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A market-based method for reconfiguration of distribution network

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ABSTRACT

This paper presents a model for seasonal reconfiguration of actual distribution network, which is connected to different points of transmission system via subtransmission transforms, taking into account the feature of competitive environments. The objective function is minimizing the cost of purchased energy regarding hourly Locational Marginal Prices (LMPs) of wholesale market, derived from different connection points between distribution and transmission systems, as well as bilateral contracts with Distributed Generators (DGs). The daily load curves of different load categories, i.e. residential, commercial, administrative and teaching centers are considered. Setting the tapchangers of sub-transmission transformers are accomplished along with reconfiguration process considering the 24-h load curves. DG units are assumed to be controlled in PQ mode and the best value for power factor of each DG is determined during reconfiguration. The presented model is solved by Genetic Algorithm (GA), and a straightforward sub-algorithm which is applicable for actual networks is propounded for checking the presence of loop and islanding in the network, thereby the whole feasible solution space is searched. The developed model is evaluated by executing on 16-bus and 204-bus test systems. Different cases are considered and the results are discussed.

1. Introduction

One of the main tasks of Distribution System Operator (DSO) is the optimal operation of the network in which the system costs are minimized and all equipment is operated in permitted limits. In a regulatory power system, the cost minimization is frequently summarized to system loss minimization. Distribution networks commonly have radial structure and are operated at medium and low voltage levels, so that their currents are relatively high and accordingly their losses are high too. Therefore, the loss minimization has been an important concern of DSO for long time ago. To manage and reduce the loss of distribution network, extensive researches have been conducted regarding different strategies including capacitor placement [1], applying DGs [2,3], using FACTS devices [4] and Distribution Network Reconfiguration (DNR) [5–18]. Since the latter uses no additional components, it is economically more attractive.

DNR is altering the network topology by changing the status of sectionalizing and tie switches to improve the network operation, while keeping the radial structure of the network. DNR is not a new subject, however, required to modify it's goal according to the realities of actual distribution networks and requirements of restructured power system with increasing attention to the economical aspects.

A literature review indicates that in the context of DNR, the studies can be categorized from different viewpoints including time horizon (seasonal or daily), application (operation or planning), formulation (objectives and constraints), and solution methodology which are reviewed in the following.

1.1. Time horizon

Due to existing distribution network infrastructure as well as the policies of Distribution Companies (Discos), DNR may be performed seasonally, daily or even hourly in more automated distribution networks [5,6].

1.2. Application

Although the DNR is commonly used for improving the system operation, it is also taken into consideration in planning process, such as reconfiguration with capacitor placement [7,8] and DG placement [9,10].

1.3. Formulation

In most studies, a conventional goal, i.e. power loss minimization, is considered as the main objective of the DNR problem

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Nomenclature

i, j	index for buses
t, l	index for hours and DG units respectively
k	index for connection points between distribution and transmission systems
N_C	number of connection points between distribution and transmission systems
$S_{bs,k}$	set of nodes corresponding to the sub-network which is connected to the transmission system via node k
S_{DG}, S_{TR}	set of DG units and sub-transmission transformer respectively
N_{DG}, N_{bs}	number of DG units and system buses respectively
Np_{ij}	number of path between node i and node j
$N_{bs,k}, N_{br,k}$	number of nodes and branches corresponding to the sub-network which is connected to the transmission system via node k
$Y_{ij}, \lvert Y_{ij}\rvert, \theta_{ij}$	component (i,j) of nodal admittance matrix, the absolute of component (i,j) and the phase of component (i,j) respectively
ρ_{kt}	Locational Marginal Price (LMP) at time t and connection point k in \$/kWh
E_{kt}	purchased energy from wholesale market at connection point k and time t in kWh
ρ_l	contracted price for energy delivered by DG in \$/kWh
S_l, E_l	DG capacity in kva and contracted energy produced by DG at each hour in kWh
$S_k^{\max}$	the capacity of sub-transmission transformer at connection point k in MVA
$V_i(t), \lvert V_i(t)\rvert, \delta_i(t)$	the voltage, voltage magnitude and voltage phase of node i
$\lvert V_i^n(t)\rvert$	the magnitude of nominal voltage of node i
$V_{i,min}, V_{i,max}$	lower and upper limits of voltage magnitude at node i
$S_{ij}(t)$	the power passed through the line connected between node i and node j (MVA)
$S_{ij,\max}$	the capacity of line connected between node i and node j (MVA)
$P_i(t), Q_i(t)$	active and reactive power injected to the network from node i
$pf_l, pf_{l_{\min}}, pf_{l_{\max}}$	power factor, lower and upper limits of power factor of DG l
$T_i^{\max}$	the half of number of tap steps of transformer i regardless neutral tap
TS_i	the tap setting of transformer i, $-T_i^{\max} \le TS_i \le T_i^{\max}$
$\propto_i$	taping range of transformer i in percentage

[10–14]. Besides, additional objectives have been taken into consideration, e.g. load balancing [15], reliability enhancement [16] and service restoration [17]. The common constraints of the problem include Kirchhoff's laws, voltage limits of all nodes, power flow limits of all lines, keeping the radial structure of the network and serving all loads.

Pursuant to the significance of the DNR objective function, it is contemplated by more attention. Due to moving power industry toward deregulation, more attention is recently given to the cost of losses rather than losses. In this respect, in Ref. [18] the aim of reconfiguration is minimizing the cost of power loss. Besides, the cost of energy loss is taken into account as one of the objective functions in Refs. [7–9], and calculated based on a constant energy price.

Among these useful but conventional goals, the price variation of competitive environment is neglected. Whereas, disco actually purchases energy from wholesale market at hourly LMPs derived from different connection points between distribution and transmission systems. This condition provides the opportunity to minimize the cost of purchased energy via reconfiguration, even though the cost of energy loss may be increased. Therefore, the main target of this paper is to inspect the positive role of DNR on the cost of purchased energy as a dominant part of operational cost.

1.4. Solution methodology

The solution methods can be categorized into three groups, heuristic methods [5,6,11,12,15,18], mathematical methods [13] and meta-heuristic methods [7–10,14,16,17] which are different from the view of finding the global best solution, convergence speed, precision and memory consumption. In heuristic methods, the best solution is sought in a limited search space based on the heuristic rules. Due to their high speed, these methods are suitable for large systems, although a local optimum can be reached. The main drawback of mathematical methods is that they are model-based and the precise model of system is needed for derivation. Moreover, they starts from one feasible point and it is probable to capture in a local optimum. The meta-heuristic methods (e.g. GA [7–9], harmony search algorithm [10], particle swarm optimization [16], and tabu search [14,17]) are population based, data based, and free-derivative methods. They take the advantages of different operators so that the chance of being involved in a local optimum is relatively low. Accordingly, they have the potential of obtaining a near global solution while including the constraints.

One of the most important constraints of DNR is keeping the radial structure of the network. Branch and bound technique firstly proposed in Ref. [11] and its improved version [12] guarantee the radial structure of the system. According to this method, all open switches will be closed first, and then by applying heuristic rules, the same number of switches will be opened to retain the radial structure of the network. Branch exchange-based techniques keep the radial structure of the network in each iteration by closing an open switch and opening a closed switch based on heuristic rules [5,15]. Some studies that solve the reconfiguration problem via meta-heuristic methods take the advantage of branch-exchange technique for keeping the radial structure of the system [7,8]. Due to depending on heuristic rules, the main challenge of these methods is the probability of restricting the search space of feasible solutions especially in large scale networks.

In Ref. [9], open/close status of the switches is determined by GA and then a sub-algorithm is applied for identifying the presence of loops or islanding in the network. To this aim, after closing all switches, the common branches between internal meshes and also between internal meshes and the external mesh are determined. Subsequently, the feasibility of each solution is checked by applying a set of filtering rules. This method is somewhat complicated especially for large scale systems.

The main contribution of this paper is presenting a model for seasonal reconfiguration of actual distribution feeders, which are connected to different points of transmission system via subtransmission transforms, taking into account the feature of competitive environments. The objective function is minimizing the cost of purchased energy regarding hourly LMPs of wholesale market, derived from different connection points between distribution and transmission systems, as well as bilateral contracts with DGs. Based on the network operation rules in Iran, Khoozestan, the sub-transmission transformers' taps are set seasonally based on the peak load. If tap setting and system reconfiguration are performed separately, the best solution may not be achieved. Therefore, the tap setting is performed along with reconfiguration