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Optimal placement and sizing of distributed generators and shunt capacitors for power loss minimization in radial distribution networks using hybrid heuristic search optimization technique

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A B S T R A C T

This paper attempts to minimize power losses in radial distribution networks and facilitates an enhancement in bus voltage profile by determining optimal locations, optimally sized distributed generators and shunt capacitors by hybrid Harmony Search Algorithm approach. To overcome the drawback of premature and slow convergence of Harmony Search Algorithm (HSA) over multi model fitness landscape, the Particle Artificial Bee Colony algorithm (PABC) is utilized to enhance the harmony memory vector. In the first approach, the formulation echoes the determination of loss sensitivity factor to decide the sensitive nodes and thereafter decides on the optimal rating through the use of hybrid Algorithm. The second approach encircles the role of hybrid Algorithm to search for both the optimal candidate nodes and sizing of compensating devices by significant increase in loss reduction with the former approach. The procedure travels to examine the robustness of the proposed hybrid approach on 33 and 119 node test systems and the result outcomes are compared with the other techniques existing in the literature. The simulation results reveal the efficiency of the proposed hybrid algorithm in obtaining optimal solution for simultaneous placement of distributed generators and shunt capacitors in distribution networks.

Introduction

The power generation capacities around the world are to be expanded at dizzying speed to meet out the increased load demand and thereby to avoid power blackouts which have significant economic impact on developing countries. Moreover the location of electricity generation is spatially isolated from the consumer load. This poses huge challenge in electricity transportation over long distance which leads to more power loss.

Solution of above said problems to some extent is achieved by the installation of shunt capacitors and Distributed Generators (DG) close to the load center in the power system network. Industrialized and emerging countries are opening up for investment in renewable energy based distributed energy sources due to fast decline in fossil fuel resources as well as to reduce the emission. Installation of such sources has several advantages such as deferment in construction of new transmission and distribution lines, curtailment in power loss along with improved bus voltage profile, power quality enhancement and improved system reliability. Prior to placing these devices in the distribution network, there is a pre requisite to explore their effect in the system parameters like change in bus voltage profile, direction of power flows and associated power loss, harmonic distortion and system voltage stability and reliability.

An appropriate planning methodology must be carried out for incorporating shunt capacitors and DG units into the distribution network to get the constructive benefits. The installation of these units at non-appropriate places with improper sizing leads to negative consequences such as increase in power loss, Poor system reliability and voltage instability state of the power system network.

Heuristic optimization algorithms are capable of producing the best solution for the placement and sizing problem of DG units and shunt capacitors in distribution networks when compared with conventional optimization techniques. Newly developed evolutionary algorithms namely teaching learning based optimization technique to locate the apt position with appropriate rating of capacitors in RDN to minimize the power loss and energy cost has been addressed in [1]. Artificial bee colony approach has been utilized to get the optimum sizing of static capacitors and loss sensitivity factors are utilized to find the potential nodes for capacitor installation has been addressed in [2]. HSA based approach for

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Nomenclature

P_{i+1}	real power flows out of node $i+1$
Q_{i+1}	reactive power flows out of node $i+1$
$R_{i,i+1}$	resistance of line between nodes i and $i+1$
$X_{i,i+1}$	reactance of line between nodes i and $i+1$
$P_{i,i+1}$	active power flows out of node i to node $i+1$
$Q_{i,i+1}$	reactive power flows out of node i to node $i+1$
P^{L}_{i+1}	real power load demand at node $i+1$
Q^{L}_{i+1}	reactive power load demand at node $i+1$
α_{PDG}	active power multiplier which is equal to zero if there is no active power injection source or equal to 1 if any active power injection source (DG unit) is present.
α_{qDG}	reactive power multiplier which is set to zero if there is no reactive power injection or set to 1 if any reactive power injection sources (Type-III DG unit) are present.
α_{qcp}	reactive power multiplier which is set to zero if there is no reactive power injection or set to 1 if any reactive power injection (by the shunt capacitor) sources are present.
P^{DG}_{i+1}	real power injection by the DG unit at node $i+1$
Q^{DG}_{i+1}	reactive power injection by the DG unit at node $i+1$
Q^{C}_{i+1}	reactive power injection by the shunt capacitor at node $i+1$
n	total number of nodes in the RDN
nb	total number of branches in the RDN
nl	total number of load buses in the RDN
n_c	total number of capacitors to be installed in RDN
$I_{i,i+1}$	current flows between the nodes i and $i+1$
$I_{i,i+1\ \max}$	allowable maximum permissible current of the branch $i+1$
$\lvert I_{P(i,i+1)}\rvert$	real part of the branch current flows between the nodes i and $i+1$
$\lvert I_{q(i,i+1)}\rvert$	reactive part of the branch current between the nodes i and $i+1$
P_{lossT}	total power loss in the RDN without DG's and shunt capacitors
$P^{DGCP}_{loss(i,i+1)}$	real power loss in the branch connected between nodes i and $i+1$ with DG's and shunt capacitors
P^{DGCP}_{lossT}	total power loss in the RDN with DG units and shunt capacitors
$\lvert V^{sys}_{i}\rvert$	nominal bus voltage magnitude of ith bus of the RDN
$\lvert V^{spec}_{min}\rvert$	the specified lower bound of bus voltage of the RDN
$\lvert V^{spec}_{max}\rvert$	the specified upper bound of bus voltage of the RDN
P^{DG}_{max}	maximum size of DG unit in kilowatts
P^{DG}_{min}	minimum size of DG unit in kilowatts
$p.f^{DG}_{i}$	operating power factor of ith DG unit
$p.f^{DG}_{min}$	minimum operating power factor of DG unit
$p.f^{DG}_{max}$	maximum operating power factor of DG unit
Q_{i+1eff}	total effective reactive power supplied beyond node $i+1$
P_{i+1eff}	total effective active power supplied beyond node $i+1$
Qc^{L}	sum of total kVAR demand of the RDN
Q_cj	kVAR injection by the jth shunt capacitor
P^{DG}_{i}	Size of ith DG unit in kilowatts
Q^{DG}_{i}	Size of ith DG units in kilovolt amperes reactive
$P_{lossi,i+1}$	Power loss associated with the branch between the nodes i and $i+1$
p.f	power factor
SCP	Single Capacitor Placement
MCP	Multiple Capacitor Placement

capacitor allocation and rating in unbalanced and balanced radial networks was proposed in [3–5]. Hybrid approach of fuzzy and GA for capacitor allocation with varying load conditions has been introduced in [6]. Integration of evolutionary algorithm like differential Evolution and pattern search approach for shunt capacitor allocation to realize maximum savings has been developed in [7]. The impact of DG integration in the distribution network which leads to abrupt changes in system operational characteristics has been addressed in [8–10]. Differential Evolution Technique used to determine the optimal DG sizing and its location with power loss minimization as objective has been addressed in [11]. For optimum DG allocation and sizing, a novel power stability index was proposed in [12] to locate the most sensitive buses in the radial distribution network. An analytical approach was presented in [13] for optimum sizing and sitting of DG and shunt capacitor simultaneously to achieve power loss reduction. A hybrid approach using imperialist competitive algorithm and GA for the placement of DG units and shunt capacitor has been addressed in [14]. The weak nodes in radial distribution network was identified by computing Voltage Stability Index (VSI) in [15,16]. Analytical approach and modeling aspects of different types of DG units integration in distribution system has been addressed in [17]. DG planning in distribution networks with different load models has been addressed in [18]. Various heuristic algorithms have been adopted by the researchers to solve complex optimization problems. Few modifications or improvisation of the algorithms by hybridizing the existing algorithms are necessary in order to balance and accelerate the exploration and exploitation ability of heuristic optimization algorithms for searching optimal solutions in multi model fitness landscape.

The present work is aimed to develop a fast and novel hybrid heuristic optimization technique by integrating harmony search algorithm with PSO embedded artificial bee colony (HSA–PABC) to find the optimal location and sizing of DG units and shunt capacitors for power loss minimization and to enhance bus voltage profile in radial distribution network at three different load levels subject to certain operating constraints. In hybrid HSA–PABC approach, the exploration ability of HSA and the exploitation ability of PABC are integrated to synthesize the strength of both algorithms to evaluate the DG units and shunt capacitors location and sizing in the RDN. Simulation results reveals that the proposed hybrid HSA–PABC algorithm is capable of obtaining optimum solution with less computational time, with improved convergence characteristics than classical HSA.

In this article, different test scenarios are considered with an aim to quantify the benefits for distribution networks with the placement of shunt capacitors and DG units with real power injection (Type-I DG units) as well as real and reactive power injection capability (Type-III DG units). Simulation work carried on 33 node and 119 node radial distribution systems and the effectiveness of the proposed hybrid algorithm is validated with the classical HSA and the existing algorithms present in the literature.

This article is organized as follows: Formulation of objective function of the problem and its associated constraints is described