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Review on Capacitor Placement Techniques in Distribution Feeders and Use in ICT

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Abstract

Capacitors are mainly used in power system for reactive power compensation. Reactive power compensation can be done in two ways: Series compensation and shunt compensation. The placement of capacitors is one of the most important methods to achieve loss reduction and enhance the voltage characteristics of distribution systems. Different optimization methods can be used to determine the optimal values of the capacitors in electrical distribution networks. The problems related to determining the optimal size and location of shunt capacitors on distribution feeders has received much thought from researchers for many years. Capacitors are frequently used as mandatory devices in information and communication technologies (ICTs). This paper presents an extensive review of the different solution methods found in the literature.

Keywords: Capacitor placement; Radial distribution systems; Optimization techniques; Analytical methods; Numerical programming methods; Heuristics methods; Genetic algorithm; Particle swarm optimization

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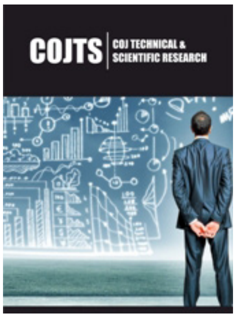

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Introduction

Series compensation and shunt compensation are the way techniques by which capacitors are placed in an electric network. Series compensation alters the reactance of the transmission or distribution lines, while shunt compensation changes the equivalent load impedance. Shunt compensation technique is widely used due to various problems associated with series compensation such as increase in fault current, mal operation of distance relays, problems due to sub-synchronous resonance and ferro-resonance. Some of the benefits of shunt reactive power compensation are: improvement in system power factor, reduction in network losses, reduction in consumption of reactive power, increase in system capacity, saving of cost on new installations and improvement of voltage regulation in the network. The benefits of compensation depend substantially on the manner in which capacitors are placed in the distribution system, particularly on the placement and sizing of the added capacitors. Capacitors have wide applications in ICTs. Prior to 1950s the shunt capacitor banks (SCB) were placed nearer to the main substation for capacitive reactive power compensation. The trend then shifted to install capacitors out on the primary distribution feeders rather than at the substation. This was due both to the availability of pole-mounted equipment and because of the economics favoring placement of the capacitor closer to the loads. Two benefits are generally of importance in placing the capacitor out on the primary feeders: the voltage rise which is caused by the capacitors, and the added loss reduction which results from moving the capacitors from the substation out to the load area [1]. To achieve benefits of shunt compensation under various operating constraints, it is required to determine the optimal locations, types and sizes of capacitors to be placed. The power factor correction capacitors can be installed at high voltage bus, distribution, or at the load but the optimal location can be found using different optimization techniques.

Review of optimization techniques

Different authors have proposed different methods considering different fitness function including minimization of power losses, reduction in installation cost, and improvement in voltage profile; lessen the burden on existing lines, maximization of system stability and others. These techniques are classified into four categories. They are analytical methods, numerical programming methods, heuristic search methods and artificial intelligence (AI) based methods. Analytical Methods: When powerful computing resources were unavailable or expensive, the author's proposed simple calculus based analytical algorithm. Some approximations were done in order to reduce the computation procedure. These assumptions (e.g. load variation neglected) and scenarios (e.g. distributed non-distributed) as considered by the authors in developing that algorithm may lead to errors such as overvoltage problem or loss savings ($) less than the calculated one. The initial work was carried out by Neagle [1] in 1956 for optimum single and multiple capacitor bank in case of uniform and non-uniform distribution of load. According to [1], the maximum loss reduction on a feeder with distributed load is obtained by locating the capacitor bank where its capacitive kvar is equal to twice the system kvar. He determined that the for maximum loss reduction, the location of the capacitor should be [1 – (½)*(capacitive kvar/ system kvar)] distance from the main substation. Cook, in 1959, worked on the same guideline as given by Cook [2] and proposed a more practical algorithm for fixed capacitor bank for uniformly distributed considering average reactive load in the system. He suggested the location of each capacitor is two-thirds pu instead of the optimum location for each capacitor rating. Cook also suggested that the optimum size of SCB must be 2LF/3 where LF stands for reactive load factor. Cook later extended his work in to include switched capacitors [3].

Schmill [4] extended the work of Cook [3] in 1961. Equations are given for sizing and placement of fixed or switched capacitors on uniformly or none uniformly loaded feeders. The necessary conditions for optimal sizing and placement of one or two capacitors on a feeder are presented. An iterative approach is suggested to solve the problem. Numerical Programming Methods: These are iterative techniques used to maximize (or minimize) an objective function of decision variables. The values of these variables must also satisfy a set of constraints. With the availability of fast computing skills and large memory availability, the utilization of numerical methods in power system has increased Dura H [5] proposed a dynamic programming approach to find the number, locations, and sizes of fixed capacitor banks on a feeder with discrete loads? Algorithms are presented for the special cases of no capacitor cost, capacitor cost proportional to installed capacity, and cost proportional to installed capacity plus a fixed cost per capacitor bank Ponnavsikko M et al. [6] included the effect of load growth and energy cost increase into the objective function and solve the problem using the Method of Local Variations. In this procedure, the capacitor at each bus is a state variable. The procedure starts with any solution which satisfies all voltage constraints. A check is made to determine if additional savings will result from increasing the size of the capacitor at a bus by a discrete amount, which is determined by the minimum available capacitor size. In such case the capacitor value is set to the new size. Otherwise, a check is made to see if a decrease in size will result in an increase in savings. If so, the capacitor size at the bus is decreased, otherwise no change is made and the method proceeds to the next bus. Iteration is complete when all buses have been checked. Convergence is reached when all state variables remain unchanged throughout an entire iteration. Khodr HM et al. [7] solved the SCB problem using mixed-integer linear problem and considered overall energy saving as fitness function. The problem was formulated as the maximization of the NPV of the compensation project. The objective was to maximize the global savings obtained from loss reduction and capacity release in the expansion of the network. After a suitable linearization, the optimization problem was formulated as a mixed-integer linear problem and successfully solved by using a widespread commercial package.

Heuristics Methods

Heuristics methods are "hints", "suggestions", or "rules of thumb" based methods that are developed through intuition, experience, and judgment. Heuristic methods produce fast and practical strategies which reduce the exhaustive search space and can lead to a solution that is nearer to the optimal solution with confidence. The solution to the capacitor problem using heuristic rules involves searching through a set of possible solutions. Abdel-Salam et al. [8] presented a new technique for reducing the energy losses arising from the flow of reactive power in a distribution system by placing compensating capacitors at a few specific locations in the network termed "sensitive nodes" to achieve a maximum annual dollar saving. A cost study is performed taking into consideration the load variations during the year and the costs of capital and installation of the compensating capacitors. Chis et al. in [9] extended the work of Abdel TS et al. [8] and considered cost of capacitor bank (size) from both energy and peak power loss reductions. Some advantages of this method are: reduced size of the problem, reduced computation time and better savings. In Ramalinga RM et al. [10] the authors have used direct search algorithm to determine the optimal sizes of fixed and switched capacitors together with their optimal locations in a radial distribution system so that net savings are maximized and improvement in the voltage profile is achieved. AI Methods: The simplest of search algorithms in optimization is exhaustive search that tries all possible solutions from a predetermined set and subsequently picks the best one. However such methods are considered as non-efficient in terms of computation time and space requirement. Heuristic techniques which are smart and inspired from nature have also been proposed in literature, commonly known as artificial intelligent (AI) methods. When a realistic problem formulation with all considerations is to be solved, however, most other methods are unable to work well whereas AI methods provide reliable and optimal solutions in a short CPU time. Some examples of such methods are based on genetic algorithms (GA), fuzzy, immune algorithm, Tabu search, fuzzy-GA, particle swarm optimization, plant growth simulation algorithm, memetic-algorithm approach, teaching learning based optimization algorithm, ant colony, graph search algorithm, etc. However in large systems, AI methods suffers from high computation time and large memory space requirement, in such cases hybrid methods are considered more powerful. Sundharajan [11] proposed new optimization method using a Genetic Algorithm is proposed to determine the optimal selection of capacitors. The objective function is to minimize the peak power losses and the energy losses in the distribution system considering the capacitor cost. Genetic Algorithms are basically search mechanisms based on the Darwinian principle of natural evolution. Only information needed to in GA is the objective function. The five components that are needed to implement this algorithm are representation, initialization, evaluation function, genetic operators and schemata. Likewise genetic parameters such as population size, crossover rate and mutation rate help to tune the performance of the genetic algorithms.

The number of function evaluations is greater and hence GAS are slower compared to traditional optimization algorithms. However, the function evaluation for each string is independent and hence they could be processed in parallel. This implicit parallelism makes them the most suitable for design optimization in a parallel computing environment. Chung Fu [12] attempted to solve the capacitor placement problem by using Ant Colony Search Algorithm (ACSA) based the natural behavior of ants in locating food sources and retrieve them to their colony by the construction of unique paths. The objective is to minimize the system power loss, subject to operating constraints under a certain load pattern. The main computational processes of ACSA are i) initiation ii) Estimation of the fitness iii) Ant placement and reconfiguration iv) Local/global updating rule v) Termination of the algorithm. From the application results, it was observed that the feeder reconfiguration and capacitor placement process reduced the power loss and improved the voltage profile. In addition, the computational results showed that the performance of the ACSA method was better than those obtained by the Simulated Anneling (SA) and Genetic Algorithm (GA). It was also observed that the ACSA method is especially suitable for application to large-scale distribution systems. Singh and Rao [13] discussed the Optimal allocation of capacitors in distribution systems using particle swarm optimization. The objective is to minimize the sum of energy loss and the capacitor costs satisfying operational and power balance constraints. The buses having higher sensitivities would be candidate locations in order to reduce the search space. After the selection of buses with higher sensitivity factors as candidate locations, optimization is done by particle swarm algorithm. Comparison of PSO is carried out with other methods like Tabu Search, Hybrid Method and Genetic Algorithm. Results demonstrate that PSO yields greater savings, lesser losses and better voltage profile compared to other methods. Computation time of PSO is very less when compared with Genetic Algorithm.

Conclusion

Researchers have devised different methods to solve the problem of optimal placement of capacitor banks. This paper presents a review of these methods. It is clear from the existing literature that each method has several advantages and several demerits too. The issues associated with both the design and control problems of different methods need to be addressed, which opens a whole new possibility for future research on this topic.

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