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A Transmission Plan Considering Uncertainties Under a Deregulated Market

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Abstract. In a deregulated power market, the transmission is required to supply a nondiscriminatory service. The location of power producers and power purchasers does not matter in terms of participation in national electricity market. Therefore, criteria for transmission planning in a deregulated market are different from those in a monopoly power market. This paper will propose a model for transmission expansion to meet the requirement of the deregulated power market. The contingency analysis and nodal price analysis are used to find all the candidate lines to add to the transmission system. Considering the investment cost, operation cost, and risk cost, a method combining the Monte Carlo Simulation and the Greedy Algorithm is proposed to find the optimum transmission expansion plan.

Keywords: Deregulated Power Market, Greedy Algorithm, Monte Carlo Simulation, Transmission Expansion Plan.

1. Introduction

The Open Access Tariff of 1966 (created through FERC Order 888) requires functional separations of genaration and transmission within a vertically integrated utility. A generation queue process is now required to ensure that generation interconnection requests are processed in a nondiscriminatory fashion and in a first-come, first-served order. FERC order 889 established the OASIS(Open Access Same-time Information System) process that requires transmission service requests to be publicly posted and processed in the order in which they are entered.

These landmark orders have removed barriers to market participation but complicated the planning process. A good transmission plan is now supposed to address the economic objectives of all users of the transmission grid. In the IEEE Power & Energy Magazine, 2007, No. 5, a series of papers [1-4] are presented to discuss the challenge met by the transmisssion planning.

In [5-8], A new market-based transmission planning in deregulared environments is presented in these paper. These papers introduce a new probabilistic tool to compute the probability density functions of nodal prices to handle the random uncertainties and present a new approach for transmission expansion planning. The scenario technique is used to model nonrandom uncertainties. The final plan is selected using risk assessment or fuzzy risk assessment.

In [9], some important issues related to transmission planning under a competitive market environment are extensively discussed. One of the challenges is more uncertain factors and risks faced by the transmission planning under competitive environment. In [10], a new transmission planning model is developed to consider a variety of market-driven power-flow patterns while a decision analysis scheme is incorporated to minimize the risk of the selected plan.

From surveys of these papers, it can be seen that uncertainties play an important role on the transmission planning under competitive environment. This brings a new challenge to the transmission planning problem. A new transmission planning strategy is therefore proposed in this paper. In order to provide a security and nondiscrimination of service, the security analysis and nodal price analysis are used to form the candidates of the transmission planning model. Considering the investment cost, operation cost, and risk cost, a method combining the Monte Carlo Simulation and the Greedy Algorithm is proposed to deal with the random uncertainties and find the optimum transmission expansion plan. The IEEE 24-bus reliablity test system is adopted to verify the proposed model.

2. The IEEE Reliabilty Test System

The transmission network consists of 24 bus locations connected by 38 lines and transformers, as shown in Fig. 1. The transmission lines are at two voltages, 138 kV and 230 kV. The 230 kV system is the top part of Fig. 1, with 230/138 kV tie stations at buses 11, 12, and 24. The generating capacity data and load data are twice of the data in [11]. The transmission line data and their investment costs can be obtained in [10]. The outage data of these transmission line and generating units are described [11]. The marginal costs of these generating units are shown in table 1.

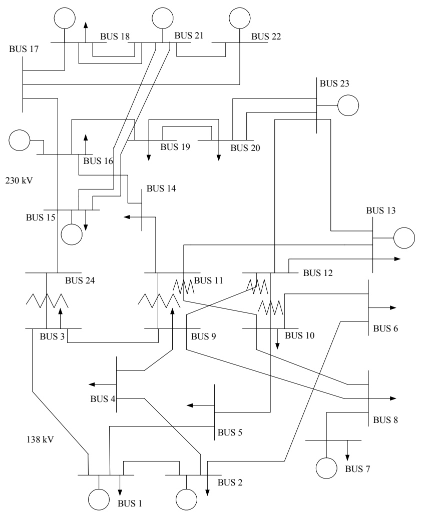

Fig. 1: The IEEE 24-bus reliability test system

The annual peak load for the test system is also twice of the default value. This test system provides hourly peak load as a percentage of the daily peak load. Using these data, the load profile is shown in Fig. 2.

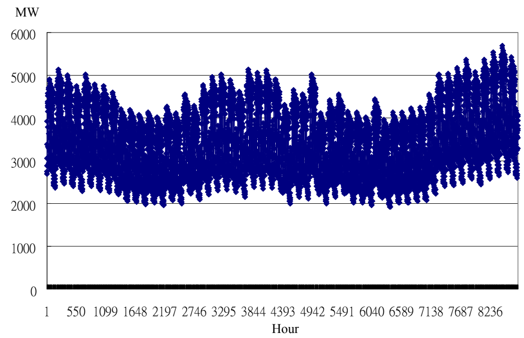

Fig. 2: The load profile of the test system

Table 1: The marginal cost of the generating units

Bus	Marginal cost (US$/MW-hr)
1	30
2	30
7	46
13	23
15	57
16	65
18	35
21	35
22	5
23	25

3. The proposed model

In order to provide a security and nondiscrimination of service, the security analysis and nodal price analysis are used to form the candidates of the transmission planning model. According to the scenarios of the load growth rate and the generation expansion plans, the optimal transmission expansion plan is solved by the method combining the Monte Carlo Simulation and the Greedy Algorithm for each scenario. Fig. 3 demonstrates the flow diagram of the propsed model.

1. Security analysis

The security analysis contains the line outage analysis and the genaerator outage analysis. The line outage analysis is to measure how much a particular line outage might affect the power system. The performance index (PI) of this analysis is shown in (1). The generator outage analysis is to let one genarator outage one time and selects the overloaded lines.

$$PI = \sum_{\text{all branches } \ell} \left(\frac{P_{flow,\ell}}{P_{\ell}^{max}} \right)^2 \tag{1}$$

where $P_{flow,\ell}$ is the line flow of the line ℓ, and P_{ℓ}^{max} is the maximum line flow rating of the line ℓ.

2. Nodal price analysis

In a deregulated power market, the transmission is required to supply a nondiscriminatory service. The location of power producers and power purchasers does not matter in terms of participation in national electricity market. Therefore, to have a competitive electric market nodal prices must be made equal and congestion must be alleviated. Nodal prices are computed by the following optimization. The objective function is to minimize the operation cost. The first constraint is dc power flow. The second and third constraint are line flow limit and generator output limit respectively. Nodal prices are the Lagrange multiplier of dc power flow constraints.

$$\begin{aligned} &\text{Min} \quad \sum_{i \in NG} C_i P_{Gi} \\ &\text{S.T.} \ \mathbf{B}'\boldsymbol{\theta} = \mathbf{P_G} - \mathbf{P_D} \\ &\qquad -P_\ell^{max} < \frac{\theta_i - \theta_j}{x_\ell} < P_\ell^{max} \quad \text{for all line } \ell \\ &\qquad P_{Gi}^{min} < P_{Gi} < P_{Gi}^{max} \quad i \in NG \end{aligned} \tag{2}$$

where C_i is the operational cost of generator i, NG is the generator bus set.

The flow diagram of the new candidate lines created by the nodal price analysis is shown in Fig. 4. The new candidate line is created between the maximum nodal price bus and the minimum nodal price bus. The process lasts until the nodal price difference is small than the tolerance. For this system, the new candiate lines created by the nodal price analysis are line 16-17, and line 8-9.

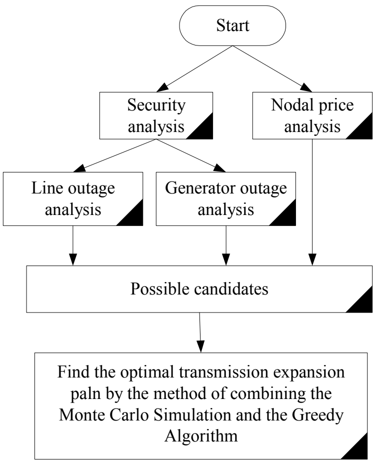

Fig. 3 The flow diagram of the proposed model

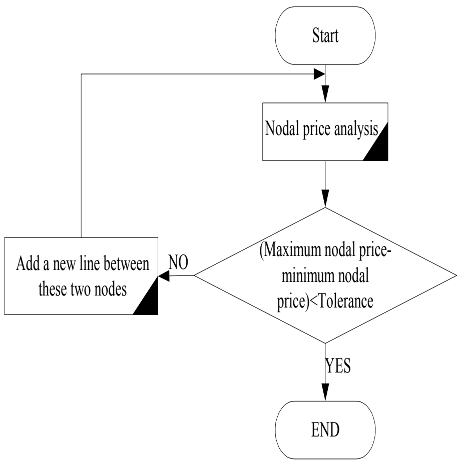

Fig. 4: The flow diagram of the new candidate lines created by the nodal price analysis

3. Cost analysis

The costs of the transmission expansion plan contains the investement cost, the operation cost, and the risk cost. The objective function is to minimize these three costs as shwon in (3).

$$\text{Min} \quad TC=IC+OC+RC \tag{3}$$

where TC is the total cost, IC is the investement cost, OC is the operation cost, and RC is the risk cost.

The annual investment cost of the transmission line is shown in (4). The operation cost and the risk cost are calculated by the Monte Carlo simulation according to the load data, and parameters and outage rates of the transmission lines and generators described in section 2. Equation (5) is the operation cost and the risk cost for each hour. The first part of the objective function is the operation cost, and the second part is the risk cost. Accumulating the cost of each hour, the cost of one year can be obtained.

$$Inv = V * \frac{i(1+i)^n}{(1+i)^n - 1} \tag{4}$$

where Inv is the annual investment cost, V is the actual investment cost, i is the discount rate, and n is the economic life of the investemnt.

$$
\begin{aligned}
&\text{Min} \sum_{i \in NG} C_i P_{Gi} + \sum_{i \in ND} d_c Cur_i \\
&\text{S.T. } \mathbf{B}'\boldsymbol{\theta} = \mathbf{P_G} + \mathbf{Cur} - \mathbf{P_D} \\
&\quad -P_\ell^{max} < \frac{\theta_i - \theta_j}{x_\ell} < P_\ell^{max} \quad \text{for all line } \ell \\
&\quad 0 \le Cur_i \le P_{Di} \quad i \in ND \\
&\quad P_{Gi}^{min} < P_{Gi} < P_{Gi}^{max} \quad i \in NG
\end{aligned}
\tag{5}
$$

where ND is the load bus set, Cur_i is the curtailment of electricity at bus i, and d_c is the curtailment cost.

The investment cost, operation cost, and risk cost of one year can be obtained by (4) and (5). During the planning horizons, the present value of the total cost is calculated by (6).

$$
PV = \sum_{j=1}^{m} \frac{TC_j}{(1+i)^{j-1}} \tag{6}
$$

where PV is the present value, TC_j is the total cost of the j^{th} year, and m is the planning horizon.

4. The method combining the Monte Carlo Simulation and the Greedy Algorithm

The flow diagram of the proposed method combining the Monte Carlo Simulation and the Greedy Algorithm to find the optimal expansion plan is demonstrated in Fig. 5. The planning horizon is 5 years, and one line from the possible candidate lines is added to the network one time to perform the Monte Carlo Simulation. If the minimum total cost of these network topologies is smaller than the original network topology, update the original topology by adding this line as the initial network topology for the next iteration of the Greedy Algorithm. This iteration process continues until no line added to the network can reduce the total cost.

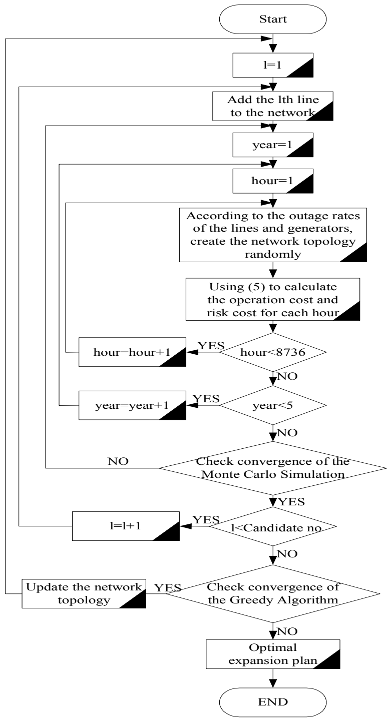

Fig. 5 The flow diagram of the method that combine the Monte Carlo Simulation and the Greedy Algorithm to find the optimal expansion plan

4. Test results

This paper adopts the IEEE 24 bus reliability test system as the demonstrating example. The associated parameters of this system is described in section 2. In this system, the economic life of the transmission line is 45 years, the planning horizon is 5 years, and the discount rate is 10%. The load curtailment cost US$1964/MW-hr is caluculated according to [2] which is based on a gross domestic product divided by total electric energy consumption. According to the security analysis and nodal price analysis, the 11 possible candidate lines are listed in table 2.

Table 2: All possible candidate lines of the test system

Candidate lines created by the line outage analysis	3-24
	15-24
	11-13
	15-21
	10-12
Candidate lines created by the generator outage analysis	18-21
	20-23
	7-8
	14-16
Candidate lines created by the nodal price analysis	16-17
	8-9

The load growth rate is 5%, bus 7 will have a generation expansion of 100MW at the second year, and bus 16 will have a generation expansion of 100 MW at the 4th year. Based on the proposed solution method, the iterative process of this scenario is shown in table 3. The optimal expansion plan is adding two lines between bus 7 and 8, and one line between 11 and 13. The total cost of no transmission expansion is $3.71735*10^7$ US$, and this cost can be downed to $3.51406*10^7$ US$ after performing the expansion plan solved by the proposed model. For the further studies, more scenarios will be considered, and the risk assessment technique is used to select the final plan.

Table 3: The iterative process of the optimal expansion plan

Iteration	Network state	Total cost(US$)
0	Initial network state	$3.71735*10^7$
1	Add line 7-8	$3.56565*10^7$
2	Add line 7-8	$3.52285*10^7$
3	Add line 11-13	$3.51406*10^7$

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