# Requirements of Load Following Power Plants Operating in South Korea under Deep Penetration of Variable Renewable Energy Grid Environment

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

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 two road maps on Oct. 18th 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 what load following technologies are required to reach such goal when most load following sources today are based on fossil fuel.

Hydropower is one of the very limited option of carbon-free load following power. However, various options may be available in the future as development for different technologies are in progress. Boron-free SMRs (Small Modular nuclear Reactors) with fast load following capabilities are currently being developed. Hydrogen turbines supplied by clean hydrogen can be an option. ESSs (Energy Storage Systems) and fuel cells can also be utilized if cost can be significantly reduced. Natural gas power with carbon capture can also be an option.

As variable renewable energy (VRE) penetration increases in the grid, the intermittency of the supply increases and more aggressive ramp rates are required for load following plants. Overgeneration of VRE results in curtailment, which leads to increased cost and decreased environmental benefits [3, 4, 5]. Several studies have been conducted to effectively store the overgenerated energy [6, 7, 8]. This paper aims to present the ramp rate required for load following power sources and storage technologies that are being developed under the grid condition with deep penetration of VREs.

## 2. Methodology

The total electricity generation required for 2050 was predicted to be 1208.8 to 1257.7TWh 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 1257.7TWh.

For the sake of a sensitivity study, VRE penetration is increased from 0% to 100% in this study. The remaining power is assumed to be supplied by a load following power plant, which can be any of the sources mentioned above (e.g. SMR, Hydrogen, Fuel Cell, Gas Turbine with CCS). The hourly demand curve was compared to the generation curve of the scenario. VRE sources are curtailed when supply exceeds demand as no energy storage is assumed for simplicity.

Supply curve for VRE sources 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. The supply curve of actual plant generation data was scaled up to meet the target generation capacity.

## 3. Results

The first scenario uses only wind power for VRE. Wind power plant capacity factor in Korea (i.e. 20~25%) is usually higher than that of solar power plants but power output is more random. As shown in Fig. 1, maximum ramp up rate was estimated to be 60%/hr when 80% of VRE occupies the grid while maximum ramp down rate was -80%/hr at the same condition.

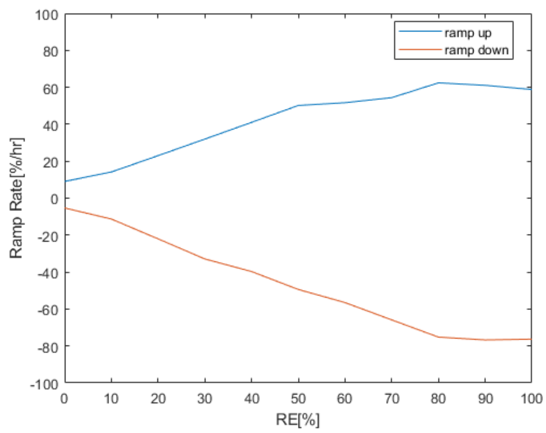


Fig. 1. Ramp Speed Requirement for Load Following Plant when VRE is only wind

The second scenario uses only solar power for VRE. Solar power plants in Korea usually have a lower capacity factor (i.e. 15%) than that of wind power plants but supplies a more regular output. Higher ramp rates are required because output starts at 0 at dawn and reaches a maximum around noon and decreases rapidly to 0 in the evening. As shown in Fig. 2, maximum ramp up rate was 80%/hr at 60% VRE while maximum ramp down rate was -80%/hr at 60% VRE.

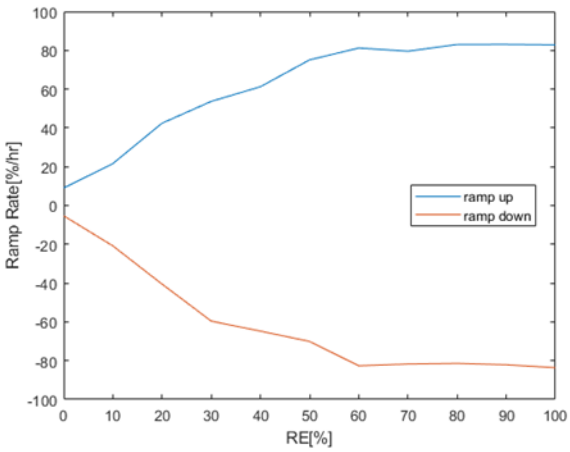


Fig. 2. Ramp Speed Requirement for Load Following Plant when VRE is only solar

Each of solar and wind power supplies half of the renewable portfolio in the third scenario. As shown in Fig. 3, maximum ramp up rate was 60%/hr at 80% VRE while maximum ramp down rate was -80%/hr at 80% VRE.

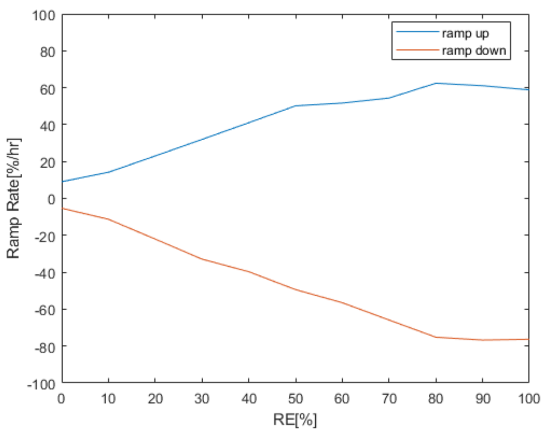


Fig. 3. Ramp Speed Requirement for Load Following Plant when VRE is 50% Solar and 50% Wind

## 4. Conclusions

Three scenarios of energy mix for South Korea is reviewed to reach carbon neutrality in 2050. Maximum ramp speed requirements were compared for the three scenarios. Wind power, solar power, and a combination of the two were used to supply power for the renewable portfolio in the three different cases. Out of the three, the solar only case (Scenario 2) required the most demanding ramp speed for load following sources while the other two cases showed somewhat similar results. Therefore, utilizing wind power, solely or mixing with solar power, contributes to making a less demanding operating condition for load following sources. However, in deciding the optimum energy mix, one must also consider cost, energy security, and many other factors. Further studies on finding the optimum energy mix considering the different factors is required.

## REFERENCES

[1] IPCC, 2018: Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [V. Masson-Delmotte, P. Zhai, H. O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, T. Waterfield (eds.)]. In Press.
[2] 2050 탄소중립위원회, 2050 탄소중립 시나리오, Oct. 2021
[3] Rose, Stephen, and Jay Apt. "The cost of curtailing wind turbines for frequency regulation and ramp-rate limitation." Proc. 29th USAEE/IAEE North American Conference on Energy and the Environment: Conventional and Unconventional Solutions. 2010.
[4] Denholm, Paul, Matthew O'Connell, Gregory Brinkman, and Jennie Jorgenson. Overgeneration from solar energy in california. a field guide to the duck chart. No. NREL/TP-6A20-65023. National Renewable Energy Lab.(NREL), Golden, CO (United States), 2015.
[5] Golden, Rachel, and Bentham Paulos. "Curtailment of renewable energy in California and beyond." The Electricity Journal 28, no. 6 (2015): 36-50.
[6] Denholm, Paul, and Mark S. Mehos. Enabling greater penetration of solar power via the use of CSP with thermal energy storage. Golden, CO, USA: National Renewable Energy Laboratory, 2011.
[7] Marcos, J., O. Storkël, Luis Marroyo, M. Garcia, and E. Lorenzo. "Storage requirements for PV power ramp-rate control." Solar Energy 99 (2014): 28-35.
[8] Alvaro, Daniel, Rafael Arranz, and Jose A. Aguado. "Sizing and operation of hybrid energy storage systems to perform ramp-rate control in PV power plants." International Journal of Electrical Power & Energy Systems 107 (2019): 589-596.