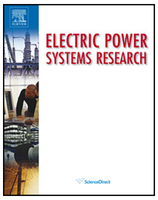
Electric Power Systems Research xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Electric Power Systems Research

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



Identification of relevant routes for static expansion planning of electric power transmission systems

Isabela Miranda de Mendonça[a,b], Ivo Chaves Silva Junior[a], Bruno Henriques Dias[a,*], André L.M. Marcato[a]

[a] Department of Electrical Energy, Federal University of Juiz de Fora (UFJF), Juiz de Fora, MG, Brazil
[b] Department of Science and Technology, Federal Institute of Science and Technology at Juiz de Fora (IFET), Juiz de Fora, MG, Brazil

ARTICLE INFO

Article history:
Received 12 November 2015
Received in revised form 2 May 2016
Accepted 7 May 2016
Available online xxx

Keywords:
Transmission expansion planning
Heuristics
Search space reduction
Multimodal optimization

ABSTRACT

This study presents a new strategy aimed at the search space reduction and initialization of the multimodal optimization process to solve the problem of static expansion planning of electric power transmission systems. To this end, the proposed methodology first uses a constructive heuristic algorithm based on a portfolio of indices, in which the expansion decisions are relaxed and represented through the hyperbolic tangent function. By considering different slopes of the hyperbolic tangent function, within a predetermined range, associated with the main sensitivity indices existing in the literature, it is possible to extract a reduced set of expansion alternatives and feasible solutions. Thus, based on the heuristic information obtained, a bio-inspired algorithm is used to obtain a final expansion plan for electric power transmission systems. The electric power transmission network is represented by a linearized load flow, direct current (DC) model. The final expansion plans obtained by the proposed methodology were satisfactory, showing that the use of the hyperbolic tangent function added to the adopted heuristics yielded an effective decision strategy.

1. Introduction

The electric power system planning problem is a complex task, aiming to guarantee consumer supply at the lowest possible cost. Agents must individually decide when (dynamic view) and where (static view) to invest in order to optimise the financial resources available and ensure the reliable and proper operation of the electric power system. In this study, these decisions aim to find the optimal expansion plan for transmission lines, that is, to specify the circuits that must be installed on the network to allow the viable operation in a predefined horizon at minimal cost, which is a complex and broad optimization problem.

This classical optimization problem has the following characteristics: (i) a non-convex solution region, that is, several solutions, which leads many algorithms to converge towards a local optimal solution; (ii) the combinatorial nature of the planning process that usually leads to the combinatorial explosion phenomenon, related to the investment alternatives, resulting in a high computational effort; (iii) the existence of disconnected electrical systems (isolated); and (iv) the mixed-integer nonlinear programming problem (MINLP), which is therefore difficult to solve. These features illustrate the main challenges in the development of rapid, efficient, and robust algorithms to solve the transmission network expansion problem (TNEP).

Generally, three groups of algorithms are used to solve the TNEP: (i) Constructive heuristic algorithms use continuous optimization techniques. These algorithms are robust and generally find solutions of reasonable quality with little computational effort but rarely find the global optimal solution, especially regarding real and/or large systems [1–4]. (ii) classical optimization algorithms use mathematical decomposition techniques and usually find global optimal solutions of small and medium-sized systems. These algorithms are used for large-sized systems and may present computational effort problems and, in some cases, convergence problems [5–8]. (iii) Metaheuristics use a combination of random choices and knowledge of historical results previously obtained by the method for guidance to conduct their searches in their vicinities within the search space, which prevents premature stops in local optima. These algorithms find optimal or sub-optimal solutions of even larger size systems but may require a prohibitive computational effort in some cases and are competitive to find excellent quality solutions for complex systems [9–13]; this method has been increasingly used, as discussed below.

---

* Corresponding author.
E-mail address: bdias@ieee.org (B.H. Dias).

http://dx.doi.org/10.1016/j.epsr.2016.05.011
0378-7796/© 2016 Elsevier B.V. All rights reserved.

Please cite this article in press as: I.M.d. Mendonça, et al., Identification of relevant routes for static expansion planning of electric power transmission systems, Electr. Power Syst. Res. (2016), http://dx.doi.org/10.1016/j.epsr.2016.05.011

Nomenclature

nr	Number of fictitious generators;
c_m	Cost of the energy deficit (US$/MW-year);
c_l	Construction cost of the candidate line l (US$/year);
g_i	Production of the generator unit in busbar i (MW);
$\bar{g}_i$	Maximum production limit in busbar i (MW);
r_i	Production of the fictitious generator unit in busbar i (MW);
$\bar{r}_i$	Maximum fictitious production limit in busbar i (MW);
Ωi	Set of busbars connected to busbar i;
Ωc	Set of candidate transmission line;
EP_l	Expansion parameter of candidate line l, binary variable 0/1;
f_l	Active power flow of line l (MW);
$\bar{f}_l$	Active power flow limit of line l(MW);
γ_l	Susceptance of line l;
d_i	Demand in busbar i (MW);
φ_l	Angular difference of the fictitious line l between busbars;
θ_l	Angular difference between busbars of line l;
$\gamma_{l_{\mathrm{FIC}}}$	Susceptance of fictitious line l;
$\mathrm{SI}^{\mathrm{ga}}$	Garver sensitivity index;
$\mathrm{SI}^{\mathrm{gam}}$	Modified Garver sensitivity index;
$\mathrm{SI}^{\mathrm{me}}$	Minimal effort sensitivity index;
$\mathrm{SI}^{\mathrm{mcc}}$	Minimal sensitivity index load shedding;
λ_i	Lagrange multiplier associated with the balance equation of busbar i;

Accordingly, several recent studies have used metaheuristic techniques to solve this problem. The bee colony technique was applied in [10] to solve the TNEP based on the DC model. The results indicate that it is possible to obtain the minimum investment cost for the systems. As in [11], there are several mathematical optimization problems that can be effectively solved by metaheuristic algorithms. In this context, the three metaheuristic algorithms, the firefly, bat, and cuckoo searches, were used to find the best solutions. Firefly is inspired by the behaviour of fireflies, the bat algorithm is based on the echolocation behaviour of bats, and the cuckoo search is based on a nest pattern. A series of computational experiments using each algorithm was performed. The experimental results were analysed, and the firefly algorithm was found to have the best performance.

Mendonça et al. [14] present a constructive heuristic algorithm that evaluates the optimal set of transmission expansion routes of an electrical system. To do this, the discrete variables of transmission system are mitigated with the use of a linear function (line), which is valid for the [0,1] interval. Therefore, the proposed algorithm is started taking into account different starting points (random). In [15] the reduction obtained in [14] is used to solve the TNEP problem using the particle swarm optimization (PSO) metaheuristics to obtain the minimal cost expansion plan. The methodology proposed in this paper differs from [14] and [15], by using the hyperbolic tangent function presented by [4] but modified by the parameter A that varies in a predefined range representing the discrete variable. So by the control of the inclination of the tangent function, the parameter A, and a portfolio composed of four sensitivity indexes, it is possible to determine a reduced set of candidate routes to the transmission expansion. So, reducing the search space in an efficient manner.

In [16] a strategy to reduce the number of expansion circuits in each candidate route is presented. This approach uses the concept of the binary numeral system and GRASP_CP, together with the disjunctive model to solve the problem. It must be highlighted that, different from what is proposed in this work, this approach only deals with the number of circuits and does not minimize the number of routes.

Torres & Castro [17] solved the TNEP using the alternate current (AC) network model using a specialized application of the improved differential evolution.

Heuristics have been often used because they enable feasible solutions to be obtained within an acceptable computational time. Thus, considering the low processing time, robustness, and the fact that many properties and results based on constructive heuristics find high applicability in the development of complex algorithms, this study is motivated by developing a heuristic strategy of search space reduction and obtaining feasible solutions for applying a bio-inspired optimization process aimed at solving the static expansion planning of electric power transmission systems.

The main contribution of this study is the proposal of a new heuristic to reduce the search space for the TNEP problem. This proposed approach represents the discrete decision variable by a hyperbolic tangent function in the DC flow model. Through the variation of the hyperbolic tangent function together with the portfolio of four sensitivity indices based on previous developed heuristic techniques applied to the TNEP problem, it is possible to achieve a reduced set of candidate routes. So, reducing the search space. From this reduced set the candidate routes are provided as the input of an optimization algorithm based on PSO.

This article is organized as follows: Section 2 shows the TNEP formulation, and the proposed methodology is described in Section 3. Section 4 states the results for different case studies. Section 5 presents the conclusions.

2. Problem formulation

A DC load flow model is usually used for the TNEP. This model is based on the coupling between the active power and the voltage angle and allows for determining the active power flow distribution in the transmission network in a simple manner, with low computational effort and acceptable accuracy. Thus, with E being the set of circuits existing in the base topology of an electric power system, C being the set of candidate circuits for expansion, and F being the set of fictitious circuits, the optimization problem can be formulated as:

$$\text{Min} \sum_{m=1}^{nr} c_m.r_m + \sum_{l \in \Omega c} c_l.\mathrm{EP}_l \tag{1}$$

subject to:

$$g_i + r_i - \sum_{j \in \Omega i} f_l = d_i \tag{2}$$

$$\left|f_l\right| \leq \bar{f}_l \qquad \forall(l) \in E, C \tag{3}$$

$$0 \leq g \leq \bar{g} \tag{4}$$

$$0 \leq r \leq \bar{r} \tag{5}$$

$$0 \leq \mathrm{EP}_l \leq 1 \qquad \forall(l) \in C \tag{6}$$

$$f_l = \gamma_l \theta_l \qquad \forall(l) \in E \tag{7}$$

$$f_l = \gamma_{l_{\mathrm{FIC}}} \varphi_l \qquad \forall(l) \in F \tag{8}$$

$$f_l = \mathrm{EP}\gamma_l \theta_l \qquad \forall(l) \in C \tag{9}$$

$$\varphi_l >> \frac{\bar{f}_l}{\gamma_l} \qquad \forall(l) \in F \tag{10}$$

$$\gamma_{l_{\mathrm{FIC}}} << \gamma_l \qquad \forall(l) \in F \tag{11}$$

Please cite this article in press as: I.M.d. Mendonça, et al., Identification of relevant routes for static expansion planning of electric power transmission systems, Electr. Power Syst. Res. (2016), http://dx.doi.org/10.1016/j.epsr.2016.05.011