# Coordinated Expansion Planning of Generation and Transmission Systems considering Outage Cost

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***Abstract*-- This paper proposes a method for choosing the best coordinated expansion planning of generation and transmission systems considering an annual outage cost and a probabilistic power system reliability criterion ($_{R}LOLE_{GTS}$). The objective method minimizes a total cost which are not only an investment budget for constructing new generators and transmission lines but also an annual outage cost. Main constraint is the composite power system probabilistic reliability criterion, which considers the uncertainties of power system facilities. The proposed method models the generation system coordinated transmission system expansion problem as an integer programming problem. It solves for the optimal strategy using a probabilistic branch and bound method that utilizes a network flow approach and the maximum flow-minimum cut set theorem. Test results on a 2-buses sample system are introduced. It demonstrated the suitability of the proposed method for solving the generation system coordinated transmission system expansion planning problem subject to practical future uncertainties.**

***Index Terms*—Generation system coordinated transmission system expansion planning, outage cost, probabilistic reliability criteria, Branch and bound.**

## Nomenclature:

*pdf*: abbreviation of probability distribution function
$NG$ : number of generators
$NT$ : number of transmission lines
$CG_i$ : capacity of generator # $i$ ($i$ = 1,…, $NG$)
$q_{gi}$ : forced outage rate of generator # $i$
$CT_i$ : capacity of transmission line # $i$ ($i$ = 1,…, $NT$)
$q_{ti}$ : forced outage rate of transmission line # $i$
$_{k}AP_{ij}$ : maximum arrival power for system state $j$ at load point #$k$ considering operation of generators from #$1^{st}$ to # $i^{th}$
$_{k}q_{ij}$ : state probability for system state $j$ at load point #$k$ considering operation of generators from #$1^{st}$ to # $i^{th}$
$_{k}AP_{sij}$ : operating power of SFEG at load point #$k$ considering operation of generators from #$1^{st}$ to # $i^{th}$
$_{k}q_{sij}$: operating state probability of SFEG at load point #$k$ considering operation of generators from #$1^{st}$ to # $i^{th}$
$_{k}f_{osi}$ : outage capacity *pdf* of SFEG at load point #$k$ considering operation of generators from #$1^{st}$ to # $i^{th}$
$_{k}x_e$ : random variable of the effective load at load point #$k$
$_{k}x_L$ : random variable of the original load at load point #$k$
$_{k}x_{oj}$ : random variable of the probabilistic load caused by the forced outage of generators and transmission lines at load point #$k$
$NS$ : total number of system states (contingency states)
$_{k}\overline{AP}_i$ : the largest value of maximum arrival powers ($_{k}AP_{sij}$) (=supremum($_{k}AP_{sij}$))
$_{k}\Phi_i$ : nodal equivalent load duration curve at load point #$k$ considering operation of generators from #$1^{st}$ to # $i^{th}$
$_{k}\Phi_0$ : original load duration curve at load point #$k$
$\otimes$ : the operator meaning convolution integral
$T$ : study period (8760 hours was used in here)

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## I. Introduction

GENERATION system coordinated transmission system expansion planning (GTSEP) is a hot issue in recent years in South Korea even if Korean electric market access has moved the industry from conventional monopolistic electricity markets to competitive markets. The reason comes from very strict feasibility of location(right of way) of new transmission lines. In recent, feasible location for new lines is stricter than generators in South Korea. Therefore, market signal for new lines looks like prior than new generators.

Generally, transmission system expansion planning(TSEP) has been followed to generation system expansion planning(GSEP) in power system expansion planning. The TSEP is usually performed after generation expansion planning because of it is difficult to obtain the optimal solution of a composite power system considering the generators and transmission lines simultaneously in an actual system. Deterministic reliability criteria such as an N-1 or N-2 contingency criteria and load balance constraints are used in a most transmission system and generation system expansion planning because of computation time problems.

Under situation of too strict right of way for new lines, however, the process may be changed and coordination expansion planning(GTSEP) of generation and transmission system may be considered.

The GTSEP addresses the problem of broadening and strengthening an existing generation system and transmission network to optimally serve a growing electricity market while satisfying a set of economic and technical constraints [1],[2].

Normally, the GSEP and TSEP problems can be also classified in two models which are heuristic and mathematical optimization models[3]. The firstly, the heuristic models describe all the plan scenarios such as techniques, economic (investment, operation cost), reliability, quality and etc. to search the best optimal solution. Various techniques including genetic algorithms(GAs), risk analysis(RA), game theory, simulated annealing(SA), expert system, fuzzy set theory, GRASP(Greedy Randomized Adaptive Search Procedure), tabu search, and etc. have been used to study this problem [3]-[13]. The secondly, the mathematical optimization models find an optimum solution by computing through a set of mathematical formulations which its variation parameters also describe a set of techniques, economic (investment, operation cost, reliability cost…), reliability, quality and etc. Several methods have been used a linear programming (LP), dynamic programming (DP), nonlinear programming, mixed integer programming and etc.

This paper proposes an alternative method for choosing the best coordinated the GTSEP. The objective function is to minimize total cost for constructing new generators and transmission lines which are a investment cost and the annual outage cost, subject to probabilistic composite power system reliability criterion (${}_{R}LOLE_{GTS}$) which considers the uncertainties of generators and transmission system elements. The annual outage cost of power system can be obtained by a yearly power system based outage energy *EENS* [MWh/year] times *IEAR* [\$/kWh]. The conventional branch and bound and network flow methods are used to search for the optimum mix of generation system and transmission network expansion [15]-[18]. Therefore, the proposed method includes the ability to include generation additions in the determination of the optimum mix of generation and transmission facilities required to meet the composite power system probabilistic reliability criterion. It models the GTSEP problem as an integer programming problem. It solves for the optimum mix of generation system and transmission network expansion using a probabilistic branch and bound method that utilizes a network flow approach and the maximum flow-minimum cut set theorem [19],[20]. In this paper, the generation system coordinated transmission system expansion planning problem is called conveniently as composite power system expansion planning problem.

## II. The Composite Power System Expansion Planning Problem

A composite power system that includes generation and transmission facilities is shown in Fig.1. *TS* refers to the transmission system, *NG* is the number of generators, ${}_{k}\Phi_{0}$ is the inverted load duration curve at load point *k*, and *NL* is the number of load points. In this paper, a composite power system is designated as HLII (Hierarchical level II) and HLI (Hierarchical level I) is used to designate generation and load components only [21]. It is assumed that the generation system and transmission system plans are separated and the construction of new generators is determined independently by GENCOs. Table I shows two kinds of optimal model for generation and transmission systems expansion planning problem. Where, *IEAR*(*VOLL*) is an interrupted energy assessment rate [\$/kWh].

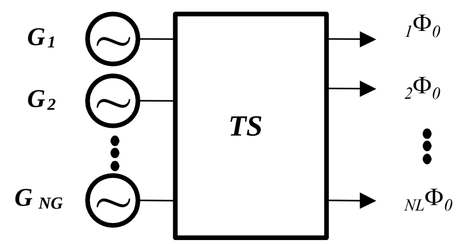



Fig. 1. A composite power system including the transmission system.

TABLE I
TWO KINDS OF OPTIMAL MODEL FOR COMPOSITE POWER SYSTEM EXPANSION PLANNING PROBLEM

| | Model I | Model II |
|---|---|---|
| Objective function | Minimize z = Investment cost + Operating cost | Minimize z = Investment cost+ Outage cost |
| Main constraints | Reliability criterion (*LOLE*) or N-1 contingency critrion | - |
| Method for assessing outage cost | - | $IEAR_{sys} \times EENS_{sys}$ |

### A. The Objective Function

The conventional composite power system expansion planning problem is to minimize the total cost ($C^T$) which is construction cost associated with investing in new generators and transmission lines and annual outage cost (*OTC*) which is yearly system *EENS* [MWh/year] times *IEAR* [\$/kWh] as expressed in (1) [22]-[27].

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

where,

$\rho$: 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 $y$

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

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

$OTC^{i}_{(x,y)}$ : annual outage cost of the construction of the new generators and lines *1st* through *i-th* that connect buses $x$ 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).

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

$$U^{i}_{(x,y)} = \begin{bmatrix} 1 & P_{(x,y)} = P^{0}_{(x,y)} + P^{i}_{(x,y)} \\ 0 & P_{(x,y)} \neq P^{0}_{(x,y)} + P^{i}_{(x,y)} \end{bmatrix} \tag{2}$$

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

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 $y$.

### *B. Constraints*

The basic reliability criteria normally considered in a composite power 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, *Lp*. This is also referred to as the bottleneck capacity. Therefore, a no shortage power supply constraint can be expressed by (3)

$$P_c(S,T) \geq L_p \quad (s \in S,\ t \in T) \tag{3}$$

Where, $P_c(S,T)$ is the capacity of the minimum cut-set of two subsets, $S$ and $T$, containing source nodes $s$ and terminal nodes $t$ respectively when all nodes are separated by a minimum cut-set.

The demand constraint (3) can be expressed by (4) with $k$ being the cut-set number ($k$ = 1,…,$n$), where, $n$ is number of cut-set.

$$\sum_{(x,y)\in(S_k,T_k)} \left[ P_{(x,y)} = P^{0}_{(x,y)} + \sum_{i=1}^{m(x,y)} P^{i}_{(x,y)} U^{i}_{(x,y)} \right] \geq L_p \tag{4}$$

In the probabilistic approach, the probabilistic reliability criterion index, *LOLE* (Loss of Load Expectation), can be used as in (5).

$$LOLE_{TS}(P^{i}_{(x,y)}, \Phi) \leq {}_{R}LOLE_{GTS} \tag{5}$$

Where, ${}_{R}LOLE_{GTS}$ is the required composite power system reliability criterion for the new system. $\Phi$ is a function of the load duration curve. A detailed discussion of $\Phi$ and *LOLE* is presented in Section III.

## III. Outage Cost Assessment of Composite Power System

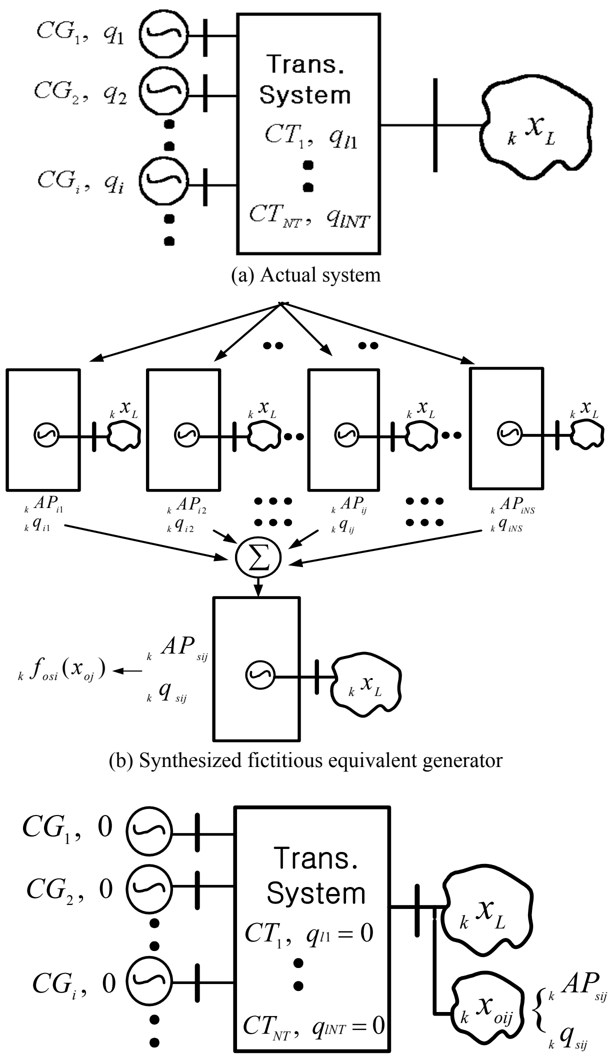
### *A. Reliability Evaluation at hierarchical level II (HLII)*

The reliability indices at HLII can be classified as load point indices and bulk system indices depending on the object of the evaluation. The reliability indices can be evaluated using a Composite power system Equivalent Load Duration Curve (CMELDC) of HLII based on the composite power system effective load model in Fig.2 [26]-[28]. Formulating the SFEG mathematically is the core of the proposed model, and the definitions of the components of the model follow.

#### *1) Reliability indices at the load points(buses)*

Fig.2 presents the main components of the nodal equivalent system and the nodal effective load for HLII developed recently in [24]. Fig. 2(a) is the original power system. Let's consider operation of generators from #$1^{st}$ to # $i^{th}$. It is possible to calculate the maximum arrival power(${}_{k}AP_{ij}$) at the load point and the state probabilities(${}_{k}q_{ij}$) for system state j using optimal power flow analysis with maximum arrival power being the objective function. Then, the same maximum arrival power for different states may be obtained. The probabilities of the states with the same maximum arrival power (${}_{k}AP_{ij}$) can be cumulated. The cumulated state probability and the same maximum arrival power were designated as ${}_{k}q_{sij}$ and ${}_{k}AP_{sij}$ respectively in here. The *pdf* composed from the ${}_{k}q_{sij}$ and ${}_{k}AP_{sij}$ is equivalent to it of a supply source unit with the outage state probability, ${}_{k}q_{sij}$ and operating power, ${}_{k}AP_{sij}$ with multi-operating states at load point #$k$. This is designated as SFEG and the capacity of the SFEG is the largest value of maximum arrival powers (${}_{k}AP_{sij}$). Fig. 2(b) shows the SFEG at load point #$k$ and ${}_{k}f_{osNG}$ is the outage capacity *pdf*. This generator is referred to here as SFEG or nodal SFEG. The *pdf* of the SFEG can be extended to multi-states (partial failures) although the *pdf* in this example uses two states (on or off). Therefore, the nodal effective load for the HLII criterion is defined by the summation of the original load and the probabilistic load caused by the forced outage of generators and transmission lines. This can be formulated as in Equation (6)[24]. Fig. 2(c) shows the nodal effective load model for HLII criterion. Finally, when the effective load is composed as load duration curve, it is called a Composite power system Equivalent Load Duration Curve (CMELDC) of HLII.

$$ {}_k x_e = {}_k x_L + \sum_{j=1}^{NS} {}_k x_{oj} \tag{6} $$




(a) Actual system

(b) Synthesized fictitious equivalent generator

(c) Equivalent system

Fig. 2. Composite power system effective load model at HLII

Therefore, The load point reliability indices, $LOLE_k$ and $EENS_k$ can be calculated using (7) and (8) with the CMELDC, ${}_k\Phi_{NG}(x)$

$$ LOLE_k = {}_k\Phi_{NG}(x)\,\Big|_{x=AP_k} \qquad \text{[hours/year]} \tag{7} $$

$$ EENS_k = \int_{AP_k}^{AP_k+Lp_k} {}_k\Phi_{NG}(x)dx \qquad \text{[MWh/year]} \tag{8} $$

where, $L_{pk}$: peak load at load point $k$[MW]
$AP_k$: maximum arrival power at load point $k$[MW]

$$ {}_k\Phi_i(x_e) = {}_k\Phi_o(x_e) \otimes_k f_{osi}(x_{oi}) = \int {}_k\Phi_o(x_e - x_{oi})_k f_{osi}(x_{oi})dx_{oi} $$

with,

$\otimes$: the operator representing the convolution integral
${}_k\Phi_0$ = original load duration curve at load point #$k$
${}_k f_{osi}$: outage capacity *pdf* of the synthesized fictitious generator created by generators *1* to *i*, at load point #*k*.

### 2) Reliability indices of the bulk system

While the $EENS_{HLII}$ of a bulk system is equal to the summation of the $EENS_k$ at the load points as shown in (9), the *LOLE* of a bulk system is entirely different from the summation of the $LOLE_k$ at the load points. The $ELC_{HLII}$ (Expected load curtailed) of bulk system is equal to the summation of $ELC_k$ at the load points. The $LOLE_{HLII}$ of the bulk system can be calculated using (12)[32].

$$ EENS_{HLII} = \sum_{k=1}^{NL} EENS_k \qquad \text{[MWh/year]} \tag{9} $$

$$ ELC_{HLII} = \sum_{k=1}^{NL} ELC_k \qquad \text{[MW/cur.year]} \tag{10} $$

$$ LOLE_{HLII} = EENS_{HLII} / ELC_{HLII} \qquad \text{[hours/year]} \tag{11} $$

$$ EIR_k = 1 - EENS_k / DENG_k \quad \text{[pu]} \tag{12} $$

where,
$NL$ : number of load points
$ELC_k = EENS_k / LOLE_k$
$DENG_k$ : demand enegy at bus #$_k$

## B. Outage Cost Assessment

The annual outage cost assessment can be formulated by taking annual $EENS^i_{(x,y)}$ (Expected energy not served) of the construction element of the new generators and lines *1st* through *i-th* that connect buses *x* and *y* multiplied with power system *IEAR* (Interrupted Energy Assessment Rate), that is some time called *VOLL* (Value of Loss Load) as in (13)

$$ OTC^i_{(x,y)} = IEAR \times \sum_{k=1}^{NL} EENS^i_{k(x,y)} \quad \text{[M\$]} \tag{13} $$

where,
*IEAR*: interrupted energy assessment rate of power system [$/kWh]

## IV. Solution Algorithm

The solution algorithm for the proposed approach follows.

1. Check the need for transmission expansion for the system and its possibility using the candidate lines. Need and possibility can be checked respectively by the reliability evaluation for systems considering no candidate lines and considering all candidate lines.
2. Set $j$=1 (initial system), $jopt$ =0, $jmax$ =0, $C^T_{opt}=\infty$ and $ENNOD_j$=0.
3. If $ENNOD_j$=1, the #$j$ system is an end node at which the branch operation of a branch and bound is finished (bound) in the solution graph used to obtain the optimal solution, and there is no need to consider any of the other graphs following this system. Go to 13.
4. Calculate the minimum cut-set using the maximum flow method for system $j$ (solution $j$ in the solution graph.)
5. Select a #$i$ branch/line of the candidate branches/ lines set ($S_j$) involved in the minimum cut-set and add to the #$j$ system. In what follows, the new system is named the system $ji$.
6. If the system $ji$ is already considered in the solution graph. Go to step 13.
7. Probabilistic reliability evaluation indices of system $ji$, ($LOLE_{ji}$, $EENS_{ji}$), and calculate an outage cost of the system $ji$, ($OTC_{ji}=IEARxEENS_{ji}$)
8. Calculate the total cost $C^T_{ji} = C^T_j + C(P^{(i)}_{(x,y)}) + OTC(P^{(i)}_{(x,y)})$ for the system $ji$ and evaluate the composite power system reliability index, $LOLE_{GTSji}$ of the system.
9. If $C^T_{ji} < C^T_{jopt}$, the current system ($ji$) with a cost of $C^T_{ji}$ can be optimal. If not, go to 11.
10. Set $jmax = jmax$ +1.
11. If $LOLE_{GTSji}$ <$_RLOLE_{GTS}$, set $C^T_{opt}=C^T_{ji}$, and $_RLOLE_{opt}$= $LOLE_{ji}$, $jopt = jmax$, and go to 12.
12. Set $C^T_{jmax}=C^T_{ji}$ , $ENNOD_{jmax}$ =1, and go to 13.
13. Add the solution $jmax(ji)$ to the solution graph.
14. If all the candidate branches/lines in the cut-set $S_j$ have been considered, go to 14. Otherwise, set $i=i$+1 and go to 5.
15. If $j = jmax$, continue the next step. Otherwise, set $j = j$ +1 and go to 4.
16. For $j = jmax$, the solution graph has been constructed fully and the optimal solution $jopt$ with $C^T_{jopt}$ being the lowest cost and satisfies the required reliability criteria is obtained in 10.

## V. Sample System Study

The proposed method is tested to 2-buses sample system. Fig.3 shows the existed system and future load in the sample system. Total generation install capacity is 50MW and the forecasted load is expected as 70MW in future. Specially, rapid increase of load at bus #1 is forecasted. Table II shows the system capacity and construction cost data. The $IEAR$sys is assumed as 10[US$/kWh] in this sample study.

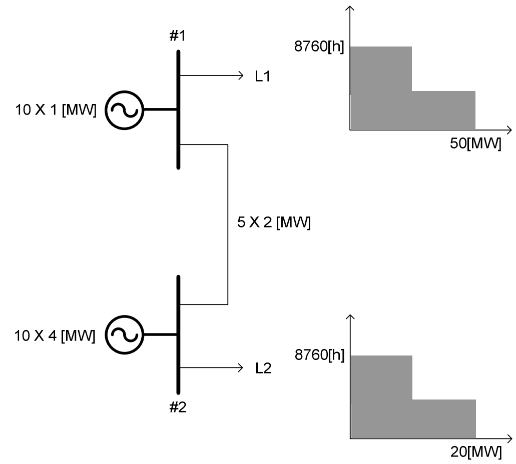



Fig. 3. Existed power system and future load in 2-buses sample system

TABLE II
SYSTEM CAPACITY AND COST DATA
(P(*): (MW) AND C(*): (M$))

| | SB | EB | ID | $\Delta P^0_{xy}$ | $\Delta P^1_{xy}$ | $\Delta P^2_{xy}$ | $\Delta P^3_{xy}$ | $\Delta P^4_{xy}$ | $\Delta C^0_{xy}$ | $\Delta C^1_{xy}$ | $\Delta C^2_{xy}$ | $\Delta C^3_{xy}$ | $\Delta C^4_{xy}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 1 | GN | 10 | 10 | 10 | 10 | 10 | 0 | 10 | 10 | 10 | 10 |
| 2 | 0 | 2 | GN | 50 | 10 | 10 | 10 | 10 | 0 | 8 | 8 | 8 | 8 |
| 3 | 1 | 2 | TL | 10 | 5 | 5 | 5 | 5 | 0 | 4 | 4 | 4 | 4 |
| 4 | 1 | 3 | LD | 50 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 2 | 3 | LD | 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

### A. Coordinated planning

Fig. 4 and Fig. 5 show the best coordinated optimal plans(systems) for $_RLOLE_{GTS}$=50~9 and $_RLOLE_{GTS}$=8~4 respectively.

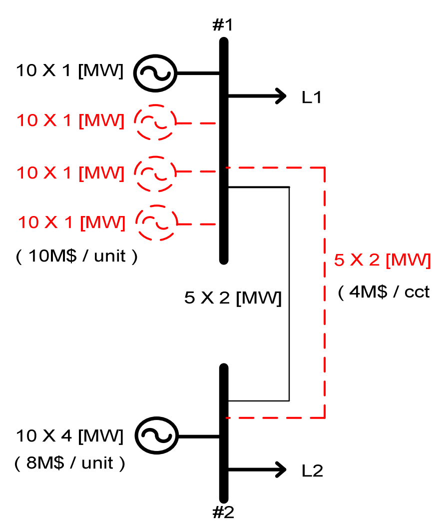



Fig. 4. The best coordinated optimal solution for $_RLOLE_{GTS}$=50~9

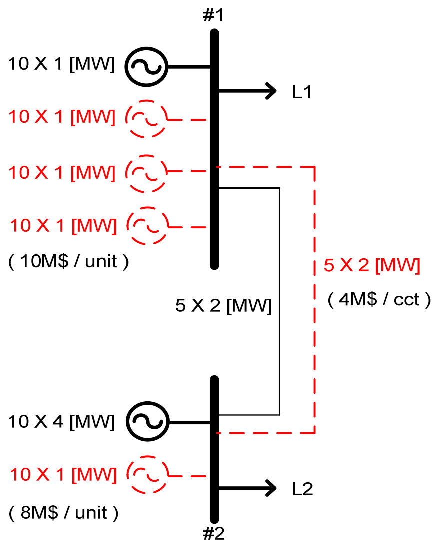



Fig. 5. The best coordinated optimal solution for ${}_{R}LOLE_{GTS}$=8~4

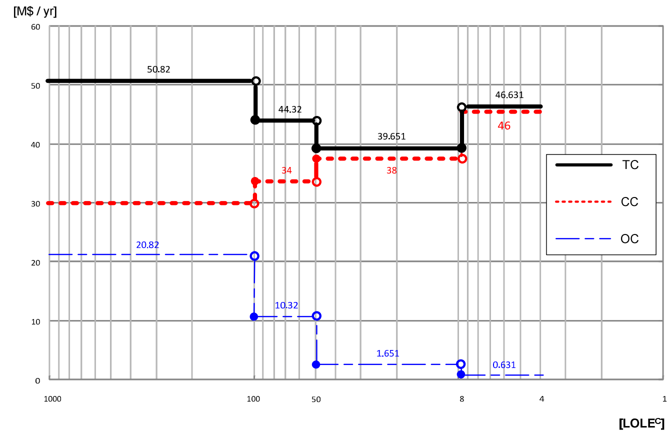



Fig. 6. Cost curves according to changing of ${}_{R}LOLE_{GTS}$

Table III shows costs according to changing of reliability criteria Where, GSC, TSC, OTC and TTC designate construction cost of new generators, construction cost of new transmission systems, outage cost and total cost respectively. Fig. 6 is the cost curves according to changing of ${}_{R}LOLE_{GTS}$. Table IX shows the reliability indices according to changing of reliability criteria in case of the generation system coordinated transmission expansion planning. Table X shows various optimal solution of composite power system expansion planning due to increase of ${}_{R}LOLE_{GTS}$. From the Table III and Fig. 6, optimal reliability criteria, ${}_{R}LOLE^{*}_{GTS}$ can be decided as range of 50 to 9[hours/year] for the power system under assumption of the *IEAR*sys =10[$/kWh].

TABLE III
COSTS ACCORDING TO CHANGING OF RELIABILITY CRITERIA

| ${}_{R}$LOLE$_{GTS}$ | CC | | | OTC [M$/Yr] | TTC [M$/Yr] |
|---|---|---|---|---|---|
| | GC [M$/Yr] | TC [M$/Yr] | TCC [M$/Yr] | | |
| **1000~103** | **30** | **0** | **30** | **20.82** | **50.82** |
| **102~51** | **30** | **4** | **34** | **10.32** | **44.32** |
| **50~9** | **30** | **8** | **38** | **1.651** | **39.651** |
| **8~4** | **38** | **8** | **46** | **0.631** | **46.631** |

TABLE IX
RELIABILITY INDICES ACCORDING TO CHANGING OF RELIABILITY CRITERIA

| ${}_{R}$LOLE$_{GTS}$ | EENS [MWh/Yr] | | LOLE [Hrs/Yr] |
|---|---|---|---|
| | EENS$_{Bus1}$ | EENS$_{Bus2}$ | |
| 1000~103 | 2081.97 | | 102.793 |
| | 1504.36 | 577.603 | |
| 102~51 | 1032.04 | | 51.04 |
| | 744.711 | 287.331 | |
| 50~9 | 165.115 | | 8.183 |
| | 118.929 | 46.186 | |
| 8~4 | 63.089 | | 3.135 |
| | **45.33** | **17.759** | |

TABLE X
VARIOUS OPTIMAL SOLUTION OF COMPOSITE POWER SYSTEM EXPANSION PLANNING DUE TO INCREASE OF ${}_{R}LOLE_{GTS}$, (*IEAR*sys=10 [US$/kWh])

| ${}_{R}LOLE_{GTS}$ | GS Optimal solution | TS Optimal solution |
|---|---|---|
| 1000 | $G_1^1,G_1^2,G_1^3$ | - |
| 100 | $G_1^1,G_1^2,G_1^3$ | $T_{1-2}^1$ |
| 50 | $G_1^1,G_1^2,G_1^3$ | $T_{1-2}^1$, $T_{1-2}^2$ |
| 8 | $G_1^1,G_1^2,G_1^3,G_2^1$ | $T_{1-2}^1$, $T_{1-2}^2$ |
| 4 | $G_1^1,G_1^2,G_1^3$, $G_2^1$ | $T_{1-2}^1$, $T_{1-2}^2$ |

### *B. Comparison with not coordinated planning*

Fig. 7 shows the not coordinated optimal solution for ${}_{R}LOLE_{GTS}$=50 under assumption that new generators will be constructed separately from transmission system. It has already been decided that two generators of new three generators at bus #1 in Fig. 4(coordinated planning) are constructed at bus #2 in stead of bus #1.

A GENCOs may be prefers bus #2 to bus #1 because the construction cost(8M$) bus #2 is cheaper than the cost(10M$) of bus #1. In case of not coordinated planning, however, a lot of transmission lines should be constructed in order to requirement reliability criterion, $_RLOLE_{GTS}=50$. Table XI shows the costs of not coordinated planning according to changing of reliability criteria. The total cost is more expensive as shown in Table XI. Specially, the line construction cost will be increased rapidly if the right of way of new line is stricter. Table XII shows reliability indices according to changing of reliability criteria in case of the generation system fixed, as it is, not coordinated transmission expansion planning.

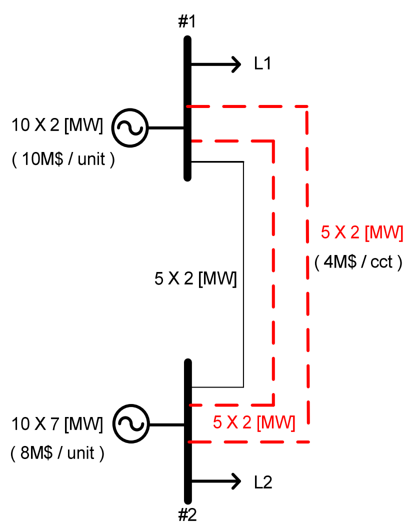



Fig. 7. Not coordinated (generation system fixed) solution for $_RLOLE_{GTS}=50$

TABLE XI
COSTS ACCORDING TO CHANGING OF RELIABILITY CRITERIA (NOT COORDINATED PLANNING)

| $_R$LOLE$_{GTS}$ | GC [M$/Yr] | TC [M$/Yr] | OTC [M$/Yr] | TTC [M$/Yr] |
|---|---|---|---|---|
| 1000~707 | 34 | 12 | 141.399 | 187.399 |
| 706~21 | 34 | 16 | 4.138 | 54.138 |
| 20~4 | 34 | 20 | 0.072 | 54.072 |

TABLE XII
RELIABILITY INDICES ACCORDING TO CHANGING OF RELIABILITY CRITERIA IN CASE OF NOT COORDINATED PLANNING

| $_R$LOLE$_{GTS}$ | EENS [MWh/Yr] | | LOLE [Hrs/Yr] |
|---|---|---|---|
| | EENS$_{Bus1}$ | EENS$_{Bus2}$ | |
| 1000~707 | 14139.9 | | 706.907 |
| | 10101.1 | 4038.79 | |
| 706~21 | 413.770 | | 20.6876 |
| | 295.562 | 118.208 | |
| 20~4 | 7.179 | | 0.3590 |
| | **5.128** | **2.051** | |

## VI. CONCLUSIONS

This paper addresses GTSEP problem considering annual outage cost assessment (*OTC*) associated with construction cost (*C*), subject to the probabilistic composite power system reliability criterion ($_RLOLE_{GTS}$). The best coordinated optimal placements and the capacity of new generators, transformers as well as transmission lines can be determined using the proposed method. It presents a new alternative and practical approach that should serve as a useful guide for the decision maker to select a reasonable expansion plan. The proposed method finds the optimal GTSEP considering uncertainties associated with the forced outage rates of generators, transformers and transmission lines. It models the problem as a probabilistic integer programming one and considers problem uncertainties through probabilistic modeling. A proposed probabilistic 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 2-buses sample system analysis used to illustrate the method show that quite different expansion plans may be obtained from applying various *IEAR*. It is expected that the proposed methodology can be used to serve the generation system coordinated transmission system expansion planning(GTSEP) that includes the reliability index (*EENS*) in view point of economics.

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