RESEARCH ARTICLE OPEN ACCESS

Application of Optimization Techniques for Optimal Capacitor Placement and Sizing in Distribution System: A Review

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ABSTRACT
A power distribution network is a collection of radial feeders that are interconnected or linked with one another via different tie-switches and tie-lines. The decrease of power loss in the grid system is a major issue of the electric distribution system. Several approaches are employed. One of these methods is optimum reconfiguration and capacitor placement. The capacitor is a device that is used to recover reactive power in a dispersed network. Capacitors are used for a variety of purposes, including as lowering voltage profiles, enhancing voltage profiles, and so on. The major advantage of decreasing or recovering reactive power is depending on the allocation or size of the capacitors. Traditionally, two approaches were employed to reduce power losses: ideal capacitor placement and optimal distribution network reconfiguration. However, using both approaches at the same time increases the complexity of the optimization process. This article gives a brief description of recent optimization techniques to find optimal capacitor placement and sizing in distribution system. These techniques are responsible to reduce the annual operating cost and power losses in the system.

Keywords: -Distribution network; Optimization techniques, Optimal capacitor size, Annual operating cost.

I. INTRODUCTION

The capacitor is a device that is used to recover reactive power in a dispersed network. Capacitors are used for a variety of purposes, including as lowering voltage profiles, enhancing voltage profiles, and so on. The major advantage of decreasing or recovering reactive power is depending on the allocation or size of the capacitors. Traditionally, two approaches were employed to reduce power losses: ideal capacitor placement and optimal distribution network reconfiguration. However, using both approaches at the same time increases the complexity of the optimization process.

Advantages of Capacitor Placement

The advantages of capacitor placement are as below:

- Reduction in total system losses.
- Improvement in power factor of the units.

Work in different sectors has grown both easier and more challenging as technology has advanced. The advancement of technology has given rise to a slew of issues in a variety of fields. Such issues exist in the electrical industry as well. The major issue that arises is the network's load requirement. As a result, the electrical sector is attempting to establish such a system or power plant that can meet the load demand of the network. If the transmission process is interrupted due to a difficulty, several equations are derived to recover the lost transmission. As a result, numerous computations are utilised or examined to reduce transmission loss. These transmission loss estimates appear to be simple, but they are not. Variations in transmission power, power factors, voltage level fluctuations, and other variables add to the complexity. When the voltage level in a system is high, the transmission loss is low, but when the voltage level is low, the transmission loss is significant. As a result, the approaches used to reduce loss origin should be simple, less complex, and dependable, so that the lost origin or transmission can be readily located.

In most electrical distribution businesses, there are two categories of loads: resistive and inductive. As a result of being heated, resistive loads produce light. In the case of a pure resistive load, the parameters voltage (V), resistance (R), and current (I) are linearly linked to each other as follows:

$$V = (I\times R) \quad (1.1)$$

$$\text{Power (kW)} = (V\times I) \quad (1.2)$$

Inductive loads include A.C. motors, furnaces, transformers, and blast lamps. The inductive load necessitates two forms of power: active and reactive.

The active power is utilised for processing, while the reactive power is used to generate and sustain the system's electro-magnetic fields. (kW) kilo Watts is the unit of measurement for active power. Reactive power is measured in (kVar) kilo Volt-Amperes. Reactive. The quantity of active power used is added to the amount of reactive power used to determine the total consumed power. The whole power is then utilised to complete the specified task. The unit of measurement for total power is (kVA) kilo Volts-Amperes. The diagram in Figure 1 depicts the connection between various power kinds. The sum of these powers yields the apparent power, represented by S in the power system.

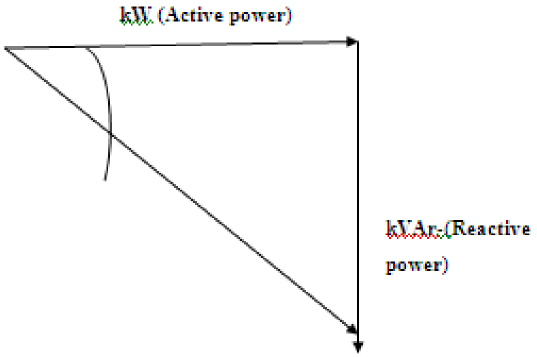

Fig.1. kW, kVAr and kVA Vector

In above Fig the active power is needed in kW and similarly reactive power is needed in kVAr. The reactive power is at the distance of 〖90〗^°in the pure inductive circuit. The active power is treated as pure or true power in the circuit. Both of the powers are added in order to generate the apparent power.
The apparent power shows the total sum of actual electrical load on the system. Power factor is denoted by pf it defines the ratio between active and apparent power. The value of the ratio is always less than or equal to unity. In circuit if all of the nodes have unity power factor than in such cases the maximum power is supplied to the same distribution in the circuit. These loads are inductive in nature and the power factor varies from 0.2 to 0.9. The energy lost at the time of transmission is of two type i.e. resistive loss and reactive loss. If energy lost takes place at the earlier phase then the reason behind this lost is the resistive component of the load and this kind of loss is not avoidable lost. The reason behind other loss of energy is reactive objects of the load. This kind of loss can be avoided or reduced also by using some techniques of reduction. Let us consider an example that a heavy inductive load is attached to the grid and hence large positive reactive power component will also be attached to the grid which leads to the increment in the actual or observed power which is denote by S. the increment in the observed power has the following impact on the circuit:

- It can also increase the number of transmission losses which occurs because of reactive load current.
- Increase the need of KVA
- Increase the amount of energy consumed by customer too.
- Reduces the performance of voltage profile.
- Degrade the amount of revenue.

II. LITERATURE REVIEW

M. Damodar Reddy et. al (2008) – A novel approach known as the fuzzy and real coded Genetic Algorithm, i.e. (RCGA). The capacitors were installed on the principal feeders of the radial distribution systems using the recommended approach. It aided in the reduction of power losses as well as the improvement of the voltage profile. To tackle the capacitor placement difficulty, two stage methods were used in this procedure. In the first step of the method, fuzzy was utilised to identify the best position of the capacitor, while in the second stage, a real coding genetic algorithm was applied. It aided in determining the size of the capacitors. The capacitor sizes that result in the greatest yearly savings are identified. The suggested technique has been tried on 15-bus, 34-bus, and 69-bus test systems, and the findings have been reported [8].

Anwar Shahzad Siddiqui et. al (2010) - Shunt capacitors are used to improve the performance of distributed systems, resulting in an energy-efficient distributed system. The major challenge is determining the best position for the capacitor in order to obtain the lowest energy-to-peak power loss. In this study, a radial system with ten buses is suggested for implementing the requested task. The load flow software is implemented using the MATLAB simulation environment. The suggested approach is based on the use of load flow data in conjunction with a fuzzy method. The fuzzy method is used because it is easy and includes less complicated calculations [6].

Ikbal Ali et. al (2011) - An energy efficient power distribution system is one that creates a cost-effective and collaborative environment, which is required for the implementation of a smart distribution system. The notion of appropriate capacitor placement can only improve the system's performance. The combination of PLI and MLI was presented in this study as a novel approach for optimum capacitor placement. This has the potential to enhance the system's load capacity while simultaneously lowering power loss. The IEEE 15 bus system is used in the testing. The power load model has a direct impact on capacitor size selection. The findings demonstrate that the proposed work can improve load capability and minimise power loss in comparison to previous approaches. As a result, by reducing the power demand and feeding capacity, the system becomes more energy efficient [4].

Anwar S Siddiqui et. al (2012) – A distributed system is utilised to facilitate high voltage data transfer between multiple nodes or connections. As a result, in such a system, the nodes waste a lot of energy when transmitting data. This may have an effect on the entire system. The energy consumption is determined by the overall performance of the system. As a result, in order to enhance the efficiency of the distributed system's power consumption system, the overall performance of the system should be improved. The use of a shunt capacitor may be the best approach for increasing the system's power capacity. The issue that arises in capacitor allocation is the maximizing of energy and the minimization of peak-power loss. In this work, MATLAB is utilised for simulation, and a fuzzy algorithm is employed as a solution and in the suggested work. The fuzzy is used because of its simplicity and less complicated computations, as well as its ability to generate quick output [1].

Mr. Manish Gupta et. al (2012) - To overcome all of the issues associated with capacitor placement in power systems, careful planning for distributed system installation is required. The planning entails employing strategies that allow the capacitors to be placed in the most appropriate or ideal location. The phrase optimum placement refers to a point in the network where power consumption is low and cost savings are large. The author suggested Tabu Search, a unique approach for locating the best placement for shunt capacitors. The results section compares the network's performance before and after executing the recommended work [2].

M. Yarmohamaddi et. al (2012) - The suggested method is a hybrid strategy that employs two approaches, PSO and HBMO, which stands for Honey Bee Mating Optimization. This approach determines the best position for capacitor placement in the network, as well as the quantity of shunt capacitors, to decrease power loss and regulate the voltage profile of the power system. First, the approach identifies the number and size of shunt capacitors that will be used in a network, and then it employs the hybrid technique, which is a mix of PSO and HBMO, to assess the number of optimum bus capacitors at the optimal sizes. The major rationale for utilising this hybrid method is the technique's simplicity and lack of complexity. The approach is implemented by employing IEEE 15 bus transmission technologies. After simulation, it is discovered that the suggested system gives a better solution than existing approaches [8].

Pravin Machindra et. al (2013) - PSO, or Particle Swarm Optimization, was used to define capacitor location and size. The numerous issues that emerge in this sector include voltage profile level, line losses, and power loss factor when transmission. There is only one answer to the described difficulties, and that is the capacitor, but only if it is used efficiently. The simulation is carried out utilising 30 bus systems in the study. The optimal placement of capacitors improves the performance and efficiency of the distributed system. PSO is used in bus systems to measure objective functions and sizing [13].

Ahmed Elsheikh et. al (2014) - Capacitors have numerous advantages in distributed systems, including decreased power loss, increased system voltage level, and improved or enhanced flow from the cables. The capacitor placement has numerous advantages, including the possibility to increase the system's loads without the need for more cabling. The purpose of this research is to determine the optimal location in the network for capacitor installation. Loss sensitivity and discrete PSO are used to identify the optimum position for capacitor placement and capacitor size, respectively. The proposed method takes into consideration the discrete nature of design elements. This study also includes a results section to illustrate the efficacy of the proposed strategy[12].

P.M Sonwane et. al (2015) – The researchers are interested in the notion of capacitor location and size. Because there is a lot of study being done on this issue. The report examines numerous research studies that have been conducted in this subject. The research demonstrates how various parameters affect the functioning of the system in which the capacitor is installed. These characteristics or variables include the quantity of power lost, the cost of investment, an unbalanced voltage profile, power quality concerns, and so on. This article gives a review of previous or current work in this subject. As a result, this study is beneficial to researchers since it will advise them. The author discusses several capacitor installation strategies in this article. The literature offers an overview of the studies conducted by various scholars [17].

Prof. Jaikaran Singh et. al (2014) - A unique technique for capacitor placement was developed using an ant colony optimization method. The state transition algorithm is used in conjunction with ACO. The state transition rule is used to connect nodes that are more close and neighboring to one another. The results section shows that the proposed technique may reduce power loss while also balancing the voltage level. It also has the potential to improve net savings [19].

V.Tamilselvan et. al (2017) proposed the flower pollination algorithm (FPA), a novel metaheuristic algorithm that simulates the pollination process of flowers, has been developed in this work for the solution of the optimum capacitor placement (OCP) issue in a radial distribution system (RDS). The goal of this challenge is to reduce overall power loss and capacitor installation costs by locating and sizing capacitors optimally. The voltage profile is also improved by OCP. The power flow and losses in the network are determined in this study utilising load flow analysis and data structures. The suggested FPA method was used to solve RDSs for buses 33, 34, 69, and 85. The outcomes of the analytical technique, fuzzy real coded genetic algorithm, two stage fuzzy approach, and teaching learning based optimization algorithms are compared. The comparison demonstrates that FPA is an excellent optimization method for resolving capacitor placement issues [24].

Sarika et. al. (2020) proposed an novel approach determining the most appropriate nodes on the essential feeders, laterals, and sub-laterals of any radial distribution network for ideal capacitor integration in order to improve power loss reduction and also to enhance the voltage profile. The well-known LSF method is used to find the most suited nodes, and the ideal capacitor size is determined via a hybrid ABC-PSO computation. Because capacitor size is such a nonlinear issue, the fuzzy inference system (FIS) methodology is chosen as the best transport method for the capacitor location. The capacitor sizes that correspond to the least actual power hardship are determined. On IEEE 69-node and 34-node radial distribution networks, the suggested method has been tested [21].

Dharoj et. al. (2021) proposed the Optimal Capacitor Placement (OCP) problem in a radial distribution system, unlike traditional methods, which focus on an optimal solution for a single feeder, the suggested method takes into account all feeders within a sub region. Furthermore, the proposed method employs simultaneous capacitor placement by treating acquired capacitor banks as durable products that are allotted within the confines of a budget acquired for each fiscal year. This can be accomplished by utilising energy loss signals and the concept of a reactive power compensation zone. As a test system, a 5-feeders substation in a north-eastern PEA region 2 with a three-level load model is used. The acquired data may reflect the impact of a new capacitor on a system's energy loss [26].

Thompson et. al. (2021) presents the novel solution to the problem of optimum shunt capacitor location and size in radial distribution systems. To minimise the search space for optimum buses that need shunt capacitor placement, the technique adapts and partially leverages standard loss sensitivity factors (LSFs) using MATLAB's is member and any commands. Following that, the multiverse optimizer (MVO) is utilised to conduct a concurrent search for the best buses and capacitor sizes. Simulations of the 10-, 33-, and 69-bus radial distribution systems were conducted to assess the effectiveness of the suggested method. The simulation results for all of the test systems show that the developed approach produces results that are comparable to those obtained when searching for the most optimal buses in unreduced search spaces, indicating that the approach is effective in reducing computation time while maintaining the required accuracy. Finally, the MVO's performance was compared to the performance of the other 11 optimization methods, and it was shown to be superior in every case [28].

III. OPTIMIZATION TECHNIQUES

The primary issue in multi-objective mixed integer non-linear programming is equality and inequality requirements, which emerge when different power loss reduction strategies are used. There are a variety of approaches that may be utilised to solve these issues.

A. Archimedes Optimization Algorithm (AOA)

The Real-world numerical optimization problems have become increasingly challenging and complicated, necessitating the use of effective optimization algorithms. Various metaheuristic methods have been proposed to far, but only a handful have gained traction in the scientific community. To address optimization issues, a novel metaheuristic method named Archimedes optimization algorithm (AOA) is proposed in this work. AOA is based on Archimedes' Principle, which is a fascinating physics principle. It mimics the concept that the weight of the displaced fluid is proportionate to the buoyant force produced upward on an object partially or fully immersed in fluid. The suggested AOA method is evaluated using the CEC'17 test cases and four engineering design challenges. Genetic algorithms (GA), particle swarm optimization (PSO), differential evolution variants L-SHADE and LSHADE-EpSin, whale optimization algorithm (WOA), sine-cosine algorithm (SCA), Harris' hawk optimization (HHO), and equilibrium optimizer outperformed well-known state-of-the-art and recently introduced metaheuristic algorithms such as genetic algorithms (GA), particle swarm optimization (PSO), differential evolution variants L-SHADE and LSHADE-E (EO). The experimental results show that AOA is a high-performance optimization tool in terms of fast convergence and exploration-exploitation balance, and that it can be used to solve difficult problems successfully.

Algorithms that preserve simplicity, ease of implementation, and the capacity to avoid local optima are those that stand out from the crowd. This is why, despite the proliferation of new metaheuristic algorithms, only a handful remain interested in the research community, while others fade away. For metaheuristic algorithms, the tradeoff balance between exploration and exploitation is always essential [21]. The algorithms that maintain this equilibrium over a wide range of optimization problems are the ones that succeed. Nonetheless, Algorithm 1 may be used to describe the overall method of any metaheuristic algorithm.

B. Polar Bear Optimization Technique (PBO)

The polar bear optimization algorithm (PBOA) was presented by Karen Miu, et al. in 2017 [22]. It's a metaheuristic optimization method inspired by polar bear hunting behaviour. Polar bears are the world's largest non-aquatic carnivores, and they live in the harsh Arctic environment. Their dense white fur effectively insulates them from the cold. Seals are the primary food source for polar bears, although they also consume fish and other arctic creatures. Their keen sense of smell, exceptional eyesight, and acute hearing allow their survival in the harsh circumstances of the Arctic. Furthermore, they are elite swimmers capable of swimming hundreds of kilometres without stopping. The mathematical model of PBOA is based on polar bear hunting behaviour. With only a few parameters, PBOA can solve a wide range of issues and produce results that are comparable to those of other metaheuristic approaches. The PBOA was evaluated on 13 benchmark functions and four engineering-designed challenges by its original developers [22]. They compared it to 11 other metaheuristic approaches and found that the results were equivalent.

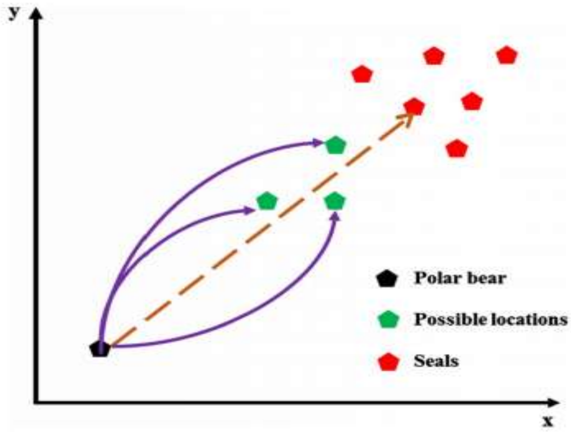

Fig. 2. Global Search for Polar Bear Optimization Algorithm

IV. RESULTS & CONCLUSION

The work was carried out in a radial distribution system with the goal of determining the best technique to get optimal location and sizes for capacitors in order to reduce energy loss and the capacitor's annual cost. By explaining the Archimedes optimization algorithm (AOA) and polar bear optimization algorithm (PBOA), we have concluded that these are techniques that can be used to find optimal location and size of capacitor in distribution system that will reduce the annual operating cost and power losses of the system. These algorithms can be integrate or performed with IEEE standard test system.

V. FUTURE WORK

For the location of capacitors in the bus system, the suggested work employs optimization techniques. This study work's competition opens up various topics for future reference. Similarly, multi-constrained optimization techniques can be utilised to make appropriate decisions about capacitor allocation for different numbers of buses and varied capacitor sizes. Multiple objectives can be considered by these optimization algorithms. As a result, capacitors will be diligently placed on the bus, resulting in lower power loss and lower cost. Furthermore, in the future, DSTATCOM allocation can be explored, which will be accommodating when transients are present.

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