Development of Methodology and Engineering Model for Generation Expansion Planning Considering Environmental Policy and Energy Storage System

Soonhyun Hwang and Balho H. Kim
Power Economics Lab, Hongik University, Seoul, Republic of Korea
Email: {hsoon0313, bhkim0711}@gmail.com

***Abstract*—Korea has expanded the supply of the Energy Storage System (ESS) after the establishment of K-ESS 2020, but the criteria for adequate install capacity are insufficient. In addition, the Wien Automatic System Planning (WASP) program is used in Korea when establishing generation expansion planning, but there are difficulties in reflecting environmental and new facility supply policies. In this paper, a generation expansion planning model considering environmental policy and ESS facility characteristics is proposed, and the change of the generation expansion plan according to the reflection of various policies is examined by conducting case studies.**

***Index Terms*—Dynamic programming, energy storage system, environmental policy, generation expansion planning, optimization**

I. Introduction

Globally, the installed capacity of energy storage system (ESS) is estimated to be 3.1 GW by 2018, 1.4 GW higher than 2017, and it is expected to continue to increase [1]-[3]. As part of this trend, Korea established the 'Energy Storage Technology Development and Industrialization Strategy (K-ESS 2020)' in 2011 and conducted various ESS demonstration projects for substation, renewable energy complex, large scale generator, and buildings. Also, ESS is expanding through various policies such as 'ESS Financial Support Policy, 2016', 'Mandatory Establishment of ESS to Public Institutions, 2017' and 'New Energy industry Convergence System Dissemination Business, 2018'. Through the policy, Korea is operating a 1.8 GWh of ESS in 2018, which is 20 times more than in 2017. National support for ESS installation will continue in the future, but it is necessary to estimate the appropriate ESS capacity at the national perspective to prevent resource waste due to excessive dissemination. Currently, a number of studies have been carried out on the economics of ESS and the estimation of the appropriate capacity, but most of them are related to small-scale [4]-[6] or renewable energy linkage [7]-[9] or frequency regulation [10]-[11], and the analysis of the national view on ESS for peak load reduction is very few. In [12], the appropriate capacity analysis of ESS for each application was performed from the national perspective, but only a short-term analysis was made. It is necessary to study the methodology or model that can be used for long-term planning in the situation that ESS supply is continuously expanding. In this paper, a Generation Expansion Planning (GEP) model that reflects environmental policy and ESS characteristics is proposed, and a case study using the model is presented.

Manuscript received July 23, 2019; revised August 25, 2019; accepted October 15, 2019.

Corresponding author: Soonhyun Hwang (email: kerobes13 @nate.com)

II. GEP Model Considering Environmental Policy and ESS Characteristics

A. Outline of the Proposed Model

In [13], the optimal ESS capacity from the national perspective was calculated as a previous research. However, in the previous research, the charge/discharge characteristics of the ESS were not applied within the model. The ESS was treated as a renewable source such as wind power or photovoltaic power, which is a non-dispatchable source, and the daily schedule of ESS was specified based on past load data by an external module. In this paper, the constraints about ESS charge/discharge characteristics are added to the existing model so that our improved model can find the optimal schedule of ESS during the planning horizon.

Fig. 1 outlines the proposed GEP model, which consists of three parts: input module, optimization module, and output module. The input module constitutes input data (facility information, load information, environmental policy information, economic index, etc.) necessary for the operation. The output module outputs the results (optimal fuel mix for each year, the total cost for each item, CO_2 emission, etc.) of the optimization module. The optimization module, which is the core of this model, is divided into three modules: reliability module, operating cost module, and dynamic programming module. The reliability module creates a facility combination of states for each step for dynamic

doi: 10.18178/ijeetc.9.2.68-72

planning and calculates the installed reserve rate for each combination. After that, the combination that does not meet the reliability constraint is deleted to improve the overall convergence speed. The operating cost module calculates the minimum annual operating cost that satisfies various constraints for each combination generated in the reliability module. In the dynamic programming module, a yearly fuel mix and construction plan is derived based on the operating cost of each facility combination by year and the construction cost due to the construct of new facility, which minimizes the total cost during the planning horizon.

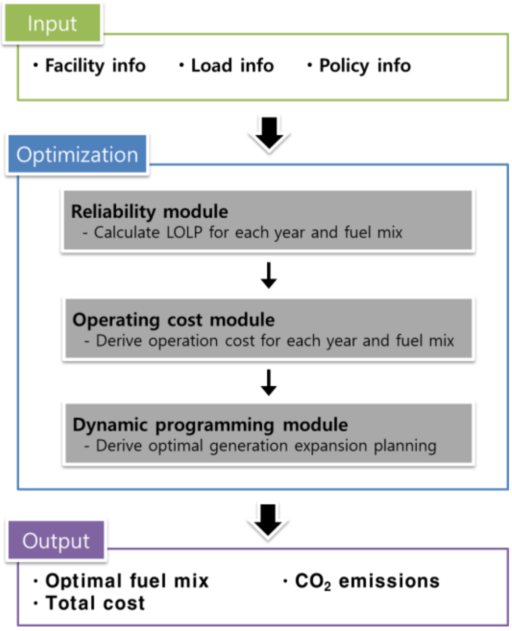


Fig. 1. Overview of the proposed model.

B. Formulation

The objective function is designed to minimizes the total cost during the planning period, it consists of the sum of operating cost, construction cost, and emission trading cost for one full year, expressed as follows:.

$$\min \sum_{y}\left(C_y^{\text{Oper}} + C_y^{\text{Const}} + C_y^{\text{ETS}}\right) \tag{1}$$

$$\text{s.t.} \sum_{i} X_{i,y,t} + \sum_{\text{ESS}} X_{\text{ESS},y,t} = D_{y,t} + \sum_{\text{ESS}} X_{\text{ESS},y,t}^{\text{charge}} \tag{2}$$

$$X_{i,y,t} \le \text{Cap}_{i,y} \tag{3}$$

$$\sum_{t}^{24} X_{\text{ESS},y,t} \le \sum_{t}^{24} X_{\text{ESS},y,t}^{\text{charge}} \cdot \eta_{\text{ESS}} \tag{4}$$

$$X_{\text{ESS},y,t}^{\text{charge}} \le \text{Cap}_{\text{ESS},y} \tag{5}$$

$$\text{ET}_y^{\text{Emission}} = \text{ET}_y^{\text{Trade}} + \text{ET}_y^{\text{Cap}} \tag{6}$$

$$\text{ET}_y^{\text{Emission}} = \sum_{i}\sum_{t}\left(X_{i,y,t} \cdot \text{Coef}_i\right) \tag{7}$$

$$\text{Res}^{\min} \le \text{Res}_y \le \text{Res}^{\max} \tag{8}$$

$$X_{i,y,t},\ X_{\text{ESS},y,t},\ X_{\text{ESS},y,t}^{\text{charge}} \ge 0 \tag{9}$$

where y represents year, t represents time, and i stands for generator type. The other are as follows:

C_y^{Oper} : Operating cost in period y
C_y^{Const} : Construction cost in period y
C_y^{ETS} : Emission trading cost in period y
$X_{i,y,t}$: Power produced by generator i in time t
$X_{\text{ESS},y,t}$: Discharge amount of ESS in time t
$X_{\text{ESS},y,t}^{\text{charge}}$: Charge amount of ESS in time t
$D_{y,t}$: Demand in time t
$\text{Cap}_{i,y}$: Capacity of generator i in period y
$\text{Cap}_{\text{ESS},y}$: Capacity of ESS in period y
η_{ESS} : Efficiency of ESS
$\text{ET}_y^{\text{Emission}}$: Emission in period y
$\text{ET}_y^{\text{Trade}}$: Emission trading in period y
ET_y^{Cap} : Emission criterion in period y
Coef_i : Emission coefficient of generator i
Res_y : Installed reserve rate in period y
$\text{Res}^{\min}$: Minimum installed reserve rate in period y
$\text{Res}^{\max}$: Maximum installed reserve rate in period y.

The operating cost is calculated as the sum of annual generation cost and maintenance cost:

$$C_y^{\text{Oper}} = C_y^{\text{Gen}} + C_y^{\text{O\&M}} \tag{10}$$

The generation cost and maintenance cost are calculated by

$$C_y^{\text{Gen}} = \sum_{i}\sum_{t}\left(X_{i,y,t} F_i\right) \tag{11}$$

$$C_y^{\text{O\&M}} = \sum_{i}\left(\text{Cap}_{i,y} M_i\right) + \sum_{\text{ESS}}\left(\text{Cap}_{\text{ESS},y} M_{\text{ESS}}\right) \tag{12}$$

where F_i is the unit generation cost of generator i and M_i and M_{ESS} are the unit maintenance cost of generator i and ESS, respectively.

The construction cost consists of the difference between the construction cost of the new facility and the salvage value, calculated by

$$C_y^{\text{Const}} = C_y^{C} - C_y^{S} \tag{13}$$

where C_y^{C} is the construction cost in period y and C_y^{S} is the salvage value in period y.

The construction cost is the product of new input capacity and unit construction cost for each facility, calculated by

$$C_y^{C} = \sum_{i} K_i \cdot \text{Add}_{i,y} + \sum_{\text{ESS}} K_{\text{ESS}} \cdot \text{Add}_{\text{ESS},y} \tag{14}$$

where K_i and K_{ESS} are the unit construction cost of generator i and ESS, respectively, and Add_y is the capacity of the newly installed facility in period y.

And the salvage value is the ratio of the remaining life after the planned period to the lifetime of the facility, calculated by

$$C_y^{S} = \sum_{i}\left[K_i \cdot \text{Add}_{i,y} \cdot \frac{\text{life}_i - Y_T + y - y_s}{\text{life}_i}\right] + \sum_{\text{ESS}}\left[K_{\text{ESS}} \cdot \text{Add}_{\text{ESS},y} \cdot \frac{\text{life}_{\text{ESS}} - Y_T + y - y_s}{\text{life}_{\text{ESS}}}\right] \tag{15}$$

where life represents the lifetime, Y_T is the total planning period, and y_s is the start year of the plan.

The emission trading cost is the product of the total annual emission trading and the price of the emission credit in the year, calculated by

$$C_y^{\mathrm{ETS}} = \mathrm{ET}_y^{\mathrm{Trade}} \cdot \mathrm{ET\_P}_y \tag{16}$$

where $\mathrm{ET\_P}_y$ is the emission credit price in period *y*.

If the volume of emissions trading is positive, it means that the amount of CO_2 emissions in the relevant year is higher than the allowable emission amount, which means that the emission credit must be purchased. If the emission amount is negative, the emission credit is sold.

Equation (2) is a supply-demand constraint. The sum of the generation of each facility and ESS discharge by time should be equal to the sum of demand and ESS charge at the same time. Equations (3) and (4) are generation capacity constraints. The generation capacity of each facility cannot exceed the total capacity of the facility as (3). The amount of discharge of ESS for one day (24 hours) cannot be greater than the total amount of charge for that day multiplied by the efficiency as (4), and the maximum charge amount cannot exceed the facility capacity of the ESS as (5). The CO_2 emissions by year are constrained by annual CO_2 emissions as (6), which is the sum of the emission trading and the emission allowance for the year. The total CO_2 emission per year is calculated by multiplying the total annual generation amount and the emission coefficient of each facility as (7). In order to maintain proper reliability, the installed reserve rate should be maintained every year as (8).

III. Case Study

A. Case Study Premise

In this paper, a case study was conducted based on the 8th Basic Plan for Long-term Electricity Supply and Demand [14], and detailed scenarios are shown in Table I. After the Fukushima nuclear power plant accident that occurred in 2011, there is a growing concern about the expansion of nuclear facilities in Korea. The plans for the nuclear power plants that were planned to be newly constructed are being canceled. In order to reflect the above background, the scenario was selected by separating the possible and impossible cases of nuclear power plant expansion, and specific cases were selected according to the environmental constraints (emission trading system, target management system) and whether to install ESS. In addition, since the ESS will not be economically feasible due to the high installation cost, the case of reducing the installation cost of ESS is also applied.

TABLE I: CASE STUDY SCENARIOS

Case	Nuclear power	Environmental policy	ESS	Construction cost of ESS	Emission credit price
Case1	O	X	X		
Case2	O	X	O		
Case3	O	X	O	-90%	
Case4	O	O	X		
Case5	O	O	O		
Case6	O	O	O	-90%	
Case7	O	O	O	-90%	-30%
Case8	X	X	X		
Case9	X	X	O		
Case10	X	X	O	-90%	
Case11	X	O	X		
Case12	X	O	O		
Case13	X	O	O	-90%	
Case14	X	O	O	-90%	-30%

The basic premise for carrying out the case study is as follows.

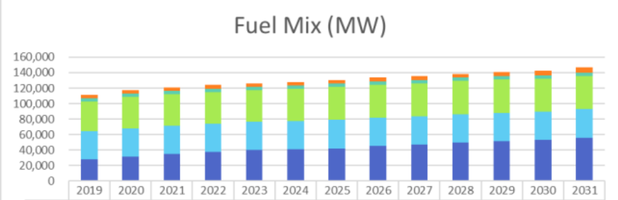
- All facility and load are connected to one node.
- The maximum load for the future year is based on the forecast data of the 8th Basic Plan for Long-term Electricity Supply and Demand.
- The planning horizon is from 2019 to 2031, equal to the 8th Basic Plan for Long-term Electricity Supply and Demand.
- The discount rate is 6%
- Candidate facilities include nuclear, coal, LNG, oil and ESS (LiB)
- The construction cost is calculated as over-night cost.
- Installed reserve rate constraints are at least 13% and up to 22%

B. Case Study Results

Table II summarizes the results of case studies and shows the total cumulative construction capacity of each facility during the planning horizon and the cumulative cost by item.

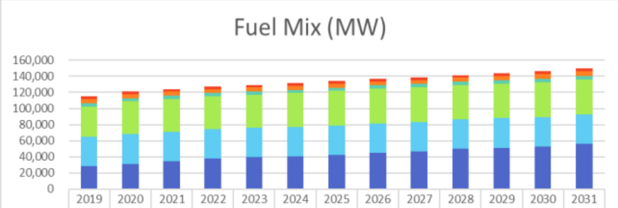
TABLE II: CASE STUDY RESULT

Case	Newly Added Facilities (MW)			Cumulative cost (million won)			
	Nuclear	Coal	ESS	Operation	Construction	Emission Trading	Total
Case 1	36,800	0	0	290,632,603	31,416,016	0	322,048,619
Case 2	36,800	0	0	290,632,603	31,416,016	0	322,048,619
Case 3	36,800	0	3,200	289,984,285	32,001,008	0	321,985,293
Case 4	36,800	0	0	291,093,986	31,416,016	-2,775,945	319,734,057
Case 5	36,800	0	0	291,093,986	31,416,016	-1,843,659	320,666,342
Case 6	36,800	0	0	291,093,986	31,416,016	-1,843,659	320,666,342
Case 7	36,800	0	500	290,522,050	31,507,421	-889,249	321,140,222
Case 8	0	32,400	0	346,368,881	19,335,813	0	365,704,694
Case 9	0	32,400	0	346,368,881	19,335,813	0	365,704,694
Case 10	0	32,400	3,550	345,644,388	19,984,789	0	365,629,177
Case 11	0	27,000	0	350,210,006	16,690,647	23,659,973	390,560,626
Case 12	0	27,000	0	350,210,006	16,690,647	23,659,973	390,560,626
Case 13	0	27,000	0	350,210,006	16,690,647	23,659,973	390,560,626
Case 14	0	30,000	1,050	347,812,697	18,082,084	17,381,240	383,276,020



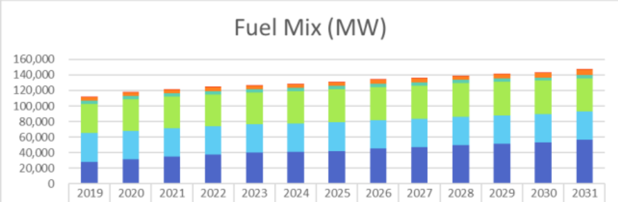
	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
ESS	0	0	0	0	0	0	0	0	0	0	0	0	0
PSH	4,700	4,700	4,700	4,700	4,700	4,700	4,700	4,700	4,700	4,700	5,500	6,100	6,700
Oil	4,319	4,264	4,264	4,264	4,264	4,264	4,264	4,264	4,264	4,264	4,264	4,264	4,264
LNG	37,779	40,655	40,655	40,655	40,655	41,915	42,915	42,915	42,915	42,915	42,915	42,915	42,915
Coal	36,594	36,594	36,594	36,594	36,594	36,594	36,594	36,594	36,594	36,594	36,594	36,594	36,594
Nuck	28,250	31,450	34,650	37,650	40,000	40,650	42,250	45,150	46,700	49,850	51,400	53,000	56,200

Fig. 2. Fuel mix of Case 1, Case 2, Case 4, Case 5, and Case 6.



	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
ESS	3,200	3,200	3,200	3,200	3,200	3,200	3,200	3,200	3,200	3,200	3,200	3,200	3,200
PSH	4,700	4,700	4,700	4,700	4,700	4,700	4,700	4,700	4,700	4,700	5,500	6,100	6,700
Oil	4,319	4,264	4,264	4,264	4,264	4,264	4,264	4,264	4,264	4,264	4,264	4,264	4,264
LNG	37,779	40,655	40,655	40,655	40,655	41,915	42,915	42,915	42,915	42,915	42,915	42,915	42,915
Coal	36,594	36,594	36,594	36,594	36,594	36,594	36,594	36,594	36,594	36,594	36,594	36,594	36,594
Nuck	28,250	31,450	34,650	37,650	40,000	40,650	42,250	45,150	46,700	49,850	51,400	53,000	56,200

Fig. 3. Fuel mix of Case 3.



	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
ESS	500	500	500	500	500	500	500	500	500	500	500	500	500
PSH	4,700	4,700	4,700	4,700	4,700	4,700	4,700	4,700	4,700	4,700	5,500	6,100	6,700
Oil	4,319	4,264	4,264	4,264	4,264	4,264	4,264	4,264	4,264	4,264	4,264	4,264	4,264
LNG	37,779	40,655	40,655	40,655	40,655	41,915	42,915	42,915	42,915	42,915	42,915	42,915	42,915
Coal	36,594	36,594	36,594	36,594	36,594	36,594	36,594	36,594	36,594	36,594	36,594	36,594	36,594
Nuck	28,250	31,450	34,650	37,650	40,000	40,650	42,250	45,150	46,700	49,850	51,400	53,000	56,200

Fig. 4. Fuel mix of Case 7.

In Case 1 to Case 7, including nuclear power in the candidate facility, the generation cost of nuclear power is considerably low, resulting in the result that all the new facilities during the planning horizon are constructed by nuclear power.

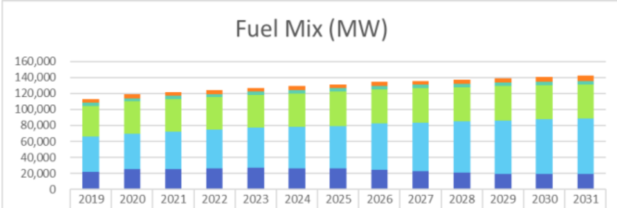
Case 1 and Case 2 are scenarios in which ESS is installed or not in the situation where environmental constraints are not applied, respectively, but the same results are obtained, because ESS was not economically feasible due to high installation costs. However, if the installation cost of the ESS is reduced by 90% (Case 3), economic feasibility will be secured, and 3200 MW of ESS will be installed during the planning horizon.

Case 4 shows that the total cost is reduced compared to Case 1, even though the environment constraint is added, because nuclear power which has a very low emission coefficient has been built in large quantities, and total emissions have been reduced by more than the target amount, thereby generating revenues by selling the remaining emission credits.

Case 5 and Case 6 show the ESS construction when the environmental constraint is added. Despite the 90% reduction in ESS installation cost, none of the ESS was installed. When ESS is installed, most of the charge is made by coal and discharged at the peak load period where LNG is generated. However, when the emission constraint is applied, the total cost increase and the ESS becomes meaningless because, as the coefficient of coal is high, the increment of emission trading cost is more considerable than the reduction of the generation cost.

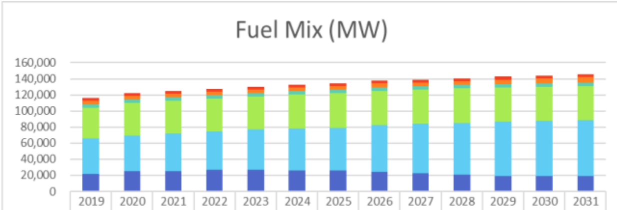
In Case 7, the cost of emission credit is reduced by 30%. In this case, the ESS has secured economic feasibility, and 500MW of ESS is installed.

Case 8 to Case 14 are cases where nuclear power is excluded from the candidate facility, and the results are similar to Case 1 to Case 7. With the exclusion of nuclear power which the coefficient and the generation cost is low, the total cost is increased by increased costs of generation and emission trading. In the case of ESS, the fact that ESS is installed when the installation cost is reduced by 90% and the emission credit cost is reduced by 30% is identical, but the amount is higher. In other words, the economic feasibility of ESS could be higher in the case when the expansion of nuclear power is restricted.



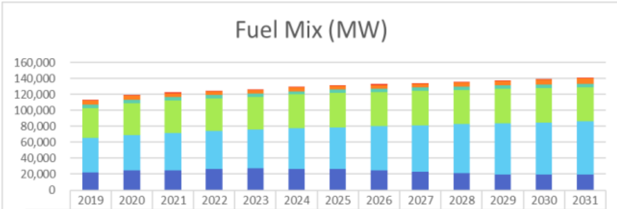
	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
ESS	0	0	0	0	0	0	0	0	0	0	0	0	0
PSH	4,700	4,700	4,700	4,700	4,700	4,700	4,700	4,700	4,700	4,700	5,500	6,100	6,700
Oil	4,319	4,264	4,264	4,264	4,264	4,264	4,264	4,264	4,264	4,264	4,264	4,264	4,264
LNG	37,779	40,655	40,655	40,655	40,655	41,915	42,915	42,915	42,915	42,915	42,915	42,915	42,915
Coal	44,194	44,194	46,994	47,994	49,994	51,994	52,994	57,994	60,994	63,994	66,994	67,994	68,994
Nuck	21,850	25,050	25,050	26,450	27,200	26,250	26,250	24,350	22,700	21,050	19,400	19,400	19,400

Fig. 5. Fuel mix of Case 8, Case 9, Case 11, Case 12, and Case 13.



	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
ESS	3,550	3,550	3,550	3,550	3,550	3,550	3,550	3,550	3,550	3,550	3,550	3,550	3,550
PSH	4,700	4,700	4,700	4,700	4,700	4,700	4,700	4,700	4,700	4,700	5,500	6,100	6,700
Oil	4,319	4,264	4,264	4,264	4,264	4,264	4,264	4,264	4,264	4,264	4,264	4,264	4,264
LNG	37,779	40,655	40,655	40,655	40,655	41,915	42,915	42,915	42,915	42,915	42,915	42,915	42,915
Coal	44,194	44,194	46,994	47,994	49,994	51,994	52,994	57,994	60,994	63,994	66,994	67,994	68,994
Nuck	21,850	25,050	25,050	26,450	27,200	26,250	26,250	24,350	22,700	21,050	19,400	19,400	19,400

Fig. 6. Fuel mix of Case 10.



	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
ESS	1,050	1,050	1,050	1,050	1,050	1,050	1,050	1,050	1,050	1,050	1,050	1,050	1,050
PSH	4,700	4,700	4,700	4,700	4,700	4,700	4,700	4,700	4,700	4,700	5,500	6,100	6,700
Oil	4,319	4,264	4,264	4,264	4,264	4,264	4,264	4,264	4,264	4,264	4,264	4,264	4,264
LNG	37,779	40,655	40,655	40,655	40,655	41,915	42,915	42,915	42,915	42,915	42,915	42,915	42,915
Coal	43,594	43,594	46,594	47,594	48,594	51,594	52,594	55,594	58,594	61,594	64,594	65,594	66,594
Nuck	21,850	25,050	25,050	26,450	27,200	26,250	26,250	24,350	22,700	21,050	19,400	19,400	19,400

Fig. 7. Fuel mix of Case 14.

IV. CONCLUSION

In this paper, a generation expansion planning model reflecting environmental policy and ESS facility characteristics is proposed, and case studies were carried out using the model.

Base on the result of the case studies, under the current circumstances, it is difficult to secure the economic feasibility of ESS due to the high installation cost. In order for ESS to be economically feasible as a role of reducing peak loads, installation costs should be reduced by 90% from the current level.

In this paper, only thermal power and ESS have considered during the case study. In future studies, renewable facilities should also be carried out, and detailed scenarios will be selected to analyze the potential for ESS installation.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Soonhyun Hwang and Balho H. Kim conceived and designed the analysis and conducted the research; Soonhyun collected the data and performed the analysis and wrote the paper; all authors had approved the final version.

ACKNOWLEDGMENT

This research was supported by Korea Electric Power Corporation. (NO: R17XA05-77)

REFERENCES

[1] World Energy Investment 2019. IEA, 2019.

[2] Luis Munuera. (June 18, 2019). Energy storage, tracking clean energy progress. [Online]. Available: https://www.iea.org/tcep/energyintegration/energystorage/

[3] Electricity Storage and Renewables: Costs and Markets to 2030, IRENA. October 2017.

[4] B. H. Ku and J. M. Cha, "A study on the evaluation of the ESS capacity of considering for charge-discharge characteristic and CO_2 emission in Jeju," *The Transactions of the Korean Institute of Electrical Engineers*, vol. 63, no. 4, pp. 455-460, 2014.

[5] J. Y. Park, H. Jung, H. Kim, S. Shin, "Capacity determination of ess for peak load shaving based on the actual measurement of loads in the substation of urban railway," *The transactions of The Korean Institute of Electrical Engineers*, vol. 63, no. 6, pp. 860-865, 2014.

[6] B. Kim, K. S. Ryu, D. J. Kim, M. S. Jang, H. S. Ko, and D. Rho, "Optimal operation method and capacity of energy storage system (ESS) in primary feeders with step voltage regulator (SVR)," *Journal of the Korea Academia-Industrial cooperation Society*, vol. 19, no. 6, pp. 9-20, 2018.

[7] Y. H. Kim, J. M. Park, H. S. Lee, S. H. Han, J. H. Jung, Y. R. Choi, and T. H. Lim, "A study on estimation of ESS capacity for inputting wind and solar power in frequency stability," *Journal of the Korean Institute of Illuminating and Electrical Installation Engineers*, vol. 33, no. 2, pp. 53-59, 2019.

[8] H. J. Lee and J. W. Choi, "Calculation of photovoltaic, ESS optimal capacity and its economic effect analysis by considering university building power consumption," *Journal of the Korean Society of Industry Convergence*, vol. 21, no. 5, pp. 207-217, 2018.

[9] H. S. Shin, J. S. Hue, and S. Y. Yun, "A study on sizing of battery for effective operation of stand-alone renewable generation system," *The Transaction of The Korean Institute of Electrical Engineers P*, vol. 67, no. 1, pp. 15-20, 2018.

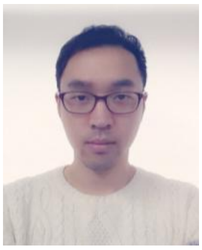
[10] J. G. Lee, S. S. Choi, M. K. Kang, and D. S. Rho, "A study on the performance verification and economic evaluation of ESS for frequency regulation application," *Journal of the Korean Institute of Illuminating and Electrical Installation Engineers*, vol. 18, no. 5, pp. 738-744, 2017.

[11] H. O. Lim, W. Y. Choi, H. N. Gwon, and K. S. Kook, "Effective capacity calculation of the electrical energy storage providing the primary frequency control service based on the contribution to the frequency response of Power Systems," *The Transactions of The Korean Institute of Electrical Engineers*, vol. 66, no. 11, pp. 1561-1567, 2017.

[12] J. H. Kim and S. M. Youn, "A study on establishing operation mathematical model for optimum capacity estimation of the ESS applications for each in the nationwide perspective," *The Transactions of The Korean Institute of Electrical Engineers*, vol. 65, no. 6, pp. 969-978, 2016.

[13] S. Lee, S. Hwang, and B. H. Kim, "A study on the optimal fuel mix and ESS capacity considering environmental policy," presented at MATEC Web of Conferences, May 2017.

[14] The 8th Basic Plan for Long-term Electricity Supply and Demand. Ministry of Trade, Industry & Energy. Korea, 2017.



Soonhyun Hwang He received his M.Sc. degree in electronic and electrical engineering from the Hongik University, Korea, in 2014. Currently, he is pursuing a Ph.D. degree in Electronic and Electrical Engineering at the Hongik University. His research interests include optimization modeling and analysis for generation expansion planning and power system operation & planning.

Balho H. Kim He received his B.Sc. degree from the Seoul National University, Korea, in 1984, and his M.Sc. and Ph.D. degrees from the University of Texas at Austin in 1992 and 1996, respectively. He was with KEPCO (Korea Electric Power Corporation) from 1984 to 1990 and joined Hongik University in 1997 where he is presently a professor of Electronic and Electrical Engineering. His research fields include optimal power flow, public utility pricing, electricity market design & operation, Smart grid, resource planning and demand management.