Preliminary Study on effects of ESS integrated nuclear and coal power plants based on RE3020 plan

Jai Oan Cho[a], Jeong Ik Lee[a]*
[a]*Dept. Nuclear & Quantum Eng., KAIST, 291, Daehak-ro, Yuseong-gu, Daejeon, 34141, Republic of Korea*
[*]*Corresponding author: jeongiklee@kaist.ac.kr*

1. Introduction

Korea has been one of the leading nation in the nuclear industry. The country is a nuclear exporter and has had 30% of its electricity from nuclear power before the anti-nuclear policies started. However, the new administration proposed an energy plan to reduce the nuclear portion in the national grid and increase the renewable energy to 20% by 2030. The plan is called RE3020[1].

Significantly increasing the proportion of renewable energy (RE) in the grid brings challenges to the grid. The biggest problem may be the oversupply of power at parts of the day and undersupply at others. The major players in Korea's grid will be nuclear, coal, gas, and RE by 2030. If power from RE is bought with priority, power from gas, coal and nuclear will be curtailed in order considering the fuel cost. Even with just 20% of RE, nuclear power may have to be curtailed from time to time in order to maintain the grid stability. However, curtailing power comes with a cost. Fluctuating supply from fossil fuel plants generate more greenhouse gas (GHG) per energy generated than a stable supply. Load following with nuclear power plants (NPP) creates more radioactive waste and requires more safety precautions dealing with the fuel. Also, nuclear requires heavy initial capital investment while fuel cost is comparatively cheap. Therefore, maximizing the use of nuclear power once installed is crucial in maintaining the economics of nuclear power. Integrating energy storage systems (ESS) to base load plants is an attempt to utilize the excess power in oversupply situations.

There are many types of energy storage systems. The most common system for large grids is the pumped-storage hydro plant. Electrochemical storage system industry for small and medium grids is growing fast. Compressed air energy storage, thermal energy storage are also great candidates for the grid. This study examines the benefits of storing excess power from base load plants in energy storage systems (ESS).

In this study, the authors attempted to predict the future electricity demand and supply based on the current government plan first. From the prediction, the scale of ESS integration to the base load power plants such as nuclear and coal can be determined.

2. Methods and Results

2.1 Methods

The hourly demand curve of 2017 was used as a reference. The 8th Basic Plan for Electricity Supply and Demand predicts that the capacity would increase by a yearly average of 1.3%. [2] Generation loss of 0.31% and transmission loss of 0.913% is assumed.

Predicting electricity generation from RE in the future is very challenging if not impossible. Since the government promotes distributed power, it is even more difficult to predict the spatial distribution across the country and the power generated from each area. Therefore, actual data of electricity generated from RE in selected regions was used and the data was simply scaled up to the national level assuming that regional characteristics do not vary substantially in Korea.

2 wind power plant and 8 solar power plant data was provided by KOSPO (Korea Southern Power) and 3 solar power plant data was provided by Korea Rural Community Corporation. 41MW of Wind power plant data and 6.251 MW of solar power plant data was used. Reference year was 2017. These were all the RE hourly generation history data found by the authors available to the public. All the solar power data was summed up hour by hour and scaled up to 36.5 GW capacity. All the wind power data was summed up and scaled up to 17.7 GW capacity as proposed in the RE3020 plan [1]. However, the total electricity generated from the two major RE sources fell short to the 20% plan so a coefficient of 1.5569 was multiplied to secure 20% of total electricity production at 2030.

Coal and Nuclear power were used for base load sources. Total capacity of coal and nuclear are also specified in the 8th Basic Plan [2]. The total electricity generation proportion is also specified. Using the total demand and generation ratio, we can calculate the capacity factor of coal and nuclear plants. The total capacity and capacity factor of nuclear are 20.4 GW and 88.59%. The total capacity and capacity factor of coal are calculated to be 39.9 GW and 68.42%. Therefore, the power supply from nuclear and coal are given as stable values as 18.07 GW and 27.30 GW respectively. Gas power plants are regarded as peak load plants and are the plants we want to replace as much as possible with ESS so gas power is not modelled in this calculation.

Energy storage systems are integrated to nuclear and coal plants. When oversupply of power occurs, energy from coal is stored in ESS first. When there is still more oversupply, energy from nuclear is stored in ESS. During undersupply, stored energy from coal ESS is used first. When there is still undersupply, stored energy from nuclear is used next.

2.2 Results

The ESS capacity and amount of energy stored must be determined first. Therefore, histograms were drawn. It is assumed that it cannot supply more than the energy stored, and stored energy comes from oversupply. Therefore, to maximize ESS usage, Oversupply and undersupply must be similar in scale. Fig. 1. Shows that the storage and discharge histogram meets at around 200GWh. Considering the ratio of coal and nuclear electricity generation of 6 to 4, 120 GWh of ESS was attached to coal power plants and 80 GWh of ESS was attached to nuclear power plants.

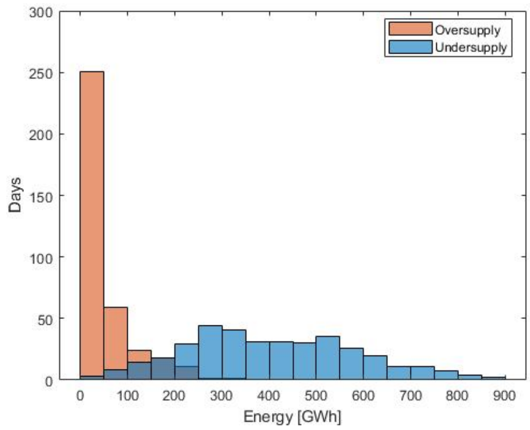

Fig. 1. Histogram of ESS daily stored energy required over one year.

ESS required capacity was also plotted on a histogram. If we consider the capacity ratio between storage and discharge to be 1:1, we can see that 20GW is where the two histograms meet. Therefore, the total capacity of ESS was set as 20GW. Considering the generation ratio between coal and nuclear, the capacity was also addressed as 12 GW to coal and 8 GW to nuclear.

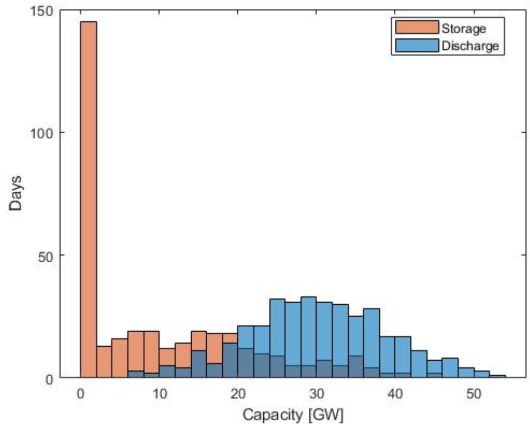

Fig. 2. Histogram of ESS daily maximum capacity required over one year.

The hourly demand curve was subtracted from total supply (RE, coal, and nuclear) and shown in Fig. 3. Positive values show the storage capacity required to stabilize the grid and negative values show the capacity of discharge required. The goal of ESS system is to store as much energy from the oversupply and release it in the undersupply region. Fig. 4. shows the same graph with ESS integrated to coal and nuclear plants. We can clearly see a sharp decrease in the positive range which tells that ESS has helped grid stability greatly.

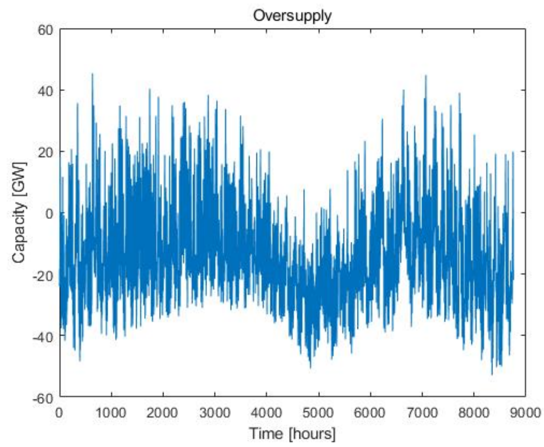

Fig. 3. Oversupplied capacity (Demand subtracted from RE+Coal+Nuclear Supply) without ESS.

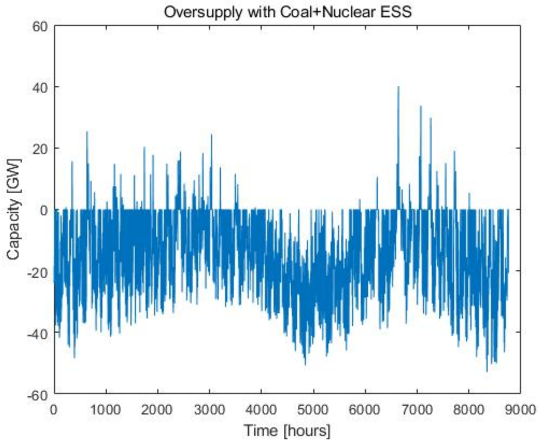

Fig. 4. Oversupplied capacity (Demand subtracted from RE+Coal+Nuclear Supply) with ESS.

Fig. 5 shows the oversupply capacity of a single week without the ESS and that with the ESS, we can see that areas with oversupply have been flattened out a lot.

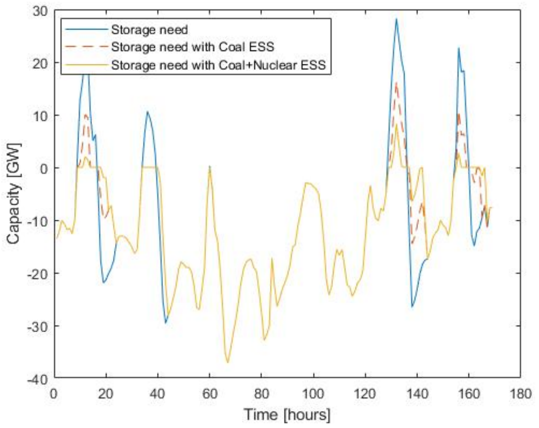

Fig. 5. Oversupplied capacity (Demand subtracted from RE+Coal+Nuclear Supply) of week 40.

The demand and supply (RE, coal, and nuclear) curve of week 40 was drawn to see the effect of ESS on the grid up close. As can be seen from Fig. 6, there is excess power on 4 days which would have to be curtailed if there is no ESS. Plants would have to reduce their output and some plants may even have to stop completely.

However, with the help of ESS integrated base load plants, energy can be stored when it is abundant and used when it is scarce. When supply from RE, coal, and nuclear is not enough, gas power plants have to be operated to follow the peak load. It can be seen in Fig. 7 that with the help of ESS on coal and nuclear plants, almost no energy is wasted on week 40.

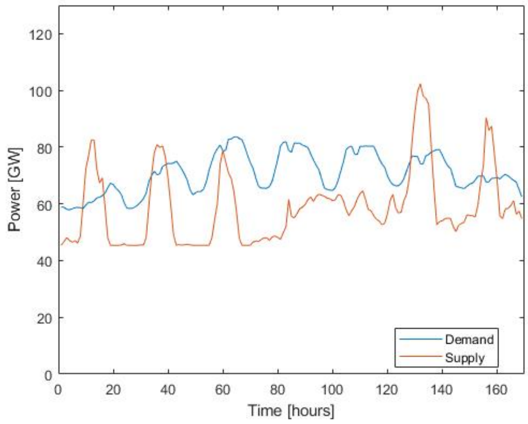

Fig. 6. Demand and Supply curve of week 40 without ESS.

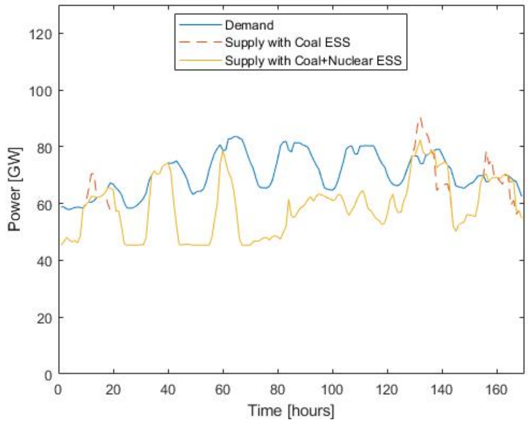

Fig. 7. Demand and Supply curve of week 40 with coal and nuclear ESS.

Integrating the ESS to base load plants can increase the amount of energy generated from base load plants. Over the course of year, 1255 GWh was stored in coal ESS meaning an additional 1255 GWh was generated. For nuclear, the value was 548 GWh.

Another benefit of integrating ESS to base load plants is GHG emission reduction. The total amount of energy stored is the amount of energy less produced from peak load gas plants. Even with carbon emission from natural gas production excluded (250 gCO_2eq/kWh), nuclear (4 gCO_2eq/kWh) has a much lower carbon footprint than peak gas plants (2000 gCO_2eq/kWh); GHG emission can be reduced to a considerable extent [3]. The total amount of GHG reduced adds up to 1,093,808 tons of CO_2 per year.

In contrast to common belief, utilizing more coal energy also reduces GHG emissions. Gas plants generally emit less GHG than coal plants if operated consistently. However, the gas plants replaced in these cases are peak load gas plants. In this case, maintaining constant power coal plants (800 gCO_2eq/kWh) has less of a carbon impact than peak load gas plants (2000 gCO_2eq/kWh). The total amount of GHG reduced by replacing gas with coal powered ESS system was 1,506,000 tons of CO_2 per year. Therefore, the total amount of GHG reduced with coal and nuclear powered ESS system was 2,599,808 tons of CO_2 per year.

3. Conclusions

RE proportion in the Korean grid by year 2030 is planned to be increased to 20%. With more intermittent energy sources, more excess energy will be produced. If RE is not curtailed as in Germany, baseload plants will have to load follow. By integrating ESS to baseload plants, we can enhance grid stability, generate more energy from already installed facilities, and also reduce GHG emissions.

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