Challenges of Nuclear Power for the Sustainable Role in Korean Energy Policy

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Abstract

This study aims to introduce the current role of nuclear power in Korea as the economic and low carbon emitter in the long term expansion planning and to improve the public acceptance of nuclear as the environmentally friendliness energy source. Nuclear and coal have been selected as the major electricity sources due to the insufficient domestic energy resources, and will provide more than 60% of total electricity generation in Korea for quite some time. National energy policy addressing environmental friendliness, stable supply and least cost has made it difficult to decide which energy resource is the best for the long term energy planning. Climate change regime will diminish the coal power plants in generation amount, the public still keeps nuclear at a distance and insists to replace nuclear by renewable. The renewable doesn't any guarantee of stable supply although its economics is being speedily improved. 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 nuclear power by comparing the different types of scenarios in terms of the system cost changes, CO2 emission reduction and system reliability. The results from this analysis are useful for the Korean government in charge of long-term energy policy to go over what kinds of role can each electric resources play and what are the best way to solve the triangular dilemma as economics, environmental friendliness, stable supply of the electricity.

1. Background

There are many important issues to decide the reliable role of the nuclear power in the long term expansion program in Korea power system. Climate changes regime, increasing demand

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on renewable energy, public acceptance of looking for a site for the nuclear facility and so on are currently faced with the nuclear industry. These many challenges and risk of climate changes to the electric industry are making the energy decision makers concerning the various points. Low carbon fuels are preferred and the phase-out of coal power plants can be guessed or fuel switch from coal to LNG is considered. This study analyzes the reliable role and portion of the nuclear power in the fuel mix of the power generation system under the CO2 emission constraints. For examples, what kind of pros and cons can be expected when the low carbon fuel like a nuclear or renewables make role of major resources? How much do carbon price and LNG price effect on the competitiveness of fuel switch? What is the optimal CO2 emission target in terms of the system reliability in Korea power system? Finally it shows how many nuclear power plants need to be added to meet the increased electricity demand according to the different emission target, changes of the total system cost and CO2 savings due to the increase of nuclear power generation.

2. Scenario Approach and Concept of Modeling

The purpose of this study is to estimate the system cost changes, CO2 emission reduction and system reliability, based on the Business-As-Usual (BAU). 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 (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:

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

like;

$$B_j = \sum_{t=1}^{T} [I_{j,t} - S_{j,t} + L_{j,t} + F_{j,t} + M_{j,t} + O_{j,t}]$$

- Bj is the objective function attached to the expansion plan j,
- T it's the time in years
- T is the length of the study period (total number of years) and all values are have the meaning of discounted values to a reference data at a given discount rate i.

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 → 0.11)

3. Analysis Results

3.1 Reference Scenario

Reference case of BAU is the scenario without any constraints and is defined at the point which have the lowest system cost. The reserve margin (RM) means the surplus capacity over the peak load. Usually a lower RM is better than a higher RM because an extra capacity due to the higher RM can be non-economical, however, in Korea a lower RM cause a higher system cost which means that nuclear and coal plants with a large capacity as the base load can have major roles for an optimized system. In other words, the operation by nuclear and coal plants even though they create a RM higher is better than the operation of LNG or Oil with a lower RM. Reference case of this study is a 103,512,848 k$ system cost with a 45% RM .

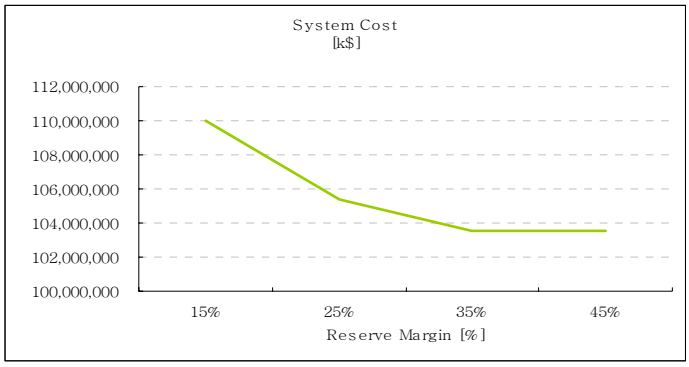

Fig. 1 Reserve Margin and System Cost of Reference Scenario

3.2 Carbon Regulation Scenario

The higher system cost can be expected when 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.

Change of fuel mix, i.e., number of plants shows the more strict carbon emission limit introduces the more nuclear plants to mitigate the carbon level and the nuclear plants is 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.

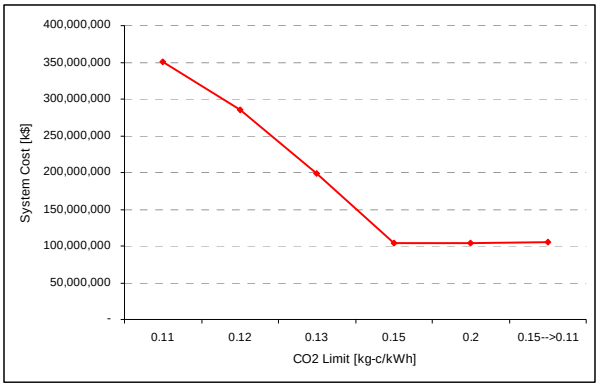

Fig. 2. System Cost Changes according to the Various CO2 limit

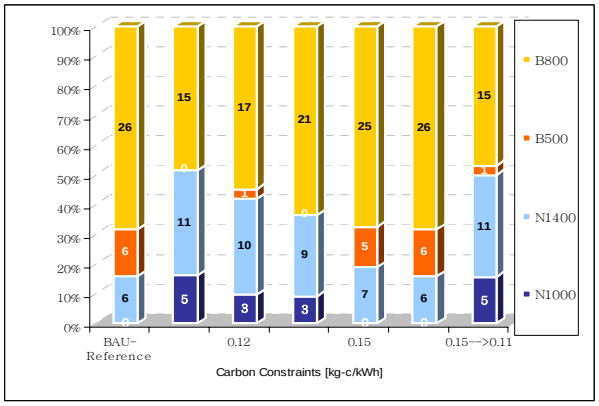

Fig. 3. Fuel Mix Changes according to the Various CO2 limit

• The Korean government is considering the CO2 emission target of whole power system as 0.11kg-c/kWh. The unconditionally tight CO2 limit without the sufficient alternative resources can restrict the additional coal plants, however, it may cause the shortage of sustainable power supply. Therefore, low CO2 limit needs to be delayed until more nuclear plants come on line, i.e., currently optimal limit in power system can be 0.15kg-c/kWh before the 2012 when more nuclear plants are constructed.

Estimation of the actual CO2 emission according to the different carbon emission limit derived 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, total CO2 emissions are decreased.

3.3 Alternative Resource Scenario

Even though it is not realistic, the very conservative assumption was made for analyzing the effect of the wind power. This scenario assumed that all of new nuclear plants would be replaced by the wind power. If new nuclear plants are replaced by wind power with the capacity factor of just 0.3, the system cost goes up over 45% higher than that of nuclear power and it comes from the high investment cost of wind power. Wind must have advantages to offset this very expensive system cost, however, the scenario of increasing wind power doesn't has the outstanding credit of the carbon reduction. From this result of high system cost and low CO2 reduction, it can be said that the replacement of nuclear by wind is not so much beneficial in terms of CO2 in Korean Power System. Another problem of the wind power in Korea is the economic wind speed. Many people in Korea accept that the economics of investment and O&M cost of the wind power doesn't matter any more due to the rapid technology advancement. But average wind speed in Korea is around 2 ~ 3 m/s which are far away from the range with economic advantage (7 ~ 8 m/s).

Another alternative scenario in Korea is to switch the fuel form the coal into the LNG. This case seems generally advantageous, however, in detail analysis it is unlikely to say that this option can be always the cost effective. The system cost exists between the replacement of wind and only nuclear power generation. From the point of CO2 reduction, it is the middle of the replacement of wind and the only nuclear, i.e, at any scenarios, whatever we selected, nothing is effective as much as increase of dependence on nuclear

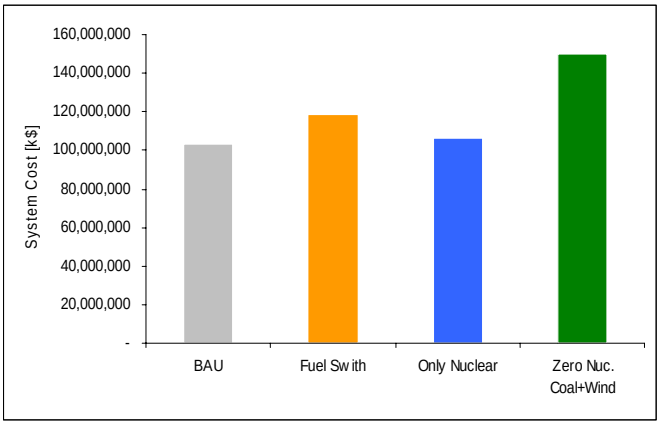

Fig. 4. System Cost of Alternative Scenarios

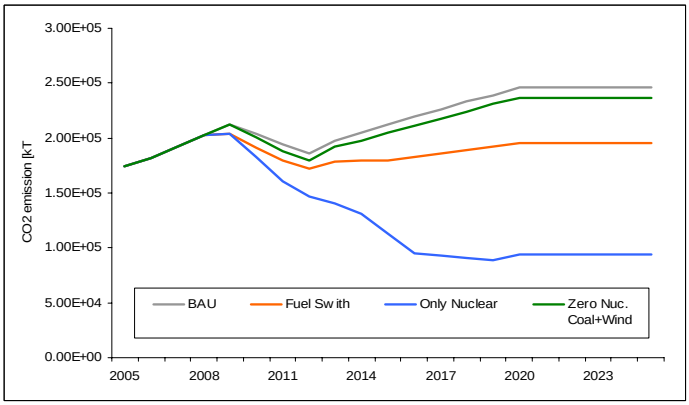

Fig. 5. CO2 Reduction of Alternative Scenarios

3.4 Volatilities of Fuel Price and Carbon Price in the Fuel Switch Scenario

To validate the role and competitiveness of nuclear, it should be shown that the merit order from nuclear to fossil fuel like a gas and oil is not changed at any condition of fuel cost and carbon price. Even though the fuel cost and carbon price do not impact the economics of nuclear, the change of role of fossil fuel can give some effect on how much generation of nuclear can be expanded in the future power system. Adding the carbon price to the coal power can introduce the Gen.Co's fuel switch into low carbon fuel, however, gas favored strategy is very dependent on the gas price and it is not easy to say that gas plant may be always preferred under the carbon constrained world due to the possibility of gas price hike. Due to these reason this paper analyzes the relationship between the carbon price and gas fuel price.

First, as the carbon price goes up at a current LNG price, the merit order in terms of the production cost is seldom changed until 60$/ton-c which is very unreasonable value of carbon. Therefore this result explains the relative competitiveness between gas and coal may not be

changed under the reasonable carbon price range unless the LNG price significantly drops. As low as 50% of current LNG price, LNG becomes more economic than coal at the 26.5$/ton-c of carbon price

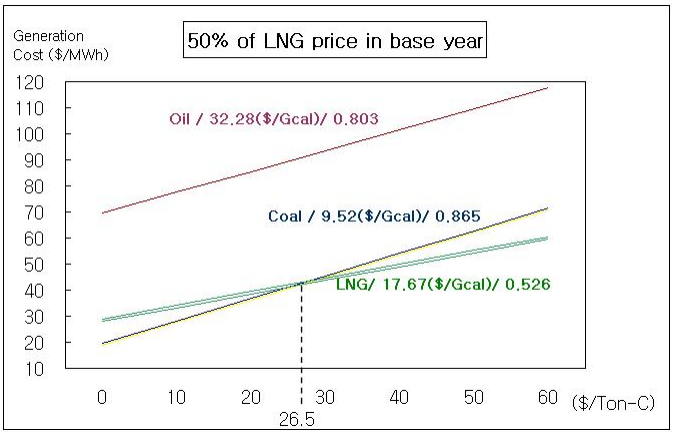

Fig. 6. Merit Order of Fossil Power according to the change of Fuel Cost and Carbon Price

The reason why the nuclear does not appear this graph is that its production cost, i.e., variable cost including the fuel cost and O&M cost much lower than these of coal and LNG.

In summary, to be a LNG preferred, it is not possible at the current LNG price level due to the unrealistic carbon price over than 80$/ton-c. Below 25$/ton-c coal becomes competitive only provided the LNG price keeps over than 50% of current price.

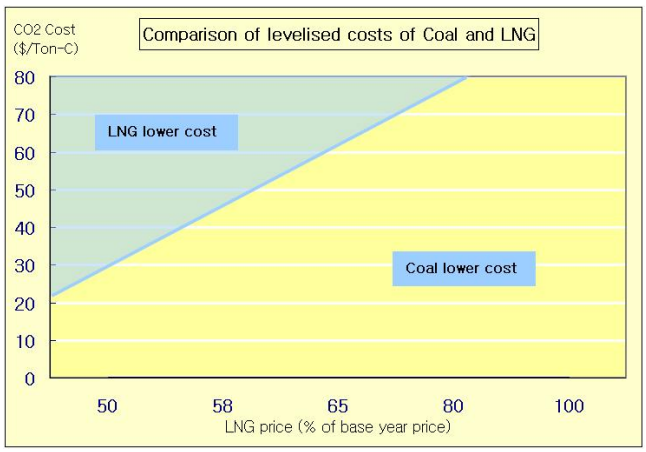

Fig. 7. Comparison of Competitiveness between LNG and Coal

4. Conclusion

This paper is to make it clear that Korea have no options in terms of the economics and less CO2 emission except use of nuclear energy and its 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 of each electric resources play and what are the pros and cons of power generation strategies in terms of triangular dilemma as economics, environmental friendliness, and stable supply of the electricity. This paper is to show the possibility how to analyze the effects of fuel price volatility on the merit order and effectiveness of economic carbon constraints like a adding it to the generation cost. Finally to be a LNG preferred to coal, LNG price has to go down as low as 50% of current price or carbon price has to go up much higher. In addition, economic constraint of carbon may not work better in the market as expected previously.

Acknowledgement

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