

**Different Tactics of Capacitor Placement in Distribution System: A Retrospection**Amanpreet Kaur¹, Amarjeet Kaur²¹Electrical Deptt., BBESBEC Fatehgarh Sahib²Asst. Proff., Electrical Deptt., BBESBEC Fatehgarh Sahib

Abstract— The problem of capacitor placement for loss reduction in distribution system has been thoroughly, abundantly researched over the past many years. This paper describes the advancement of the research and provides an estimation and opinion about practicability and accuracy of the capacitor placement on the basis of conclusions. The purpose of this paper is to explain the different techniques with the aim of determining optimal location and size of shunt capacitor banks (SCBs) in distribution systems. These tactics include the three objective functions: decreasing active power losses, improving voltage stability for buses and balancing current in system sections. Results of various techniques are discussed and concluded that which method will be better to find the appropriate size and location of capacitor.

Keywords—THD-total harmonic distortion, NLP-nonlinear programming, HHBC-hybrid honey bee colony, CBs-capacitor banks, DGs-distribution generators, OPF-optimal power flow

I. INTRODUCTION

Generally capacitors have been employed to provide reactive power compensation in distribution systems. They are used to reduce power losses and to maintain the voltage profile within acceptable limits. The benefit of compensation depends greatly on how the capacitors are placed in the system, specifically on the location and size of the added or placed capacitors [1]. The electrical energy is generated, transmitted and distributed in the form of alternating currents and 13% of total power generated is consumed as I^2R losses at the distribution level. Reactive currents account for a portion of these losses. Most of loads are inductive in nature and hence have low lagging power factor. The low power factor is highly undesirable as it causes increases in current, resulting in additional losses of active power in all the elements of power system from power station generator down to the utilization devices. In order to get economical supply system, it is important to have power factor as close to unity as possible [2]. This can be achieved by installing shunt capacitor banks at suitable location with appropriate size. So there are variety of methods that have been studied or scrutinized to find optimal number, types, the proper location and size of capacitor banks such that minimum cost due to power/energy losses and cost of capacitors installation can be achieved annually, while the operational and power quality constraints are maintained within the required limits. To solve this problem different mathematical programming techniques can be employed.

II. LITERATURE SURVEY

Most of the reported techniques for capacitor placement assume sinusoidal operating conditions and these methods includes:-nonlinear programming Simulate annealing(SA), tabu search (TS), and GAs were three near global optimization techniques that has been demonstrated with fine capabilities for capacitor allocation, but the computational burden was nevertheless heavy [3]. There have been analytical approaches, numerical programming methods and AI-based techniques devised to solve this capacitor placement problem. Although, these methods have various merits but, their efficiency relies entirely on the goodness of the data used.

In some recent works, the presence of distorted substation voltage has been considered for solving the capacitor placement problem. The presented mathematical optimal methods for shunt capacitor placement include extensive or complete search, local variations, mixed integer-non-linear programming heuristic methods, maximum sensitivities selection, fuzzy set theory, and genetic algorithms (GAs). Some of these publications ignore the couplings between harmonic voltages and currents; use a harmonic power flow that considers harmonic couplings caused by the non-linear loads [4].

Plant growth optimization was introduced for optimal allocation of capacitor with the objective of improving voltage profile and reduction of power loss. Genetic Algorithm was used to find the optimal sizing of fixed and switched capacitor at different load levels. Fuzzy based GA was used to determine the optimal size with the multi objective of minimizing the energy cost and to enhance voltage profile of the system. Similarly direct search algorithm was introduced to find the optimal location and size of fixed and switched capacitor and it was tested on IEEE 22, 69, 85 bus radial distribution system with the objective of maximizing net savings and minimizing the power loss. Ant colony optimization algorithm was proposed to solve capacitor placement in radial distribution system. Taher and Bagherpour proposed the hybrid honey bee colony optimization algorithm to place the shunt capacitor in IEEE 25, 37 bus radial distribution system to minimize power loss and maintains total harmonic distortion. Antunes et al. proposed the non-dominated sorting genetic algorithm to solve the optimal

capacitor placement in radial distribution system for reactive power compensation. Baran and Wu introduced mixed integer programming for the capacitor placement. Chis et al. have chosen more sensitivity nodes for optimal location and sizing by heuristic search strategies to maximize the net savings. Mohammad et al. introduced the supervisory control and data acquisition system (SCADA) with fuzzy based decision maker to calculate the suitable capacitor required to enhance the power factor according to the measured parameters. Prakash and Sydulu introduced the particle swarm optimization to determine the optimal size of the capacitor bank to minimize the power loss[5].

A. PSO Algorithm

Particle swarm optimization algorithm was applied for the discrete optimization problem of fixed shunt capacitor placement and sizing in the presence of voltage and current harmonics. Power and energy losses due to installed capacitors and cost of fixed capacitors were used as an objective function. The PQ limits of IEEE-519 standard, maximum and minimum of bus r.m.s. voltages and the allowed number of capacitor banks at each bus were considered as constraints. The main contributions of the proposed PSO algorithm could be summarized as follows:

- 1) PQ and cost index of the power system are improved simultaneously by optimal capacitor placement.
- 2) Improving particles in the course of several steps is used to improve the objective function and PQ constraints.
- 3) The dependency of the PSO solution on the initial conditions is weak and can escape local optimal and converge to the near global solution.
- 4) The inclusion of PQ constraints in the proposed fitness functions prevents the occurrence of harmonic parallel resonance.
- 5) As a result, harmonic resonances were shifted to other non-disturbing frequencies by relocating and resizing capacitor banks.
- 6) Compared with the previous studies, the proposed method utilizes a wider search space and avoids numerical problems by computing fitness functions, also generates more suitable results (e.g. lower THDv and/or greater annual benefits within the permissible region of constraints) [6].

B. Hybrid Honey Bee Colony Algorithm

A bee colony algorithm is a new approach which was proposed for the discrete optimization problem of fixed and switched shunt capacitor placement and sizing in distorted unbalanced radial distribution systems using HHBC algorithm. This method was tested on two systems namely an IEEE 25-bus and a modified IEEE37-bus radial distribution systems to evaluate the optimal locations and sizes of shunt capacitors while taking harmonics in to account. Results were compared with other artificial intelligence techniques including GA, PSO, ICA and ABC. The objective was to minimize the total cost of the system real power loss and shunt capacitors to be installed as well as the cost of occupying system capacity. The objective function was subjected to some operating constraints and power quality constraints, aiming to decrease power system unbalancing by optimal capacitor placement. The results showed that the HHBC algorithm was more effective than other methods investigated that in decreasing total cost function, satisfying the IEEE standard (IEEE-519) and maximizing net saving. The study suggested that, in the presence of DGs, optimal capacitor placement is necessary to avoid high harmonic distortion levels [7].

C. Efficient Heuristic Algorithm

A heuristic algorithm was presented to solve the optimum capacitor placement problem in radial distribution systems. The algorithm presented satisfactory results in terms of quality for the solution found and with a relatively small processing effort as it solves a reduced number of non-linear programming problems. The algorithm works with no difficulty in systems where different cost switched and fixed capacitors can be placed. However, the presented proposal corresponds to a heuristic strategy and, at least from a theoretical point of view, may be not compete in quality with the solutions found with recent meta heuristics, but the solution obtained in the test was better in quality than mainly because it has represented less investment and more savings, and close to the solution. This is true taking into account that main substations “usually” have voltage regulators or load tap changer transformers. In the tests, it was also observed that the capacitor placement is efficient in the reduction of losses of the system but it cannot always solve problems of voltage drop, especially, in systems highly loaded. This problem must be overcome by placement of voltage regulators. In this work, the voltage drop problem was adequately overcome considering that the voltage magnitude in the substation can be seen as a variable that was optimized by the non-linear programming algorithm. In the case of highly loaded systems, it is believed that the most adequate strategy is the optimum capacitor placement and optimum operation point setting of voltage regulators, being that the capacitors solve the diminishing of losses more adequately and the voltage regulators solve the voltage drop problems in a better manner[8].

D. Genetic Algorithms

It is common to allocate only capacitors or voltage regulators to resolve problems of losses, low power factor and voltage profile. But the author proposed a methodology to place both capacitors and voltage regulators to analyze the effects of each one at the same time. This work determined a multi-objective problem which considers the costs of the equipment and losses. It includes the violations of voltage limits, voltage drops along the feeder and conciliating them at the same strategy. The CB and VR allocation's methodology was formulated using GA. Each solution for above mentioned problems was evaluated using an OPF instead of the traditional load flows. The OPF was chosen because it makes possible the optimization of tap regulators that assure the voltage level maintenance specified by the GA for different load platforms and to obtain the nominal current of the VRs allocated. Analyzing the results, the appropriate solution in terms of total cost is obtained by simultaneous CB's and VR's allocation. Solution is better with GA and more benefits can be achieved by the reduction of losses [9].

E. Fuzzy-Based Approach

A fuzzy-based approach for optimal capacitor allocation and sizing has been presented. A new membership function for active sectional and total active power losses has been proposed and constant active sectional power loss concept has been implemented. A voltage membership function has been used. The application of the proposed approach on 9-bus and 34-bus systems led to the following conclusions:

- (1) The proposed membership function proved its proper behavior.
- (2) The increase in fixed cost resulted from the proposed method is compensated by the decrease in the running cost and generally lower total cost has been obtained.
- (3) The proposed approach was characterized by simple capacitor allocation and sizing technique [10].

F. Bacterial Foraging Optimization Algorithm

Capacitor placement in the distribution system is used to compensate the reactive power which leads to minimize the power loss, enhance the voltage profile, improve the overall system stability, etc. It is necessary to place the capacitor in right location with optimal size to ensure the maximum benefits of the system. A new method of finding the optimal location was proposed and the optimal size was determined by using BFOA. The proposed method was applied on IEEE 34-bus and 85-bus radial distribution system. Also implementation on these systems with all possible load variations was an added advantage of the proposed method. The simulated results were compared with the results of MINLP, PGS, PSO, HS-based methods. The results obtained by the proposed method were found to be better than the other existing techniques. The equation got from the curve fitting tool is very much useful to the DNOs to choose the optimal size of the capacitor according to the load changes. Hence, the proposed method can be easily applied to any kind of radial distribution system.

G. Fuzzy Logic and Immune-Based Algorithm

A hybrid fuzzy and immune algorithm based approach to find the optimal locations and capacities of shunt capacitors to be installed in the harmonics polluted power systems. In the solution procedure, the fuzzy logic is first implemented to determine the most suitable locations. Then, the corresponding capacitor sizes at candidate buses are determined by the proposed algorithm. By comparing the results with those obtained by using fuzzy and GA-based methods for two test systems, it is shown that the proposed method was effective for placement and sizing shunt capacitors with the least cost while all constraints were met. It was noted that the immune-based algorithm is superior to GA for searching the global optimal solution via comparing affinities and diversities between antibodies and maintaining a better population for next generation. The GA's roulette wheel mechanism is kept less elite in the parent chromosomes for next generation and with higher affinity between chromosomes, which tends to be easily trapped in the local optimal solution. The proposed method can be extended to include more load levels if more accurate results were required. In addition to the proposed two-stage solution method, future work will investigate more approaches, such as applying GA to tune the fuzzy membership functions for improving the optimal solution, where the capacitor locations and sizes can be solved simultaneously [11].

H. Nonlinear programming approach

This method was used to find location and size of capacitors in distribution system. Capacitors are required in distribution systems to supply reactive power for minimizing the losses, power flow control, improving system stability, power factor correction, voltage profile management and the reduction in active energy losses. The placement of capacitors should be appropriate to ensure that system has minimum power losses and capacitor installation costs. A mixed integer nonlinear programming approach for capacitor placement in radial/mesh distribution systems was used to determine the optimal location and sizing of capacitors. The proposed method was applied to 10, 34 and 85-bus radial distribution systems and CIVANLAR mesh distribution system. Various-scale application systems were used to compare the performance of the proposed method with the Fuzzy reasoning, particle swarm optimization (PSO), plant growth simulation algorithm (PGSA), and Heuristic based. Numerical results show that the performance of the proposed MINLP method was better than the other methods. Also, the MINLP method was superior to some other methods in terms of solution power loss and costs [12].

I. Multi objective particle swarm optimization

A new approach was the multi objective particle swarm optimization (MOPSO) with the aim of determining optimal location and size of distributed generators (DGs) and shunt capacitor banks (SCBs) simultaneously. In this method author considered load uncertainty in distribution systems. Fuzzy MOPSO algorithm has been applied to find the better solution of DGs and SCBs sizing and locating problem. The decreasing active power losses, improving voltage stability for buses and balancing current in systems sections were multi objective optimization functions. The proposed method first used Pareto optimal solutions to solve the problem and finally the best optimum solution were extracted by a fuzzy-based mechanism. The method was implemented on IEEE 33 bus RDS and an actual realistic 94 bus Portuguese RDS and the results were compared with methods of SPEA, NSGA MODE and ICA/GA. Numerical results shown that the performance of the fuzzy proposed MOPSO method was better than the other methods in MOPSO optimization problems of systems with load uncertainty in terms of using DGs and SCBs simultaneously, power losses reduction, voltage stability maximization, voltage profile improvement, load balancing. In addition to improving technical problems economic benefit provided that optimal placement of DGs and SCBs is the main motivation in power distribution system planning[13].

J.Plant Growth Simulation Algorithm

A new and efficient approach for capacitor placement in radial distribution system determines the optimal location and size of capacitors with an objective of improving the voltage profile and reducing the power loss. In this loss sensitivity factors and PGSA for capacitor placement has been proposed. The loss sensitivity factors were used to determine the candidate locations of the buses required for compensation. The PGSA was used to estimate the required level of shunt capacitive compensation at the optimal candidate locations to enhance the voltage profile the system and reduce the active power loss. The simulation results based on 10, 34, 85-bus systems have produced the best solutions that have been found using a number of approaches available in the literature. The advantages of the proposed method were:

- (1) It handled the objective function and the constraints separately, avoiding the trouble to determine the barrier factors.
 - (2) The proposed approach did not require any external parameters.
 - (3) The proposed approach has a guiding search direction that continuously changes as the change of the objective function.
- This method places the capacitors at less number of locations with optimum size and offers much net annual saving in initial investment[14].

K.Direct search algorithm

A new algorithm was proposed to determine the optimal sizes of fixed and switched capacitors together with their optimal locations in a radial distribution system so that net savings were maximized and improvement in the voltage profile was achieved. The presented algorithm for designing the compensation in distribution system, resulted in improving the voltage profile and maximizing the net savings. Cost analysis was demonstrated on 69 bus radial distribution system. This algorithm can be classified under direct search algorithm as the approach was methodic and sequential. The process generally terminates fast and faster if implemented by an expert. Standard 69 bus and 85 bus systems have been considered for which known results were there with implementation of PSO and genetic algorithm. It has been clearly observed for the given loading conditions, the total distribution loss was significantly less than the one obtained in the other two methods. The algorithm was also tested on 22 bus practical agricultural distribution system. However, the future work can be carried out considering the installation and maintenance costs[15].

L. Teaching learning based optimization

Teaching learning based optimization (TLBO) approach to minimize power loss and energy cost by optimal placement of capacitors in radial distribution systems. Teaching-learning based optimization (TLBO) technique which was one of the recently developed population based optimization technique was implemented and successfully applied on small, medium and large scale radial distribution network to improve the cost and to reduce the power loss. The simulation results demonstrate the effectiveness of the proposed algorithm to solve optimal capacitor placement problem. Moreover, the performance of proposed TLBO technique was compared with the GA, PSO, Fuzzy-GA and DSA. The comparison confirms the effectiveness and the superiority of the proposed TLBO approach over the other techniques. However, in TLBO algorithm single teacher was used to improve the results of a class which comprises a large number of learner's. Moreover, the teaching factor used in TLBO algorithm was either 2 or 1 which means learner learns either cent percent or zero percent from the teacher. This may result in slower convergence rate for large scale non-linear optimization problem. Therefore, to speed up the search process and to improve the convergence rate, some modifications may be possible and this was left for further research[16].

M. Imperialist Competitive Algorithm (ICA) and genetic algorithm (GA)

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A new combined method was proposed to solve siting and sizing problems for DG and capacitor banks simultaneously in distribution system. In this method, first the ICA algorithm was used to find location and size of the DGs and the capacitors. In the next step, GA method was used to generate a new set of colonies and solutions in the all search spaces. Combined method was implemented on IEEE 33 bus and 69 bus radial distribution systems to minimize the losses, to increase the voltage stability, to improve the voltage regulation index and to balance the loads. Results from proposed method were compared to the results from GA/PSO and advantages and disadvantages were discussed. Considering active power losses, reactive power, voltage stability, the voltage regulation index, load balancing and the value for objective function along with economic issues, it can be concluded that the proposed method exhibited a higher capability in finding optimum solutions compared to GA/PSO method[17].

N. Gravitational Search Algorithm

Author adopted two methods where the first method being the sensitivity analysis and the second method was the Gravitational Search Algorithm (GSA) to determine location and size of capacitor banks. GSA for optimal placement and sizing of fixed capacitor banks so as to minimize the kW loss of the Radial Distribution Network (RDN) and maximize the net savings. The GSA technique was found predominantly appropriate for answering optimization problems with discontinuous solution space and objectives when the global optimum was desired. The optimal solution in GSA was achieved by movement of agents in search space and its direction was based on the overall force of all other agents. Therefore, the search direction en route for the optimal solution was effective in this algorithm. The recommended method was verified on 33-Bus, 69-Bus, and 85-Bus and 141-Bus radial network. The results obtained that the GSA method was superior to few other techniques discussed in preceding literatures in terms of solving the objective function[18].

III. CONCLUSION

Different methods have been devised to solve the problem of capacitor allocation in distribution system. So, it can be concluded that fuzzy approach is very simple to apply for finding location of capacitor and GA can be used for any type of radial system. But to determine the location of capacitor with fuzzy approach gives better results. Immune based method combined with fuzzy and GA combined with fuzzy has used to improve the cost and to reduce the power losses than only GA and only immune based method. MINLP method is superior to the PGSA and PSO because it offered much net annual savings. ICA approach exhibited a higher capability in finding optimum solutions compared to GA/PSO method. Results of BFOA is better than the results of other discussed techniques (MINLP, PGS, PSO and HS-based methods) to minimize the cost of capacitor installation and maximize the net savings. But among all these methods, to minimize the power loss and maximize the net savings, GSA is found better. To find the location of capacitor placement in the given system, loss sensitivity method is simple to use. Furthermore, in every step comparisons between more than three methods is given and can be predict that which method will be better to solve the problem of capacitor allocation.

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