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Strategic multiyear transmission expansion planning under severe uncertainties by a combination of melody search algorithm and Powell heuristic method

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A B S T R A C T

In this paper, a new strategic multiyear model is presented for Transmission Expansion Planning (TEP) in deregulated environments. This methodology is based on a tri-level decision making whose fundamental elements are pool-based electricity market and strategic behavior of market participants. In addition, to minimize risks of planning arising from severe uncertainties, an information gap decision theory (IGDT) is used. By using the IGDT, the TEP model is formulated for the risk-averse and risk-seeker decision makers through the robustness and opportunity models, respectively. The offered model is formulated as a non-convex mixed-integer non-linear optimization problem. With this regards, a combination of melody search algorithm and improved Powell heuristic method is widely used to determine the optimal solution. The planning methodology has been applied to the IEEE 30-bus test system and to the large-scale Iranian 400-kV transmission grid. Simulation results demonstrate the feasibility and effectiveness of the proposed model, and the fact that it can be profitable for the real-world networks.

1. Introduction

1.1. Motivations and literature review

Since the mid-1980s, deregulation in the power industry has gradually modified approaches of planning of the power systems, all over the world [1]. Transmission Expansion Planning (TEP) is one of the main steps of power system planning, which undergone major changes in the deregulated environments. In these open competitive environments, the main purposes of a well-organized TEP are not only determine optimal configuration of transmission network to satisfy growing demand, but also provide a non-discriminatory access to transmission network for all market participants [2]. As a result, an appropriate strategy for the TEP should be able to consider i) different planning indices within a deregulated environment, ii) different stakeholders' interests, and iii) effects of severe absence of information about uncertain variables. By considering investment, operation and load shedding costs in the objective function, a hybrid genetic algorithm and linear programming in Ref. [2] and a bender decomposition in Ref. [3] are reported for obtaining optimal expansion plans. In Ref. [4], a market-based approach is proposed to solve multi-objective TEP under normal and contingency operating states by incorporating NSGA-II and fuzzy satisfying methods. In Ref. [5], optimal topology of the transmission network is found by a genetic algorithm based on roulette wheel selection. In Ref. [6], a stochastic approach is modeled for considering future contracts in the TEP problem under environmental constraints. In Ref. [7,8], a scenario analysis-based approach is presented to evaluate investment costs associated with the TEP problem. These models resulted in a static formulation of the TEP without taking i) effects of expansion plans on strategic behavior of participants, ii) a suitable mechanism for assessment of value-based reliability, iii) real behavior of market participants, and iv) effects of uncertain variables into account. In addition, various studies have been published in the power systems literature on the multi-level TEP. A two-level model is described for the TEP problem within a competitive market by using a fuzzy-based genetic algorithm in Ref. [9], and by using a firefly optimization algorithm in Ref. [10]. In Ref. [11], by considering a pool-based electricity market as operating sub-problem, a two-level TEP framework is addressed to minimize cost of installing transmission lines. In another study [12], a market-driven model is introduced for the TEP problem as a bi-level optimization problem under N-1 security constraInt A

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multiyear bi-level approach is presented for the TEP problem by considering uncertainties of demand, outage of lines and outputs of alternative generation in Ref. [13]. In order to handle uncertain parameters, a stochastic combination of genetic algorithm and Monte-Carlo method is employed for solving two-level TEP in Ref. [14]. A bi-level programming model is proposed in Ref. [15] to solve cost-based TEP problem. This bi-level model is reduced to a mixed-integer nonlinear programming using the duality theory and Karush-Kuhn-Tucker (KKT) optimality conditions. In Ref. [16], a simplified form of the network expansion planning is developed as a three-level optimization problem. In another study [17], a mixed-integer linear optimization model is presented for the TEP problem by considering future generation expansion scenarios. In Ref. [18], learning-based methods, in Ref. [19], a hybrid Monte-Carlo method and linear programming, and also in Ref. [20], a simple linear approximated model are employed to solve the TEP problem. These studies showed that there are some shortcomings both in modeling—such as considering single (or double) objective models, disregarding market participants' strategic interactions, ignoring value-based reliability assessment, etc., and in optimization techniques—such as high computational burden, and low convergence and precision, etc. On the other hand, the deregulation in the electric power grid has introduced additional uncertainties and have escalated existing ones [21]. To handle these uncertain parameters, various non-deterministic methods have been employed, such as scenario technique [4], decision making analysis [9], Monte-Carlo method [14], and point estimation method [22]. In general, these techniques need some information about the uncertainty behavior similar fuzzy membership function (FMF) or probability distribution function (PDF). Therefore, these techniques cannot be useful when information is insufficient. With this regards, an innovative decision-making theory was developed named information-gap decision theory (IGDT) in Ref. [23] to model severe uncertainties. The application of this technique in the TEP problem has already been investigated in Refs. [24,25]. In Ref. [24], a risk-averse approach is presented to handle cost and demand uncertainties in the TEP problem based on the IGDT. A genetic-based method is also reported to solve the TEP problem under wind and demand uncertainties using the IGDT in Ref. [25].

1.2. Aims and contributions

In this paper, a new strategic multiyear model is proposed for TEP in deregulated environments. In the proposed planning methodology, with a new point of view, effects of expansion plans are scrutinized on strategic behavior of both Generation Companies (GenCos) and Distribution Companies (DisCos) to provide a well-planned strategy for the TEP. The proposed strategic multiyear model consists of a planning master problem and an operating slave problem. In the operating slave problem, the lower-level problem represents a pool-based electricity market. The intermediate-level problem indicates strategic behaviors of market participants, whiles they have incomplete information about their rivals' actions. In this case, each participant provides its strategic bids based on supply function equilibrium (SFE) model, and it amends its strategic actions until Nash equilibrium points are calculated in a non-cooperative game. In the planning master problem, however, optimization of investment, and congestion costs, and also expected customer interruption cost (EEIC) are taken for multiyear TEP problem into account. In this study, severe twofold uncertainties of price and demand are applied by the IGDT in the TEP problem. This technique does not depend on structure of uncertainties; and therefore, does not need the FMFs and PDFs.

To the best of our knowledge, the main contributions of this paper compared with previous papers in the area of the TEP problem are fourfold:

1) A new strategic multiyear model is developed for TEP in the deregulated environments;
2) A well-founded strategy is proposed to handle uncertainties of price and demand in the TEP problem, when no FMF or PDF of them is available;
3) A new melody search algorithm is employed in order to solve non-convex mixed-integer non-linear TEP problem.
4) An innovative improved Powell heuristic method is used in order to enhance efficiency the melody search algorithm.

1.3. Paper organization

This paper is organized into six sections. The mathematical model of the proposed TEP model is described in Section 2. The IGDT-based TEP is presented in Section 3. The solution algorithm of the proposed model is given in Section 4. Simulation results are demonstrated and discussed in Section 5. Finally, conclusions and further research are given in Section 6.

2. Mathematical model of the multiyear TEP

As indicated earlier, the proposed planning methodology consists of a planning master problem and an operating slave problem. In the operating slave problem, the independent system operator (ISO) supplies individual market participants with LMPs and scheduled generation and consumption. The individual market participants supply the ISO's market clearing model with their strategic bid coefficients. Then, the outcomes of operating slave problem are used as input for the planning master problem. These problems and their interdependencies are demonstrated in Fig. 1.

2.1. Lower level: strategic interactions among market participants

In this level, with a new point of view, to evaluate effects of expansion plans on the strategic behavior of participants, a double-sided strategic interaction is formulated based on the generalized form of Eq. (1) [9,17,19].

$$\underset{k_g,k_d}{\text{Max}}\, \Pi_G(g,k_g),\ \ \Pi_D(d,k_d)\ \ ;\ \ \text{s.t.}\ \zeta_{equal}(g,d)=0,\ \ \zeta_{unequal}(g,d)\le 0 \tag{1}$$

In here, decision variables are strategic bid coefficients,k_g,k_d. In the lower level, market participants provide their strategic bids

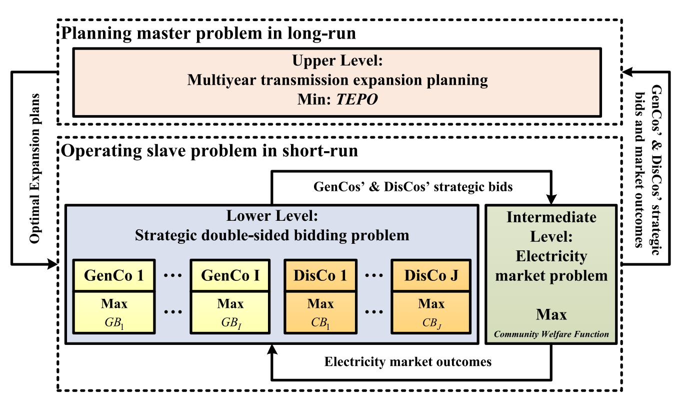

Fig. 1. Conceptual illustration of the proposed tri-level model.