
A.N. AFANDI
Electrical Engineering, Faculty of Engineering
Universitas Negeri Malang
Jl. Semarang 5, Malang, Jawa Timur
INDONESIA
an.afandi@um.ac.id, an.afandi@ieee.org

Abstract: - This paper presents an application of the novel evolutionary algorithm for assessing an economic power system operation throughout a combined economic and emission dispatch problem required by various technical limitations. Moreover, this problem considers pollutant production and fuel consumption problems for covering environmental protection and fuel usage aspects as a constrained objective function. Running out simulations show, minimum costs depend on various weighting factors implemented in the defined problem. Reducing the total fuel cost focused on the dispatching priority and the pollutant target based on the emission production have different implications as its contribution on the economic operation. The increased power demand leads to generated powers, costs and emission discharges associated with its parameters and schedules.

Key-Words: - economic dispatch, emission dispatch, intelligent computation, load demand, weighting factors

1 Introduction
Practically, a power system is developed using interconnected structures to deliver electric energy from generator sites to the some areas of loads with various scheduled capacities for existing the daily operation. In particular, separated load centers are normally supplied using operated electric power plants with a least fuel cost strategy considered several operational constraints for the power system operation. Moreover, the power system is divided into three sub sections covered in generation, transmission, distribution and utilization [1]. These sections are managed accurately for producing energy with suitable operating cost of the power system expressed in optimal fuel cost of generating stations throughout an economic dispatch (ED) due to a certain load.

In recent years, pollutant emission has become attention in combustions of fossil fuels at thermal power plants [2]. The fossil fuel combustion discharges pollutants in various types like CO, CO₂, SO₂, and NOₓ [3]. By considering pollutants, the ED becomes a complex problem with considering an emission dispatch (EmD). It also becomes a crucial task in the power system operation for determining economically the committed problem of scheduled power outputs [4]. In the past years, many methods were proposed to solve power system problems with various type efforts to find out cases which have applied mathematical programming principles and optimization techniques [5]. There were proposed in traditional and evolutionary methods depend on the problem in what it would be solved. The traditionally method covers classically approaches such as linear programming, lambda iteration, quadratic programming, gradient search, Newton’s method, interior point method, Lagrangian method [6], [7], [8]. On the other hand, the evolutionary method is consisted of several intelligent techniques, for examples, genetic algorithm, simulated annealing, evolutionary programming, ant colony algorithm, particles swarm optimization and neural network [9], [10], [11].

This paper focuses on dispatching problems modeled in a nonlinear objective function for integrating ED and EmD problems in a combined economic and emission dispatch (CEED) problem based on weighting factor scenarios. To carry out the CEED problem, this paper also concern in a harvest season artificial bee colony (HSABC) algorithm as a novel evolutionary method of bee’s generation proposed in 2013 [12].

2 Pollutant and Fuel Problems
As mentioned before, the power system is commonly established using main sections covered in generation; transmission; distribution and utilization. In particular, the generation section is supported by various power plants for producing electric energy at certain locations with plotting in a
balanced power output combination to meet a total demand at separated usage areas in all operating periods [12], [13]. Moreover, it should be generated economically during existing the interconnected structures to delivers electric energy from generator sites to energy users with considering technical constraints. Recently, it also conduct to control pollutant productions of thermal power plants. These problems have to take double attentions for reducing pollutant discharges as an environmental protection efforts and decreasing the operating budget as a reasonable operating cost [2], [14].

In this section, CEED problem is subjected to optimize the total operating cost considered several technical limitations for ED. CEED is also used to minimize emission discharges through EmD. In general, ED reduces the total fuel cost and EmD decreases the total emission discharge which are provided in single objective function in order to get a balanced result for the economic power system operation. Moreover, the CEED is expressed using nonlinear equation for providing electric energy from joined power stations and for assessing fuel consumptions and pollutant productions. In detail, CEED includes an including weighting factor for balancing ED and EmD problems in terms of compromised and penalty factors [3], [12], [15], [16]. This function can be formulated using following expression:

\[
\text{Minimize CEED: } \Phi_t = w_{\text{eco}} F_t + w_{\text{emi}} h E_t, \quad (1)
\]

\[
\text{Minimize ED: } F_t = \sum_{i=1}^{ng} \left( c_i + b_i P_i + a_i P_i^2 \right), \quad (2)
\]

\[
\text{Minimize EmD: } E_t = \sum_{i=1}^{ng} \left( y_i + b_i P_i + a_i P_i^2 \right), \quad (3)
\]

where \( \Phi_t \) is the CEED, \( w_{\text{eco}} \) and \( w_{\text{emi}} \) are weighting factors for ED and EmD, \( h \) is a factor penalty, \( F_t \) is the total fuel cost of generating units ($/hr), \( a_i, b_i, c_i \) are coefficients of the quadratic fuel cost by the \( i^{th} \) generating unit, \( P_i \) is the power output of the \( i^{th} \) generating unit, \( ng \) is the number of generator, \( E_t \) is the total emission discharge of generating units (kg/hr), \( \alpha_i, \beta_i, \gamma_i \) are coefficients of emission characteristics by the \( i^{th} \) generating unit.

## 3 Novel Intelligent Computation

For carrying out ED and EmD problems, an intelligent based computation is implemented to solve the CEED associated with a new evolutionary algorithm. In this section, HSABC algorithm is introduced clearly as an instrument for determining the optimal solution. As mentioned before, HSABC algorithm is a novel method consisted of multiple food sources (MFSs) to express many flowers located randomly at certain positions in the harvest season area [12]. The MFSs is consisted of the first food source (FFS) and the other food sources (OFSs) with each position of OFSs is directed by a harvest operator (ho) from the FFS. In general, HSABC has three agents for exploring the space area, those are employed bees; onlooker bees; and scout bees with each different tasks for the hierarchy. Each agent also has different abilities in the process and it is collaborated to obtain the best food based on certain pseudo-codes covered generating population; food source exploration; food selection; and abandoned replacement, as detailed in [12], [15], [17].

In principles, a set of MFSs is prepared to provide candidate foods for every foraging cycle. The foraging for foods is preceded by searching the FSS and it will be accompanied by OFSs located randomly at different positions. A set initial population is generated and created randomly by considering objective constraints located at difference positions which is formed using (5) and (6) for the FSS and OFSs. For each solution, it is corresponded to the number of the parameter to be optimized, which is populated using equation (4). Moreover, structures and hierarchies of HSABC algorithm are discussed clearly in [17]. Mathematically, its main functions are developed using following main expressions:

\[
x_{ij} = x_{\text{min}j} + \text{rand}(0,1) \ast (x_{\text{max}j} - x_{\text{min}j}), \quad (4)
\]

\[
v_{ij} = x_{ij} + \theta_{ij}(x_{ij} - x_{kj}), \quad (5)
\]

\[
H_{\text{ho}} = \begin{cases} 
\alpha_{kj} + \beta_{ij}(x_{ij} - x_{kj}).(\text{ho} - 1), & \text{or } R_j < MR \\
x_{kj}, & \text{otherwise}
\end{cases}, \quad (6)
\]

here, \( x_{ij} \) is a current food, \( i \) is the \( i^{th} \) solution of the food source, \( j \in \{1,2,3,...,D\} \), \( D \) is the number o variables of the problem, \( x_{\text{min}j} \) is a minimum limit of \( x_{ij} \), \( x_{\text{max}j} \) is a maximum limit of \( x_{ij} \), \( v_{ij} \) is the food position, \( x_{kj} \) is a random neighbor of \( x_{ij} \), \( k \in \{1,2,3,...,\text{SN}\} \), \( \text{SN} \) is the number o solutions, \( \alpha_{kj} \) is a random number within [-1.1], \( H_{\text{ho}} \) is the harvest season food position, \( ho \in \{2,3,...,\text{FT}\} \), \( \text{FT} \) is the total number of flowers for harvest season, \( x_{kj} \) is a random harvest neighbor of \( x_{ij} \), \( f \in \{1,2,3,...,\text{SN}\} \), \( R_j \) is a randomly chosen real number within \([0,1]\), and MR is the modified rate of probability food.

## 4 Tested System Model

The balanced value of ED and EmD problems is measured using the CEED applied to IEEE-30 bus system as a sample model as shown on Figure 1. Its data for simulations associated with generating units
are listed respectively in Table 1, Table 2 and Table 3.

Table 1. Cost coefficients and power limits

<table>
<thead>
<tr>
<th>Bus No</th>
<th>Gen</th>
<th>$a$ (S/MWh$^3$)</th>
<th>$b$ (S/MWh)</th>
<th>$c$</th>
<th>$P_{\text{min}}$ (MW)</th>
<th>$P_{\text{max}}$ (MW)</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>G1</td>
<td>0.00375</td>
<td>2.00000</td>
<td>0</td>
<td>-50</td>
<td>200</td>
</tr>
<tr>
<td>2</td>
<td>G2</td>
<td>0.01750</td>
<td>1.75000</td>
<td>0</td>
<td>20</td>
<td>80</td>
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<tr>
<td>5</td>
<td>G3</td>
<td>0.06250</td>
<td>1.00000</td>
<td>0</td>
<td>15</td>
<td>50</td>
</tr>
<tr>
<td>8</td>
<td>G4</td>
<td>0.00835</td>
<td>3.25000</td>
<td>0</td>
<td>10</td>
<td>35</td>
</tr>
<tr>
<td>11</td>
<td>G5</td>
<td>0.02500</td>
<td>3.00000</td>
<td>0</td>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td>13</td>
<td>G6</td>
<td>0.02500</td>
<td>3.00000</td>
<td>0</td>
<td>12</td>
<td>40</td>
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</tbody>
</table>

Figure 1. IEEE-30 bus system model

Table 2. Emission coefficients

<table>
<thead>
<tr>
<th>Bus No</th>
<th>Gen</th>
<th>$\alpha$ (kg/MWh$^2$)</th>
<th>$\beta$ (kg/MWh)</th>
<th>$\gamma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>G1</td>
<td>0.0126</td>
<td>-1.1000</td>
<td>22.9830</td>
</tr>
<tr>
<td>2</td>
<td>G2</td>
<td>0.0200</td>
<td>-0.1000</td>
<td>25.3130</td>
</tr>
<tr>
<td>5</td>
<td>G3</td>
<td>0.0270</td>
<td>-0.0100</td>
<td>25.5050</td>
</tr>
<tr>
<td>8</td>
<td>G4</td>
<td>0.0291</td>
<td>-0.0050</td>
<td>24.9000</td>
</tr>
<tr>
<td>11</td>
<td>G5</td>
<td>0.0290</td>
<td>-0.0040</td>
<td>24.7000</td>
</tr>
<tr>
<td>13</td>
<td>G6</td>
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<td>-0.0055</td>
<td>25.3000</td>
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</tbody>
</table>

Table 3. Load data for each bus

<table>
<thead>
<tr>
<th>Bus No</th>
<th>MW</th>
<th>Mvar</th>
<th>Bus No</th>
<th>MW</th>
<th>Mvar</th>
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<td>0</td>
<td>15</td>
<td>15</td>
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<td>2</td>
<td>21.7</td>
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<td>17</td>
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<td>5.8</td>
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<tr>
<td>3</td>
<td>2.4</td>
<td>1.2</td>
<td>18</td>
<td>3.2</td>
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<tr>
<td>4</td>
<td>7.6</td>
<td>1.6</td>
<td>19</td>
<td>9.5</td>
<td>3.4</td>
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<tr>
<td>5</td>
<td>94.2</td>
<td>19.0</td>
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<td>2.2</td>
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<tr>
<td>6</td>
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<td>21</td>
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<td>7</td>
<td>22.8</td>
<td>10.9</td>
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<td>0.0</td>
</tr>
<tr>
<td>8</td>
<td>30.0</td>
<td>30.0</td>
<td>23</td>
<td>3.2</td>
<td>1.6</td>
</tr>
<tr>
<td>9</td>
<td>0.0</td>
<td>0.0</td>
<td>24</td>
<td>8.7</td>
<td>6.7</td>
</tr>
<tr>
<td>10</td>
<td>5.8</td>
<td>2.0</td>
<td>25</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>11</td>
<td>0.0</td>
<td>0.0</td>
<td>26</td>
<td>3.5</td>
<td>2.3</td>
</tr>
<tr>
<td>12</td>
<td>11.2</td>
<td>7.5</td>
<td>27</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>13</td>
<td>0.0</td>
<td>0.0</td>
<td>28</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>14</td>
<td>6.2</td>
<td>1.6</td>
<td>29</td>
<td>2.4</td>
<td>0.9</td>
</tr>
<tr>
<td>15</td>
<td>8.2</td>
<td>2.5</td>
<td>30</td>
<td>10.6</td>
<td>1.9</td>
</tr>
</tbody>
</table>

5 Results
In this section, simulation results of CEED are demonstrated using weighting factor scenarios in Table 4. To show roles of dispatching factors, the tested system model considers the total load 283.4 MW. Three case studies are used to assess the performance of CEED using weighting factors. To show the domination of ED or EmD, CEED uses WF$_1$. To describe the component contribution of objective function, the simulations consider WF$_2$ and WF$_3$. In these studies, pure ED is expressed by CEED$_1$ used $w_{\text{eco}}=1$ and $w_{\text{emi}}=0$ in WF$_1$ and WF$_2$, but the pure EmD is expressed by CEED$_1$ used $w_{\text{eco}}=0$ and $w_{\text{emi}}=1$ in WF$_3$ or CEED$_3$ in WF$_1$. Assessing results are given in Table 5, Table 6 and Table 7 for generated powers, costs and emissions.

Table 4. Weighting factor scenarios

<table>
<thead>
<tr>
<th>Types</th>
<th>WF$_1$</th>
<th>WF$_2$</th>
<th>WF$_3$</th>
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<tbody>
<tr>
<td></td>
<td>$w_{\text{eco}}$</td>
<td>$w_{\text{emi}}$</td>
<td>$w_{\text{eco}}$</td>
</tr>
<tr>
<td>CEED$_1$</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>CEED$_2$</td>
<td>0.7</td>
<td>0.3</td>
<td>0.7</td>
</tr>
<tr>
<td>CEED$_3$</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>CEED$_4$</td>
<td>0.3</td>
<td>0.7</td>
<td>0.3</td>
</tr>
<tr>
<td>CEED$_5$</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>CEED$_6$</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 5, Table 6 and Table 7 show the results of simulations. From these tables are known that pure ED neglects the pollutant emission 422.99 kg/hr and produces 292.67 MW of the power with 9.27 MW of the total loss. In contrast, pure EmD discharges 340.06 kg/hr of an accumulated emission and produces 288.71 MW of the power with the total loss is 5.31 MW. According to these tables, the full CEED has 345.55 kg/hr of the emission, 289.47 MW of the power and 6.07 MW of the total loss. In total, the operating payments are $1447.30$ $/hr$ of the full CEED, $1558.87$ $$/hr$ of the pure ED and $1461.46$ $$/hr$ of the pure EmD. Based on various combinations $w_{\text{eco}}$ and $w_{\text{emi}}$ the lowest cost is $1447.26$ $$/hr$ of CEED$_1$ using the weighting factor 0.5 as shown in Table 5.

In detail, by using a constant $w_{\text{emi}}=1$ of WF$_3$, the increasing of $w_{\text{eco}}$ gives an effect on the decreasing pollutant emission. The pollutant reduces 18.25% from CEED$_1$ to CEED$_5$. In contrast, by considering a fluctuation of $w_{\text{emi}}$ on the constant $w_{\text{eco}}=1$ of WF$_2$, the pollutant emission is climbed up. On the other hand, the pollutant increases 54.78% from CEED$_1$ to CEED$_5$.

Figure 2, Figure 3 and Figure 4 illustrate typical convergence speeds for determining the optimal solutions of assessments. Its convergences are quick and stable as shown in these figures. According to Figure 2, the pure ED has 26 iterations for obtaining the solution $801.72$ $$/hr$ of CEED$_1$ after starting at...
810.71 $/hr. The full CEED expressed on CEED needs 38 iterations to remain 1447.30 $/hr from 1460.68 $/hr as shown on Figure 4. According to Figure 3, it is known that the optimal solution is obtained in 45 iterations to get 723.63 $/hr from 730.03 $/hr of the first point using 0.5 of the equal weighting factor.

Practically, power outputs of generating units are associated with load demand behaviors at a certain time to set the fixed schedule of power outputs. The least operating cost becomes a very crucial decision to set the fixed schedule of power outputs. The least operating cost becomes a very crucial decision caused by the fluctuation of load demand. To evaluate these effects on the increasing load demand and to assess it on the total cost are studied in this section.

In addition, this load condition also affects to the system. In this section, the weighting factors are compromised in 0.5 for an equality contribution of ED and EmD because of the CEED for this case is minimum as given in Table 5. Power demands are assumed to increase gradually at load buses as listed in Table 8. The simulation results are shown in Table 9 and Table 10.

Table 5. Optimum results used WF

<table>
<thead>
<tr>
<th>Subject</th>
<th>CEED</th>
<th>CEED</th>
<th>CEED</th>
<th>CEED</th>
<th>CEED</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1 (MW)</td>
<td>176.26</td>
<td>137.46</td>
<td>126.55</td>
<td>119.45</td>
<td>112.69</td>
</tr>
<tr>
<td>G2 (MW)</td>
<td>48.38</td>
<td>50.21</td>
<td>49.48</td>
<td>48.39</td>
<td>46.88</td>
</tr>
<tr>
<td>G3 (MW)</td>
<td>20.87</td>
<td>25.27</td>
<td>27.8</td>
<td>30.27</td>
<td>34.26</td>
</tr>
<tr>
<td>G4 (MW)</td>
<td>22.71</td>
<td>31.33</td>
<td>31.87</td>
<td>31.68</td>
<td>31.58</td>
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<tr>
<td>G5 (MW)</td>
<td>12.45</td>
<td>22.95</td>
<td>26.63</td>
<td>29.08</td>
<td>30.00</td>
</tr>
<tr>
<td>G6 (MW)</td>
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<td>22.87</td>
<td>27.13</td>
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Table 6. Optimum result used WF

<table>
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<th>CEED</th>
<th>CEED</th>
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<tr>
<td>G1 (MW)</td>
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<td>137.46</td>
<td>126.55</td>
<td>119.45</td>
<td>112.69</td>
</tr>
<tr>
<td>G2 (MW)</td>
<td>48.38</td>
<td>50.21</td>
<td>49.48</td>
<td>48.39</td>
<td>46.88</td>
</tr>
<tr>
<td>G3 (MW)</td>
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<td>27.8</td>
<td>30.27</td>
<td>34.26</td>
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<tr>
<td>G4 (MW)</td>
<td>22.71</td>
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<td>31.68</td>
<td>31.58</td>
</tr>
<tr>
<td>G5 (MW)</td>
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<td>22.95</td>
<td>26.63</td>
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<td>G6 (MW)</td>
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<td>27.13</td>
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Table 7. Optimum result used WF

<table>
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<th>CEED</th>
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<td>G2 (MW)</td>
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Table 8. Increased load assumptions

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<th>Increased load % (MW)</th>
<th>New load (MW)</th>
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<td>10</td>
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<tr>
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<td>20</td>
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<tr>
<td>NL3</td>
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<td>NL4</td>
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Table 9. Summary results considered various loads

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<td>G3 (MW)</td>
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<td>G6 (MW)</td>
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<tr>
<td>Total G (MW)</td>
<td>7.26</td>
</tr>
<tr>
<td>Loss (MW)</td>
<td>402.53</td>
</tr>
<tr>
<td>Emission (kg/hr)</td>
<td>89.20</td>
</tr>
<tr>
<td>CEED ($/hr)</td>
<td>1461.47</td>
</tr>
<tr>
<td>EmD cost ($/hr)</td>
<td>801.72</td>
</tr>
<tr>
<td>ED cost ($/hr)</td>
<td>827.26</td>
</tr>
<tr>
<td>Total cost ($/hr)</td>
<td>1798.20</td>
</tr>
</tbody>
</table>
Table 9 shows simulation results of generating units used NL₁ - NL₄ of loads. Six generators produce different power outputs to face the load demand. Specifically G5 and G4 feed to the power system in the constant power 30 MW and 35 WM because of the upper limitation of operating powers. G1 increases from 137.13 MW to 182.73 MW associated with NL₁ to NL₄. In total, generating units deliver powers to the load demand from 319.00 MW to 409.71 MW with increasing losses from 7.26 MW to 12.95 MW.

Comparing result in Table 9 and CEED₃ in Table 5, percentage performances on various loads are shown in Table 10. The most interesting point is NL₄ because the increasing load demand is only changed up 40% but the costs are passed 50% and also losses are over 100%. According to these results, cost values are rose up, the fluctuation of total costs are ranged in 15% to 69%, the fuel costs are moved up from 13% to 56% and the emission costs are paid more from 16% to 85% for increasing pollutants.

6 Conclusions
This paper presents the pollutant production and fuel consumption assessments throughout the CEED using various weighting factor scenarios, which is demonstrated clearly for determining a financial balance on IEEE-30 bus system. The simulation results show that the computation converged smoothly during assessment the minimum costs. The weighting factor scenarios for ED and EmD affect to the CEED. The increasing demands also give effects to the generated powers, emissions and costs. From these studies, the revealing convergence speed and a real test system are devoted to the future work on the higher implementation.

References
A. N. Afandi 

A. N. Afandi was born in Malang, he received B.Eng. from University of Brawijaya, and he was graduated from Gadjah Mada University for M.Eng., both in Indonesia. He got PhD from Kumamoto University in Japan. Since 1999, he joins Universitas Negeri Malang (State University of Malang) for working at Electrical Engineering, Indonesia. Currently, he concerns in Power and Energy Systems Center. He also focuses on industrial automation and control system, intelligent computation and engineering optimization, engineering education and applied technology. He is a member of Institute of Electrical and Electronics Engineers (IEEE), International Association of Engineering (IAEng), International Association of Engineers and Scientists (IAEST), World Association of Science Engineering (WASE), Integrated Micro Hydro Development and Application Program (IMIDAP), Indonesia National Committee on Large Dam (INACOLD), Institution of Indonesian Engineers (IIE), Institute of Electrical Engineers of Japan (IEEJ), Energy Systems and Technology Benchmarking Association (ESTBA), Society of Asian Scientists and Engineers (SASE), Power and Energy System Community (PESC).