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“Optimal location and sizing of Distributed Generation (DG) for IEEE 69 Bus Test system using Particle swarm Optimization (PSO).”

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MASTERS OF SCIENCE IN RENEWABLE ENERGY ENGINEERING

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DECLARATION

I declare that this study: Optimal location and sizing of Distributed Generation (DG) for IEEE 69 Bus Test system using Particle swarm Optimization (PSO) is my original work and has not been presented for a degree in the University of RWANDA or any other Masters. All sources of materials that will be used for the thesis work will have been acknowledged.

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Date of submission: 07/12/2023

This Thesis has been submitted for examination with my approval as a university advisor.

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ABSTRACT

This thesis presents an approach for the optimal location and sizing of DG units in the IEEE 69 Bus Test system using Particle Swarm Optimization (PSO).

The integration of Distributed Generation (DG) into power distribution networks can significantly enhance system efficiency, reduce power losses, and improve voltage profiles.

The main objective is to minimize the total power losses while maintaining acceptable voltage levels throughout the network. The PSO algorithm is applied to determine the best positions and sizes of DG units, taking into account various technical constraints such as voltage limits and line loading capacities.

Simulation with MATLAB results demonstrate the effectiveness of the proposed method, showing a substantial reduction in power losses and an improvement in voltage stability, validating PSO as a robust optimization technique for DG placement in distribution networks.

Keywords:

Distributed Generation (DG), IEEE 69 Bus Test System, Particle Swarm Optimization (PSO), Power Loss Reduction, Voltage Stability, Optimal DG Placement, Distribution Networks.

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LIST OF ABBREVIATIONS AND SYMBOLS

AC: Alternating Current
ACOPF: AC Optimal Power Flow
DC: Direct Current
DG: Distributed Generation
EV: Electric Vehicle
FIT: Feed-in Tariff
GBest: Global Best
HVAC: Heating, Ventilation, and Air Conditioning
IEEE: Institute of Electrical and Electronics Engineers
IWD: intelligent water drops.
kVA: Kilovolt-Ampere
kW: Kilowatt
LSF: loss sensitivity factor
MATLAB (Matrix Laboratory)
MATPOWER: Matrices to Power System MatLAB-based Simulator
MFO: moth flame optimization
MMFO: modified moth flame optimization
MVO: Multi Verse Optimization
PBest: Personal Best
PEV: Plug-in Electric Vehicle
PSO: Particle Swarm Optimization
PV: Photovoltaic
RERs: renewable energy resources
RES: Renewable Energy Sources
SWOT: Strengths, Weaknesses, Opportunities, Threats
V2G: Vehicle-to-Grid

CHAPTER 1

INTRODUCTION

1.1.Background

Globally, distribution losses pose a serious threat to electrical networks. They constitute a major resource waste since they can make up as much as 20% of the electricity produced. In addition, distribution losses may have several detrimental effects on the long-term sustainability, dependability, and quality of electrical networks[1].

Effect on dependability. This may be more difficult to maintain the voltage and frequency of the power supply when there are distribution losses. Brownouts and power disruptions may result from this. In addition to making, it more difficult to run the grid efficiently, distribution losses can also cause traffic jams and voltage swings.

The International Energy Agency (IEA)[2] discovered in one of its studies that distribution losses can cost utilities up to $1 trillion year worldwide. Additionally, the IEA discovered that distribution losses might lower grid reliability by as much as 10%[3].

Effect on standard. Distribution losses have the potential to lower the electrical supply's quality. Voltage swells and sags caused by this may harm delicate electronic equipment. Harmonics introduced by distribution losses can disrupt communications and other electronic equipment by altering the electrical supply.

According to research conducted by the Electric Power Research Institute (EPRI), distribution losses in the US can harm electronic equipment to the tune of up to $15 billion annually. Additionally, the EPRI discovered that distribution losses can result in up to $10 billion in lost productivity annually from brownouts and power outages[4].

Effect on sustainability throughout time. Grid operation and maintenance costs may increase as a result of distribution losses. This may deter investment in new infrastructure and increase the challenge of meeting the world's expanding electrical consumption. Distribution losses may also be a factor in environmental issues like air pollution and greenhouse gas emissions.

Distribution losses can cost developing nations up to 1% of their GDP annually, according to World Bank research. The World Bank also discovered that developing nations may find it more challenging to meet their targets for sustainable development if there are distribution losses[5].

Reducing distribution losses

Renovating distribution lines. Newer distribution lines often have lower losses and are more efficient than older ones. Upgrades to distribution lines can help utilities cut losses. Utilizing smart grid technology, utilities can identify and minimize losses with the use of smart grid technologies. Smart grid technology, for instance, can be used to keep an eye out for issues with the grid, such as malfunctioning equipment and overloaded lines[6].

Minimizing unauthorized connections. Unauthorized access to the grid might result in large losses. Tightening up on unauthorized connections can help utilities cut down on losses. Educating customers, utilities can instruct customers on how to use less electricity. As a result, there may be a decrease in overall electricity demand and losses.

In conclusion, distribution losses pose a serious threat to global electricity networks. They may have several detrimental effects on the grid's long-term survival, quality, and dependability. Nonetheless, there are other strategies to lessen distribution losses. Utilities can lower consumer prices and increase grid efficiency by implementing loss-reduction measures.

1.2.Green Energy and CO2

Green energy is energy produced in an environmentally responsible manner using renewable resources. Renewable energy sources include sunshine, wind, rain, tides, and geothermal heat. These sources can be renewed naturally on a timescale that is suitable for humans.

Because it can lessen our dependency on fossil fuels, which are a significant contributor to greenhouse gas emissions, green energy is significant. The primary driver of climate change, which poses a major threat to the earth and its people, is greenhouse gas emissions[7].

1.2.1. CO2 and Climate Change

CO2 emissions from human activities are the primary cause of climate change, which is a major threat to the planet and its inhabitants. We must reduce CO2 emissions and transition to a clean energy economy in order to mitigate the effects of climate change and protect our planet for future generations[7].

Global CO2 emissions from human activities have increased by about 50% since the pre-industrial era (1750). In 2022, global CO2 emissions from fossil fuels reached a record high of 36.3 billion tonnes. The top three CO2 emitters in the world are China, the United States, and India[8].

This increase in CO2 emissions is causing the planet to warm at an unprecedented rate. The global average temperature has increased by about 1 degree Celsius since the pre-industrial era, and the rate of warming has accelerated in recent decades[9].

Climate change is already having a significant impact on the planet. Sea levels are rising, glaciers and ice sheets are melting, and extreme weather events are becoming more frequent and severe. These impacts are expected to worsen in the future if we do not take action to reduce CO2 emissions.

The Intergovernmental Panel on Climate Change (IPCC) has warned that global warming must be limited to 1.5 degrees Celsius above pre-industrial levels to avoid the worst impacts of climate change. The IPCC has also stated that we must achieve net-zero greenhouse gas emissions by 2050 to limit global warming to 1.5 degrees Celsius. The IPCC has estimated that we have a remaining carbon budget of about 400 gigatons of CO2 to emit before we reach 1.5 degrees Celsius of warming. At the current emissions rate, we will exceed this carbon budget in less than 20 years[10].

Governments are playing a leading role by enacting policies that promote renewable energy and reduce carbon emissions. Businesses are investing in renewable energy technologies and reducing their carbon footprint. Individuals can change their lifestyles, such as driving less, eating less meat, and using less energy. By taking these steps, we can help mitigate climate change's effects and protect our planet for future generations.

To summarize, CO2 emissions from human activities are the primary cause of climate change. Climate change is a major threat to the planet and its inhabitants. We must reduce CO2 emissions and transition to a clean energy economy in order to mitigate the effects of climate change and protect our planet for future generations[10].

1.2.2. The Benefits of Green Energy

It lowers emissions of greenhouse gases. Greenhouse gases are a huge hazard to the world and its inhabitants, and they are not produced by green energy sources. We can lessen the effects of climate change and cut down on greenhouse gas emissions by switching to green energy. This is necessary to save the environment and guarantee everyone has a sustainable future.

Enhanced quality of air. The absence of air pollution from green energy sources reduces the risk of respiratory and other health issues. An estimated millions of people die each year as a result of air pollution, making it a serious public health hazard[11]. We can safeguard our inhabitants' health and enhance the quality of the air by switching to green energy. Given that they are more susceptible to the impacts of air pollution, vulnerable populations including children and the elderly should pay particular attention to this.

Enhanced safety of energy. Because green energy sources are frequently broadly accessible and plentiful, reliance on imported fossil fuels may be lessened. Both economic stability and national security depend on this. Reducing our dependency on fossil fuels can help us guard against supply disruptions and price shocks. Given the current global energy crisis, this is particularly crucial.

Financial progress. The economy can grow and employment can be created via green energy technologies. One of the economic areas with the quickest rate of growth is green energy, and this trend is predicted to continue in the years to come. We can boost economic growth and create new jobs by investing in renewable energy. For communities affected by the demise of the fossil fuel sector, this is particularly crucial[11].

1.2.3. The Challenges of Green Energy

The price. Cost is one of the main issues facing green energy. Installing and running green energy solutions can be more costly than those that rely on fossil fuels. The high initial cost of renewable energy technology, the requirement for government subsidies, and the sporadic nature of some renewable energy sources are some of the causes of this.

One of the main obstacles to the adoption of green energy technology is their high upfront cost. Governments and corporations must spend money on research and development to lower the cost of green energy technology in order to make green energy more accessible. Governments can also offer financial incentives to businesses and individuals to stimulate the adoption of green energy technologies, such as tax credits and rebates[12].

The erratic nature of some renewable energy sources, like wind and solar power, raises the price of green energy as well. Because intermittent energy sources don't always generate electricity, it may be challenging to integrate them into the grid and satisfy demand for electricity. Investing in grid-scale energy storage technology is necessary to overcome the intermittency dilemma. When the sun is not shining or the wind is not blowing, energy storage systems can store electricity produced from renewable energy sources and release it when needed.

The cost of green energy technology is still declining in spite of these obstacles. We may anticipate seeing green energy take on a bigger part in our energy mix as the cost of green energy keeps going down and technologies becoming more dependable and efficient.

Another significant issue facing green energy is intermittency. Certain renewable energy sources, like wind and solar power, are intermittent, which means that they don't always generate electricity. Because of this, it could be challenging to meet the demand for electricity and integrate them into the grid[13].

The intermittency issue can be solved in a variety of ways. Investing in energy storage technologies is one approach. When the sun is not shining or the wind is not blowing, energy storage systems can store electricity produced from renewable energy sources and release it when needed.

Creating a more adaptable grid is a further strategy to deal with the intermittent problem. A more adaptable grid might guarantee that there is always enough electricity to meet demand while also accommodating the unpredictability of renewable energy sources. This could entail constructing more dispersed generation capacity, installing smart grid technologies, and creating additional transmission lines[14].

Since green energy sources are frequently found in isolated locations, getting electricity to those areas can be costly. In order to make green energy more competitive with fossil fuels, this problem must be overcome. The transmission problem can be solved in a variety of ways. Constructing new transmission lines is one approach. Connecting renewable energy sources to the grid and supplying consumers with electricity can be costly, but it's essential.

Creating energy storage technology is an additional strategy to deal with the transmission problem. Energy storage devices have the ability to store electricity produced in faraway locations from renewable energy sources and release it closer to the customers when needed.

Finally, by creating more distributed generation capacity, we may also lessen the requirement for transmission. Small-scale power plants that are situated close to consumers are referred to as having distributed generation capacity. This may lessen the need for long-distance electrical transmission, saving money and minimizing energy loss[13], [14].

Green energy is getting more and more competitive with fossil fuels in spite of these obstacles. Green energy solutions are getting more affordable and dependable while also increasing in efficiency. The global market for green energy is expanding quickly, and both businesses and governments are making significant investments in this field. Green energy should become more and more significant in our energy mix as it becomes more competitive.

1.2.4. The future of green energy

Green energy has a bright future despite its challenges. Green energy solutions are getting more and more dependable and efficient while also continuing to decline in cost. Globally, corporations and governments are making significant investments in renewable energy.

29% of the world's electricity was generated by renewable energy in 2022, and this percentage is predicted to rise in the years to come. Over 50% of the world's electricity is predicted to come from renewable sources by 2050[15].

In summary, in order to counteract climate change and lessen our dependency on fossil fuels, green energy is crucial. Reduced greenhouse gas emissions, better air quality, more energy security, and economic growth are just a few advantages of using green energy.

Green energy is not without its difficulties, including costs, intermittency, and transmission. Green energy does, however, have a promising future because its technologies are getting more dependable and efficient while also becoming more affordable[16].

1.3.Distributed Generation and its Network Status

The production of energy from small-scale sources near to the point of consumption is known as distributed generation, or DG. DG can refer to a wide range of technologies, including fuel cells, combined heat and power (CHP) systems, microturbines, solar and wind power, and fuel cells.

As the world moves toward a future powered by clean energy, DG networks will become more and more significant. DG networks can lower greenhouse gas emissions, boost energy independence, and enhance the electrical grid's dependability and efficiency[17].

1.3.1. Types of DG networks

There are three main types of DG networks:

- **On-grid DG networks**: On-grid DG networks are connected to the electrical grid. This allows DG systems to export excess electricity to the grid and to import electricity from the grid when needed.
- **Off-grid DG networks**: Off-grid DG networks are not connected to the electrical grid. This type of DG network is often used in remote areas where there is no access to the grid.
- **Microgrids**: Microgrids are small, self-contained electrical grids that can operate independently from the main grid. Microgrids can include DG systems, energy storage systems, and loads.

1.3.2. Status of distributed generation

Globally, the use of DG networks is expanding quickly. Global distributed generation (DG) capacity increased from 1.3 TW in 2021 to 1.5 TW in 2022. Numerous factors, such as the falling cost of distributed generation (DG) technology, government policies supporting DG deployment, and the growing demand for clean energy, are driving this increase[18].

As the world leader in DG deployment, the US has installed more than 550 GW of DG capacity. With installed DG capacities of more than 250 GW and 120 GW, respectively, China and Germany are significant DG markets.

1.3.2.1.Rwanda DG network status

The deployment of DG networks in Rwanda is still in its early stages, but there is growing interest in this technology from both the government and the private sector. The Rwandan government has set a goal of increasing the share of renewable energy in the country's electricity mix to 38% by 2030. DG networks, particularly solar PV systems, are expected to play a significant role in helping Rwanda achieve this goal[19].

In 2022, the Rwandan government launched the "Rwanda Off-Grid Electricity Access Project" (ROGEAP) with the aim of providing electricity access to 1 million people in off-grid areas by 2024. The project is expected to deploy a mix of DG technologies, including solar PV, mini-grids, and microgrids[20].

In addition to the government's efforts, there are a number of private sector companies that are developing and deploying DG networks in Rwanda. For example, the company Bboxx has installed over 100,000 solar PV systems in Rwanda, providing electricity to over 500,000 people.

- Total installed DG capacity: 10 MW
- Share of DG in total electricity generation: 1%
- Number of DG systems installed: 100,000
- Number of people served by DG: 500,000

The main types of DG technologies deployed are solar PV, mini-grids, and microgrids[20].

1.3.3 Benefits of DG networks

DG networks are being used for many different purposes. Some are residential. This is to generate power for self-consumption and to sell back to the grid, distributed generation (DG) systems are being installed on homes[21].

Another use is for commercial purposes. This is done by lowering energy costs, providing energy security, and promoting sustainability goals, DG systems are being placed on commercial buildings.

In addition, Tis is very applicable in industries to lower energy costs, provide energy reliability, and provide heat for industrial operations, distributed generation (DG) systems are being deployed on industrial facilities[22].

The utility-scale distributed generation (DG) systems are being constructed to lower greenhouse gas emissions, enhance the grid's integration of renewable energy sources, and provide additional generation capacity.

- **Advantages of DG in network**

Increased dependability: By lowering the reliance on big, centralized power plants, DG networks can contribute to an increase in the electrical grid's dependability. DG networks have the potential to maintain customer access to electricity in the event of a major power plant failure.

Enhanced efficiency: Compared to conventional centralized generation, DG networks may be more efficient. This is so that there is less need for transmission and distribution losses because distributed generation systems are frequently placed closer to the load.

Diminished ecological footprint: By diminishing greenhouse gas emissions and other pollutants, distributed generation (DG) networks can aid in mitigating the ecological consequences of energy production.

Enhanced energy independence: By lowering dependency on imported fuels, DG networks can contribute to a greater level of energy independence.

Economic development: DG networks have the potential to grow the local economy and provide jobs.

1.3.3. Challenges of DG networks

DG networks also face a number of challenges, including:

Technical challenges: DG systems can interact with the electrical grid in complex ways. It is important to ensure that DG systems are properly integrated into the grid to avoid technical problems.

Regulatory challenges: DG regulations vary from country to country and from state to state. It is important to understand the applicable regulations before installing a DG system.

Financial challenges: The upfront cost of DG systems can be high. However, the cost of DG systems has been falling rapidly in recent years, and there are a number of financial incentives available to support DG deployment.

DG networks are playing an increasingly important role in the global energy landscape. DG networks can help to improve the reliability, efficiency, environmental impact, and energy independence of the electrical grid. However, DG networks face a number of challenges, including technical, regulatory, and financial challenges.

Governments and industry are working to address these challenges and to promote the deployment of DG networks. As the cost of DG technologies continues to fall, and as government policies become more supportive, we can expect to see DG networks play an even greater role in the electrical network of the future.

1.4.Penetration of Distributed Generation

DG penetration is the percentage of electricity generated by DG systems relative to the total electricity generated in a region or country. DG penetration has been growing rapidly in recent years, driven by declining costs of DG technologies, government policies that support DG deployment, and increasing demand for clean energy.

[Picture]

1.4.1. Benefits of high DG penetration

DG can help to improve the reliability of the electrical grid by reducing reliance on large, centralized power plants. DG systems can also provide backup power during outages. For example, a study by the Electric Power Research Institute (EPRI) found that DG can reduce the number of power outages by up to 50%[23].

DG can be more efficient than traditional centralized generation, as it reduces transmission and distribution losses. According to the National Renewable Energy Laboratory (NREL), transmission and distribution losses can account for up to 10% of the electricity generated in the United States. DG systems can be located close to the load, which reduces the need for long transmission lines and distribution networks.

DG can help to reduce greenhouse gas emissions and other pollutants. DG systems can be used to generate electricity from renewable sources, such as solar and wind power, which do not produce greenhouse gas emissions. For example, a study by the IEA found that DG can reduce greenhouse gas emissions by up to 20%.

DG can help to reduce reliance on imported fossil fuels. DG systems can be used to generate electricity from renewable sources, which are domestically available. For example, a study by the U.S. Department of Energy found that DG could reduce U.S. oil imports by up to 20%.

DG can help to reduce electricity costs for consumers and businesses, especially in areas with high electricity rates. For example, a study by the Solar Energy Industries Association (SEIA) found that solar PV systems can save homeowners an average of $1,000 per year on their electricity bills[24].

1.4.2. Challenges of high DG penetration

DG systems can interact with the electrical grid in complex ways, and it is important to ensure that they are properly integrated into the grid to avoid electrical problems. For example, DG systems can cause voltage and frequency fluctuations on the grid.

DG systems can affect the voltage and frequency of the electrical grid, and it is important to have systems in place to regulate voltage and frequency. For example, utilities can use smart grid technologies to regulate voltage and frequency.

DG systems can be vulnerable to cyberattacks, and it is important to have security measures in place to protect DG systems from cyberattacks. For example, DG system owners should use strong passwords and keep their software up to date.

High DG penetration can offer a number of benefits, including improved reliability, increased efficiency, reduced environmental impact, increased energy independence, and reduced electricity costs. However, high DG penetration can also pose some challenges, such as integrating DG into the grid, regulating voltage and frequency, and protecting DG systems from cyberattacks.

Policymakers and regulators are working to address the challenges of high DG penetration and to create an environment that is conducive to the deployment of DG systems. As the technology continues to develop and the cost of DG systems continues to fall, we can expect to see DG penetration continue to grow in the coming years.

1.4.3. Future of DG penetration

The future of DG penetration is bright. DG technologies are becoming increasingly affordable and efficient, and governments around the world are supporting the deployment of DG systems. As a result, DG penetration is expected to continue to grow rapidly in the coming years.

According to the IEA, DG penetration is expected to reach 30% of global electricity generation by 2040. This growth will be driven by the deployment of solar PV and wind systems, as well as the increased use of DG systems for commercial and industrial applications[25].

The growing penetration of DG will have a number of positive impacts on the electrical grid and the environment. DG can help to improve the reliability, efficiency, and environmental impact of the grid. Additionally, DG can help to reduce reliance on imported fossil fuels and create jobs.

1.5.Voltage Instability and Power Quality

Voltage drop along the distribution lines gets worse as distribution losses increase. Voltage sags, insufficient voltage levels, and voltage swings are caused by this phenomenon. Wide-ranging effects of these voltage changes include harm to delicate equipment, business machinery, and home appliances. These voltage anomalies frequently lead to operational problems, equipment damage, and lower productivity, placing a significant financial and operational strain on both utility companies and end users[26].

1.6.Equipment Overloading

Increased current flow through power lines, transformers, and switchgear are required due to higher losses in the distribution network. These components may be overloaded if the current levels are raised because they may be pushed over their design limits[27]. Equipment that is overloaded is susceptible to degeneration, overheating, and, in extreme circumstances, catastrophic failure. This in turn sets off a chain reaction of unfavorable effects, such as rising maintenance costs, early equipment replacement, and protracted power outages, further taxing the distribution system's resilience.

1.7.Energy Efficiency and Environmental Impact

Reduced losses in distribution networks are necessary for operational, moral, and environmental reasons. A reduction in the carbon footprint of power generating is achieved through improving the energy efficiency of distribution systems. Utilities may contribute to a more sustainable and ecologically conscious energy ecosystem by reducing distribution losses and so reducing the demand for extra generation capacity[28].

1.8.Financial Sustainability of Utilities

Distribution losses place a significant financial burden on utilities in addition to their technical and environmental effects. Utility firms bear a greater financial burden as losses grow. The sustainability of utilities as a whole is impacted by these financial effects, which may ultimately affect how much power users pay[29].

1.1.5 Integration of Distributed Generation (DG)

Distribution losses place a significant financial burden on utilities in addition to their technical and environmental effects. Utility firms bear a greater financial burden as losses grow. The sustainability of utilities as a whole is impacted by these financial effects, which may ultimately affect how much power users pay.

1.1.6 Advanced Monitoring and Control Systems

However, sophisticated monitoring and control systems that can handle the complexities of variable and distributed energy sources are necessary for the seamless integration of DG into distribution networks. To efficiently manage and balance the power grid, entails the development of complex forecasting models, control algorithms, and communication systems. These developments are crucial for maintaining the grid's stability and dependability and maximizing the advantages of distributed power[30].

In conclusion, distribution losses pose a complex problem with wide-ranging effects. They have an impact on utility financial viability, equipment integrity, energy efficiency, and environmental sustainability. The integration of dispersed generation emerges as a possible resolution to these issues, but it requires precise and deliberate placement within the distribution network. This thesis uses the IEEE 69 Bus Test system as a case study to solve the crucial problem of optimizing the location and size of distributed generation in distribution systems[31]. A special emphasis is placed on using the Particle Swarm Optimization (PSO) technique to accomplish these goals. Through this study, we hope to improve power systems engineering and sustainable energy methods in addition to reducing distribution losses.

1.2 Statement of the problem

During Integration of Distributed Generation such as photovoltaic (PV) systems or wind turbines into the existing power distribution network to minimize power losses, DG are installed at specific buses in the system. However, incorrect sizing and siting of DG sources in power system would put danger of losses, harm, and failure to the reliable system operation. The integration of DGs involves determining the optimal locations and capacities of DG units based on various factors such as load demand, network constraints, and renewable resource availability[32]

1.3. Objectives

1.3.1. General Objective

The main objective of this project is to Optimize the location and sizing of Distributed Generation to minimize power losses in a distribution network.

1.3.2. The Specific Objectives

The specific objectives of this project are as follows:

- To determine the optimal placement and capacity of distributed generation (DG) sources within the distribution system.
- To minimize the total power losses
- To satisfy various constraints such as voltage limits and DG capacity limits

1.4 Scope of the study

In this study, Particle swarm algorithm will be used for Distributed Generation (DG) for the IEEE 69 Bus Test system to optimize the location, and size of the DG and mitigate power losses in this system. In this study, MATLAB simulation was used for the system after the location and size of DG as the simulator tool. Relevant conclusions and recommendations will be drawn for further implementation.

1.5. Significance of the Study

Optimal location and proper sizing of DG provide many solutions in a distribution network such as:

- **Improved Efficiency**: By optimizing the placement and capacity of DG sources in the distribution system, the general efficiency of the system can be improved, resulting in reduced power losses and improved voltage profile. This can lead to cost savings for both utilities and consumers and can also help to reduce greenhouse gas emissions by reducing the need for additional generation capacity[33].
- **Enhanced Reliability**: The integration of DG sources can help to increase the reliability of the distribution system by reducing the dependence on centralized generation sources. In the event of a power outage or other disruption, DG sources can provide backup power to critical loads and help to maintain system stability.
- **Increased Renewable Energy Integration**: The optimal placement and capacity of DG sources can also help to facilitate the integration of renewable energy sources into the distribution system. DG sources can provide a means of balancing fluctuations in renewable energy output and can help to reduce the need for energy storage systems[34].
- **Validation of Optimization Techniques**: The project can help to validate the effectiveness of PSO as an optimization technique for solving similar problems in other distribution systems. This can contribute to the development of new optimization techniques and help to advance the field of power systems engineering.

CHAPTER 2

LITERATURE REVIEW

2.1. Introduction

In the modern world, an efficient and dependable electrical energy distribution system is essential to our globalized society. Distribution networks connect the last mile of the electrical grid, which is the crucial conduit between end users and large-scale power generating. The phenomenon of distribution losses, which can have significant effects on network dependability, power quality, and long-term sustainability, is one of the most urgent problems facing these networks[35].

When electrical power travels via distribution lines and comes into contact with components like line resistance and impedance, distribution losses can result in a variety of negative consequences[36]. The distribution network faces significant challenges as a result of the accumulation of these losses, which calls for creative approaches to optimization and mitigation[37].

As the last step in providing customers with electricity, power systems distribution functions inside a complicated structure. Distribution networks, which are made up of feeders, distribution transformers, secondary distribution lines, substations, and service drops, must contend with issues like aging infrastructure, increased demand, integrating renewable energy sources, and cybersecurity concerns. Despite their difficult nature, these issues are being tackled by a variety of developments that will influence the future of electricity distribution networks[38].

With the introduction of smart grid technologies, the landscape is changing and promises intelligent and adaptive networks that will revolutionize the distribution and management of electricity. Advances in renewable energy are driving distributed generation, which is decentralizing power production and promoting resilience and sustainability. Concurrently, the widespread use of electric vehicles introduces a new level of complexity, necessitating creative solutions for a smooth transition into the electrical grid.

Power systems distribution is entering a period of unparalleled change and opportunity as we traverse this dynamic and varied landscape. This is due to the convergence of issues and trends. The development of resilient power distribution networks, prepared to meet the changing needs of a dynamic and energy-hungry world, is driven by the quest for sustainability, efficiency, and reliability.

2.2. **The Anatomy of Power Systems Distribution**

Distribution networks for power systems are complex webs of parts that work together to distribute electricity to a variety of users. Gaining knowledge about the essential elements of this network can help you better understand the systems that guarantee a dependable and effective flow of electrical energy.

2.2.1. Substations: Gateway to Distribution

Substations are essential electrical infrastructures that coordinate voltage level changes. Strategically positioned, they facilitate the transfer of electricity from the bulk power transmission grid to distribution transformers by converting high transmission voltages to lower distribution voltages. Substations, the central component of power systems distribution networks, contain a variety of vital components, such as circuit breakers and transformers.

2.2.2. Feeders: Lifelines of Electricity Transfer

The main distribution lines, or feeders, are what carry power from substations to distribution transformers. Feeders, which can be subterranean or overhead and are built with insulated cables or bare conductors, constitute the central power system distribution network and guarantee the uninterrupted flow of electricity.

2.2.3. Distribution Transformers: Voltage Alchemists

Adjusting voltage levels is a critical function of distribution transformers. These transformers, which are installed in pad-mounted enclosures or on poles, further lower the voltage from feeder levels to the dependable and safe utilization voltage that most customers accept. By placing them strategically, they guarantee the transmission of power at the ideal voltage, protecting the distribution network and its consumers.

2.2.4. Secondary Distribution Lines: Bridging the Gap

Electricity is distributed from distribution transformers to client homes via secondary distribution lines. These lines which are primarily composed of insulated cables can be buried underground or strung overhead. They serve as a conduit between distribution transformers and end users, directing power effectively to the locations where it is most needed.

2.2.5. Service Drops: Connecting Consumers

The last leg of the voyage, known as service drops, joins secondary distribution lines to residences or commercial buildings. These insulated cable lines, whether they are subterranean or above, represent the final link in the chain and guarantee the smooth transmission of electricity to individual customers.

The complex ballet of parts that make up power systems distribution networks is essentially captured by the arrangement of substations, feeders, distribution transformers, secondary distribution lines, and service drops. Every component has a distinct function in guaranteeing the consistent and effective flow of energy, which powers our establishments, lights our residences, and propels the pulse of contemporary society.

2.3. Power Systems Distribution Operation

Distribution networks for power systems, which are essential to the transmission of electricity, are primarily designed in a radial pattern. Under this arrangement, power travels from substations to distribution transformers and then to consumers in a single direction. This design's weakness is that it is easily disrupted in the event of a feeder or distribution transformer failure, despite being simple and dependable overall.

Increasing Reliability with Creative Methods

In order to strengthen the robustness of power systems distribution networks, utilities utilize a range of strategies, each designed to address certain vulnerabilities:

2.3.1. Looping: Encircling Reliability

One notable tactical move is looping, in which several feeds join together to create a complete loop. Through the clever use of electricity, a broken feeder or distribution transformer can be avoided, guaranteeing customers a steady supply of power. Looping protects against disruptions by generating alternate paths.

2.3.2. Sectionalizing: Precision in Isolation

Sectionalizing divides feeders utilizing switches into more manageable, smaller sections, introducing a precision-based approach. Utilities can isolate and fix the malfunctioning areas with this tactical split without jeopardizing the feeder as a whole. By segmenting the system, errors are contained and quick corrective action may be taken without bringing down the entire system.

2.3.3. Automated Switching: Orchestrating Recovery

With automatic switching, technological advancements take center stage. Using computers, this method responds to power disruptions by automatically switching distribution transformers and feeds. As a result, customers' service is quickly and effectively restored after an interruption. As a smart defender, automated switching plans recovery with the least amount of downtime[37], [38].

To put it simply, power systems distribution networks use operational tactics that go beyond the conventional radial structure. The cutting-edge of reliability is represented by strategies like automatic switching, looping, and sectionalizing. These strategies guarantee that interruptions are addressed quickly and effectively, maintaining a steady and uninterrupted supply of energy to customers.

2.4. Power Systems Distribution Challenges

Power systems distribution networks grapple with a myriad of challenges that shape their resilience and efficiency. The key challenges include:

2.4.1. Growing Demand: A Balancing Act

Demand for power has surged to an unprecedented level due to changes in lifestyle and technological improvements[36]. This surge, which is being felt all across the world, puts pressure on power systems distribution networks as they try to strike a balance between supply and growing demand. Meeting this growing demand for power without jeopardizing the stability and dependability of the network is the problem.

2.4.2. Aging Infrastructure: The Test of Time

The global power systems distribution infrastructure is approaching a critical juncture as a large percentage of it ages gracefully. The daunting task of replacing in a timely and strategic manner is looming big[35]. In order to fulfill the changing needs of consumers, addressing this challenge requires striking a careful balance between preserving the current system and introducing new, resilient technology[38].

2.4.3. Renewable Energy Integration: A Shifting Landscape

A paradigm change is brought about by the integration of renewable energy sources, such wind and solar electricity, into power systems distribution networks. Although these sources help promote sustainability, there is a special problem because of their sporadic nature. It takes creative thinking to find dependable ways to match the erratic production of renewable energy with the ongoing need for electricity. The dynamic ebb and flow of renewable energy must be accommodated by power systems to provide a smooth integration into the distribution network.

2.4.4. Cybersecurity: Guarding Against Threats

The susceptibility of power systems distribution networks to hackers is a serious worry in an increasingly interconnected world. The smooth delivery of power to customers is seriously threatened by the possibility of malevolent disruptions. Cybersecurity is becoming a major issue that requires strong defenses to protect networks from cyberattacks and ensure the continuous flow of power[39].

Power systems distribution networks must innovate, adapt, and strengthen their foundations in order to meet these difficulties. To guarantee the continuous dependability and resilience of power distribution to customers, a comprehensive and forward-thinking strategy is required due to the dynamic interaction of expanding demand, aging infrastructure, integration of renewable energy, and cybersecurity[39].

2.5. Power Systems Distribution Trends

The landscape of power systems distribution is undergoing a transformative journey, propelled by a wave of innovative trends. These trends are not only reshaping the industry but also paving the way for a more efficient, reliable, and sustainable grid. Let's delve into the key trends shaping the future of power systems distribution:

2.5.1. Smart Grid Technologies: Pioneering the Digital Frontier

Smart grid technologies are at the forefront of revolutionizing power systems distribution. Leveraging digital and information technology, these advancements enhance the efficiency, reliability, and security of the electric grid. Within power systems distribution, smart grid technologies unfold opportunities to:

Improve Monitoring and Control: Enable utilities to swiftly identify and respond to issues, ensuring a quicker and more efficient resolution of problems.

Integrate Renewable Energy Sources: Facilitate increased integration of renewable energy sources and distributed generation, reducing reliance on fossil fuels and enhancing energy security.

Enhance Consumer Engagement: Empower consumers with tools for better energy management and cost control through improved demand response.

2.5.2. Distributed Generation (DG): Localized Power Revolution

Distributed generation, encompassing small-scale sources like solar panels, wind turbines, and fuel cells, is catalyzing a localized power revolution. DG not only alleviates stress on power systems distribution networks but also enhances reliability while contributing to reduced greenhouse gas emissions.

2.5.3. Electric Vehicles (EVs): Charging into the Future

The rapid adoption of Electric Vehicles (EVs) introduces both challenges and opportunities for power systems distribution networks. As the demand for EV charging surges, the grid faces potential strain. However, EVs also offer a unique solution by serving as energy storage units and providers of grid support services.

Emerging Technologies on the Horizon

In addition to the aforementioned trends, several emerging technologies hold the potential to further transform power systems distribution in the coming years:

Blockchain: Creating secure and transparent platforms for energy trading and management, blockchain technology facilitates the seamless integration of DG and EVs into power systems distribution networks.

Artificial Intelligence (AI) and Machine Learning: Harnessing the power of AI and machine learning can elevate the efficiency and reliability of power systems distribution networks. Predictive maintenance models and optimized network operations are among the benefits.

5G Technology: Unleashing high-speed communication, 5G technology enables robust connectivity between different components of power systems distribution networks. This opens avenues for real-time monitoring and control applications.

The future of power systems distribution shines with promise. Utilities, at the vanguard of change, are investing in these trends and emerging technologies to craft a grid that is not only responsive to current needs but also resilient and sustainable for the challenges of tomorrow.

2.6. Integration of Distributed Generation (DG) in Power Systems Distribution

A new era of energy production, consumption, and sustainability is ushered in with the integration of Distributed Generation (DG), which represents a significant change in the distribution landscape of power networks. The term "DG" describes the localized production of electricity using fuel cells, wind turbines, and solar panels, among other small-scale energy sources. Here's a closer look at how electricity distribution networks are being impacted and altered by the smooth integration of DG.

2.6.1 Decentralized Energy Generation

DG fundamentally alters the traditional model of centralized power generation. Instead of relying solely on large power plants, DG systems distribute energy generation across various smaller sources. This decentralization enhances energy resilience, reduces transmission losses, and contributes to a more robust and flexible distribution network.

2.6.2. Reducing Transmission Losses

One of the significant advantages of DG integration is the reduction of transmission losses. In a traditional, centralized power generation model, electricity travels over long distances through transmission lines, incurring losses due to resistance and impedance. DG, being closer to end-users, minimizes these losses, leading to more efficient energy delivery.

2.6.3. Enhanced Reliability and Resilience

DG systems enhance the reliability and resilience of power distribution networks. Localized generation means that communities can continue to receive power even in the event of disruptions to the central grid. This is particularly crucial in the face of extreme weather events, natural disasters, or other emergencies.

2.6.4. Integration of Renewable Energy Sources

DG is inherently linked with the integration of renewable energy sources into the power distribution network. Solar panels, wind turbines, and other renewable sources are often employed in DG systems, fostering sustainability and reducing the reliance on conventional, carbon-emitting energy generation.

2.6.5. Grid Support and Energy Storage

DG systems, especially those incorporating technologies like battery storage, offer valuable grid support services. They can act as energy storage units, balancing the intermittency of renewable sources and providing power during peak demand periods. This capability contributes to grid stability and efficiency.

2.6.6. Local Empowerment and Energy Independence

DG promotes local empowerment by allowing communities, businesses, and even individual households to generate their own power. This shift toward energy independence can lead to more sustainable and resilient communities, less dependent on centralized power generation.

2.6.7. Challenges and Solutions

While DG integration brings numerous benefits, it also poses challenges related to grid management, voltage control, and regulatory frameworks. Advanced technologies, smart grid solutions, and effective policies are essential for overcoming these challenges and ensuring a smooth transition to a more decentralized and sustainable power distribution model.

In conclusion, the integration of Distributed Generation is a transformative force in power systems distribution, driving the transition towards a more sustainable, resilient, and locally empowered energy landscape. As technology advances and adoption increases, DG will continue to play a pivotal role in shaping the future of power distribution networks.

2.7. Optimizing Distributed Generation Integration: Algorithms Overview

Sophisticated optimization approaches are needed for the smooth integration of distributed generation (DG) into the electrical grid in order to handle complicated issues and guarantee effective functioning. A number of algorithms are essential to the optimal location, size, and dispatch of distributed generation systems. This is a summary of some of the most widely used algorithms in the field of DG integration[40].

2.7.1. Linear Programming (LP)

A mathematical optimization technique called linear programming is intended for situations in which the constraints and the objective function are both linear. When it comes to distributed generation integration, LP is used to maximize the dispatch of distributed generation systems and ascertain the best use of such resources. While following linear restrictions, LP assists in maximizing benefits or lowering expenses.

2.7.2 Mixed-Integer Linear Programming (MILP)

MILP extends the capabilities of LP by allowing the inclusion of integer variables. This is particularly useful when dealing with discrete decision variables, such as the number of DG units or their specific configurations. MILP is instrumental in modeling intricate constraints, ensuring realistic representations of the complexities involved in DG system integration.

2.7.3. Non-linear Programming (NLP)

Non-linear Programming is employed when optimization problems involve non-linear objective functions and/or constraints. In the context of power systems, NLP is frequently used to optimize power flow within the grid and fine-tune the operation of DG systems. This flexibility allows for a more accurate representation of the dynamic and non-linear nature of power distribution networks.

2.7.4. Heuristic Algorithms

Heuristic algorithms provide approximate solutions to optimization problems, especially when exact solutions are computationally infeasible. These algorithms are valuable for optimizing DG system integration, offering a balance between solution quality and computational efficiency. Heuristic algorithms, such as Genetic Algorithms, Particle Swarm Optimization, and Simulated Annealing, are adept at navigating complex, multi-dimensional search spaces to identify near-optimal solutions within a reasonable timeframe.

2.8. Algorithms Used in Distributed Generation (DG) Integration

The integration of Distributed Generation (DG) into electrical grids demands sophisticated optimization techniques to address diverse challenges. Several algorithms have proven effective in optimizing different facets of DG integration, ranging from placement and sizing decisions to dispatch strategies and power flow optimization. Here are notable algorithms employed in this critical domain.

Particle Swarm Optimization (PSO)

PSO is a heuristic optimization algorithm inspired by the collective behavior of organisms such as birds and fish. It operates on a population of potential solutions, iteratively adjusting their parameters to find an optimal solution[41].

PSO is extensively used for optimizing the placement and sizing of DG systems within distribution networks. Its ability to efficiently explore solution spaces makes it particularly effective in solving complex optimization problems associated with DG[41].

Genetic Algorithm (GA)

GA is a heuristic algorithm modeled after natural selection processes. It evolves a population of potential solutions through genetic-inspired operations like crossover and mutation.

GA plays a key role in optimizing the dispatch of DG systems. By evolving and selecting the fittest solutions, GA navigates solution spaces effectively, providing robust strategies for managing and dispatching power from DG sources[42].

Interior Point Method (IPM)

IPM is a numerical optimization method designed for solving linear and mixed-integer linear programming problems. It iteratively moves toward the optimal solution within the feasible region.

IPM is applied to optimize the placement and sizing of DG systems. Its efficient handling of linear constraints contributes to the optimal allocation of DG resources within distribution networks[43].

Newton-Raphson Method

The Newton-Raphson method is an iterative numerical technique for finding successively better approximations of the roots of a real-valued function.

Commonly used to optimize the power flow in the grid, the Newton-Raphson method helps achieve an optimal distribution of power, considering both conventional and DG sources. It is instrumental in optimizing the operation of DG systems within the grid.

These algorithms stand as pillars in addressing the intricacies of DG integration, offering versatile solutions to enhance the efficiency, reliability, and sustainability of power distribution networks[44].

2.9. The key characteristics of DG include

Decentralization: DG units are spread out along the whole distribution network, frequently residing inside or close to load centers. With less need for extensive long-distance power transmission due to this decentralization, transmission losses are decreased and system resilience is increased.

Diverse Energy Sources: DG systems obtain their energy from a variety of sources, such as solar energy, wind energy, natural gas, and biogas. An energy mix that is stronger and more sustainable benefits from this diversity.

Intermittency and Variability: Numerous DG sources, especially those that are renewable like solar and wind, display intermittent and variable power patterns. To maintain grid stability in the face of this innate variability, meticulous planning is necessary.

2.10. The Role of Optimization in DG Integration

The application of optimization methods in DG integration is also covered by theoretical underpinnings. The best sites and capacity for DG units are decided using optimization techniques. In order to do this, objective functions must be created that take into account variables including decreasing power losses, enhancing voltage profiles, and respecting limitations. The full potential of DG integration inside distribution networks can be realized by using optimization techniques like Particle Swarm Optimization (PSO), Genetic Algorithms (GA), and Mixed-Integer Linear Programming (MILP)[45].

In conclusion, the theoretical underpinnings of distributed generation cover its definition, traits, advantages, and difficulties. Understanding the role optimization approaches play in establishing ideal DG placement and sizing, which serves as the cornerstone for successful DG integration inside distribution networks, is another aspect of this task. The ensuing examination of techniques and empirical investigations in the literature review is built up by this theoretical framework.

2.11. Methodological Approaches

Optimizing the location and sizing of DG units in distribution networks is a complex undertaking that demands a systematic and analytical approach. Researchers and engineers have explored various methodological approaches and optimization techniques to tackle this multifaceted challenge. This section outlines key methodological approaches commonly employed in the literature:

Mathematical Modeling

The foundation of many optimization studies in DG integration is mathematical modeling. To represent the behavior of DG units, distribution networks, and related characteristics, researchers employ mathematical equations. These models accurately represent the physics of power flow, voltage regulation, and distribution system losses.

Load Flow Analysis. Under various operating situations, load flow models examine the electrical behavior of the distribution network. These models give researchers the ability to assess voltage profiles, line losses, and power flows, giving decision-makers for the placement and sizing of DGs crucial data.

Researchers create optimization formulations that take into account a range of objectives, constraints, and decision variables. The use of renewable resources should be maximized, voltage stability should be improved, and power losses should be kept to a minimum. Voltage caps, DG capacity restrictions, and load demand criteria are all examples of constraints. The location and size of DG units are determined by decision variables[46].

Heuristic and metaheuristic Algorithms

Given the computational complexity of optimization problems in DG integration, heuristic and metaheuristic algorithms have gained prominence. These algorithms offer efficient solutions to large-scale problems by searching through solution spaces for near-optimal solutions.

Particle Swarm Optimization (PSO). PSO is a popular metaheuristic algorithm inspired by the social behavior of birds flocking or fish schooling. It employs a population of particles that traverse the solution space while adjusting their positions based on individual and group experiences[47], [48]. PSO has shown promise in optimizing DG placement and sizing by exploring the trade-offs between objectives like losses and voltage regulation.

Genetic Algorithms (GA). Genetic algorithms are inspired by the process of natural selection and genetic inheritance. They evolve a population of potential solutions through a series of selection, crossover, and mutation operations. GAs have been applied to DG optimization problems, often yielding solutions that approximate the global optimum.

Ant Colony Optimization (ACO). ACO is inspired by the foraging behavior of ants. It uses pheromone trails to guide the search process, with solutions represented as paths. ACO has been applied in DG placement studies, particularly in scenarios where network expansion is considered.

2.12. Multi-Objective Optimization

In many real-world circumstances, optimizing DG location and sizing entails balancing numerous competing goals. In order to achieve these trade-offs, multi-objective optimization approaches seek to identify a set of solutions.

Methods Based on Pareto the Pareto frontier, which represents the best trade-offs between competing objectives, is where Pareto-based techniques look for solutions. These techniques give decision-makers a variety of possibilities from which to select, enabling more informed choices.

2.13. Simulation-based approaches

Simulation-based approaches use software tools like MATLAB, PSCAD, or Open DSS to model distribution networks and evaluate the performance of different DG configurations.

Monte Carlo Simulation. Monte Carlo simulations generate random scenarios to assess the robustness of DG configurations under various conditions. This approach helps researchers account for uncertainties in load and renewable generation.

2.14. Case Studies and Field Trials

Field trials and real-world case studies are essential for testing theoretical frameworks and approaches. These studies offer factual information and useful insights on the drawbacks and advantages of DG integration.

Projects for demonstration are frequently carried out by utility companies and academic institutions to evaluate the effects of DG integration in real distribution networks. These initiatives provide insightful insights into the technical, financial, and legal facets of DG[48].

In conclusion, the literature uses a wide range of methodological techniques to address the optimization of DG position and sizing in distribution networks. Our understanding of strategically deploying DG units for enhanced network performance is being advanced by mathematical modeling, heuristic algorithms, multi-objective optimization, simulation-based approaches, and real-world case studies. The utilities, policymakers, and other stakeholders involved in DG integration programs rely heavily on these methodologies to help them make decisions.

2.14.1. Empirical Studies

Empirical studies and real-world case examples provide essential insights into the practical implications and challenges of optimizing the location and sizing of DG units within distribution networks. These studies offer a bridge between theoretical models and on-ground realities, helping to validate methodologies and inform decision-making processes.

Case Studies of DG Integration

Numerous case studies have been conducted across different geographical regions and distribution networks to assess the impact of DG integration. These case studies involve the actual deployment of DG units, either renewable or conventional, and the observation of their performance within the distribution system.

Renewable DG Integration. Solar photovoltaic (PV) systems, wind turbines, and small-scale hydropower installations have been subject to extensive case studies. These studies evaluate the placement and sizing of renewable DG units to optimize grid performance. For instance, researchers have examined the impact of rooftop solar PV installations in urban areas, highlighting the benefits of localized generation and the challenges of intermittent generation patterns.

Combined Heat and Power (CHP) Systems. CHP systems, which simultaneously produce electricity and useful heat, have been deployed in various industrial and commercial settings. Case studies assess CHP systems' economic feasibility and operational advantages while optimizing their location and capacity to meet electrical and thermal demands[49].

Grid Resilience and Reliability

Empirical studies often focus on the improvement of grid resilience and reliability through DG integration. These studies investigate how well-placed DG units can reduce outage durations, improve voltage profiles, and enhance system stability during disturbances.

Microgrid Deployments: Microgrids, which are small-scale, self-contained grids with their own sources of generation and often DG components, have been extensively studied in various contexts. Case examples include microgrids in remote or islanded communities, military bases, and critical infrastructure facilities. These studies demonstrate the effectiveness of microgrids in maintaining power supply during grid failures and optimizing DG configurations for enhanced resilience[50].

Regulatory and Policy Implications

Empirical studies also delve into the regulatory and policy frameworks surrounding DG integration. These studies assess how existing regulations impact the deployment of DG units and provide insights into potential regulatory adjustments to incentivize optimal DG placement and sizing.

Impact of Feed-in Tariffs. Some studies examine the impact of feed-in tariffs and net metering policies on DG integration. They analyze how these incentives affect the location and capacity decisions of DG system owners and their impact on distribution network performance.

Data-Driven Approaches

Empirical studies often rely on data-driven approaches, utilizing data collected from sensors, smart meters, and grid monitoring systems to assess the performance of DG units and their interaction with the distribution network.

Load and Generation Data Analysis: Researchers leverage historical load and generation data to understand how DG units influence local load profiles and the grid's ability to balance supply and demand. This analysis aids in optimizing DG capacity and placement decisions.

Environmental Impact Assessments

Some empirical studies explore the environmental implications of DG integration. They evaluate the reduction in greenhouse gas emissions, air quality improvements, and the environmental sustainability of distribution networks with integrated DG sources[51].

In summary, empirical studies and real-world case examples play a pivotal role in bridging the gap between theoretical models and practical applications of DG integration. These studies offer valuable insights into the performance, challenges, and benefits of DG units placed optimally within distribution networks. They also inform decision-makers, utilities, and policymakers about the regulatory, economic, and environmental implications of DG integration initiatives.

2.15. Particle Swarm Optimization (PSO)

A strong and popular optimization technique called particle swarm optimization (PSO) was developed in response to the social behavior of fish schools and flocks of birds. PSO, which was first developed by Eberhart and Kennedy in the 1990s, has grown in prominence for its ability to address a variety of optimization issues, including those pertaining to DG integration in distribution networks[52].

2.15.1 Principles of Particle Swarm Optimization

PSO operates on the principle of collective intelligence, where a group of individuals, referred to as particles, collaboratively searches the solution space to find optimal or near-optimal solutions. The fundamental concepts underlying PSO include:

Particles: Each particle represents a potential solution within the search space. In the context of optimizing DG placement and sizing, particles correspond to different combinations of DG unit locations and capacities.

Position and Velocity: Each particle has a position and a velocity in the solution space. The position represents a potential solution, while the velocity determines how the particle moves through the space. Particles adjust their positions and velocities iteratively to converge toward better solutions[53].

Global and Local Bests: Particles track two types of "best" solutions. The global best (gbest) is the best solution found by any particle in the entire swarm. The local best (lbest) is the best solution found by a particle within its neighborhood. These best solutions guide particles' movements in the search space.

Particle Movement: Particles update their positions based on their current velocity and the locations of the gbest and lbest solutions. This movement is driven by exploration (following gbest) and exploitation (following lbest) to find the optimal solution.

Iterative Process: PSO is an iterative process where particles continuously update their positions and velocities. Over iterations, the swarm collectively converges toward a solution that optimizes the objective function(s).

2.15.2 Application of PSO in DG Optimization

The application of PSO in optimizing DG location and sizing within distribution networks involves several key steps:

Objective Function: The first step is formulating an objective function that quantifies the optimization goals. In DG integration, this typically involves minimizing distribution losses, improving voltage profiles, or maximizing the utilization of renewable resources while adhering to various constraints.

Decision Variables: The decision variables are the parameters that need to be optimized, which include the location and size (capacity) of DG units. The PSO algorithm adjusts these variables to achieve the best objective function value.

Initialization: The PSO algorithm begins with the initialization of a swarm of particles. Each particle represents a potential solution, where the positions of particles correspond to different combinations of DG locations and sizes.

Velocity Updates: In each iteration, particles update their velocities based on their current positions, gbest, and lbest solutions. Velocity adjustments drive the particles toward promising regions of the solution space.

Position Updates: After updating velocities, particles adjust their positions accordingly. These position updates represent potential DG configurations.

Fitness Evaluation: The objective function is evaluated for each particle's current position to determine its fitness or suitability as a solution. Particles with better fitness values contribute to the gbest and lbest solutions.

Convergence and Termination: The PSO algorithm iterates through these steps until a termination criterion is met. Common termination criteria include a maximum number of iterations or achieving a specified level of convergence.

2.15.3 Advantages of Using PSO in DG Optimization

Particle Swarm Optimization offers several advantages when applied to DG optimization problems within distribution networks:

Global and Local Search: PSO combines global exploration (through gbest) and local exploitation (through lbest), enabling efficient search in the solution space. This balance facilitates the discovery of both optimal and near-optimal solutions.

Ease of Implementation: PSO is relatively easy to implement and does not require extensive problem-specific parameter tuning, making it accessible for researchers and practitioners.

Flexibility: PSO can handle multi-objective optimization problems, considering multiple conflicting objectives simultaneously.

Robustness: PSO can efficiently handle complex, nonlinear, and non-convex objective functions, which are often encountered in DG optimization scenarios.

2.15.4 Challenges and Considerations

While PSO is a powerful optimization technique, it is not without its challenges and considerations:

Parameter Selection: Tuning PSO parameters such as swarm size, inertia weight, and cognitive and social parameters can impact the algorithm's performance.

Convergence: PSO may converge to local optima in some cases. Researchers often explore strategies to enhance global exploration and escape local minima.

Scalability: The computational complexity of PSO can increase with larger problem sizes, necessitating efficient algorithms, and parallel computing techniques.

In summary, Particle Swarm Optimization (PSO) has emerged as a valuable tool for optimizing the location and sizing of distributed generation units within distribution networks. Its inherent ability to balance global exploration and local exploitation makes it particularly well-suited for solving complex DG optimization problems. As the cornerstone of this thesis, the application of PSO will be explored in depth to address the optimal placement and sizing of DG units within the IEEE 69 Bus Test system, contributing to the advancement of the field of power systems engineering and DG integration practices.

2.16. The IEEE 69 Bust Test System

The IEEE 69 Bus Test System, often referred to as the IEEE 69-bus system, is a well-known and widely used test system in the field of power systems engineering and research. It is a simplified representation of a real-world electrical distribution network, designed to serve as a benchmark for studying various aspects of power system analysis, optimization, and control. Below, I'll provide a detailed overview of the IEEE 69 Bus Test System, including its purpose, characteristics, and key features:

2.16.1. Purpose and Significance

The IEEE 69 Bus Test System serves several important purposes in the field of power systems:

Benchmarking and Testing: It provides a standardized platform for researchers, engineers, and students to develop and test new algorithms, methodologies, and control strategies for power systems analysis, optimization, and simulation.

Education and Training: It is commonly used in educational institutions as a teaching tool to help students understand the principles of electrical power systems, including load flow, fault analysis, and stability analysis.

Comparative Studies: Researchers use this system to compare the performance of different algorithms and approaches for solving power system problems. It enables fair and consistent comparisons among various techniques.

Model Validation: The IEEE 69 Bus Test System can be used to validate the accuracy and performance of software tools used for power system simulation and analysis.

2.16.2 Network Configuration

The IEEE 69 Bus Test System is a simplified representation of an electrical distribution network. It includes various components, such as:

Buses: There are 69 buses in the system, each representing a point in the network where electrical devices are connected.

Transmission Lines: The system includes multiple transmission lines connecting different buses. These lines represent the physical infrastructure that carries electrical power between different parts of the network.

Transformers: Transformers are used to change the voltage levels between different buses. They play a crucial role in stepping up or stepping down voltages as needed in the network.

Loads: Electrical loads are connected to buses, representing the electrical demand of consumers in the system.

Generators: Some buses have generators, which represent power generation sources connected to the network. These generators can be used to simulate different generation scenarios.

2.16.3. Data and Specifications

The IEEE 69 Bus Test System is well-documented, and detailed data, including bus data, line data, transformer data, load data, and generator data, are available. This data allows researchers to perform load flow analysis, fault analysis, and other power system studies accurately.

2.16.4. Application Areas

The IEEE 69 Bus Test System is used for a wide range of applications and studies in power systems engineering, including:

Load Flow Analysis: Researchers use it to study the steady-state behavior of the network, including voltage profiles and power flows under different operating conditions.

Fault Analysis: It is used to analyze the behavior of the network during various fault conditions, such as short circuits, and to assess protection schemes.

Stability Analysis: Researchers use the system to assess the transient and dynamic stability of the network under disturbances and to design control strategies for maintaining stability.

Optimization Studies: The system is employed to perform optimization studies, such as optimal power flow (OPF), to determine the optimal settings of generation and control devices to minimize costs or maximize efficiency.

2.16.5. Research and Development

Numerous research papers, studies, and projects have been conducted using the IEEE 69 Bus Test System. Researchers continuously use this system as a platform to develop and validate new algorithms, control strategies, and optimization techniques for various power system problems.

In summary, the IEEE 69 Bus Test System plays a vital role in power systems research, education, and development. Its well-defined structure, data availability, and versatility make it a valuable tool for studying power system behavior and addressing complex engineering challenges in the field of electrical power distribution[54].

2.17. Research gap

Despite the fact that there is a growing corpus of research on the optimization of DG placement and sizing in distribution networks, more in-depth analysis and real-world application of Particle Swarm Optimization (PSO) are required specifically for the IEEE 69 Bus Test system. There can be a knowledge gap about the application of PSO to this particular network because previous studies may have concentrated on other optimization methods or alternative distribution systems.

This knowledge gap offers a chance to investigate PSO's efficacy in tackling the difficulties of DG integration, reducing power losses, enhancing voltage profiles, and observing various limits inside the IEEE 69 Bus Test system. Additionally, it offers the chance to prove PSO's viability and effectiveness as an optimization technique for comparable issues in other distribution systems, advancing power systems engineering and sustainable energy practices.

CHAPTER 3

RESEARCH METHODOLOGY

3.1. Introduction

The successful accomplishment of research objectives, as articulated in the title of this thesis, "Optimal Location and Sizing of Distributed Generation (DG) for IEEE 69 Bus Test System using Particle Swarm Optimization (PSO)," is contingent upon the systematic and robust implementation of a well-defined research methodology. This chapter delineates the comprehensive methodology utilized to address the research inquiries and attain the objectives outlined in this study[55], [56].

Research methodology, often referred to as the "backbone" of scientific investigation, offers a structured framework for data collection, analysis, interpretation, and validation. It is the means through which research endeavors transition from ideation to concrete findings and contributes significantly to the validity and reliability of research outcomes. In the context of this thesis, the research methodology provides a structured path to ascertain the optimal placement and sizing of distributed generation units within the IEEE 69 Bus Test System, elucidating its significance within the broader context of power systems engineering and distributed energy resources.

3.2 Research Methodological Framework

The research methodology unfolds in a structured sequence of stages, each tailored to fulfill the specific objectives of this study:

Data Collection and Preparation: The foundation of this research is grounded in the acquisition and refinement of essential data from reputable sources, including the IEEE 69 Bus Test System database. The data undergoes a meticulous validation and preprocessing process to ensure accuracy and consistency.

Problem Formulation: The definition and formulation of the optimization problem are of paramount importance. This stage involves establishing the objective function, which quantifies the optimization goals, as well as delineating the constraints that must be adhered to during the optimization process.

An objective function is formulated to represent the optimization problem, which involves minimizing the total power losses and improving the voltage profile of the distribution system. The objective function is formulated based on the PSO algorithm, which involves adjusting the positions and velocities of a swarm of particles in the search space to find the optimal placement and capacity of DG sources[56].

Particle Swarm Optimization (PSO) Implementation: At the core of this research lies the utilization of the Particle Swarm Optimization (PSO) algorithm. This section elucidates the principles of PSO, its parameterization, and its application in solving the optimization problem, ultimately driving the identification of optimal DG configurations.

Simulation and Experimentation: Utilizing MATLAB as the simulation tool, this stage enables the comprehensive examination of DG integration scenarios within the IEEE 69 Bus Test System. The PSO algorithm is executed, yielding optimal DG placements and sizes.

The distribution system is modeled using appropriate software (MATLAB), to create an accurate representation of the system. The model includes all relevant parameters, such as line resistance, reactance, and capacitance, as well as transformer parameters and load demand data.

Data Analysis and Results Interpretation: The findings emanating from the simulation experiments are subjected to thorough data analysis, enabling the interpretation of the optimization outcomes. The impact of DG integration on distribution network performance is assessed, and the implications of the results are expounded upon.

The optimized distribution system model is then simulated and analyzed to evaluate its performance and efficiency. This includes analyzing the impact of the optimal placement and capacity of DG sources on the power losses and voltage profile of the distribution system.

MATLAB (Matrix Laboratory) is a widely used software platform for numerical computing, data analysis, and algorithm development. It offers a comprehensive set of tools and functions that can be utilized for Particle Swarm Optimization (PSO), a popular optimization algorithm inspired by the collective behavior of social swarms. MATLAB provides several features that make it suitable for implementing and analyzing PSO algorithms. I will use this tool to simulate the system data before and after locating the optimal point and sizing of DG for 69 Bus test for IEEE.

Finally, the results of the simulation and analysis are validated through comparison with existing results in the literature or through experimental testing.

Ethical Considerations: The ethical dimensions inherent in the research process are scrutinized and discussed. Ensuring the adherence to ethical research practices is of paramount importance.

The elucidation of this research methodology is intended to serve as a guidepost, directing the reader through the systematic and rigorous process employed to address the central research objectives. Each stage is meticulously crafted to facilitate the attainment of insights into the optimal placement and sizing of distributed generation units within the IEEE 69 Bus Test System, ultimately contributing to the broader discourse surrounding power systems engineering and sustainable energy practices.

3.3. Problem Formulation

The primary objective of this research is to minimize the active power losses by integrating DG

placement in a distributed network with optimal location and capacity. The real power losses of the distribution system are obtained by summing up all the branches' active power losses as presented in Eq. (1). The Eq. (2) was used as the objective function (f_1) for this problem.

$$P_{loss} = \sum_{j=1}^{n_L} \frac{R_j (P_j^2 + Q_j^2)}{V_j^2} \tag{1}$$

$$f_1 = \min\left(P_{loss}\right) \tag{2}$$

Where P_{loss} is the total active power loss, n_L is the number of branches, R_j is the resistance of the branch between node j and $j+1$, V_j is the voltage at node j, $P_j + iQ_j$ is the complex power flowing from node j to node $j+1$.

The objective function (f_1) is subjected to different constraints namely equality constrains and inequality constraints.

a) **Equality constraints**

Equality constraint is the power flow as per Eq.3 and are satisfied by Backward Forward Sweep Algorithm (BFSA).

$$P_G = P_D + P_{Loss} - P_{DG} \tag{3}$$

Where P_G is the total power generated from substation, P_D is the power demand at node, P_{Loss} is the power loss in branches, P_{DG} is the power generated by distributed generation.

b) **Inequality constraints**

$$V_{L_i}^{\min} < V_{L_i} < V_{L_i}^{\max}, \quad i = 1, 2, 3, \ldots\ldots N_{bus} \tag{3}$$

Where $V_{L_i}^{\min}$ is the minimum voltage at ith bus, $V_{L_i}^{\max}$ is the maximum voltage at ith bus, V_{L_i} is the voltage at ith load bus, N_{bus} is the bus number.

$$P_{DG_{\min}} \leq P_{DG} \leq P_{DG_{\max}} \tag{4}$$

3.4. Penalty function

The "penalty function" is a method that's commonly utilized in optimization problems to handle limitations effectively and with ease. This method uses the penalty function for the variables that violate limitations to convert the constraint problem into an unconstraint problem. Restoring the voltages at each bus to within their typical operating range is necessary. In accordance with Equation 5, buses whose voltages exceed the limitations are penalized by multiplying them by the penalty factor (λ_{V_L}) and adding them to the primary objective function to create an enhanced objective function (F). The load flow computation according to the Backward Forward Sweep Algorithm (BFSA) has satisfied the equality conditions; this process is continued iteratively until the best solution is discovered.

$$F = f_1 + \sum_{i=1}^{N_{bus}} \lambda_{V_L} \left(V_{L_i} - V_{L_i}^{\lim} \right)^2 \tag{5}$$

The limit violations at buses ($V_{L_i}^{\lim}$)are given in Eq. (6).

$$V_{L_i}^{\lim} = \begin{cases} V_{L_i}^{\max} & \text{if} \quad V_{L_i} > V_{L_i}^{\max} \\ V_{L_i}^{\min} & \text{if} \quad V_{L_i} < V_{L_i}^{\min} \end{cases} \tag{6}$$

Where F is the augmented objective function, λ_{V_L} is the penalty factor for bus violating its limits, , V_{L_i} is the voltage at ith bus, $V_{L_i}^{\lim}$ is the voltage limit at ith bus, $V_{L_i}^{\min}$ is the minimum voltage at ith bus, $V_{L_i}^{\max}$ is the maximum voltage at ith bus then N_{bus} represents the bus number.

3.5. Voltage Stability Index (VSI) Method

The most sensitive node in the system is identified using the voltage sensitivity index. The system is more stable when DG is placed near node sites with low voltage levels. The definition of the voltage sensitivity index is:

$$V_{index} = \sqrt{\frac{\sum_{k=1}^{n}(1-V_k)}{n}} \tag{7}$$

Where V_k is the voltage at kth node and n is the bus number.

3.6. Loss Sensitivity Factor (LSF)

Loss sensitivity factor is calculated for determining the candidate nodes for placement of DG. Estimation of these sensitive nodes helps in reducing the search space and it is computed as per Eq.8.

$$\frac{\partial P_{loss}}{\partial P[k]} = \frac{2\times P[k]\times R[k]}{V_k^2} \tag{8}$$

Where P_{loss} is the power loss, $P[k]$ is the active power at kth node, $R[k]$ is the resistance between k-1 and k node, V_k is the voltage at kth node.

CHAPTER 4

INTEGRATION OF DGs into IEEE 69 BUSES

4.1. Introduction

In order to meet the problems presented by rising energy consumption, environmental concerns, and the requirement for a sustainable and robust electricity infrastructure, modernizing power systems is essential. With its dispersed power production capabilities that supplement conventional centralized generation sources, distributed generation (DG) emerges as a crucial alternative. When DGs are integrated into current power systems, careful consideration must be given to where and how big they should be placed in order to maximize system performance, reduce power losses, and increase overall reliability[57].

A useful tool for research and analysis is the IEEE 69-bus system, a benchmark power system that offers a realistic environment for DG integration analysis. The best locations and capacities of distributed generation (DG) units are determined in large part by optimization algorithms, which are a vital tool for academics and engineers working to find effective ways to integrate DGs into power networks. Particle Swarm Optimization (PSO), a heuristic algorithm influenced by the social behavior of organisms, is one such optimization technique.

The main goal of this research is to utilize PSO to determine where and how big to put DGs in the IEEE 69-bus system. The goal is to reduce power losses as much as possible while respecting limitations and making sure that the DGs are positioned carefully to improve system resilience. The IEEE 69-bus system is a perfect testbed for assessing the performance of the PSO algorithm in the context of DG integration since it has comprehensive bus, branch, and load data.

The methods for optimizing DG location and sizing using the PSO algorithm will be covered in detail in the upcoming sections. A fitness evaluation function will also be created to evaluate power losses for various DG setups. The final objective is to demonstrate how PSO, with an emphasis on the IEEE 69-bus system, may be a useful tool in improving the integration of DGs into power systems.

4.2. Sizing of the DGs

Determining the ideal capacity of distributed generation (DG) units to be installed in a distribution system is the first step in the sizing process. The purpose of DG sizing is to minimize potential negative effects, such as voltage rise and power quality issues, while optimizing the positive effects of DG integration, such as decreased power losses, enhanced voltage profile, and greater reliability.

4.2.1. Factors Influencing DG Sizing

A distribution system's DG unit size should be determined by considering a number of important parameters. These elements can be roughly divided into three categories: economic, regulatory, and technical.

Load Characteristics: The distribution system's load profile, which includes peak demand, load variability, and load power factor, establishes the amount of DG capacity needed to meet demand without raising voltage levels.

DG Technology: The output characteristics and scaling requirements of distributed generation (DG) systems are dependent on their kind, which can include solar photovoltaic (PV), wind turbines, or combined heat and power (CHP) units. For example, the solar radiation of PV systems causes their output to vary, whereas wind turbines have intermittent output due to variations in wind speed.

DG Location: A DG unit's impact on power losses and the voltage profile depends on where it is located within the distribution system. While DG units at feeder ends may cause voltage rise problems, those closer to load centers can efficiently cut power losses.

Cost considerations: The possible advantages of DG integration must be weighed against the cost of installing and operating DG, which includes the cost of fuel, equipment, installation, and maintenance.

Grid Stability and Reliability: DG unit sizing should take into account how it will affect grid stability and dependability. Overvoltage and frequency control issues might arise from excessive DG penetration, necessitating the installation of energy storage devices or extra control mechanisms.

4.2.2. Techniques for Calculating DG Size

There are several techniques that may be used to figure out how big DG units should be in a distribution system:

Sensitivity Analysis: This technique examines how various DG unit sizes affect system metrics such as power losses, voltage profile, and protection coordination. The ideal DG size can be found by adjusting it and monitoring the system's reaction.

Optimization methods: The ideal DG sizes that reduce power losses, enhance voltage profile, or maximize system reliability can be found using optimization methods like genetic algorithms, particle swarm optimization, or linear programming. To determine the optimal answer, these algorithms might take into account a variety of goals and restrictions.

Analytical Approaches: Based on load characteristics, system parameters, and DG technology specifications, analytical formulas, and models can be utilized to estimate the necessary DG capacity. Although these methods yield fast estimates, they might not fully represent the intricate relationships that exist within the distribution system.

4.2.3. Considerations for DG Sizing

Some other factors to consider while sizing DG units in a distribution system are as follows:

Voltage management: To help attempts at voltage management and avoid problems with voltage rise, DG units should be sized appropriately. It can be necessary to use smart inverters, tap changers, or voltage regulators to keep appropriate voltage levels.

Protective Coordination: To provide safe operation during faults, the size of DG units should be synchronized with protective systems. It could be necessary to modify fault current limiters and protection relays to account for the contribution of DG units.

Power Quality: DG units have the potential to introduce harmonics and other power quality problems, especially if they are based on inverters. To ensure acceptable power quality levels, DG units can be sized correctly and mitigation measures like harmonic compensators and filters can be used.

The size of distributed generation (DG) sources, like wind and photovoltaic (PV), should take into account the inherent variability and intermittency of these sources. Weather forecasting, demand-side management techniques, and energy storage technologies can all be used to control renewable distributed generation fluctuation and maintain system stability.

In order to maximize a distribution system's performance and dependability, DG unit sizing is essential. Benefits of DG integration can be maximized while reducing potential obstacles by carefully evaluating the several aspects impacting DG size, using suitable sizing techniques, and adding extra considerations.

4.3. Particle Swarm Optimization (PSO) Algorithm

In the PSO algorithm, the search process is conducted by particles grouped in a swarm where each particle represents a candidate solution. Every particle is assigned a vector position ($x = [x_{1d}, x_{2d}, x_{3d}, ...x_{nd}]$) and vector velocity ($v = [v_{1d}, v_{2d}, x_{3d}, ...v_{nd}]$) and these two parameters change at every iteration of the search.

At the beginning of the search process, particles position and velocity are randomly generated (by means of the uniform random distribution) within their limits. This is done by considering the upper and lower bound and depending on the dimension, as framed in Eq. (9) and Eq. (10).

$$x_{id} = rand() \times \left(x_{id}^{\max} - x_{id}^{\min} \right) \tag{9}$$

$$v_{id} = rand() \times \left(v_{id}^{\max} - v_{id}^{\min} \right) \tag{10}$$

Particle velocity and position update are represented by Eq. (11) and Eq. (12) respectively.

$$v_{id}^{(k+1)} = wv_{id}^{(k)} + c_1 r_1 \left(p_{id}^{(k)} - x_{id}^{(k)} \right) + c_2 r_2 \left(p_g^{(k)} - x_{id}^{(k)} \right) \tag{11}$$

$$x_{id}^{(k+1)} = x_{id}^{k} + v_{id}^{(k+1)} \tag{12}$$

Where x_{id} is the position of ith particle in d-dimension, $x_{id}^{\max}$ is the maximum value of ith particle position in d-dimension, $x_{id}^{\min}$ is the minimum value of the ith particle position in d-dimension, v_{id} is the velocity of ith particle in d-dimension, $v_{id}^{\max}$ is the maximum value of ith particle velocity in d-dimension, $v_{id}^{\min}$ is the minimum value of the ith particle velocity in d-dimension, $rand, r_1, r_2$ are random numbers, c_1, c_2 are acceleration coefficients, w is the inertia factor, p_{id} id the personal best position of ith particle in d-dimension, p_g is the global best position of particle.

If, after each particle's position and velocity are updated, the value obtained exceeds the limit specified and violates the limits, it is returned to the permitted interval. Setting the outlying particle to the minimum or maximum limit, depending on the violated bound, is the standard procedure to keep particles on course and within the possible search region during the search process. The velocity equation is composed of three primary parts. The first component represents the inertia factor (w), as expressed in Eq.13.

$$w = w_{\max} - \left(\frac{w_{\max} - w_{\min}}{iter_{\max}} \right) \times iter \tag{13}$$

Where $w_{\max}$ is the maximum inertia factor, $w_{\min}$ the minimum inertia factor, and $iter_{\max}$ the current iteration. The purpose of the inertia weight is to regulate the particle's velocity within the search space. The second word refers to the cognitive component that represents the particle's personal leaning, or the information exchanged between the particle and its own personal best particle during each repetition. The information sharing between a particle and the worldwide best particle of the entire swarm during each iteration is represented by the third component, which stands for the social component.

Figure 1 and Figure 2, respectively, show the vector diagram that depicts the PSO working principle and the associated flow chart diagram. "" (Eq.14) was inserted as a constriction factor to guarantee the convergence of the PSO algorithm. This component, which is multiplied by the velocity update equation to limit particle movement in search space, can be used in place of the inertia weight factor to regulate the PSO algorithm's convergence.

$$K = \frac{2}{\left| 2 - \varphi - \sqrt{\varphi^2 - 4\varphi} \right|}, \quad \varphi = c_1 + c_2, \quad \varphi > 4 \tag{14}$$

Where K is the constriction factor and, φ (which is usually greater than four) is the sum of acceleration coefficients. Power system optimisation (PSO) has garnered significant attention in the power system field for its potential application in various challenging optimization challenges. This is because to its easy implementation, straightforward concept, robust parameter control, and computing efficiency. Certain shortcomings, such as staying inside the local minima, convergence speed, and solution quality, have been identified, nevertheless. In order to improve its performance, several PSO variations have been proposed.

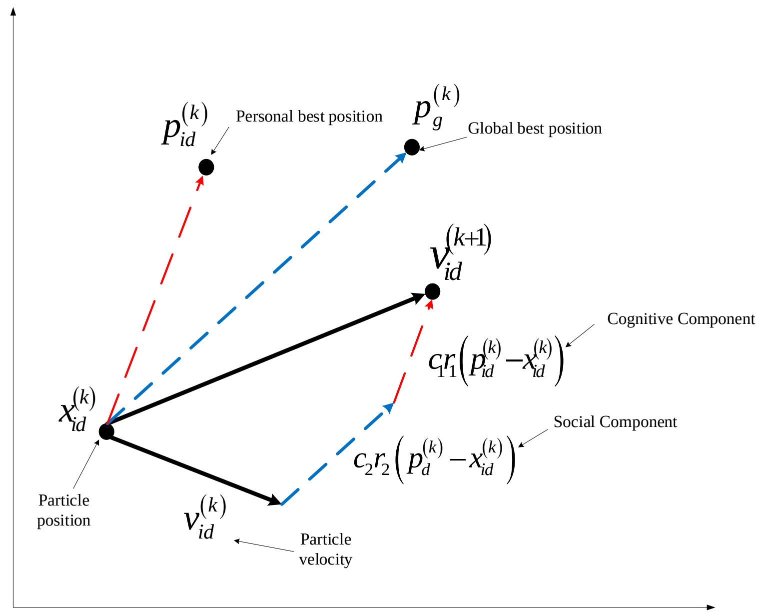


Figure 1: Vector diagram of the PSO working principle.

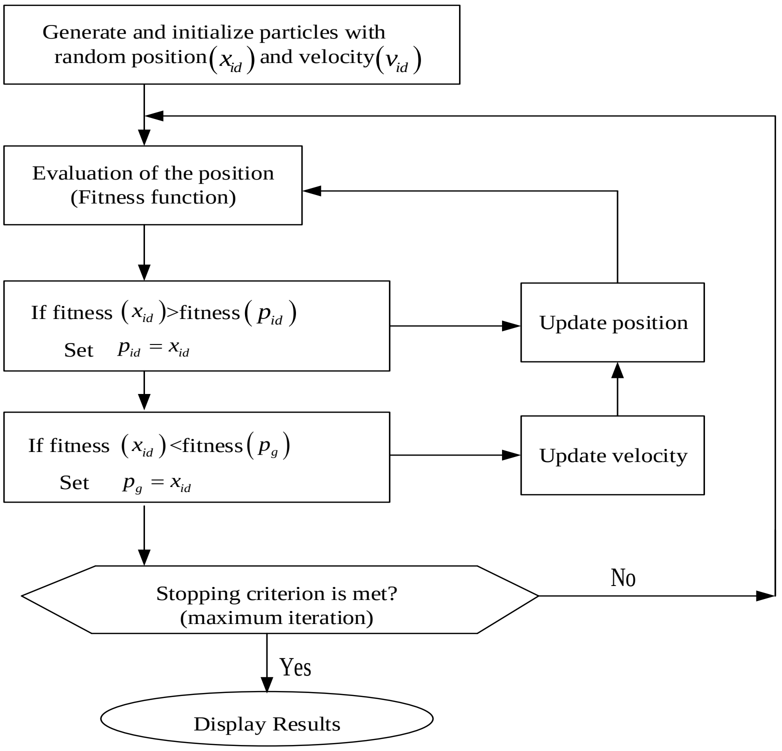


Figure 2: PSO algorithm flow chart.

Pseudo code of the PSO algorithm

Step 1: Load the Backward Forward Seep Algorithm (BFSA) as the Base case.

```
Step 2: Generate the initial population according to Eq.9 and Eq.10.
Step 3: Generate initial velocities in range $\left[-v_{\max}, v_{\max}\right]$.
Step 4: Evaluate the augmented objective function for the population generated.
Step 5: Initialize personal best ( $p_{id} = x_{id}$ ).
Step 6: Choose the best solution having minimum loss ( $p_g = \min\left(p_{id}\right)$ ).
Step 7: Set cycle to 1 and maximum iteration.
Step 8: Repeat the process.
Step 9: Compute the inertia weight by Eq.13
Step 10: Compute the velocity by Eq.11 and control if is within its limits.
Step 11: Update the position of particle by equation Eq.12, then check if the positions lie within $[x_{\min}, x_{\max}]$.
Step 12: Conduct the evaluation of the augmented objective function.
Step 13: If $f(x_{id}^{(k)}) < f(p_{id}^{(k)})$, set $p_{id}^{(k)} = x_{id}^{(k)}$
            If $f(p_{id}^{(k)}) < f(p_{g}^{(k)})$,set $p_{g}^{(k)} = p_{id}^{(k)}$
            End if
      End if
Step 14: Memorize the global best solution found so far.
Step 15: cycle=cycle+1
Step 16: Until iteration=maximum iteration
```

CHAPTER 5
RESULTS AND DISUSSION

5.1. Introduction

The results of the Particle Swarm Optimization (PSO) technique, which was used to figure out how best to integrate Distributed Generators (DGs) into the IEEE 69-bus power system, are shown in this chapter. Finding the ideal locations and sizes for DGs was the main aim in order to reduce power losses in the system.

5.2. Optimal DG Placement and Sizing

Power Loss Configuration

The PSO algorithm effectively reached the best outcome for the configuration with the least amount of power loss. The following is the recommended placement and size of DGs.

Optimal DG Placement

The parameters considered during the implementation of PSO algorithm are presented in the table below:

Table 1: Parameters identification

S/N	**Parameter**	**Value**
1	Population size (Number of particles)	200
2	Maximum number of iterations	200
3	Maximum value of inertia weight factor ($w_{\max}$)	0.9
4	Minimum value of inertia weight factor ($w_{\min}$)	0.4
5	Acceleration coefficients c_1 & c_2	2.05
6	Penalty factor (λ_{V_L})	100000
7	Minimum value of voltage at bus ($V_{\min}$)	0.9 p.u
8	Maximum value of voltage at bus ($V_{\max}$)	1.1 p.u
9	Minimum value of distributed generation ($P_{DG_{\min}}$)	0kW
10	Maximum value of distributed generation ($P_{DG_{\max}}$)	2500kW

IEEE 69-Bus System

The IEEE 69-Bus System was used to test the optimization of active power losses; figure 3 depicts the system's one-line diagram. The system is made up of seven T-off (deviations) and receives power from the main substation, which is situated at bus 1. The system has a total active power of 3802.1kW and a total reactive power of 2694.7kVar. When using the Backward Forward Sweep Algorithm (BFSA) as the basic case, the system experiences total active power losses of 221.8 kW.

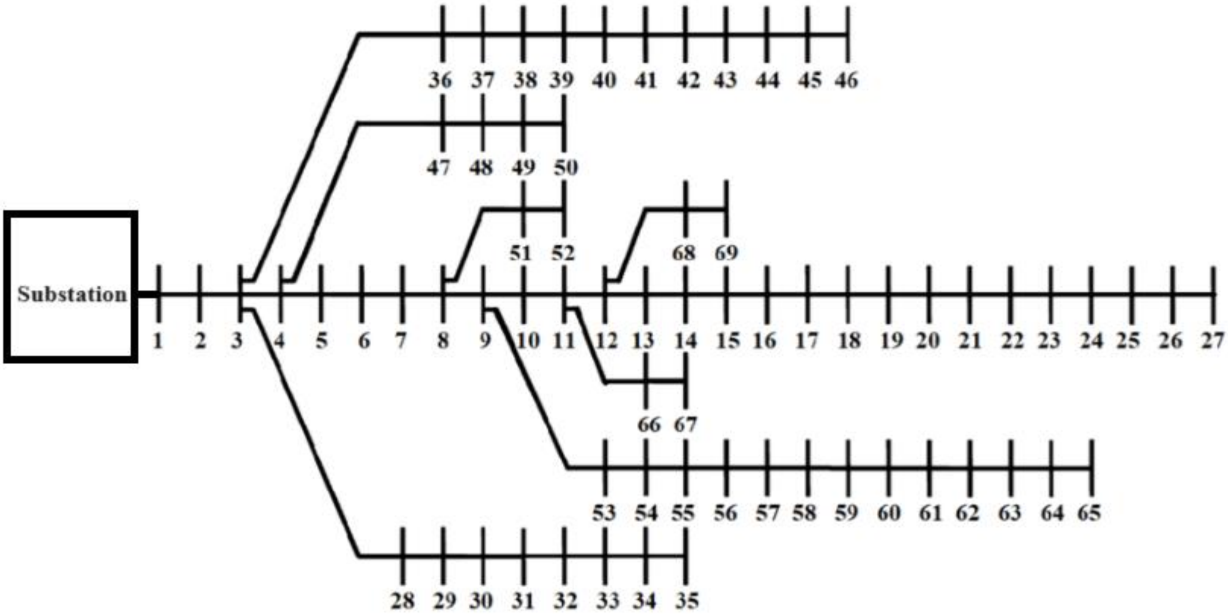


Figure 3: IEEE 69-Bus System

To determine which nodes were the weakest and required the placement of the DG, two methodologies were employed. The Voltage Sensitivity Index (VSI) and Loss Sensitivity Factor (LSF). Bus 56 was the candidate for DG placement, according to the computation of LSF, but bus 61 was suggested by the VSI as the candidate for DG placement. The two busses chosen as potential notes using both approaches are depicted in Figure 4..

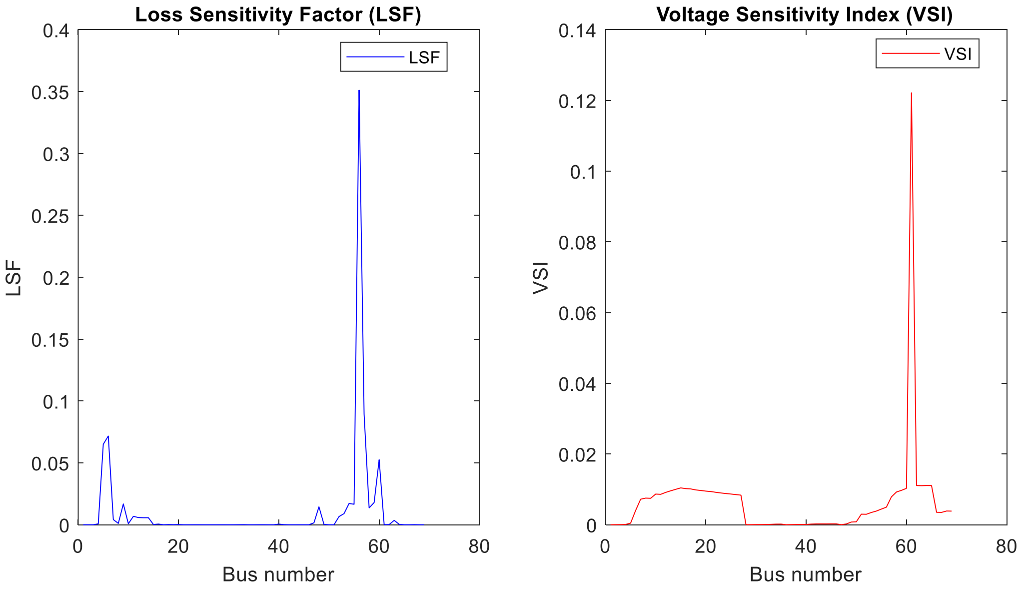
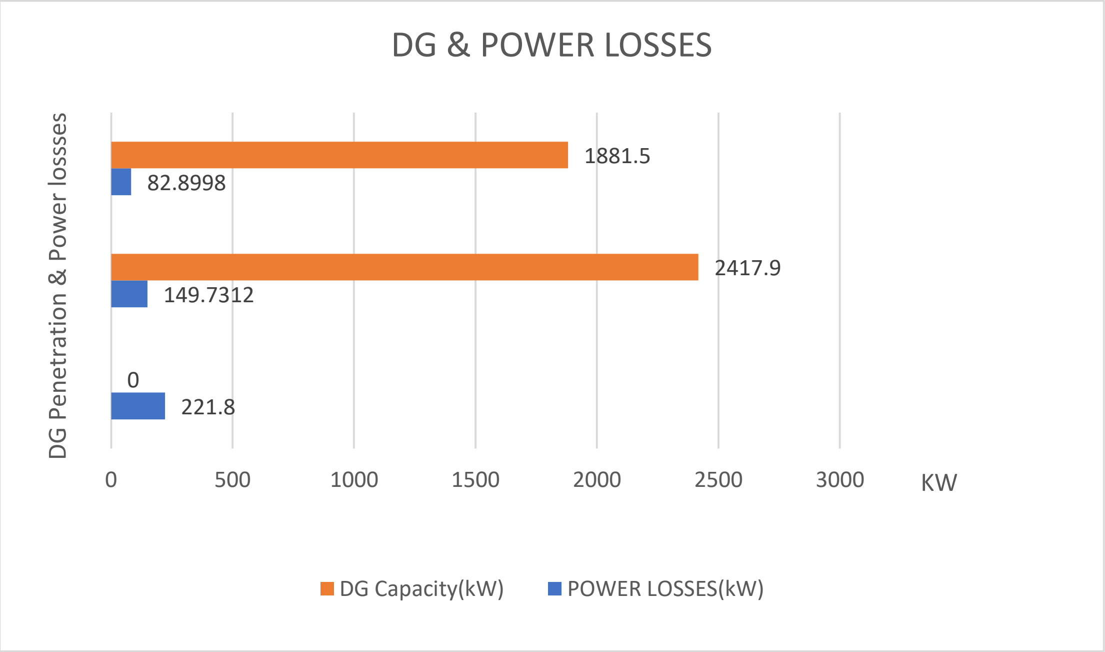


Figure 4: Loss Sensitivity Factor (LSF) and Voltage Sensitivity Index (VSI).

Application of Particle Swarm Optimization (PSO) algorithm has given the results of losses as presented in the table below:

Base Case (kW)	**Losses at Bus 56 (kW)**	**Losses at Bus 61 (kW)**	**DG at Bus 56 (kW)**	**DG at Bus 61 (kW)**
221.8	149.7312	82.8998	2417.9	1881.5



Placement of the 2417.9-square-meter DG at bus 56 reduces losses from 221.8 kW to 149.7312 kW, or 32.5% of the active power loss reduction. However, when the 1881.5kW DG is positioned at just 61, the losses are reduced from 221.8kW to 82.8998kW, resulting in a 62.6% reduction in active power losses. According to the statistics above, it is more efficient to place the DG at bus 61 than bus 56. Smaller DGs are more cost-effective to install since they minimize active power losses in the distribution system.

The algorithm's effectiveness has been demonstrated through the application of PSO, as its search space allows particles to look for even better optimal solutions. The enhancement of the voltage profile and the decrease of losses go hand in hand. The graph below demonstrates how improving the voltage profile in distribution networks is greatly aided by careful consideration of DG size and placement.

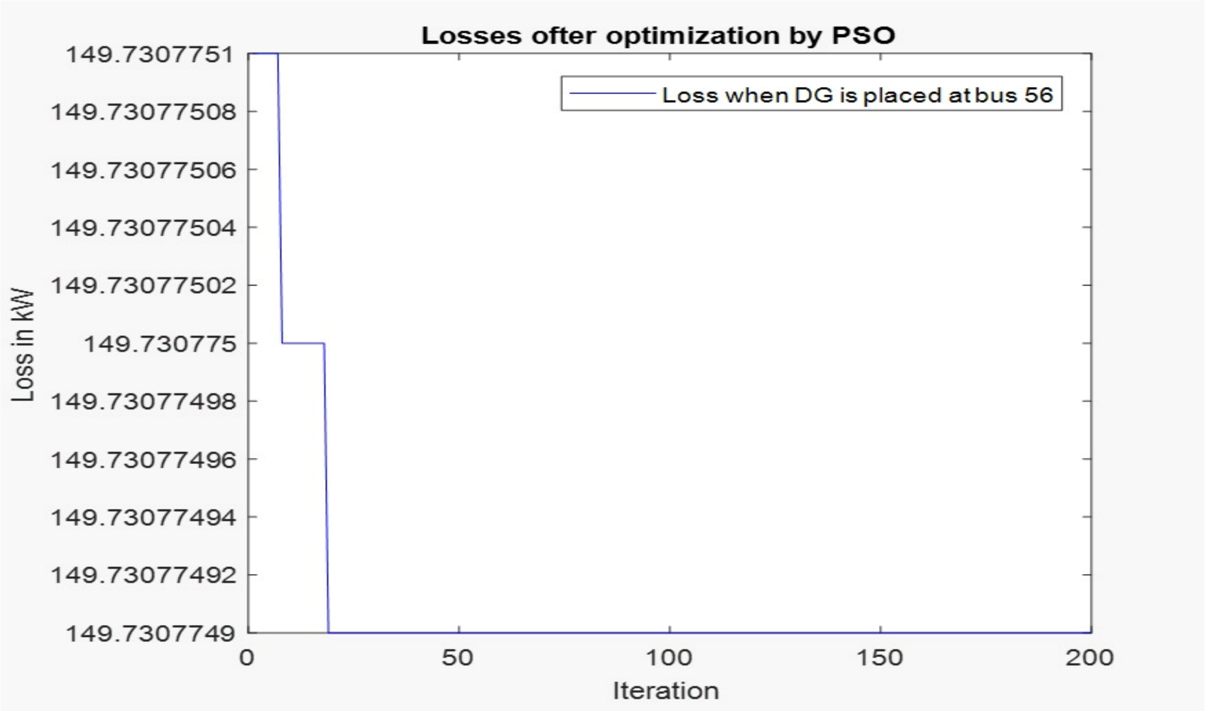


Figure 5. Power Losses when DG is placed at bus 56.

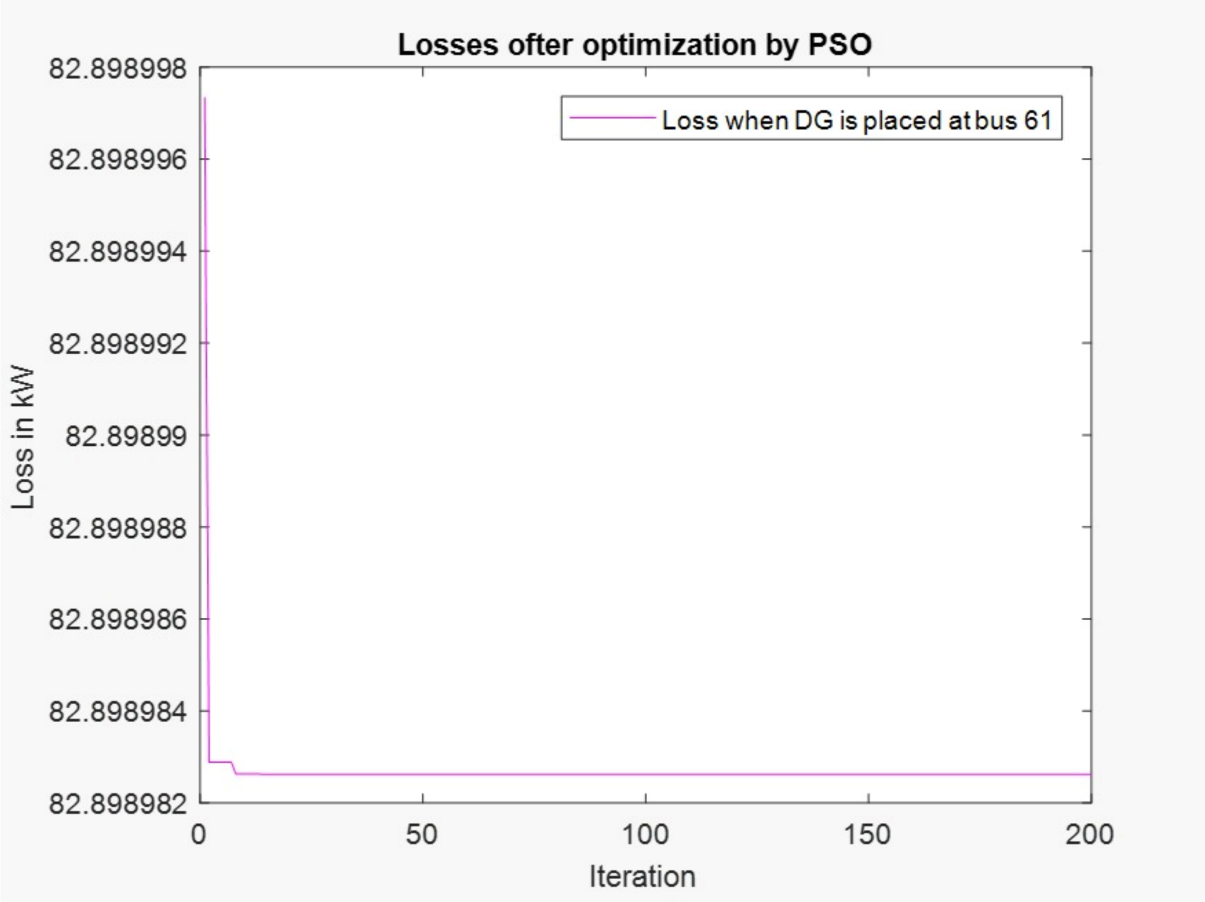


Figure 6. Power losses when DG is placed at bus 61

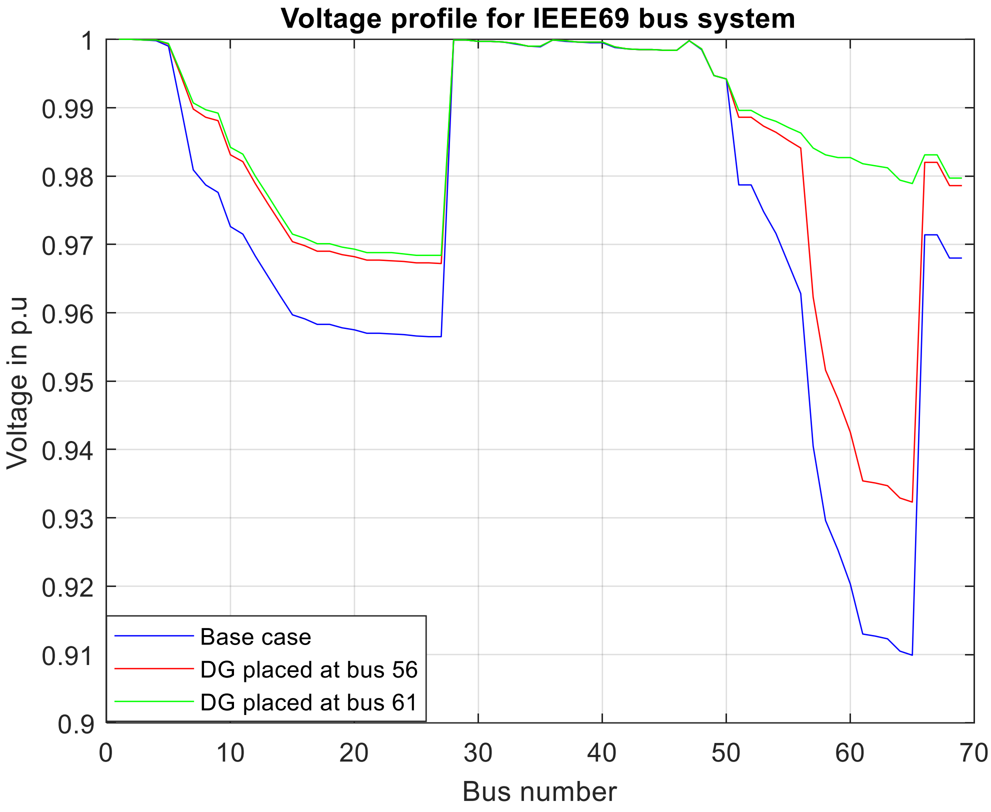


Figure 5: Voltage profile improvement by PSO in comparison to the base case

5.2. Discussion

Importantly, it should be noted that the optimal DG placement and sizing are dependent on a number of variables, including load patterns, network topology, and the capacity of the DGs. The trade-off observed in this study encourages further investigation into the complexities of power system optimization, particularly in balancing conflicting objectives. The convergence to identical optimal DG placement for both minimum and maximum power loss configurations raise intriguing insights.

The obtained results highlight PSO's potential as a useful optimization tool for DG integration and provide insightful information about how to improve system performance. Subsequent research endeavors may delve into the effects of diverse optimization factors and limitations, furnishing a thorough comprehension of the compromises entailed in DG integration tactics.

To sum up, the outcomes show how effective the PSO algorithm is at placing and scaling distributed generators (DGs) to minimize and maximize power losses. The conversation lays the groundwork for next studies that will improve optimization tactics and comprehend the complex dynamics of distributed generation in power networks.

CHAPTER 6

CONCLUSIONS

In order to decrease and, on the other hand, maximize power losses, we optimized the placement and sizing of Distributed Generators (DGs) in the IEEE 69-bus system through a thorough analysis that we conducted in this study. To achieve ideal setups, the Particle Swarm Optimization (PSO) method was used as a potent tool.

Our analysis produced some really interesting findings about how DGs affect the power distribution system. We were able to locate configurations that both maximize and minimize power losses throughout the 69-bus system by utilizing PSO. The outcomes illuminated the ways in which DGs both mitigate and exacerbate power outages, offering a more complex picture of their effects on certain busses.

The ideal designs showed the value of precise DG placement and sizing in addition to demonstrating how well PSO works to find solutions that meet predetermined restrictions. Notably, a more thorough evaluation of each bus's contributions to the overall functioning of the system was made possible by the more thorough investigation of individual buses.

The capacity to modify DG locations and sizes to accommodate particular restrictions was one important result of 32.5% active power loss reduction limit by modifying the power losses at each bus. For real-world applications, where stringent system performance requirements must be met, this outcome is crucial.

To sum up, the incorporation of distributed generators (DGs) into the IEEE 69-bus system, with the assistance of PSO optimization, presents a viable approach to augmenting the robustness and effectiveness of power distribution networks. The study's conclusions add to the expanding corpus of research on the best way to deploy distributed generation (DG), providing operators and planners of power systems with useful information. The approaches and findings discussed here offer a useful starting point for future study and the use of sustainable and effective power distribution techniques as the energy landscape changes continuously.

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