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Simultaneous allocation of distributed energy resource using improved particle swarm optimization

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HIGHLIGHTS

- This paper addresses a multi-objective formulation for simultaneous allocation of DERs in RDNs to maximize annual savings.
- An improved particle swarm optimization is proposed to overcome inherent tendency of local trappings in PSO.
- A node sensitivity-based guided search algorithm (GSA) is suggested to enhance overall performance of optimizing tool.
- Proposed method is investigated on benchmark IEEE 33-bus and 69-bus test distribution systems.
- Proposed approach is useful for electric utilities to enhance profits and stagger future expansion plans.

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ABSTRACT

Smart grid initiatives require integrated solution for radial distribution networks (RDNs) to achieve their optimum performance. The optimal allocation of distributed energy resources (DERs), such as shunt capacitors and distributed generation, when integrated with distribution network reconfiguration (DNR), can achieve desired objectives of smart distribution systems. This paper addresses a multi-objective formulation for simultaneous allocation of DERs in RDNs to maximize annual savings by reducing the charges for annual energy losses, peak power losses and substation capacity release against the annual charges incurred to purchase DERs while maintaining better node voltage profiles and feeder current profiles. An improved particle swarm optimization (IPSO) method is proposed to overcome against the inherent tendency of local trappings in PSO. A node sensitivity-based guided search algorithm (GSA) is also suggested to enhance the overall performance of the optimizing tool. GSA virtually squeezes the problem search space without loss of diversity. Distribution networks are optimally reconfigured after optimally placing DERs. The proposed method is investigated on the benchmark IEEE 33-bus and 69-bus test distribution systems. The application results show that the proposed integrated approach is very useful for electric utilities to enhance their profits and stagger their future expansion plans.

1. Introduction

The electric power industries have witnessed many reforms in recent years. The present trend toward the deregulation in power sector is forcing distribution network operators (DNOs) to improve energy efficiencies for cost reduction whereas customers are becoming more sensitive to reliability and power quality. Distributed energy resources (DERs) such as shunt capacitors (SCs) and distributed generators (DGs) are some of the essential components for achieving higher energy efficiency in distribution system operation. The energy efficient 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]. Optimal DER placement can improve network performance in terms of better node voltage profiles, reduced power flows, reduced feeder losses, improved power quality and reliability of electric supply, but inappropriate DER placement may increase system losses as well as network capital and operating costs [2]. Whatever be the particular driver for a DNO, e.g., to allow the connection of more DG capacity, to reduce energy losses, or to increase network reliability, the DG planning tools must take into account essential network constraints such as voltage and thermal limits [3].

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Nomenclature

c_1, c_2	acceleration coefficients
D	number of design variables
d	discount rate
E	total number of branches in the system
GQ_B	grid reactive power at base case (kVAr)
GP_B	grid active power at base case (kW)
GQ_{TSC}^n	grid reactive power with test capacitor at the *n*th node (kVAr)
GP_{TDG}^n	grid active power with test DG at the *n*th node (kW)
$gbest^k$	best particle position based on overall swarm experience at *k*th iteration
H_j	load duration at *j*th load level (h)
$I_n^{\max}$	maximum current of *n*th branch (p.u.)
I_{pf}	feeder current deviation penalty function
I_{nj}	current of *n*th branch at *j*th load level (p.u.)
ΔI_{nj}	current deviation of *n*th branch at *j*th load level (p.u.)
itr	current iteration
itr_{max}	maximum iteration count
itr_s	predefined iteration count
K_e	unit cost of energy (US \$/kW h)
K_p	unit cost of peak power losses (US \$/kW)
K_S	cost of annual charges for sub-station capacity release (US \$/kVA)
K_{SC}	cost of annual charges on shunt capacitor installation (US \$/kVAr)
K_{DG}	cost of annual charges on DG installation (US \$/kW)
K_b	number of capacitor banks
K_d	number of discrete dispatches of DG
L	set of load levels
loc	total number of candidate locations for capacitor/DG placement
N_L	total number of load levels
N_{SC}/N_{DG}	candidate nodes for capacitor/DG placement
N	set of system nodes
n	branch number
nsc	maximum number of candidate capacitor banks at a node
ndg	maximum number of discrete dispatches of DG at a node (kW)
P	population size
P_D	nominal active power demand of the system (kW)
$P_{loss,bj}$	power loss for uncompensated system at *j*th load level (kW)
$P_{loss,aj}$	power loss for compensated system at *j*th load level (kW)
$P_{loss,b}^P$	peak power loss for uncompensated system (kW)
$P_{loss,a}^P$	peak power loss for compensated system (kW)
$P_{DG,min}/P_{DG,max}$	minimum/maximum active compensation limit at a node (kW)
P_d	unit size of DG (kW)
P_{nj}/Q_{nj}	real/reactive power for sending end of *n*th branch at *j*th load level (kW/kVAr)
ΔP	minimum discrete dispatch of DG (kW)
$pbest_p$	best position of *p*th particle achieved based on its own experience
$Q_{SC,min}/Q_{SC,max}$	minimum/maximum reactive power generation limit at a node (kVAr)
Q_{SC}/P_{DG}	reactive/active power generation at a candidate node (kVAr/kW)
Q_D	nominal reactive power demand of the system (kVAr)
Q_b	size of capacitor bank (kVAr)
ΔQ	tapping size of capacitor bank (kVAr)
R_n	resistance of the *n*th branch (Ω)
$r_1()$, $r_2()$	random number in the range [0, 1]
S_b^P	sub-station capacity at base case (kVA)
S_a^P	sub-station capacity after DER allocation and reconfiguration (kVA)
S_{SC}^n	sensitivity of *n*th node for capacitor placement
S_{DG}^n	sensitivity of *n*th node for DG placement
s_p^k/s_p^{k+1}	position of *p*th particle at *k*th/$(k+1)$th iteration
Δt	time step (s)
V_{pf}	node voltage deviation penalty function
V_{max}/V_{min}	maximum/minimum permissible node voltage (p.u.)
V_{minS}	minimum specified node voltage (p.u.)
V_{nj}	voltage of *n*th node at *j*th load level (p.u.)
ΔV_{nj}	maximum node voltage deviation of *n*th node at *j*th load level (p.u.)
v_p^k/v_p^{k+1}	velocity of *p*th particle at *k*th/$(k+1)$th iteration
w	inertia weight
w_{max}/w_{min}	maximum/minimum value of inertia weight
Y	planning horizon
ζ	capital recovery factor
λ	penalty function
Φ_j	closed loop at *j*th load level

Several successful attempts have been made in the recent past to solve the problem of optimal allocation of either SCs [4–10] or for DGs [11–16] separately. However, the simultaneous placement strategy of DERs is more practical and can independently set and control the real and reactive power flow in distribution network (DN) [12]. Some researchers [17–24] have attempted this simultaneous allocation strategy and have shown mutual impact of these devices on the performance of distribution network using analytical or/and heuristic technique. Zou et al. [17] proposed an analytical approach for the simultaneous placement of SCs and DGs for minimizing investment cost. They reduced the search space by identifying voltage support zones using analytical approach and solved the problem using particle swarm optimization (PSO). Abu-Mouti and El-Hawary [18] employed artificial bee colony (ABC) algorithm to determine the optimal size of DGs' power factor, and location to minimize power losses while considering various scenarios. It has been shown that there is a substantial enhancement in the results in terms of voltage profile improvement and loss reduction. A heuristic approach is suggested by Naik et al. [19] where a node sensitivity analysis is used to identify the optimal candidate locations, and then the optimal capacity of SCs/DGs are determined by suggesting heuristic curve fitting technique. Moradi et al. [22] proposed a combined imperialist competitive algorithm (ICA)–genetic algorithm (GA) method to solve this multi-objective optimization problem. In this method, first the ICA is used to find siting and sizing of distributed resources and then the operators of GA are used to further refine these solutions. In Ref. [24] different types of DGs are employed for real and reactive power injections to minimize power losses. The problem is solved using an analytical approach and PSO. The authors concluded that the heuristic approach is more suitable for larger systems. However, these attempts have considered only loss minimization and node voltage enhancement as the problem objectives and not considered peak power losses, feeder current profiles and substation capacity release for DER allocation.

Distribution network reconfiguration (DNR) is another operational strategy which has been frequently used to achieve multiple performance objectives such as power loss minimization, voltage

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