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Glances at flexibility in Korean Electric System Expansion Plan

J.E. Joo [a], M.K. Lee [a*]
[a]*Nuclear Policy Research Center, Korea Atomic Energy Research Institute,*
989-111 Daedeok-daero, Yuseong-gu, Daejeon, Korea
[*]*Corresponding author: mklee@kaeri.re.kr*

1. Introduction

In the past decades, climate change policies have been introduced to the world. This policies including reduction of Greenhouse Gas (GHG) emission have led to adopt renewable sources of electrical power generation in some countries, for example, Canada, France, Germany, and the United States [1].

The Republic of Korea is one of the most aggressive country, which has a plan to increase the share of renewable energy in electrical power system, as an outcome of national energy transition policy declared in 2017 to reduce GHG emission. The 8th National Electricity Plan (2017), as an acting plan of energy transition policy, proposed the electric power generation from nuclear and coal resources will be replaced with LNG and renewable energy in the ROK [2]. Moreover, Korean government submitted its ambitious Nationally Determined Contribution (NDC) in 2015 to the new climate regime complying with the Paris Agreement [3]

The major grid management is reliability and flexibility to serve the electricity for consumers. However, increasing penetration of renewables will affect the reliability and flexibility of the power supply on grid due to their intermittent production of electricity. Therefore, this study focused on flexibility of electric system in Korea by reviewing the general description of flexibility. Moreover, yearly energy demand was analyzed and Korean electric system expansion planning from the respective of flexibility was evaluated through the ESEP_ KAERI model, which is based on MESSAGE (Model for Energy Supply Strategy Alternatives and their General Environmental Impacts) software.

2. General description of flexibility

Reliability refers to the resource adequacy and operation capability of an electrical system, which operating on different time scales from short-term (millisecond to hour) to long-term [4]. The power system flexibility is defined as the ability of a source, whether any component or set of components of the power system, to respond to the known and unknown changes of power system conditions at various operational timescale [5]. The operating reliable and flexible power supply system is required to match electricity generation to demand, providing reserve, and adoption of variable renewable generation [6].

In the case of the Republic of Korea, nuclear and coal power plants are currently major electric generation sources accounting for approximately 70%. These plants provide base load not providing load following. By the way, when introducing a significant share of renewable sources, the electric supply system is expected to face greater uncertainties in matching supply to demand [1]. In this situation, several options are proposed in order to secure flexibility of power system; open cycle gas turbine (OCGT), energy storage such as battery and pumped storage power, flexibility of base-load power plant, and demand response resources.

An open cycle gas turbine referred to as OCGT, is considered as flexible option to change its power in a very short time period. Table 1 presented the comparison of load following capability in power plants.

Table 1 Comparison of load following ability of dispatchable power plants [7]

	Start-up time	Max Power change in 30s	Max ramp rate (%/min)
Gas (OCGT)	10-20 min	20-30%	20
Gas (CCGT)	30-60 min	10-20%	5-10
Coal	1-10 hrs	5-10%	1-5
Nuclear	2 hr ~ 2 days	Up to 5%	1-5

When the surplus base-load generation is generated, it could not be reduced but saved through energy storage. For example, early stored energy in a day can be useful to meet the evening peak load. Battery or pumped storage power (PPS) is the most representative form of energy storage.

In response to the increasing need for load following technology in today's electrical grids, nuclear reactor designs have been proposed for their potential load following capabilities [8]. There are some facilities achieving load following in nuclear power generation. The introduction of a flexibility of power plant would likely make nuclear more competitive.

Among the previous three options providing flexibility, the last option is demand management, demand response (DR). This is a service that provides compensation for electricity demand reductions that have been pre-agreed by electric power consumer.

The intermittent power generation of renewable energy, frequency control and power fluctuations of other generation facilities cause the cost of the power system to increase. Thus, measures to mitigate the increase of power system cost are raised as major issues. When we are interested in the economics of flexibility of NPP, the assessment should be performed taking into account these options together. However, the economics of flexibility is market specific issue. Therefore, economics of flexibility depends on; share of renewables out of total power generation; power mix in the electric power system; gird connection to foreign countries; electricity market structure as deregulated or regulated.

There is no reference model available for economic assessment of flexibility in electric supply system. It is a new challenge for energy modelers to deal with intermittent power generation from renewables.

3. Korean Electric System Expansion Planning (ESEP) from the respective of flexibility

The Electric system expansion planning (ESEP) starts from electricity demand forecast, once demand is given, power options to meet the demand are considered. Load region should be well defined to describe demand profile and output profile of intermittent renewables. In order to propose Korean electric system expansion plan, it is needed to do the analysis of demand and identification of load region. In Korean case, the forecasted electricity demand is given until 2030, and there are four types of major power option; nuclear, coal, LNG, and renewables. First of all, yearly demand in ROK is presented in Figure 1.

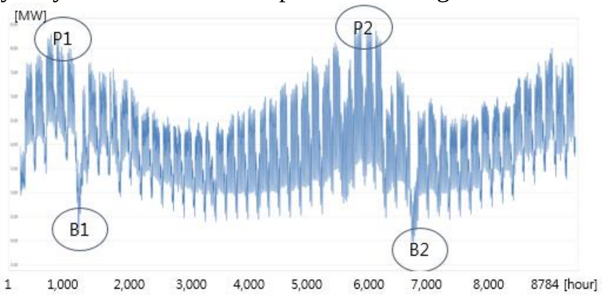

Figure 1 Electricity demand profile in 2016

Figure 1 shows the hourly chronological load pattern in Korea 2016. There are some seasonal variations in electric demand profile. Especially, the weather affects to peak load demand labelled P1 (peak 1) and P2 (peak 2), which are summer and winter peak. Also, great national holidays are presented as base load season labelled B1 (base 1 as Seol-nal) and B2 (base 2 as Chu-seok).

There are significant variations in electricity generation from photovoltaic (PV) and wind power plant, which are expected to dominant renewables in ROK in 2030. The variations of yearly electric production profile for PV and wind are presented in Figure 2.

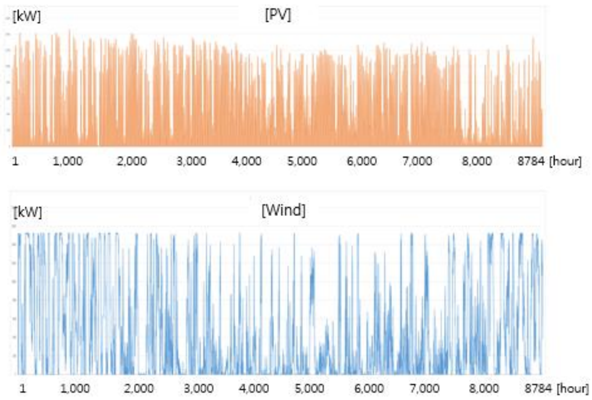

Figure 2 Production load profiles of PV and Wind plants in 2015

As shown in Fig2, photovoltaic power plant cannot generate electricity in night time. Similarly, wind power plant cannot make electricity when the wind does not blow. In order to consider significant variations from both electricity demand and electricity output from renewables, 140 load regions are defined in the analysis. 140 load regions consist of 16 seasons (Jan to Dec, 2 Peaks and 2 Bases) with 2 day types (working day and weekend for 12 seasons except for peak and base) and 5 part types in a day. The way how to set parts in a day is illustrated in Figure 3.

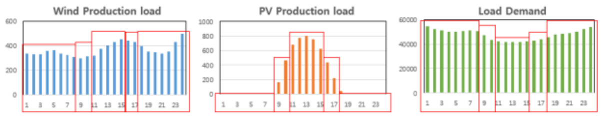

Figure 3 How to set the load region in a day (e.g. 08-Feb-2016) *Part 1: 8hours, Part 2: 2hours, Part 3: 5hours, Part 4: 2hours, Part 5: 7hours*

Korean electric system expansion plan from the respective of flexibility was evaluated through the ESEP_ KAERI model [9]. There are two scenarios to compare the power mix in electric power system; BAU (Business-As-Usual) and NEP (New Energy Policy). BAU is developed based on the 8th national electricity plan in ROK. As an alternative scenario to BAU, NEP is developed considering long term operation of NPPs and introduction of new installation of NPPs after 2027. The power generation mixes of each scenario for the period from 2016 to 2045 are obtained from ESEP_KAERI model, illustrated in Figure 4.

As shown in Fig 4, BAU describes the projection of current national electricity plan, showing that renewables accounts for 20% in 2030 and nuclear and coal are replaced with LNG and renewables. In NEP scenario, share of nuclear increases while the share of renewables stay at the same level of 20% as in BAU scenario.

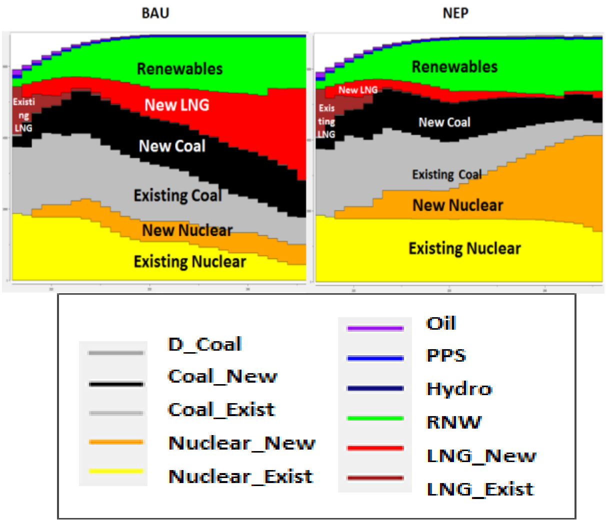

Figure 4 The power mixes of BAU and NEP scenarios

From the perspective of providing flexibility expected power generations in a typical year over the load region are shown in in Figure 5 and 6.

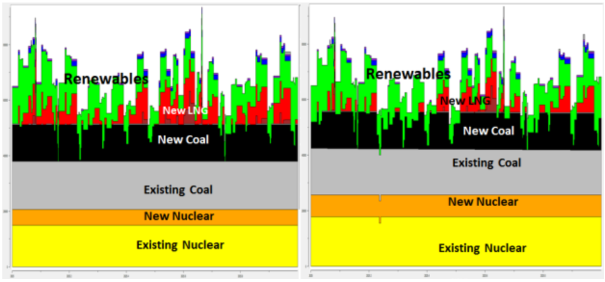

Figure 5 Comparison of electric power mix in 2025

In Figure 5, the left side is BAU scenario and the other is NEP. In the BAU case, nuclear power accounts for 28.8% but renewables accounts for 14.2% in 2025. Among the base load power, only coal power ramps up and down from time to time. While in NEP scenario, the share of nuclear is 45.4% and renewables is 14.2%, not only coal but also nuclear is required to do load following.

This fluctuation phenomenon becomes more severe over time. The comparisons of generation power mix for each scenario in 2030 are presented in figure 6.

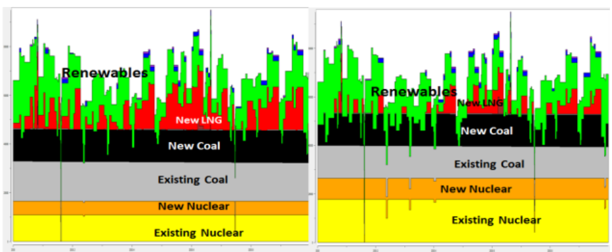

Figure 6 Comparison of electric power mix in 2030

In figure 6, the left side is BAU and the right side is NEP. While the share of nuclear is 22.9% (BAU), but renewables is the same as 20% in both BAU and NEP. The share of nuclear is likely to increase by 52.3% in NEP.

The figures show that both nuclear and coal are operating as base load power plant, with pumped storage providing peak load. However, over the period from 2025 to 2030, the output of new coal has been penetrated by the intermittency of renewables. Especially, in 2030, all the base load power plants stop providing electricity in some load region represented on the lowest demand. Compared to BAU, NEP scenario presents that the share of base power plants increases as the proportion of nuclear power plants increases. It means that the significant penetration of renewable power prevents the nuclear power from providing electricity constantly over the year.

4. Conclusions

This study shows that nuclear power is required to be operated flexibly when renewables grow accounting for almost 20% out of total power generation in Korean electric supply system.

The flexibility requirement for nuclear power generation should be emphasized especially when the electricity generation in electric power system comes more from the renewables and nuclear power.

It is suggested that load region be divided into hourly to assess economics of NPP flexibilities. More disaggregation of the load region together with the introduction of storage technologies, like batteries, is expected to assess economics of flexibility in electric power system.

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