Electrical Power and Energy Systems 47 (2013) 168–180

Contents lists available at SciVerse ScienceDirect

Electrical Power and Energy Systems

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

A simulated rebounding algorithm applied to the multi-stage security-constrained transmission expansion planning in power systems

V.H. Hinojosa [a,*], N. Galleguillos [a], B. Nuques [b,1]

[a] Department of Electrical Engineering, Universidad Técnica Federico Santa María, Av. España 1680, Valparaíso, Chile
[b] Department of Electrical Engineering, Escuela Politécnica Nacional, Ladrón de Guevara E11-253, Quito, Ecuador

ARTICLE INFO

Article history:
Received 12 March 2012
Received in revised form 28 September 2012
Accepted 12 October 2012
Available online 5 December 2012

Keywords:
Transmission expansion planning
Mathematical approaches
Heuristic approaches
Static and multi-stage planning
Security constraint

ABSTRACT

This research discusses the multi-stage security-constrained transmission network expansion planning. In modern power systems, the problem is formulated as a large-scale, mixed-integer, non-linear programming problem, which for a real power systems is very difficult to solve. Although remarkable advances have been made in optimization techniques, finding an optimal solution to a problem of this nature can still be extremely challenging. In this paper, a new constructive heuristic approach, based on a local controlled random search (simulated rebounding algorithm) is proposed to choose the decision variables. The model can produce better solutions than other references techniques such as particle swarm optimization, evolutionary particle swarm optimization, genetic algorithms, and simulated annealing algorithm, among other evolutionary methods. The methodology is applied to assess the capabilities of the proposed approach in the Ecuadorian and Chilean Power Systems as an example of application. Simulation results show that the proposed approach is accurate and very efficient, and it has the potential to be applied to real power system planning problems. The algorithm has been presented and applied to the multi-stage security-constrained transmission expansion planning.
© 2012 Elsevier Ltd. All rights reserved.

1. Introduction

For the last 25 years, the electric power industry has been experimenting with a liberalization and restructuring process that started in Chile in 1982, spread to England and Wales in 1990, and then continued to Australia, New Zealand, and the United States, along with other countries in Latin America and Europe.

A solution to a planning problem specifies *where*, *how many* and *when* new equipment must be installed in an electric power system, so that it operates adequately within a given planning horizon. In addition, the planners have to design the lowest cost transmission plan based on certain reliability criteria.

Traditionally, generation expansion and transmission expansion are sub-tasks of a power system planning process performed by a regulated power utility. In the new market environment, however, transmission expansion planning is usually performed separately by transmission network service providers, while generation expansion becomes the task of generation companies or investors. These changes have imposed new objectives and uncertainties on transmission planners, making the transmission planning problem much more difficult.

In the literature review, the model most accepted by researchers is the so-called DC model. The AC model is generally used in the later planning stages when the most attractive topologies have been determined. In addition, Transmission Network Expansion Planning (TNEP) of power systems can be classified into static transmission network expansion planning (STNEP) and dynamic transmission network expansion planning (DTNEP).

- *STNEP*: The planning is static if the planner seeks the additional optimal circuit set for a single year on the planning horizon. That is, STNEP has to determine where and what types of new facilities should be installed at the lowest cost for a given generation and load profile in a particular planning period. The planner is not interested in determining when the circuits should be installed but rather in finding the final optimal network state for a future single definite situation.
- *DTENP*: On the other hand, if multiple years are considered and an optimal expansion strategy is outlined along the whole planning period, the planning is classified as dynamic (multi-stage). In DTNEP, the timing of when the new facilities should be installed within the planning horizons is also determined.

1.1. Transmission planning methodologies – literature review

The TNEP problem can be mathematically formulated as a large scale, multi-period, non-linear, mixed-integer and constrained

* Corresponding author. Tel.: +56 32 265 4357.
E-mail addresses: victor.hinojosa@usm.cl (V.H. Hinojosa), bnuques@gmail.com (B. Nuques).
[1] Tel.: +593 2 250 7126.

0142-0615/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ijepes.2012.10.052

optimization problem, where the objective function, which changes with time, is non-differentiable. Moreover, the region of feasible solutions is generally non-convex. The choice of optimization technique depends on the form and mathematical properties of the objective function, along with the constraints and the decision variables.

The problem has been largely discussed in specialized literature (transactions, magazines, and conference proceedings from the IEEE, International Journal of Electrical Power and Energy Systems, Electric Power Systems Research, among other journals) since 1965 [1] to 2012 [2,3]. An initial overview of TNEP can be found in [4]. These publications have resulted in the development of numerous algorithms, which are classified into two categories: mathematical approaches and heuristic approaches.

1.1.1. Mathematical approaches

Mathematical-based methods for finding the most economical plan under practical constraints have been well documented in the state of the art. According to the reviewed literature, the most important approaches in this category are the following: linear programming [5,6], dynamic programming [7], non-linear programming [8], mixed-integer programming [9–12], and Benders' decomposition [13–15].

1.1.2. Heuristic approaches

Although these heuristic methods do not always guarantee the globally optimal solution, they will provide a reasonable solution or a suboptimal/optimal solution. The TNEP problem has been solved using genetic algorithms (GAs) [16–23], Object-Oriented Models [24], Game Theory [25,26], Expert Systems [27,28], Evolutionary Algorithms [29], Differential Evolution [30,29], Artificial Immune Systems [29], Fuzzy Approach [31–33], Simulated Annealing Algorithm (SAA) [34,35], Particle Swarm Optimization (PSO) [36,29], Evolutionary Particle Swarm Optimization (EPSO) [37,38], Ant Colony Optimization [39,29], Greedy Randomized Adaptive Search Procedure [40,41], Ordinal Optimization [42], Harmony search algorithm [43], Constructive Heuristic algorithm [2], Chaos Optimal algorithm [44], and Tabu Search [45,46].

In DTNEP, the main studies performed are presented in [19–21,35,15,22,39,12,38]. Additionally, in real power systems, few works can be found in the technical literature.

In this study, an evolutionary algorithm is applied to the problem of TNEP in power systems (investment and operation problem) considering the $N-1$ security constraints for the multi-stage planning problem. Besides, the authors have considered three (small and medium size) power systems with several different load levels to represent seasons of a year. In the entire specialized literature review, no other study has been found with a similar approach to solve the DTNEP problem. Therefore, the contributions of this paper are as follows:

1. Transmission expansion planning has been meticulously analyzed, based on information obtained from the review of the Journals found in the international technical literature.
2. The simulated rebounding algorithm has been presented and applied to the multi-stage security-constrained transmission expansion planning problem. The model can produce better solutions than other reference techniques such as PSO, EPSO, GA, and SAA, among other evolutionary methods.
3. Two realistic approaches have been successfully analyzed (the Power System from Ecuador and the Central Interconnected Power System from Chile).

2. Multi-stage security-constrained transmission network expansion planning formulation

In a TNEP model, the operation and maintenance costs of the transmission lines are negligible compared with the investment cost in the optimization problem. If in the fitness function the operation and annual maintenance costs are not modeled, the mathematical problem using a DC model can be formulated as follows:

$$Z = min\left\{\sum_{l=1}^{LT}\left[\sum_{t=1}^{T}\left(\frac{\sum CI_{(ij)} * n_{ij}}{(1+d_r)^t} + \frac{\sum CC_{gi(l,t)}}{(1+d_r)^t} + \frac{\rho \sum g^{v}_{(l,t)}}{(1+d_r)^t}\right)\right]\right\} \tag{1}$$

The fuel cost of the generation system can be defined by $CC_{gi(l,t)} = b_{gi} \cdot g_{gi(l,t)}$; where b_{gi} is the linear coefficient of the $g$ith thermal unit.

The proposed optimization problem is subject to the following equality and inequality constraints at pre- and post-contingencies:

$$\begin{aligned}
&S_{(l,t)} * f_{(l,t)} + g_{(l,t)} + g^{v}_{(l,t)} = \bar{d}_{(t)}\\
&f_{ij(l,t)} + \gamma_{ij}\left(n^0_{ij} + n_{ij}\right)(\theta_{i(l,t)} - \theta_{j(l,t)}) = 0\\
&|f_{ij(l,t)}| \leqslant \left(n^0_{ij} + n_{ij}\right)\bar{f}_{ij}\\
&0 \leqslant g_{(l,t)} \leqslant \bar{g}_{(t)}\\
&0 \leqslant g^{v}_{(l,t)} \leqslant \bar{d}_{(t)}\\
&0 \leqslant n_{ij(t)} \leqslant \bar{n}_{ij}\\
&\sum_{t=1}^{T} n_{ij(t)} \leqslant \bar{n}_{ij}
\end{aligned} \tag{2}$$

where Z, LT, T, $CI_{(ij)}$, γ_{ij}, n_{ij}, n^0_{ij}, θ, f_{ij} and $\bar{f}_{ij}$ represent respectively, the objective function of the optimization problem, the total number of the credible contingencies, the number of years in the planning horizon, the cost of a circuit that can be added to right-of-way $i-j$, the susceptance of that circuit, the number of circuits added in right-of-way $i-j$ (decision variables of the optimization problem, $n_{ij} \geqslant 0$ and integer), the number of circuits in the base case, the vector of nodal voltage angles, the power flow, and the corresponding maximum power flow.

S is the branch-node incidence matrix, f is a vector with elements f_{ij} (power flows), g is a vector with elements g_k (generation in bus k) whose maximum value is $\bar{g}$, $\bar{d}$ is the load vector for each bus k, $\bar{n}_{ij}$ is the maximum number of circuits that can be added in right-of-way $i-j$, g^v is the vector of artificial generations with elements g^v_k (loss of load in bus k) whose maximum value is $\bar{d}$, ρ is the penalty parameter associated with loss of load caused by lack of transmission capacity, and d_r is the annual discount rate.

Notice that the optimization problem is always feasible due to the presence of the loss of load factor in the objective function; thus, whenever a tentative solution set is inadequate, feasibility is achieved by using artificial generators.

3. Methodology applied to the TNEP problem

Transmission planning is a problem with continuous and integer variables. The optimization problem is broken down into two subproblems: the investment problem and the operation problem. The investment subproblem is solved through the application of an efficient evolutionary algorithm (simulated rebounding algorithm), whereas the operation subproblem is solved by a DC optimal power flow (DC-OPF).

Download English Version:

https://daneshyari.com/en/article/399570

Download Persian Version:

https://daneshyari.com/article/399570

Daneshyari.com