CO2 배출량제한을 고려한 최적전력구성

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The Best Generation Mix considering CO2 Air Pollution Constraint

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Abstract - A new approach considering CO2 air pollution constraints in the long-term generation mix is proposed under uncertain circumstances. A characteristic feature of the presented approach in this paper is what effects give the air pollution constraints in long term best generation mix. Best generation mix problem is formulated by linear programming with fuel and construction cost minimization with load growth, reliability (reserve margin rate) and air pollution constraints. The proposed method accommodates the operation of pumped-storage generator. It was assumed in this study that the construction planning of the hydro power plants is given separately from the other generation plans. The effectiveness of the proposed approach is demonstrated by applying to the best generation mix problem of KEPCO-system, which contains nuclear, coal, LNG, oil and pumped-storage hydro plant multi-years.

1. Introduction

There is a global trend towards liberalization and privatization of the electricity supply industry. This is coupled with growing environmental awareness and increasing prospects ratification of the Kyoto Protocol.[1] Electricity is the indispensable form of energy in modern societies. Its demand has been increasing more and more quantity, quality and reliable at minimize production cost. The restructuring of electricity market has been moving from monopolistic to competitive that split generation, transmission and distribution sector in power system into GENCO, TRANSCO and DISCO respectively.[2] In this paper, a new approach for the long-term generation mix with multi-criteria considering air pollution constraints, which are not only SO2 and NOX but also CO2 emission limitations, under the uncertain circumstances is proposed using linear programming [4-5]. The effectiveness of the proposed approach is demonstrated by applying to the best generation mix problem of KEPCO-system, which contains nuclear, coal, LNG, oil and pumped-storage hydro plant multi-years. This case study in this paper is mainly focused on CO2 emission limitation effect in the best generation mix. The method can accommodate the operation of the pumped-storage generator which has a relationship with operation of nuclear power plant with some strict for load following [6].

2. The LP Formulation of Best Generation Mix

2.1 Problem statement

The system for the proposed method can be modeled as shown in Fig. 1.

2.2 Objective function

Minimize

\[ Z = \sum_{m=1}^{NG} K_m d_m \Delta x_m + \sum_{n=1}^{N} K_n f_n y_n \]

\[ = F(\Delta x_m, y_n) \]  

where, \( i \): unit type number (1 for nuclear, 2 for coal, 3 for LNG, 4 for oil, and 5 for pumped-storage generators are specified in this paper)

\( N \): number of total study stage year

\( NG \): number of unit type

\( K_m = ((1+ e_t i)/(1+r))n \)

\( K_n = ((1+ e_t i)/(1+r))n \)

\( e_t \): apparent escalation rate of construction materials of i-unit

\( e_t \): apparent escalation rate of fuel of i-unit

\( r \): discount rate

\( T \): step size years of study years

\( d_m \): construction cost of the i-unit in n year

\( f_m \): marginal fuel cost of the i-unit in n year [$/MWh]

\( i \): annual expenses rate of the i-unit

\( x_m \): construction capacity of the i-unit in n year [MW]

\( y_n \): generation capacity of the i-unit in n year [MWh]

2.3 Constraints

1) Installed capacity constraint

\[ \sum_{i=1}^{NG} (x_m + \Delta x_m) \geq L_n^e (1 + R_n) - HYD_n \quad n = 1 \sim N \]  

where, \( R_n \): supply reserve rate in n year. [p.a]

\( HYD_n \): capacity of hydro generator in n year. It is assumed that the HYDn is given in this study.
2) Energy constraint of demand
\[
\sum_{i=1}^{NG} y_{in} \geq (L_{in}^P + L_{in}^S) \times 8760 / 2 + V_n
\]
\[- HYD_n \times 8760 \times CF_H \quad n = 1 \sim N \quad (3)
\]
where, \( L_{in}^P \): peak load at n year
\( L_{in}^b \): base load at n year
\( V_n \): the added demand energy is caused by pumped-storage generator
\( CF_H \): average capacity factor of hydro generator

3) Production energy constraint of generation system
\[
y_{in} \leq (x_{in} + \Delta x_{in}) \times 8760 \times CF_i \quad i = 1 \sim NG, \ n = 1 \sim N \quad (4)
\]
where, \( CF_i \): average capacity factor of the i-unit

4) Capacity constraint in initial year
\[
x_{in,\text{EX}} \leq i = 1 \sim NG \quad (5)
\]
where, \( EX_i \): capacity of the i-existing unit

5) Constraint of mutual relationship between existing generator capacity and new generator capacity (state equation)
\[
x_{in,\text{NEW}} = x_{in} + \Delta x_{in} \quad i = 1 \sim NG, \ n = 1 \sim N \quad (6)
\]

6) Energy constraint of LNG thermal plant
\[
y_{in} \geq \text{LEP}_{\text{min}} \quad i = 1 \sim N \quad (7)
\]
where, \( \text{LEP}_{\text{min}} \): LNG thermal generator production energy for LNG minimum due to consumption in n year

7) Constraints of reservoir capacity of pumped-storage generator
\[
y_{in} \leq (x_{in} + \Delta x_{in}) \times 8760 \times CF_i \quad i = 1 \sim N \quad (8)
\]
where, \( PSM \): pumped-storage maximum possible time per day of pumped-storage generator

8) Energy balance constraints between pumped-storage and pumped-generator
\[
y_{in} = \eta_{pg} \times V_n \quad (9)
\]
where, \( \eta_{pg} \): efficiency of pumped-storage generator

9) No load following power constraints of nuclear power plant
\[
(x_{in} + \Delta x_{in}) \leq L_{in}^P + (x_{in} + \Delta x_{in}) \eta_{pg} \quad (10)
\]

10) No load following energy constraints of nuclear power plant
\[
y_{in} = (x_{in} + \Delta x_{in}) \times 8760 \times CF_i \quad (11)
\]

11) Upper-lower constraints of new unit capacity
\[
\Delta X_{\text{min},\text{in}} \leq \Delta X_{\text{in}} \leq \Delta X_{\text{max},\text{in}} \quad (12)
\]
where, \( X_{\text{min},\text{in}} \) and \( X_{\text{max},\text{in}} \) are minimum and maximum capacity of new unit at n years(period) respectively.

12) CO2 air pollution constraint
\[
\sum_{i=1}^{NG} \text{CO}_2_{in} \times P_i \times y_{in} \leq \text{CO}_2_{\text{MAXin}} \quad (13)
\]
where,
\( \text{CO}_2_{in} \): CO2 density of the i-unit in n year [ppm/Ton]
\( \text{CO}_2_{\text{MAXin}} \): maximum quantity of CO2 permitted in n year

\[ \text{i: fuel consumption rate of the i-unit [Ton/MWyr]} \]

13) SOX air pollution constraint
\[
\sum_{i=1}^{NG} \text{SO}_{2_{in}} \times P_i \times y_{in} \leq \text{SO}_{2_{\text{MAXin}}} \quad (14)
\]
where, \( \text{SO}_{2_{in}} \): SOX density of the i-unit in n year [ppm/Ton]
\( \text{SO}_{2_{\text{MAXin}}} \): maximum quantity of SOX permitted in n year [Ton/yr]

14) NOX air pollution constraint
\[
\sum_{i=1}^{NG} \text{NOX}_{in} \times P_i \times y_{in} \leq \text{NOX}_{\text{MAXin}} \quad (15)
\]
where, \( \text{NOX}_{in} \): NOX density of the i-unit in n year [ppm/Ton]
\( \text{NOX}_{\text{MAXin}} \): maximum quantity of NOX permitted in n year [Ton/yr]

3. Case Studies

The step size of planning year is assumed as five years (T=5). The maximum, minimum load and hydro capacity in standard years are listed in Table 1. The characteristics and economic data are summarized in Table 2 and Table 4, respectively.

<table>
<thead>
<tr>
<th>Years</th>
<th>Peak load LP [MW]</th>
<th>Base load LB [MW]</th>
<th>Hydro [MW]</th>
<th>LEP (103Ton)</th>
</tr>
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<tbody>
<tr>
<td>2006</td>
<td>48,108</td>
<td>30,340</td>
<td>1,800</td>
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<tr>
<td>2011</td>
<td>57,340</td>
<td>34,200</td>
<td>2,000</td>
<td>4500</td>
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<tr>
<td>2016</td>
<td>69,500</td>
<td>42,500</td>
<td>2,200</td>
<td>5500</td>
</tr>
<tr>
<td>2021</td>
<td>78,200</td>
<td>47,500</td>
<td>2,400</td>
<td>6500</td>
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<tr>
<td>2026</td>
<td>87,000</td>
<td>53,500</td>
<td>2,600</td>
<td>7500</td>
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</table>

Table 2. Maximum load, minimum load, and hydro plant at standard years

<table>
<thead>
<tr>
<th>Gen Type</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
<th>(7)</th>
<th>(8)</th>
<th>(9)</th>
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<tr>
<td>Nucl</td>
<td>16,715</td>
<td>145.0</td>
<td>6.8</td>
<td>19</td>
<td>80</td>
<td>--</td>
<td>--</td>
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<tr>
<td>Coal</td>
<td>17,465</td>
<td>100.0</td>
<td>17.8</td>
<td>17</td>
<td>70</td>
<td>0.4020</td>
<td>700</td>
<td>450</td>
<td>500</td>
<td>--</td>
</tr>
<tr>
<td>LNG</td>
<td>14,313</td>
<td>85.0</td>
<td>21.5</td>
<td>17</td>
<td>65</td>
<td>0.0500</td>
<td>450</td>
<td>200</td>
<td>300</td>
<td>--</td>
</tr>
<tr>
<td>Od</td>
<td>4,308</td>
<td>75.0</td>
<td>142.0</td>
<td>0</td>
<td>17</td>
<td>0.05214</td>
<td>600</td>
<td>200</td>
<td>100</td>
<td>--</td>
</tr>
<tr>
<td>P-G</td>
<td>2,000</td>
<td>45.0</td>
<td>1.0</td>
<td>0</td>
<td>13</td>
<td>30</td>
<td>--</td>
<td>--</td>
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</tr>
</tbody>
</table>

(Where: AER means the apparent escalation rate and the discount rate is assumed at 10%)
The results yield that the mix of nuclear power plants is increasing and that of coal power plants is decreasing. Fig. 2 and Fig. 3 shows total capacity and percent ratio results for conventional method and proposed method considering air pollution constraints.

Table 4. Total cost evaluation of best generation mix in the two cases. [ Billion Won ]

<table>
<thead>
<tr>
<th></th>
<th>Construction Cost</th>
<th>Operation Cost</th>
<th>Total Cost</th>
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<tbody>
<tr>
<td>Conventional method</td>
<td>3,463.10</td>
<td>7,751.29</td>
<td>11,214.39</td>
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<tr>
<td>Mix with CO2 APC</td>
<td>4,065.65</td>
<td>7,221.03</td>
<td>11,286.68</td>
</tr>
</tbody>
</table>

4. Conclusions

In this paper, a new approach for the long-term generation mix with multi-criteria considering air pollution constraints, which are not only SO2and NOX but also CO2 emission limitations, under the uncertain circumstances is proposed using linear programming. The effectiveness of the proposed approach is demonstrated by applying to the best generation mix problem of KEPCO-system, which contains nuclear, coal, LNG, oil and pumped-storage hydro plantsmulti-years. The CO2 air pollution constraint is more strict, the nuclear or LNG power plant construction is recommended as shown in the case study although the total cost is increasing. This case study in this paper is mainly focused on CO2 emission limitation effect in the best generation mix. The method can accommodate the operation of the pumped-storage generator which has a relationship with operation of nuclear power plant with some strict for load following.

5. Acknowledgement

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6. References