Electrical Power and Energy Systems 100 (2018) 320–330

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

Candidate line selection for transmission expansion planning considering long- and short-term uncertainty

Xuan Zhang[a,*], Antonio J. Conejo[b]

[a] Department of ECE, The Ohio State University, Columbus, OH 43210, USA
[b] Departments of ISE and ECE, The Ohio State University, Columbus, OH 43202, USA

ARTICLE INFO

Keywords:
Candidate line selection
Transmission expansion planning
Robust optimization

ABSTRACT

The objective of transmission expansion planning (TEP) is to expand and/or reinforce the transmission network to satisfy the increasing future demand for electricity and to integrate new power plants while maintaining an efficient operation of the system. The candidate lines initially considered for investment largely depend on the expertise of the system planner, which may result in inaccuracies if large networks are considered, as a result of the necessarily limited expertise of the planner. In this paper, we propose an algorithm to generate an effective candidate-line set for TEP considering both long- and short-term uncertainty. The long-term uncertainty includes the peak demand and available generating capacity of the system during the target year (e.g., 10 years from now) and it is described via an uncertainty set. Then, within the target year, the short-term uncertainty pertaining to different operating conditions is represented via a scenario set.

1. Introduction

1.1. Motivation and aim

The objective of transmission expansion planning (TEP) is to expand and/or reinforce the transmission network to satisfy the increasing future demand for electricity and to integrate new power plants while maintaining an efficient operation of the system [1]. To achieve this target, a fundamental prerequisite is to consider an appropriate set of candidate lines for the TEP exercise. However, most existing practical approaches to select candidate lines, which are generally heuristic, show limitations when planning the expansion of a very large system.

Transmission expansion studies are usually conducted by an independent system operator (ISO), or a regional transmission organization (RTO) [2]. It is important to note that when devising candidate expansion plans, alternative options are usually evaluated and the final expansion plan is chosen as the one that best balances the trade-off between investment and operation costs, while complying with technical, environmental and administrative requirements [3]. The candidate lines initially considered for investment largely depend on the expertise of the system planner, which may result in inaccuracies if large networks are considered, as a result of the necessarily limited expertise of the planner.

Since candidate lines are selected by planners based on their experience, it is possible that an effective candidate line is overlooked, which may result in a suboptimal final expansion plan. On the other hand, with the increasing penetration of weather-dependent renewable units (e.g., solar and wind units), the uncertainty of these stochastic power units need to be explicitly considered when generating an appropriate candidate-line set and when solving the TEP problem. Since transmission expansion planning is a medium-term planning problem that usually spans a 10-year horizon [4], the generation of the candidate-line set to be considered in the TEP exercise needs to include both long- and short-term uncertainty. Long-term uncertainty pertains to annual changes, i.e., the future installed generating capacity and the future peak demand, and short-term uncertainty pertains to daily variability, i.e., the stochastic production of weather-dependent renewable units and the load variability.

In addition, the expertise available for a given network is usually limited to specific areas, and thus heuristic approaches may not scale well to large interconnected systems. We conclude indicating that an approach that generates an appropriate candidate-line set based on objective information and considers real-world uncertainties is of great importance.

1.2. Literature review and objective

While a number of models have been proposed to solve TEP problems [1,2,5–14], studies about candidate-line selection are limited. An economic ratio to identify possible candidate lines to solve a TEP

---

[*] Corresponding author at: Room 205, Dreese Labs, 2015 Neil Av., Columbus, OH 43210, USA
E-mail addresses: zhang.3262@osu.edu (X. Zhang), conejonavarro.1@osu.edu (A.J. Conejo).

https://doi.org/10.1016/j.ijepes.2018.02.024
Received 17 November 2017; Received in revised form 12 January 2018; Accepted 16 February 2018

problem is proposed in [13]. Reference [14] proposes a set of criteria for selecting candidate lines to solve a TEP problem that incorporates an AC power flow model. The studies that specifically focus on candidate line selection are [15,16]. An automatic candidate selection algorithm depending on nodal price difference within a stochastic programming framework is proposed in [15]. Benders' decomposition is used to solve a relaxed version of the TEP problem to identify the best candidate-line set. In addition to the nodal price difference, additional criteria (i.e., transmission congestion) is included in the approach proposed in [16]. It is important to note that these models are based either on a deterministic framework or on stochastic programming, and do not differentiate between long- and short-term uncertainty. Moreover, a systematic approach to manage the candidate-line set while tackling the computational complexity involved is not available.

In this paper, we propose an algorithm to generate an effective candidate-line set considering both long- and short-term uncertainty. The long-term uncertainty includes the future peak load and the available generating capacity in the system during the target year (e.g., 10 years from now) and it is described via an uncertainty set. Then, within the target year, the short-term uncertainty represents different operating conditions using a scenario set.

1.3. Contributions

Given the above framework, the contributions of this paper are twofold:

1. To propose a framework for candidate-line selection in TEP studies that explicitly differentiates long- and short-term uncertainties, and that is based on adaptive robust optimization (ARO).
2. To develop an algorithm based on a set of systematic rules to generate and manage a candidate-line set to achieve high computational efficiency while maintaining an appropriate accuracy level.

1.4. Paper organization

The rest of the paper is organized as follows. The proposed line selection algorithm is described in Section 2. The formulation of the underlying TEP model is briefly presented in Section 3. An illustrative example is provided in Section 4, and a large case study is analyzed in Section 5. Concluding remarks are provided in Section 6.

2. Candidate-line selection algorithm

Notations

Indices

k	Iteration index in the candidate-line selection algorithm.
l	Transmission lines.
$r(l)$	Receiving-end node of the lth transmission line.
$s(l)$	Sending-end node of the lth transmission line.
w	The short-term operation scenarios.
ν	Iteration index in the primal Benders' algorithm to solve the TEP problem.

Constants

b_l	Susceptance of the lth transmission line.
β	Parameter to make the investment and operation costs comparable.
e^w	Factor associated with the realization of the long-term uncertain variables in vector u in the wth scenario.
$f_l^{\max}$	Transmission capacity of the lth transmission line.
I_l	Annualized investment cost of the lth transmission line.
Π	Investment budget for transmission expansion.
Γ_z^S	Uncertainty budget of stochastic units in zone z.
Γ_z^T	Uncertainty budget of conventional units in zone z.
Γ_z^D	Uncertainty budget of load demands in zone z.
σ^w	Weight of the wth scenario.

Variables

f_l^w	Power flow of the lth transmission line in the wth scenario.
u	Uncertain variable vector within uncertainty set U.
x_l	Binary variable that equals to 1 if the lth line is built, and 0 otherwise.
η	Auxiliary variable that approximates operation costs given the investment decision in a Benders' decomposition framework.
$\theta_{s(l)}^w$	Voltage angle at the sending-end node of the lth transmission line in the wth scenario.
$\theta_{r(l)}^w$	Voltage angle at the receiving-end node of the lth transmission line in the wth scenario.

Sets

$\Omega_B^{(k)}$	Set of candidate lines to be built at iteration k.
$\Omega_E^{(k)}$	Set of candidate lines that are economically attractive at iteration k.
$\Omega_C^{(k)}$	Set of candidate lines at iteration k.
Ω^{CP}	Set of the candidate-line pool.
$\Omega_H^{(k)}$	Set of candidate lines from the solution history at iteration k.
Ω_N	Set of all buses.
Ω_W	Set of all scenarios.
Ω_Z	Set of zones.

The algorithm consists of three subsequent stages and is illustrated through the flowchart in Fig. 1. First, we describe this algorithm and then provide its rationale.

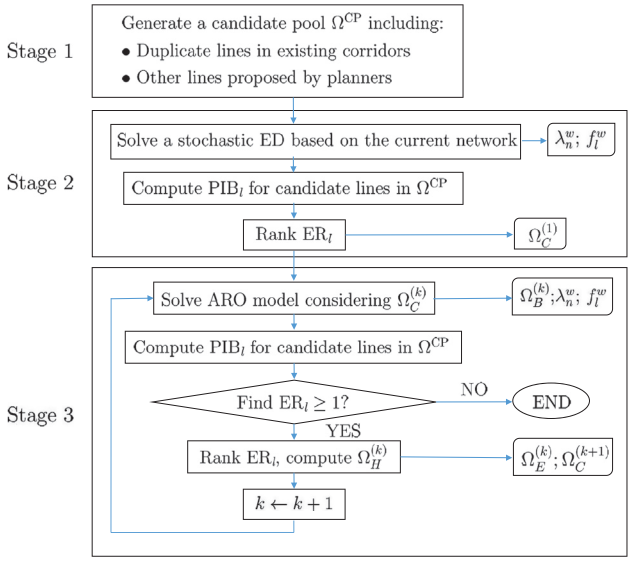

Fig. 1. Flowchart of the algorithm.