Maximizing Nuclear Power for 2050 Carbon Neutral Energy Mix in Korea

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1. Introduction

Transition to a carbon neutral society is a big issue around the world. The IPCC(Intergovernmental Panel on Climate Change) proposed that the world should reach carbon neutrality by the year 2050 in order to keep global warming under 1.5℃[1]. To reach the goal, the South Korean Presidential Committee on Carbon Neutrality presented three road maps on Aug. 5th 2021[2]. However, the report has received criticism for many reasons. The biggest reason is that the plan is based on many technologies that are not commercially available today or the near future. Another reason is that it does not address how much ESS(Energy Storage System) is required to reach such goal.

With the decrease of baseload power and increase of intermittent energy sources, the grid becomes inherently unstable. In order to mitigate the instability, large scale Energy Storage Systems must be introduced to the grid. Although large scale batteries are still very costly, there is very limited options when it comes to large scale implementations. Pumped hydro systems are the only reasonable option but in a densely populated country like Korea, not many sites are left for such systems.

Among the many areas, this paper presents 3 different carbon neutral scenarios of energy mix in South Korea for year 2050. It will be based on energy technologies currently available in the market today or in the near future. Also, ESS requirements will also be taken into consideration.

2. Methodology

The total electricity generation required for 2050 was predicted to be 1207.7 to 1259.4TWh according to the Committee's reports[2]. The hourly electricity demand profile of year 2017 was used assuming that the profile remains the same and a multiplication factor was multiplied to make the total electricity generated as 1259.4TWh.

Commercially available low carbon energy sources are very limited in South Korea. They are nuclear, solar, wind, and hydro energy. However, hydroelectric dams have specific requirements on landscape and are thus difficult to add in large capacities. Therefore, only three low carbon sources are considered.

Nuclear power plants are very good baseload energy sources, especially in Korea since the nuclear plants supply the most cost-effective electricity in the grid. However, it is less advantageous to reduce the power following the load because of the big capital costs. Solar and wind power plants do not require fuel to run so once installed, they can continuously generate power for their engineered lifetime with minimum maintenance. However, the same reason makes them heavily dependent on weather conditions, which makes power generation inflexible. Three scenarios with a combination of these three low carbon sources with ESS is reviewed.

Supply curve for renewable energy was derived from actual electricity generation data from solar and wind farms. Data from KOSPO (Korea Southern Power) and Korea Rural Community Corporation was used. Totally, data from 41MW of wind power generation and 6.3MW of solar photovoltaic power generation was used. The supply curve of actual plant generation data was scaled up to meet our target generation capacity.

The hourly demand curve was compared to the generation curve of the scenario. Excess electricity was stored in ESS and when demand was higher than supply, the energy stored in ESS was used. Charge/Discharge efficiency of 90% was used. Although current nuclear reactor technology can provide load-following, load-following was not implemented in this study.

3. Results

The first scenario is nuclear 100%(1259.4TWh) with ESS. Assuming electricity demand profile remains the same with 2017, nuclear can provide 66%(831.2TWh) of demand without power reduction. To power more than 66%, either the plants need to reduce their power depending on the load or the excessive energy needs to be stored in ESS. The cost competitiveness of load-following and ESS storage have to be thoroughly analyzed to find the most effective solution but for this preliminary study, ESS storage strategy was selected.

Fig. 1. shows that maximum battery storage capacity required is 48.5GW, while maximum discharge capacity is 50.0GW. Fig. 2. Shows that a maximum of 28,795 GWh must be stored in batteries during fall season to use for the winter. From the figure, it can be seen that the energy status goes up, meaning excess energy is being stored in ESS, during the spring and fall and goes down, meaning energy stored in ESS is being used to supply for high demand, during summer and winter. The stored energy empties by the end of winter. Fig. 1. shows the discrepancy between the electricity supply and demand curve. Positive numbers show excessive energy that needs to be stored while negative numbers show ESS discharge needed to cope with high demand.

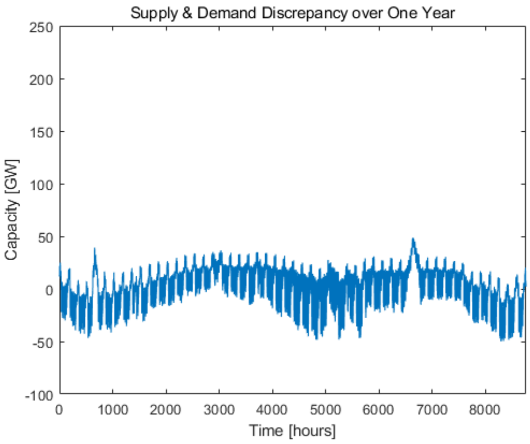

Fig. 1. Supply & Demand Discrepancy over One Year for Scenario 1

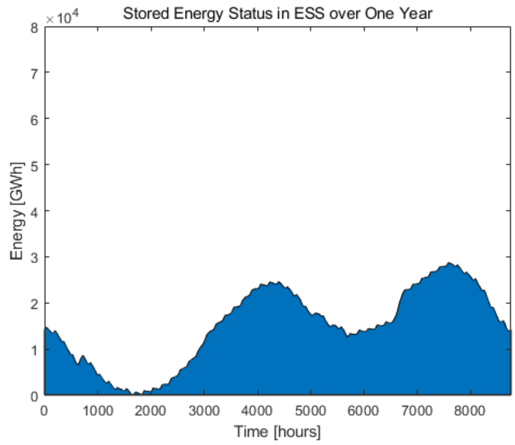

Fig. 2. Stored Energy Status in ESS over One Year for Scenario 1

The second scenario uses nuclear for 66% as baseload with 34% from solar along with ESS to store excessive energy. Nuclear power plants run on full power throughout the year and electricity from solar power plants are either used or stored in ESS depending on the demand curve.

Fig. 3. shows that maximum battery storage capacity required is 243.4GW while discharge capacity of 95.7GW is required. Fig. 4. shows that maximum of 50,552GWh must be stored for use in the summer and winter.

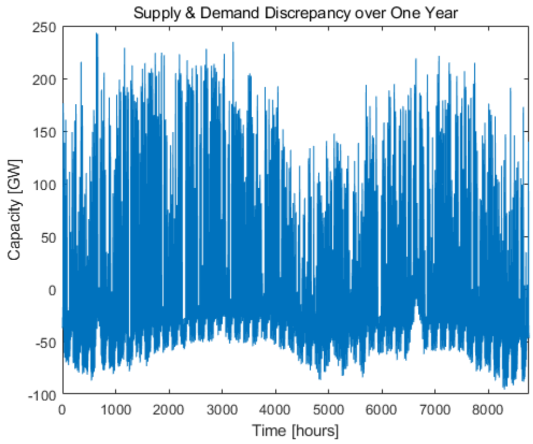

Fig. 3. Supply & Demand Discrepancy over One Year for Scenario 2

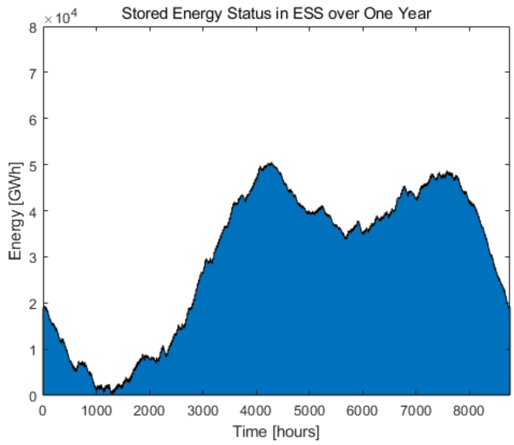

Fig. 4. Stored Energy Status in ESS over One Year for Scenario 2

The third is similar with the second but with wind power plants instead of solar. So, nuclear plants take care of baseload and supply 66% of the total generation with 34% of generation supplied by wind with ESS to supply flexibility.

Maximum storage capacity of 152.8GW is required while discharge capacity of 97.0GW is needed. 76,988 GWh must be stored by the end of spring in order to supply for summer.

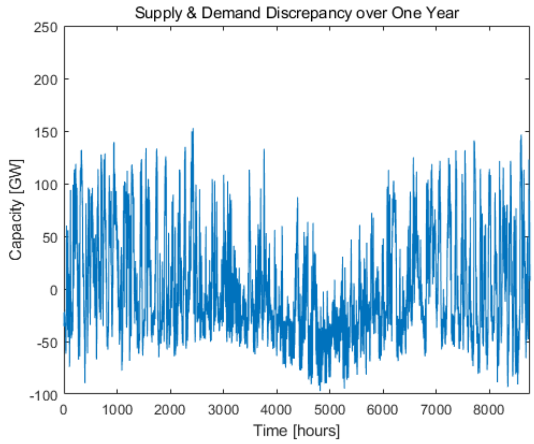

Fig. 5. Supply & Demand Discrepancy over One Year for Scenario 3

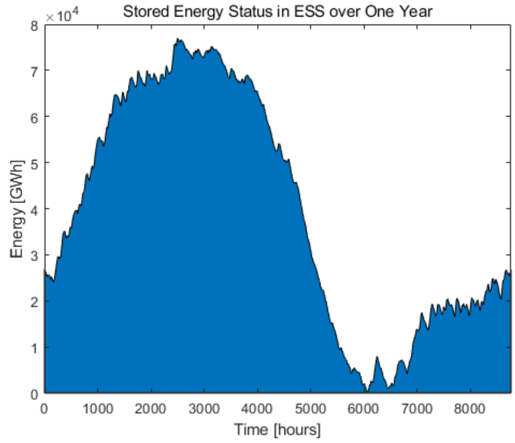

Fig. 6. Stored Energy Status in ESS over One Year for Scenario 3

Table I: ESS Requirement Comparison for 3 Scenarios

	Scenario1: N100	Scenario2 N66+S34	Scenario3 N66+W34
Max. Storage	48.5GW	243.4GW	152.8GW
Max. Discharge	50.0GW	95.7GW	97.0GW
Max. Energy Stored	28,795GWh	50,552GWh	76,988GWh

With the absence of flexible power sources, all three scenarios have very challenging requirements for ESS. The ESS requirements are compared in Table I. Out of the three, scenario 1 has the least demanding ESS requirement. Scenario 2 has the biggest storage power requirement since solar energy is only available for a few hours during the day. Comparing with scenario1, scenario2 needs five times the storage capacity. Scenario3 needs to store the most energy among the three. More than 2.6 times of that of scenario 1 is required.

4. Conclusions

Three scenarios of energy mix for South Korea is reviewed to reach carbon neutrality in 2050. Different combinations of nuclear, solar, and wind power is used for the scenarios. Without load-following power sources, ESS requirements are demanding. However, the nuclear 100% scenario has least challenging ESS requirements compared to the other scenarios with renewable sources.

REFERENCES

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