Minimization of Power Loss with Reconfiguration of Distribution Systems

Dr. Alka Thakur [1]

[1] Research Supervisor, Department of Electrical Engineering,
Sri Satya Sai University of Technology and Medical Sciences, M.P., India.

Ramakoti Bhukya [2]

[2] Research Scholar, Department of Electrical Engineering,
Sri Satya Sai University of Technology and Medical Sciences, M.P., India.

Abstract

The solution that has been suggested combines sophisticated optimization algorithms with power flow analytic tools. A systematic methodology for determining the optimal reconfiguration of distribution systems to minimize power losses while adhering to various technical and operational constraints is presented in the thesis. This methodology is accomplished by utilizing mathematical optimization techniques such as mixed-integer linear programming (MILP), genetic algorithms, and particle swarm optimization. The crucial goal of decreasing power losses via the strategic redesign of distribution networks is the primary emphasis of this thesis. This study addresses important obstacles and possibilities in distribution system reconfiguration, beginning with a complete analysis of the current literature and approaches in the field. In order to provide the groundwork for the creation of innovative optimization strategies that are specifically suited to meet the requirements of power loss reduction, it is necessary to conduct comprehensive research of the theoretical underpinnings and practical consequences of distribution system optimization. One of the most important strategies for improving the effectiveness and dependability of electrical networks is the reconfiguration of distribution systems, which has seen significant growth in recent years. A comprehensive investigation of the theoretical underpinnings, techniques, and practical consequences of distribution system reconfiguration is presented in this paper. It starts with a review of the current literature in order to identify the most important difficulties, approaches, and applications that are linked with the reconfiguration of distribution systems. Subsequently, various optimization strategies are suggested in order to solve these issues and optimize the reconfiguration of the distribution system. When it comes to ensuring that contemporary power grids are able to supply energy in a manner that is both efficient and dependable, the optimization of distribution networks is of tremendous significance. Clarification is provided about the actual use of the optimization approaches that have been established within the operations of distribution networks in the real world. This highlights the tangible advantages that are available to utility companies, grid operators, and end-users alike. The approaches and insights that are presented in this article provide the framework for additional technological advancements in distribution system optimization.

Keywords: *Mixed-Integer Linear Programming, Tremendous Significance, Reconfiguration.*

1. Introduction

The motivation for distribution system reconfiguration in the context of minimizing power loss is multifaceted, driven by the imperative to enhance network efficiency, accommodate renewable energy integration, leverage smart grid technologies, meet regulatory requirements, and achieve economic benefits. Utility companies have the ability to reduce power losses, improve voltage control, strengthen system resilience, and promote the transition to a more sustainable and resilient energy future by proactively restructuring the distribution network. However, in order to realize these advantages, it is necessary for stakeholders to work together, investments to be made in infrastructure and technology, and a dedication to innovation and continual improvement in the design and management of distribution systems. This helps to ensure that the supply of energy to end-users is continuous and smooth.

Voltage stability may be compromised, voltage fluctuations can be made worse, and the danger of voltage violations and equipment failures can be increased when there is an excessive amount of power wasted. Grid operators are able to improve system dependability, keep voltage within acceptable limits, and reduce the danger of cascade failures and blackouts by significantly reducing the amount of power that is lost by intentional reconfiguration of distribution networks. In addition, legal obligations, worries about the environment, and economic incentives all give further impetus for the reconfiguration of distribution systems. An growing number of regulatory agencies are mandating that utilities increase their energy efficiency, cut their emissions of greenhouse gases, and strengthen their grid's resilience to the effects of climate change and severe weather events.

The reduction of the carbon footprint of electricity generating, the optimization of resource usage, and the enhancement of system dependability are all goals that may be aligned with the reconfiguration of distribution networks to reduce power losses. In addition, utilities are encouraged to invest in measures that increase network efficiency and lower operating costs over the long term by encouraging them to do so via the use of financial incentives such as performance-based regulation, energy efficiency incentives, and carbon pricing systems. In addition, the increasing focus placed on grid modernization and smart grid technology is a driving force behind the reconfiguration of distribution systems. Recent developments in sensing, communication, and control technology have made it possible for utilities to generate data in real time, monitor the operation of their systems, and react in a dynamic manner to changing circumstances. Utility companies are able to develop optimum reconfiguration techniques that are able to react to swings in load, generation, and market circumstances by using data analytics and prediction algorithms. Smart grid solutions, which include advanced metering infrastructure (AMI), distribution automation (DA), and demand response (DR) programs, further improve the efficiency of reconfiguration by providing more granular control over network operations and supporting demand-side management activities. These solutions are examples of smart grid solutions. There is a growing penetration of renewable energy sources and distributed generating technologies, which is another key impetus for the reconfiguration of distribution systems. Distributed energy resources (DERs) are becoming more popular in distribution networks. These DERs include solar photovoltaics (PV), wind turbines, and energy storage devices. This trend presents both new issues and possibilities for the optimization of distribution systems.

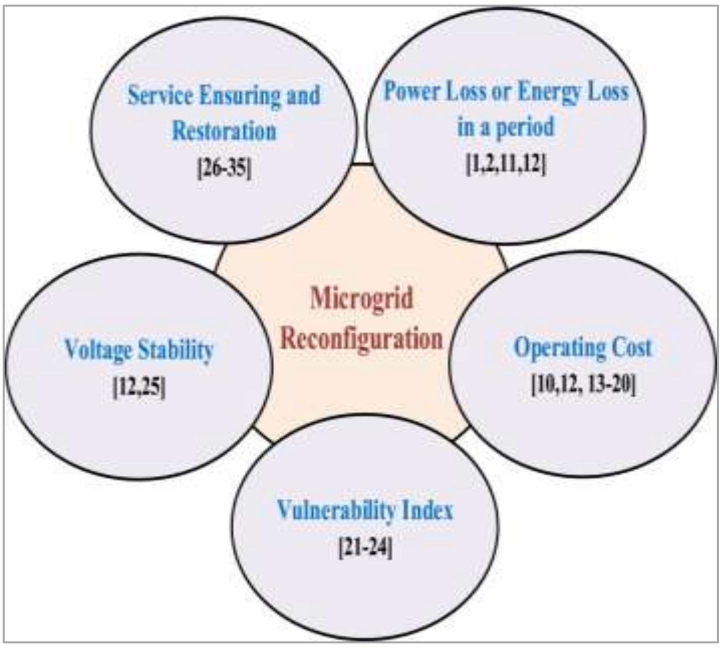

Figure 1: System Reconfiguration in Microgrids

The integration of distributed energy resources (DERs) into the distribution network requires meticulous coordination in order to guarantee dependable operation and make the most of the advantages of integrating renewable energy sources. The reconfiguration of the distribution system may assist in accommodating dispersed generation, minimizing the reduction of renewable energy, and optimizing the exploitation of existing resources, all while lowering dependence on centralized generation and fossil fuels. The possibility of reducing power losses and enhancing the overall efficiency of the network is the fundamental impetus behind the reconfiguration of distribution systems. The architecture of the distribution network may be deliberately altered by utilities in order to maximize the flow of energy, minimize line losses, and improve voltage control. This is accomplished by opening or shutting switches in a strategic manner. Especially in regions with high demand or scattered generation, reconfiguration enables operators to redistribute loads more equally across feeders, prevent overloading of distribution equipment, and decrease voltage drop difficulties. This is especially beneficial in locations where the generation is spread. In addition, utilities are able to enhance system utilization and postpone expensive expenditures in infrastructure improvements if they optimize the architecture of the network to fit load patterns and generation profiles.

Reasons for the Distribution System's Decision In order to achieve the main objective of improving the effectiveness, dependability, and long-term viability of electrical power distribution networks, reconfiguration is conducted with the intention of reducing power loss as much as possible. Distribution networks are essential to the operation of contemporary societies since they are responsible for providing power to establishments such as homes, companies, and factories. It is important to note that these systems are naturally susceptible to a variety of inefficiencies, such as resistive losses in conductors, reactive losses in transformers, and voltage dips in distribution lines. Not only do these losses lead to the waste of energy, but they also contribute to variations in voltage, decreased system capacity, and higher operating expenses. On account of this, there is an urgent need to investigate novel approaches in order to reduce the amount of power that is lost and to enhance the efficiency of distribution networks.

The purpose of these systems is to distribute energy from substations to residential areas, commercial establishments, and industrial facilities in an effective manner. These systems consist of a complicated network of components. Transformers, switches, circuit breakers, wires, and protective devices are all essential components of distribution systems. Through their collaborative efforts, these components ensure that customers get power in a dependable and secure manner. When it comes to the supply of electrical power, distribution systems are the most important component since they are the last connection between the transmission network and the end-users. The purpose of these systems is to distribute energy from substations to residential areas, commercial establishments, and industrial facilities in an effective manner. These systems consist of a complicated network of components. Transformers, switches, circuit breakers, wires, and protective devices are all essential components of distribution systems. Through their collaborative efforts, these components ensure that customers get power.

2. Literature Review

M. Mahdavi (2022): The reconfiguration of feeders is an efficient method for lowering the amount of electricity that is lost via distribution networks. In this manner, the structure of the distribution system is altered in order to achieve the lowest possible losses, while at the same time satisfying the demand for power from customers. A significant part in the process of feeder reconfiguration is played by the power demand of consumers. This is due to the fact that any change in demand immediately impacts power losses. The nature of load demand, on the other hand, is that it is both variable and stochastic due to the fact that it is dependent on consumption patterns and the accuracy of anticipated load quantities. In this regard, reconfiguration models must to be strong enough to withstand the uncertainties and changes associated with load. Therefore, the purpose of this research is to offer a model that is both efficient and resilient for reconfiguring distribution feeders in the presence of unpredictable and fluctuating loads. Despite the fact that its implementation is very straightforward, the reconfiguration model that has been developed is sufficiently resilient and efficient. The findings demonstrate that the suggested model is more efficient and has a lower level of complexity when compared to other resilient reconfiguration techniques that are already in use.

A. M. Shaheen (2022): In this research, an improved heap-based optimizer (IHBO) is presented for the purpose of dealing with the optimum combination of power distribution system reconfiguration and distributed generators allocation in power distribution systems (PDSs). With the intention of enhancing its global search capabilities and avoiding being stuck in a local optimum, the proposed IHBO makes an effort to improve upon the traditional HBO by including an effective exploitation mechanism. This mechanism is designed to enhance the amount of exploration that has been done around the leadership position. Three power distribution systems (PDSs) are investigated, one of which is a normal IEEE PDS consisting of 33 buses, and two real PDSs consisting of a 59-bus Cairo distribution system in Egypt and an 84-bus Taiwan Power Company (TPC) in Taiwan. The suggested IHBO algorithm is capable of achieving a maximum decrease in power losses of 69.44%, 72.29%, and 74.725% for low, nominal, and heavy loadings, respectively, when applied to the IEEE standard system. The IHBO that was suggested achieves the best performance for the Cairo PDS, with the lowest minimum, average, and maximum fitness values of 1.4149, 1.444, and 1.496, respectively. It achieves the lowest minimum, average, and maximum losses for the Taiwan Power Distribution System (PDS), which are 240.88, 264.16, and 308.49 kW, depending on the specifics. Additionally, it demonstrated a striking enhancement in the voltages throughout the whole of the PDS buses.

S. Pemmada (2022): In this paper, a unique enhanced Elitism oppositional Jaya method is presented for the purpose of optimizing the reconfiguration of power distribution networks, as well as optimizing the scale and placement of multiple distributed generators (DGs) using P, PQV buses. The PQV bus is a voltage-specified PQ type bus that is controlled by the P bus in this scenario. In the planning model that has been presented, the fundamental Jaya algorithm has been changed by including variable inertia weight, vicinity seeking capacity, elitism property, and a strategy that is based on opposition learning. In the pursuit of the best possible answer, this allows for the establishment of an efficient strategy that combines global search with local search. For the purpose of concurrently optimizing both technical and economic goals, a multi objective framework is designed. Attributing optimal weights to each aim is accomplished via the use of an enhanced analytical hierarchy process approach. In order to determine the ideal placements of DGs while simultaneously taking critical loads into consideration, novel indices have been presented. A method based on smart graph theory is responsible for rearranging the line data sequence while the reconfiguration is taking place. As an additional point of interest, the approach that was recommended has been used to investigate several strategies on the IEEE 33 and 69 bus distribution test systems. The usefulness and validity of the suggested approach was shown by the outcomes of the research, which were obtained by comparing it to particle swarm optimization (PSO) and improved leader PSO.

N. Liu (2022): The issue of power fluctuation in the power system may be effectively addressed by the reconfiguration of distribution networks using an effective manner. For the purpose of determining the most effective reconfiguration method, previous research has concentrated on mathematical optimization techniques that include intricate modelling procedures and heuristic algorithms that involve solving processes that take a significant amount of time. In this paper, a framework for hybrid data-driven and model-based distribution network reconfigurations developed. The model-based module of the framework incorporates model reduction and goal-oriented clustering in order to cluster the same reconfiguration techniques. To learn the mapping mechanism between load distribution and optimum reconfiguration techniques, the data-driven module is implemented here using a long short-term memory network. This serves the purpose of learning the mapping mechanism. The suggested hierarchical network recovery procedure, which displays the reconfiguration outcomes layer by layer, is what allows the model-driven module and the data-driven module to be linked together.

3. Methodology

This technique makes it possible to identify globally optimum solutions as quickly as possible within a limited amount of computing time. The optimization methods that were used within the experimental framework for the purpose of decreasing power loss via the reconfiguration of distribution systems included a wide variety of mathematical methodologies and computational approaches. In the next part, a comprehensive explanation of the primary optimization algorithms that were applied in the experimental setup is presented. This section also highlights the theoretical foundations, algorithmic techniques, and practical consequences of these algorithms. Significant power loss reductions have been obtained via rigorous experimentation and simulation studies, demonstrating the potential for strategic distribution system reconfiguration to boost system efficiency and dependability.

These reductions have been accomplished through the use of simulation studies. A systematic methodology for identifying optimal configurations that balance conflicting objectives and constraints while minimizing power loss has been provided by the experimental framework. This methodology has been achieved through the utilization of advanced optimization algorithms, power flow analysis tools, and comprehensive problem formulation techniques. Power engineering is a field that is driven by the desire to improve the efficiency, dependability, and sustainability of contemporary electrical grids. One of the most important endeavours in power engineering is the quest of decreasing power loss via the reconfiguration of distribution networks. In this thesis, the theoretical foundations, methodological developments, and practical consequences connected with distribution system reconfiguration have been investigated.

The results of this investigation have provided insights into the problems, possibilities, and prospective solutions for improving distribution network operations. High levels of power loss need the operation of extra generating capacity in order to fulfil demand. This often results in higher emissions of greenhouse gases and pollutants from power plants that are powered by fossil fuels. Because of the reduction in power loss that occurs as a result of the reconfiguration of distribution systems, the need for extra generating capacity is reduced, which ultimately results in a smaller environmental footprint and fewer emissions. The aims of sustainability and environmental stewardship are supported by this, since it is in line with worldwide efforts to prevent climate change and move towards a future with low carbon energy. The economic significance of power outages lies in the fact that they pose a considerable strain on the economy for utility firms, grid operators, and customers alike. During the process of transmission and distribution, utility companies experience a loss of income due to the fact that they are required to either create new power or buy additional electricity in order to compensate for the energy that is lost. These expenses are eventually passed on to consumers in the form of increased power rates, which contributes to the financial strains that are placed on homes and companies. It is possible for utility companies to decrease these operating expenses by limiting power loss via the reconfiguration of distribution systems. This will result in greater financial performance and lower energy rates for customers. Consequently, this not only improves economic competitiveness but also encourages the accessibility and affordability of energy for all individuals. The reduction of power loss is a fundamental goal in the field of distribution system optimization.

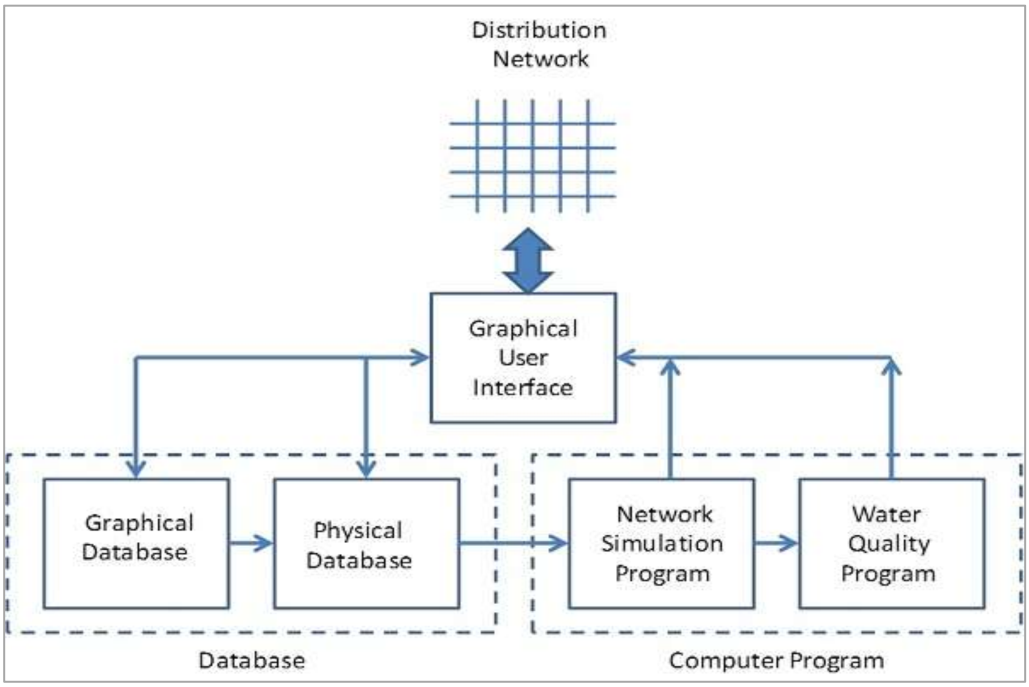

Figure 2: Network Distribution System Fundamentals of Electrical Distribution Systems

This target has significant repercussions for the effectiveness, dependability, and long-term viability of electrical grids. When electricity travels through transmission and distribution lines, it will always come into contact with resistance, which will result in the loss of energy in the form of heat. This issue, which is referred to as power loss, not only leads to economic inefficiencies but also creates problems for the stability of the grid and makes it difficult to maintain environmental sustainability. When it comes to the reconfiguration of distribution systems, limiting power loss emerges as a strategic priority with multifarious relevance. This significance encompasses economic, environmental, and operational issues. the significance of minimizing power loss within distribution networks goes beyond the realm of economic considerations to embrace concerns about environmental sustainability, operational efficiency, grid modernization, and technical innovation. By strategically reconfiguring distribution systems and optimizing network configurations, it is possible to minimize power loss, which in turn leads to improved system efficiency, decreased operational costs, reduced environmental impact, enhanced grid reliability, and increased support for the integration of renewable energy sources. In the future, new ideas and technologies will play a critical part in determining the future of energy distribution and progressing toward a more sustainable energy future. This is because distribution system operators and policymakers will continue to emphasize power loss reduction as a primary priority.

The reduction of power loss is a driving force behind technical innovation and optimization in the area of distribution system engineering. This has resulted in the development of sophisticated optimization algorithms, simulation tools, and grid management tactics. It is possible to reduce the amount of power that is lost. This may be accomplished by strategically reconfiguring distribution systems and optimizing network topologies. This will ultimately result in enhanced system efficiency and performance. This provides an incentive for investments to be made in research and development projects that are targeted at increasing methodologies for distribution system optimization, improving grid intelligence, and encouraging the use of novel technologies such as smart grids, energy storage systems, and predictive analytics. The operators of distribution systems have the ability to uncover new prospects for efficiency improvements, cost reductions, and environmental advantages by using technological innovation.

The reduction of power loss is an essential component of the modernization and resilience of electrical grids. This is especially true in light of the fact that new problems are being introduced, such as the occurrence of severe weather events, the introduction of cybersecurity risks, and the growth of distributed energy resources. Grid operators have the potential to improve grid flexibility, adaptability, and response to changing demand patterns and operating circumstances by increasing the efficiency of distribution system operations and reducing power loss. This makes it easier to include renewable energy sources, demand response programs, and grid-edge technology, which ultimately results in an electrical grid that is more robust, decentralized, and adaptable, and is able to satisfy the ever-changing requirements of society. The reduction of power loss is a factor that contributes to the operational efficiency and reliability of electrical grids.

4. Experiment Result

In order to assess the performance and effectiveness of the optimization algorithms in reducing power loss via distribution system reconfiguration, a comparative study of the algorithms is carried out. In order to evaluate the strengths and weaknesses of each algorithm under a variety of operating settings and problem cases, performance indicators such as convergence speed, solution quality, computing efficiency, and resilience are taken into consideration. The purpose of comparative studies is to determine which algorithm or combination of algorithms is the most appropriate for certain distribution network designs, load situations, and optimization goals. This will allow for more informed decision-making and algorithm selection in actual implementations. SA is a probabilistic optimization approach that was inspired by the process of annealing in metallurgy. Annealing is a process in which materials are heated and slowly cooled in order to attain a state of low energy.

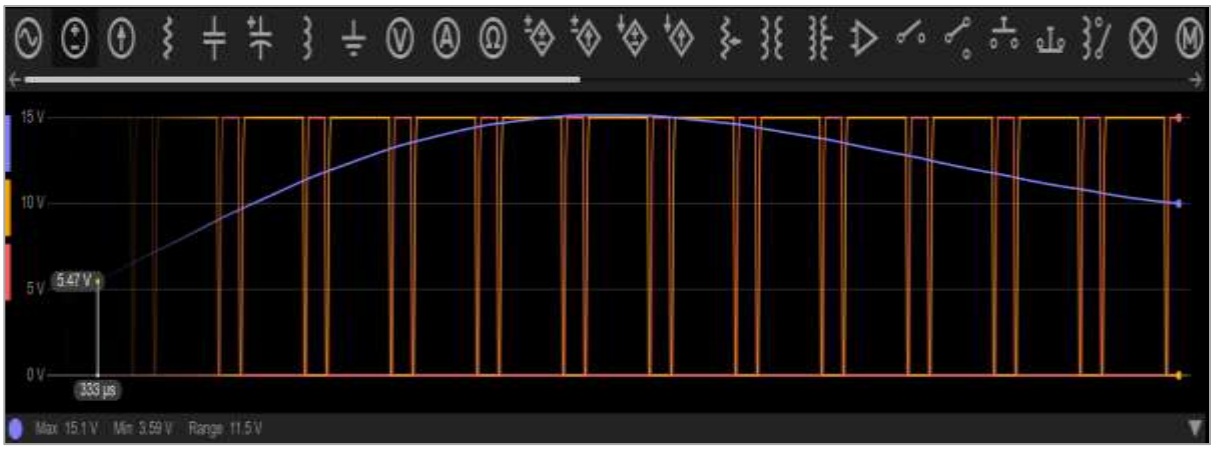

Figure 3

Within the framework of distribution system reconfiguration, SA functions by iteratively exploring the solution space, accepting or rejecting candidate solutions based on their fitness and a probabilistic acceptance criterion. This process determines whether or not the solutions are acceptable. In the beginning, SA conducts a thorough investigation of the solution space, which enables a more extensive investigation of a variety of areas. There is a progressive convergence towards ideal configurations as the algorithm continues to evolve, which results in the exploration becoming more selective. The chance of accepting poorer answers is governed by the acceptance criteria, which is based on a temperature parameter that lowers with time. This allows SA to break out of local optimum solutions and find solutions that are ideal on a global scale. SA has a number of benefits, including robustness, flexibility, and the capacity to deal with non-convex and discontinuous objective functions. As a result, it is well suited for optimization problems that include complicated and irregular solution spaces. PSO is a method for population-based optimization that was inspired by the collective behaviour of swarms or flocks that occur in nature. The Particle Swarm Optimization (PSO) algorithm is used to reconfigure distribution systems. It does this by repeatedly updating a population of particles, each of which represents a proposed solution, depending on their individual and collective knowledge of the search space. In the search space, the direction and amplitude of movement are determined by the velocity of each particle, while the location of each particle corresponds to a possible solution. Particle swarm optimization (PSO) is a technique that dynamically explores the solution space by means of iterative updates that are led by the particle's personal best and global best locations. This process ultimately leads to optimum designs that minimize power loss.

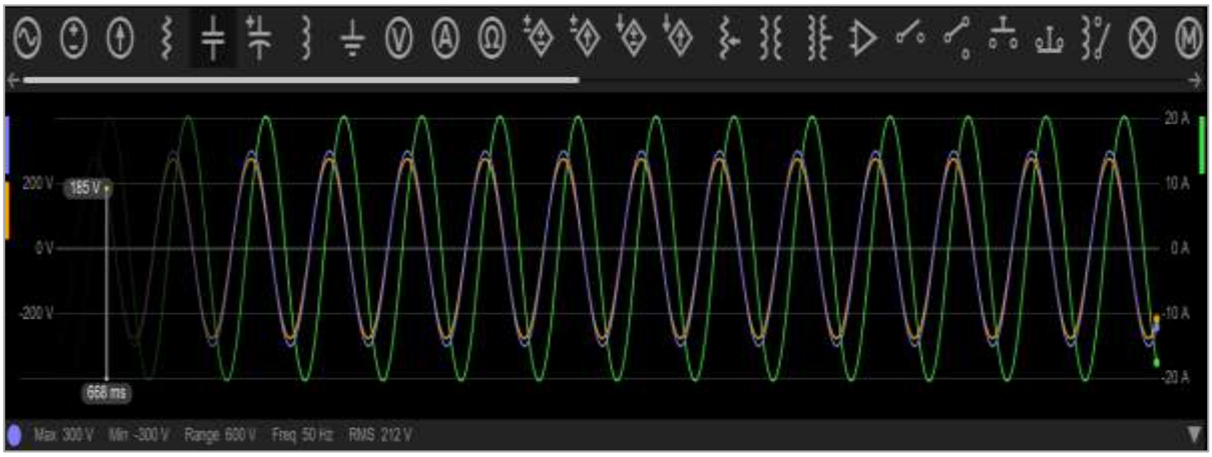

Figure 4

Because of its many benefits, including its ease of use, its effectiveness, and its rapid convergence, PSO is an excellent choice for solving optimization problems that include high-dimensional search spaces and non-linear goals. GA is an algorithm for population-based optimization that is influenced by the ideas of natural selection and evolution. In the context of the reconfiguration of distribution systems, genetic algorithms (GA) function by iteratively developing a population of possible solutions via the use of selection, crossover, and mutation operators. This assessment is based on the fitness of each candidate solution, which is represented as a chromosome that encodes the state of switches and network topology configurations. The fitness of each candidate solution is defined by the objective function, which is total power loss. Solutions that show promise are chosen to go through crossover and mutation processes, which might result in the generation of offspring solutions that have the potential to increase their fitness. The evolutionary method operates in an iterative manner until convergence is reached, which ultimately results in optimal designs that reduce power loss while also fulfilling operational limitations. Because GA has benefits such as robustness, parallelizability, and the capacity to explore multiple solution spaces, it is well suited for optimization problems that include complicated search spaces and non-linear goals. All of these characteristics make GA an attractive choice. The Mixed-Integer Linear Programming (MILP) approach is a sophisticated optimization technique that is used to tackle problems containing both continuous and discrete decision variables. Because of this, it is well suited for the optimization of distribution system reconfiguration. For the purpose of minimizing power loss, MILP formulations often express the topology of the network as a set of binary decision variables. Each variable in this set corresponds to the status of a switch, which may be either open or closed. Both the objective function and the constraints work together to guarantee that the optimized configurations are feasible. The constraints include voltage restrictions, current constraints, and switch operating limitations. The objective function's goal is to minimize the overall power loss. A rigorous and mathematically tractable method to optimization is provided by MILP formulations.

5. Conclusion

In conclusion, when taken together, the outcomes of the experiments, the theoretical insights, and the developments in algorithmic development, illustrate the promise of distribution system reconfiguration as a proactive technique for improving the efficiency, reliability, and sustainability of electricity grids. Mixed-integer linear programming (MILP), genetic algorithms (GA), particle swarm optimization (PSO), and simulated annealing (SA) are some of the optimization techniques that have been used inside the experimental framework. Each of these algorithms has brought a distinct set of skills and insights to the optimization process. Through comparative assessments, it has been possible to determine the strengths and weaknesses of algorithms across a wide range of operating settings. This has helped to direct the selection of algorithms and the decision-making process in actual applications. Furthermore, the full explanation of optimization algorithms has highlighted the flexibility and adaptability of the experimental framework, which is capable of handling a wide variety of optimization targets and issue situations during the process of distribution system reconfiguration. This thesis presents experimental data that illustrate the effectiveness and practical application of the suggested optimization framework for reducing power loss via distribution system reconfiguration. These results showed that the framework was both effective and practicable.

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