Electrical Power and Energy Systems 85 (2017) 200–211

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

A dynamic method for feeder reconfiguration and capacitor switching in smart distribution systems

Amir Ameli [a,*], Amir Ahmadifar [b], Mohammad-Hossein Shariatkhah [c], Mehdi Vakilian [a], Mahmoud-Reza Haghifam [c]

[a] Electrical Engineering Department, Sharif University of Technology, Tehran, Iran
[b] Electrical Engineering Department, Iran University of Science and Technology, Tehran, Iran
[c] Electrical and Computer Engineering Department, Tarbiat Modares University, Tehran, Iran

ARTICLE INFO

Article history:
Received 8 June 2016
Received in revised form 1 September 2016
Accepted 20 September 2016

Keywords:
Feeder reconfiguration
Capacitor switching
Harmony search algorithm
Ant colony optimization
Power distribution economic

ABSTRACT

In distribution systems, feeder reconfiguration (FR) can lead to loss reduction, reliability improvement and some other economic savings. These advantages can be intensified by proper control and switching of Capacitor Banks (CBs). In this paper, using Ant Colony Optimization (ACO) technique, a novel method is proposed for simultaneous dynamic scheduling of FR and CB switching in the presence of DG units having uncertain and variant generations over time. This method is applicable to both smart and classic distribution systems. While for the latter, state estimation method should be used to estimate the loads at different buses by employing a limited number of measurements. The objective of this method is to minimize the total operational cost of the grid, including the cost of power purchase from the subtransmission substation, cost of customer interruption penalties, Transformers Loss of Life (TLoL) expenses, and the switching costs (CBs and disconnecting switches). To perform this study, the planning period is divided into several intervals for each of them the network topology and CBs reactive power are determined to satisfy the objective function. Additionally, due to the curse of dimensionality, a Case Reduction Technique (CRT) is proposed in order to decrease the computational burden of the proposed method. Finally, the efficiency of the proposed method is verified through its application on the IEEE 118-bus distribution test system, and evaluating its economic and operational characteristics.

1. Introduction

Distribution system may have different types of loads such as residential, commercial and industrial with different demand levels changing during a day. This brings about variations in the system operational condition according to its heavily or lightly loaded condition [1]. Reconfigurable distribution systems are capable of changing their topology under both normal and abnormal conditions based on load variations and changes in distribution generation [2]. This is an optimization procedure called reconfiguration which changes the open/close status of network switches to interconnect feeders with the objective of increasing the grid efficiency [3]. Network reconfiguration helps flatting out the peak demands, improving voltage profile, reducing power loss and enhancing power system reliability. Hence, in distribution networks which have the major contribution to power system losses and power outages, reconfiguration is growingly employed.

Besides reconfiguration, another strategy which is widely being used for improving the operational condition of power grids is the capacitor banks switching. Installing these banks limits the reactive power flow in the grid which results in real power losses and voltage drops reduction. Also, financial benefits, increased feeder capacity, congestion alleviation, etc. can be obtained using this strategy. However, after each reconfiguration process the implemented capacitor banks should be reformed and adjusted to yield the desired objectives.

On the other hand, the increased application of renewable resources in power systems has added to the complexity of this optimization problem. This originates mainly from the variant generations of many DG technologies like wind turbines. This cause distribution system reconfiguration to be faced with uncertainty in such cases [4].

The numerous advantages of reconfiguration have brought the attention of many researchers to this concept. In this regard, different objectives are defined. Many studies have been done with the objective of loss reduction [3–27]. Some have based their approaches on reliability improvement [9,11,18,19,25,26]. In [8],

* Corresponding author.
E-mail address: aameli@uwaterloo.ca (A. Ameli).

http://dx.doi.org/10.1016/j.ijepes.2016.09.008
0142-0615/

a voltage stability index has been proposed to improve voltage stability of a radial distribution system through network reconfiguration. Voltage profile improvement is also another objective function being concentrated on by the authors of [4,13,16]. Additionally, power quality issues such as load balancing and voltage sag improvement have also been investigated in [6,7,27]. Besides the operational issues mentioned, some researchers have worked on economic aspects of grids as objective functions while network reconfiguring [3,4,16–19,22–25]. Also while determining objective functions, some papers have concentrated only on one of the criteria mentioned above [5,10,12,14,15,20,21] unlike others which have used multi-objective functions [3,4,6–8,9,11,13,16–19,22–24]. Despite the fact that most of the papers have considered distribution system reconfiguration as a static problem [3,4–17,20–24], some have considered it as a dynamic one [18,19,25]. Another issue considered in [3–5,17,19,22,25] is load variations. In these references, different formulations are proposed for the problem in order to properly optimize network reconfiguration. Furthermore, simultaneous application of capacitor banks and reconfiguration is studied in [5,20–24]. Some researchers [4,7,13,16,17] also explored the incremental use of distribution generations besides network reconfiguring. The literature review of this section is briefly categorized in Table 1.

In this paper, the objective of Distribution Network Operator (DNO) is to reduce its total cost and the network power losses. This is achieved through a proper reconfiguration scheme as well as switching the capacitor banks in a smart distribution system by using Ant Colony Optimization (ACO) method. It is assumed that capacitor banks and reconfiguration switches are already installed in the network and DNO only intends to schedule their switching times.

This algorithm is used dynamically in presence of a DG unit with variant generation in order to minimize the total cost of the grid. This cost is related to: electric energy purchase, customer interruption penalty, transformer loss of life, and switching devices wear. Furthermore, due to the curse of dimensionality a case reduction method is proposed in order to increase the efficiency and reduce the complexity of the proposed method. Contributions of the proposed method are as follows:

(1) A new grid cost minimization scheme is proposed by considering system reconfiguration besides capacitor banks switching in presence of distributed generation.
(2) Reconfiguration and capacitor banks switching schemes are implemented dynamically while load is continuously varying.
(3) Stochastic methods are used for handling the uncertainty related to the generation of the distributed generation unit.
(4) The objective function considers the following costs: power purchased, energy not supplied, transformer loss of life, and switching devices loss of life.

In this paper two different optimization algorithms, i.e. ACO and Harmony Search (HS) algorithms, with completely different features are used. HS tries to find the best answers while optimizing (minimizing or maximizing) a certain objective function [28]. However, ACO is a probabilistic technique to solve a computational problem which can be reduced to finding good paths through graphs [29]. Hence, HS is more appropriate for the first part of this optimization problem or case reduction part, whereas ACO is suitable for the second part of the optimization process which looks for the best path for cost minimization.

Furthermore, in this paper it is assumed that the impact of the load uncertainty is not as much as the wind generation uncertainty impact, and therefore it is neglected. The reason for this assumption is that the time horizon for which the load should be forecasted is a week and this assumption is reasonable particularly in a smart environment equiped with advanced meters. However, in cases in which load uncertainty is required to be considered [30], a stochastic model similar to the DG unit uncertainty model can be employed for the loads.

Table 1
Summary of the reviewed literature's optimization features.

Ref. #	Loss reduction	Reliability improvement	Voltage stability	Voltage profile	Economic issues	Load balancing	Power quality	Capacitor placement/ switching	Load model	DG presence	Optimization method
[3]	✓				✓						Genetic
[4]	✓			✓	✓						AMPSO
[5]	✓							✓	✓		Mixed-integer nonlinear Programming
[6]	✓						✓				Differential evolution
[7]	✓					✓				✓	Ant colony
[8]	✓		✓								Fuzzy-based method
[9]	✓	✓									Micro-genetic
[10]	✓										Circular-updating
[11]	✓	✓									Branch-exchange (BE)
[12]	✓										Modified PSO
[13]	✓			✓						✓	Harmony search
[14]	✓										UVDA
[15]	✓										Integer coded PSO
[16]	✓			✓	✓					✓	Adaptive PSO + Fuzzy
[17]	✓				✓				✓	✓	Genetic
[18]	✓	✓			✓						Binary PSO
[19]	✓	✓			✓				✓		HS + DP
[20]	✓							✓			Ant colony
[21]	✓							✓			Adaptive genetic
[22]	✓				✓			✓	✓		BE + Discrete genetic
[23]	✓				✓			✓	✓		Dedicated genetic
[24]	✓				✓			✓			Modified PSO
[25]	✓	✓			✓				✓		Scenario theory + PSO
[26]	✓	✓									Artificial immune systems
[27]	✓						✓				Branch exchange
Proposed method	✓	✓			✓			✓	✓	✓	ACO + HS