Multi-Energy Systems Optimization of an Educational Building in South Korea

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Abstract

This paper proposes the optimization of the multi-energy source that combines combined heat and power (CHP), solar photovoltaic (PV), energy storage system (ESS), thermal energy storage system (TES), and absorption chiller (AC). This configuration is designed to meet optimal and efficient electricity, cooling, and heating load requirements. As a result, this installation minimizes electricity bills and still considers the emissions factor to keep the energy load reliable. This proposed optimization approach can reduce energy bills by 29.6%, making it a feasible option for minimizing energy bills

Ⅰ. Introduction

Nowadays, the smart grid has been developed across several countries owing to its numerous advantages, including ease of control of energy exchange. Problems such as fluctuating energy generated by solar photovoltaic and wind energy can lead to an imbalance in energy supply and demand. ESS can be utilized to increase the reliability of renewable energy generation [1].

In general, energy demand can be classified into three categories: electrical, cooling, and heating. However, both cooling and heating loads are related to electricity consumption. When utilizing a boiler, for example, the energy from the gas is converted into heat. On the other hand, air conditioners utilize electrical energy to satisfy cooling load requirements [2]. As a result, this issue is addressed in this study to avoid duplicate counting, which leads to improper optimization results. Furthermore, CHP, the optimal power-to-heat ratio component, is integrated with ESS and TES to store surplus energy [3].

Ⅱ. Experimental Methodology

The data for this study were obtained by modeling one of Kyungpook National University's buildings in DesignBuilder. The data includes energy load, PV generation, educational building electricity pricing, heat load, cooling load, and gas prices. The objective function of this study is to minimize electricity bills, gas bills, and emissions by installing TES and ESS. The objective function can be written as:

$$OF = C_{elec} + C_{gas} + C_{emiss} \quad (1)$$

The electricity bill depends on how much power is purchased from the grid and used to charge the battery. To reduce the bill, the battery should charge the power during on-peak periods and discharge during the on-peak period. Mathematically,

$$C_{elec} = P_{e,t}(C_{e,grid+} + (SOC_{ESS,t} - SOC_{ESS,t-1}) \times k_{ESS,cap}) \quad (2)$$

The gas bill also depends on the amount used to meet the heat load and charge the TES. The gas bill of the building is as follows:

$$C_{gas} = P_{g,t}(C_{g,utility+} + (SOC_{TES,t} - SOC_{TES,t-1}) \times k_{TES,cap}) \quad (3)$$

At this stage, the system's capacity to purchase electricity and gas should be constrained by imposing an emission penalty. The penalty consists of the carbon tax and emission rate per kWh. As a result, the system doesn't rely on a single type of energy to supply the load. The emission is calculated as follows:

$$C_{Emiss} = C_{tax}(C_{e,grid+} \times \varepsilon_{elec} + C_{e,utility} \times \varepsilon_{gas}) \quad (4)$$

The TES and ESS operation is constrained by the state of charge (SOC). The SOC update equation is given as follows:

$$SOC_{ESS,t} = SOC_{ESS,t-1} + \frac{p_{ESS}}{k_{ESS,cap}} \quad (5)$$

$$SOC_{TES,t} = SOC_{TES,t-1} + \frac{p_{TES}}{k_{TES,cap}} \quad (6)$$

CHP is also used to convert natural gas into heat and electricity [4]. In addition, an Absorption chiller (AC) can store excess heat from the CHP to provide an additional cooling load. The components used in the system have the parameters described in Table 1.

From Equations (1)-(6), optimizations are conducted using Mixed Integer Linear Programming with additional constraints to ensure that the components do not operate exceeding the limit.

Table 1. Parameters of the components.

	ESS [kWh]	TES [kWh]	CHP [kW]	AC [kW]
Capacity	800	1000	-	-
Power	400	500	400	100

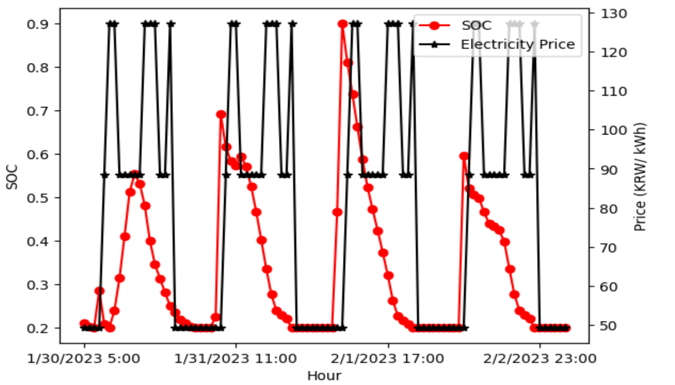

Figure 1. ESS operation in winter

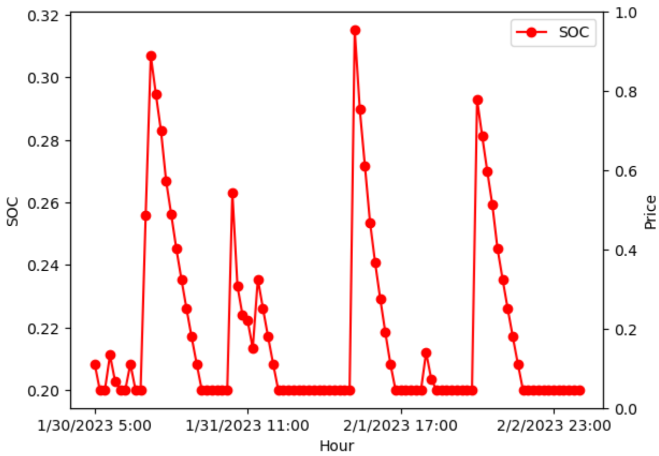

Figure 2. TES operation in winter

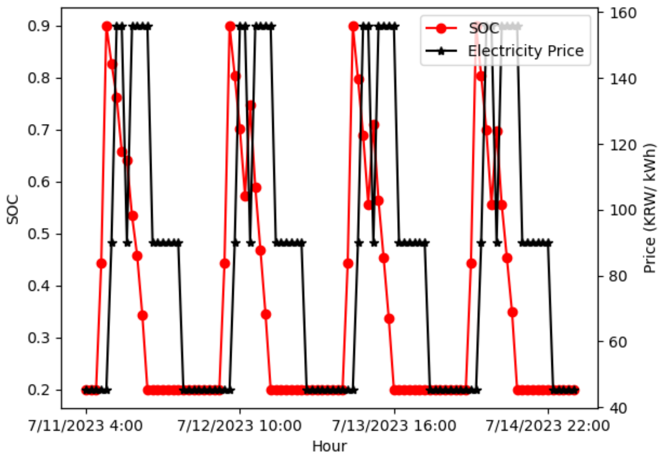

Figure 3. ESS operation in the summer

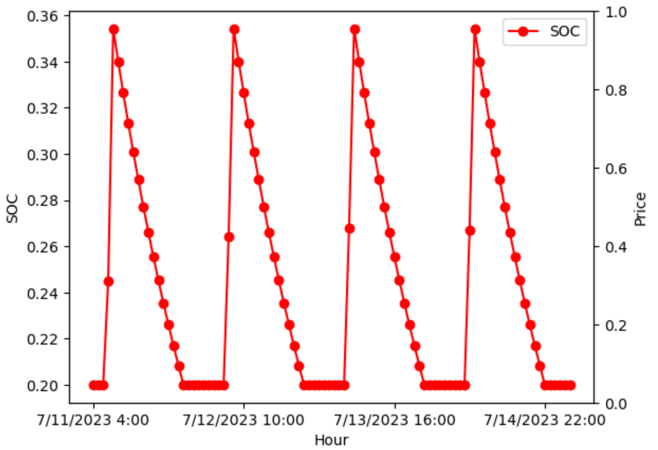

Figure 4. TES operation in the summer

Table 2. Comparison of different energy storage installations.

Components	Gas Bill [KRW]	Electricity Bill [KRW]	Total Bill [KRW]
No ESS and TES	679,695	25,353,685	26,033,380
ESS only	679,695	22,390,465	23,070,160
TES only	676,635	25,353,685	26,030,320
ESS and TES	763,853	17,573,894	18,337,747

Ⅲ. Result and Conclusion

Figures 1 and 2 show the sample optimal operation of the ESS and TES for four consecutive days in winter beginning on January 30th. ESS charges when electricity prices are low and discharges when electricity prices are high. SOC values are limited to 0.2 as minimum and 0.9 as maximum. TES keeps operating during the winter to help the system meet the cooling load requirements by utilizing the absorption chiller

Both TES and ESS keep operating to fulfill energy demand in summer on July 11th, as seen in Figures 3 and 4. Table 2 shows the gas and electricity bills comparison based on 1-year TES and ESS charging-discharging processes.

Coupling ESS and TES can lower the energy bill by 29.6% compared to not utilizing ESS or TES. However, the installation of CHP, which uses natural gas to supply heating load requirements, raises the gas cost by 12.38%.

Overall, the proposed optimization to minimize gas and electricity expenses in this study can reduce energy bills based on a comparison of four alternative configurations, allowing it to be an optimum configuration strategy for energy saving of the building.

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