Available online at www.sciencedirect.com

SCIENCE DIRECT

Electric Power Systems Research 76 (2006) 549–556

ELECTRIC POWER SYSTEMS RESEARCH

www.elsevier.com/locate/epsr

Optimal network reconfiguration for congestion management by deterministic and genetic algorithms

G. Granelli [a,*], M. Montagna [a], F. Zanellini [a], P. Bresesti [b], R. Vailati [b], M. Innorta [c]

[a] *University of Pavia, Department of Electrical Engineering, Via Ferrata, 1 I-27100 Pavia, Italy*
[b] *CESI S. p. A., T&D Network Department, Milan, Italy*
[c] *Consultant, Milan, Italy*

Received 3 May 2005; received in revised form 28 July 2005; accepted 20 September 2005
Available online 21 November 2005

Abstract

In this paper, the problem of finding the optimal topological configuration of a power transmission system is considered with the aim of providing system operators with a tool suited for congestion management. Network reconfiguration looks particularly appealing since it allows transmission system operators to alleviate overloads by means of switching operations that may avoid costly generation or load curtailments. The techniques of corrective switching proposed in the 1980s are profitably employed to formulate the problem of network reconfiguration for the purpose of congestion management. The solution of the resulting large-scale mixed-integer programming problem is carried out both by a deterministic branch-and-bound algorithm included in the CPLEX optimization package and by a genetic algorithm. Tests were performed on a 33-bus CIGRE test system and on an actual 432-bus network of Italian origin.

Keywords: Congestion management; Network reconfiguration; Mixed-integer linear programming; Genetic algorithms

1. Introduction

Today the liberalization of the electricity market is in an application phase in several countries around the world. While competition involves generation companies and eligible customers, this is not the case of electric grids that have to support an ever increasing amount of energy exchanges with heavy constraints to the installation of new transmission capacity. Transmission system operators (TSOs), responsible for the secure and reliable operation of the network, experiment dangerous operating conditions that, in some case, can evolve towards partial or total blackout.

In this framework, any methodology that can help TSOs in managing (with the lowest impact on market schedules) networks with limited security margins appears very useful. The network reconfiguration, in terms of switching and change over of lines inside electric substations, represents a well known tool for security assessment and enhancement. In some cases, reconfiguration is capable of reducing overloads considerably, therefore avoiding re-dispatching actions that imply the modification of the generation and consumption patterns cleared out by the energy market.

The optimal network configuration is a combinatorial optimization problem that can require a remarkable computation effort for large electric systems. This problem, however, is not completely new to the power system community. Indeed corrective switching was proposed as a means to alleviate network overloads as early as the 1980s [1–7]. An excellent survey about corrective switching is presented in [8] where other references on the subject can be found.

A renewed interest in the problem of optimal network reconfiguration is witnessed by recent papers [9–12]. The most suitable optimization techniques today available for the solution of this kind of problems are branch-and-bound algorithms [10] and artificial intelligence procedures like genetic or evolution algorithms. In particular, the solution algorithm employed in [11,12] belongs to the evolution strategies which differ from GAs in the transition rules used to evolve the population; corrective switching is coordinated with transformer taps and shunt elements adjustment as well as generation redispatch.

* Corresponding author. Tel.: +39 0382 985264; fax: +39 0382 422276.
E-mail address: granelli@unipv.it (G. Granelli).

0378-7796/$ – see front matter
doi:10.1016/j.epsr.2005.09.014

In the present work, both deterministic and genetic based approaches are applied to the problem of finding the best topological network arrangement with respect to the most widely employed security criteria.

The proposed deterministic procedure generalizes the model presented in [10] by including the possibility of carrying out line or transformer change over according to the method suggested in ref. [5]. Change over consists in disconnecting a line or a transformer from one substation busbar to reconnect it to another. Such operations are preferable to line openings since they do not weaken the transmission system. The problem of network reconfiguration is modeled as a mixed-integer linear program, which is solved by using the well known CPLEX optimization environment [13]. The objective function to be minimized includes the sum of branch overloads and a suitable term taking into account the cost of performing line switching.

The network reconfiguration problem is also handled by a non-deterministic procedure based on the application of genetic algorithms (GAs). Basic GAs [14] operate on populations consisting of individuals, each representing a particular selection of the control actions. Starting from a randomly generated initial population, new solutions are formed by effect of the genetic operators of "crossover" and "mutation", which mimic the evolution process occurring in the nature. To complete the biologic metaphor underlying GAs, the fitness of each population individual is obtained by evaluating the objective function to be optimized and this provides the GA method with the necessary evolutionary drift towards the optimum. More recently, newer GA implementations have been proposed to gain computational efficiency by reducing the population size. In particular, the so called micro-genetic algorithm (μGA) [15] was introduced and successfully applied to seismic data analysis, laser physics and power system applications [16].

The two proposed approaches were tested with reference to a 33-bus CIGRE sample system used for illustration purposes as well as to a 432-bus network derived from the Italian grid. The reconfiguration operations suggested by the two procedures are consistent and in several cases allow to completely relieve all overloads. Whenever security restoration requires stronger corrective actions to remove the violations, network reconfiguration succeeds in reducing them to a minimum. Moreover, the developed procedures are not too time expensive also in the case of medium-size networks.

2. Deterministic approach

2.1. List of symbols

The following list contains the description of the symbols used in Section 2.2.

- c_k^S $k \in \mathrm{LC}$ cost of opening line k
- $c_l^L (c_t^T)$ cost associated to line l (transformer t) overload
- $i = 1, \ldots, N$ bus index
- I_i real power injection at bus i
- I_k^S $k \in \mathrm{LC}$ set of fictitious power injections used to simulate line k opening
- $l = 1, \ldots, L$ line index
- L number of network lines
- LC set of indices corresponding to lines that are candidate to opening
- $\mathrm{LCU}_i(\mathrm{LCE}_i)$ set of indices of those lines leaving (entering) bus i, that are candidate to opening
- $\mathrm{LU}_i(\mathrm{LE}_i)$ set of indices corresponding to lines coming out of (entering) bus i
- M large positive constant
- N number of network buses
- $S_l(S_t)$ line l (transformer t) overload
- $t = 1, \ldots, T$ transformer index
- T number of transformers
- $T_l(T_t)$ maximum power flow through line l (transformer t)
- $\mathrm{TU}_i(\mathrm{TE}_i)$ set of indices corresponding to transformers coming out of (entering) bus i
- $x_l(x_t)$ reactance of line l (transformer t)
- γ_k $k \in \mathrm{LC}$ binary variables (closed line: $\gamma_k = 0$; open line: $\gamma_k = 1$)
- θ_i voltage phase angle at bus i
- $\theta_h^t(\theta_j^t)$ voltage phase angle at the sending (receiving) end of transformer t
- $\theta_h^l(\theta_j^l)$ voltage phase angle at the sending (receiving) end of line l

2.2. Mixed-integer linear programming formulation

The aim of network reconfiguration is that of minimizing branch overloads $S_l(S_t)$ and the amount of control action consisting in suitable line opening operations. Of course, the best expected solution is the one leading to a complete relief of all the overloads.

The problem can be formulated as a linear program with mixed (real and integer) variables according to the following model:

$$\min \sum_{l=1}^{L} c_l^L S_l + \sum_{t=1}^{T} c_t^T S_t + \sum_{k \in \mathrm{LC}} c_k^S \gamma_k \quad \text{subject to :} \tag{1}$$

$$\begin{aligned} & I_i + \sum_{k \in \mathrm{LCU}_i} I_k^S - \sum_{k \in \mathrm{LCE}_i} I_k^S \\ & \quad = \sum_{l \in \mathrm{LU}_i} \frac{\theta_i - \theta_j^l}{x_l} - \sum_{l \in \mathrm{LE}_i} \frac{\theta_h^l - \theta_i}{x_l} + \sum_{t \in \mathrm{TU}_i} \frac{\theta_i - \theta_j^t}{x_t} \\ & \qquad - \sum_{t \in \mathrm{TE}_i} \frac{\theta_h^t - \theta_i}{x_t} \end{aligned} \tag{2}$$

$$-T_k - S_k - M\gamma_k \le \frac{\theta_h^k - \theta_j^k}{x_k} \le T_k + S_k + M\gamma_k \quad k \in \mathrm{LC} \tag{3}$$

$$-T_l - S_l \le \frac{\theta_h^l - \theta_j^l}{x_l} \le T_l + S_l \quad l = 1, \ldots, L; \quad l \notin \mathrm{LC} \tag{4}$$

$$-M\gamma_k \le I_k^S \le M\gamma_k \quad k \in \mathrm{LC} \tag{5}$$