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A Control Approach of Battery Energy Storage Systems to Reduce kW Demand

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Abstract. This paper presents a control approach of battery energy storage systems to reduce kW demand under the two-part tariff pricing environment. The proposed algorithm is to minimize the maximum peak load using the forecasting load information during each interval for the charging and discharging periods of a storage system; the optimization of each interval is solved using the dynamic programming technique. The simulation result shows that it is greatly useful to reduce the maximum peak load as well as accomplish load leveling. This work will contribute to electricity cost savings.

1 Instruction

A two-part tariff pricing for electrical power has been adopted in most of the countries. It estimates for the rates of the connected kW demand and electrical kWh usage for electricity consumers. The first part of the two-part tariff considers maintenance and depreciation fees for electrical facilities that have been invested in providing consumers with electricity, and the second part considers fuel costs used for generating electricity.

Battery energy storage systems (BESSs) have been popular among industry areas because of its economic benefits and power quality enhancement [1]. In economic aspects of BESSs, peak load shaving or load leveling has been utilized in various sites such as factories, campuses, microgrids, etc. as a technique to reduce utility power consumption and energy costs during peak-load periods. In [2], a peak load shaving method in power grids with utility owned a BESS is proposed. Using energy bars and the utilization factor of the BESS, the total loss, purchased power and demand reductions are estimated. In [3], a dispatch method to enhance unbalanced low voltage on distribution grids is proposed using a BESS. It emphasizes the reduction in annual maximum demand and enhanced load leveling effect. In [4], an economic operation method in isolated islands is proposed. Using the operation plans of generators and a BESS, it shows the reduction of the annual system costs. Above-mentioned studies accomplish the peak shaving objective based the electrical kWh usage. It is also necessary to reduce the connected kW demand on the demand side in a two-part tariff pricing environment.

In Korea, the monthly electrical power price is calculated by adding the basic price based the kW demand and the electrical kWh usage price for industrial customers [5]. After finding the maximum peak load for December, January, February, July, August and September among the previous year including the current month, the basic price is calculated by multiplying the selected maximum peak load and the constant price. The candidates for the maximum peak load are calculated with the consumed load during each 15 minutes for the periods; most of the countries adopt 15 minutes as a certain amount of time to determine the maximum peak load to avoid a temporary peak power due to faults.

This paper proposes the peak load shaving algorithm to reduce the basic price based on dynamic programming and load forecasting. The kW demand is determined considering the state of charge (SOC), the target values of the BESS and the forecast load for the discharging and charging periods.

2 Proposed algorithm

2.1 Assumptions

There are some assumptions to simplify the proposed algorithm.

- An application for forecasting day-ahead electricity load is performed in the test system.
- Charging and discharging periods of a BESS during each day is decided.
- A meter which can measure electricity load supplied by the utility each minute has been installed in the test system.

2.2 BESS operation strategy

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In order to ensure the life of a BESS, charging and discharging is composed of a 24-hour cycle, and it has a one charging period and one discharging period, respectively as shown in Fig. 1. The charging (or discharging) might be temporarily suspended during the charging period (or discharging period). Though the supplied power from the utility during each 15 minutes for a 24-hour cycle is lower than the past maximum peak load, the basic price is not lower; however, the electrical kWh usage price can be lower. Therefore, it is more effective in the energy cost that the BESS should be operated to reduce the supplied power from the utility as far as possible.

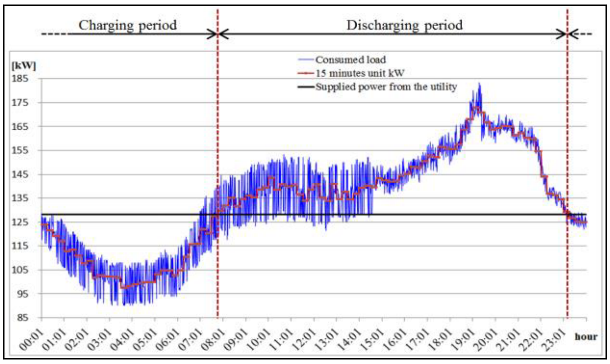


Figure 1. Example of a BESS operation.

2.3 Definition of the problem

2.3.1 Nomenclature

k	A 15-minute interval for the discharging (or charging) period within a 24-hour cycle ($k \in [k_1, k_{end}]$; k is one of the only discharging (or charging) period.)
k_{cur}	The current 15-minute interval
$P_{base}(k)$	The supplied power from the utility during the interval k
$P_{LF}(k)$	The forecasting load during the interval k; k is one of the future intervals.
$P_{E_{given}}$	The power which the BESS could discharge after completing its charge within a 24-hour cycle
$P_{E_{dis}}(k)$	The power which the BESS discharges during the interval k
$P_{E_{chg}}(k)$	The power which the BESS charges during the interval k
$P_{Dif_{dis}}(k)$	The power which the BESS will discharge during the interval k; k is one of the future intervals.
$P_{Dif_{chg}}(k)$	The power which the BESS will charge during the interval k; k is one of the future intervals.
$P_{E_{SOC\min}}$	The minimum value of the BESS' state of charge (SOC)
$P_{E_{SOC\max}}$	The maximum value of the BESS' state of charge (SOC)
$P_{E_{dis\max}}$	The maximum discharge value of the BESS; it is set by the operator.
$P_{E_{chg\min}}$	The minimum charge target value of the BESS; it is set by the operator.
$P_L(k)$	The consumed power from the load components during the interval k (i.e., in the discharging period, $P_L(k)$ is the sum of the supplied power and the BESS' discharged power, and in the charging period, $P_L(k)$ is the sum of the supplied power and the BESS' charged power.)

2.3.2 Objective function and constraints for discharging

As we consider discharging of a BESS, the objective is to minimize the supplied power from the utility. The objective function is formulated as:

$$\text{Min} \quad P_{base}(k) \tag{1}$$

As a constraint, the sum of the past discharged power and future discharging power (i.e., the sum of differences between the forecasting load and the supplied power since the current interval k until the last interval) is less than or equal to the maximum discharging power as expressed as:

$$\sum_{k=1}^{k_{cur}-1} P_{E_{dis}}(k) + \sum_{k=k_{cur}}^{k_{end}} P_{Dif_{dis}}(k) \le P_{E_{given}} - P_{E_{SOC\min}} \tag{2}$$

The maximum discharge value of the BESS is constrained as:

$$\sum_{k=1}^{k_{cur}-1} P_{E_{dis}}(k) + \sum_{k=k_{cur}}^{k_{end}} P_{Dif_{dis}}(k) \ge P_{E_{dis\max}} \tag{3}$$

During the interval k, if the consumed load is greater than the supplied power, the difference between them will be the discharging power of the BESS; otherwise, the BESS will not discharge. This constraint is expressed as:

$$P_{E_{dis}}(k) = \begin{cases} P_L(k) - P_{base}(k) & if \;\; P_L(k) > P_{base}(k) \\ 0 & if \;\; P_L(k) \le P_{base}(k) \end{cases} \tag{4}$$

Finally, during the interval k, one of the future intervals, if the forecasting load is greater than the supplied power, the difference between them will be the discharging power of the BESS; otherwise, the BESS will not discharge. This constraint is expressed as:

$$P_{Dif_{dis}}(k) = \begin{cases} P_{LF}(k) - P_{base}(k) & if \;\; P_{LF}(k) > P_{base}(k) \\ 0 & if \;\; P_{LF}(k) \le P_{base}(k) \end{cases} \tag{5}$$

The above objective function and constraints should be fulfilled during each interval for the only discharging period (i.e., $k \in [k_1, k_{end}]$). Since the optimization is performed at each interval, the problem can be solved using the dynamic programming technique [6].

2.3.3 Objective function and constraints for charging

In this section, we consider charging of a BESS. The objective for the charging is to minimize the supplied power from the utility. The objective function is the same as shown in (1).

As a constraint, the sum of the past charged power and future charging power (i.e., the sum of differences between the supplied power and the forecasting load since the current interval k until the last interval) is less than or equal to the maximum value of the BESS' SOC as expressed in (6).

$$\sum_{k=1}^{k_{cur}-1} P_{E_{chg}}(k) + \sum_{k=k_{cur}}^{k_{end}} P_{Dif_{chg}}(k) \le P_{E_{SOC\max}} \tag{6}$$

The minimum charge target value of the BESS is constrained as:

$$\sum_{k=1}^{k_{cur}-1} P_{E_{chg}}(k) + \sum_{k=k_{cur}}^{k_{end}} P_{Dif_{chg}}(k) \ge P_{E_{chg\min}} \tag{7}$$

During the interval k, if the consumed load is less than the supplied power, the difference between them will be the charging power of the BESS; otherwise, the BESS will not charge. This constraint is expressed as:

$$P_{E_{chg}}(k) = \begin{cases} 0 & if \;\; P_L(k) \ge P_{base}(k) \\ P_{base}(k) - P_L(k) & if \;\; P_L(k) < P_{base}(k) \end{cases} \tag{8}$$

Finally, during the interval k, one of the future intervals, if the forecasting load is less than the supplied power, the difference between them will be the charging power of the BESS; otherwise, the BESS will not charge. This constraint is expressed as:

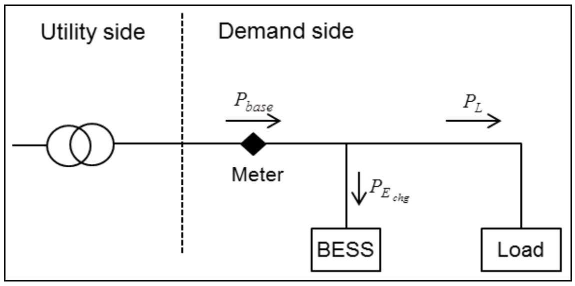
$$P_{Dif_{chg}}(k) = \begin{cases} 0 & if \;\; P_{LF}(k) \ge P_{base}(k) \\ P_{base}(k) - P_{LF}(k) & if \;\; P_{LF}(k) < P_{base}(k) \end{cases} \tag{9}$$

The above constraints and equation (1) should be fulfilled during each interval for the only charging period. Since the optimization for the charging is performed at each interval during the charging period, this problem can be also solved using the dynamic programming technique.

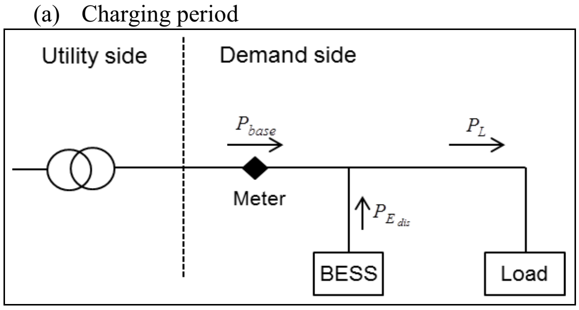
3 Simulation studies

3.1. Test system environment

A factory site which owns a 300 kWh BESS and an electrical power meter is studied as shown in Fig. 2. The maximum and minimum values of the BESS' SOC are 300 kWh and 30 kWh, respectively, and the past maximum peak load of the site is 142 kW. The meter only measures the supplied power from the utility side to the demand side.



(a) Charging period



(b) Discharging period

Figure 2. Test system.

According to the two-part tariff pricing, the basic and the electrical kWh usage prices for the test system are given in Table 1; the kWh usage price is decided by the time of use (TOU) rate.

Table 1. Electricity prices

Basic price [$/kW]	kWh usage price [$/kWh]	
7	Low load (00:00 ~ 06:00)	0.05
	Middle load (06:00 ~ 09:00)	0.10
	Peak load (09:00 ~ 00:00)	0.17

3.2 Computer simulations

This section describes the simulation results for the charging and discharging periods of the BESS in the test system. Then the comparison of the system with and without the BESS is discussed.

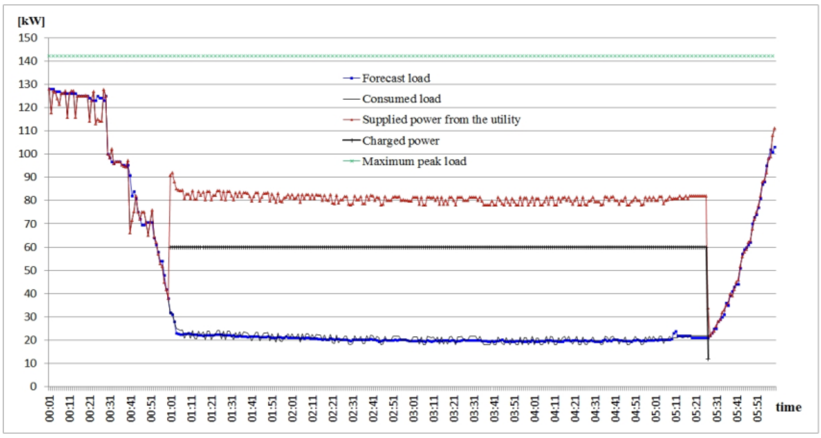
3.2.1 Charging period

Figure 3 (a) shows the simulation result in the charging period. During the period from 01:00 to 05:27, the BESS charges about 60 kW, the consumed load is about 20 kW; therefore, the supplied power from the utility is about 80 kW. It is noted that the supplied power does not exceed the past maximum peak load and the current peak load, and the purely consumed load on the load follows the forecast load closely.

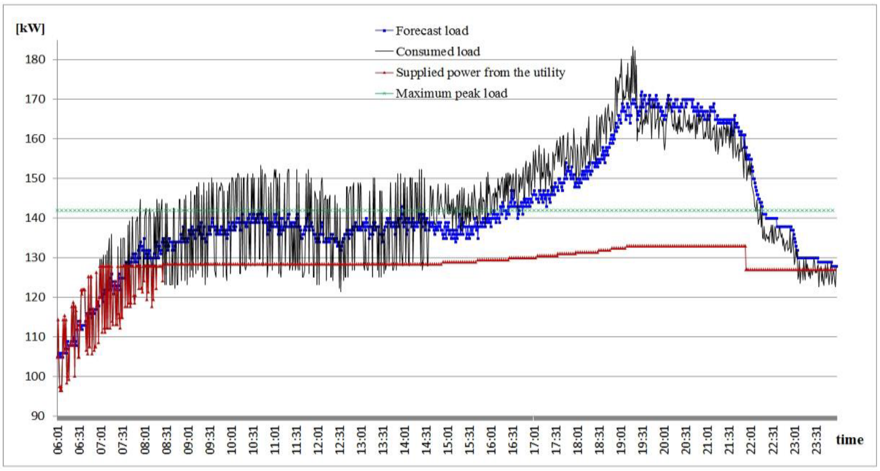
3.2.2 Discharging period

Figure 3 (b) shows the simulation result in the discharging period. The supplied power is calculated by the proposed algorithm. During the period from 06:00 to 07:00, the BESS does not either charge or discharge. The BESS starts the discharging from 07:00. After that time the consumed load follows the forecast load closely, and the supplied power keeps almost constant value, 128.5 kW until 14:54. Subsequently, the consumed load rises than the forecast load until 19:30, and the supplied power increases to 133 kW in a unit step function. In the final period, the consumed load is lower than the forecast load until 24:00, and the supplied power keeps constant for a while and decreases to 127 kW afterward. From this discharging simulation result, the features of the proposed algorithm are observed as follows:

1) When the consumed load follows the forecast load closely, the supplied power keeps almost constant value.
2) When the consumed load tends to be higher than the forecast load, the supplied power increases not to exceed the maximum discharge power limit of the BESS.
3) When the consumed load tends to be lower than the forecast load, the supplied power decreases to maximize the discharge power of the BESS.



(a) Charging period



(b) Discharging period

Figure 3. Simulation result of the test system.

3.2.3 Comparison of the test system

The effectiveness of the BESS using the proposed algorithm is shown in Table 2. The maximum peak load is determined as 133 kW; therefore, the kW demand reduction is 26.5 % and kW demand price also decreases. In addition, the kWh usage price is reduced because of the TOU rate and the optimal operation of the BESS.

Table 2. Comparison of the test system with and without the BESS.

	Without BESS	With BESS
Peak load [kW]	180.9	133.0
kW demand reduction [%]	0	26.5
kW demand price [$]	1,266.3	931.0
kWh usage price [$]	421.0	390.4
kWh usage price reduction [%]	0	7.3

4 Conclusion

An algorithm to reduce kW demand under the two-part tariff pricing environment has been proposed. The kW demand is optimized depending on the difference between the forecast load and the real consumed load during the interval for the charging and discharging periods. The simulation results show that peak load shaving and the kW demand reduction have been achieved. Additionally, kWh usage reduction has been accomplished. In the next study, a research to reduce both kW demand and kWh usage using BESSs will be performed.

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