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Particle swarm optimization algorithm for capacitor allocation problem in distribution systems with wind turbine generators

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ABSTRACT

This paper aims at adopting the Particle Swarm Optimization (PSO) technique to find the near-optimal solutions for the capacitor allocation problem in distribution systems for the modified IEEE 16-bus distribution system connected to wind energy generation based on a cost function. The proper allocation and the optimized number of capacitors have led to adequate power losses reduction and voltage profile enhancement. Because of the wind power generation variations due to the nature of wind speed intermittency and the lack of reactive power compensation, the problem under study have been presented involving a nonlinear fitness function. In order to solve it, the corresponding mathematical tools have to be used. The formulated fitness cost function has consisted of four terms: cost of real power loss, capacitor installation cost, voltage constraint penalty, and capacitor constraint penalty. PSO technique has been used to obtain the near-optimum solution to the proposed problem. Simulation results demonstrate the efficiency of the proposed fitness cost function when applied to the system under study. Furthermore, the application of PSO to the modified IEEE 16-bus system has shown better results in terms of power losses cost and voltage profile enhancement compared to Genetic Algorithm (GA). In order to verify the successful adaptation of PSO toward attaining adequate near-optimal capacitor allocations in distribution systems, this metaheuristic technique has been employed to the large-scale IEEE 30-bus system. The proposed PSO technique has provided adequate results while modifying the objective function and constraints to include the power factor and transmission line capacities for normal and contingency (N-1) operating conditions.

Introduction

Distribution systems, typically passive radial networks with unidirectional power flow, have a high R/X ratio and significant voltage drop that may cause significant undesirable power losses. Distribution systems capture about 13% of the overall power generation [1–3]. From the utility point of view, the system efficiency is directly influenced by real power losses. However, the reactive power flow should be accounted for in order to maintain voltage within acceptable limits and to release the transmission capacity especially for system reliability and stability purposes [4]. In order to reveal the estimated minimized power loss in distribution networks, capacitor placement, feeder reconfiguration, and Distributed Generation (DG) allocation have been used [1].

Capacitors provision in power systems are mainly for voltage profile management, power factor correction, power flow control, system stability improvement and reactive power compensation. Due to capacitor installations, a part of the reactive currents will be cancelled that results in a considerable decrease in the overall supplied current [2]. Reactive power loss minimization and voltage profile improvement are successfully accomplished through either/both DG sources or/and capacitors banks in distribution systems. In order to reduce the system losses and enhance its performance, the most convenient installation location and the related capacity of these components should be identified. This considerable identification will keep the power generation/consumption coincidence which leads to minimum power losses [5]. An economical momentum can be harnessed through power losses minimization delivered by capacitor banks investment [6]. Therefore,

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perceptible challenges dealt with near-optimal capacitor placement for both voltage control and loss minimization have been proposed [6]. For attaining this goal, selecting the most appropriate number of capacitor units, their locations and sizing have to be determined. Therefore, power loss reduction, voltage profile regulation, and power flow control could be realized.

Many optimization techniques have been developed to find the best capacitor placement and sizing in distribution systems. These techniques can be classified into four categories: analytical methods, numerical programming approaches, heuristic methods and Artificial Intelligent (AI) based techniques [7,8]. To successfully reach the most convenient solution, advanced stochastic techniques can replace the time-consuming analytical optimization approaches particularly for complex problems. Therefore different optimization techniques such as dynamic programming, evolutionary programming, tabu search, genetic algorithm, simulated annealing, particle swarm optimization (PSO), ant colony system, fuzzy based optimization approaches, honey bee mating optimization and shuffled frog leaping algorithm have been investigated [3,9,10]. Despite of the fact that heuristic methods do not assure a global optimal solution, reasonable near-optimal ones with an admissible computation time have been demonstrated [10]. For more favorable optimization results, hybrid approaches can be considered [10–17].

The main contribution of this paper deals with proposing PSO technique, in favor its simplicity and relative short convergence time, to determine the near-optimum capacitor locations and their relevant sizes to improve the performance of the modified IEEE 16-bus, three feeder systems with one wind generator. The objective function, employed by PSO, has included the annual net saving and the cost of power losses resulting from the reduction of peak power losses while accounting for the total cost of the capacitor [18–22]. To verify the adequacy of the PSO technique for the determination of the near-optimum capacitor location/size in the modified IEEE 16-bus, the simulation results are compared to those reached from using the GA approach. Furthermore, the PSO is applied to the IEEE 30-bus system to confirm the effectiveness of such metaheuristic technique toward estimating the near-optimum solutions of capacitor placement/size in the system. For all simulation studies, the insertion of the capacitor penalty cost is considered as a constraint in the objective function. Precisely, if the allocated capacitor size required for fitness function minimization is not one of the available capacitor standards, a defined penalty is added in the objective function to reject such capacitive candidate and to search for another capacitor that satisfies both the cost function minimization and the given constraints [18–22].

The rest of the paper is organized as follows: a comprehensive literature review has been presented in section 'Literature review'. In section 'System under study and problem formulation', the IEEE modified 16-bus system under study has been presented. Moreover, an overview of the problem formulation besides the construction of the fitness function and system constraints has been illustrated. Section 'Solution approach based on PSO' has briefly demonstrated the PSO technique. Simulation results have been explicitly discussed in section 'Simulation results' for exhibiting the PSO technique performance and its effectiveness compared to the base case (before using the proposed optimization method). In addition, the PSO technique has been compared to the GA when applied to the modified IEEE 16-bus system. In section 'PSO method validation', the verification of the proposed PSO technique has been considered. The capability of the proposed PSO technique in enhancing the voltage profile of the IEEE 30-bus system and minimizing its relevant power losses cost has been demonstrated. Then, validity of the PSO methodology has been verified through a modified objective functions with new constraints such as the power factor and the line capacities when applied to the original IEEE 16-bus system. Finally, the conclusions and the forthcoming research perspectives have been drawn in section 'Conclusions'.

Literature review

Since 2010, abundant researches have highlighted the importance of optimal placement and sizing of capacitor for real power loss reduction and voltage profile regulation in distribution systems. Segura et al. have proposed an efficient heuristic algorithm for optimal capacitor allocations in radial distribution systems [23]. De Oliveira et al. have used the Mixed Integer Non-Linear Programming (MINLP) technique for optimal reconfiguration and capacitor allocation solutions for energy loss minimization of radial distribution networks considering different load levels [24]. Eajal et al. have developed an efficient hybrid PSO algorithm to find a convenient solution for optimal allocation and sizing of the capacitors while satisfying operating and power quality constraints [25]. Guimaraes et al. have sought for optimal capacitor placement and reconfiguration solutions via GA in distribution systems [26]. Carpinelli et al. have applied GA in order to find the optimal allocation and sizing of capacitors in unbalanced multi-converter distribution systems [27]. Tabatabaei et al. have suggested the bacterial foraging solution with a fuzzy logic decision for optimal capacitor allocation in radial distribution system [28]. Szuvovivski et al. have studied both GA algorithms and optimal power flow for allocating simultaneously capacitors and voltage regulators at distribution networks [29]. Singh et al. have used the PSO approach to determine the optimal capacitor placement for cost savings' maximization [30]. Kansal et al. have presented the optimal allocation of different DG using PSO technique for active and reactive power compensation to minimize the real power losses in the primary distribution networks [31,32].

Nojavan et al. have presented the optimization approach based on MINLP approach for optimal capacitor placement in radial/mesh distribution systems. The superiority of the considered optimization technique compared to others in terms of both power loss and investment costs reduction has been demonstrated [33]. Ramadan et al. have considered fuzzy set optimization approach for optimal capacitor allocation solution in radial distribution system. Different membership functions for voltage profile constraint, active power losses and total power losses constraints have been proposed in the optimization process [2]. Furthermore, Karimyan et al. have presented a worthy bibliographical survey in which a comprehensive literature review concerning the common techniques and the related optimization approaches used for distribution systems' loss minimization have been illustrated [1].

Gholami et al. have developed a GA-based approach for the optimal sizing and placement of either fixed or switchable capacitors both to guarantee the benefits of capacitor installation at different load levels and to minimize the investment cost of capacitors [34]. Augugliaro et al. have presented the GA to solve optimization problems with many discrete variables such as the best allocation/sizing of DG systems or the relevant optimal compensation [35]. Injeti et al. have proposed the Bio-Inspired Optimization (BIO) algorithm for the optimal capacitors placement/sizing in radial distribution systems in order to minimize the power loss and maximize the network savings [36].

Devabalaji et al. have studied the optimal allocation of capacitor bank in radial distribution systems in order to minimize the power loss based on the loss sensitivity factor and voltage stability index [37]. For this purpose, the Bacterial Foraging Optimization (BFO) approach has been considered for the optimal sizing/allocation for the capacitors in such distribution system. Duque et al. have presented the Monkey Search Optimization (MSO) technique for the allocation of fixed capacitors banks in order to optimize the