Electrical Power and Energy Systems 41 (2012) 1–10

Contents lists available at SciVerse ScienceDirect

Electrical Power and Energy Systems

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

Duration based reconfiguration of electric distribution networks using dynamic programming and harmony search algorithm

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ARTICLE INFO

Article history:
Received 29 August 2011
Received in revised form 15 December 2011
Accepted 18 December 2011
Available online 23 April 2012

Keywords:
Distribution network
Reconfiguration
Dynamic programming
Harmony search algorithm
Graph theory

ABSTRACT

Feeder reconfiguration is one of the most important tasks for loss reduction and reliability improvement in distribution networks. Most of studies so far have investigated reconfiguration problem as a static problem considering fixed level of loads. This assumptions lead to suboptimal solution because of time-varying nature of loads in distribution networks. The switching operation should be cost effective and the reconfiguration scheme should balance the benefits in system loss reduction and reliability improvement against the costs of switching. Moreover, this is a dynamic problem and switching operations of time intervals over a year are not independent. This paper presents a method to determine annual feeder reconfiguration scheme considering switching costs and time-varying variables such as load profiles. In the first stage of the proposed method, to obtain effective configurations, optimal configuration for each day of year is determined independently using harmony search algorithm (HSA) and graph theory. After determination of effective configurations for the network, in the second stage, year is divided into multi equal periods and considering loss cost, interruption cost and also switching cost from a configuration to another configuration, dynamic programming algorithm (DPA) is used to find the optimum annual reconfiguration scheme. The proposed method has been tested on 95-bus distribution network and the obtained results denote that to have an optimum solution it is necessary to compare operation costs dynamically.

1. Introduction

Failure statistics reveal that distribution networks constitute the greatest risk to the uninterrupted supply of power. Moreover, distribution networks have the major portion of power system losses. Therefore, reliability improvement and loss reduction of these networks are necessary. Distribution network reconfiguration is one of the traditional methods implemented for these purposes exploiting normally opened and normally closed switches.

Lots of researches have been conducted for distribution networks reconfiguration so far. *Marilyn* presented the idea of distribution network reconfiguration for the first time in 1975 [1]. He presented a linear model for distribution network reconfiguration and solved it using discrete branch and bound method. In this method, initially all normally open switches are considered to be closed and subsequently normally closed switches which lead to loss reduction are opened. In [2] one proper normally open switch is selected and is assumed to be closed, then in the obtained loop, normally closed switches are opened respectively to find critical switch which leads to the most power loss reduction. This procedure is repeated for all of normally open switches until finding optimum feeder configuration. Disadvantage of this method is that the obtained solution is dependent on the primary configuration. In [3] Shirmohammadi has extended Merilyn Beck's method. In this method first all normally open switches are closed and using load flow in created meshed network, switch which minimum current flow across is opened, this procedure is repeated until new radial configurations found. In [4] unlike previous methods, first all switches are opened and in each stage switch which closing of it leads to minimum increase in cost function is selected. Cost function in each stage is equal to proportion of increased loss to connected load in that stage. In [5] branch exchange method has been implemented for distribution network reconfiguration. Graph theory is used for reconfiguration of distribution networks in [6]. In this method distribution network is considered as a graph and each sub graph of the main graph which has a tree structure can be considered as a network configuration. In this method starting with a feasible configuration, all tree based configurations are obtained using graph theory and after comparing cost of each configuration, optimal solution is achieved. Advantage of this method is finding global optimal solutions but its disadvantage is that this method cannot be implemented in large distribution networks.

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doi:10.1016/j.ijepes.2011.12.014

In last decades intelligent search methods have been implemented for network reconfiguration problem widely. In [7] distribution network reconfiguration problem has been investigated using simulated annealing method. In [8,9] genetic algorithm has been implemented for reconfiguration of distribution networks. In [10] particle swarm optimization (PSO) method has been implemented for reconfiguration problem considering distributed generators; the feasibility of the proposed approach is compared with other evolutionary methods such as genetic algorithm (GA), tabu search (TS) over a realistic distribution test system. In [11] a new hybrid evolutionary (EA) algorithm based on the combination of the honey bee mating optimization (HBMO) and the Discrete Particle Swarm Optimization (DPSO), called DPSO–HBMO, is implemented to solve a multi objective and non-differentiable distribution feeder reconfiguration problem. Ref. [12] introduces an ant colony search algorithm (ACSA) to solve the optimal network reconfiguration problem for power loss reduction. In [13] ant colony optimization method is used for reconfiguration of distribution networks with distributed generation. Using interval analysis technique, Ref. [14] presented a methodology to deal with uncertainties in reliability inputs, electrical parameters and load data in the reconfiguration problem. In [15] the feeder reconfiguration problem is formulated as non-linear optimization problem and bacterial foraging optimization algorithm (BFOA) is used to find optimal configuration with minimum loss. In [16], non-dominated sorting genetic algorithm (NSGA) is used to solve reconfiguration problem with the objective of operation cost minimization in restructured environment.

Most of presented methods so far have implemented reconfiguration methods for fixed level of power demand whereas this assumptions lead to suboptimal solution because of time-varying nature of loads in distribution networks. In Ref. [17] network reconfiguration and capacitor allocation are implemented for loss reduction using mixed integer nonlinear programming (MINLP) method. The proposed method considers the daily load curve represented by a given number of load levels; however, it does not consider switching costs. Ref. [18], is one of the few researches which considers time-varying nature of loads and switching costs during reconfiguration process. The objective function consists of loss cost, outage cost and switching costs. In this method annual load curve is divided into multi periods load levels and the feeder configuration of each load level is optimized using BPSO method. Disadvantage of this method is that configuration of each load level is achieved based on load profile in that period and switching cost from configuration in previous period network. Therefore, only network configuration in the previous period is considered in determination of one period and configurations of other periods are not considered. Whiles, one switching have impact on reliability and loss costs of multiple periods, so it is not optimal to compare the switching cost only with reliability and loss cost of the previous period.

In this paper, a novel method has been presented to determine the annual feeder reconfiguration scheme of a network considering variable load profile. In order to achieve an optimal solution, the costs of system loss, customer interruption and switching, are compared dynamically to determine economical time and situation for a switching operation. The proposed method is implemented on 95-bus distribution systems and the obtained results are presented to show the effectiveness of the proposed method.

This paper is organized as follows: Sections 2 and 3 are dedicated to the problem formulation and description of the proposed method respectively. Section 4 presents the results obtained with the test system and finally conclusions about the results are discussed in Section 5.

2. Problem formulation

Metering devices are usually being installed in distribution networks to monitor and control the system. Using the data of feeder/substation loading, three models can be established to demonstrate load varying of residential, commercial and industrial customers over a year. Each of these models includes 8760 elements. Based on the type of customers and annual average loading, using Eq. (1), annual load profile of each customer will be obtained:

$$Load_c^m(d,t) = \sum_{m \in R,C,I} Load_c^{ave} \times W_m(d,t) \quad (1)$$

where $Load_c^m(d,t)$ and $W_m(d,t)$ are the estimated load of customer c and the load weighting for day d, time t, respectively. $Load_c^{ave}$ denotes the average customer load for a customer c. Moreover, m is the type of the customer and can be residential, commercial or industrial.

Since load profile and energy loss varies with time, for calculation of loss cost over a day or period based on load curves, it is necessary to use a load flow solution and compute loss for each hour of the period. Therefore the cost of energy loss over a period can be expressed as:

$$CLOSS = \sum_{d=1}^{ND} \sum_{t=1}^{24} \sum_{l=1}^{Nl} C_{energy}(d,t) * R_l * I_l^2(d,t) \quad (2)$$

where $CLOSS$ is the cost of energy losses, $C_{energy}(d,t)$ represents the energy cost ($/KW h) and can be assumed time-varying in different hours of period, Nl is the number of distribution network lines, ND represents number of days in each time period. Moreover R_l and I_l are line resistance and line current, respectively.

Similar to loss cost formulation customer interruption cost varies with time too. To determine this cost, it should be computed that when a feeder is interrupted with a probability, which customers will be interrupted, with which duration and how much is the cost of the interruption for interrupted customers. Therefore the customer interruption cost over a period is calculated as follows [18]:

$$CCI = \sum_{d=1}^{ND} \sum_{t=1}^{24} \sum_{i=1}^{Nl} \lambda_i(d) l_i \left(\sum_{j=1}^{Nload} C_j(d,t) L_j(d,t) \right) \quad (3)$$

where CCI represents customer interruption cost over a period, λ_i is outage rate (failure/km) and can be assumed variable with time, l_i is length of line i, $Nload$ is the number of interrupted customers due to interruption in line i and should be determined for each new configuration, L_j represents the load of customer j and also C_j is the interruption cost ($/kW) of load j. Note that interruption cost of residential, commercial and industrial customers are different and also can be assumed time-varying.

It is assumed that there is a breaker at the beginning of each feeder and when a fault occurs, it operates. So $Nload$ is equal to the number of all customers that are supplied from a feeder, which includes line i. Graph theory is implemented to determine $Nload$ for all lines of each new configuration.

In this paper a year is divided into several periods and costs of switching operation between these periods are considered in the objective function. If the number of time intervals in a year is NT, the total annual switching cost is calculated by:

$$TCSW = \sum_{s=1}^{NT-1} CSW_s \quad (4)$$

$$CSW_s = SW \times NSW_{x,y} \quad (5)$$

where $TCSW$ represents total switching operation cost over a year. Moreover, CSW_s and $NSW_{x,y}$ represent switching cost and total num-