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A Study on the Optimal Fuel Mix and ESS Capacity considering Environmental Policy

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Abstract. Korea has been enforcing the environmental policies(ETS(Emission Trading Scheme), RPS(Renewable Portfolio Standard)) to reduce the greenhouse gas, and has been promoting the expansion of the ESS(Energy Storage System) supply through the K-ESS 2020 strategy. Accordingly, the role of the ESS in the power system has been attracting the recent interest and the effects are being verified. However, there is no standard for the optimal input capacity. It is rational to increase the ESS capacity as much as possible in order to optimize the proper function actualized by the ESS. However, since it is difficult to greatly increase the ESS capacity input as of this point due to high investment cost of the ESS, it is necessary to set up a standard for calculating the most economic input capacity. Accordingly, in this paper, in the process for establishing the generation plan, the environmental policies are considered into calculating the optimal fuel mix as well as the ESS optimal capacity per year.

1 Introduction

In Korea, approximately 87% of the greenhouse gas is emitted from the energy field, and approximately 42% of that is emitted from the power generation field[1]. Accordingly, in the power generation field, various greenhouse gas reduction policies(RPS, ETS and etc.) are enforced to reduce the greenhouse gas emission[2]. In addition, through the K-ESS 2020 strategy, an investment of approximately 6.4 trillion won in the ESS-related technology development and unit until 2020 is being promoted[3].

The ESS allows the generated power to be stored in the respective connection systems such as power plant, substation and transmission line, so that the stored power can be selectively/efficiently used to maximize the energy efficiency and stabilize the power system operatioin. According, to cope with the future power load increase and renewable energy expansion, the world has been promoting a strategy to develop and supply the ESS technology. As part of that strategy, diverse empirical projects are being performed through applying the ESS to substation, renewable energy complex, large-scale generator, house and building[3].

The main role of the ESS can be summarized into three processes: a peak load reduction after connecting the system; an ancillary service for the frequency regulation; and stabilization of the renewable energy output. Through such processes, the ESS contributes to enhancing the power quality[4]. However, as of this point, the price competitiveness of the ESS is insufficient in comparison to other power generation sources, and, therefore, in reality, there are difficulties in supplying the ESS. Accordingly, it is necessary to consider the strengths of the ESS into calculating the optimal capacity suitable for the installation purpose. However, as of this point, the economic feasibility based on the current supply of the ESS has not been analyzed, and the methodology to be used for calculating the optimal capacity does not exist.

Accordingly, in this paper, through the generation planning model to which the environmental policy is applied, the optimal fuel mix and the ESS optimal capacity per year are calculated.

2 Main subject

2.1 ESS capacity calculation methodology

Instead of directly generating the energy, the ESS is operated through storing and selectively using the energy generated from other power generation sources. Accordingly, it is difficult to view the ESS as other power generation sources such as nuclear, coal. In order to calculate the ESS capacity through the generation planning model, the ESS converted into the generation to which its characteristics are applied must be applied to the model. In the generation planning model, the non-dispatch such as wind power unit and photovoltaic unit contribute through modifying the shape of the load curve. Accordingly, in the generation planning model used in this paper, the ESS is treated and applied as the non-dispatch renewable generation, so that the load increases during charging and decreases during discharing.

2.2 Model for generation planning

2.2.1 Outline of model for generation planning

The power plant construction plan is an important part of the power industry investment plan. The power plant construction requires a considerable investment cost. Since the constructed power plant is operated for at least 30 years, it is influential on the operational cost of the overall power system throughout its lifespan. In addition, the generators for construction vary in terms of economic/technical characteristics. Accordingly, in the process for planning a generation unit, the generators specified above must be adequately combined to minimize the operation cost of the future power system.

The computer model used in this paper is the generation unit plan, and the purpose of this model is to consider the environmental policies(ETS and RPS) in Korea into deducting a plan for constructing the optimized power plant per year, and the functions/roles are as shown in Figire 1[5].

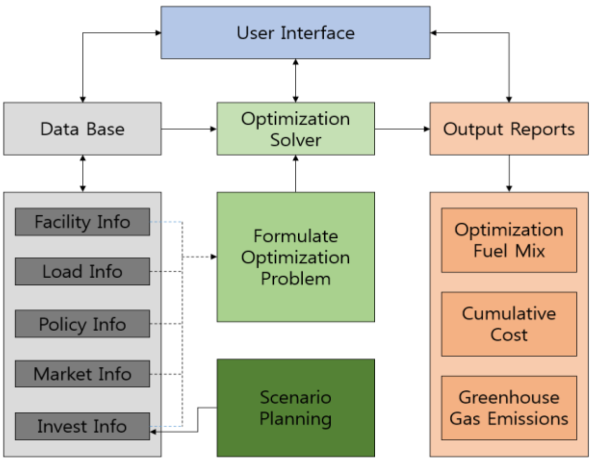

Figure 1. Generaion Planning Model.

2.2.2 Formulation

$$\mathrm{Min} \sum_y \left(C_y^{Gen} + C_y^{Env} + C_y^{Const}\right) \quad (1)$$

$$\mathrm{S.t} \sum_i X_{i,y,t} = D_{y,t} \quad (2)$$

$$X_{i,y,t} \le I_{Cap,i} \quad (3)$$

$$\left(\sum_F \sum_t X_{F,y-1,t}\right) \times RPS_y^{Rate} \le \sum_R \left[\sum_t \left(X_{R,y,t}\right) \times REC_R^{weight}\right] + REC_R^{Penalty} \quad (4)$$

$$ET_y^{Emission} = ET_y^{Trade} + ET_y^{Cap} \quad (5)$$

Where,

y : Year
t : Time
i : Generation Unit
C_y^{Gen} : Generation Cost in period y
C_y^{Env} : Environmental Policies Execution Cost in period y
C_y^{Const} : Construction Cost in period y
$X_{i,y,t}$: Generation for t, in period y
$D_{y,t}$: Demand in period t (MWh)
$I_{Cap,i}$: Capacity for Unit i (MW)
$X_{F,y,t}$: Generation Produced by Coal Generator
$X_{R,y,t}$: Generation Produced by Renewable Unit
RPS_y^{Rate} : RPS Obligation Rate
REC_R^{Weight} : REC Weight
$REC_R^{Penalty}$: Amount of Penalty in period y
$ET_y^{Emission}$: Emission in period y
ET_y^{Trade} : Emission Trading in period y
ET_y^{Cap} : Emission Criterion in period y

Formula (1) is the function for minimizing the overall cost, and it consists of generation cost, environmental policy execution cost and new unit construction cost. The generation cost, as shown in Formula (6), is formulated into a sum of fuel/maintenance costs per each unit/year/hour.

$$C_y^{Gen} = \sum_i \sum_y \sum_t \left(X_{i,y,t} \times C_i\right) + \sum_y \left(I_{Cap,i} \times M_i\right) \quad (6)$$

where,

C_i : Fuel cost of Conventional generator for i (won/MW)
M_i : Operating & Maintenance Cost for i (won/MW)

The environmental policy execution cost consists of RPS-nonfulfillment penalty cost and greenhouse gas emission trading cost, which are formulated into Formulas (7) and (8) respectively. The REC(Renewable Energy Certificate) penalty cost is 150% of the annual average REC trading cost.

$$\sum_y \left(REC_y^{Penalty} \times REC_y^{Penalty\_P}\right) \quad (7)$$

$$\sum_y \left(ET_y^{Trade} \times ET_y^{P}\right) \quad (8)$$

where,

$REC_y^{Penalty\_P}$: REC Penalty Cost in period y
ET_y^{P} : Emission Price in period y

The new unit construction cost, as shown in Formula (9), consists of new unit construction cost and salvage value difference. The unit construction cost and salvage value per unit are formulated into Formulas (10) and (11) respectively.

$$C_y^{Const} = C_y^C - C_y^S \quad (9)$$

$$C_y^C = \sum_i K_i \times Add_{i,t} \quad (10)$$

$$C_y^S = \sum_i K_i \times Add_{i,t} \times \left(\frac{P_{life-i} - Y_T + y - y_s}{P_{life-i}}\right) \quad (11)$$

where,

C_y^C : Construction Cost (won)
C_y^S : Salvage Value (won)
K_i : Unit Construction Cost for i (won/MW)
$Add_{i,t}$: New Unit Construction Cost in period y
P_{life-i} : Life Time for i
Y_T : Total Planning Period
y_s : Start year

Formula (2) signifies the restriction in supply and demand and Formula (3) signifies the restriction in generation per unit type. Formula (4) is the contraint condition for calculating the compulsory RPS-based fulfillment volume. The compulsory RPS-based fulfillment volume is calculated through multiplying the gross thermal power generation from the immediately preceding year by the compulsory execution volume from the involved year. The calculated value must be smaller than the sum of generation per renewable energy unit to which REC-issued weighted value is applied and RPS nonfulfillment penalty.

Formula (5) is the restriction in greenhouse gas emission per year. The gross greenhouse gas emission per year is the sum of emission trading volume and greenhouse gas emission permit from the involved year. The annual gross greenhouse gas emission, as shown in Formula (12), is calculated through multiplying the annual gross generation per generation unit by the greenhouse gas emission coefficient.

$$ET_y^{Emission} = \sum_i \sum_t (X_{i,y,t} \times Coef_i) \qquad (12)$$

where,

$Coef_i$: CO2 Emission Coefficient (tCO2/MWh)

3 Case study

3.1 Peak reduction

The ESS-based peak-load reduction stores the energy during light-load hours and discharges the energy during peak-load hours, and thereby standardizes the load and allows the system to be operated efficiently. Namely, through reducing the peak-load, the operating hours of the high-costing generator is shortened, the operational cost of the system is reduced, the power supply is stabilized, and the reliability is enhanced. At this point, since the operational effects vary depending on how the standard charge/discharge hours are set, it is necessary to determine an adequate charge/discharge pattern[4]. Accordingly, in this paper, a scaling is executed through using the load performance data from 2011, and the ESS charge/discharge pattern is constructed.

3.2 Scenario premise

In this paper, the input data from the 7th Basic Plan for Long-Term Electricity Supply and Demand[6] is used to conduct a case study. The key premises are as follows.

❙ All generation unit and load are connected to one node.

❙ The plan period ranges from 2015 to 2029, and the discount rate is 6.5%/year.

❙ The load data per 8760H time zone will be used.

Table 1. ESS Information[7].

Fuel Cost	0
Maintenance Cost (10^3won/MW)	70,708
Capacity(MW)	50
Greenhouse Gas Emission Coef	0
Construction Cost (10^3won /MW)	3,535,400

Table 2. Case Study Scenario.

Scenario	Environmental Policy	ESS	Note
1	X	X	-
2	O	X	-
3	O	O	-
4	O	O	ESS construction cost reduced 90%

3.3 Case study result

Table 3. Case Study Scenario Result (10^6won).

Scenario	Add ESS	Construction Cost	Generation Cost
1	-	4,856,614	305,736,458
2	-	10,266,737	304,423,288
3	-	10,266,737	304,423,288
4	600MW	10,440,705	304,213,269
Scenario	**Emission Trading Cost**	**RPS Penalty Cost**	**Total Cost**
1	-	-	310,593,072
2	19,846,540	22,607,071	357,143,635
3	19,846,540	22,607,071	357,143,635
4	19,873,131	22,611,565	357,138,670

3.3.1 Scenario 1

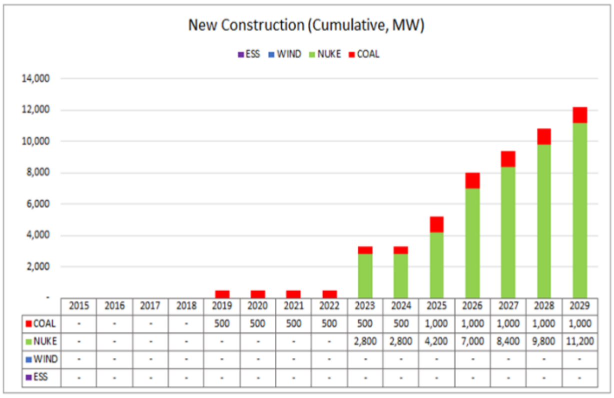

Figure 2. Scenario 1. New Construction Unit.

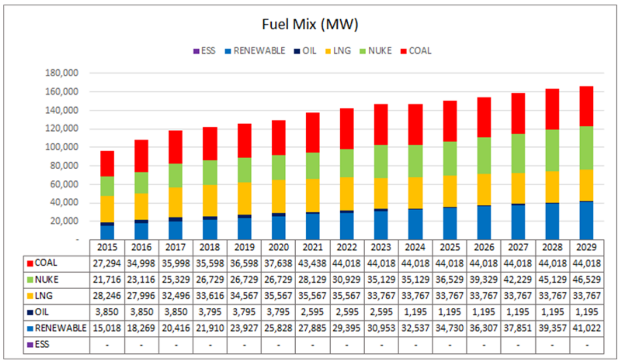

Figure 3. Scenario 1 Fuel Mix.

Scenario 1 is a scenario to which the environment policy and ESS are not applied, and the additionally constructed unit is mainly a neclear generator. In addition, since no environmental policy is executed, a tendency of contructing additional reeawable energy unit is not displayed. As of this point, considering the fact that it is necessary to construct additional generators although the demand can be sufficiently satisfied through the confirmed unit and intention-reflected unit included in the 7th Basic Plan for Long-Term Electricity Supply and Demand, it is possible to deduct a conclusion that the overall operation cost can be reduced through constructing additional generators.

3.3.2 Scenario 2

Scenario 2, as the environmental policies (RPS and ETS) are included as the constraint conditions, shows a unit construction different from that of Scenario 1. Since the environmental policy is required to be executed, the renewable unit is additionally constructed, and no coal thermal power generator is additionally constructed to satisfy the target emission. However, even the results from the above scenario is not enough to completely satisfy the environmental policy, the environmental policy execution cost is additionally included in the overall operational cost, and, therefore, a rapid cost increase in comparison to Scenario 1 is caused. This signifies that not constructing additional generators, but imposing penalties may decrease the overall cost within the plan period.

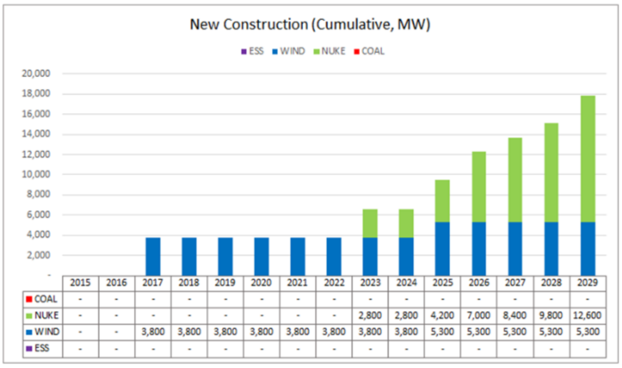

Figure 4. Scenario 2 New Construction Unit.

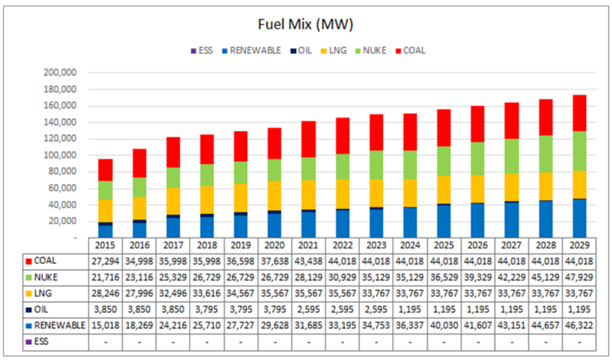

Figure 5. Scenario 2 Fuel Mix.

3.3.3 Scenario 3

Scenario 3 is a case to which the ESS is applied, and the results are identical to those of Scenario 2. The reason for this is because the current cost of the ESS displays no economic feasibility. Namely, it is determined that applying the ESS for peak-load reduction to the system will only increase the overall operational cost.

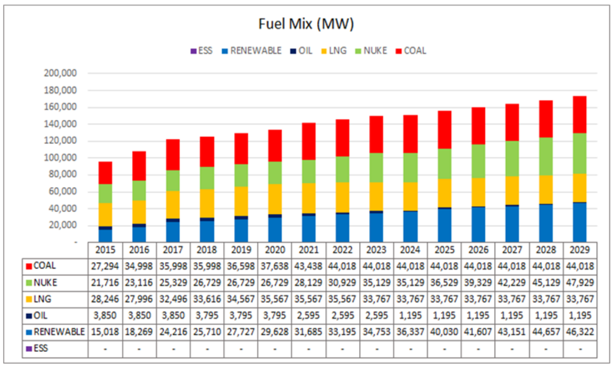

Figure 6. Scenario 3 New Construction Unit.

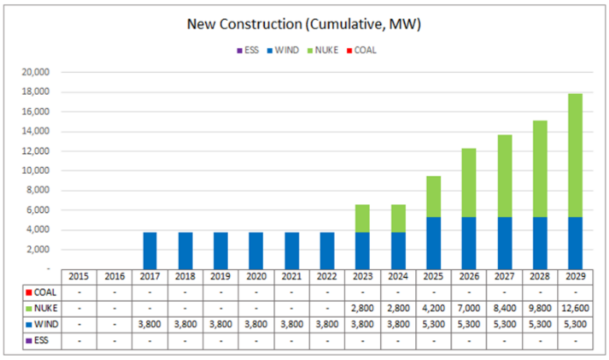

Figure 7. Scenario 3 Fuel Mix.

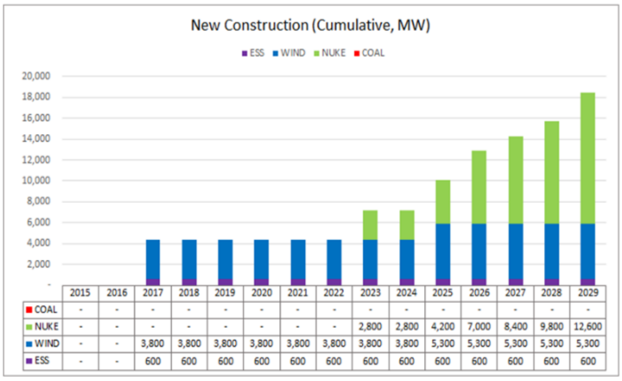

Figure 8. Scenario 4 New Construction Unit.

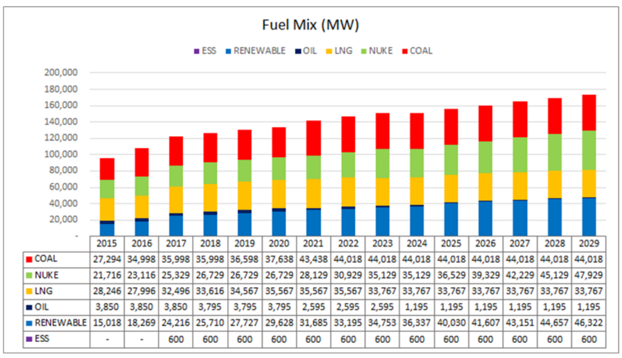

Figure 9. Scenario 4 Fuel Mix.

3.3.4 Scenario 4

Scenario 4 was processed through decreasing the current cost by 90%. As a result, 600MW is applied to the system. It is determined that the cost for operating the ESS is more economical than the cost for constructing the generaion unit due to the technological enhancement of the ESS.

4 Conclusion

In this paper, through the generation planning model to which the environment policy is applied, the optimal fuel mix and ESS optimal capacity per year are calculated. Namely, the ESS capacity is calculated to optimize the overall cost for operating the system. When it is determined that there is no conomic feasibility, the cost variation is deducted to secure the economic feasibility of the ESS.

Based on the result of the scenarios processed in this paper, for the ESS reducing the peak-load within the system, it is confirmed that it is difficult to secure the economic feasibility due to the current installation cost. For the ESS to contribute to the operational cost reduction through reducing the peak-load, the current cost must be decreased by 90%. For the photovoltaic unit, considering that the unit cost has been decreased by approximately 80% for the past 5 years, it is determined that the economic feasiblity of the ESS will be secured in the future.

In this paper, of the roles of the ESS, only the peak-load reduction is considered. In the future, the frequency regulation as well as the renewable energy output smoothing must be considered into calculating the optimal capacity.

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