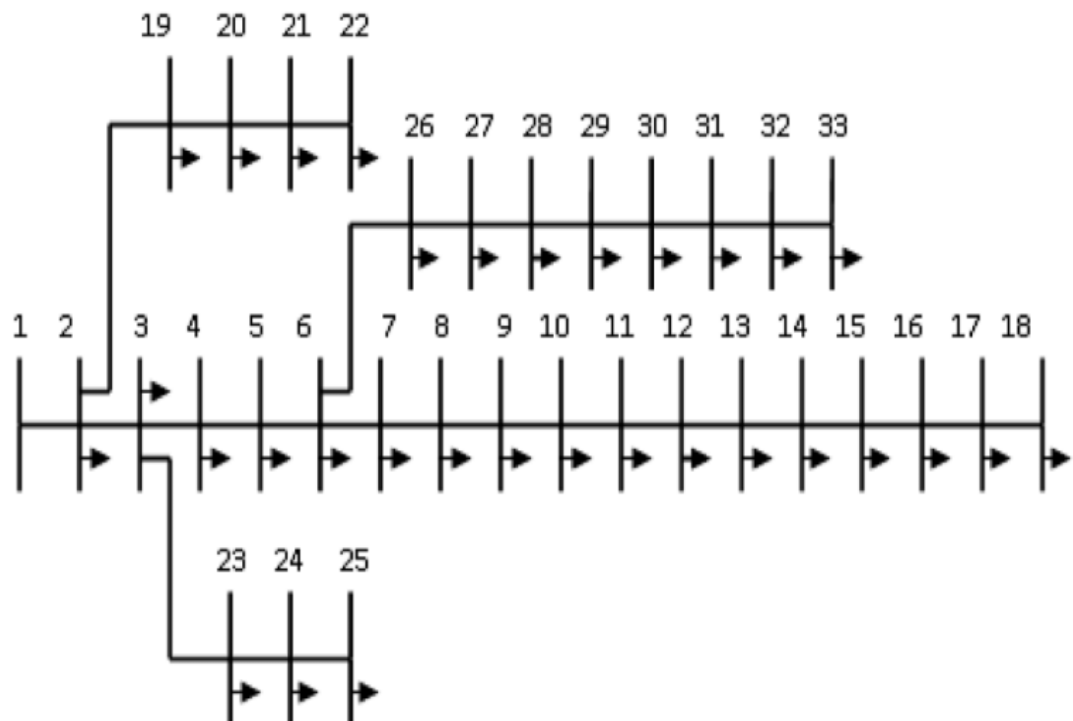
Fig.2 IEEE 33-bus distribution network

(ii) IEEE 69-bus system:

The IEEE 69 bus system is a well-known benchmark test case in power systems research and education. It is a simplified model of a transmission network that consists of 69 buses, including 5 generators and 63 loads. The system has a base voltage is 12.7 KV and a base MVA is 10 MVA. It is designed to represent a balanced three-phase system. The IEEE 69 bus system is commonly used for testing new algorithms and methods for power flow analysis, transient stability analysis, and optimal power flow. Its complexity and diversity make it an attractive test case for studying the behavior of large-scale power systems.

The base case of the IEEE 69-bus test system comprises 69 nodes, 5 looping lines, 7 lateral feeders, and branches connecting every part of the system. The total connected loads on this hypothetical system are 3802.19 kW and 2694.60 KVar, while the system operates at a voltage of 12.7 KV. The data of this system is attached in **Appendix 2**. IEEE 69-bus test distribution system as Fig. 3 below

IEEE 69-bus distribution network as Fig. 3 below
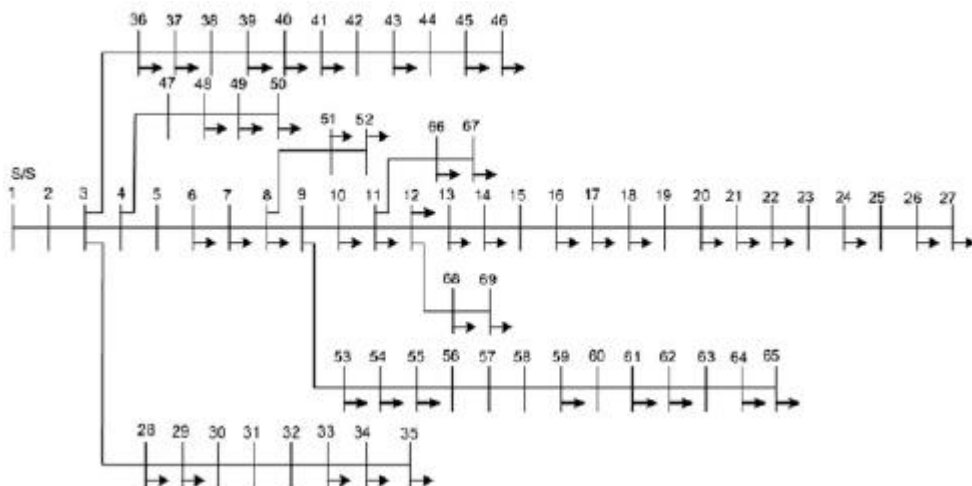
Fig.3 IEEE 69-bus distribution network

(iii) Sankhu feeder network:

The Sankhu Feeder Network is a part of the distribution system of the Nepal Electricity Authority (NEA) that serves the Sankhu area in Nepal. It is located in the northeastern part of the Kathmandu Valley and covers an area of about 16.2 square kilometers. The network consists of a single 33 kV transmission line that supplies power to four 11 kV substations, which further distribute the power to various 11 kV and 400 V feeders. The Sankhu Feeder Network serves a mix of residential, commercial, and industrial customers, with a total of about 14,000 customers connected to the network. The peak demand on the network is around 10 MW, and the average demand is around 5 MW. The network faces several challenges, including high losses, voltage regulation issues, and reliability problems. To address these issues, the NEA has implemented various measures, such as upgrading the substation equipment, improving the distribution system's insulation, and installing voltage regulation devices. Additionally, the NEA has been promoting the use of renewable

energy sources, such as solar and wind power, to reduce the network's reliance on fossil fuels and improve its sustainability. The Sankhu Feeder Network in Nepal is a distribution system that can be modeled as a bus system consisting of multiple buses, branches, and loads. The buses in the network represent the connection points of different electrical components, such as transformers, substations, and loads. The branches represent the transmission lines or distribution lines that connect the buses. The loads in the network represent the electrical loads that consume power from the network.

The Sankhu Feeder Network can be modeled as a radial distribution system, where power flows from the source (the 33 kV transmission line) to the loads through a series of branches and buses. The network has one source bus, which is connected to the 33 kV transmission line, and multiple load buses, which are connected to the 11 kV and 400 V feeders. The network also has intermediate buses, which are connected to the transmission and distribution lines and serve as connection points for transformers and other equipment. The Sankhu Feeder Network can be analyzed using various power systems analysis techniques, such as load flow analysis, fault analysis, and voltage regulation analysis. The analysis can help identify the network's performance characteristics, such as power losses, voltage drops, and overloading of equipment. Based on the analysis results, the network can be optimized for better performance, such as by adjusting the tap settings of transformers, reconfiguring the network topology, or upgrading the equipment.

The Sankhu feeder network has a base MVA of 10, base voltage is 11kv and pf is 0.7. It has 53 buses. The data are attached in **Appendix 3**. The diagram of this network is as below.
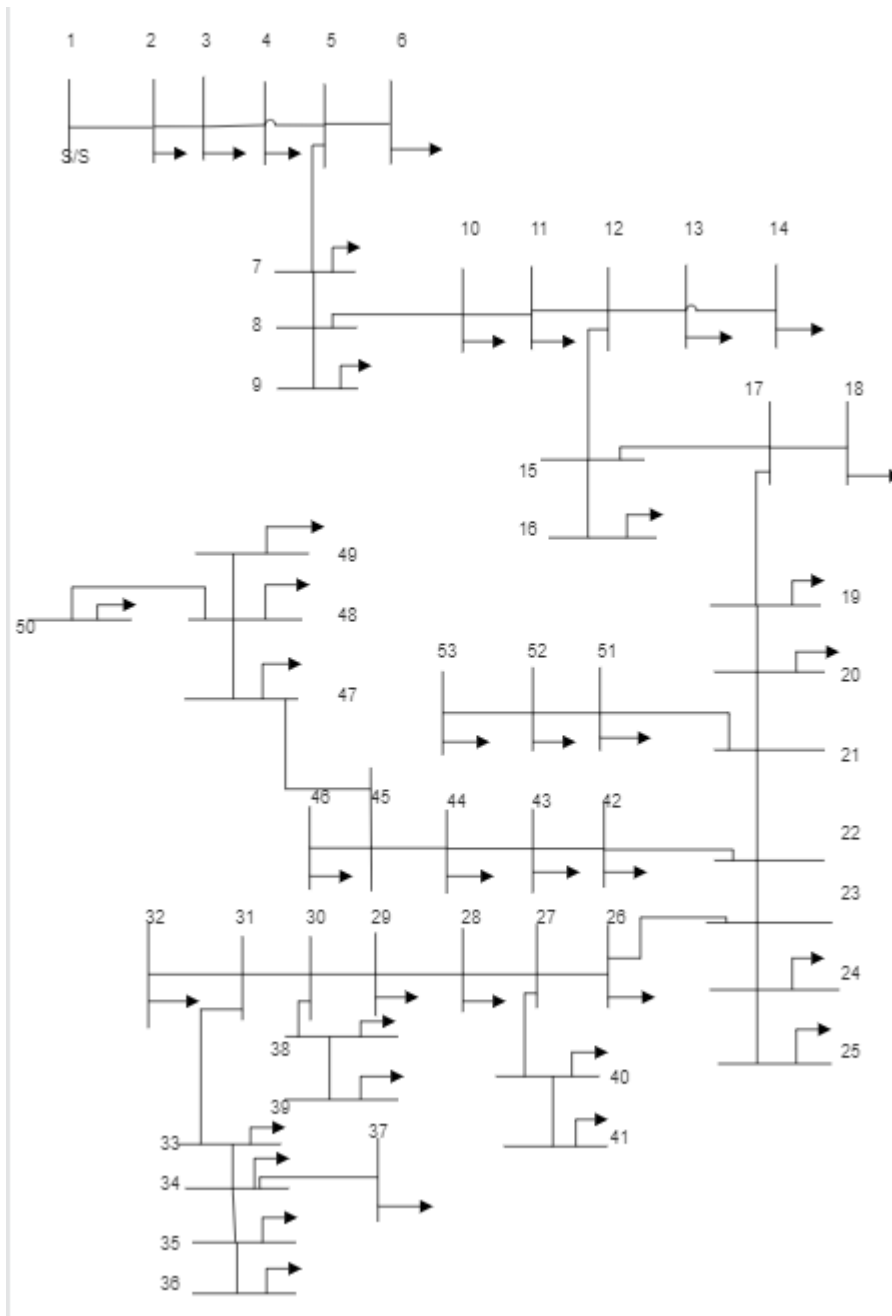
Fig.4 Sankhu feeder network

4.2 Tools and software used:

MATLAB is a widely used programming language and computational environment known for its applications in various scientific and engineering fields. It offers a range of capabilities for analyzing data, visualizing results, and developing algorithms, making it a valuable tool for researchers, engineers, and students.

MATPOWER, on the other hand, is a MATLAB-based package that specifically focuses on power system simulation and analysis. It provides a comprehensive set of tools, including solvers for power flow, optimal power flow, and other optimization problems in the field of power systems. Additionally, MATPOWER incorporates commonly used algorithms that are essential for power system analysis. Its user-

friendly interface and adaptable nature have made it a preferred choice among professionals and researchers in the power systems community.

Given the requirement of performing numerous power flow computations in this particular thesis work, it is crucial to find an efficient method for calculating power flow results. This is where the MATPOWER package proves to be advantageous. By utilizing a collection of MATLAB M-files, MATPOWER enables the solving of power flow and optimal power flow problems. It serves as a simulation tool that can be easily customized and tailored to specific research or educational needs. The development of MATPOWER was initially led by Ray D. Zimmerman, Carlos E. MurilloS´anchez, and Deqiang Gan at Cornell University, under the guidance of Robert J. Thomas.

In summary, MATLAB and the MATPOWER package provide a versatile and efficient platform for performing power system simulations and analysis. These tools offer simplicity, flexibility, and high performance, making them valuable assets for researchers, engineers, and educators in the field of power systems.

CHAPTER FIVE

RESULTS AND DISCUSSION

5.1 Results for the IEEE 33-Bus System:

The results of load flow are tabulated below.

Table1: Summary of Load flow report for IEEE 33- bus system.

For Base case	
Minimum bus voltage (pu)	0.913 (18)
Active power loss (KW)	202.667
Reactive power loss (KVar)	135.141
Power factor	0.849

Table 2: Results of different cases studied on the IEEE 33- bus system.

IEEE-33 BUS SYSTEM	ACHIEVED RESULTS	REFERENCE PAPER RESULTS	
Case I (capacitors only)	**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 capacitor (MVar)	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)	**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 DG (MW)	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)
IEEE-33 BUS SYSTEM	**ACHIEVED RESULTS**	**REFERENCE PAPER RESULTS**	
Case III (Capacitors and DGs with unity pf simultaneously)	**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 of capacitor (MVar)	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 of DG (MW)	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-33BUS SYSTEM**	**ACHIEVED RESULTS**
Case IV (Capacitors and DGs with controllable pf simultaneously) for only technical objectives	**WCA**	Case V (Capacitors and DGs with controllable pf simultaneously) for techno-economic objectives	**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(KVar)	13.169	Reactive Power loss(KVar)	57.933
Loss reduction (%)	92.04	Loss reduction (%)	63.67
Placement of capacitor (MVar)	0.194 (32), 0.333 (25), 0.708 (30)	Placement of capacitor (MVar)	0.333 (14), 0.827 (30), 0.161 (33)

Placement of DG (MW)	0.796 (14), 1.712 (3), 0.999 (30)	Placement of 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

Results of Case I (Capacitor only) while running in MATLAB:

```
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

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.
```

Fig 5. Result window for the case I (capacitors bank placement and sizing) for IEEE 33-Bus System.
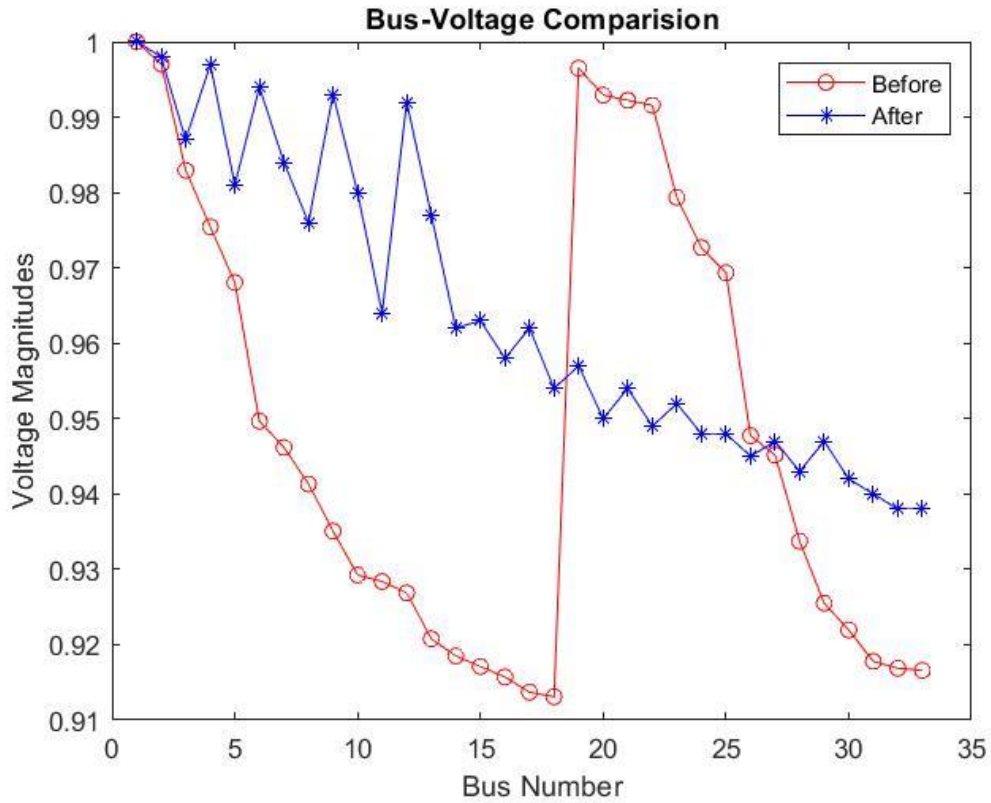
Fig.6 Bus Voltage comparison of case I (capacitors only) for IEEE 33-Bus System

Results of Case II (DGs only) while running in MATLAB:

```
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.

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
```

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


The locations of DGs is at Buses:   14   6   31
```

Fig 7. Result window for case II (DGs placement and sizing) for IEEE 33-Bus System.
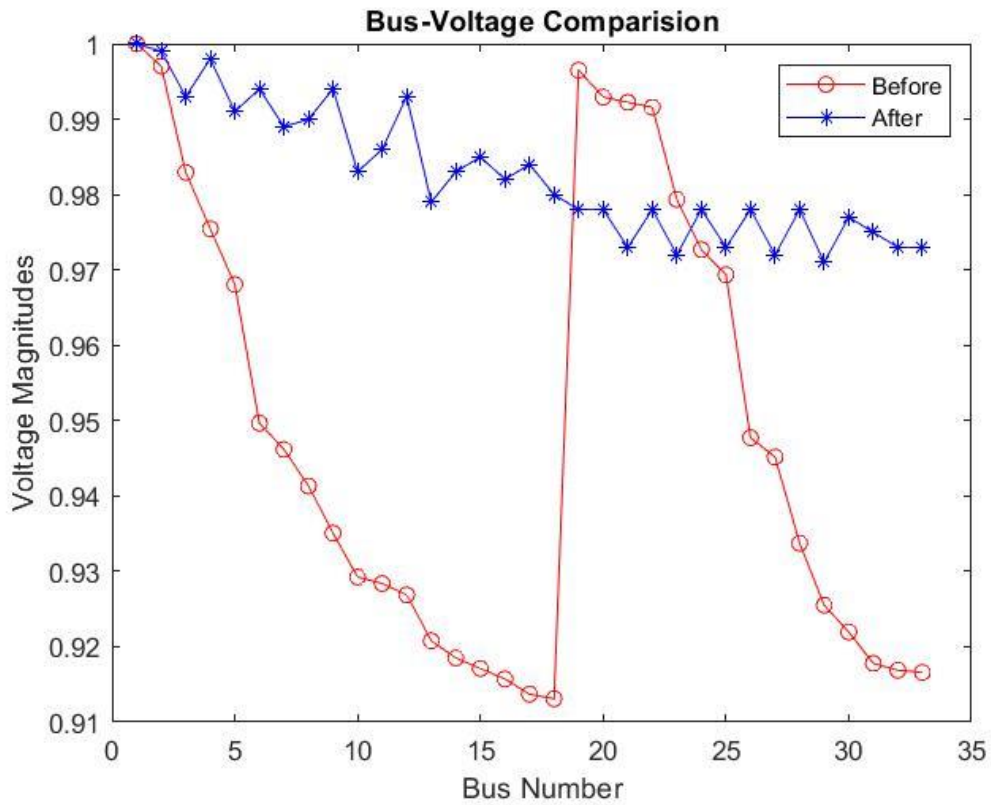
Fig.8 Bus voltage comparison of case II (DGs only) for IEEE 33-Bus System.

Results of Case III (Capacitors and DGs with unity pf simultaneously) while running in MATLAB:

```
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.
```

```
--------------         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

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

Fig 9. Result window for case III (Capacitors and DGs with unity pf simultaneously) for the IEEE 33-Bus System.
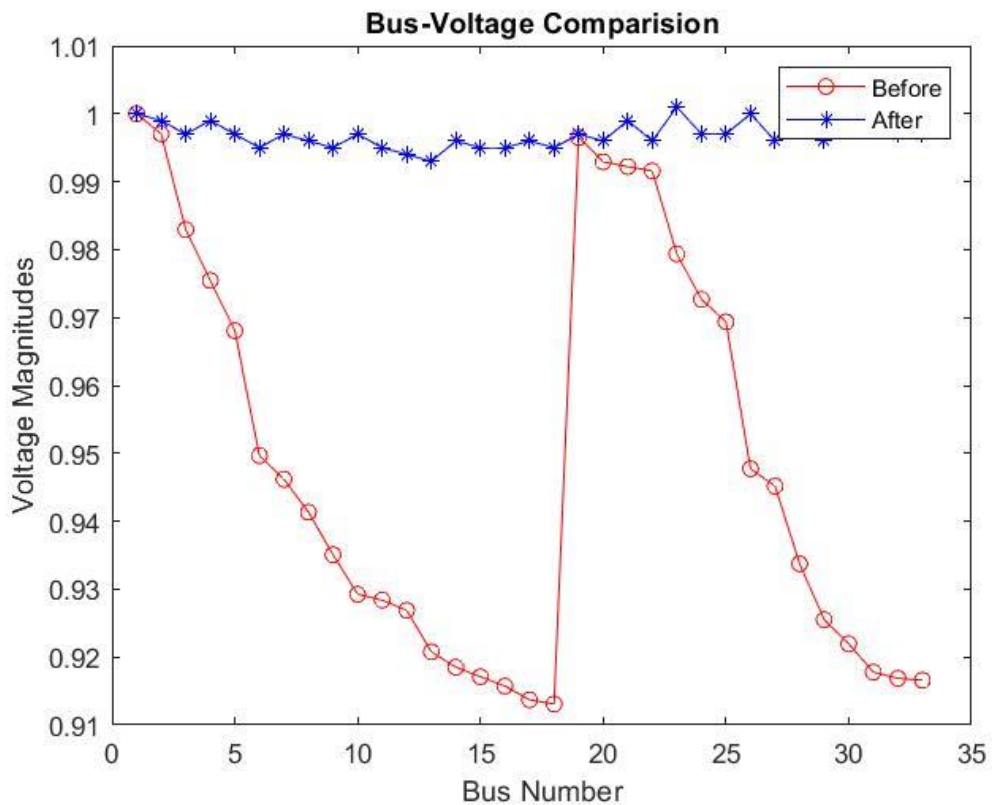
Fig.10 Bus voltage comparison of Case III (Capacitors and DGs with unity pf simultaneously) for the IEEE 33-Bus System.

Results of Case IV (Capacitors and DGs with controllable pf simultaneously) for only technical objectives while running in MATLAB:

```
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.



The best solution was found in Iteration No. 299.

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

   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:  194.49       333.8634       708.6524  kVar each.

The size of DGs is: 0.79628      1.7124      0.99965  MW each
The optimal pf for the DGs is:  0.90583      0.96131      0.99583  each
The locations of DGs is at Buses:   14   3   30
```

Fig 11. Result window for case IV (Capacitors and DGs with controllable pf simultaneously) for only technical objectives for IEEE 33-Bus System.
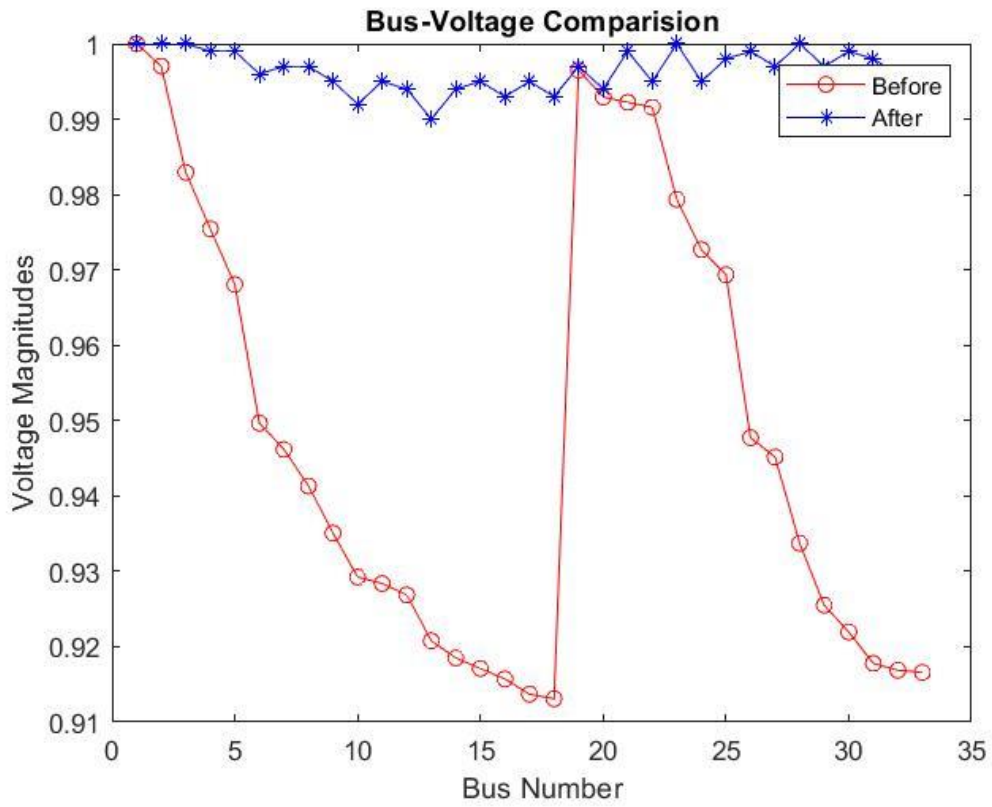
Fig.12 Bus voltage comparison of Case IV (Capacitors and DGs with controllable pf simultaneously) for only technical objectives for the IEEE 33-Bus System.

Results of Case V (Capacitors and DGs with controllable pf simultaneously) for techno- economic objectives while running in MATLAB

```
******************************************************************
------------------------------------------------------------------
--------------     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
```

```
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
```

Fig 13. Result window for case V (Capacitors and DGs with controllable pf simultaneously) for techno-economic objectives for the IEEE 33-Bus System.
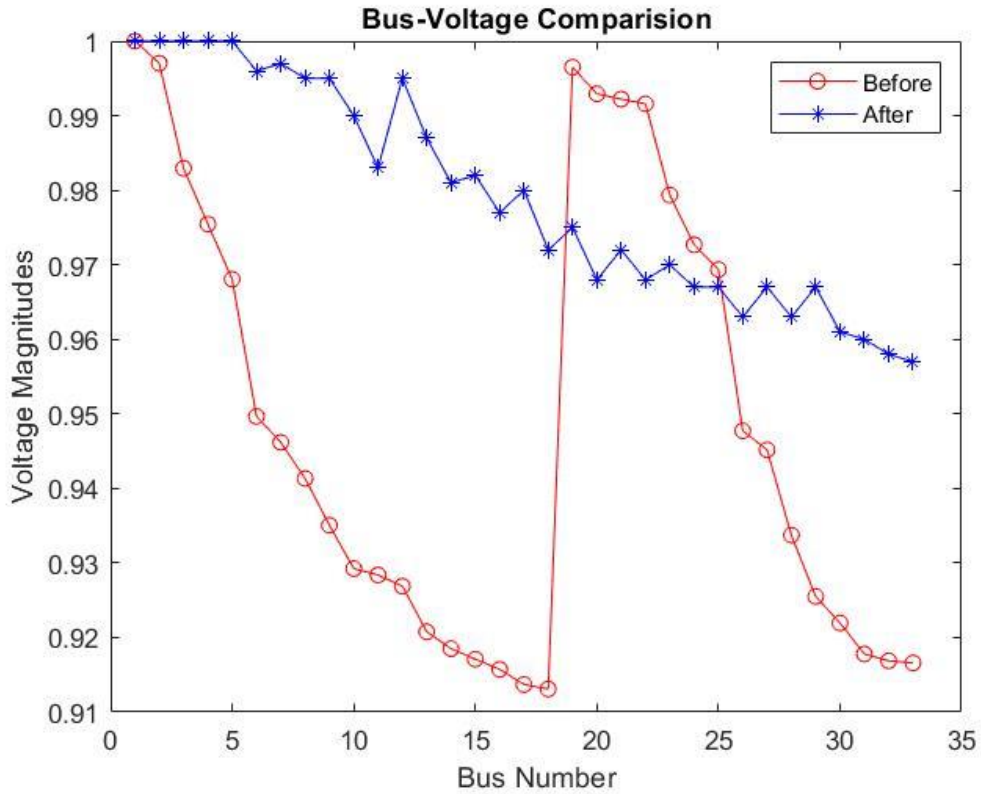
Fig.14 Bus voltage comparison of Case V (Capacitors and DGs with controllable pf simultaneously) for techno-economic objectives for IEEE 33-Bus System.

5.2 Results for IEEE 69-bus system:

The results of load flow are tabulated below.

Table 3: Summary of Load flow report for the IEEE 69- bus system.

For Base case	
Minimum bus voltage (pu)	0.909 (65)
Active power loss (KW)	225.001
Reactive power loss (KVar)	102.165
Power factor	0.821

Table 4: Results of different cases studied on IEEE 69- bus system.

IEEE-69 BUS SYSTEM	ACHIEVED RESULTS	REFERENCE PAPER RESULTS	
Case I (capacitors only)	**WCA**	**GSA**	**PSO**
Minimum voltage (pu)	0.932 (62)	0.952	0.934
Active Power loss(KW)	145.49	145.90	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)	**WCA**	**CVSI**	**GA**
Minimum voltage	0.979(64)	0.968 (27)	0.969
Active Power loss(KW)	69.428	83.18	88.50
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

IEEE-69 BUS SYSTEM	ACHIEVED RESULTS	REFERENCE PAPER RESULTS	
Case III (Capacitors and DGs with unity pf simultaneously)	**WCA**	**DICA**	
Minimum voltage	0.985 (66)	0.979	
Active Power loss(KW)	12.681	17.20	

Reactive Power loss(KVar)	10.012		
Loss reduction (%)	94.36	92.36	
Placement of capacitor (MVar)	0.023 (34), 1.5 (36), 1.298 (61)	0.35 (11), 0.25 (20)	
Placement of DG (MW)	0.380 (64), 1.309 (61), 0.795 (12)	2.25	
IEEE-69 BUS SYSTEM	**ACHIEVED RESULTS**	**IEEE-69BUS SYSTEM**	**ACHIEVED RESULTS**
Case IV (Capacitors and DGs with controllable pf simultaneously) for only technical objectives	**WCA**	Case V (Capacitors and DGs with controllable pf simultaneously) for techno- economic objectives	**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 of capacitor (MVar)	0.568 (49), 0.267 (18)	Placement of capacitor (MVar)	1.237(61),0.337(66),0.266 (18)
Placement of DG (MW)	0.864 (66), 1.244 (2), 2.073 (61)	Placement of 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

Results of Case I (Capacitor only) while running in MATLAB:

```
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. 200.

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

--------------     CALCULATIONS COMPLETED      ---------------------
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YOU CHOSE PLACEMENT AND SIZING OF CAPACITOR BANKS.
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Location of Capacitors is at Buses: 53  18   61

Size of Capacitors is:  425.41895      312.31573      1205.7974 kVar each.
```

Fig 15. Result window for case I (capacitors bank placement and sizing) for the IEEE 69-Bus System.
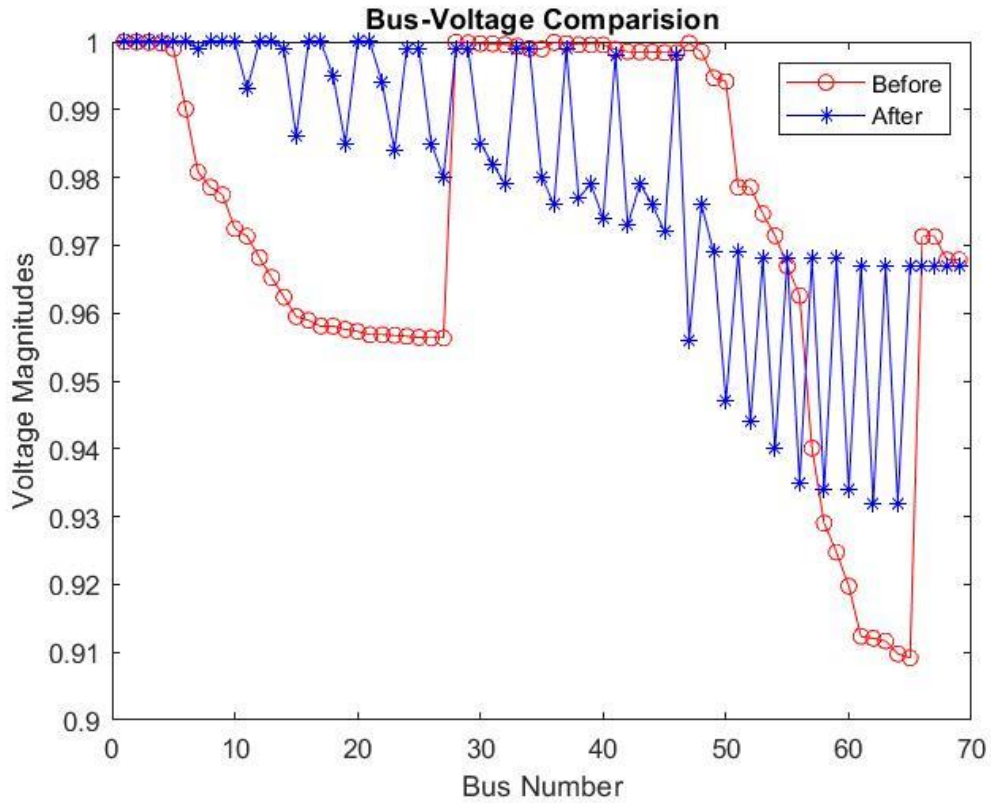
Fig.16 Bus Voltage comparison of case I (capacitors only) for the IEEE 69-Bus System.

Results of Case II (DGs only) while running in MATLAB:

```
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.


The best solution was found in Iteration No. 60.

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
```

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


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

Fig 17. Result window for case II (DGs placement and sizing) for the IEEE 69-Bus System.
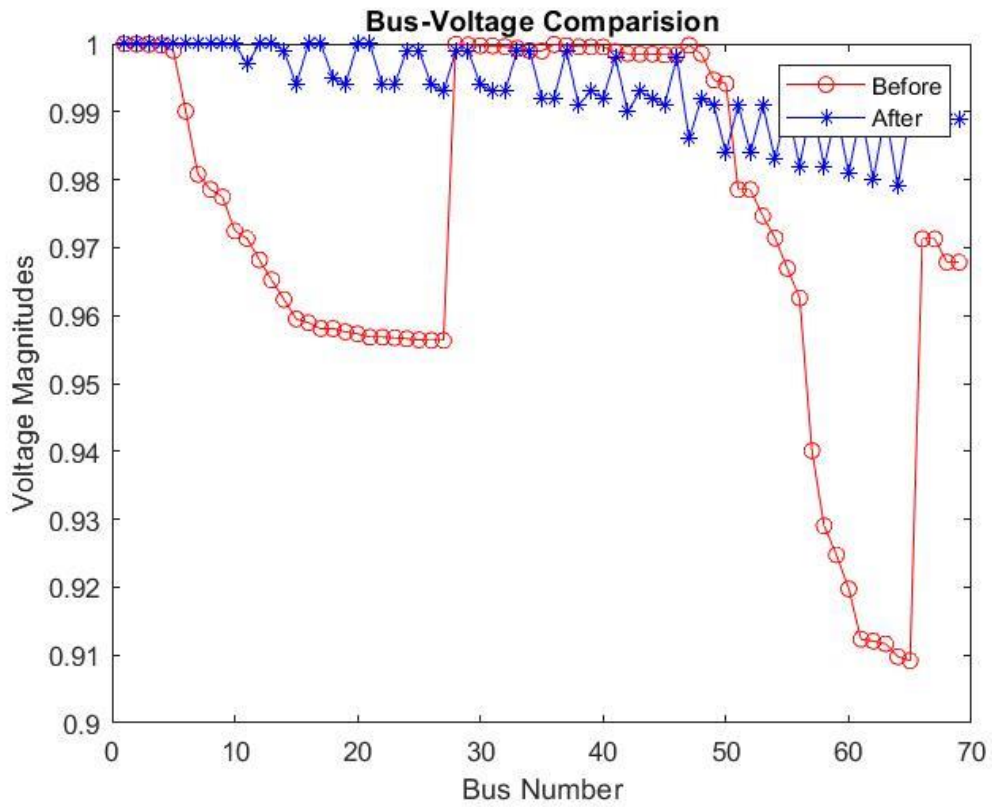
Fig.18 Bus voltage comparison of case II (DGs only) for the IEEE 69-Bus System.

Results of Case III (Capacitors and DGs with unity pf simultaneously) while running in MATLAB:

```
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.


The best solution was found in Iteration No. 164.

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

--------------     CALCULATIONS COMPLETED     ---------------------
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-------------------------------------------------------------------
*******************************************************************
*******************************************************************
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
```

Fig 19. Result window for case III (Capacitors and DGs with unity pf simultaneously) for the IEEE 69-Bus System.
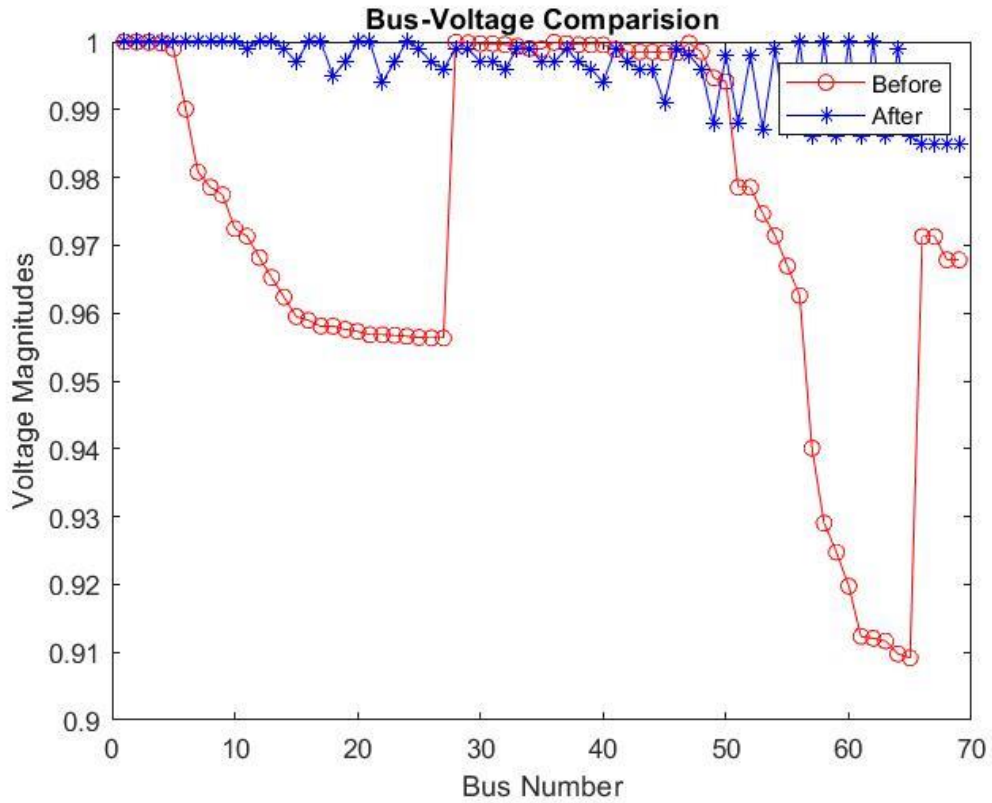
Fig.20 Bus voltage comparison of Case III (Capacitors and DGs with unity pf simultaneously) for IEEE 69-Bus System.

Results of Case IV (Capacitors and DGs with controllable pf simultaneously) for only technical objectives while running in MATLAB:

```
--------------          CALCULATIONS COMPLETED       ---------------------
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  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
```

```
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.


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
```

Fig 21. Result window for case IV (Capacitors and DGs with controllable pf simultaneously) for only technical objectives for IEEE 69-Bus System.
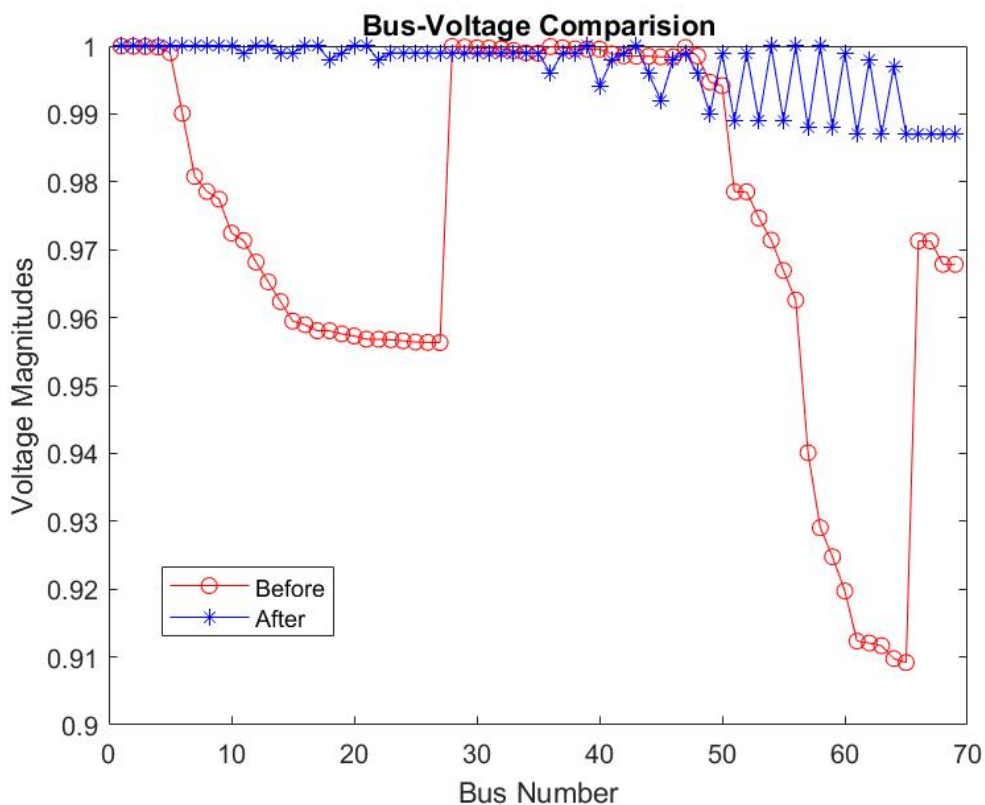
Fig.22 Bus voltage comparison of Case IV (Capacitors and DGs with controllable pf simultaneously) for only technical objectives for IEEE 69-Bus System.

Results of Case V (Capacitors and DGs with controllable pf simultaneously) for techno- economic objectives:

```
******************************************************************
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------------------------------------------------------------------
--------------        CALCULATIONS COMPLETED        ----------------
------------------------------------------------------------------
------------------------------------------------------------------
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    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
```

Fig 23. Result window for case V (Capacitors and DGs with controllable pf simultaneously) for techno-economic objectives for the IEEE 69-Bus System.
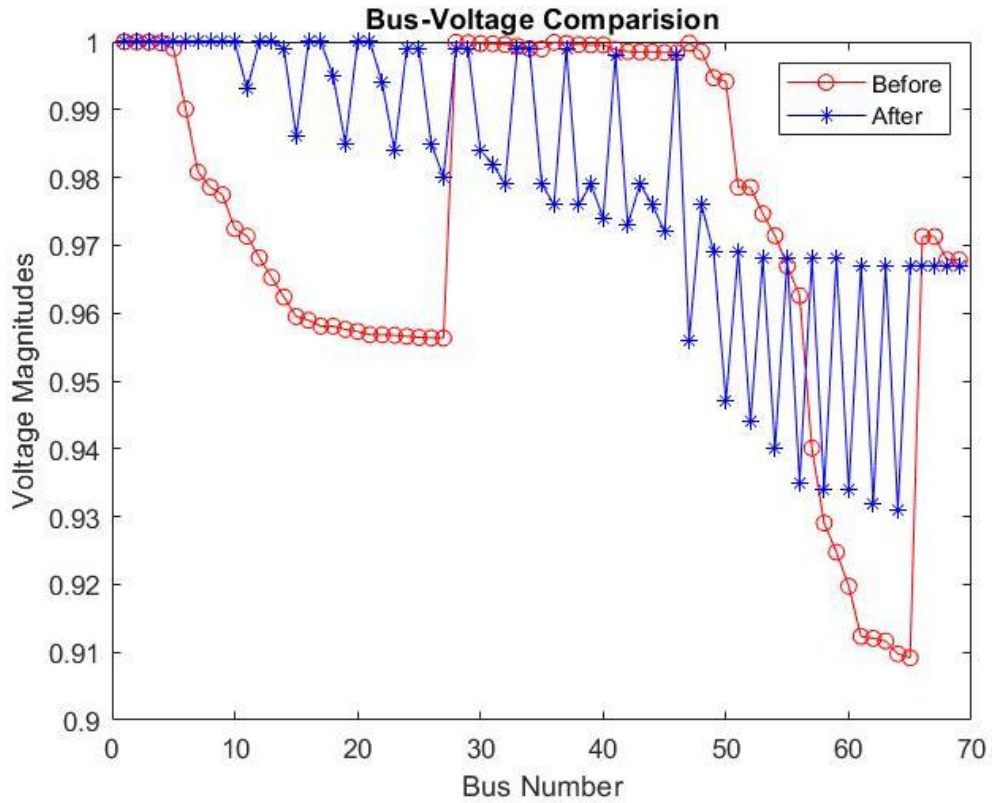
Fig.24 Bus voltage comparison of Case V (Capacitors and DGs with controllable pf simultaneously) for techno-economic objectives for the IEEE 69-Bus System.

5.3 Results for the Sankhu feeder network:

Table 5: Summary of Load flow report for the Sankhu feeder network.

For Base case	
Minimum bus voltage (pu)	0.809 (37)
Active power loss (KW)	1296.991
Reactive power loss (KVar)	345.701
Power factor	0.757

Table 6: Results of different cases studied on the Sankhu feeder network.

Sankhu feeder system	Achieved Results
Case I (capacitors only)	**WCA**
Minimum voltage (pu)	0.821 (52)
Active Power loss(kW)	1037.276
Reactive Power loss(KVar)	276.476
Loss reduction (%)	20.024
Placement capacitor (KVar)	435.3224 (24), 420.3678 (3), 330.3348 (30)
Sankhu feeder system	**Achieved Results**
Case II (DGs only)	**WCA**
Minimum voltage (pu)	0.955 (50)
Active Power loss(KW)	519.332
Reactive Power loss(KVar)	138.423
Loss reduction (%)	59.96
Placement DG (MW)	0.97736 (17), 1.9638 (22), 1.4295 (31)
Sankhu feeder system	**Achieved Results**
Case III (Capacitors and DGs with unity pf simultaneously)	**WCA**
Minimum voltage (pu)	0.986 (50)
Active Power loss(KW)	64.064
Reactive Power loss(KVar)	17.076
Loss reduction (%)	95.02
Placement capacitor (KVar)	1000 (33), 1000 (22), 1000 (27)
Placement of DG (MW)	1.5933 (30), 1.2331 (44), 1.5708 (19)

Sankhu feeder system	Achieved Results
Case IV (Capacitors and DGs with controllable pf simultaneously) for only technical objectives	**WCA**
Minimum voltage (pu)	0.993 (9)
Active Power loss(KW)	17.752
Reactive Power loss(KVar)	4.732
Loss reduction (%)	98.63
Placement capacitor (KVar)	428.9224 (34), 1000 (12), 802.6335 (29)
Placement DG (MW)	0.94534 (47), 2.6617 (21), 1.2381 (33)
Power factor of DGs	0.8, 0.82763, 0.97458
Sankhu feeder system	Achieved Results
Case V (Capacitors and DGs with controllable pf simultaneously) for techno-economic objectives	**WCA**
Minimum voltage (pu)	0.903 (52)
Active Power loss(KW)	308.149
Reactive Power loss(KVar)	82.134
Loss reduction (%)	76.24
Placement capacitor (KVar)	1000 (27), 1000 (33), 1000 (45)
Placement DG (MW)	0.49 (2), 2.6116 (3), 2.94 (7)
Power factor of DGs	0.8, 0.93285, 0.94519

Results of Case-I (Capacitors only) while running in MATLAB, Sankhu Feeder system:

```
Minimum bus voltage is 0.821 pu at 52 bus.
Power Losses are:
-------------------
Active Power Loss = 1037.276 kW.
Reactive Power Loss = 276.476 kVar.
Power Factor = 0.82




|

For Base case:
---------------
Minimum bus voltage was 0.809 pu at 37 bus.
Active power loss was 1296.991 kW.
Reactive power loss was 345.701 kVar.
Power Factor was 0.757

YOU CHOSE PLACEMENT AND SIZING OF CAPACITOR BANKS.
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Location of Capacitors is at Buses:     24      3       30

Size of Capacitors is:  435.3224      420.3678      330.3348 kVar each.
```

Fig 25. Result window for the case I (capacitors bank placement and sizing) the for Sankhu feeder network.
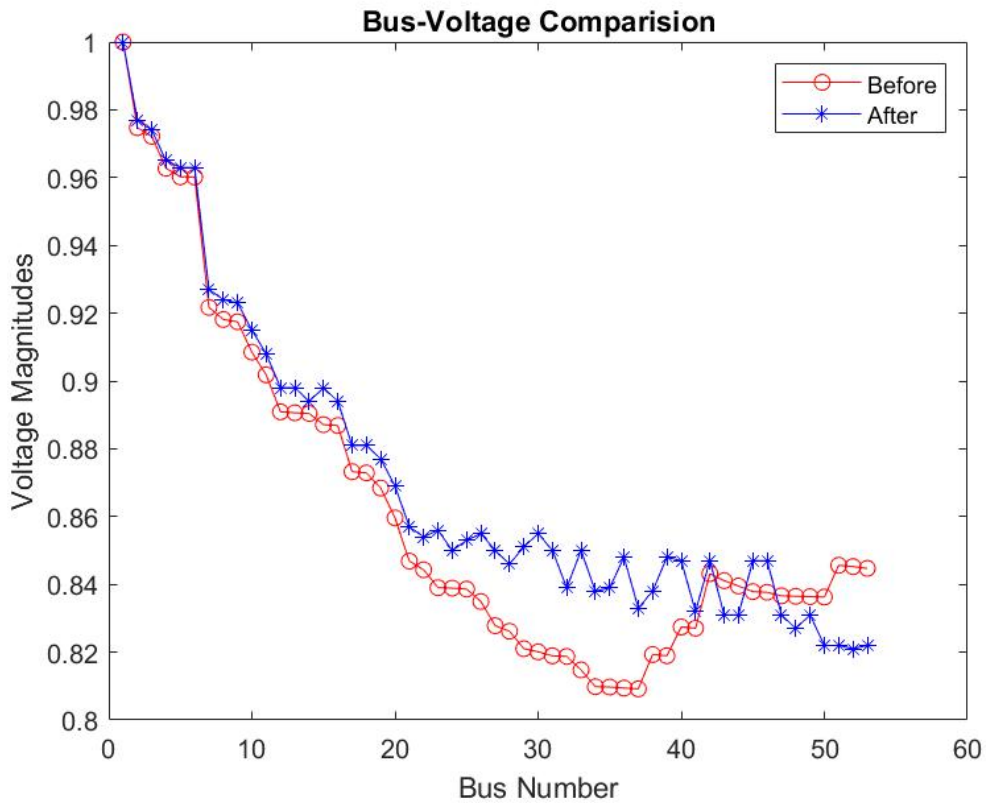
Fig.26 Bus Voltage comparison of case I (capacitors only) for the Sankhu feeder network.

Results of Case-II (DGs only) while running in MATLAB, Sankhu Feeder system:

```
Minimum bus voltage is 0.955 pu at 50 bus.
Power Losses are:
--------------------
Active Power Loss = 519.332 kW.
Reactive Power Loss = 138.423 kVar.
Power Factor = 0.20


OBJECTIVE FUNCTION for the best solution = 519.332.


The best solution was found in Iteration No. 211.

For Base case:
---------------
Minimum bus voltage was 0.809 pu at 37 bus.
Active power loss was 1296.991 kW.
Reactive power loss was 345.701 kVar.
Power Factor was 0.757
```

```
YOU CHOSE PLACEMENT and SIZING OF DGs.
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The size of DGs is:     0.97736      1.9638       1.4295   MW each.


The locations of DGs is at Buses:      17      22       31
```

Fig 27. Result window for case II (DGs placement and sizing) for Sankhu feeder.
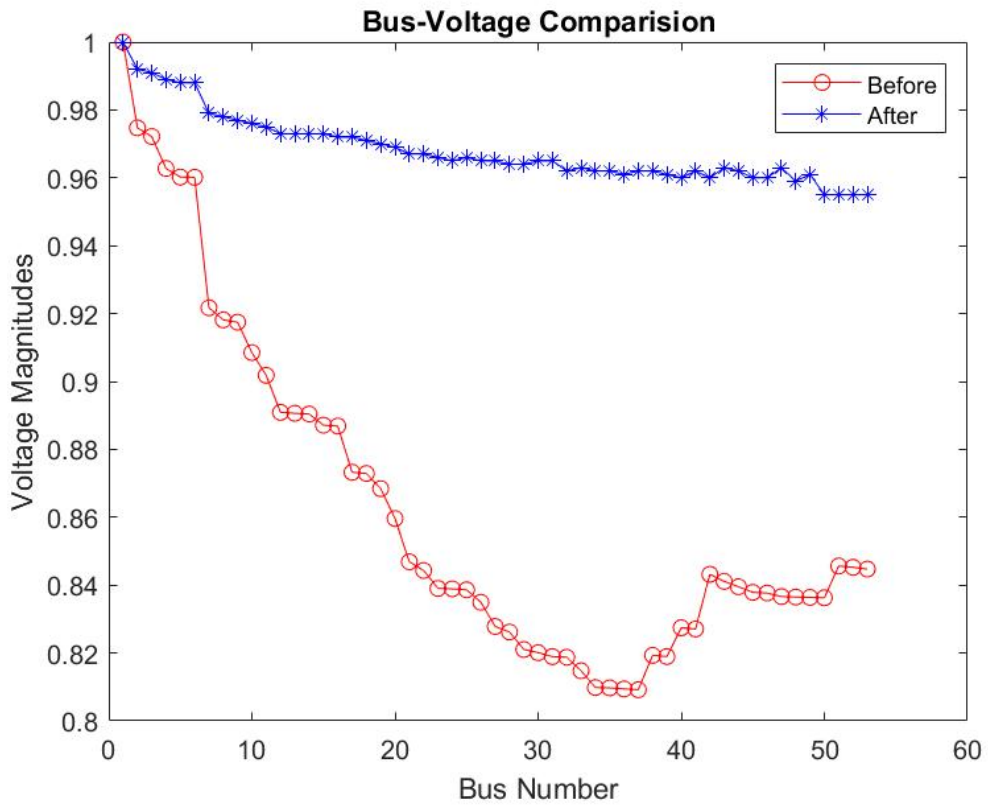
Fig.28 Bus voltage comparison of case II (DGs only) for the Sankhu feeder network.

Results of Case-III (Capacitors and DGs with unity pf simultaneously) while running in MATLAB, Sankhu Feeder system:

```
Minimum bus voltage is 0.986 pu at 50 bus.
Power Losses are:
------------------
Active Power Loss = 64.064 kW.
Reactive Power Loss = 17.076 kVar.
Power Factor = 0.27

OBJECTIVE FUNCTION for the best solution = 64.064.


The best solution was found in Iteration No. 234.

For Base case:
---------------
Minimum bus voltage was 0.809 pu at 37 bus.
Active power loss was 1296.991 kW.
Reactive power loss was 345.701 kVar.
Power Factor was 0.757


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

Location of capacitors is at Buses:      33      22      27
Size of capacitors is:  1000  1000  1000  kVar each.

The size of DGs is:      1.5933      1.2331      1.5708  MW each
The locations of DGs is at Buses:        30      44      19
```

Fig 29. Result window for case III (Capacitors and DGs with unity pf simultaneously) for Sankhu feeder network.
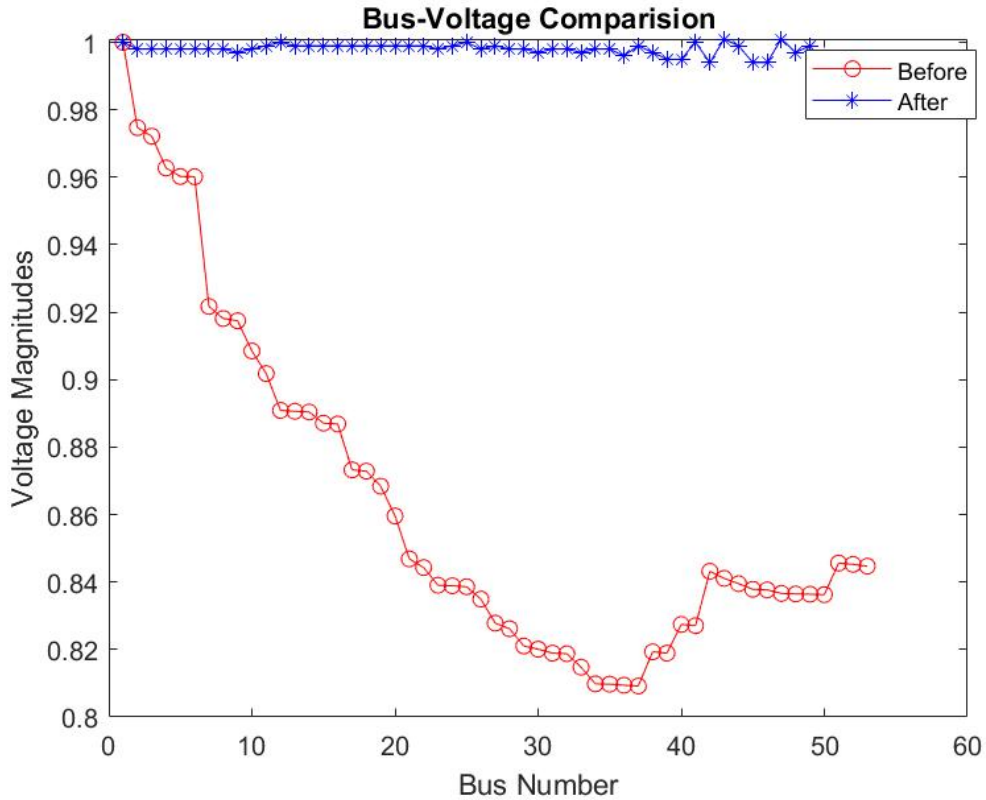
Fig.30 Bus voltage comparison of Case III (Capacitors and DGs with unity pf simultaneously) for the Sankhu feeder network.

Results of Case IV (Capacitors and DGs with controllable pf simultaneously) for only technical objectives while running in MATLAB: Sankhu Feeder system:

```
Minimum bus voltage is 0.993 pu at 9 bus.
Power Losses are:
------------------
Active Power Loss = 17.752 kW.
Reactive Power Loss = 4.732 kVar.
Power Factor = 0.87


OBJECTIVE FUNCTION for the best solution = 8.896.



The best solution was found in Iteration No. 300.

For Base case:
---------------
Minimum bus voltage was 0.809 pu at 37 bus.
Active power loss was 1296.991 kW.
Reactive power loss was 345.701 kVar.
Power Factor was 0.757
```

```
|-----------------------------------------------------------------
|-------------        CALCULATIONS COMPLETED        --------------------
|-----------------------------------------------------------------
|-----------------------------------------------------------------
|-----------------------------------------------------------------
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   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:      34      12      29
Size of capacitors is:  428.92239          1000      802.63347  kVar each.

The size of DGs is:      0.94534      2.6617      1.2381  MW each
The optimal pf for the DGs is:  0.8      0.82763      0.97458  each
The locations of DGs is at Buses:      47      21      33
```

Fig 31. Result window for case IV (Capacitors and DGs with controllable pf simultaneously) for only technical objectives for the Sankhu feeder network.
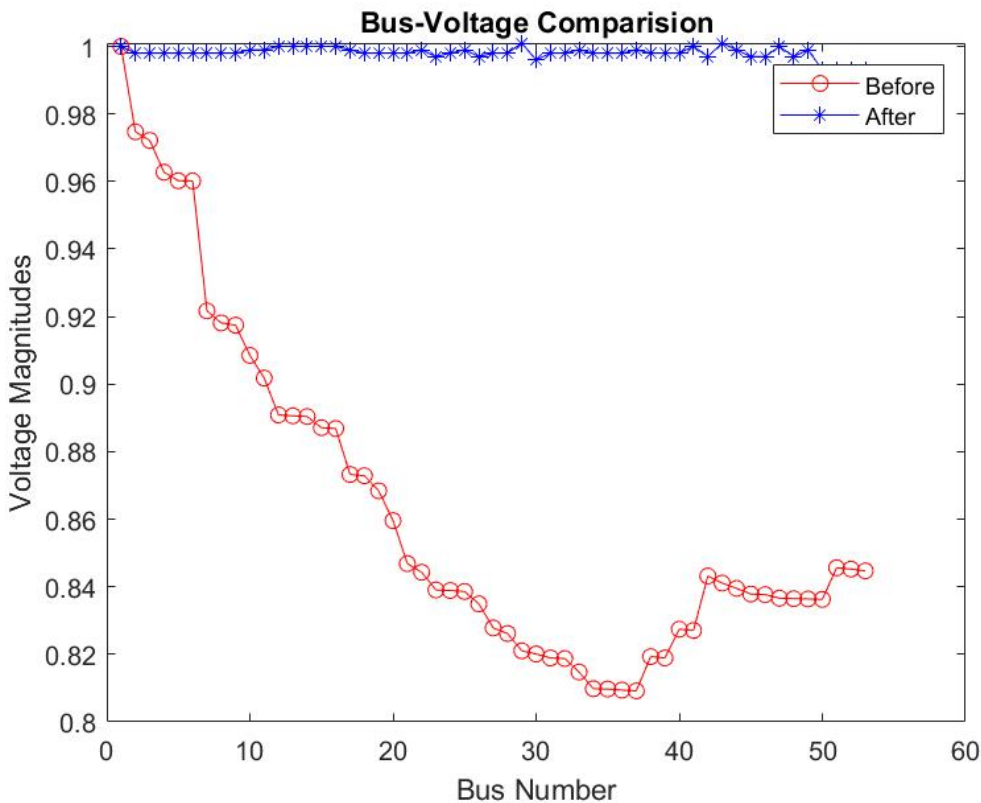
Fig.32 Bus voltage comparison of Case IV (Capacitors and DGs with controllable pf simultaneously) for only technical objectives for the Sankhu feeder network.

Results of Case V (Capacitors and DGs with controllable pf simultaneously) for techno-economic objectives while running in MATLAB: Sankhu Feeder system:

```
-----------------------------------------------------------------
-------------      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:      27      33      45
Size of capacitors is:   1000  1000  1000  kVar each.

The size of DGs is:      0.49      2.6116      2.94  MW each

The optimal pf for the DGs is:  0.8     0.93285     0.94519  each

The locations of DGs is at Buses:        2       3       7
Bus Voltages are:
                      Bus No.      ||    Voltage (pu)
                      ----------------------------------
                         1                      1
                         2                    1.001
                         3                    1.001
                         4                    0.998
                         5                    0.997
                         6                    0.997
                         7                    0.985
                         8                    0.983
                         9                    0.982
                        10                    0.975
                        11                     0.97
                        12                    0.962
                        13                    0.962
```

14	0.959
15	0.962
16	0.959
17	0.949
18	0.949
19	0.946
20	0.939
21	0.93
22	0.928
23	0.929
24	0.925
25	0.927
26	0.928
27	0.924
28	0.922
29	0.926
30	0.928
31	0.924
32	0.917
33	0.925
34	0.916
35	0.917
36	0.924
37	0.912
38	0.917
39	0.924
40	0.923
41	0.912
42	0.923
43	0.911
44	0.911
45	0.923
46	0.923

```
47                                    0.911
48                                    0.908
49                                    0.911
50                                    0.904
51                                    0.904
52                                    0.903
53                                    0.904

Minimum bus voltage is 0.903 pu at 52 bus.
Power Losses are:
------------------
Active Power Loss = 308.149 kW.
Reactive Power Loss = 82.134 kVar.
Power Factor = 0.96


The best solution was found in Iteration No. 157.

For Base case:
---------------
Minimum bus voltage was 0.809 pu at 37 bus.
Active power loss was 1296.991 kW.
Reactive power loss was 345.701 kVar.
Power Factor was 0.757
-------------------------------------------------------------------------
```

Fig 33. Result window for case V (Capacitors and DGs with controllable pf simultaneously) for techno-economic objectives for the Sankhu feeder network.
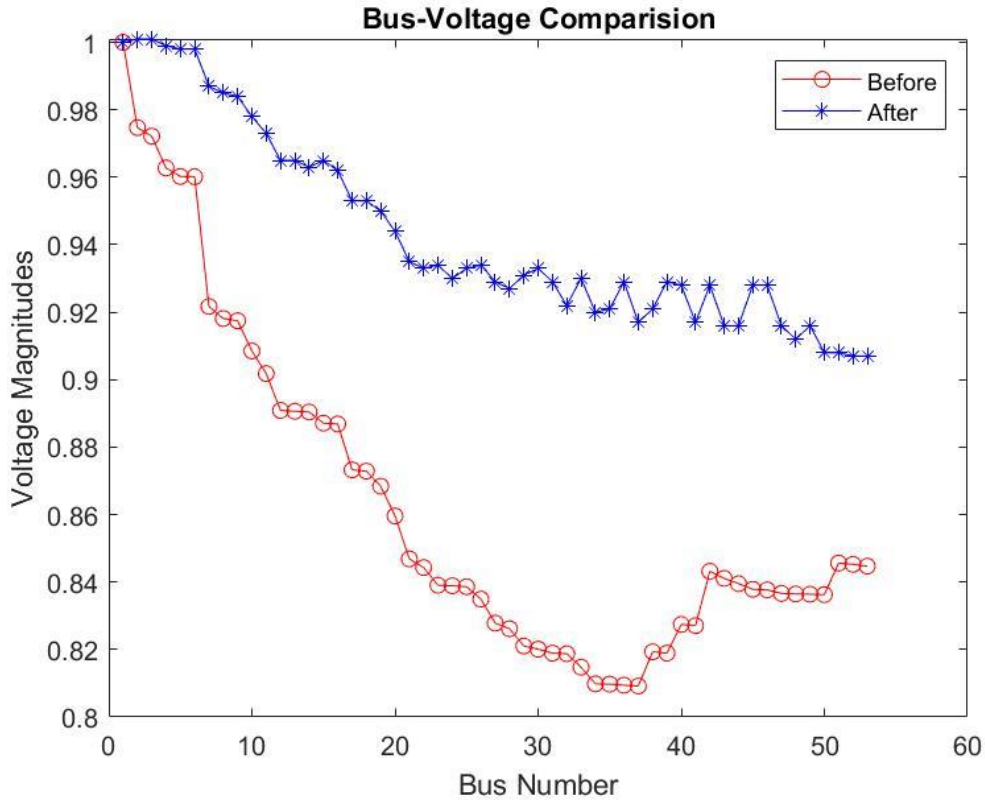
Fig.34 Bus voltage comparison of Case V (Capacitors and DGs with controllable pf simultaneously) for techno-economic objectives for the Sankhu feeder network.

5.4 Discussion on the result:

Significant improvements were observed in the power loss reduction and minimum bus voltage enhancement for different cases studied in both the IEEE 33-Bus System and the IEEE 69-Bus System. In the IEEE 33-Bus System, power loss decreased by up to 92.04%, while the minimum bus voltage showed significant improvement. Similarly, in the IEEE 69-Bus System, power loss decreased by up to 96.24%, and the minimum bus voltage experienced notable enhancement for all cases examined.

The application of distributed generation (DGs) and capacitor banks (CBs) placement and sizing in the Sankhu feeder of Kathmandu Valley yielded significant positive outcomes. Notably, power loss was reduced by up to 98.63%, and the minimum bus voltage improved to a minimum of 0.821pu for Case I and up to 0.993pu for Case IV.

To validate the effectiveness of the proposed method, a test distribution system was employed, and simulation results affirmed its capability to determine the optimal size and placement of DG and CB in the system. These optimal configurations resulted in improved voltage profiles, reduced power losses, and enhanced system reliability.

The proposed approach offers an intriguing and promising solution to address the challenge of optimizing the placement and sizing of DG and CB in distribution systems. Notably, the utilization of the Water Cycle Algorithm (WCA) sets it apart from other approaches and proves to be effective in achieving optimization

objectives. Nonetheless, it would be valuable to compare the proposed approach with other commonly used optimization techniques in the field to establish its superiority.

In conclusion, the proposed approach exhibits practical potential for applications in the realm of power distribution systems. Further research and experimentation are necessary to evaluate its performance across diverse distribution systems and under varying conditions.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 Conclusion:

The proposed methodology utilizes the Water Cycle Algorithm (WCA) to optimize the allocation of Capacitor Banks (CBs) and Distributed Generators (DGs) in radial distribution networks, resulting in superior performance compared to other optimization algorithms such as PSO, BFOA, GA, GSA, CVSI, and DICA. The practical application of this methodology was extended to the Sankhu feeder network in Kathmandu Valley, Nepal. MATLAB coding and load flow analysis using the MATPOWER tool were employed for implementation.

The analysis involved several cases starting with the base case where bus power loss and voltage profiles were determined. Subsequently, CBs were allocated and sized (Case I) followed by the analysis of DG allocation and sizing (Case II). The simultaneous placement and sizing of DGs and CBs with unity power factor were examined (Case III), as well as their allocation and sizing with adjustable power factor for technical objectives (Case IV) and techno-economic objectives (Case V).

For the IEEE 33-bus system, the power loss was reduced by 34.79% (Case I), 62.10% (Case II), 90.23% (Case III), 92.04% (Case IV), and 63.67% (Case V) compared to the base case. The minimum bus voltage significantly improved across all cases. Similar trends were observed for the IEEE 69-bus system, with reductions in power loss and improvements in minimum bus voltage achieved through the proposed methodology.

Furthermore, the Sankhu feeder network demonstrated a reduction in power loss of 20.024% (Case I) and notable improvements in the minimum bus voltage for all cases. Overall, the simultaneous allocation and sizing of DGs and CBs yielded the best results in terms of reducing system loss and improving bus voltage profile, aligning with the objectives of the thesis.

The research highlights the effectiveness of the WCA algorithm in optimizing the allocation and sizing of DGs and CBs, showcasing its superior convergence rate compared to other metaheuristic algorithms. By reducing power loss and improving voltage profiles, the proposed methodology enhances the efficiency and performance of distribution systems. Thus, the objective of the thesis work has been successfully accomplished.

6.2 Recommendations:

Here are some suggestions for further exploration on the topic of analyzing the effectiveness of DGs and CBs in Distribution Systems using the WCA:

Comparative Analysis: It would be beneficial to conduct a detailed comparison between the Water Cycle Algorithm (WCA) and other commonly used optimization techniques in power system engineering, such as genetic algorithms, particle swarm optimization, and ant colony optimization. This comparison will help identify the

strengths and weaknesses of the WCA and demonstrate its applicability in practical scenarios.

Testing on Complex Systems: It is important to find the performance of the proposed approach on larger and more complex distribution systems. By conducting tests on such systems, researchers can gain insights into the scalability and effectiveness of the WCA-based approach and identify any potential limitations or challenges it may face.

Sensitivity Analysis: Performing a sensitivity analysis will enable researchers to assess how the proposed approach responds to variations in system parameters and operating conditions. This analysis will provide a better understanding of the algorithm's performance and guide necessary adjustments or enhancements.

Real-World Implementation: Validating the effectiveness of the proposed approach through real-world implementations is crucial. Implementing the WCA-based optimization approach in practical distribution systems and assessing its performance under real operating conditions will provide valuable feedback and validate its applicability.

Overall, the findings presented in this thesis demonstrate promising results and showcase the potential of the Water Cycle Algorithm in optimizing the placement and sizing of distributed generation and capacitor banks in distribution systems. However, further research and testing are required to comprehensively evaluate the approach and uncover any potential limitations.

6.3 Future Scope:

Exploring the effectiveness of DGs and CBs using the WCA offers several avenues for further research:

Integration of Renewable Energy Sources: With the growing demand for renewable energy, it is crucial to incorporate these sources into distribution systems. Researchers can extend the use of the Water Cycle Algorithm to optimizing location and sizing of various types of distributed generation, such as gas turbine, wind, and hydrogen energy power plants.

Energy Storage Systems: To address the intermittent nature of renewable energy sources, investigating the optimal placement and sizing of distributed energy storage systems (e.g., batteries and flywheels) using the Water Cycle Algorithm is essential.

Real-Time Optimization: The emergence of smart grids highlights the importance of real-time optimization in distribution systems to handle dynamic changes. Modifying the Water Cycle Algorithm to handle real-time optimization problems will enhance its applicability in such scenarios.

Robust Optimization: Ensuring the robustness of the optimizing location and sizing of CBs along with DGs requires accounting for variations in load and generation. Adapting the Water Cycle Algorithm to handle robust optimization problems will lead to more reliable solutions.

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Appendix

Appendix 1

Appendix 1 contains the data of the IEEE 33-bus system as below:

From Bus	To Bus	R (Ohms)	X (Ohms)	Bus No.	Pload(KW)	Qload(KVAR)
1	2	0.0922	0.047	1	0	0
2	3	0.493	0.2511	2	100	60
3	4	0.366	0.1864	3	90	40
4	5	0.3811	0.1941	4	120	80
5	6	0.819	0.707	5	60	30
6	7	0.1872	0.6188	6	60	20
7	8	0.7114	0.2351	7	200	100
8	9	1.03	0.74	8	200	100
9	10	1.044	0.74	9	60	20
10	11	0.1966	0.065	10	60	20
11	12	0.3744	0.1238	11	45	30
12	13	1.468	1.155	12	60	35
13	14	0.5416	0.7129	13	60	35
14	15	0.591	0.526	14	120	80
15	16	0.7463	0.545	15	60	10
16	17	1.289	1.721	16	60	20
17	18	0.732	0.574	17	60	20
2	19	0.164	0.1565	18	90	40
19	20	1.5042	1.3554	19	90	40
20	21	0.4095	0.4784	20	90	40
21	22	0.7089	0.9373	21	90	40
3	23	0.4512	0.3083	22	90	40
23	24	0.898	0.7091	23	90	50
24	25	0.896	0.7011	24	420	200
6	26	0.203	0.1034	25	420	200
26	27	0.2842	0.1447	26	60	25
27	28	1.059	0.9337	27	60	25
28	29	0.8042	0.7006	28	60	20
29	30	0.5075	0.2585	29	120	70
30	31	0.9744	0.963	30	200	600
31	32	0.3105	0.3619	31	150	70
32	33	0.341	0.5302	32	210	100
				33	60	40
	Base KVA	12.66				
	Base MVA	100				

Appendix 2

Appendix 2 contains the data of the IEEE 69-bus system as below:

Column1	Column2	Column3	Column4	Column5	Nominal Load at Receiving Bus	Column6
Branch No.	Sending Bus	Receiving Bus	Resistance (Ohm)	Reactance (Ohm)	P (kW)	Q (kVAR)
1	1	2	0.0005	0.0012	0	0
2	2	3	0.0005	0.0012	0	0
3	3	4	0.0015	0.0036	0	0
4	4	5	0.0251	0.0294	0	0
5	5	6	0.366	0.1864	2.6	2.2
6	6	7	0.3811	0.1941	40.4	30
7	7	8	0.0922	0.047	75	54
8	8	9	0.0493	0.0251	30	22
9	9	10	0.819	0.2707	28	19
10	10	11	0.1872	0.0619	145	104
11	11	12	0.7114	0.2351	145	104
12	12	13	1.03	0.34	8	5
13	13	14	1.044	0.345	8	5.5
14	14	15	1.058	0.3496	0	0
15	15	16	0.1966	0.065	45.5	30
16	16	17	0.3744	0.1238	60	35
17	17	18	0.0047	0.0016	60	35
18	18	19	0.3276	0.1083	0	0
19	19	20	0.2106	0.069	1	0.6
20	20	21	0.3416	0.1129	114	81
21	21	22	0.014	0.0046	5	3.5
22	22	23	0.1591	0.0526	0	0
23	23	24	0.3463	0.1145	28	20
24	24	25	0.7488	0.2475	0	0
25	25	26	0.3089	0.1021	14	10
26	26	27	0.1732	0.0572	14	10
27	3	28	0.0044	0.0108	26	18.6
28	28	29	0.064	0.1565	26	18.6
29	29	30	0.3978	0.1315	0	0
30	30	31	0.0702	0.0232	0	0
31	31	32	0.351	0.116	0	0
32	32	33	0.839	0.2816	14	10
33	33	34	1.708	0.5646	9.5	14
34	34	35	1.474	0.4873	6	4
35	3	36	0.0044	0.0108	26	18.55

36	36	37	0.064	0.1565	26	18.55
37	37	38	0.1053	0.123	0	0
38	38	39	0.0304	0.0355	24	17
39	39	40	0.0018	0.0021	24	17
40	40	41	0.7283	0.8509	1.2	1
41	41	42	0.31	0.3623	0	0
42	42	43	0.041	0.0478	6	4.3
43	43	44	0.0092	0.0116	0	0
44	44	45	0.1089	0.1373	39.22	26.3
45	45	46	0.0009	0.0012	39.22	26.3
46	4	47	0.0034	0.0084	0	0
47	47	48	0.0851	0.2083	79	56.4
48	48	49	0.2898	0.7091	384.7	274.5
49	49	50	0.0822	0.2011	384.7	274.5
50	8	51	0.0928	0.0473	40.5	28.3
51	51	52	0.3319	0.1114	3.6	2.7
52	52	53	0.174	0.0886	4.35	3.5
53	53	54	0.203	0.1034	26.4	19
54	54	55	0.2842	0.1447	24	17.2
55	55	56	0.2813	0.1433	0	0
56	56	57	1.59	0.5337	0	0
57	57	58	0.7837	0.263	0	0
58	58	59	0.3042	0.1006	100	72
59	59	60	0.3861	0.1172	0	0
60	60	61	0.5075	0.2585	1244	888
61	61	62	0.0974	0.0496	32	23
62	62	63	0.145	0.0738	0	0
63	63	64	0.7105	0.3619	227	162
64	64	65	1.041	0.5302	59	42
65	11	66	0.2012	0.0611	18	13
66	66	67	0.0047	0.0014	18	13
67	12	68	0.7394	0.2444	28	20
68	68	69	0.0047	0.0016	28	20

Appendix 3

Appendix 3 contains the data of Sankhu feeder network as below:

Branch Number	From Bus	To Bus	Length (m)	R (Ohm)	X (Ohm)	P (MW)	Q (MVAR)	S (kVA)
1	1	2	232	0.4026509	0.1073228	0.14	0.14282857	200
2	2	3	24	0.0416535	0.0111024	0.07	0.07141428	100
3	3	4	90	0.1562008	0.0416339	0.14	0.14282857	200
4	4	5	25	0.0433891	0.011565	0	0	0
5	5	6	53	0.0919849	0.0245177	0.07	0.07141428	100
6	5	7	386	0.6699278	0.178563	0.14	0.14282857	200
7	7	8	37	0.0642159	0.0171161	0	0	0
8	8	9	240	0.4165354	0.1110236	0.14	0.14282857	200
9	8	10	103	0.1787631	0.0476476	0.07	0.07141428	100
10	10	11	73	0.1266962	0.0337697	0.07	0.07141428	100
11	11	12	121	0.2100033	0.0559744	0	0	0
12	12	13	49	0.0850427	0.0226673	0.14	0.14282857	200
13	13	14	73	0.1266962	0.0337697	0.14	0.14282857	200
14	12	15	45	0.0781004	0.0208169	0	0	0
15	15	16	176	0.3054593	0.0814173	0.07	0.07141428	100
16	15	17	168	0.2915748	0.0777165	0	0	0
17	17	18	127	0.2204167	0.05875	0.14	0.14282857	200
18	17	19	61	0.1058694	0.0282185	0.21	0.21424285	300
19	19	20	118	0.2047966	0.0545866	0.21	0.21424285	300
20	20	21	182	0.3158727	0.0841929	0	0	0
21	21	22	43	0.0746293	0.0198917	0	0	0
22	22	23	134	0.2325656	0.0619882	0	0	0
23	23	24	95	0.1648786	0.0439469	0.035	0.03570714	50
24	24	25	372	0.6456299	0.1720866	0.035	0.03570714	50
25	23	26	109	0.1891765	0.0504232	0.21	0.21424285	300
26	26	27	216	0.3748819	0.0999213	0	0	0
27	27	28	58	0.1006627	0.0268307	0.14	0.14282857	200
28	28	29	204	0.3540551	0.0943701	0.14	0.14282857	200
29	29	30	43	0.0746293	0.0198917	0	0	0
30	30	31	67	0.1162828	0.0309941	0	0	0
31	31	32	58	0.1006627	0.0268307	0.14	0.14282857	200
32	31	33	294	0.5102559	0.1360039	0.21	0.21424285	300
33	33	34	521	0.904229	0.2410138	0.21	0.21424285	300
34	34	35	29	0.0503314	0.0134154	0.07	0.07141428	100
35	35	36	199	0.3453773	0.0920571	0.07	0.07141428	100
36	34	37	410	0.7115814	0.1896654	0.07	0.07141428	100
37	30	38	165	0.2863681	0.0763287	0.14	0.14282857	200
38	38	39	243	0.4217421	0.1124114	0.07	0.07141428	100
39	27	40	81	0.1405807	0.0374705	0.14	0.14282857	200
40	40	41	241	0.418271	0.1114862	0.07	0.07141428	100
41	22	42	54	0.0937205	0.0249803	0.14	0.14282857	200
42	42	43	119	0.2065322	0.0550492	0.14	0.14282857	200

43	43	44	109	0.1891765	0.0504232	0.175	0.17853571	250
44	44	45	155	0.2690125	0.0717028	0	0	0
45	45	46	120	0.2082677	0.0555118	0.07	0.07141428	100
46	45	47	135	0.2343012	0.0624508	0.21	0.21424285	300
47	47	48	31	0.0538025	0.0143406	0.07	0.07141428	100
48	48	49	64	0.1110761	0.0296063	0.07	0.07141428	100
49	48	50	139	0.2412434	0.0643012	0.07	0.07141428	100
50	21	51	127	0.2204167	0.05875	0.175	0.17853571	250
51	51	52	64	0.1110761	0.0296063	0.14	0.14282857	200
52	52	53	173	0.3002526	0.0800295	0.14	0.14282857	200

Column1	Column2	Column3	Column4	Column5
conductor	R per km	X per km		
Swanate/Weasel	1.735564	0.462598		
			Base MVA	10
			Base KV	11
			Base Z	12.1
			pf	0.7

Bus No.	Pload (MW)	Qload (MVAR)
1	0	0
2	0.14	0.142828569
3	0.07	0.071414284
4	0.14	0.142828569
5	0	0
6	0.07	0.071414284
7	0.14	0.142828569
8	0	0
9	0.14	0.142828569
10	0.07	0.071414284
11	0.07	0.071414284
12	0	0
13	0.14	0.142828569
14	0.14	0.142828569
15	0	0
16	0.07	0.071414284
17	0	0
18	0.14	0.142828569
19	0.21	0.214242853

20	0.21	0.214242853
21	0	0
22	0	0
23	0	0
24	0.035	0.035707142
25	0.035	0.035707142
26	0.21	0.214242853
27	0	0
28	0.14	0.142828569
29	0.14	0.142828569
30	0	0
31	0	0
32	0.14	0.142828569
33	0.21	0.214242853
34	0.21	0.214242853
35	0.07	0.071414284
36	0.07	0.071414284
37	0.07	0.071414284
38	0.14	0.142828569
39	0.07	0.071414284
40	0.14	0.142828569
41	0.07	0.071414284
42	0.14	0.142828569
43	0.14	0.142828569
44	0.175	0.178535711
45	0	0
46	0.07	0.071414284
47	0.21	0.214242853
48	0.07	0.071414284
49	0.07	0.071414284
50	0.07	0.071414284
51	0.175	0.178535711
52	0.14	0.142828569
53	0.14	0.142828569

Appendix 4:

This appendix contains Sample Format of execution of Program in MATLAB. The executed results below for IEEE 33-Bus test System.

```
*********************** WELCOME ****************************
***************** Start of Program ***************************
-------------------------------------------------------------------------
-------------------------------------------------------------------------
-------------------------------------------------------------------------
                                           - Author: Bijay Kumar Sah


~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
*******************************************************************
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
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
```

```
-------------------------------------------------------------------
-------------------------------------------------------------------
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.): 1000
Minimum Bus Voltage at any Bus (in per unit) ? (Default is 0.90 pu.): 0.9
Minimum Source Power Factor ? (Default is 0.20 pu.): 0.2


==================================================================
Created initial population and formed sea, rivers, and streams
Sea Formed
Rivers Formed
Streams Formed
Designated streams to rivers and sea
******************** Water Cycle Algorithm (WCA)********************
*******************************************************************


=============Start of Iteration 1 ==============
Moving Stream to Sea
Moving Streams to Rivers
Moving Rivers to Sea
Evaporation condition and Raining Process
Checking the Evaporation condition for Rivers and Sea
Checking the Evaporation condition for Streams and Sea
Iteration: 1   Fmin= 141.0071

=============Start of Iteration 2 ==============
Moving Stream to Sea
Moving Streams to Rivers
Moving Rivers to Sea
Evaporation condition and Raining Process
Checking the Evaporation condition for Rivers and Sea
Checking the Evaporation condition for Streams and Sea
Iteration: 2   Fmin= 139.5481

=============Start of Iteration 3 ==============
Moving Stream to Sea
Moving Streams to Rivers
Moving Rivers to Sea
Evaporation condition and Raining Process
Checking the Evaporation condition for Rivers and Sea
Checking the Evaporation condition for Streams and Sea
Iteration: 3   Fmin= 135.0553
```

```
==============Start of Iteration 4 ==============
Moving Stream to Sea
Moving Streams to Rivers
Moving Rivers to Sea
Evaporation condition and Raining Process
Checking the Evaporation condition for Rivers and Sea
Checking the Evaporation condition for Streams and Sea
Iteration: 4   Fmin= 134.9957

==============Start of Iteration 5 ==============
Moving Stream to Sea
Moving Streams to Rivers
Moving Rivers to Sea
Evaporation condition and Raining Process
Checking the Evaporation condition for Rivers and Sea
Checking the Evaporation condition for Streams and Sea
Iteration: 5   Fmin= 134.4105

==============Start of Iteration 6 ==============
Moving Stream to Sea
Moving Streams to Rivers
Moving Rivers to Sea
Evaporation condition and Raining Process
Checking the Evaporation condition for Rivers and Sea
Checking the Evaporation condition for Streams and Sea
Iteration: 6   Fmin= 134.1306


==============Start of Iteration 7 ==============
Moving Stream to Sea
Moving Streams to Rivers
Moving Rivers to Sea
Evaporation condition and Raining Process
Checking the Evaporation condition for Rivers and Sea
Checking the Evaporation condition for Streams and Sea
Iteration: 7   Fmin= 134.1306

==============Start of Iteration 8 ==============
Moving Stream to Sea
Moving Streams to Rivers
Moving Rivers to Sea
Evaporation condition and Raining Process
Checking the Evaporation condition for Rivers and Sea
Checking the Evaporation condition for Streams and Sea
Iteration: 8   Fmin= 133.515

==============Start of Iteration 9 ==============
Moving Stream to Sea
Moving Streams to Rivers
Moving Rivers to Sea
Evaporation condition and Raining Process
Checking the Evaporation condition for Rivers and Sea
Checking the Evaporation condition for Streams and Sea
Iteration: 9   Fmin= 133.4207
```

```
==============Start of Iteration 82 ==============
Moving Stream to Sea
Moving Streams to Rivers
Moving Rivers to Sea
Evaporation condition and Raining Process
Checking the Evaporation condition for Rivers and Sea
Checking the Evaporation condition for Streams and Sea
Iteration: 82    Fmin= 132.2143

==============Start of Iteration 83 ==============
Moving Stream to Sea
Moving Streams to Rivers
Moving Rivers to Sea
Evaporation condition and Raining Process
Checking the Evaporation condition for Rivers and Sea
Checking the Evaporation condition for Streams and Sea
Iteration: 83    Fmin= 132.2143

==============Start of Iteration 84 ==============
Moving Stream to Sea
Moving Streams to Rivers
Moving Rivers to Sea
Evaporation condition and Raining Process
Checking the Evaporation condition for Rivers and Sea
Checking the Evaporation condition for Streams and Sea
Iteration: 84    Fmin= 132.2143
```

```
=============Start of Iteration 125 =============
Moving Stream to Sea
Moving Streams to Rivers
Moving Rivers to Sea
Evaporation condition and Raining Process
Checking the Evaporation condition for Rivers and Sea
Checking the Evaporation condition for Streams and Sea
Iteration: 125    Fmin= 132.2143

=============Start of Iteration 126 =============
Moving Stream to Sea
Moving Streams to Rivers
Moving Rivers to Sea
Evaporation condition and Raining Process
Checking the Evaporation condition for Rivers and Sea
Checking the Evaporation condition for Streams and Sea
Iteration: 126    Fmin= 132.2143

=============Start of Iteration 127 =============
Moving Stream to Sea
Moving Streams to Rivers
Moving Rivers to Sea
Evaporation condition and Raining Process
Checking the Evaporation condition for Rivers and Sea
Checking the Evaporation condition for Streams and Sea
Iteration: 127    Fmin= 132.2143

=============Start of Iteration 300 =============
Moving Stream to Sea
Moving Streams to Rivers
Moving Rivers to Sea
Evaporation condition and Raining Process
Checking the Evaporation condition for Rivers and Sea
Checking the Evaporation condition for Streams and Sea
Iteration: 300    Fmin= 132.2143
Elapsed time is 746.118270 seconds.


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

Location of Capacitors is at Buses:     30      13      24

Size of Capacitors is:  1000      388.30696      552.18382 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	0.961
18	0.954
19	0.956
20	0.95
21	0.953
22	0.949
23	0.951
24	0.948
25	0.947
26	0.945
27	0.946

```
        27              0.948
        28              0.943
        29              0.946
        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 = 132.214 kW.
Reactive Power Loss = 88.339 kVar.
Power Factor = 0.99

OBJECTIVE FUNCTION for the best solution = 132.214.

The best solution was found in Iteration No. 126.

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

Following plot shows the bus-voltage comparision before and after....
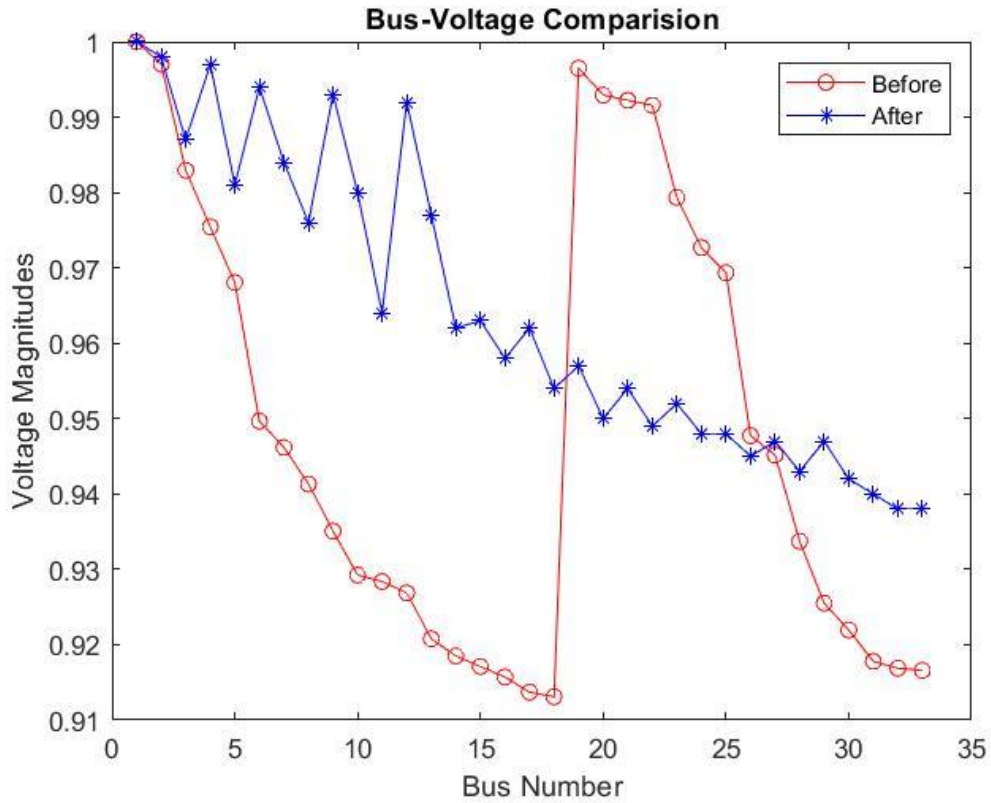
Appendix 5: The MATLAB CODES

Main.m_Code
```matlab
clc
clear
close all

%% Declarations
global D
global nDG
global nC
global ourcase
global choice
global bestIter
global P0
global Q0
global minBusVoltage
global minSourcePF


%% Ask whether to do capacitor placement only or DG placement only or both simultaneously

fprintf('\n');
disp('******************* WELCOME ***************************');
```

```matlab
disp('***************** Start of Program **************************');
disp('------------------------------------------------------------------');
disp('------------------------------------------------------------------');
disp('------------------------------------------------------------------');
disp('                                      - Author: Bijay Kumar Sah');
disp(' ');
disp(' ');
disp('~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~');
disp('*****************************************************************************');
disp('Consider the following options:');
disp('-------------------------------');
disp(' ');
disp('[1] ENTER 1 for PLACEMENT AND SIZING OF CAPACITOR BANKS.');
disp('~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~');
disp('[2] ENTER 2 for PLACEMENT and SIZING OF DGs.');
disp('~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~');
disp('[3] ENTER 3 for OPTIMAL PLACEMENT AND SIZING COMBINATION OF CBs/DGs');
disp('~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~');
disp('[4] ENTER 4 for MULTIOBJECTIVE OPTIMAL PLACEMENT AND SIZING OF CBs/DGs.');
disp('           (DGs are operated with controllable PF,)');
disp('         three Technical Objectives are considered.)');
disp('~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~');
disp('[5] ENTER 5 for MULTIOBJECTIVE OPTIMAL PLACEMENT AND SIZING OF CBs/DGs.');
disp('           (DGs are operated with controllable PF,');
disp('       Technical and Economic Objectives are optimized.)');
disp('~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~');
disp(' ');

choice = input('Enter the value:  ');

disp('-------------------------------------------------------------------');
if isempty(choice)
   disp('You did not enter anything. So, value 1 was used.');
   choice = 1;
end

%% Problem settings
objective_function = @fobj;              % Fitness function

%% Algorithm parameters
```

```matlab
popNum = 30;                        % Population Size

disp('--------------------------------------------------------------------');
iter = input('How many Iterations? (Minimum of 200 recommended):   ');      % No.
of iterations
if isempty(iter)
    fprintf('\nYou did not enter anything. So, iterations = 200 was used.\n');
    iter = 200;
end


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


SystemChoice = input('Enter your choice:   ');

if isempty(SystemChoice)
    disp('You did not enter anything. So, value 1 was used.');
    SystemChoice = 1;
end

if SystemChoice==1
    ourcase = loadcase('caseieee33');

elseif SystemChoice==2
    ourcase = loadcase('caseieee69');

else

disp('~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
~~~~~~~~~~');
    disp('Type the filename with extension in the format "filename.extension" ');
    disp('Place the Bus Data in Sheet1 and Branch Data in Sheet2');
    disp('Bus Data Format:')
    disp('-------------------------------');
    disp('BusNo.| Pload(MW) | Qload (MW)');
    fprintf("\n");
    disp('Branch Data Format:');
```

```matlab
disp('------------------------------------------');
disp('FromBusNo. | ToBusNo. | R in Ohms | X in Ohms');
fprintf("\n");
filename = input('Enter the filename:  ','s');
disp('~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~');
while ischar(filename)==0
    disp('You did not enter the filename in proper format.');
    disp('Type the filename with extension in the format "filename.extension" ');
    disp('Place the Bus Data in Sheet1 and Branch Data in Sheet2');
    disp('Bus Data Format:')
    disp('--------------------------------');
    disp('BusNo.| Pload(MW) | Qload (MW)');
    fprintf("\n");
    disp('Branch Data Format:');
    disp('--------------------------------------------');
    disp('FromBusNo. | ToBusNo. | R in Ohms | X in Ohms');
    fprintf("\n");
    filename = input('Enter the filename:  ');
end

disp('~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~');
basekV = input('What is the Base Voltage (System Voltage) in kV?   ');
if isempty(basekV)
    disp('You did not enter anything. So, Default Base Voltage 11 kV was used.');
    basekV = 11;
end
disp('~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~');

onecase = loadcase('case13659pegase');
onecase.bus = []; onecase.branch = [];

twocase = loadcase('case69');
onecase.bus([1 2],:) = twocase.bus([1 2],:);
onecase.branch([1 2],:) = twocase.branch([1 2],:);

onecase.baseMVA = twocase.baseMVA;
onecase.gen = twocase.gen;
onecase.gencost =[];

fprintf("Base MVA for this analysis is %d MVA.\n",onecase.baseMVA);
disp('-----------------------------------------------------------');

busdata = readtable(filename,'sheet','Sheet1');
branchdata = readtable(filename,'sheet','Sheet2');
fprintf("\n");

baseZ = basekV*basekV/onecase.baseMVA;
branchdata.(3) = branchdata.(3)/baseZ; % converting in pu
branchdata.(4) = branchdata.(4)/baseZ;
```

```matlab
    fprintf("Base Impedance for this analysis is %0.3f Ohms.\n",baseZ);
    disp('------------------------------------------------------------');

    bus_lengthh = max(size(busdata));
    onecase.bus(2:bus_lengthh,:) = repmat(onecase.bus(2,:),[bus_lengthh-1,1]);
    onecase.bus(1:bus_lengthh,1) = busdata.(1);
    onecase.bus(1:bus_lengthh,3) = busdata.(2);
    onecase.bus(1:bus_lengthh,4) = busdata.(3);
    onecase.bus(1:bus_lengthh,13) = 0.1*ones(bus_lengthh,1);
    onecase.bus(1:bus_lengthh,10) = basekV*ones(bus_lengthh,1);

    branch_lengthh = max(size(branchdata));
    onecase.branch(1:branch_lengthh,:) =
repmat(onecase.branch(1,:),[branch_lengthh,1]);
    onecase.branch(1:branch_lengthh,1) = branchdata.(1);
    onecase.branch(1:branch_lengthh,2) = branchdata.(2);
    onecase.branch(1:branch_lengthh,3) = branchdata.(3);
    onecase.branch(1:branch_lengthh,4) = branchdata.(4);

    ourcase = onecase;
end

mpopt=mpoption('pf.alg','ISUM','verbose',0,'out.all',0,'out.lim.v',0);
res0 = radial_pf(ourcase,mpopt);
P0 = sum(abs(res0.branch(:,14)+res0.branch(:,16)))*1000;
Q0 = sum(abs(res0.branch(:,15)+res0.branch(:,17)))*1000;
V0 = res0.bus(:,8);
p1 = res0.branch(1,14);
q1 = res0.branch(1,15);
s1 = (p1^2 + q1^2)^0.5;
pf0 = p1/s1;

xaxis = 1:size(res0.bus,1);
%plot(xaxis,V0,'ro-');
%xlabel('Bus Number');ylabel('Voltage Magnitudes');
%legend('Base Case Voltage Profile');



switch choice

    case 1          % Capacitor placement and sizing only

        disp('-----------------------------------------------------------');
        nC = input('How many Capacitor Banks? (Default is 3.): ');

        if isempty(nC)
            disp('No input was given. Default value 3 was taken.');
            nC = 3;
        end
```

```matlab
    maxCapSize = input('Maximum capacity of Capacitor Bank in kVAR ? (Default
is 1000.): ');

    if isempty(maxCapSize)
        disp('No input was given. Default value 1000 kVAR was taken.');
        maxCapSize = 1000;
    end

    minBusVoltage = input('Minimum Bus Voltage at any Bus (in per unit) ?
(Default is 0.90 pu.): ');

    if isempty(minBusVoltage)
        disp('No input was given. Default value 0.90 per unit was taken.');
        minBusVoltage = 0.90;
    end

    minSourcePF = input('Minimum Source Power Factor ? (Default is 0.20 pu.): ');

    if isempty(minSourcePF)
        disp('No input was given. Default value 0.20 was taken.');
        minSourcePF = 0.20;
    end

    l1 = size(ourcase.bus,1);

    upper = l1;

    D = 2*nC;

    LB = 2*ones(1,D); LB(nC+1:D) = 0;
    UB = ones(1,D); UB = upper* UB; UB(nC+1:D) = maxCapSize;


    nvars = length(UB); Nsr = 4; dmax = 1e-16; max_it = iter;



[bestsol,bestobj,NFEs,Elapsed_Time]=WCA(objective_function,LB,UB,nvars,popNu
m,Nsr,dmax,max_it);

    case 2        % DG placement and sizing only

    disp('-------------------------------------------------------------');
    nDG = input('How many Distributed Generators? (Default is 3.): ');

    if isempty(nDG)
        disp('No input was given. Default value 3 was taken.');
        nDG = 3;
    end
```

```matlab
    minBusVoltage = input('Minimum Bus Voltage at any Bus (in per unit) ?
(Default is 0.90 pu.): ');

    if isempty(minBusVoltage)
       disp('No input was given. Default value 0.90 per unit was taken.');
       minBusVoltage = 0.90;
    end

    minSourcePF = input('Minimum Source Power Factor ? (Default is 0.20 pu.): ');

    if isempty(minSourcePF)
       disp('No input was given. Default value 0.20 was taken.');
       minSourcePF = 0.20;
    end

    D = 2*nDG;

    Pload = sum(ourcase.bus(:,3));
    lower = 0.1*Pload;
    upper = 0.6*Pload;
    l1 = size(ourcase.bus,1);
    LB = ones(1,D); LB(1:nDG) = 2; LB(nDG+1:D) = lower;
    UB = l1 * ones(1,D); UB(nDG+1:D) = upper;


    nvars = length(UB); Nsr = 4; dmax = 1e-16; max_it = iter;


[bestsol,bestobj,NFEs,Elapsed_Time]=WCA(objective_function,LB,UB,nvars,popNu
m,Nsr,dmax,max_it);

  case 3          % Optimal placement and Sizing of Capacitor and DG (pf 1)

    disp('-------------------------------------------------------------');
    nDG = input('How many Distributed Generators? (Default is 3.): ');

    if isempty(nDG)
       disp('No input was given. Default value 3 was taken.');
       nDG = 3;
    end

    nC = input('How many Capacitors? (Default is 3.): ');

    if isempty(nC)
       disp('No input was given. Default value 3 was taken.');
       nC = 3;
    end

    maxCapSize = input('Maximum capacity of Capacitor Bank in kVAR ? (Default
is 1000.): ')
```

```matlab
    if isempty(maxCapSize)
        disp('No input was given. Default value 1000 kVAR was taken.');
        maxCapSize = 1000;
    end

    minBusVoltage = input('Minimum Bus Voltage at any Bus (in per unit) ?
(Default is 0.90 pu.): ');

    if isempty(minBusVoltage)
        disp('No input was given. Default value 0.90 per unit was taken.');
        minBusVoltage = 0.90;
    end

    minSourcePF = input('Minimum Source Power Factor ? (Default is 0.20 pu.): ');

    if isempty(minSourcePF)
        disp('No input was given. Default value 0.20 was taken.');
        minSourcePF = 0.20;
    end

    D = nDG*2 + nC*2;

    data = ourcase;
    Pload = sum(data.bus(:,3));
    lower = 0.1*Pload;
    upper = 0.4*Pload;
    l1 = size(ourcase.bus,1);
    LB = 2*ones(1,D); LB(nC+1:2*nC) = 0; LB(D-nDG+1:D) = lower;
    UB = 11 * ones(1,D); UB(nC+1:2*nC) = maxCapSize; UB(D-nDG+1:D) =
upper;


    nvars = length(UB); Nsr = 4; dmax = 1e-16; max_it = iter;



[bestsol,bestobj,NFEs,Elapsed_Time]=WCA(objective_function,LB,UB,nvars,popNu
m,Nsr,dmax,max_it);


  case 4          % Optimal placement and Sizing of Capacitor and DG with three
                  % three technical objectives considered. Adujstable
                  % power factor of DGs.

    disp('------------------------------------------------------------');
    nDG = input('How many Distributed Generators? (Default is 3.): ');

    if isempty(nDG)
        disp('No input was given. Default value 3 was taken.');
        nDG = 3;
    end
```

```matlab
    nC = input('How many Capacitors? (Default is 3.): ');

    if isempty(nC)
       disp('No input was given. Default value 3 was taken.');
       nC = 3;
    end

    maxCapSize = input('Maximum capacity of Capacitor Bank in kVAR ? (Default
is 1000.): ');

    if isempty(maxCapSize)
       disp('No input was given. Default value 1000 kVAR was taken.');
       maxCapSize = 1000;
    end

    minBusVoltage = input('Minimum Bus Voltage at any Bus (in per unit) ?
(Default is 0.90 pu.): ');

    if isempty(minBusVoltage)
       disp('No input was given. Default value 0.90 per unit was taken.');
       minBusVoltage = 0.90;
    end

    minSourcePF = input('Minimum Source Power Factor ? (Default is 0.20 pu.): ');

    if isempty(minSourcePF)
       disp('No input was given. Default value 0.20 was taken.');
       minSourcePF = 0.20;
    end

    D = nC*2 + nDG*2 + nDG;

    data = ourcase;
    Pload = sum(data.bus(:,3));
    lower = 0.1*Pload;
    upper = 0.6*Pload;
    l1 = size(ourcase.bus,1);
    LB = 2*ones(1,D); LB(nC+1:2*nC) = 0; LB(2*nC+nDG+1:2*nC+2*nDG) =
lower; LB(D-nDG+1:D) = 0.8;
    UB = ones(1,D); UB(1:nC) = l1; UB(nC+1:2*nC) = maxCapSize;
UB(2*nC+1:2*nC+nDG) = l1; UB(2*nC+nDG+1:2*nC+2*nDG) = upper; UB(D-
nDG+1:D) = 1;


    nvars = length(UB); Nsr = 4; dmax = 1e-16; max_it = iter;


[bestsol,bestobj,NFEs,Elapsed_Time]=WCA(objective_function,LB,UB,nvars,popNu
m,Nsr,dmax,max_it);
```

```matlab
    otherwise        % Optimal placement and Sizing of Capacitor and DG with three
                     % Technical and Economic objectives optimized. Adujstable
                     % power factor of DGs.

    disp('---------------------------------------------------------');
    nDG = input('How many Distributed Generators? (Default is 3.): ');

    if isempty(nDG)
        disp('No input was given. Default value 3 was taken.');
        nDG = 3;
    end

    nC = input('How many Capacitors? (Default is 3.): ');

    if isempty(nC)
        disp('No input was given. Default value 3 was taken.');
        nC = 3;
    end

    maxCapSize = input('Maximum capacity of Capacitor Bank in kVAR ? (Default
is 1000.): ');

    if isempty(maxCapSize)
        disp('No input was given. Default value 1000 kVAR was taken.');
        maxCapSize = 1000;
    end

    minBusVoltage = input('Minimum Bus Voltage at any Bus (in per unit) ?
(Default is 0.90 pu.): ');

    if isempty(minBusVoltage)
        disp('No input was given. Default value 0.90 per unit was taken.');
        minBusVoltage = 0.90;
    end

    minSourcePF = input('Minimum Source Power Factor ? (Default is 0.20 pu.): ');

    if isempty(minSourcePF)
        disp('No input was given. Default value 0.20 was taken.');
        minSourcePF = 0.20;
    end

    D = nC*2 + nDG*2 + nDG;

    data = ourcase;
    Pload = sum(data.bus(:,3));
    lower = 0.1*Pload;
    upper = 0.6*Pload;
    l1 = size(ourcase.bus,1);
```

```matlab
    LB = 2*ones(1,D); LB(nC+1:2*nC) = 0; LB(2*nC+nDG+1:2*nC+2*nDG) =
lower; LB(D-nDG+1:D) = 0.8;
    UB = ones(1,D); UB(1:nC) = l1; UB(nC+1:2*nC) = maxCapSize;
UB(2*nC+1:2*nC+nDG) = l1; UB(2*nC+nDG+1:2*nC+2*nDG) = upper; UB(D-
nDG+1:D) = 1;


    nvars = length(UB); Nsr = 4; dmax = 1e-16; max_it = iter;


[bestsol,bestobj,NFEs,Elapsed_Time]=WCA(objective_function,LB,UB,nvars,popNu
m,Nsr,dmax,max_it);

end


fprintf('\n\n');
res = powerflow(bestsol);


disp('************************************************************
****');
disp('************************************************************
****');
disp('----------------------------------------------------------------');
disp('-------------    CALCULATIONS COMPLETED    -------------------');
disp('----------------------------------------------------------------');
disp('----------------------------------------------------------------');
disp('************************************************************
****');
disp('************************************************************
****');


if choice==1

    disp('YOU CHOSE PLACEMENT AND SIZING OF CAPACITOR BANKS.');

disp('~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
~~~~~~~~~');
    loc_of_cap = bestsol(1:nC);
    fprintf('\nLocation of Capacitors is at Buses:\t');
    fprintf('%d\t',loc_of_cap);
    fprintf('\n\nSize of Capacitors is:\t%s kVar each.\n',num2str(bestsol(nC+1:2*nC)));

    disp('Bus Voltages are:');
    Vbus = res.bus(:,8); Vbus = round(Vbus,3);
    [Vbusmin,busnum] = min(Vbus);
    Vdisp(:,2) = Vbus; Vdisp(:,1) = 1:length(Vbus);
    disp('                    Bus No.    ||   Voltage (pu)');
```

```matlab
    disp('            --------------------------------');
    disp(Vdisp);

    fprintf('Minimum bus voltage is %0.3f pu at %d bus.\n',Vbusmin,busnum);

    disp('Power Losses are:');
    disp('------------------');
    P_Loss_least = sum(abs(res.branch(:,14)+res.branch(:,16)))*1000;
    fprintf('Active Power Loss = %0.3f kW.\n',P_Loss_least);
    Q_Loss_least = sum(abs(res.branch(:,15)+res.branch(:,17)))*1000;
    fprintf('Reactive Power Loss = %0.3f kVar.\n',Q_Loss_least);

    p = res.branch(1,14);
    q = res.branch(1,15);
    s = (p^2 + q^2)^0.5;
    pf = abs(p/s);
    fprintf('Power Factor = %0.2f\n',pf);

elseif choice==2

    disp('YOU CHOSE PLACEMENT and SIZING OF DGs.');

disp('~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
~~~~~~~~');
    fprintf('\n\nThe size of DGs is:\t%s  MW
each.\n',num2str(bestsol(nDG+1:2*nDG)));
    fprintf('\n\nThe locations of DGs is at Buses:\t');
    fprintf('%d\t',bestsol(1:nDG));

    fprintf('\nBus Voltages are:\n');
    Vbus = res.bus(:,8);  Vbus = round(Vbus,3);
    [Vbusmin,busnum] = min(Vbus);
    Vdisp(:,2) = Vbus; Vdisp(:,1) = 1:length(Vbus);
    disp('            Bus No.   ||   Voltage (pu)');
    disp('            --------------------------------');
    disp(Vdisp);

    fprintf('Minimum bus voltage is %0.3f pu at %d bus.\n',Vbusmin,busnum);

    disp('Power Losses are:');
    disp('------------------');
    P_Loss_least = sum(abs(res.branch(:,14)+res.branch(:,16)))*1000;
    fprintf('Active Power Loss = %0.3f kW.\n',P_Loss_least);
    Q_Loss_least = sum(abs(res.branch(:,15)+res.branch(:,17)))*1000;
    fprintf('Reactive Power Loss = %0.3f kVar.\n',Q_Loss_least);

    p = res.branch(1,14);
    q = res.branch(1,15);
    s = (p^2 + q^2)^0.5;
    pf = abs(p/s);
```

```matlab
        fprintf('Power Factor = %0.2f\n',pf);
elseif choice==3

    disp('YOU CHOSE OPTIMAL PLACEMENT AND SIZING COMBINATION
OF CBs/DGs');

disp('~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
~~~~~~~~');
    loc_of_cap = bestsol(1:nC);
    fprintf('\nLocation of capacitors is at Buses:\t');
    fprintf('%d\t',loc_of_cap);
    fprintf('\nSize of capacitors is:\t%s  kVar each.\n',num2str(bestsol(nC+1:2*nC)));
    fprintf('\nThe size of DGs is:\t%s  MW
each\n',num2str(bestsol(2*nC+nDG+1:D)));
    fprintf('The locations of DGs is at Buses:\t');
    fprintf('%d\t',bestsol(2*nC+1:2*nC+nDG));

    fprintf('\n\nBus Voltages are:\n');
    Vbus = res.bus(:,8);  Vbus = round(Vbus,3);
    [Vbusmin,busnum] = min(Vbus);
    Vdisp(:,2) = Vbus; Vdisp(:,1) = 1:length(Vbus);
    disp('                Bus No.   ||   Voltage (pu)');
    disp('               ----------------------------------');
    disp(Vdisp);

    fprintf('Minimum bus voltage is %0.3f pu at %d bus.\n',Vbusmin,busnum);

    disp('Power Losses are:');
    disp('------------------');
    P_Loss_least = sum(abs(res.branch(:,14)+res.branch(:,16)))*1000;
    fprintf('Active Power Loss = %0.3f kW.\n',P_Loss_least);
    Q_Loss_least = sum(abs(res.branch(:,15)+res.branch(:,17)))*1000;
    fprintf('Reactive Power Loss = %0.3f kVar.\n',Q_Loss_least);

    p = res.branch(1,14);
    q = res.branch(1,15);
    s = (p^2 + q^2)^0.5;
    pf = abs(p/s);
    fprintf('Power Factor = %0.2f\n',pf);

elseif choice==4

    disp('  YOU CHOSE MULTIOBJECTIVE OPTIMAL PLACEMENT AND
SIZING OF CBs/DGs.');
    disp('         (DGs are operated with controllable PF,)');
    disp('         three Technical Objectives are considered.)');

disp('~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
~~~~~~~~');
    loc_of_cap = bestsol(1:nC);
```

```matlab
    fprintf('\nLocation of capacitors is at Buses:\t');
    fprintf('%d\t',loc_of_cap);
    fprintf('\nSize of capacitors is:\t%s  kVar each.\n',num2str(bestsol(nC+1:2*nC)));
    fprintf('\nThe size of DGs is:\t%s  MW
each\n',num2str(bestsol(2*nC+nDG+1:2*nC+2*nDG)));
    fprintf('The optimal pf for the DGs is:\t%s
each\n',num2str(bestsol(2*nC+2*nDG+1:D)));
    fprintf('The locations of DGs is at Buses:\t');
    fprintf('%d\t',bestsol(2*nC+1:2*nC+nDG));

    fprintf('\n\nBus Voltages are:\n');
    Vbus = res.bus(:,8);  Vbus = round(Vbus,3);
    [Vbusmin,busnum] = min(Vbus);
    Vdisp(:,2) = Vbus; Vdisp(:,1) = 1:length(Vbus);
    disp('                 Bus No.    ||    Voltage (pu)');
    disp('                 ----------------------------------');
    disp(Vdisp);

    fprintf('Minimum bus voltage is %0.3f pu at %d bus.\n',Vbusmin,busnum);

    disp('Power Losses are:');
    disp('------------------');
    P_Loss_least = sum(abs(res.branch(:,14)+res.branch(:,16)))*1000;
    fprintf('Active Power Loss = %0.3f kW.\n',P_Loss_least);
    Q_Loss_least = sum(abs(res.branch(:,15)+res.branch(:,17)))*1000;
    fprintf('Reactive Power Loss = %0.3f kVar.\n',Q_Loss_least);

    p = res.branch(1,14);
    q = res.branch(1,15);
    s = (p^2 + q^2)^0.5;
    pf = abs(p/s);
    fprintf('Power Factor = %0.2f\n',pf);


else

    disp('  YOU CHOSE MULTIOBJECTIVE OPTIMAL PLACEMENT AND
SIZING OF CBs/DGs.');
    disp('         (DGs are operated with controllable PF,');
    disp('      Technical and Economic Objectives are optimized.)');
    loc_of_cap = bestsol(1:nC);
    fprintf('\nLocation of capacitors is at Buses:\t');
    fprintf('%d\t',loc_of_cap);
    fprintf('\nSize of capacitors is:\t%s  kVar each.\n',num2str(bestsol(nC+1:2*nC)));
    fprintf('\nThe size of DGs is:\t%s  MW
each\n',num2str(bestsol(2*nC+nDG+1:2*nC+2*nDG)));
    fprintf('\nThe optimal pf for the DGs is:\t%s
each\n',num2str(bestsol(2*nC+2*nDG+1:D)));
    fprintf('\nThe locations of DGs is at Buses:\t');
    fprintf('%d\t',bestsol(2*nC+1:2*nC+nDG))
```

```matlab
    fprintf('\nBus Voltages are:\n');
    Vbus = res.bus(:,8);   Vbus = round(Vbus,3);
    [Vbusmin,busnum] = min(Vbus);
    Vdisp(:,2) = Vbus; Vdisp(:,1) = 1:length(Vbus);
    disp('                Bus No.   ||   Voltage (pu)');
    disp('                ---------------------------------');
    disp(Vdisp);

    fprintf('Minimum bus voltage is %0.3f pu at %d bus.\n',Vbusmin,busnum);

    disp('Power Losses are:');
    disp('-----------------');
    P_Loss_least = sum(abs(res.branch(:,14)+res.branch(:,16)))*1000;
    fprintf('Active Power Loss = %0.3f kW.\n',P_Loss_least);
    Q_Loss_least = sum(abs(res.branch(:,15)+res.branch(:,17)))*1000;
    fprintf('Reactive Power Loss = %0.3f kVar.\n',Q_Loss_least);

    p = res.branch(1,14);
    q = res.branch(1,15);
    s = (p^2 + q^2)^0.5;
    pf = abs(p/s);
    fprintf('Power Factor = %0.2f\n',pf);


end


fprintf('\nOBJECTIVE FUNCTION for the best solution = %0.3f.\n\n',bestobj);


fprintf('\nThe best solution was found in Iteration No. %d.\n\n',bestIter);


[V0min,bnum] = min(V0);
disp('For Base case:');
disp('--------------');
fprintf('Minimum bus voltage was %0.3f pu at %d bus.\n',V0min,bnum);
fprintf('Active power loss was %0.3f kW.\n',P0);
fprintf('Reactive power loss was %0.3f kVar.\n',Q0);
fprintf('Power Factor was %0.3f\n',pf0);
disp('---------------------------------------------------------------------');
fprintf('\n\nFollowing plot shows the bus-voltage comparision before and after....\n');
xaxis = 1:size(res.bus,1);
plot(xaxis,V0,'ro-',xaxis,Vbus,'b*-');
xlabel('Bus Number');ylabel('Voltage Magnitudes');title('Bus-Voltage Comparision');
legend('Before','After');
```

Fobj.m_Code

```matlab
function [fvalue]=fobj(solution)


    global nC
    global nDG
    global P0
    global Q0
    global choice
    global minBusVoltage
    global minSourcePF


    if choice==1
        result = powerflow(solution);result = order_radial(result);
        Vb = result.bus(:,8);
        Ploss = sum(abs(result.branch(:,14)+result.branch(:,16)))*1000;
        Qloss = sum(abs(result.branch(:,15)+result.branch(:,17)))*1000;
        p = result.branch(1,14);
        q = result.branch(1,15);
        s = (p^2 + q^2)^0.5;
        power_factor = abs(p/s);


        I=max(Vb>1.05);
        J=max(Vb<minBusVoltage);
        K=max(power_factor>1);
        L=max(power_factor<minSourcePF);

        M = 0;
        if Ploss>P0 || Qloss>Q0
            M = 1;
        end

        U=0;
        if length(unique(solution(1:nC)))~=length(solution(1:nC))
            U=1;
        end

        if I==1||J==1||K==1||L==1||U==1          %||M==1
            fvalue = 1000000000000000;
        else
            fvalue = Ploss;%*8760*0.06 + 3*sum(solution(nC+1:2*nC)) +
nC*(1000+300);
        end


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```matlab
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%
   elseif choice==2

      result = powerflow(solution);result = order_radial(result);
      Vb = result.bus(:,8);
      I=max(Vb>1.05);
      J=max(Vb<minBusVoltage);

      Ploss = sum(abs(result.branch(:,14)+result.branch(:,16)))*1000;
      Qloss = sum(abs(result.branch(:,15)+result.branch(:,17)))*1000;


      p = result.branch(1,14);
      q = result.branch(1,15);
      s = (p^2 + q^2)^0.5;
      power_factor = abs(p/s);

      K=max(power_factor>1);
      L=max(power_factor<minSourcePF);


      V=0;
      if length(unique(solution(1:nDG)))~=length(solution(1:nDG))
         V=1;
      end

      M = 0;
      if Ploss>P0 || Qloss>Q0
         M = 1;
      end

      if I==1||J==1||L==1||K==1||V==1   %||M==1
         fvalue = 1000000000000000;
      else
         fvalue = Ploss;%*8760*0.06 + sum(solution(1:nDG))*1000*8760*0.06;
      end


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
   elseif choice==3

      result = powerflow(solution);result = order_radial(result);
      Vb = result.bus(:,8);
      Ploss = sum(abs(result.branch(:,14)+result.branch(:,16)))*1000;
      Qloss = sum(abs(result.branch(:,15)+result.branch(:,17)))*1000;

      p = result.branch(1,14);
      q = result.branch(1,15);
```

```matlab
        s = (p^2 + q^2)^0.5;
        power_factor = abs(p/s);

        I=max(Vb>1.05);
        J=max(Vb<minBusVoltage);

        K=max(power_factor>1);
        L=max(power_factor<minSourcePF);

        M = 0;
        if Ploss>P0 || Qloss>Q0
            M = 1;
        end

        U=0;
        if length(unique(solution(1:nC)))~=length(solution(1:nC))
            U=1;
        end

        V=0;
        if
length(unique(solution(2*nC+1:2*nC+nDG)))~=length(solution(2*nC+1:2*nC+nDG
))
            V=1;
        end

        if I==1||J==1||U==1||K==1||L==1||V==1  %||M==1
            fvalue = 1000000000000000;
        else
            fvalue = Ploss;%*8760*0.06 + sum(solution(1:nDG))*1000*8760*0.06 +
3*sum(solution(nC+1:2*nC)) + nC*(1000+300);
        end


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%
  elseif choice==4

        result = powerflow(solution);
        result = order_radial(result);

        vsi = VSI(result);
        F3 = min(1./vsi);

        Vb = result.bus(:,8);

        F2 = sum(((Vb-1)/(1.05-0.95)).^2);

        Ploss = sum(abs(result.branch(:,14)+result.branch(:,16)))*1000;
```

```matlab
        Qloss = sum(abs(result.branch(:,15)+result.branch(:,17)))*1000;

        F1 = Ploss;

        p = result.branch(1,14);
        q = result.branch(1,15);
        s = (p^2 + q^2)^0.5;
        power_factor = abs(p/s);

        I=max(Vb>1.05);
        J=max(Vb<minBusVoltage);

        K=max(power_factor>1);
        L=max(power_factor<minSourcePF);

        M = 0;
        if Ploss>P0 || Qloss>Q0
           M = 1;
        end

        U=0;
        if length(unique(solution(1:nC)))~=length(solution(1:nC))
           U=1;
        end

        V=0;
        if
length(unique(solution(2*nC+1:2*nC+nDG)))~=length(solution(2*nC+1:2*nC+nDG))
           V=1;
        end

        if I==1||J==1||U==1||K==1||L==1||V==1   %||M==1
           fvalue = 1000000000000000;
        else
           fvalue = 0.5*F1 + 0.25*F2 + 0.25*F3;%*8760*0.06 +
sum(solution(1:nDG))*1000*8760*0.06 + 3*sum(solution(nC+1:2*nC)) +
nC*(1000+300);
        end


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
   else

      result = powerflow(solution);
      result = order_radial(result);

      p = result.branch(1,14);
      q = result.branch(1,15);
```

```
s = (p^2 + q^2)^0.5;
power_factor = abs(p/s);

Pgrid = p;
Pr = 0.044;
Csub = Pgrid * Pr;

ei = nC*1000;
Cci = 30000;
Qci = sum(solution(nC+1:2*nC))/1000;
lifeTimeCap = 15;
Ccb = (ei + Cci*Qci)/(lifeTimeCap*8760);

fuelCost = 0; % $ per kWh
capitalCost = 3985; % $ per kW
OMcost = 0.01207; % $ per kWh
b = OMcost + fuelCost;
maxCapacity = sum(solution(2*nC+1:2*nC+nDG))*1000;
PG = 8760*maxCapacity;
a = capitalCost*maxCapacity;
Cdg = 1.3*a + b*PG;

F4 = Cdg + Csub + Ccb;

Vb = result.bus(:,8);

Ploss = sum(abs(result.branch(:,14)+result.branch(:,16)))*1000;
Qloss = sum(abs(result.branch(:,15)+result.branch(:,17)))*1000;

F1 = Ploss;


I=max(Vb>1.05);
J=max(Vb<minBusVoltage);

K=max(power_factor>1);
L=max(power_factor<minSourcePF);

M = 0;
if Ploss>P0 || Qloss>Q0
   M = 1;
end

U=0;
if length(unique(solution(1:nC)))~=length(solution(1:nC))
   U=1;
end

V=0;
```

```matlab
        if
length(unique(solution(2*nC+1:2*nC+nDG)))~=length(solution(2*nC+1:2*nC+nDG
))
            V=1;
        end

        if I==1||J==1||U==1||K==1||L==1||V==1    %||M==1
            fvalue = 1000000000000000;
        else
            fvalue = 0.75*F1 + 0.25*F4;%*8760*0.06 +
sum(solution(1:nDG))*1000*8760*0.06 + 3*sum(solution(nC+1:2*nC)) +
nC*(1000+300);
        end


    end
```

WCA.m_code

```matlab
function
[Xmin,Fmin,NFEs,Elapsed_Time]=WCA(objective_function,LB,UB,nvars,Npop,Nsr
,dmax,max_it)
%% Information

% Water Cycle Algorithm (ER-WCA)

% INPUTS:

% objective_function:        Objective function which you wish to minimize or
maximize
% LB:               Lower bound of a problem
% UB:               Upper bound of a problem
% nvars:            Number of design variables
% Npop              Population size
% Nsr               Number of rivers + sea
% dmax              Evporation condition constant
% max_it:           Maximum number of iterations

% OUTPUTS:

% Xmin:             Global optimum solution
% Fmin:             Cost of global optimum solution
% NFEs:             Number of function evaluations
% Elapsed_Time        Elasped time for solving an optimization problem

global choice
global nDG
global nC
global bestIter
```

```matlab
%% Default Values for ER_WCA
format long g
if (nargin <5 || isempty(Npop)), Npop=50; end
if (nargin <6 || isempty(Nsr)), Nsr=4; end
if (nargin <7 || isempty(dmax)), dmax=1e-16; end
if (nargin <8 || isempty(max_it)), max_it=1000; end
%% -------------------------------------------------------------------------
% Create initial population and form sea, rivers, and streams
disp(' ');
disp(' ');
disp('=========================================================
===========');
disp('Created initial population and formed sea, rivers, and streams');

tic
N_stream=Npop-Nsr;

ind.position=[];
ind.cost=[];

pop=repmat(ind,Npop,1);

for i=1:Npop
    pop(i).position=LB+(UB-LB).*rand(1,nvars);

    P = pop(i).position;
    %% Round off the bus numbers
    if choice==1
        P(1:nC) = round(P(1:nC)); %Bus Number to nearest integer
    elseif choice==2
        P(1:nDG) = round(P(1:nDG));
    else
        P(1:nC) = round(P(1:nC)); %Bus Number to nearest integer
        P(2*nC+1:2*nC+nDG) = round(P(2*nC+1:2*nC+nDG));
    end
    %% Rounding off completed

    pop(i).position = P;

    pop(i).cost=objective_function(pop(i).position);
end

[~, index]=sort([pop.cost]);
%------------- Forming Sea ---------------------------------------
disp('Sea Formed');
sea=pop(index(1));
%-------------Forming Rivers ---------------------------------------
disp('Rivers Formed');
```

```matlab
river=repmat(ind,Nsr-1,1);

for i=1:Nsr-1
    river(i)=pop(index(1+i));
end

%------------ Forming Streams---------------------------------------------
disp('Streams Formed');
stream=repmat(ind,N_stream,1);
for i=1:N_stream
    stream(i)=pop(index(Nsr+i));
end
%--------- Designate streams to rivers and sea -----------------------
disp('Designated streams to rivers and sea');
cs=[sea.cost;[river.cost]';stream(1).cost];
f=0;
if length(unique(cs))~=1
    CN=cs-max(cs);
else
    CN=cs;
    f=1;
end

NS=round(abs(CN/sum(CN))*N_stream);
if f~=1
    NS(end)=[];
end
NS=sort(NS,'descend');
% ----------------------- Modification on NS ----------------------
i=Nsr;
while sum(NS)>N_stream
    if NS(i)>1
        NS(i)=NS(i)-1;
    else
        i=i-1;
    end
end

i=1;
while sum(NS)<N_stream
    NS(i)=NS(i)+1;
end

if find(NS==0)
    index=find(NS==0);
    for i=1:size(index,1)
        while NS(index(i))==0
            NS(index(i))=NS(index(i))+round(NS(i)/6);
            NS(i)=NS(i)-round(NS(i)/6);
        end
```

```matlab
        end
    end

    NS=sort(NS,'descend');
    NB=NS(2:end);
    %%
    %----------- Main Loop for ER-WCA -------------------------------------------
    disp('****************** Water Cycle Algorithm
    (WCA)*******************');
    disp('************************************************************************
    ****');FF=zeros(max_it,1);
    ER=zeros(1,Nsr-1);
    %--------------------- Evaporation rate for different rivers -------------
    for k=1:Nsr-1
        ER(k)=(sum(NS(k+1))/(Nsr-1)).*rand;
    end

    for i=1:max_it

        fprintf('\n============Start of Iteration %d ============\n',i);
        comp1 = sea.cost;
        %---------- Moving stream to sea--------------------------------------
        disp('Moving Stream to Sea');
        for j=1:NS(1)
            stream(j).position=stream(j).position+2.*rand(1).*(sea.position-
    stream(j).position);

            stream(j).position=min(stream(j).position,UB);
            stream(j).position=max(stream(j).position,LB);

            P = stream(j).position;
            %% Round off the bus numbers
            if choice==1
                P(1:nC) = round(P(1:nC)); %Bus Number to nearest integer
            elseif choice==2
                P(1:nDG) = round(P(1:nDG));
            else
                P(1:nC) = round(P(1:nC)); %Bus Number to nearest integer
                P(2*nC+1:2*nC+nDG) = round(P(2*nC+1:2*nC+nDG));
            end
            %% Rounding off completed

            stream(j).position = P;

            stream(j).cost=objective_function(stream(j).position);

            if stream(j).cost<sea.cost
                new_sea=stream(j);
                stream(j)=sea;
                sea=new_sea;
```

```matlab
        end
    end
    %---------- Moving Streams to rivers--------------------------------
    disp('Moving Streams to Rivers');
    for k=1:Nsr-1
        for j=1:NB(k)

stream(j+sum(NS(1:k))).position=stream(j+sum(NS(1:k))).position+2.*rand(1,nvars).*(river(k).position-stream(j+sum(NS(1:k))).position);

            stream(j+sum(NS(1:k))).position=min(stream(j+sum(NS(1:k))).position,UB);
            stream(j+sum(NS(1:k))).position=max(stream(j+sum(NS(1:k))).position,LB);

            P =  stream(j+sum(NS(1:k))).position;
            %% Round off the bus numbers
            if choice==1
                P(1:nC) = round(P(1:nC)); %Bus Number to nearest integer
            elseif choice==2
                P(1:nDG) = round(P(1:nDG));
            else
                P(1:nC) = round(P(1:nC)); %Bus Number to nearest integer
                P(2*nC+1:2*nC+nDG) = round(P(2*nC+1:2*nC+nDG));
            end

            %% Rounding off completed
             stream(j+sum(NS(1:k))).position = P;


stream(j+sum(NS(1:k))).cost=objective_function(stream(j+sum(NS(1:k))).position);

            if stream(j+sum(NS(1:k))).cost<river(k).cost
                new_river=stream(j+sum(NS(1:k)));
                stream(j+sum(NS(1:k)))=river(k);
                river(k)=new_river;

                if river(k).cost<sea.cost
                    new_sea=river(k);
                    river(k)=sea;
                    sea=new_sea;
                end
            end
        end
    end
    %---------- Moving rivers to Sea -------------------------------------
    disp('Moving Rivers to Sea');
    for j=1:Nsr-1
        river(j).position=river(j).position+2.*rand(1,nvars).*(sea.position-river(j).position);

        river(j).position=min(river(j).position,UB);
```

```matlab
        river(j).position=max(river(j).position,LB);

        P =  river(j).position;
        %% Round off the bus numbers
        if choice==1
            P(1:nC) = round(P(1:nC)); %Bus Number to nearest integer
        elseif choice==2
            P(1:nDG) = round(P(1:nDG));
        else
            P(1:nC) = round(P(1:nC)); %Bus Number to nearest integer
            P(2*nC+1:2*nC+nDG) = round(P(2*nC+1:2*nC+nDG));
        end

        %% Rounding off completed
        river(j).position = P;

        river(j).cost=objective_function(river(j).position);

        if river(j).cost<sea.cost
            new_sea=river(j);
            river(j)=sea;
            sea=new_sea;
        end
    end
end
%============= Evaporation condition and raining process =============
disp('Evaporation condition and Raining Process');
% Check the evaporation condition for rivers and sea
disp('Checking the Evaporation condition for Rivers and Sea');

for k=1:Nsr-1
    if ((norm(river(k).position-sea.position)<dmax) || rand<0.1)
        for j=1:NB(k)
            stream(j+sum(NS(1:k))).position=LB+rand(1,nvars).*(UB-LB);
        end
    end
end

% Check the evaporation condition for streams and sea
disp('Checking the Evaporation condition for Streams and Sea');
for j=1:NS(1)
    if ((norm(stream(j).position-sea.position)<dmax))
        stream(j).position=sea.position+sqrt(0.1)*randn(1,nvars);
    end
end
% Check the evaporation condition among rivers
for k=1:Nsr-1
    if (exp(-i/max_it)<rand) && (NB(k)<ER(k))
        for j=1:NB(k)
            stream(j+sum(NS(1:k))).position=LB+rand(1,nvars).*(UB-LB);
        end
```

```
            end
        end
        %
        ==============================================================
        ========
        dmax=dmax-(dmax/max_it);

        disp(['Iteration: ',num2str(i),'   Fmin= ',num2str(sea.cost)]);
        FF(i)=sea.cost;

        comp2 = sea.cost;
        if comp2 < comp1
            bestIter = i;
        end
    end
    %% Results and Plot
    toc;
    Elapsed_Time=toc;
    NFEs=Npop*max_it;
    Xmin=sea.position;
    Fmin=objective_function(Xmin);
end


function [send_priority] = VSI(varargin)

global nDG
global ourcase

if nargin==1

    result = varargin{1};

    Vb = result.bus(:,8);

    find_vsi = zeros(size(result.bus,1),1);

    for i=1:size(result.bus,1)-1

        index = result.branch(:,1)==i+1;
        index1 = result.branch(:,2)==i+1;
        send_node = result.branch(index1,1);

        Vi = Vb(send_node);

        Piplus1 = sum(abs(result.branch(index,14)))/result.baseMVA;
        Qiplus1 = sum(abs(result.branch(index,15)))/result.baseMVA;

        Rk = result.branch(index1,3);
```

```matlab
        Xk = result.branch(index1,4);

        find_vsi(i+1) = (Vi)^4 - ...
                4*(Piplus1*Xk-Qiplus1*Rk)^2 - ...
                4*(Piplus1*Rk+Qiplus1*Xk)*(Vi)^2;


    end



    [find_vsi,index] = sort(find_vsi,'ascend');

    find_vsi(:,1)=find_vsi;   find_vsi(:,2)=index;

    find_vsi(1,:)=[];

    send_priority = find_vsi(:,2);

else

    temp_data = ourcase;
    mpopt=mpoption('pf.alg','ISUM','verbose',0,'out.all',0,'out.lim.v',0);
    result=radial_pf(temp_data,mpopt);

    Vb = result.bus(:,8);

    find_vsi = zeros(size(result.bus,1),1);

    for i=1:size(result.bus,1)-1

        index = result.branch(:,1)==i+1;
        index1 = result.branch(:,2)==i+1;
        send_node = result.branch(index1,1);

        Vi = Vb(send_node);

        Piplus1 = sum(abs(result.branch(index,14)))/result.baseMVA;
        Qiplus1 = sum(abs(result.branch(index,15)))/result.baseMVA;

        Rk = result.branch(index1,3);
        Xk = result.branch(index1,4);

        find_vsi(i+1) = (Vi)^4 - ...
                4*(Piplus1*Xk-Qiplus1*Rk)^2 - ...
                4*(Piplus1*Rk+Qiplus1*Xk)*(Vi)^2;


    end
```

```matlab
        [find_vsi,index] = sort(find_vsi,'ascend');

        find_vsi(:,1)=find_vsi;   find_vsi(:,2)=index;

        find_vsi(1,:)=[];

        send_priority = find_vsi(1:nDG,2);


end



```

Powerflow.m_code

```matlab
function [result] = powerflow(configuration)

global nC
global nDG
global ourcase
global choice



if choice==1

    temp_data = ourcase;

    configuration(nC+1:nC*2) = configuration(nC+1:nC*2)/1000; %converted kVAR
into MVAR

    for n=1:nC
        temp_data.bus(configuration(n),4)= temp_data.bus(configuration(n),4)-
configuration(n+nC);
    end

    mpopt=mpoption('pf.alg','ISUM','verbose',0,'out.all',0,'out.lim.v',0);

    result=radial_pf(temp_data,mpopt);
    result = order_radial(result);

elseif choice==2

    temp_data = ourcase;

    for n=1:nDG
        temp_data.bus(configuration(n),3)= temp_data.bus(configuration(n),3)-
configuration(n+nDG);
```

```matlab
    end

    mpopt=mpoption('pf.alg','ISUM','verbose',0,'out.all',0,'out.lim.v',0);

    result=radial_pf(temp_data,mpopt);
    result = order_radial(result);

elseif choice==3

    temp_data = ourcase;

    configuration(nC+1:nC*2) = configuration(nC+1:nC*2)/1000;     %converted
kVAR into MVAR

    for n=1:nC
        temp_data.bus(configuration(n),4)= temp_data.bus(configuration(n),4)-
configuration(n+nC);
    end

    for n=1:nDG
        temp_data.bus(configuration(2*nC+n),3)=
temp_data.bus(configuration(2*nC+n),3)-configuration(n+2*nC+nDG);
    end

    mpopt=mpoption('pf.alg','ISUM','verbose',0,'out.all',0,'out.lim.v',0);

    result=radial_pf(temp_data,mpopt);
    result = order_radial(result);

elseif choice==4

    temp_data = ourcase;

    configuration(nC+1:nC*2) = configuration(nC+1:nC*2)/1000;     %converted
kVAR into MVAR

    for n=1:nC
        temp_data.bus(configuration(n),4)= temp_data.bus(configuration(n),4)-
configuration(n+nC);
    end

    for n=1:nDG
        temp_data.bus(configuration(2*nC+n),3)=
temp_data.bus(configuration(2*nC+n),3)-
configuration(n+2*nC+nDG)*configuration(2*nC+2*nDG+n);
        temp_data.bus(configuration(2*nC+n),4)=
temp_data.bus(configuration(2*nC+n),4)-configuration(n+2*nC+nDG)*sqrt(1-
configuration(2*nC+2*nDG+n)*configuration(2*nC+2*nDG+n));
    end
```

```matlab
    mpopt=mpoption('pf.alg','ISUM','verbose',0,'out.all',0,'out.lim.v',0);

    result=radial_pf(temp_data,mpopt);
    result = order_radial(result);

else

    temp_data = ourcase;

    configuration(nC+1:nC*2) = configuration(nC+1:nC*2)/1000;     %converted
kVAR into MVAR

    for n=1:nC
        temp_data.bus(configuration(n),4)= temp_data.bus(configuration(n),4)-
configuration(n+nC);
    end

    for n=1:nDG
        temp_data.bus(configuration(2*nC+n),3)=
temp_data.bus(configuration(2*nC+n),3)-
configuration(n+2*nC+nDG)*configuration(2*nC+2*nDG+n);
        temp_data.bus(configuration(2*nC+n),4)=
temp_data.bus(configuration(2*nC+n),4)-configuration(n+2*nC+nDG)*sqrt(1-
(configuration(2*nC+2*nDG+n))^2);
    end

    mpopt=mpoption('pf.alg','ISUM','verbose',0,'out.all',0,'out.lim.v',0);

    result=radial_pf(temp_data,mpopt);
    result = order_radial(result);

end

 PLI.m_Code

function [candidates] = PLI()

global ourcase

no_of_buses=length(ourcase.bus);
PL=zeros(no_of_buses,1); V0=zeros(no_of_buses,1);

for i=1:no_of_buses

    if i==1
        data=ourcase;
        mpopt=mpoption('pf.alg','ISUM','verbose',0);
        result=radial_pf(data,mpopt);
        PL(i)=sum(abs(result.branch(:,14)+result.branch(:,16)))*1000;
%sum(real(get_losses(result)));
```

```matlab
        V0(i)=result.bus(i,8);
    else
        data=ourcase;
        data.bus(i,4)=0;
        mpopt=mpoption('pf.alg','ISUM','verbose',0);
        result=radial_pf(data,mpopt);
        PL(i)=sum(abs(result.branch(:,14)+result.branch(:,16)))*1000;
%sum(real(get_losses(result)));
        V0(i)=result.bus(i,8);
    end
end
PL1=PL(1)*ones(no_of_buses-1,1);
LR=PL1-PL(2:no_of_buses);
pli(:,1)=(2:no_of_buses);
pli(:,2)=(LR-min(LR)*ones(no_of_buses-1,1))/(max(LR)-min(LR));
pli(:,3)=V0(2:no_of_buses);

pli=sortrows(pli,2,'descend');

disp('----------------------------------------------------------------');
disp('What minimum per unit bus voltage would you like to use to calculate PLI? ');
disp(' ');
x = input('Recommended Value is 0.95. Please enter here: ');
disp(' ');
disp('----------------------------------------------------------------');
if isempty(x)
    disp('You did not enter anything. So, default value 0.95 was used.');
    x = 0.95;
end

index=find(pli(:,3)<x);

while isempty(index)
    disp('----------------------------------------------------------------');
    disp('----------------------------------------------------------------');
    fprintf('\nThe minimum per unit voltage you entered in PLI calculation was
%0.2f.\n',x);
    fprintf('However, none of the Buses in the base case had bus voltage below %0.2f
pu. So,\n',x);
    fprintf('Please input the minimum bus voltage for PLI calculation, above %0.2f:
\n',x);
    disp('----------------------------------------------------------------');
    x = input('Please enter the value: ');
    while isempty(x)
        disp('You did not enter anything. So, Default Value 0.95 was used.');
        x = 0.95;
    end
    index = find(pli(:,3)<x);
    disp('----------------------------------------------------------------');
end
```

```
candidates=pli(index,1)
```

Verify.m_code

```matlab
function verify



   temp_data = loadcase(case69);



  %solution = [ first 3 capacitor location, next 3 capacitor size in kVar, next 3 DG
location, next 3 DG size in MW, next 3 in pf]
   solution = [15 33 22 18.8 457.8 558.6 61 36 19 1.8247 1.0414 0.1063 0.877 0.916
0.904 ];

  % reactive load of given location = reactive load of given location - capcitor size

  %temp_data.bus(66,4) = temp_data.bus(66,4) - 248.6/1000;
   temp_data.bus(solution(1),4) = temp_data.bus(solution(1),4) - solution(4)/1000;
   temp_data.bus(solution(2),4) = temp_data.bus(solution(2),4) - solution(5)/1000;
   temp_data.bus(solution(3),4) = temp_data.bus(solution(3),4) - solution(6)/1000;

   temp_data.bus(solution(7),3) = temp_data.bus(solution(7),3) -
solution(10)*solution(13);
   temp_data.bus(solution(8),3) = temp_data.bus(solution(8),3) -
solution(11)*solution(14);
   temp_data.bus(solution(9),3) = temp_data.bus(solution(9),3) -
solution(12)*solution(15);

   temp_data.bus(solution(7),4) = temp_data.bus(solution(7),4) - solution(10)*sqrt(1-
solution(13)*solution(13));
   temp_data.bus(solution(8),4) = temp_data.bus(solution(8),4) - solution(11)*sqrt(1-
solution(13)*solution(14));
   temp_data.bus(solution(9),4) = temp_data.bus(solution(9),4) - solution(12)*sqrt(1-
solution(13)*solution(15));


   mpopt=mpoption('pf.alg','ISUM','verbose',0,'out.all',0,'out.lim.v',0);

   result=radial_pf(temp_data,mpopt);

   Vb = result.bus(:,8);
   [Vmin ind] = min(Vb)
   [Vmax ind] = max(Vb)


   Ploss = sum(abs(result.branch(:,14)+result.branch(:,16)))*1000
   Qloss = sum(abs(result.branch(:,15)+result.branch(:,17)))*1000
```

```
p = result.branch(1,14);
q = result.branch(1,15);
s = (p^2 + q^2)^0.5;
power_factor = p/s
```

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