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송전계통확충계획을 위한 확률론적 최적신뢰도 기준설정에 관한 연구

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A Study on Probabilistic Optimal Reliability Criterion Determination in Transmission System Expansion Planning

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Abstract - This paper approaches a methodology for deciding the optimal reliability criteria for an optimal composite power system expansion planning considering generation and transmission systems simultaneously. A probabilisticreliability criterion, *LOLE*$_R$*(Loss of Load Expectation)*, is used in this study. The optimalreliability criterion *LOLE*$_R$* is decided at minimum cost point of total cost curve which is the sum of the utility cost associated with construction cost and the customer outage cost associated with supply interruptions for load considering forced outage rates of elements(generators and lines) in long term forecasting. The characteristicsand effectiveness of this methodology are illustrated by the case study using MRBTS size system.

1. Introduction

This study proposes a new methodology for deciding the optimal reliability criteria in a composite power system expansion planning (CPSEP). A probabilistic reliability index, *LOLE* is used in this study. The optimal reliability criterion, *LOLE*$_R$*, for a CPSEP is determined at the minimum cost point of the total cost curve, which is the sum of the utility cost associated with the construction cost and the customer outage cost associated with supply interruptions. Therefore, the approach is an extension of the conventional concept of optimal reliability criterion for generation system expansion planning (GSEP). A maximum flow-minimum cut set theorem is used in this study to obtain the optimal solution at the objective minimization construction cost and subjective satisfaction of probabilisticreliability constraints and capacity limitation and right of way constraints. The two curves, utility cost (reliability cost) and customer outage cost (reliability worth) are required in this methodology [6]-[8].

The first step is to create the utility cost (reliability cost) curve by using *CmExpP.For*[9]-[13]. The second step is to create the customer outage cost (reliability worth) curve associated with probabilistic reliability level of the composite power system. This third step is composed of two sub-steps. One sub-step is the reliability evaluation of the composite power system and the other sub-step is an assessment of the Interrupted Energy Assessment Rate (*IEAR*) or Value of Loss of Load (*VOLL*) by outage cost assessment [7],[8]. The characteristics and effectiveness of this methodology are illustrated by a case study of a test system (MRBTS).

2. Optimal Reliability Criterion Determination

Fig. 1 shows that utility cost will generally increase as customers are provided with higher reliability. On the other hand, customer outage costs associated with supply interruptions will decrease as the reliability increases. The total cost to society is the sum of these two individual costs. This total cost exhibits a minimum point at which an "optimal" or target level of reliability is achieved [6]-[8].

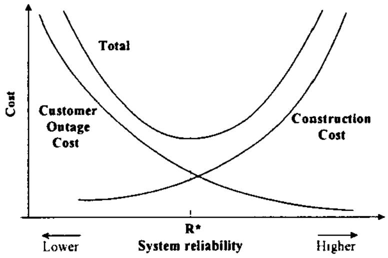


Fig. 1 utility and total cost as a function of system reliability

3. Optimal composite Power System Expansion Planning

The Objective function

The conventional CPSEP problem is to minimize the total construction cost *CT* associated with investing in new generators and transmission lines as expressed in (1)[6],[9]-[13].

$$\text{minimize} C^T = \sum_{(x,y)\in\rho}\left[\sum_{i=1}^{m(x,y)} C_{(x,y)}^{(i)} U_{(x,y)}^{(i)}\right] \tag{1}$$

Constraints

The deterministic constraint, which is 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* as expressed by (2).

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

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

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

The probabilistic reliability criterion called *LOLE* (Loss of

Load Expectation) can be used as in (4). Where, *LOLER* is the required reliability criterion for the new system and is a function of the load duration curve discussed as shown in (4).

$$LOLE(P^{(i)}_{(x,y)},\Phi) \le LOLE_R \tag{4}$$

4. Composite power System Reliability Evaluation

Reliability Evaluation of HLI

Reliability indices of $LOLE_{HLI}$ and $EENS_{HLI}$ (Expected energy not supplied) of only the generation system using the *ELDC* (Effective load duration curve) ${}_{HLI}\Phi(x)$ of HLI are calculated by (5) and (6) respectively.

$$LOLE_{HLI} = {}_{HLI}\Phi\ (x)\ \Big|_{x=IC} \quad \text{[days]} \tag{5}$$

$$EENS_{HLI} = \int_{IC}^{IC+Lp} {}_{HLI}\Phi(x)dx \quad \text{[MWh]} \tag{6}$$

Where, IC : total installed capacity of generators[MW]

$$\begin{aligned} {}_{HLI}\Phi_i(x_e) &= {}_{HLI}\Phi_{i-1}(x_e) \otimes {}_{HLI} f_{oi}(x_{oi}) \\ &= \int {}_{HLI}\Phi_{i-1}(x_e - x_{oi})\, {}_{HLI} f_{oi}(x_{oi})dx \end{aligned} \tag{7}$$

Reliability Evaluation of HL II

The indices of HLII can be classified in terms of load point indices and bulk system indices according to the objective of the evaluation[14],[15]. The reliability indices can be evaluated from the CoMposite power system Equivalent Load Duration Curve (*CMELDC*) at HLII using the Synthesized Fictitious Equivalent Generator (*SFEG*) model shown in Fig.3. [16]-[20]. In this figure, ${}_kAP_{ij}$ *and* ${}_kq_{ij}$ are the arrival power and state probability of contingency state =*j* at load point =*k* respectively.

Reliability indices at load points

The load point reliability indices, $LOLE_k$ and $EENS_k$ can be calculated using (8) and (9) with the nodal CMELDC, ${}_k\Phi_{NG}(x)$ of (10).

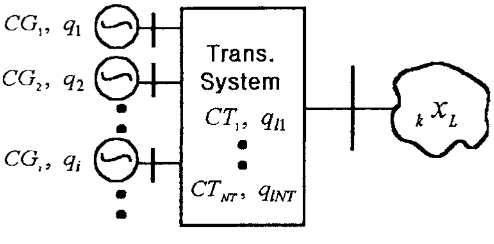
$$LOLE_k = {}_k\Phi_{NG}(x)\ \Big|_{x=AP_k} \quad \text{[day]} \tag{8}$$

$$EENS_k = \int_{AP_k}^{AP_k+Lp_k} {}_k\Phi_{NG}(x)dx \quad \text{[MWh]} \tag{9}$$

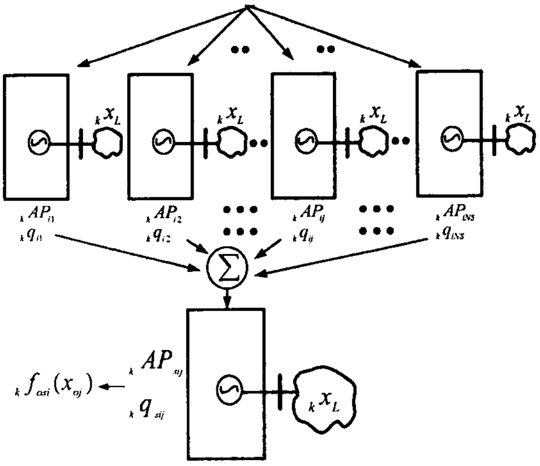
where, AP_k : maximum arrival power at load point/bus =*k*

L_{pk} : the peak load at load point/bus =*k*

$$\begin{aligned} {}_k\Phi_i(x_e) &= {}_k\Phi_o(x_e) \otimes_k f_{osi}(x_{oi}) \\ &= \int {}_k\Phi_o(x_e - x_{oi})_k f_{osi}(x_{oi})dx_{oi} \end{aligned} \tag{10}$$



(a) Actual system



(b) Synthesized fictitious equivalent generator

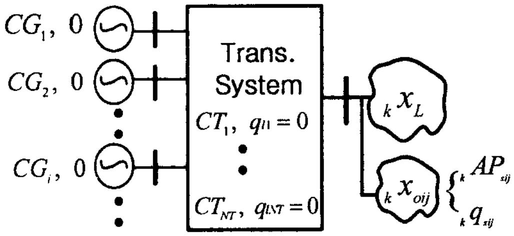


Fig. 2 Composite power system effective load model at HLII

Reliability indices of the bulk system

The $EENS_{HLII}$ of the bulk system is equal to the summation of *EENSk* at the load points as shown in (11). The *LOLE* of the bulk system is different from the summation of $LOLE_k$ at the load points. The *ELCHLII* of the bulk system is equal to the summation of the ELC_k at the load points, and the $LOLE_{HLII}$ of the bulk system can be calculated as shown in (13).

$$EENS_{HLII} = \sum_{k=1}^{NL} EENS_k \qquad \text{[MWh]} \tag{11}$$

$$ELC_{HLII} = \sum_{k=1}^{NL} ELC_k \tag{12}$$

$$LOLE_{HLII} = EENS_{HLII} / ELC_{HLII} \qquad \text{[pu]} \tag{13}$$

Where, *NL*: number of load point

R: set of states of not supplied powers

$ELC_k = EENS_k / LOLE_k$ [MW/cur.yr]

5. Case Studies

The proposed method was tested on the 5-bus model system shown in Fig.3. The deterministic and the probabilistic approaches were applied and compared in a series of case studies.

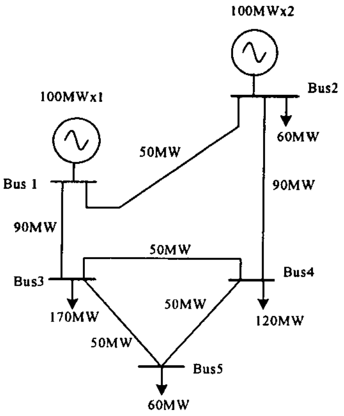


Fig. 3 5-bus MRBTS

A required probabilistic reliability criterion, $LOLE_R$=100[hrs/yr] is assumed. The optimal solution is 330[M$] for construction cost and addition new elements G_1^1, G_2^1, $T_{1\text{-}3}^1$, $T_{1\text{-}3}^2$, and $T_{2\text{-}4}^1$. The *LOLE* of the optimal system is 71.1[hrs/yr]. Table 1 shows the construction cost, customer outage and total costs obtained assuming *IEAR*=10[$/kWh]. The budget for generators and transmission lines construction is 330[M$].The red line shows the monotonic increasing characteristics of the construction cost due to changing the reliability criterion, $LOLE_R$. The monotonic decreasing characteristics of the customer outage cost are shown at dark-blue line. The total cost as the sum of the construction cost and customer outage cost as shown at the blue line. The $LOLE_R$* for CPSEP is given by the minimum point on this curve as shown in Fig. 4.

Table 1. Construction cost, reliability and outage cost at each case study

Cases	*LOLER*	Const. Cost [M$]	Outage Cost [M$]	Total Cost [M$]	Remark
1	1000	205	460.543	665.543	
2	800	240	389.992	629.992	
3	500	285	81.694	366.694	
4	200	285	81.694	366.694	
5	150	285	81.694	366.694	
6	100	330	33.03	363.03	**Optimal**
7	50	375	22.59	397.59	
8	30	430	13.79	443.79	

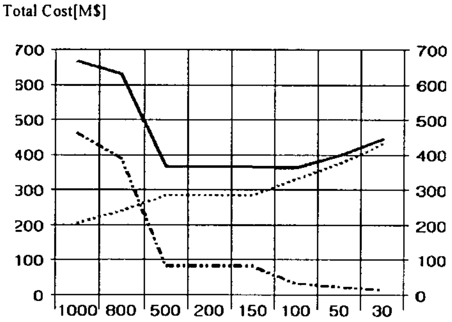


Fig.4 Curves of construction, customer outage, total costs and optimal reliability level

6. Conclusions

This study introduces a new methodology for selecting an optimal reliability criterion in composite power system expansion planning. A probabilistic reliability index, *LOLE* is used in this study. The optimal reliability criterion, $LOLE_R$*, for a composite generation and transmission system is located at the minimum cost point of the total cost curve, which is the sum of the utility cost associated with construction and the customer outage costs associated with supply interruptions. A case study using a test system (MRBTS)shows that an optimal probabilistic reliability criterion of composite power system can be determined successfully using probabilistic reliability constraints based optimal expansion planning program, *CmExp.For*. The monotonic decreasing characteristics of the customers outage cost can be obtained using probabilistic reliability criterion because outage cost come from probabilistic reliability index, *EENS*.

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8. References

1. M. Ilic, et al, Power Systems Restructuring; Engineering and Economics: Kluwer Academic Pub., 1998.
2. X. Wang. and J.R. McDonald, Modern Power System Planning: McGraw-Hill, 1994.
3. Jaeseok Choi, Trungtinh Tran, Sungrok Kang, Donghoon Jeon, Chulhoo Lee and Roy Billinton; "A Study on Optimal Reliability Criterion Determination for Transmission System Expansion Planning", IEEE, PES, GM2004, June 6-10, 2004, Denver, USA.
4. Roy Billinton and Ronald N. Allan, Reliability Evaluation of Power Systems: Second Edition, Plenum Press, 1996.
5. Jaeseok Choi, A.A. El-Keib, andTrungtinh Tran, A Fuzzy Branch and Bound-Based Transmission System Expansion Planning For the Highest Satisfaction Level of the Decision Maker, IEEE Trans. on PS, Vol.20, No.1, Feb. 2005.
6. Jaeseok Choi, Daeho Do, Seungpil Moon and Roy Billinton, "Development of a Method for ELDC Construction in a Composite Power System," LESCOPE '99 proceedings, Halifax, June 1999.
7. Jaeseok Choi, Hongsik Kim, Junmin Cha and Roy Billinton; "Nodal Probabilistic Congestion and Reliability Evaluation of a Transmission System under Deregulated Electricity Market", IEEE, PES, SM2001, July 16-19, 2001, Vancouver, Canada.
8. J. Choi, R. Billinton and M. Futuhi-Firuzabed, Development of a New Nodal Effective Load Model Considering of Transmission System Element Unavailabilities, at standby to be published by IEE proceedings on T&D , 2005.