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Improved meta-heuristic techniques for simultaneous capacitor and DG allocation in radial distribution networks

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ABSTRACT

The active and reactive power flow in distribution networks can be effectively controlled by optimally placing Shunt Capacitors (SCs) and Distributed Generators (DGs). This paper presents improved versions of three evolutionary or swarm-based search algorithms, namely, Improved Genetic Algorithm (IGA), Improved Particle Swarm Optimization (IPSO) and Improved Cat Swarm Optimization (ICSO) to efficiently handle the problem of simultaneous allocation of SCs and DGs in radial distribution networks while considering variable load scenario. The benefit of network reconfiguration has also been taken into account after optimal allocation of these devices. Several algorithm specific modifications are suggested in the standard forms of GA, PSO and CSO to overcome their inherent drawbacks. In addition, an intelligent search approach is proposed to enhance overall performance of proposed algorithms. The proposed methods are investigated on IEEE 33-bus and 69-bus test distribution systems showing promising results when compared with other recently established methods. Application results also show a marked improvement in the performance of these algorithms while compared with their respective standard counterparts.

Introduction

The electric power industries have witnessed many reforms in recent years. The present trend towards deregulation in power sector is forcing electric distribution utilities to improve their energy efficiencies for cost cutting whereas customers are becoming more sensitive to reliability and power quality. Shunt Capacitors (SCs) and Distributed Generators (DGs) are some of the essential components for realizing the concept of smart distribution systems. The smart grid requires integrated solutions to well-formulated problems that reflect facts on the ground where all such devices coexist to achieve smart grid goals of efficiency through loss minimization and high-quality power delivered to the ultimate user [1]. Different benefits of optimal allocation of SCs and DGs in distribution networks include reduction of line losses, improvement of voltage profile, peak demand shaving, relieving the overloading of distribution lines, reduced environmental impacts, increased overall energy efficiency, and deferred investments to upgrade existing generation, transmission, and distribution systems [2]. The optimal generation of active and reactive power from these devices in distribution systems reduces their power import from the substation and thus regulates feeder power flows. The SC placement achieves this goal by regulating reactive power flow, whereas DG placement does the same by regulating active power flow in the system.

In recent past AI-techniques such as the Genetic Algorithm (GA), Tabu Search (TS), Particle Swarm Optimization (PSO), Harmony Search Algorithm (HSA), ant colony search, fuzzy GA, Bacterial Foraging Optimization (BFO), immune-based optimization technique, integrated DE-PS, big bang-big crunch optimization, Plant Growth Simulation Algorithm (PGSA) and Artificial Bee Colony (ABC)-based algorithm have been successfully used to solve the problem of optimal allocation of SCs [3]. The AI-techniques such as Simulated Annealing (SA), GA, PSO, ABC, Modified Teaching-Learning Based Optimization (MTLBO), and HSA have also been successfully used to solve the problems of optimal allocation of DGs in distribution systems [4]. However, only few researchers [5–12] have optimized these two problems simultaneously to show their combined effect on the performance of distribution network. The simultaneous placement strategy is more realistic and can independently set and control the real and reactive power flow in distribution networks [13].

GA is a simple, robust and flexible method which is able to find the global or near global solution efficiently, but it has some inherent drawbacks such as high processing time and premature

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Nomenclature

c, c_1, c_2	acceleration coefficients
D	number of decision variables
db	each dimension of selected cat ($1 \leqslant db \leqslant D$)
E	total number of branches in the system
$gbest$	best particle position based on overall swarm experience
H_j	load duration at jth load level (hrs)
I_{fj}	feeder current at jth load level (p.u.)
I_{frated}	rated feeder current (p.u.)
$itr_{\max}$	maximum iteration
itr_s	specified maximum iteration
Itr	current iteration
L	set of load levels
loc	total number of candidate locations for SC/DG placement
N_c	candidate nodes for capacitor placement
N_{DG}	candidate nodes for DG placement
N	total number of system nodes
N_L	total number of load levels
N_b	branch number
nc	maximum number of candidate capacitor banks for single location
n	set of system nodes
P_{DG}	maximum DG capacity at one candidate node (kW)
$P_{DG,\max}$	maximum active compensation provided by DGs (kW)
$P_{DG,\min}$	minimum active compensation provided by DGs (kW)
P_D	nominal active power demand of the system (kW)
$P_{loss,j}$	power loss jth load level (kW)
$P_{loss,bj}$	power loss for uncompensated system at jth load level (kW)
$P_{loss,aj}$	power loss for compensated system at jth load level (kW)
P_{ij}	real power for sending end of ith branch at jth load level (kW)
p_{best}	the own's best move of the cat
$pbest_p$	best position of pth particle achieved based on its own experience
p_{pred}	preceding movement of the cat
Q_c	maximum candidate capacitor banks at one candidate node (kVAr)
Q_D	nominal reactive power demand of the system (kVAr)
$Q_{c,\max}$	maximum reactive compensation provided by capacitors (kVAr)
$Q_{c,\min}$	minimum reactive compensation provided by capacitors (kVAr)
Q_o	size of capacitor bank (kVAr)
Q_{ij}	reactive power for sending end of ith branch at jth load level (kVAr)
ΔQ	taping size of capacitor bank (kVAr)
R_i	resistance of ith branch
$r()$, $r_1()$, $r_2()$	random number in the range of [0,1]
s_p^k/s_p^{k+1}	position of pth particle at kth/$(k+1)$th iteration
Δt	time step (s)
$V_{\max}/V_{\min}$	maximum/minimum permissible node voltage (p.u.)
$V_{\min S}$	minimum specified node voltage (p.u.)
V_{ij}	voltage of ith node at jth load level (p.u.)
v_p^k/v_p^{k+1}	velocity of pth particle at kth/$(k+1)$th iteration
v_q/v_{q+1}	velocity of qth/$(q+1)$th cat
ΔV_{ij}	maximum node voltage deviation of ith node at jth load level (p.u.)
w	inertia weight
$w_{\max}/w_{\min}$	maximum/minimum value of inertia weight
x_{best}	position of the cat who has the best fitness value
x_q/x_{q+1}	position of qth/$(q+1)$th cat
λ	node voltage deviation penalty factor
Φ_j	closed loop at jth load level

convergence to a local optimum [14]. PSO is a powerful swarm intelligence-based computation technique. This technique can generate a high-quality solution and stable convergence characteristic within a shorter calculation time than other stochastic methods [15]. However, the dependency of this algorithm on the adjusting parameters and the possibility of trapping in local optima can reduce the efficiency and accuracy of the algorithm at different situations [16]. Similarly other computation techniques have their inherent advantages and disadvantages.

Chu and Tsai [17] proposed a new swarm intelligence-based high performance computational method Cat Swarm Optimization (CSO) in 2007 which mimics the natural behavior of cats. It has been successfully applied to solve diverse engineering optimization problems such as IIR system identification [18], clustering [19], Linear antenna array synthesis [20], linear phase FIR filter design [21], Traveling salesman problem [22], deployment of Wireless sensor networks (WSNs) [23], etc. However, the CSO has not been attempted for the optimal allocation of SCs and DGs in distribution systems. In CSO, the two major behaviors of the cats are modeled into two sub-models, the seeking mode and the tracing mode. In the seeking mode, the cat looks around and seeks the next position to move to, whereas in the tracing mode, the cat tracks some targets [23]. The important property of CSO is that it provides local as well as global search capability simultaneously [24], but is computationally more demanding [25].

The search for the best combination amongst the various possible combinations for the SCs–DGs allocation is computationally arduous even for a small distribution system [26]. Therefore, many researchers have squeezed the search space by reducing the number of candidate locations for SCs–DGs placement using a suitable node sensitivity analysis technique such as mentioned in [2,3,5,7,26–30]. These techniques provide a node priority list from which only top few nodes are selected to redefine the problem search space. However, the sensitivities are normally calculated for the base case conditions, where no SCs–DGs are installed [31]. Furthermore, the selection of only top nodes as the sensitive components does not give the true picture of the entire distribution network [32]. Therefore, reduction of search space using any sensitivity-based node priority list wherein only top few nodes are selected to place these devices is unreliable and may give erroneous results.

Distribution networks reconfiguration is one of the effective means to improve performance of distribution systems under changing operating conditions. The reconfiguration of a distribution network is a process that alters feeder topological structure by managing the open/close status of sectionalizing and tie-switches under contingencies or normal operating conditions [33]. Changing the network topology by reallocating loads from one feeder to another may balance loads among the feeders and decrease the real power losses [34]. Therefore, network reconfiguration is another resource that can be utilized to improve the performance of distribution systems in conjunction with the optimal placement of SCs and DGs.

In this paper, the problem of simultaneous allocation of SCs and DGs in distribution networks is modeled to maximize annual energy loss reduction and to improve system node voltage profile