2005년도 대한전기학회 하계학술대회 논문집 2005. 7. 18 - 20

안전도 제약을 고려한 복합전력계통의 확충계획에 관한 기초연구

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A Basic Method for Composite Power System Expansion Planning under Security Criteria

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Abstract - This paper proposes a method for choosing the best composite power system expansion plan considering a contingency security criterion. The proposed method minimizes the investment budget for constructing new transmission lines subject to contingency criterion. It models the power system expansion problem as an integer programming one. The method 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. Although the proposed method is applied to a simple sample study, the test results demonstrate that the proposed method is suitable for solving the power system expansion-planning problem subject to practical future uncertainties.

1. Introduction

Composite power system expansion planning (CPSEP) with open access to the power system has become a hot issue in the electricity energy industry in recent years [1],[2]. CPSEP addresses the problem of broadening and strengthening an existing generation and transmission network to optimally serve a growing electricity market while satisfying a set of economic and technical constraints [5],[6]. The problem is to minimize the cost subject to a reliability level constraint [7]. Various techniques including branch and bound, sensitivity analysis, Bender decomposition, simulated annealing, genetic algorithms, tabu search, and GRASP (Greedy Randomized Adaptive Search Procedure) have been used to study the problem [12]. It is difficult to obtain the optimal solution of the CPSEP in an actual system due to transmission system expansion planning (TSEP) is usually performed after generation expansion planning. Deterministic and probability reliability criteria such as a *N-1* or *N-2* or *N-1-1* contingency criterion and load balance constraints have used in most TSEP and CPSEP because of computation time problems. This paper proposes a method for choosing the best CPSEP which includes generation as well as transmission system using a security constraint criterion (*N-n*). The conventional branch and bound and network flow methods are used to search for the optimum mix of transmission network expansion [12]. 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 security constraint criterion (*N-n*).

2. The Composite Power System Expansion Planning Problem

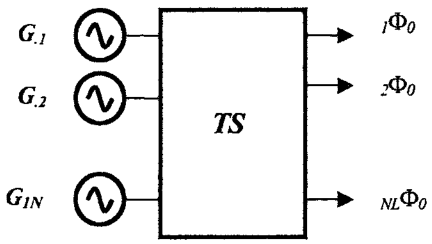


Fig. 1 A composite power system

The objective function

The CPSEP problem is to minimize the total cost $C^T$to be investments cost in new generators and transmission lines as expressed in (1) [12].

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

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 total costs of the new generators and lines *1st* through *i-th* that connect buses x and y

$C^{(i)}_{(x,y)}$: construction cost of the new *j-th*generator or line connecting nodes x and y

$U^{(i)}_{(x,y)}$: the decision variable associated with the generator or line (1 if from 1st to *i-th* generators or lines are to be constructed, and 0 otherwise).

$$\sum_{i=1}^{m(x,y)} U^{(i)}_{(x,y)} = 1$$

$$U^{(i)}_{(x,y)} = [\begin{matrix} 1 & P_{(x,y)} = P^{(0)}_{(x,y)} + P^{(i)}_{(x,y)} \\ 0 & P_{(x,y)} \neq P^{(0)}_{(x,y)} + P^{(i)}_{(x,y)} \end{matrix}$$

$$P^{(i)}_{(x,y)} = \sum_{j=1}^{i} \Delta P^{(j)}_{(x,y)}$$

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*.

Constraints

The problem considered here has a constraint, which is the security constraint criterion (*N-n*). First, no shortage of power supply requires that the total capacity of branches involved in the minimum cut-set should be greater than or equal to the system peak load demand, *Lp*. This is also referred to as the "*bottleneck*" capacity. Therefore, a no shortage power supply constraint can be expressed in (2)

$$P_C(X,\overline{X}) \geq L_P \qquad (s \in X, t \in \overline{X}) \tag{2}$$

where, $P_C(X,\overline{X})_{N-z}$ is the capacity of the minimum cut-set of two subsets, X and $\overline{X}$, containing source nodes *s* and terminal nodes *t* respectively when all nodes are separated by a minimum cut-set under *N-z* contingency analysis.

The demand constraint (2) can be expressed in (3) with *k* being the cut-set number (*k*=1..n), where, *n* is number of cut-set.

$$\sum_{(x,y)\in(X_k,\overline{X}_k)} \left[P_{(x,y)} = P^{(0)}_{(x,y)} + \sum_{i=1}^{m(x,y)} P^{(i)}_{(x,y)} U^{(i)}_{(x,y)} \right] \geq L_P \tag{3}$$

3. Testing The Proposed Approach

The proposed method was tested on the two-bus sample system shown in Fig.2. The CPSEP is a static problem, which is considered for a target year and can be described as follows. "What is the optimum mix of new generators and lines to minimize total cost and considering security constraint criterion?" The security constraint criterion is selected (*N - 1*) in this paper.

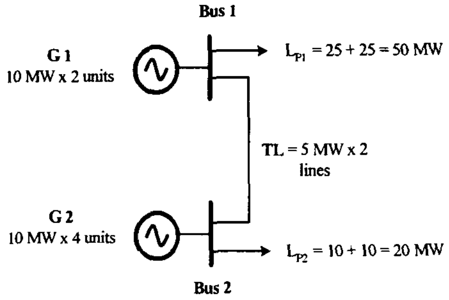
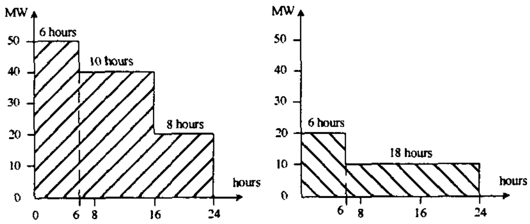


Fig. 2. Two- bus sample system

The configuration of the capacity, construction cost and number of new addition candidates (generator, transmission line)and the *FORs*(forced outage rates) of the elements are presented in Table 1. The load duration curves at buses present in Fig.3.

Table 1: Existing capacity, cost and candidate units of system

	Existing Capacity [MW]	Candidates units	Construction cost [M$]	FOR
G1	10 x 2	10 x 4	10	0.015
G2	10 x 4	10 x 4	8	0.005
T	5 x 2	5 x 4	2	0.00457



(a) LDC at bus 1 (b) LDC at bus 2

Fig. 3 Load curves of standard day in future target years at the system buses

The proposed the security constraint criterion approach, which satisfies the load balance constraints, is applied using a security constraint criterion (*N-1*). Fig..4 shows the configuration of a branch and bound search optimal solution using the security constraint criterion approach proposed in this paper. System 14, which has 24 [M$] cost and G_1^1, G_1^2, $T_{1\text{-}2}^1$ and $T_{1\text{-}2}^2$ for new construction elements is obtained as the optimal solution. Fig.5 presents the optimal system obtained using the security constraint criterion approach.

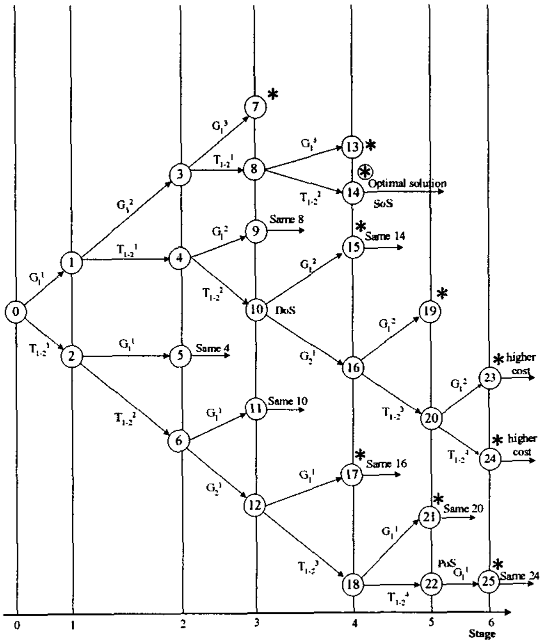


Fig. 4 Configuration of a branch and bound search optimal solution using the security constraint criterion approach

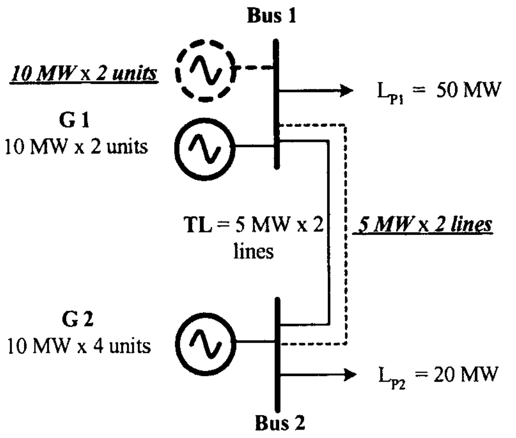


Fig. 5 Optimal system using the security constraint criterion approach

A comparison optimal CPSEP approaches which are deterministic reliability criteria, probabilistic reliability criteria and security constraint criteria, can be presented in Table 2. The case 1and case 2 are only considered investment cost of new construction elements (generator, transmission line) to satisfy their objective and subjective.

Table 2: Comparison optimal composite system expansion planning approaches

Cases	Total cost [M$]	Optimal solution	Remark
case 1	14	G_1^1, T_{1-2}^1, T_{1-2}^2	
case 2	16	G_2^1,T_{1-2}^1,T_{1-2}^2,T_{1-2}^3,T_{1-2}^4	
case 3	24	G_1^1, G_1^2, T_{1-2}^1, T_{1-2}^2	N-1

(1) Deterministic Reliability Criterion
(2) Probabilistic Reliability Criterion
(3) Security Criterion (N-1) contingency

Table 3 shows the results obtained by using security criterion with the more deep contingency analysis. The N-1G-1T in case means the contingency analysis of N-1for generator and N-1 for line. As contingency is deeper, the investment cost is increasing.

Table 3: Comparison optimal composite system expansion planning approaches

Cases	Total cost [M$]	Optimal solution	Remark
case 4	24	G_1^1, G_1^2, T_{1-2}^1, T_{1-2}^2	N-1
case 5	26	G_2^1, G_1^2, T_{1-2}^1,T_{1-2}^2,T_{1-2}^3,	N-1G-1T
case 6	32	G_1^1, G_1^2, G_1^3, T_{1-2}^1, T_{1-2}^2	N-2

4. Conclusions

This paper addresses a basic method for the CPSEP problem using a security constraint criterion. Optimal sites and the capacity of generators 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 toselect a reasonable expansion plan prior to checking system stability and dynamics in detail. The proposed method finds the optimal CPSEP considering uncertainties associated with the forced outage rates of generators and lines. A proposed integer 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 two-bus sample system has demonstrated this proposed. The paper shows that the proposed method can be used to perform CPSEP that includes the residual uncertainties existing in practical systems.

5. Acknowledgement

This study was done by the Electrical Power Reliability/Power Quality Research Center, Korea. The support of the Electrical Industry Research Center (EIRC) of the Ministry of Commerce, Industry and Energy (MOCIE) of Korea is acknowledged.

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