母線輸送傳達能力 신뢰도 기준에 의한 送電系統의 擴充計劃 -II

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Transmission System Expansion Planning by Nodal Delivery Marginal Rate Criterion -II

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Abstract – This paper proposes a method for choosing the best transmission system expansion plan using nodal/bus delivery marginal rate criterion (BMR_k) defined newly in this paper. The objective method minimizes a total cost which is an investment budget for constructing new transmission lines subject to the BMR_k which means a nodal deterministic reliability level requirement at specified load point. The proposed method models the transmission system expansion problem as an integer programming problem. It solves for the optimal strategy using a branch and bound method that utilizes a network flow approach and the maximum flow-minimum cut set theorem. Test results on an existing 21-bus system are included in the paper. It demonstrated the suitability of the proposed method for solving the transmission system expansion planning problem in competitive electricity market environment.

1. Introduction

This paper proposes an alternative method for choosing the best TSEP. The objective function is minimize total cost for constructing new transmission lines which are a investment cost, subject to the nodal delivery marginal rate criterion which consider deterministic reliability level required at specified load point. The nodal reliability criterion is one of characteristics in competitive electricity market environment. The conventional branch and bound and network flow methods are used to search for the optimum mix of transmission network expansion [1]-[6]. The proposed method also includes the ability to include generation additions in the determination of the optimum mix of generation and transmission facilities required to meet the composite system reliability criterion. It models the TSEP problem as an integer programming problem. It solves for the optimum mix of transmission network expansion using a conventional branch and bound method that utilizes a network flow approach and the maximum flow-minimum cut set theorem [7]-[12].

2. The Transmission System Expansion Planning Problem

2.1 The Objective Function

The conventional transmission system expansion planning problem is to minimize the total cost (*CT*) which is construction cost associated with investing in new generators and transmission lines as like as (1).

$$\text{minimize } C^T = \sum_{(x,y)\in B}\left[\sum_{i=1}^{m(x,y)} C^i_{(x,y)} U^i_{(x,y)}\right] \quad (1)$$

where,
B: the set of all branches (generators and transmission lines)
$m(x,y)$: the number of new candidate branches connecting nodes x and y
$C^i_{(x,y)}$: sum of the construction costs of the new generators and lines *1st* through *i-th* that connect buses x and y

$$C^i_{(x,y)} = \sum_{j=1}^{i} \Delta C^j_{(x,y)}$$

with
$P^i_{(x,y)}$: sum of the capacities of new branches (new generators or new transmission lines) between nodes x and y
$\Delta P^j_{(x,y)}$: capacity of the *j-th* element of the candidate branches connecting nodes x and y
$P^0_{(x,y)}$: capacity of the existing generators and lines that connect nodes x and y.

2.2 Constraints

The basic reliability criteria normally considered in a transmission system planning problem can be categorized as two types of constraints. One is a deterministic reliability criterion and the other is the probabilistic reliability criterion. In a deterministic approach, no shortage of power supply requires that the total capacity of the branches involved in the minimum cut-set should be greater than or equal to the system peak load demand, L_p. This is also referred to as the bottleneck capacity. Therefore, a no shortage power supply constraint can be expressed by (2).

$$P_c(S,T) \ge L_p \quad (s \in S,\ t \in T) \quad (2)$$

where, $Pc(s,t)$ is the capacity of the minimum cut-set of two subsets, S and T, containing source node, s and terminal node, t respectively, when all nodes are separated by a minimum cut-set. And, total load of system can be formulated as (3) using BMR_k.

$$L_p = \sum_{k=1}^{NL} L_{pk}\,(1+ BMR_k/100) \quad (3)$$

where, BMR_k is bus/nodal reserve/ marginal rate at load bus k, which is defined as $(AP_k-L_{pk})\text{x}100/L_{pk}$. where, L_{pk} is the peak load at load bus k. AP_k and $Lpk$are the maximum arrival power and peak load respectively at load bus k and NL is number of load buses.

3. Solution Algorithm

The objective in the proposed method using conventional branch and bound method is to minimize the total construction cost subject to a specified BMR_k reliability criterion. The proposed solution algorithm uses the following steps:

1. Check the "need" for transmission expansion for the system and the "possibility" of meeting load using the candidate lines. Need and possibility can be checked for a given reliability criterion by considering the system with no candidate lines and with all candidate lines, respectively.
2. Set j=1 (initial system), *jopt* =0, *jmax* =0, *CTopt*=8 and *ENNODj*=0, where *jopt* is a parameter of the optimal solution in a solution graph for the branch and bound *jmax* is the maximum number of branches that should be searched in a solution graph *ENNOD* is a parameter that indicates whether a branch can be terminated in a solution graph (If it is 1, the branch is bounded).
3. If *ENNODj*=1, the #*j* system is an end node at which the branch operation of branch and bound is finished (Bound) in a solution graph. In this situation, there is no need to consider any of the other graphs following the #*j* system. Go to 13.
4. Calculate the minimum cut-set using the maximum flow method for #*j* system (#*j* solution in the solution graph.)
5. Select a #*i* branch/line of the candidate branches/ lines set (*Sj*) in the minimum cut-set and add it to the #*j* system. In what follows, the new system is named the #*ji* system and it is called a Branch in a solution graph.
6. If the #*ji* system has already been considered in the solution graph, go to 13.
7. Calculate the total cost *CTji* = *CTj* + *CC ji* for the #*ji* system and evaluate thesecurity level of the system.
8. If *CTji* < *CTjopt*, the current system (#*ji*) with a cost of *CTji* may be

optimal. If not, go to 11.

9. Set *jmax* = *jmax* +1.
10. Check the BMR_k criterion If $Pc(s,t) > Lp_k (1+BMR_k/100)$, set $CTopt = CTji$, and $Fmopt = Pc(s,t)$, $jopt = jmax$, and go to 12.
11. Set $CTjmax=CTji$, $ENNODjmax=1$, and go to 13.
12. Add this #*jmax*(#*ji*) solution to the solution graph.
13. If all the candidate branches/lines in the cut-set *Sj* have been considered, go to 15. Otherwise, set $i=i+1$ and go to 5.
14. If $j = jmax$, continue to the next step. Otherwise, set $j = j + 1$ and go to 4.
15. For $j = jmax$, the solution graph has been constructed fully and the optimal solution *jopt* has the lowest cost *CTjopt*, and it also satisfies the required security criterion in step 10.

4. Case Studies

The proposed method was tested on the 21-bus model system shown in References [10] and [11]. This is a part of the south-east area (Youngnam) in Korea. This expansion planning is a static problem, which is considered for a target year and can be described as follows. "What is the optimum TSEP to minimize total cost and satisfy the required probabilistic transmission system reliability criterion, $LOLE_{TS}$ for the future forecast load?" As the input data of the system is introduced well in References [10] and [11], it is ommited in convenient in this paper. The proposed method can be solved a composite power system expansion planning (CPSEP) well but this paper focused on only TSEP problem.

Table I shows various optimal solution of transmission system expansion planning due to variation of BMR_k. Case studies have been worked for the three largest loads in convenient. The case 1, case 2 and case 3 are optimal solutions with BMR_{L2}=20[%], BMR_{L17}=20[%] and BMR_{L21}=20[%] criteria respectivly. The other cases are optimal solution with *BMR* criteria simultaneously at specified two or three load point. From the results, the total cost of case (case 4, case 5 and case 6) which has to be satisfied with *BMR* criteria at specified two or three load points is smaller the sum of the costs of cases obtained by individual BMR_k=20% criterion and also they are larger than the each cost. For example, total cost of case 4 with BMR_{L2}=20[%] (case 1) and BMR_{L17}=20[%] (case 2) criteria is 311[M$]. The costs of the cases are 288[M$] and 291[M$] respectively. As it is, the cost of case 4 is smaller than sum (579[M$]) of the two cases. And, the cost of case 4 is larger than that of case 1 or case 2. The characteristics are also applicable for case 7 which requires a specified *BMR* simultaneously at three loads. Fig. 1 shows relative characteristics of the results graphically. Fig. 1 answers to question about "How much can a given investment budget cover the increased demand load at a load point?" For example, the investment budget of 400[M$] can cover the increased demand of 20% at load point #2, 40% at load point #17 and 60% at load point #21

TABLE I
Various Optimal Solution Of Transmission System Expansion Planning Due To Variation of BMR_k

Case	*BMR* [%]	Optimal solution	Const. Cost [M$]
0	BMR_{All}=10	T^1_{21-1}, T^2_{21-1}, T^1_{1-8}, T^1_{4-8}, T^1_{8-19}, T^1_{9-10}, T^1_{9-11} and T^1_{15-17}	461
1	BMR_{L2}=20	T^1_{21-1}, T^1_{1-8}, T^1_{8-19}, T^1_{9-11} and T^1_{15-17}	288
2	BMR_{L17}=20	T^1_{21-1}, T^1_{1-8}, T^1_{13-15}, T^1_{8-19} and T^1_{9-11}	291
3	BMR_{L21}=20	T^1_{21-1}, T^1_{1-4}, T^1_{9-11} and T^1_{15-17}	227
4	BMR_{L2}=20 and BMR_{L17}=20	T^1_{21-1}, T^1_{1-4}, T^1_{13-15}, T^1_{9-10} and T^1_{9-11}	311
5	BMR_{L2}=20 and BMR_{L21}=20	T^1_{21-1}, T^1_{1-4}, T^1_{9-10}, T^1_{9-11} and T^1_{15-17}	308
6	BMR_{L17}=20 and BMR_{L21}=20	T^1_{21-1}, T^1_{1-4}, T^1_{13-15}, T^1_{9-10} and T^1_{9-11}	311
7	BMR_{L2}=20, BMR_{L17}=20 And BMR_{L21}=20	T^1_{21-1}, T^2_{21-1}, T^1_{1-4}, T^1_{13-15}, T^1_{8-19}, T^1_{9-10} and T^1_{9-11}	404

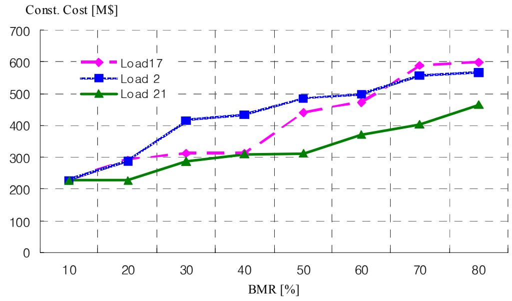

Fig. 1. Variation of the cost due to change of *BMRL17* ,*BMRL2* and *BMRL21*

5. Conclusions

This paper addresses TSEP problem considering deterministic nodal delivery marginal rate criterion associated with construction cost, subject to the deterministic nodal reliability criterion which was described as nodal/bus delivery marginal rate (*BMRk*). Optimal placements and the capacity of transformers as well as transmission lines can be determined using the proposed method. It presents a new and practical approach that should serve as a useful guide for the decision maker to select a reasonable expansion plan prior to checking system stability and dynamics in detail. The proposed method finds the optimal TSEP considering a reliability level required at specified load point. It models the problem as an integer programming one. A proposed branch and bound algorithm which includes the network flow method and the maximum flow-minimum cut set theorem is proposed to solve the problem. The 21-bus system analysis used to illustrate the method show that quite different expansion plans can result from applying various *BMR*. The paper shows that the proposed method can be used to perform the TSEP that grid owner wants to include a specified nodal reliability level in macro view point for decision making investment cost.

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