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Optimal allocation and sizing of DG units considering voltage stability, losses and load variations

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ABSTRACT

This paper proposes a new index to determine the optimal size and location of DG units, in order to minimize active power losses and enhance voltage stability margin considering load variations. A modified form of Imperialistic Competitive Algorithm (ICA) method is used to solve the optimization problem. To provide a comprehensive perspective for network scheduling, the load variations are considered. The load linear changes are from 50% to 150% of the base load (in 1% steps). At each step, the optimal size and location of the DG unit are determined and then, general expressions for DG sizes as a function of load level are concluded through curve fitting technique. These general expressions can be used as a suitable tool for network planning.

The proposed method is applied to 34-bus and 69-bus test systems and the results are compared with the results obtained from cuckoo search algorithm in order to validate the proposed methodology.

Introduction

The penetration and integration of Distributed Generation (DG) units in traditional power systems are the main milestones in forming smart grids. Furthermore, some economical and environmental concerns will accentuate the movement from centralized generation toward distributed generation [1].

DG units are typically located in distribution systems and near load centers. Allocating DG units in distribution systems may inflict unwanted challenges in traditional power systems, which have been designed radial and unidirectional. The main problems are complexity of control, reduced security, need for relays new settings, intense changes in short circuit level, DG allocation and sizing and voltage stability considerations [2–4]. The DG penetration level is a key index in foregoing challenges. A low penetration level (up to 5%) will result in negligible effects on the network, but sizeable penetration levels (up to 30%) will cause serious effects [5]. DG sizing and sitting problems have been introduced and studied in numerous researches using different optimization methods [6].

Power losses surely have important effect on the revenues of electric power companies, greenhouse gases emission, and the cost of the energy supplied [7]. Therefore decreasing technical and nontechnical losses is a running test in the most of distribution companies [8]. Installing DG units in distribution systems has been proposed as an effective measure to minimize losses [9]. The minimization of active and reactive power losses has been considered as a main goal of the DG sitting and sizing problem [10–13].

Due to the growing demand for electric energy, traditional T&D may work close to stability limits [14], which will in turn expose system security to risk [15]. In this regard, the voltage instability may cause partial and total blackouts in power system networks; for instance, a major blackout occurred in the S/SE Brazilian system due to the voltage instability in the distribution system in 1997. Hence, the voltage stability limits are very important for distribution utilities whereby these limits restrict surplus load serving [15–17]. Therefore, it is necessary to consider the voltage stability limits in DG allocation and sizing in distribution networks.

In [18] a new multi-objective performance index for evaluating the optimal DG location and size has been proposed, this strategy includes the active and reactive power losses minimization and enhancing the voltage stability level, besides; it has been suggested that choice of weighting factors depends to technical considerations. Placement of capacitors in distribution systems has been proposed as an effective measure in voltage stability improvement [19] and their placement problem has been solved considering the DG placement and sizing [20]. Combination of DG unit and capacitor have been studied in [21] as a effective tool for loss minimization and voltage stability enhancement in distribution systems. In [22], the probabilistic voltage stability has been evaluated considering renewable energy resources.

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Nomenclature

NB	total number of the buses	NBr	total number of branches in a radial distribution system
DG	Distributed Generation	Zbus	impedance matrix of network
T&D	Transmission and Distribution	s	first node of a feeder
VSI	Voltage Stability Index	m	equivalent branch between nodes s and m
VSM	Voltage Stability Margin	$r(m)$	resistance of branch m
SCIG	Squirrel Cage Induction Generator	$x(m)$	reactance of branch m
ICA	Imperialistic Competitive Algorithm	$I(m)$	current of branch m
IDGs	DG units and their locations with lower costs among all countries, namely imperialists in ICA algorithm	$V(s)$	voltage of node s
		$V(m)$	voltage of node m
CDGs	all initial DG units and their locations except IDGs, namely colonies in ICA algorithm	$P(m)$	total active power fed through node m
		$Q(m)$	total reactive power fed through node m
OFGEM	Office of Gas and Electricity Markets	DNO	Distribution Network Operators
OVSI	Overall Voltage Stability Index	P_D	total active demand of network
P_L	active power losses	Q_D	total reactive demand of network
Q_L	reactive power losses		

Ordinarily, in order to obtain PV curve, continuous power flow method has been applied, and maximum loading and voltage stability margin of the system can be obtained using this curve [23,24].

It has been shown that the minimization of power losses and the maximization of the voltage stability margin can be simultaneously considered in DG sizing and locating problem [25,26]. In [27] DG allocation and sizing considering both losses and voltage stability has been resolved, the candidate busses from the voltage stability point of view have been determined by bifurcation analysis. In [28] a new PSO-based multiobjective index for DG sizing and sitting problem has been proposed in order to enhance both voltage stability and short circuit level of distribution networks.

In [29], a new voltage stability index for radial distribution systems has been proposed that needs to a modified load flow in computation steps. Also, in [30] a new multi objective particle swarm optimization has been proposed in order to determine the optimal location and site of DG units, major concerns of this study include voltage profile and stability, loss reduction and reliability enhancement. Also, network reconfiguration has been proposed as an alternative solution to enhance the voltage stability [31,32].

In [33], it has been suggested that, uncertainties in load and generation can be modeled using a genetic-based methodology, then, DG allocation and sizing problem has been solved. In [34], the voltage stability of a radial distribution system has been investigated and enhanced in presence of SCIG-based DGs.

This paper proposes a new voltage stability-based methodology for the DG allocation and sizing problem based on three substantial concerns:

- Minimization of active power losses must be considered as a fundamental goal, because it is a necessary measure in the most of distribution companies all over the world [7,8].
- Voltage stability index in distribution systems is a main determinant factor which describes system security level. The closer to the voltage stability margin, the higher the blackout probability. A concerning subject is that along with the occurrence of voltage instability, most security measures (i.e. capacitor switching, reactive condenser switching, etc.) cannot restore the system to its normal operation. Furthermore, the system will experience self-destruction [14,17].
- Load variation in distribution systems need to be considered in short-term and long-term planning as an imminent occurrence [29]. Daily load variation is a direct consequence of costumer consumption patterns. By changing the load of the system, the operation point of DG units needs to be optimized [35,36].

In Fig. 1, PV curves for a typical distribution system (the 34-node system introduced in [37]), have been plotted using continuous power flow method. In this Figure it is obvious that by a 50% increase in load, the VSM decreases significantly. On the other hand, reducing the load by 50% increases the VSM.

In this paper, the optimization problem is solved using a modified form of ICA that consists of discrete variables; moreover, the results of the optimization problem are verified using cuckoo search algorithm.

Proposed objective function

Voltage stability index in radial distribution network

The voltage stability concept is defined as power system ability to maintain the voltages of all network buses within an acceptable range, after occurrence of a disturbance. In fact the main cause of instability is the weakness of the system to provide sufficient reactive power for the loads [17].

To derive a voltage stability index in radial distribution systems, a simple power flow method has been introduced in [15]. In Fig. 2, following equations can be expressed:

$$I(m) = \frac{V(s)\angle\delta(s) - V(m)\angle\delta(m)}{r(m) + jx(m)} \quad (1)$$

where

$$r(m) = \mathrm{Real}[(V_m\angle\delta_m - V_s\angle\delta_s)/I(m)] \quad (2)$$

$$x(m) = \mathrm{Imag}[(V_m\angle\delta_m - V_s\angle\delta_s)/I(m)] \quad (3)$$

$$P(m) - jQ(m) = V^*(m)I(m) \quad (4)$$

Using (1)–(4), we have:

$$|V(m)|^4 - \left(|V(s)|^2 - 2P(m)r(m) - 2Q(m)x(m)\right)|V(m)|^2 + \left(P^2(m) + Q^2(m)\right)\left(r^2(m) + x^2(m)\right) = 0. \quad (5)$$

Let,

$$b(m) = |V(s)|^2 - 2P(m)r(m) - 2Q(m)x(m) \quad (6)$$

$$c(m) = \left(P^2(m) + Q^2(m)\right)\left(r^2(m) + x^2(m)\right). \quad (7)$$

Using the assumptions in (4) and (5), (3) can be rewritten as follows: