Network Planning in Unbundled Power Systems

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***Abstract*—In this paper, a new approach for network planning in unbundled power systems is presented. The approach takes into account the desires of demand customers, power producers, system operator, network owner(s), and regulator in network planning. Competition, reliability, flexibility of operation, transmission expansion cost, and environmental impacts are used as planning criteria. In order to consider the importance degrees of stakeholders and planning criteria in network planning, first importance degrees of stakeholders and planning criteria are determined by a presented new method. Then, importance degrees of stakeholders and planning criteria are aggregated with appropriateness degrees of expansion plans to compute a fuzzy index for measuring the goodness of expansion plans. The final plan is selected using the presented fuzzy risk assessment method. The approach is applied to an eight-bus test system.**

***Index Terms*—Analytic hierarchy process, fuzzy decision making, market-based transmission expansion planning, power system stakeholders, probabilistic locational marginal price (LMP), scenario technique, stakeholders' desires.**

I. Introduction

RESTRUCTURING and deregulation have unbundled the roles of network stakeholders [1]–[3]. Unbundling the roles has brought new challenges for stakeholders. Stakeholders have different desires and expectations from operation and expansion of the system. Therefore, new incentives and disincentives have emerged regarding transmission expansion decisions. Moreover unbundling the roles within stakeholders has changed the objectives of network planning and increased the uncertainties [4], [5]. Hence, transmission investors have been faced with great risk in deregulated environments. Because of these new objectives and uncertainties, new approaches are required for network expansion planning in unbundled power systems.

A. Transmission Planning Objectives

In general, the main objective of network planning in unbundled power systems is to provide a nondiscriminatory competitive environment for all stakeholders while maintaining power system reliability. Specifically, the objective of transmission planning is providing for the desires of stakeholders. The desires of stakeholders in transmission expansion are [2]–[9] as follows:

- encouraging and facilitating competition among electric market participants;
- providing nondiscriminatory access to cheap generation for all consumers;
- alleviating transmission congestion;
- minimizing the risk of investments;
- minimizing the costs of investment and operation;
- increasing the reliability of the network;
- increasing the flexibility of system operation;
- reducing the network charges;
- minimizing the environmental impacts.

The above desires have different degrees of importance for different stakeholders. On the other hand, stakeholders have different degrees of importance in network expansion decisions. These must be considered in network planning [1]–[3].

B. Power System Uncertainties and Vagueness

Uncertainties can be classified in two categories: random and nonrandom uncertainties. Random uncertainties are a deviation of those parameters, which are repeatable and have a known probability distribution. Hence, their statistics can be derived from the past observations. Uncertainty in load is in this category. Nonrandom uncertainties are evolution of parameters that are not repeatable, and hence, their statistics cannot be derived from the past observations. Uncertainty in generation expansion is in this category. Besides the uncertainties, there are vague data in network planning. Vague data are the data that cannot be clearly expressed. Since methods of modeling random uncertainties, nonrandom uncertainties, and vagueness are different, power system uncertainties and vagueness must be identified and classified clearly before planning. Sources of random uncertainties in unbundled power systems are [2]–[4], [6], [10], [11] as follows:

- load;
- generation costs and consequently bid of generators;
- power and bid of independent power producers (IPPs);
- wheeling transactions;
- availability of generators, lines, and other system facilities.

Sources of nonrandom uncertainties are [3], [4], [6], [11]–[16] as follows:

- generation expansion/closure;
- load expansion/closure;
- installation/closure of other transmission facilities;
- replacement of transmission facilities;
- transmission expansion costs;
- market rules.

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There is vagueness in the following data [2], [3], [6]:

- importance degrees of stakeholders in decision making;
- importance degrees of planning criteria from the viewpoint of different stakeholders;
- occurrence degrees of possible future scenarios.

Probabilistic methods [2], [3], [6], [10], [11], scenario technique [3], [4], [6], [11]–[16], and fuzzy decision making [2], [3], [6] are used to take into account random uncertainties, nonrandom uncertainties, and vagueness, respectively.

II. Model Overview

First strategic scenarios are identified to model the nonrandom uncertainties. In each scenario, probability distribution function (PDF) of locational marginal price (LMP) for each bus is computed using probabilistic optimal power flow. Some expansion candidates are suggested based on PDFs of LMPs. Each of the candidates is added to the network, and PDFs of LMPs are computed again for each scenario. Appropriateness of expansion plans versus different planning criteria are computed based on PDFs of LMPs. Importance degrees of planning criteria and stakeholders are determined using analytic hierarchy process. Appropriateness degrees of expansion plans, importance degrees of planning criteria, and importance degrees of stakeholders in network planning are aggregated to compute a fuzzy appropriateness index for measuring the goodness of expansion plans. The final plan is selected using the presented fuzzy risk assessment method. The planning procedure consists of the following stages:

1) identifying the set of possible strategic scenarios;
2) suggesting candidates for transmission expansion based on PDFs of LMPs;
3) computing appropriateness degrees of expansion plans versus different criteria in each scenario;
4) determining the importance degrees of stakeholders and planning criteria;
5) aggregating appropriateness degrees of expansion plans with importance degrees of stakeholders and planning criteria to compute the fuzzy appropriateness index for measuring the goodness of expansion plans;
6) selecting the final plan using fuzzy risk assessment;
7) computing the capacity of selected expansion plan.

This paper is organized as follows. Identifying the set of possible strategic scenarios is discussed in Section III. A probabilistic market-based method for suggesting expansion plans is presented in Section IV. A fuzzy appropriateness index for measuring the goodness of expansion plans is defined in Section V. In Section VI, a method for fuzzy risk assessment is presented. Capacity of selected line is discussed in Section VII. The method is applied to an eight-bus test system in Section VIII. The Conclusion in Section IX closes the paper.

III. Identifying the Set of Strategic Scenarios

A scenario (future) is a set of outcomes or realizations of all uncertainties. To model the nonrandom uncertainties, all possible strategic scenarios and their occurrence degrees must be identified. Since in unbundled power systems generation expansion planning is not coordinated with network expansion planning, the main nonrandom uncertainty is related to expansion or closure of generation. Consequently, the main strategic scenarios are related to expansion or closure of generation.

IV. Suggesting Expansion Plan Candidates

In transmission planning, the set of possible expansion plans is very large since between each two buses a new transmission line can be constructed. There are $n(n-1)/2$ candidates for expansion of an n bus network. Most of these candidates do not satisfy the constraints of planning and must be eliminated. In order to determine the effective expansion candidates, first PDFs of LMPs are computed for different scenarios using Monte Carlo simulation [2], [3], [6], [10], [11]. Note that the presented approach is a midterm static approach and PDFs of LMPs are computed for the peak load of end year of planning horizon. A high mean of LMP at a bus indicates no access to cheap generation, and a low mean of LMP indicates access to excess cheap generation and no access to enough load. Hence, constructing a new line between two buses with low and high mean of LMP will allow the dispatch of the excess cheap generation. Consequently, energy flows from the low LMP bus to the high LMP bus due to price potential difference. Therefore, between each two buses that have average LMP difference greater than a specified value (SV), a new line is suggested as expansion candidate. The set of candidates is equal to union of candidates of all scenarios.

V. Measuring the Goodness of Expansion Plans

To measure the goodness of expansion plans, each of them, with the highest possible capacity, is introduced to the network, and PDFs of LMPs are computed for each scenario. Now we need an appropriateness index to measure the goodness of each expansion plan. This appropriateness index must take into account importance degrees of stakeholders in decision making, importance degrees of planning criteria from the viewpoint of different stakeholders, and appropriateness degrees of expansion plans versus different planning criteria.

A. Importance Degrees of Stakeholders and Planning Criteria

The stakeholders who have interests in transmission expansion planning and exert driving force for expansion are demand customers, power producers, system operator, network owner(s), and regulator [1]–[3]. Stakeholders' desires (planning criteria) are competition, reliability, flexibility of operation, transmission expansion cost, and environmental impacts [1]–[3]. It is very difficult and may be impassible to assign crisp values to importance degrees of stakeholders and planning criteria. In this paper, importance degrees of stakeholders and planning criteria are modeled by fuzzy numbers. In order to assign a fuzzy number to each importance degree, a survey was done. Two questionnaires were designed. In the first questionnaire respondents were asked to answer the following questions.

How important is decision of stakeholder S_i relative to decision of stakeholder S_j in decision making on network planning? Please choose one of the following options:

OL☐ VL☐ SL☐ ML☐ E☐ MM☐ SM☐ VM☐ OM☐