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RESEARCH ON SCENARIO TECHNIQUE BASED FLEXIBLE TRANSMISSION PLANNING

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ABSTRACT

Based on the review of the flexible transmission planning, two novel flexible t planning models with scenario technique are proposed. One is to minimize the expectation value of construction costs; the other is to minimize the deviation from the best expansion plans of different scenarios, both models are based on scenarios occurrence probability and the physical constraints are considered with flexible principle. The proposed models don't pursue the optimal solution for a specific scenario but the comprehensive optimal one that has the best adaptability to all the scenarios according to the occurrence probabilities. The classic Garver 6-bus system illustrates and justifies the feasibility of the models.

Keywords: *Transmission planning, Flexible planning, Flexible constraints, Multi-scenario technique, Uncertainty.*

1. INTRODUCTION

Due to the inevitable uncertain future context of the power system, the transmission planning must face the problem of uncertainty as well as all the other planning jobs. The uncertainties hide behind the authority policy, economy evolution and industry development etc. But for the planner, most of those uncertainties can be finally represented by the uncertainties of construction cost, power provision and consumption. Especially, in nowadays, with the widely introduced power system deregulation, the vertically integrated power system is unbundled in many countries; the siting, timing, capacities of new generators and closure of existing generators are becoming non-transparent for the network planning [1]. The uncertainties will hugely impact the feasibility of the planning result. Therefore the properly processing of the uncertainties is the basis of successful transmission planning. Flexible transmission planning takes into account the influence of all kinds of uncertainties to adapt to the uncertain future, namely the planning scheme obtained should be optimal with respect to the various future scenarios. The flexibility means the plan is able to fit the possible future contexts and has the best adaptability to the power system development. The related research on flexible planning can be classified in two categories. One is the planning based on scenario technique [2,3,4], which is the most common approach for

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the planning of power systems in the presence of uncertainty, the other is the planning approach with mathematical formulation for the uncertainties, the models included in this category are more complicated, e.g. the models with the application of fuzzy set theory [5,6], stochastic programming [7,8], unascertained number (blind number) [9] etc., in which, the blind model is able to describe multi-uncertainty and seems to be more universal.

In this paper, based on the analysis on various typical flexible transmission planning methods, two novel flexible planning models based on scenario technique are presented, which can well represent and solve the problem with uncertainty. The remainder of this paper is organized as follows; section 2 analyzes some typical flexible planning models, e.g. the blind model for multi-uncertainty, which is looked as more universal to represent multi-uncertainty than stochastic, fuzzy and gray methods, the planning models based on multi-scenario technique, including those based on decision preference, decision tree method or line chosen probability. Section 3 presents two flexible planning models to obtain the optimal transmission plan with the best adaptability, in which, one is to minimize expectation value of construction costs and the other is to minimize the deviation from the optimal plan by the determinate planning in different scenarios in normalized coordinate system. Moreover, the flexible constraints are considered. In section 4, the classic Garver 6-bus system is used to illustrate and justify the models, since the size of the network doesn't challenge their feasibility, while finally conclusions are drawn in section 5.

2. ANALYSIS ON CURRENTLY EXISTENT FLEXIBLE TRANSMISSION PLANNING MODELS

2.1 Multi-Scenario Techniques

The multi-scenario techniques analyze the future uncertainties and group them to form a series of scenarios. From probability point of view, the plan scheme with the best adaptability and flexibility, namely has a relatively high performance in all the scenarios, is the comprehensive optimal. The essential of multi-scenario technique is to represent uncertainties by a series of scenarios and the planning in each scenario can be easily solved by determinate method, which avoids the complicated transmission modeling and decreases the computation burden. The critical problems are how to analyze, forecast the various multi-scenario and how to evaluate the comprehensive optimal of the planning scheme.

(1) Multi-scenario techniques based on decision preference [4]

Those methods deal with the problems in the cases that the probability distribution is unknown, decision-maker's behavior is purely based on his/her attitude toward the unknown. The optimal plan is provided by some preference methods of decision theory, e.g. optimistic decision-making, pessimistic decision-making and minimum regret decision-making [10]. The models with those techniques are simple and easily to be implemented, the problems are:

- useful probabilistic information of the scenarios are not well exploited, the scenarios are treated the preference, which are not appropriate with respect to the reality.

- those methods are only based on the decision maker's preference, various preferences lead to various optimal planning scheme, hence the plan obtained is full of subjective meaning.

(2) The decision tree method based on scenario occurrence probability[11]

In decision tree method the component of the plan would be the condition for the next step decision making, the impacts of the uncertainty are quantified during the analysis stage. But the network planning is a complicated multi-variable nonlinear problem. Any changes of the scenarios' component or decision variable value will influence the planning result in an unpredictable way; hence those impacts cannot be precisely taken into account during the analysis by decision tree. Therefore, this method enlarges the number of scenarios with the decision variables transformed as the components of the scenario. Obviously, it is an enumeration method and surely brings much more scenarios for analyzing.

(3) Flexible transmission planning considering line chosen probability

This is a heuristic method with the candidate lines ordering with respect to their chosen probabilities, which is obtained by the optimal plan in each scenario. Basic idea is to transform the probabilities of the scenarios occurrence into probabilities of lines chosen, and then the plan formed by those lines with highest chosen probability is taken as the candidate optimal plan. After the feasibility (reliability, security constraints) check and adjustment, final optimal plan is obtained. The method is intuitional, practical, and easily to be understood and implemented. While due to the method is a heuristic, it is not necessary to get the global optimal, some deficiencies can be drawn as following:

1) the planning scheme is composed by the lines combination, to choose the lines according to the their chosen probability with respect to various scenarios seems blind, especially for a nonlinear, multi-variable problem, the line with high probability cannot fully represent its feasibility in final planning scheme, in other word, low probability chosen line may also present in the final optimal scheme, and the correspondent adjustment are not necessary to obtain the global optimal.

2) the scenarios for checking the feasibility of the candidate optimal plan need to be carefully selected and processed. To ask a feasible planning scheme for all the scenarios must result in much redundancy;

3) there might be small difference between the optimal and the sub-optimal, while those sub-optimal are completely abandoned. It is not rational to choose the lines only based on the optimal plan.

With the analysis above, the scenario techniques mentioned deal with all the scenarios separately, and there is no uniform index for evaluating the plan's comprehensive adaptability. Moreover, some of the methods don't use the probabilistic information, which would surely lead to improper planning.

2.2 Flexible Transmission Planning With Blind Model

Some other flexible planning models try to formulate the uncertainties with the mathematic expression, such as fuzzy set theory [5,6], gray programming, stochastic programming [7,8] etc, while each of them can only well represent one type of the uncertainty. Blind number is developed to express actual uncertainties that usually are multiple and can be looked as a universal expression. The uncertainties are expressed by the blind number in the blind model [9], with which, the flow distribution in each line and the distribution of construction cost can be obtained. Solving the optimization problem with non-overload probability expressed overload constraints and cost-benefit expressed objective function, we get the final optimal solution. By the strict mathematic formulation, the blind model precisely describes the uncertainties, and the final result is credible and subjective. While there is an assumption that could not be omitted, namely, all the components of the scenario are taken as independent during the blind number operation, e.g. A has the probability α to be $f(A)$ and B has the probability β to be $f(B)$, therefore the probability of both occurrence is $\alpha*\beta$, but that is not true in transmission planning, actually, the components are related. E.g. economy developing has similar or at least related impacts to the loads at all the buses. From this point of view, we think that the scenario technique is more convenient to take into account those correlations. What's more, the computation of blind model has an exponential increase with the increase of the dimension, although some special techniques are introduced to solve the problem [12], the huge computation burden still restrict its application.

Some conclusions can be drawn based on the analysis above:

(1) with respect to the correlation among the scenario components, to consider the uncertainty by scenario technique would be more convenient and practical than the blind model, although the latter one can formulate multi-uncertainty;

(2) due to the different scenarios' occurrence probabilities, we must treat each scenario differently with regard to their occurrence probability, the scenario with higher occurrence

probability has bigger impact on the final planning result;

(3) the planning model with scenario technique computes uncertain problem with certain technique for each scenario, which avoids the complicated mathematical modeling for uncertainty, hence has high efficiency;

(4) the target of flexible planning is not for an optimal solution under a specific scenario, but to find the comprehensively optimal plan for all the scenarios with regard to the corresponding occurrence probabilities.

3 FLEXIBLE TRANSMISSION PLANNING MODELS WITH THE BEST ADAPTABILITY BASED ON SCENARIO OCCURRENCE PROBABILITY

Based on the conclusion drawn in section 2, we propose two brand new network-planning models with scenario technique, in which novel flexible constraints are considered.

(1) Determinate transmission planning with flexible constraints

The power flow overloads are not necessarily removed by network topological modification, but can also be solved by DSM (demand side management) or FACTS (Flexible Alternative Current Transmission System). Flexible constraints consideration is to allow slight overload to save large amount of construction investment. While the traditional consideration of flexible constraints in the literatures are not enough reasonable, in which, the overload index with respect to the overload constraints is computed by the sum of the whole system's overloads. With this paradigm, 5 lines with 2% overload are equal to one line with 10% overload. Obviously, the latter is more critical. Therefore novel flexible constraints model is proposed as:

$$\text{Obj}: \min F_i(X) = \sum_{j=1}^{m} C_{ij} x_j + k_1 + k_2$$
$$\text{s.t.} \quad x_j < \overline{x}_j \tag{1}$$
$$\boldsymbol{P} = \boldsymbol{B_0 \theta}$$

Where, $F_i(X)$ is the objective function with planning scheme X in certain scenario i; m is the number of candidate branches; x_j is number of lines to be added in branch j; C_{ij} is the single line construction cost in branch j; $\boldsymbol{P}$ is the vector of nodal power injection; $\boldsymbol{\theta}$ is the vector of nodal angle; $\boldsymbol{B_0}$ is the admittance matrix; k_1 is the overload penalty with respect to the whole system; k_2 is the overload penalty with respect to the severest overload branch.

$$k_1 = \frac{M}{(m'\beta_0)^2}\left(\sum_{l\in L_i} \alpha_{il}\right)^2 ; \tag{2}$$

$$k_2 = \begin{cases} \dfrac{M}{(\beta_1-\beta_2)^2}(\max_{l\in L_i} \alpha_{il})^2 + \dfrac{-2M\beta_1}{(\beta_1-\beta_2)^2}\max_{l\in L_i} \alpha_{il} + \dfrac{M\beta_1^2}{(\beta_1-\beta_2)^2}, & \max_{l\in L_i} \alpha_{il} > \beta_1 \\ 0, & others \end{cases} \tag{3}$$

where, α_{il} is the overload ratio in branch l, $\alpha_{il} = \Delta P_{il} / \overline{P}_l = (P_l - \overline{P}_l)/\overline{P}_l, \quad l \in L_i$; ΔP_{il} is the overload quantity in branch l in scenario i. $\overline{P}_l$ is the upper bound of the power flow in branch l□L_i is the set of the overload branches in scenario i; m' is the number of branches; M can be computed as the sum of all the candidate lines construction costs; Utility theory tells us that the overload penalty should not be linear with the overload: with the overload increase, the penalty should increase much more rapidly. The value of k_1 and k_2 can be formulated by quadratic function as shown in fig.1 and fig.2. While for k_2 , more specifically, the principle is that once the severest overload exceeds the over load ratio limit β_1, k_2 begins to be active, and increases rapidly to M. The coefficient $\beta_0, \beta_1, \beta_2$ are respectively empirically set at 0.05, 0.05, 0.10.

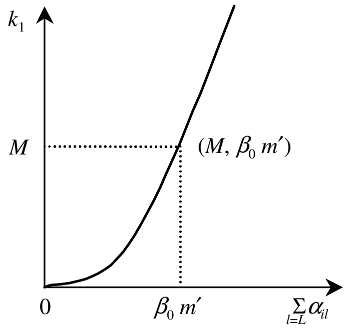

Figure1. Whole system overload penalty k_1 .

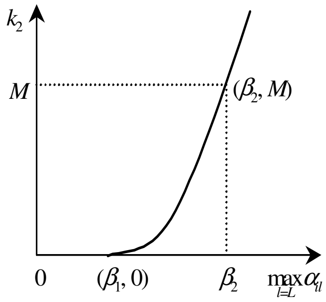

Figure 2. Overload penalty k_2 by the branch with the severest overload ratio.

(2) Transmission planning model based on scenario occurrence probability

Certain planning can be looked as the planning with expectation scenario (formed by the components with expectation values). Due to the non-linear relation between the optimal plan and the scenario's components, there is no direct corresponding relation between the expectation scenario and the comprehensive optimal plan with the best adaptability to the various scenarios. In another word, the optimal plan for the expectation scenario is not necessarily to have the best adaptability to all the scenarios. To ensure the optimal planning result is the probabilistically optimal plan with respect to all the scenarios, we present two models with different objective functions:

Model 1: Flexible planning model with the objective function of expected construction cost

$$\text{Obj}: \min F_{\sum 1}(X) = \sum_{i=1}^{n} p_i F_i(X) = Fe_1 + Fr_1 \quad (4)$$

Where p_i is the occurrence probability of scenario i, $Fe_1 = \sum_{i=1}^{n} p_i \sum_{j=1}^{m} C_{ij} x_j$, $Fr_1 = \sum_{i=1}^{n} p_i (k_1 + k_2)$ are respectively the probabilistic construction costs and overload penalty items with respect to the various scenarios; n is the number of the scenarios. Obviously, the objective value is related to both the construction costs and constraints violation penalty.

Model 2: Flexible planning model with the objective function of normalized construction cost based on the optimal plan in each scenario

$$\text{Obj}: \min F_{\sum 2}(X) = \sum_{i=1}^{n} p_i \frac{F_i(X)}{F_{\min}^i} = Fe_2 + Fr_2 \,(5)$$

Where $Fe_2 = \sum_{i=1}^{n} \frac{p_i}{F_{\min}^i} \sum_{j=1}^{m} C_{ij} x_j$,

$Fr_2 = \sum_{i=1}^{n} \frac{p_i}{F_{\min}^i} (k_1 \sum_{l \in L_i} \alpha_{il} + k_2)$ and $F_{\min}^i$ is the objective value of the optimal plan in scenario i. The objective of the model 1 is the construction costs, the final result is to obtain the comprehensive optimal plan with minimum expectation construction costs; while model 2 try to let the optimal plan owns the least deviation from the optimal plan of each scenario and the occurrence probability is taken as the weight for the comprehensive deviation definition. In this way, model 2 abandons the influence of the real value, but takes the cost deviation degree for optimization. Fig.3. and fig.4 show the difference of the two models.

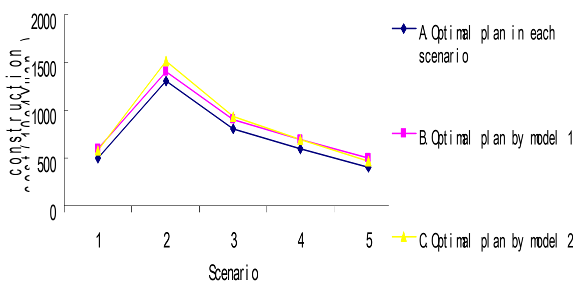

Figure 3. Objective value of the optimal plan in each scenario with the two models in real value coordinate system.

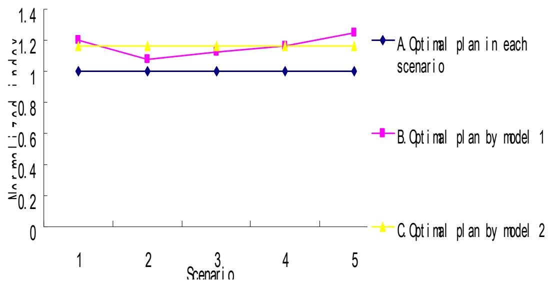

Figure 4. Objective value of the optimal plan in each scenario with the two models in normalized coordinate system.

Fig. 3 and 4 are both under the same probability distribution assumption for the scenarios occurrence (0.2 for each scenario), we observe that the optimal plan of each scenario can be very different (A in fig.3). A and B in fig.3 and A and C in fig.4 are parallel respectively. In real value coordinate system (fig.3), the differences between the optimal plan by model 1 and the optimal plans in each scenario are uniform. While in normalized coordinate system (fig.4), the optimal plan by model 1 deviates less from the optimal plan with larger real value and vice versa. And the optimal plan obtained by model 2 owns uniform deviation from the optimal of each scenario.

We apply genetic algorithm to solve the optimization problem, the computation efficiency with regard to the model proposed can be analyzed as following:

(1) with the scenario techniques, we need to compute the optimal plan in many scenarios, but if we consider the correlation among the scenario components, the number of the scenarios would be much less.

(2) when we apply the model 1, most of the computation are for the power flow, namely the computation for branch flow constraints. The branch flow can be computed by the formula $\boldsymbol{P_l} = \boldsymbol{B_l A B}^{-1}\boldsymbol{P}$, where, $\boldsymbol{B_l}$ is the branch admittance vector, $\boldsymbol{A}$ is the associated matrix, $\boldsymbol{B}$ is nodal admittance matrix, $\boldsymbol{P}$ is the nodal power injection. Obviously, only $\boldsymbol{P}$ is different with respect to different scenario. To compute $\boldsymbol{P_l}$ for the same plan in (4) (with the heuristic algorithms as genetic algorithm, it is needed to compute for each plan with different $\boldsymbol{P}$ to get the objective function value), we can use the triangular factorization or the inversion matrix repeatedly for each scenario. Therefore there are not so many computations increasing with respect to the normal certain planning.

(3) As far as for the model 2, we need to compute the optimal plan for each scenario, hence there are much more computation needed than the deteminate planning, since the optimal plan computation for each scenario is equal to one time determinate planning.

4 SAMPLE AND ANALYSIS

Multi-scenario technique is applied in this paper, the optimization algorithm for solving common determinate transmission planning problem can be directly applied to the multi-scenario problem. While the discussion on the algorithms for determinate transmission planning is out of the scope of this paper. Obviously, the size of the network doesn't influence the feasibility of the proposed models. The Garve 6-bus system as shown in fig.5 was first proposed by L.Garver (Garver, 1970) [13] and has been used as classic test case by many authors with respect to the transmission system expansion. (Pereira, 1985), (Romero, 1993), (Oliveira,1995), (Gallego, 1996), (Gallego, 1997). Therefore we use this system to illustrate and testify the models and the related scenario parameters are given in tab. 1.

Where, P_0, C_0 are respectively the original determinate nodal power injection and the lines construction costs, related value can be found in reference [13,14].

Table 1. Scenario parameters setting for the Garver 6-bus system.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Nodal power injection	0.7 P_0	0.85 P_0	P_0	1.15 P_0	1.3 P_0
Line construction cost (Yuan)	0.8C_0	0.9 C_0	C_0	1.1 C_0	1.2 C_0
Probability/%	10	25	30	25	10

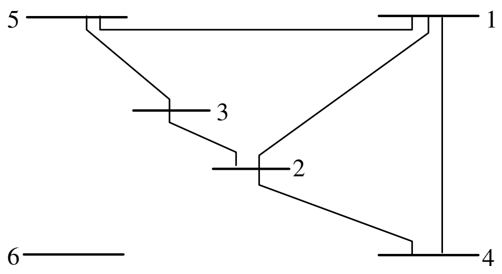

Figure 5. Garver 6-bus system.

Apparently, all the component values of scenario 3 are the expectation values with regard to the scenarios occurrence probabilities, the relation between the power injection and the lines construction costs accords to the general economical theory, namely economy development would result in load increase, commodity price increase and the economy decline will lead to load decrease and commodity decrease.

Table 2. The optimal plan with different contexts / models.

Contexts (models)	Optimal plan	Lines to be added
Scenario 1	X_1	9(3),15(1)
Scenario 2	X_2	9(3), 11(1),14(2)
Scenario 3	X_3	9(4), 11(1),14(2)
Scenario 4	X_4	9(4), 11(2),14(3)
Scenario 5	X_5	9(4), 11(2),12(1),14(3)
By model 1)	X_6	9(4), 11(2),14(4)
By model 2)	X_7	9(4), 11(2),14(4)

The planning results are reported in tab.2, the number in the bracket refers to the number of lines to be added to the corresponding branch. E.g. 9(3) means 3 lines to be added in branch 9.

Usually, the scenario used for the determinate transmission planning is formed by the expectation components. As we analyzed in section 3, due to the non-linear of the network planning problem, the expectation scenario is not necessary to lead to the expectation planning result. In another word, the plan we get from the determinate model are not necessary the one with the best adaptability. In tab.3, obviously the optimal plan of scenario 3 (all the components are at their expectation values) is given big penalties in scenario 4 and 5 due to the overload constraints. While the components are all at their maximum values in scenario 5, and the optimal plan for that scenario has a not bad comprehensive expectation value (298). But it is worse than the optimal plans obtained by our models. It is obvious that maximum condition considered leads to strict consideration of the reliability, as a consequence, the planning result would be conservative. The optimal planning results of model 1 (X_6) and 2 (X_7) are the identical and they have the best comprehensive expectation construction values. Actually, branch 9 in those plans (X_6, X_7) has a 5.76% overload in scenario 5, but with the flexible constraints consideration, X_6 and X_7 are not abandoned and still taken as the plan with the best adaptability.

5. CONCLUSIONS

We analyze the features and the deficiencies of some transmission planning models for solving uncertainties, based on which, novel flexible transmission planning models are proposed. The models are based on the scenario techniques and avoid the difficulties of describing the correlation among the uncertain components, hence can express the future uncertainties in a simple and evident way.

Table 3. Comparisons among the optimal plans.

Optimal plan	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Comprehensive expectation construction cost value
X_1	123.582	34182.8	160820	381101.1	695027.2	221582
X_2	136	153	6539.47	60204	169058	33970.5
X_3	160	180	200	1285.87	29315.5	3374.02
X_4	200	225	250	275	2457.27	465.727
X_5	238.4	268.2	298	327.8	357.6	298
X_6	224	252	280	308	403.266	286.727
X7	224	252	280	308	403.266	286.727

scenario is treated differently according to different scenario occurrence probabilities, it is more rational than those models that treat all scenarios equally. Beside the total overloads of the whole system, the flexible constraints law is built based on the severest single line overload; quadratic function is used to formulate the penalty increase with the overload increase. Compared with the penalty linear increase with the total overload increase, our model describes the impacts of the overload constraints better. What's more, there is no special requirement for optimization algorithm to solve the proposed models; the common algorithm for determinate planning can be directly applied. Model 1 needn't find the optimal plan in each scenario, hence more convenient and less computation with comparison to some other models with multi-scenario technique. Actually model 1 adds only a few more computation than the common determinate transmission planning models, while model 2 has a huge computation increasing.

With the flexible constraints consideration, we avoid to pay a high price for slight reliability improvement, only the reliability lower than a specific level is not allowed. Model 1 pursues minimum expectation construction cost, model 2 avoids the numerical value influence and minimizes the expectation percentage deviation from the optimal plan of each scenario. The two models are both reasonable, and how to choose them is up to the planner's practical consideration. The final results obtained from our models are not necessarily to be the optimal for a specific scenario, but the comprehensive optimal plan for all the scenarios. The optimal plan has the best adaptability with all the scenarios considered.

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