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

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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].

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].

$$\text{minimize} CT = \sum_{(r,s) \in \mathcal{P}} \left[ \sum_{(x,y) \in \mathcal{C}_r} m_{(x,y)} C_{(x,y)} \right]$$

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, $L_p$. This is expressed by (2).

$$P_r(X, \bar{X}) \geq L_p \quad (x \in \mathcal{X}, t \in \bar{X})$$

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

$$\sum_{(r,s) \in \mathcal{S}_r, t \in \bar{X}_r} \left[ P_{(r,s)} = P_{(x,y)} + \sum_{(x,y) \in \mathcal{C}_y} P_{(x,y)} \right] \geq L_p$$

The probabilistic reliability criterion called $LOLE$ (Loss of
Load Expectancy) 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).

\[ \text{LOLE}_{R} \left( x(x,y), \Phi \right) \leq \text{LOLE}_{R} \]  \tag{4}

4. Composite power system Reliability Evaluation

Reliability Evaluation of HLI

Reliability indices of \( \text{LOLE}_{HLI} \) and \( \text{EENS}_{HLI} \) (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.

\[ \text{LOLE}_{HLI} = HLI \Phi(x) \bigg|_{x=r} [\text{days}] \] \tag{5}

\[ \text{EENS}_{HLI} = \int_{C}^{x+r} HLI \Phi(x) dx \quad [\text{MWh}] \] \tag{6}

Where, \( C \): total installed capacity of generators [MW]

\[ HLI \Phi(x) = \int_{C}^{x+r} HLI \Phi(x, x_{f}) dx \int_{H} f_{o}(x_{o}) dx \] \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, \( \lambda P_{a} \) and \( \mu q_{k} \) 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, \( \text{LOLE}_{k} \) and \( \text{EENS}_{k} \) can be calculated using (8) and (9) with the nodal CMELDC, \( k \Phi_{NG}(x) \) of (10).

\[ \text{LOLE}_{k} = k \Phi_{NG}(x) \bigg|_{x=A P_{k}} [\text{day}] \] \tag{8}

\[ \text{EENS}_{k} = \int_{A P_{k} + \lambda q_{k}}^{\lambda P_{k} + \mu q_{k}} k \Phi_{NG}(x) dx \quad [\text{MWh}] \] \tag{9}

where, \( A P_{k} \) : maximum arrival power at load point/bus \( k \)

\[ k \Phi_{NG}(x) = \int_{k}^{x} \Phi_{o}(x_{o}) f_{o}(x_{o}) dx_{o} \] \tag{10}

\[ k \Phi_{o}(x) = k \Phi_{o}(x_{o}) f_{o}(x_{o}) \]

Fig. 2 Composite power system effective load model at HLII

Reliability indices of the bulk system

The \( \text{EENS}_{HLH} \) of the bulk system is equal to the summation of \( \text{EENS}_{k} \) at the load points as shown in (11). The \( \text{LOLE} \) of the bulk system is different from the summation of \( \text{LOLE}_{k} \) at the load points. The \( \text{ELC}_{HLH} \) of the bulk system is equal to the summation of the \( \text{ELC}_{k} \) at the load points, and the \( \text{LOLE}_{HLH} \) of the bulk system can be calculated as shown in (13).

\[ \text{EENS}_{HLH} = \sum_{k=1}^{N_{L}} \text{EENS}_{k} \quad [\text{MWh}] \] \tag{11}

\[ \text{ELC}_{HLH} = \sum_{k=1}^{N_{L}} \text{ELC}_{k} \] \tag{12}

\[ \text{LOLE}_{HLH} = \text{EENS}_{HLH} / \text{ELC}_{HLH} \quad [\text{pu}] \] \tag{13}

Where, \( N_{L} \): number of load point

\( R \): set of states of not supplied powers

\( \text{ELC}_{k} = \text{EENS}_{k} / \text{LOLE}_{k} \) [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.
A required probabilistic reliability criterion, LOLEₙ=100[hrs/yr] is assumed. The optimal solution is 330[M\$] for construction cost and addition new elements G₁, G₂, T₁, T₃, T₄, and T₅. 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 decreasing characteristics of the construction cost due to changing the reliability criterion, LOLEₙ. 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 LOLEₙ* for CPSEP is given by the minimum point on this curve as shown in Fig. 4.

<table>
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<tr>
<th>Case</th>
<th>LOLE</th>
<th>Cost [M$]</th>
<th>Outage Cost [M$]</th>
<th>Total Cost [M$]</th>
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<td>430</td>
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</table>

Total Cost [M\$]

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, LOLEₙ*, 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.

7. Acknowledgement

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8. References