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.

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, CO₂ 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
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.

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:

$$
\begin{align*}
\min & \sum_{y} \left( c_{\text{Oper}}^{y} + c_{\text{Const}}^{y} + c_{\text{ETS}}^{y} \right) \\
\text{s.t.} & \sum_{y} X_{i,y} + \sum_{y} X_{\text{ESS},y} = D_{y}, \quad \sum_{y} X_{\text{charge},y} = X_{\text{discharge},y} \\
& X_{i,y} \leq C_{\text{Gen},i}^{y} \\
& \sum_{y} X_{\text{ESS},y} \leq C_{\text{ESS},y}^{\text{cap}} \eta_{\text{ESS}} \\
& X_{\text{charge},y} \leq C_{\text{ESS},y}^{\text{cap}} \eta_{\text{ESS}} \\
& E_{\text{ET}^\text{Emission}}^{y} = E_{\text{ET}^\text{Trade}}^{y} + E_{\text{ET}^\text{Cap}}^{y} \\
& E_{\text{ET}^\text{Emission}}^{y} = \sum_{y} \left( X_{i,y} \text{Coef}_{i} \right) \\
& \text{Res}_{\text{min}} \leq \text{Res}_{y} \leq \text{Res}_{\text{max}} \\
& X_{i,y}, X_{\text{ESS},y}, X_{\text{charge},y} \geq 0
\end{align*}
$$

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

- $c_{\text{Oper}}^{y}$: Operating cost in period $y$
- $c_{\text{Const}}^{y}$: Construction cost in period $y$
- $c_{\text{ETS}}^{y}$: Emission trading cost in period $y$
- $X_{i,y}$: Power produced by generator $i$ in time $t$
- $X_{\text{ESS},y}$: Discharge amount of ESS in time $t$
- $X_{\text{charge},y}$: Charge amount of ESS in time $t$
- $D_{y}$: Demand in time $t$
- $C_{\text{Gen},i}^{y}$: Capacity of generator $i$ in period $y$
- $C_{\text{ESS},y}^{\text{cap}}$: Capacity of ESS in period $y$
- $\eta_{\text{ESS}}$: Efficiency of ESS
- $E_{\text{ET}^\text{Emission}}^{y}$: Emission in period $y$
- $E_{\text{ET}^\text{Trade}}^{y}$: Emission trading in period $y$
- $E_{\text{ET}^\text{Cap}}^{y}$: Emission criterion in period $y$
- $\text{Coef}_{i}$: Emission coefficient of generator $i$
- $\text{Res}_{\text{min}}$: Minimum installed reserve rate in period $y$
- $\text{Res}_{\text{max}}$: Maximum installed reserve rate in period $y$.
where life represents the lifetime, \( T \) is the total planning period, and \( y \) 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

\[
C_{ET} = ET_{Total} \times ET_P_y
\]

(16)

where \( ET_P_y \) 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 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.

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.
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.
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


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.