Determination of an Optimal Operating Schedule for Thermal Units with an Energy Storage System

Tomonobu Senjyu∗ Shantanu Chakraborty† Ahmed Yousuf Saber‡
Atsushi Yona** Toshihisa Funabashi††

∗University of the Ryukyus, b985542@tec.u-ryukyu.ac.jp
†University of the Ryukyus, scborty@gmail.com
‡King Abdulaziz University, aysaber@yahoo.com
**University of the Ryukyus, yona@tec.u-ryukyu.ac.jp
††Meidensha Corporation, funabashi-t@mb.meidensha.co.jp

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Abstract

This paper presents a determination methodology for finding optimal operation schedules of thermal units (namely unit commitment) integrated with an energy storage system (ESS) to minimize total operating costs. A generic ESS formulation along with a method for solving unit commitment (UC) of thermal units with ESS is proposed to serve this purpose. The problem of unit commitment with an ESS is solved using the Priority List method. Intelligent Genetic algorithm (GA) is included in the algorithm for generating new and potential solutions. The proposed method consists of two steps. The first step is to determine the schedule of ESS and the schedule of thermal units. The second step is to dispatch the hourly output of thermal units and the ESS which comply a minimized total production cost. The proposed method is applied to a power system with ten thermal units and a large ESS. The presented simulation results show that the schedule of thermal units with an ESS of a particular life cycle, achieved by the proposed method, minimizes the operating cost. The discussion regarding the determination of schedule thermal units (TU) along with the integrated ESS may interest many types of ESS due to their generalized formulations.

KEYWORDS: electric-load leveling, genetic algorithm, energy storage system, unit commitment, priority list
1 Introduction

The demand of electricity is growing due to the increasing number of consumers. The generation companies therefore, must increase electricity supply to satisfy the demand. Since the supplies are often inadequate with the demand, the gap between them is increasing specially on the peak hours. Therefore, the synchronization is required to maintain between supply and demand. Moreover electric utility technologies recently confronted with various economic, regulatory, and environmentally related pressures which complicate, and sometimes prevent construction of more generating capacity in response to load demand and hence market or service territory growth. The prime focus of these techniques is to smooth out the demand level for a certain period by moderating the peaks and valleys of fluctuations. These techniques are collectively known as demand side management (DSM). Energy conservation is such a method which provides clean and affordable means to reduce the demand gap and hence offers a way to avoid generation of new power generation facilities. In order to balance power production and consumption simultaneously and to utilize installed system capacity, energy must be stored on peak load period and dispatched on peak load period. Among the DSM schemes, pumped hydro storage plants are widely used due to their availability, high efficiency and quick response rate. However due to the site restriction these plants could not be built everywhere. In such case, Energy Storage System (ESS) could be better alternative.

Electric-water-warmer system and ice thermal storage systems are effective methods for improving the utilization factor of generation plants where System operational costs be minimized by proper scheduling of the load control [1]. Electric-water-warmer system is used to provide load demand during the off-peak hours while the ice thermal storage system is employed for shifting the load demand from daytime to night. However, that method is assumed to be directly controlled by customer demand. For example upon initial installation, the customer is expected to provide the building design load and building use schedules, startup values for cooling load profile, non-cooling electric load profile and so on. Hence customers’ cooperation is required for deployment. It is also one of the important reasons that electric power companies mainly control ESS. For this reason, this study focuses on ESS that can achieve load leveling by maintaining the operational cost as minimal as possible. However, in order to achieve maximum benefit, ESS must be integrated with thermal units.

Several studies already provide good performance which have been reported regarding optimal size of battery [2-8] and scheduling in renewable energy utility grid with battery storage [9-11]. In reference [9], precisely predicted electric energy of wind and photo voltaic was given at each hour, then unit commitment with battery storage system and load flow calculations were executed. The results show that
transmission congestion was relaxed and total production cost was saved. However, renewable energy has a lot of uncertainty, so this idea is difficult to apply to a real power system. Reference [10] used dynamic programming (DP) to determine the operation of distributed small batteries. Since DP method requires a lot of memory and calculation time, heuristic method [11] is used to improve the computation time. In order to solve the operation scheduling problem, an optimal unit commitment and the charge/discharge schedule of ESS are necessary. However, references [12,13] did not consider unit commitment.

In this paper a methodology is proposed to determine short-term schedule the thermal units of a power system integrated with ESS while minimizing the production cost. The charge/discharge schedule of ESS is also determined along with unit commitment (UC) schedule in this proposed method. For this method, genetic algorithm (GA) is chosen for evolving the optimal solution. GA is chosen over the other evolutionary techniques due to its robustness and diversity towards generating new potential solutions. The proposed method is formulated considering generalized ESS with inverter and thermal units so that it could be applied to different types of ESS, such as pumping power generation, flywheel, superconducting magnetic energy storage, redox flow cell, compressed air energy storage gas turbine system, etc. The formulation includes life cycle of ESS. The simulation is done in a power system containing an ESS and ten thermal units. The result demonstrates the applicability of this method and also a comparison of the daily operational costs with other method.

2 Problem Formulation

2.1 Notation

The following key notations are used throughout the paper. Additional notations will be introduced in associated sections.
2.2 Objective Function

The objective function is formulated considering the life cycle of ESS and the capital cost of the system. Therefore, the total system cost is the summation of operational costs of UC spanned over the life of ESS and capital cost of ESS. Operational cost of thermal system is represented as the sum of the fuel cost $F_i(P_i(t))$ and start-up cost $SC_i(t)$ for all the units.
Figure 1 shows the system configuration used in this paper. The overall objective function of the problem is:

\[
\min \ SC = \sum_{y=1}^{Y} \min TC(y) + CPL. \tag{1}
\]

\[
\min \ TC = \sum_{t=1}^{T} \sum_{i=1}^{N} [F_i(P_i(t)) + SC_i(t)]. \tag{2}
\]

where \( SC \) is the total system cost, \( TC \) is the operational cost for UC schedule and \( CPL \) is the capital cost for ESS that can be defined as follows:

\[
CPL = \text{Rated Power} \times MP + \text{Rated Capacity} \times MC + \text{Maintenance Cost}. \tag{3}
\]

where \( MP/\text{kW} \) and \( MC/\text{kWh} \) are specific costs of \textit{Rated Power} and \textit{Rated Capacity}. Maintenance Cost coefficients are defined in Table 3 [4]. Generally, the fuel cost, \( F_i(P_i(t)) \) per unit at any given time interval is a function of generator power output. The most frequently used cost function has the following quadratic form

\[
F_i(P_i(t)) = a_i + b_i P_i(t) + c_i P_i^2(t). \tag{4}
\]

where \( a_i, b_i, \) and \( c_i \) represent positive fuel cost coefficients.

The start-up cost of generator depends on time that the unit has been OFF prior to start-up. In this paper, time-dependent start-up cost is simplified using \( H_{i}^{\text{off}} \) as follows:

\[
SC_i = \begin{cases} 
\text{h-cost}_i : T_{i}^{\text{off}} \leq X_i^{\text{off}} \leq H_{i}^{\text{off}} \\
\text{c-cost}_i : H_{i}^{\text{off}} < X_i^{\text{off}}
\end{cases} \tag{5}
\]

where

\[
H_{i}^{\text{off}} = T_{i}^{\text{off}} + \text{c-s-hour}_i. \tag{6}
\]

2.3 Constraints

The objective function of minimizing the operational cost of thermal units also requires solving several system and operational constraints depending on the generator characteristics. Moreover, since the model also includes inverters, some related
constraints such as capacity limits, charge/discharge limits, etc. also need to be satisfied. The overall objective is to minimize $TC$ subject to a number of constraints as explained in the sequel.

2.3.1 System Power Balance
To operate economically, sum of the generated power from on-line thermal units and output of inverter (i.e. charge/discharge power from ESS) should be equal to the predicted load demand at each hour.

\[ P_{th}(t) + P_{inv}(t) = D(t). \]  

(7)

\[ \sum_{i=1}^{N} P_i(t) = P_{th}(t). \]  

(8)

where $P_{th}(t)$ is sum of the generated power from on-line thermal units, and $P_{inv}(t)$ is the output of inverter. From figure 1, sign of $P_{inv}(t)$ is negative when ESS charges, and positive when ESS discharges. At no charging/discharging hour $t$, $P_{inv}(t)$ is zero.

2.3.2 System Reserve Requirements
Hourly spinning reserve requirements $R^t$ must be met

\[ \sum_{i=1}^{N} I_i(t) P_{i\text{max}} \geq D(t) + R^t. \]  

(9)

where $R^t$ is 10% of $D(t)$. At charging/discharging hour of ESS, the dispatched load $D(t)$ by all of the on-line thermal units changes into $D'(t)$ as shown in (10). Since the sign of $P_{inv}$ is alternating based on the charge/discharge status of inverter, the sign of $P_{inv}$ is negative in (10). Considering the inverter output, the reserve requirement in (9) is changed as equation (11).

\[ D'(t) = D(t) - P_{inv}(t), \quad \text{for discharge / charge} \]  

(10)

\[ \sum_{i=1}^{N} I_i(t) P_{i\text{max}} \geq D'(t) + R^t. \]  

(11)

2.3.3 Generation Limit
The generation limit of each unit is as follows

\[ P_{\text{imin}} \leq P_i(t) \leq P_{i\text{max}}. \]  

(12)
2.3.4 Unit Minimum Up/down Time
Minimum up/down time limits of unit must satisfy the following:

$$
\begin{align*}
T_{\text{on}}^i & \leq X_{\text{on}}^i(t) \\
T_{\text{off}}^i & \leq X_{\text{off}}^i(t)
\end{align*}
$$

(13)

2.3.5 Initial Storage Energy
The ESS starts charge operation from any initial electric energy can be expressed as

$$
C_{\text{ini}}^{\text{sr}} = wC_{\text{max}}^{\text{sr}}
$$

(14)

where $C_{\text{ini}}^{\text{sr}}$ is initial storage energy, $w(0 < w < 1)$ is discharging coefficient, and $C_{\text{max}}^{\text{sr}}$ is the storage maximum energy.

2.3.6 Charge/discharge Constraints and Inverter Limits
Let $C_{\text{src}}(t)$ be the energy utilized for charging till hour $t$, and $C_{\text{srd}}(t)$ the energy utilized for discharging till hour $t$, which are represented as follows

$$
C_{\text{src}}(t) = \alpha \int P_{\text{inv}}(t)dt, \quad \text{for charge}
$$

(15)

$$
C_{\text{srd}}(t) = \int P_{\text{inv}}(t)dt, \quad \text{for discharge}
$$

(16)

where $\alpha(0 < \alpha \leq 1)$ is efficiency for charging operation. All efficiencies are integrated into $\alpha$, which is the combined efficiency for ESS used in this paper. $P_{\text{inv}}(t)$ is output from inverter at hour $t$ in MW. The discrete representation for storage energy at hour $t$, $C_{\text{sr}}(t)$, is given as

$$
C_{\text{sr}}(t) = C_{\text{sr}}(t - 1) + C_{\text{src}}(t) - C_{\text{srd}}(t).
$$

(17)

The constraints for charge/discharge are as follows:

$$
C_{\text{sr}}^{\text{min}} \leq C_{\text{sr}}(t) \leq C_{\text{sr}}^{\text{max}}, \quad \text{for all } t
$$

(18)

$$
kC_{\text{sr}}^{\text{max}} \leq C_{\text{sr}}(t_c) \leq C_{\text{sr}}^{\text{max}}, \quad \text{at the end of charge}
$$

(19)

$$
C_{\text{sr}}^{\text{min}} \leq C_{\text{sr}}(t_d) \leq wC_{\text{sr}}^{\text{max}}, \quad \text{at the end of discharge}
$$

(20)
where \( k(w \leq k \leq 1) \) and \( w \) are charging and discharging coefficients, respectively. \( kC_{sr}^{max}, wC_{sr}^{max} \), and \( C_{sr}^{min} \) are lower bound energy at the end of charge, upper bound energy at the end of discharge and storage minimum energy, respectively. The values of \( k \) and \( w \) are set based on the ESS technology. These symbols are used for generalized purpose. \( t_c \) and \( t_d \) are ending time of charge, and discharge operation on any range of hours, respectively. The charge operation ends when \( C_{sr}(t) \) increases up to \( k \cdot C_{sr}^{max} \), while the discharge operation ends when \( C_{sr}(t) \) decreases down to \( w \cdot C_{sr}^{max} \). The study assumed that the inverter is ideal, which is limited as following equation

\[
0 \leq |P_{inv}(t)| \leq P_{inv}^{max}.
\]

where \( P_{inv}^{max} \) is the rating of inverter.

3 Optimal Operation Schedules for Thermal Units and ESS

As per equation (1), to find the minimized system cost, the proposed method first determines the optimal operational schedule for thermal units along with ESS. In order to achieve this goal, the whole process is broken down in two steps. First step determines the suboptimal combinatorial schedule of thermal units with ESS and the second step determines the optimal hourly power output dispatched from thermal units along with ESS. The subsequent sections describe these steps in details.

3.1 Determination of Suboptimal Combination Schedule (DSCS)

Thermal unit commitment and charge/discharge schedule of ESS is determined when hourly-inverter outputs are fixed. Genetic algorithm is used to determine this suboptimal operational schedule. The steps of this procedure is outlined as follows.

Step 01: Initialize the parameters such as the size of population, the crossover rate, mutation, intelligent mutation, the maximum generation etc. and reset the generation counter by \( itr=0 \).

Step 02: Generate an initial ESS schedules (the generation process is described later). Figure 2 shows the initial solution for a particular load pattern.

Step 03: Modify the load demand curve based on ESS schedules using equation (11). ESS schedule per hour is set ‘c’, ‘d’ and ‘0’ for charge, discharge and idle
state, respectively.

**Step 04:** Solve unit commitment for thermal units by using extended priority list (EPL) method [14].

**Step 05:** Evaluate the total operating cost and $itr$ is incremented by 1.

**Step 06:** If $itr$ is reached a particular limit or no improvement in the solution found in a pre-defined number of iterations, the algorithm terminates. Return to Step 08.

**Step 07:** Apply the GA operation to generate new individuals, go back to Step 03.

**Step 08:** Print out final solution.

The following sections shed light on the important terms and operators used in the proposed method.

### 3.1.1 Generation of Initial Operation Schedules

Figure 2 shows generation of an initial operation schedule of ESS. The status of ESS become charge (c) when each hour load is less than average of load demand, the status of ESS become discharge (d) when each hour load is larger than average of load demand. Next, based on first generated operation schedule of ESS, some schedule of ESS are generated at random. A schedule of ESS is called *individual* and the set of individuals is called *population*.

### 3.1.2 GA Operators in DSCS

The following GA operators are interpreted in the context of DSCS to adjust the ESS schedule.

**A. Crossover:** A Single-point crossover operator is used in DSCS since the ideal charge/discharge schedule does not have minimum charge and discharge time. Figure 3 shows crossover operation in DSCS. First, the operator randomly selects two individuals and a particular hour $n$. Then generates new schedules by exchanging the parts of the selected individuals from $n$-th hour to 24-th hour.

**B. Mutation:** Generally, ESS keeps the same state over several hours, since there are few instances when load demand becomes relatively low or high. Hence, mutation operator is applied with very low probability. The procedure is shown in figure 4. First, this operator randomly selects an individual $i$ and an hour $n$ and then
Figure 2. Generation of an initial solution for ESS schedule.

changes the mode (c, d or 0) for a particular frame of time. For instance, in the figure 4, the ESS status modes are flipped from hour $n$ to $n + 3$.

C . Intelligent Mutation 1: Since GA operators use random numbers, without intelligent handling of the operators it is difficult to ensure feasible solution and hence reduction of the cost. To achieve a lower cost, an intelligent mutation is introduced in this method. Figure 5 shows intelligent mutation operation in DSCS. An individual $i$ is chosen randomly. ESS status is set to $d$ for load demand higher than the average load and is set to $c$ for lower load.

Figure 3. Crossover operation in DSCS
3.2 Determination of Optimal Hourly Dispatch (DOHD)

The economic dispatch output of thermal units (including ESS) is determined by DOHD algorithm. This algorithm is based on combinatorial schedule of thermal units with ESS which was determined in DSCS. Improve the thermal units schedule in order to fulfill system reserve requirement. Here are the steps of the proposed algorithm for optimal power output dispatch for thermal units and ESS.

Step 01: Initialize the parameters such as the size of population, crossover rate, mutation, intelligent mutation, maximum generation, etc. and reset the generation counter, $itr=0$.

Step 02: Generate initial inverter output schedule of ESS.
Step 03: Modify the load demand curve based on ESS schedules which has been determined previously as suboptimal operation schedule, i.e. if ESS schedule state is changed based on equation (10) for charge and discharge.

Step 04: Solve unit commitment for thermal units by using EPL method [14].

Step 05: Evaluate the total operating cost, and \( \text{itr} \) is increased by 1.

Step 06: If \( \text{itr} \) reaches a particular limit or no improvement in the solution found in a pre-defined number of iterations, the algorithm terminates. Return to Step 08.

Step 07: Apply GA operations to generate new individuals, then go back to Step 03.

Step 08: Print out final solution.

In the following sections, important terms and operators of the proposed algorithm will be described.

3.2.1 GA Coding
The solution in DOHD is represented by binary matrix of dimension \( T \times 7 \). Although hourly-inverter output is fixed in DSCS, it is modified in DOHD. The schedules in the thermal unit commitment problem are not changed by the GA operators. These schedules are solved by using EPL method after hourly-inverter outputs are determined.

3.2.2 Generation of Initial Individuals for Hourly-inverter Output of ESS
Since hourly-inverter output of ESS is fixed (and it is set to 40MW) in DSCS, this value needs to be changed and adjusted in DOHD. Figure 6 shows generation of initial individuals for hourly-inverter output of ESS. As for the implementation issue, the hourly converter output is converted into binary number (as for 40, the binary equivalent contains 7 bits) since the proposed GA method requires the base 2 representation of solution. The converted output is then changed randomly by intelligent bit flipping (which is discussed in later sections). Then each individual containing hourly data is regenerated.

3.2.3 GA Operators in DOHD
GA operators used in the proposed method are detailed in this section. These operators are used to adjust each individual hourly-inverter output of ESS.
A. **Crossover**: In DOHD, a single crossover operator is adopted in order to generate new individuals keeping the inverter output = 0 MW when ESS is idle state. Figure 7 shows crossover operation in DOHD. First, select two individuals and a bit number \( b \) randomly. Then, exchange individuals from \( b \) to 7, where crossover operation is applied from hour 1 to 24. If bit number is \( b=1 \), crossover operation is not executed.

B. **Mutation**: Figure 8 shows the adopted mutation used in this algorithm to generate new individuals. An individual \( i \) is selected at a particular time \( t \) randomly (not entirely; following sections clarify the mutations). If the state of ESS is idle, mutation operation is not executed.

i. **Intelligent Mutation 1**: The complete random mutation to generate new solution may lead to failure to generate near feasible solution. So an intelligent mutation 1 is incorporated. Figure 9 shows intelligent mutation operation 1 in DOHD. First, select an individual \( i \), a time of discharge \( t_d \) and a time of charge \( t_c \) randomly. Then bit connecting is executed at \( t_d \) and \( t_c \), which is shown in figure 9.

ii. **Intelligent Mutation 2**: Another mutation style is introduced to achieve better result. After selecting individual \( i \) randomly, the binary random output is added to the binary inverter outputs of peak-load hour and off-peak-load hour.

C. **Modification of Thermal Unit Commitment**: If hourly-inverter output of ESS is changed in (ii), thermal unit schedule which is determined in DSCS will violate system reserve requirements. Hence, the method starts up a thermal unit when system reserve requirement is violated. Then ELD calculation is executed while keep-
ing the system reserve requirement constraint satisfied. The estimation of schedule for thermal units and ESS is not executed, when the system reserve requirement is violated.

4 Simulation

For simulating the proposed method, the model considers a power system of ten thermal units and an equivalent ESS. Table 1 shows the parameter of ESS. This paper defines hourly-inverter output 40MW in DSCS, and determines the suboptimal combinatorial schedule of thermal unit commitment and charge/discharge schedule of ESS. The constants required for determining hourly-inverter output are settled by
Table 1: Parameters of ESS.

<table>
<thead>
<tr>
<th>$C_{max}$ [MWh]</th>
<th>$C_{min}$ [MWh]</th>
<th>$P_{max}$ [MW]</th>
<th>$\alpha$</th>
<th>$k$</th>
<th>$w$</th>
</tr>
</thead>
<tbody>
<tr>
<td>240</td>
<td>10</td>
<td>90</td>
<td>0.85</td>
<td>0.8</td>
<td>0.2</td>
</tr>
</tbody>
</table>

trial and error. Table 2 shows the GA parameters.

### 4.1 Result Analysis

Figure 10 shows thermal unit commitment schedule when ESS is not installed. Units 8-10, which have wrong generating efficiency are committed from 10th to 13th hours. Units 7 and 8 are committed from 20th to 22nd hours while units 1, 2 and 5 are committed from 1st to 5th hours due to light load demand. Figure 11 shows the schedule for thermal units and ESS after the proposed method is applied. From figure 11, it is noted that ESS state is the "charged (C)" when relatively few units are committed and ESS state is "discharged (D)" when most of the units are committed. Comparing figures 10 and 11, it can be found that units 8-10 are stopped from 10th to 13th hours and units 7-8 are stopped from 20th to 22nd hours. Since unit 7 is stopped between 20th and 21st hours, it does not need to be committed in order to fulfill the system reserve requirement constraint. Moreover, in spite of ESS
Table 2: GA parameters (DSCS and DOHD).

<table>
<thead>
<tr>
<th>Parameters</th>
<th>DSCS</th>
<th>DOHD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generation</td>
<td>100</td>
<td>400</td>
</tr>
<tr>
<td>Individual</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Crossover</td>
<td>0.8</td>
<td>0.55</td>
</tr>
<tr>
<td>Mutation</td>
<td>0.5</td>
<td>0.15</td>
</tr>
<tr>
<td>Intelligent mutation 1</td>
<td>0.5</td>
<td>0.75</td>
</tr>
<tr>
<td>Intelligent mutation 2</td>
<td>—</td>
<td>0.55</td>
</tr>
</tbody>
</table>

Table 3: Per unit maintenance cost for the ESS.

<table>
<thead>
<tr>
<th>Year</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>1.7</td>
<td>3.6</td>
<td>3.6</td>
<td>5.1</td>
<td>5.9</td>
<td>15.3</td>
</tr>
</tbody>
</table>

state is being charged from 2nd to 5th hours and from 16th to 18th hours, most of the units are not committed. It means that load factor of thermal units were improved. Table 4 shows a comparison of total production cost for the heuristic method and the proposed method. Note that this comparison is made based on per day (24 hours) scheduling cost of thermal units with ESS. The proposed method achieved a saving of total production cost (amount $13,580) by installing the ESS. Table 5 shows the sensitivity of the proposed method by demonstrating variation in production cost such as best, worst and average production cost obtained for a particular number of runs. Note that (by comparing tables 4 and 5), the worst production cost achieved by this method is even better than that of heuristic method.

![Figure 10. Thermal units commitment schedule without ESS](image)
Figure 11. Thermal units and ESS schedule after the proposed method

![Figure 11](image)

Figure 12 shows load demand curve after the proposed method is applied. In can be seen from this figure, that load leveling was also achieved using the proposed method. Figure 13 and 14 show hourly-inverter output and stored energy, respectively. Since the load demand is minimum at 4th hour, ESS status becomes charged and amount of charged energy is started increasing. At 5th hour, the inverter output becomes the rated power as stored energy is not full till 4th hour. Since the load demand is the maximum at 12th hour, state of ESS becomes discharged and amount of discharged energy start increasing. However, inverter output at 12th hour is smaller than inverter output at 11th hour.

![Figure 12](image)
Table 4: Comparison of total cost heuristic method and proposed method.

<table>
<thead>
<tr>
<th></th>
<th>Total cost[$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>heuristic method</td>
<td>561,012</td>
</tr>
<tr>
<td>proposed method</td>
<td>555,908</td>
</tr>
<tr>
<td>with ESS</td>
<td>547,432</td>
</tr>
<tr>
<td>without ESS</td>
<td></td>
</tr>
<tr>
<td>with ESS</td>
<td></td>
</tr>
</tbody>
</table>

5 Conclusion

This paper presents the determination method for optimal operation schedule of thermal units integrated with ESS and charge/discharge schedule of installed ESS. First, the proposed method determines schedule for thermal units and ESS, and then determines the optimal outputs dispatch for thermal units and ESS. This paper is able to reduce the production cost by the amount of $13,580 using of the proposed method. Since this paper formulates generalized ESS, the method can be applied to different types of ESS. However, since this paper did not consider determination of the optimal size of ESS, there is still a possibility optimizing system operational cost. Hence future work is determination of the optimal size of ESS, and the optimal schedule of thermal units and ESS.
Figure 14. Stored energy in ESS at each times

Table 5: Test result of proposed method.

<table>
<thead>
<tr>
<th>Total cost[$]</th>
<th>Best value</th>
<th>Worst value</th>
<th>Average value</th>
</tr>
</thead>
<tbody>
<tr>
<td>547,432</td>
<td>550,126</td>
<td>548,727</td>
<td></td>
</tr>
</tbody>
</table>

References


