Energy Conversion and Management 103 (2015) 387–400

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

Simultaneous allocation of distributed resources using improved teaching learning based optimization

Neeraj Kanwar [a], Nikhil Gupta [a,*], K.R. Niazi [b], Anil Swarnkar [a]

[a] Department of Electrical Engineering, Malaviya National Institute of Technology, Jaipur, India
[b] Dept. of Electrical Engg., Faculty of Engg., Taibah University, Madinah, KSA

ARTICLE INFO

Article history:
Received 23 February 2015
Accepted 18 June 2015
Available online 6 July 2015

Keywords:
Distributed resources
Meta-heuristic technique
Intelligent search
Smart distribution systems
Teaching learning based optimization

ABSTRACT

Active and reactive power flow in distribution networks can be effectively controlled by optimally placing distributed resources like shunt capacitors and distributed generators. This paper presents improved variant of Teaching Learning Based Optimization (TLBO) to efficiently and effectively deal with the problem of simultaneous allocation of these distributed resources in radial distribution networks while considering multi-level load scenario. Several algorithm specific modifications are suggested in the standard form of TLBO to cope against the intrinsic flaws of this technique. In addition, an intelligent search approach is proposed to restrict the problem search space without loss of diversity. This enhances the overall performance of the proposed method. The proposed method is investigated on IEEE 33-bus, 69-bus and 83-bus test distribution systems showing promising results.

1. Introduction

The electric power industries have witnessed many reforms in recent years. The present trend towards 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 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 are to 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, reduce flows and system losses and improve power quality and reliability of supply, but inappropriate DER placement may increase system losses and network capital and operating costs [2]. Whatever 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, these DG planning tools must take into account essential network constraints such as voltage and thermal limits [3].

The optimal placement of DERs involves the determination of their optimal number, sizing and siting in distribution networks. Several successful attempts have been made in the recent past using heuristic, analytical or population-based search techniques to solve the problem of optimal allocation of either SCs [4–11] or for DGs [12–20] alone while usually considering power loss, voltage profile improvement and investment cost of devices, etc. as one or more objectives. Singh and Rao [7] applied particle swarm optimization (PSO) for optimal allocation of capacitors. They reduced the problem search space using a dynamic node sensitivity analysis. Haldar and Chakraborty [8] proposed modified cultural algorithm to minimize power losses. PSO is hybridized with ant colony system and simulated annealing in [9,11], respectively for better solution quality. Kuo [11] proposed an interactive bi-objective programming with valuable trade off to provide users with more favorable solutions. Rao et al. [12] used harmony search algorithm to solve the network reconfiguration problem in the presence of DGs. A node sensitivity analysis is used to redefine the problem search space. Hedayati et al. [13] proposed an analytical approach to show that DG placement is very useful for improvement of voltage profile, reduction of power losses, increase in power transfer capacity and maximize the loading and voltage stability. Biswas et al. [14] considered both technical and economic objectives using weighting method for the optimal allocation of DGs and applied genetic algorithm (GA) as an optimizing tool.

* Corresponding author. Tel.: +91 1412529063 (O), +91 9414055654 (mobile); fax: +91 1412529063.

E-mail addresses: nk12.mnit@gmail.com (N. Kanwar), nikhil2007_mnit@yahoo.com (N. Gupta), kniazi@taibahu.edu.sa (K.R. Niazi), mnit.anil@gmail.com (A. Swarnkar).

http://dx.doi.org/10.1016/j.enconman.2015.06.057
0196-8904/

Nomenclature

D	number of design variables
$ELoss_{bj}$	energy loss for uncompensated system at jth load level (MWh)
$ELoss_{aj}$	energy loss for compensated system at jth load level (MWh)
I_i	current of ith feeder (p.u.)
I_i^{rated}	rated current of the ith feeder (A)
L	set of load levels
loc	total number of candidate locations for SCs/DGs placement
$Mean_{D,k}$	mean of the learners at Dth dimension for kth iteration
$\Delta Mean_{D,k}$	difference mean of the learners at Dth dimension for kth iteration
mc	mutation count
N_c/N_{DG}	set of candidate nodes for SCs/DGs placement
N	number of system nodes
N_L	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}	DG penetration limit at one candidate node (kW)
$P_{DG,max}$	maximum DG penetration limit for the system (kW)
$P_{DG,min}$	minimum DG penetration limit for the system (kW)
P_D	nominal active power demand of the system (kW)
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 SC (kVAr)
$Q_{c,min}$	minimum reactive compensation provided by SC (kVAr)
Q_o	size of capacitor bank (kVAr)
ΔQ	control setting of capacitor bank (kVAr)
$TF_{D,k}$	teaching factor at Dth dimension for kth iteration
$Teacher_{D,k}$	position of the teacher at Dth dimension for kth iteration
V_{max}	maximum permissible node voltage (p.u.)
V_{min}	minimum permissible node voltage (p.u.)
V_{minS}	minimum specified node voltage (p.u.)
V_{ij}	voltage of ith node at the jth load level (p.u.)
ΔV_{ij}	maximum node voltage deviation of ith node at the jth load level (p.u.)
$Xnew$	new solution of learner
$Xold$	existing solution of learner
λ	node voltage deviation penalty factor

They handled problem constraints using a penalty function approach. An improved PSO is suggested in [16] for optimal planning of multiple DGs. Ref. [18] employed evolutionary programming, [19] proposed a hybrid ant colony optimization-artificial bee colony (ABC) algorithm and [20] suggested hybrid binary enhanced PSO-modified differential evolution method to attempt the optimal allocation of DERs for the given planning period. A time-based model is proposed in [20] to minimize the investment and operation costs following the load growth in a specified planning period.

Usually, the owner of SCs is a power distribution utility whereas the owner of DGs is a private investor. However, the power distribution utility can provide coordinated solution for the sites and sizing of DERs to the DG investor so that both DGs and SCs can be allocated optimally in the distribution network simultaneously. In this way, the profits of the power distribution utility may be enhanced by achieving increased energy efficiency and better node voltage profiles can also be maintained at reduced investments on DERs. Some researchers [15,21–27] have attempted these two problems simultaneously and shown mutual impact of these devices on the performance of distribution network. Zou et al. [21] 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 PSO. Abu-Mouti and El-Hawary [22] employed 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. [23] 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. Sajjadi et al. [24] formulated the problem in a different fashion by considering active and reactive power loss reduction, energy loss reduction, enhancement of voltage profile and voltage stability while considered a more realistic multi-level annual load profile. Memetic algorithm is used to optimize the problem which is a combination of local search and GA. Moradi et al. [26] proposed a combined imperialist competitive algorithm (ICA)-GA method to solve this multi-objective optimization problem. In this method, first the ICA is used to find sites and sizing of DERs and then the operators of GA are used to further refine these solutions. In Ref. [15] 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, the variation in annual load profile is not considered in [15,21–23,25–27], as the objective function minimizes power losses. In fact, power losses can be studied in passive networks considering peak load scenarios—as is traditionally done—distribution networks with DG plants require the assessment of energy losses [3]. A multi-level annual load profile is considered in [24] to minimize annual energy loss reduction, but the benefits that could be achieved by employing the optimal dispatches of DERs under different load conditions are not taken into account. It is imperative to vary the power injections from DERs with system load demand otherwise the feeder losses may increase under light and moderate load conditions. It happens because the obtained installed capacities of DERs are influenced by the system peak load demand.

The swarm and evolutionary based optimization techniques have proven potential to obtain global or near global optima. However, the actual challenge when using these techniques is the tuning of the parameters that guide the optimization, and care should be taken to avoid premature or slow convergence, particularly in large scale applications [3]. On the contrary, the teaching learning based optimization (TLBO) [28] is recently developed technique having the prominent feature that it is free from algorithm specific parameters and requires only common control parameters like population size and maximum iterations. This makes it a class apart from other population-based search techniques. It is inspired by passing on knowledge within a classroom environment, where learners acquire knowledge from the teacher and then from the classmates [29]. It uses mean value of the population to update the solution and implements greediness to accept a good solution,