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DSTATCOM allocation in distribution networks considering reconfiguration using differential evolution algorithm

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ABSTRACT

The main idea in distribution network reconfiguration is usually to reduce loss by changing the status of sectionalizing switches and determining appropriate tie switches. Recently Distribution FACTS (DFACTS) devices such as DSTATCOM also have been planned for loss reduction and voltage profile improvement in steady state conditions. This paper implements a combinatorial process based on reconfiguration and DSTATCOM allocation in order to mitigate losses and improve voltage profile in power distribution networks. The distribution system tie switches, DSTATCOM location and size have been optimally determined to obtain an appropriate operational condition. Differential evolution algorithm (DEA) has been used to solve and overcome the complicity of this combinatorial nonlinear optimization problem. To validate the accuracy of results a comparison with particle swarm optimization (PSO) has been made. Simulations have been applied on 69 and 83 busses distribution test systems. All optimization results show the effectiveness of the combinatorial approach in loss reduction and voltage profile improvement.

1. Introduction

Nowadays distribution networks become more increasingly important in power system planning due to the changes in power delivery policies. The major function is to serve distributed customer loads along a feeder line avoiding interruption while providing reliability, stability and high quality of electric power in the competitive environment of electricity market. To complete this challenge, it requires careful design for power network planning. Utilities have constantly been looking for new technologies to provide such delivery performance. However, one might consider an additional device to be installed somewhere in the network. This could be happened in individual planning phase or later in expansion planning. Such devices are capacitor banks, shunt reactors, series reactors, automatic voltage regulators or recently developed Distribution network Flexible AC Transmission System (DFACTS) technology such as Distribution Static Compensator (DSTATCOM) [1].

Compared with the traditional reactive power compensation devices, DSTATCOM has main advantages, such as, the ability to regulate strongly, the low harmonic content, the small size, no noise and low loss without the operational problems such as resonance unlike shunt or series capacitors. When a DSTATCOM is associated with a particular load it can inject compensating current so that the total demand meets the specification for utility connection. Alternatively it can also clean up the voltage of the utility bus from any unbalance and harmonic distortion [2]. As the impact of the increasing power system load, DSTATCOM would play a more important role in power system loadability, stability, reactive power compensation, loss reduction and power quality enhancement such as flicker suppression, voltage regulation and voltage balancing [3].

The main concern of the paper is installation of DSTATCOM to mitigate losses and improve the voltage profile. Another operation task which can handle such a function is network reconfiguration. The reconfiguration of a distribution network is the process that alters feeder topological structure by changing the open/close status of sectionalizers to obtain various possible objective functions. Reconfiguration could be done for several purposes such as service restoration, load balancing, reliability improvement, power quality enhancement, loss reduction and voltage profile improvement. But the most important function is usually loss reduction and minimizing abnormal voltages which is the main concern in this work. For example, in [4] a variable scaling hybrid differential evolution algorithm is used to relieve power losses and improve voltage profile. In [5] a fuzzy genetic algorithm is used to enhance voltage stability and hence loss minimization in radial distribution systems. A combinatorial approach based on the Honey Bee Mating Optimization and the Discrete Particle Swarm Optimization has been implied in [6] to solve the multi-objective function of real power loss minimization, deviation of the nodes' voltage, the number of switching operations, and balance the loads on the feeders. Ref. [7],

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Nomenclature

f	objective function (fitness function)	X	individual vector
$P_{T,Loss}$	total power losses	M	mutating vector
V_i	voltage of bus i	F	weighting factor
I_i	current of branch i	r_i	random number from [1, 2, ..., NP]
Y	admittance matrix	U	crossing vector
P_{Li}	active load power at bus i	$rand$	random number from [0, 1]
Q_{Li}	reactive load power at bus i	I_{rand}	random integer from [1, 2, ..., D]
P_i	active power flow through ith branch	CR	crossing factor
Q_i	reactive power flow through ith branch	R_T, X_T	leakage resistance and reactance of DSTATCOM transformer
NP	number of chromosomes of DEA	S_{base}	base apparent power
G	generation number	V_{base}	base voltage
D	problem's dimension		

introduces a new reconfiguration algorithm that enhances voltage stability and improves the voltage profile besides minimizing losses. The graph theory principles and evolutionary programming have been combined to reduce the power loss and enhancement of voltage profile in [8].

Presence of compensation units like DSTATCOM with regards to their effects on network operation point, can trace on optimal configuration. Since feeder reconfiguration and reactive power control are two important means of reducing power losses of distribution systems, the idea of coordinated application of these two controls has been investigated. Several evaluation items such as new equipment installation cost, equipment utilization rate and location, reliability of the target distribution system, and loss minimization are of concern when planning [9]. In this paper a new and more comprehensive planning problem including simultaneous DSTATCOM allocation and reconfiguration is defined to minimize the cost of power loss at peak-load. The desired effect of DSTATCOM on system performance is increased by determining its best location and size among former planning items while determining the status of tie switches.

Several works have been investigated to such combinatorial optimization problems including reconfiguration and compensation devices but not yet for DSTATCOM. The presented work in [10], has investigated planning of Distributed Generators (DGs) with combination of reconfiguration in a deregulated distribution system. Ref. [11] investigates the mutual impacts of distributed generation, reactive power and network-configuration as a new and more comprehensive planning problem. In [12], the combinatorial problem of DGs allocation, sizing and reconfiguration has been investigated. The objective of the research reported in Ref. [13] is to study the optimal feeder reconfiguration problem, the optimal capacitor placement problem, and the problem of a combination of the two. In [14], the authors have presented a planning strategy to solve operating conflicts between the voltage regulation system and correct DG location and operation only by means of the corrective actions performed by the automatic voltage controls.

The defined problem in this paper is a combinatorial optimization problem because many discrete variables must be determined appropriately by taking into account various constraints in real distribution systems. To solve such a problem, classical methods, e.g. linear programming, mixed-integer programming, quadratic programming, etc., can be used. However, in some cases, the mentioned methods fail to provide the global minima and only reach local minima. Moreover, some classical methods cannot handle the integer problems. The two aforementioned shortcomings can be overcome by utilizing an evolutionary method [6]. Two evolutionary methods such as PSO and DEA have been compared to solve the problem where DEA found to be more accurate and faster.

Section 2 includes mathematical formulation and modeling. In Section 3, the optimization methods have been described. Section 4 introduces case studies and simulation results. Section 5 and 6 have been devoted to discussion and concluding remarks.

2. Mathematical modeling

2.1. Formulation of power flow

The objective function of the constrained optimization problem for (I) loss reduction and voltage profile improvement simultaneously, (II) Mitigation of losses or (III) voltage profile improvement can be expressed by minimization of following equations:

$$\begin{cases} f(x) = \frac{n}{\sum_{i=1}^{n} V_i(x)} + P_{T,Loss}(x) \quad (I) \\ f(x) = P_{T,Loss}(x) \quad (II) \\ f(x) = \frac{n}{\sum_{i=1}^{n} V_i(x)} \quad (III) \end{cases} \tag{1}$$

In Eq. (1) $P_{T,Loss}$ is the total power losses and n is the number of busses in the distribution network. Voltage magnitudes at each bus must be maintained within its limits. The current at each branch is restricted by conductor capacity ratings. These constraints can be expressed by the following equations:

$$V_{\min} \leqslant V_i \leqslant V_{\max} \tag{2}$$

$$|I_i| \leqslant I_{i \cdot \max} \tag{3}$$

where V_i is the voltage magnitude of bus i; $V_{\min}$, $V_{\max}$ are the minimum and maximum voltage limits respectively. I_i, $I_{i.\max}$ are current magnitude and maximum current limit of branch i. Fig. 1 shows a typical radial network that represents power flow in different branches.

Load flow problem could be solved through the following equation:

$$[I] = [Y][V] \tag{4}$$

where $[I]$, $[Y]$ and $[V]$ are the nodal injected current vector, admittance matrix and bus voltage vector. Overhead lines could be modeled using multiple nominal π-sections or the more accurate one, equivalent π model. The researches show that by using multiple nominal π-sections model, the error of calculations is less than 1.2% for a line segment with the length equal to ¼ of the wavelength (1500 km at 50 Hz). Thus satisfactory results could be obtained using one π-section for MV distribution feeders.

To solve (4), Gauss–Seidel (GS) method has been applied. For PQ buses where P_{Li} and Q_{Li} are active and reactive powers, the following equation should be solved [15]: