Analysis on the Role of Various Power Generation Resources for the Sustainable Development of Korean Electric Industry

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Abstract: There are many important issues on the sustainable development of electric industry in Korea such as electricity market restructuring, climate changes regime, increasing demand on renewable energy, problem of nuclear power program expansion and so on. Most decision makers in electric industry have been used to plan the electric power expansion program considering only least cost operation, although our circumstances are changed with complexities. Therefore, it is necessary to analyze the long-term power expansion planning in various points of view such as environmental friendliness, benefit of carbon reduction and system reliability as well as least cost operation. The objective and approach of this study are to analyze the proper role of each power generation resources in the long-term expansion planning by comparing the different types of scenarios in terms of the system cost changes, CO₂ emission reduction and system reliability with the Business-As-Usual (BAU). The conclusion of this paper is to make it clear that Korean government cannot but expand the nationwide nuclear power program because the increased energy demand will be inevitable and any other resources will not be the unique solution in the economic and sustainability point of view. The results from this analysis are useful for the Korean government in charge of long-term resource planning to go over what kinds of role each electric resources can play in terms of triangular dilemma as economics, environmental friendliness, and stable supply of the electricity.

Keywords: Long-term Electricity Planning, Environmental Constraints, System Cost, CO₂ Reduction, Reliability

1. INTRODUCTION

There are many important issues on the sustainable development of electric industry in Korea such as electricity market restructuring, climate changes regime, increasing demand on renewable energy, public acceptance of nuclear power program expansion and so on.

For example, first, because Korean government has suspended the progress of the market restructuring after unbundling only generation parts, it needs to design the consistent market rule for the fully competitive electricity market in order to meet the increasing demand with stable supply of electricity based on the long term power program. Second, because current world wide alert on global warming and regulation on abatement of CO₂ emission make the utilization of fossil fuel shrunken, nation-wide capacity mix strategies and optimal emission target are required in the electric industry in charge of over 30% of national CO₂ emission even though Korea has no obligation on abatement of CO₂ currently. Third, Korea cannot help keeping nuclear power plants in operation due to the limited national resources, however, sitting for new plant or radioactive wastes disposal facility has some barrier to reach the consensus and many socialists or NGOs suggest that nuclear power be replaced by renewable energy. Finally, most decision makers in electric industry have been used to plan the electric power expansion program considering only least cost operation, although our circumstances are changed with complexities.

Therefore, it is necessary to analyze the long-term power expansion planning in various points of view such as environmental friendliness, benefit of carbon reduction and system reliability as well as least cost operation. The objective and approach of this study are to analyze the proper role of each power generation resources in the long-term expansion planning by comparing the different types of scenarios in terms of the system cost changes, CO₂ emission reduction and system reliability with the Business-As-Usual (BAU).

2. METHODOLOGY

2.1 Long-term electricity planning program

The methodological tool used in the study is the WASP IV (Wien Automatic System Planning Package) for system cost and CO2 emission projection.

WASP IV code permits finding the optimal expansion plan for a power generation system over the period of up to thirty years, within constraints given by the planner. The optimum is evaluated in terms of minimum discounted total costs. A simplified description of the model follows. Each possible sequence of power units added to the system (expansion plan or expansion policy) meeting the constraints is evaluated by means of a cost function (the objective function), which is composed of:

- Depreciable capital investment cost: equipment, site installation costs (I)
- Salvage value of investment costs (S)
- Non-depreciable capital investment costs: fuel inventory, initial stock of spare parts etc (L)
- Fuel cost (F)
- Non-fuel operation and maintenance costs (M)
- Costs of the energy not served (O)

The cost function to be evaluated by WASP can be represented by the following expression:
\[ B_j = \sum_{t=1}^{T} [I_{j,t} - S_{j,t} + L_{j,t} + F_{j,t} + M_{j,t} + O_{j,t}] \]  

- \( B_j \) is the objective function attached to the expansion plan \( j \),
- \( t \) is the time in years
- \( T \) is the length of the study period (total number of years) and all values have the meaning of discounted values to a reference data at a given discount rate \( i \).

The optimal expansion plan is defined as the minimization of the objective function (B) like;

\[ \text{Minimum } B_j \text{ among all } j \]  

### 2.2 Approach of simulation

This study analyzes the long-term power expansion planning in the point of view such as benefit of carbon reduction and system reliability as well as least cost operation, which shows the trade-off between the incremental system cost and the benefit of the CO2 reduction.

Total analysis period is from 2005 to 2020 and discounted rate of 7% is used. Constraints of LOLP and reserve margin are 0.5 day/yr and 10 ~ 45 % are assumed. Different carbon emission limit [kg-c/kWh] is applied to like 0.11, 0.12, 0.13, 0.15, and 0.20. Additionally 0.15 limit is kept through 2011 and after 2011 more stringent target of 0.11 is applied (0.20 \( \rightarrow \) 0.11).

### 3. RESULTS AND DISCUSSION

#### 3.1 Reference case scenario

System cost is the sum of the investment cost, fuel cost, O&M cost, and energy not served cost. It needs to define the reference case scenario (BAU – Business As Usual) to compare with alternative scenarios in terms of the CO2 emission amounts and system cost. First of all the issues that how well model reflects the real power system and how close it is to the actual Korean system have to be checked, because exact calculation of the capacity and generation should be the basis on the estimation of CO2 emission as well as the system cost.

Capacity and generation by fuel types have the same trend as the reference of the 2\textsuperscript{nd} expansion plan by the government. Slight difference of comparison by fuel type is because the renewable and community energy system are included only in the government estimation while the model doesn’t consider them.

Reference case is the scenario without any constraints. The optimal reserve margin (RM), which is the surplus capacity over the peak load, can be specified for the minimization of the system cost. Usually lower RM is better than higher RM because much extra capacity due to the higher RM can be non-economical, however, in Korea the lower RM makes the higher system cost which means that nuclear and coal plant with the large capacity as the base load can take major roles for the optimized system. And also it can be explained that the operation by nuclear and coal plants even though they make RM higher is better than the operation of LNG or Oil with the lower RM. Reference case of this study is the 103,512,848 k$ of the system cost with the 45% of RM.
3.2 CO₂ constraint scenario
The higher system cost can be expected as the stricter CO₂ emission target from 0.20 kg-c/kWh to 0.11 kg-c/kWh is applied. It means that nuclear power can take a major role as a system stabilizer in economics point of view and as an abatement method of CO₂ emission in environmental point of view as the new nuclear power plants come on-line.

The reason why the system cost goes up according to the lower limit of CO₂ emission is due to the increase of the energy not served cost during the five years when no new plants are committed. Because the first 5 years from 2005 to 2010 is the construction period of coal and nuclear, only plants in operation have to take the demand and new coal and nuclear cannot give a contribution. However, current coal plants become restricted due to the CO₂ emission limit and power generation from the nuclear is reaching to their upper limit of capacity factor, which cause the energy not served cost as the negative reliability factor.
Change of fuel mix, i.e., the number of plant shows the stricter carbon emission limit introduces the more nuclear plants to mitigate the carbon level and the nuclear plants are added as much as the decrease of coal plants to meet the demand. From this result it can be expected that system eliminates the uneconomical plants preferentially and adds the large units.

Estimation of the actual CO₂ emission according to the different carbon emission limit from model and government estimation from 2005 to 2017 is compared. As the emission limit becomes stricter, the less CO₂ are emitted and CO₂ emission increases until 2010 and after that decreases rapidly. It means that many fossil power plants in the current system plays a major role before 2010 and as the economical and non-carbon source plants such as nuclear plants are connected to the system, the incremental CO₂ emissions are decreased.

3.3 Limitation of construction scenario

The expansion of nuclear program has the obstacles like a increased demand of renewable energy or fail to public acceptance. It is assumed that nuclear is not added and only coal plant is charge of the demand. In reverse, because coal plant cannot help being restricted due to the severe constraint like a climate change regime nuclear plants have to be added in stead of coal to meet the increased demand.

The only nuclear scenario can reduce the 62% of CO₂ emission against to reference case, while 2.6% of system cost is increased and the only coal scenario increases slightly by 0.5% of system cost, however, CO₂ emission is increased as much as 22% against the reference case. Therefore even though the system cost is increased, only nuclear option is better for the abatement of CO₂ emission. if 0.15kg-c/kWh of emission limit is applied, emission amount exceed s the reference case by 15% and if the stricter constraint of 0.11kg-c/kWh, 57% of the emission has to be reduced to meet the constraint.
3.4 Replacement of nuclear by renewable scenario

If the nuclear power can be replaced by wind, the system cost of wind goes up 45% over the reference case and four times of original wind capacity has to be installed to replace the same capacity of nuclear because its capacity factor is one forth of nuclear. As to the reduction of CO2 emission, wind can contribute the environmental benefit against the power generation by only coal, however, the power generation by only nuclear is much more effective to reduce the CO2. It is not easy to find any environmental advantages of wind to offset the 45% of system cost increase over the reference case.

4. CONCLUSION

Until now the power expansion program has been focused on the least cost point of view, however, as increasing the concerns about the CO2 problem and domestic resource availability in Korea it needs to analyze the fuel mix by combining the emission credit as well as least cost option. This study analyzes the proper role of each power generation resources in the long-term expansion planning by comparing the different types of scenarios in terms of the system cost changes, CO2 emission reduction and system reliability with reference case. As results, the cheap and large nuclear and coal plant operation even though its RM is higher can be better than the operation of LNG or Oil with the lower RM. Coal is the important resource to keep the system cost low, however, it cannot be the sustainable fuel under the situation becoming the stricter CO2 regulation. As to replacing the nuclear by wind to response the public opinion being afraid of the hazardous of nuclear, it is not easy to find any definite advantages of CO2 reduction to offset the 45% of system cost increase over the reference case. Therefore, the conclusion of this paper is to make it clear that the dependency on the base load such as coal and nuclear is not evitable under the insufficient domestic resources and also Korean government cannot but expand the nationwide nuclear power program because of the increased energy demand. It is unrealistic the specific electric resource will be the unique solution in the economic and sustainability point of view. The results from this analysis are useful for the Korean government in charge of long-term resource planning to go over what kinds of role each electric resources can in terms of triangular dilemma as economics, environmental friendliness, and stable supply of the electricity.
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6. REFERENCES

