Preliminary Study on the Strategic Role of SMRs in South Korea's Energy Transition to Carbon Neutrality

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***Keywords :** Small Modular Reactor, Decarbonization, Repowering, Thermal Power Plant Replacement*

1. Introduction

As a critical energy source in the fight against climate change and the pursuit of carbon neutrality by 2050, the role of next-generation nuclear power is undergoing significant reconsideration. In the realm of fourth-generation reactors, global competition for next-generation nuclear power technology has intensified greatly over the past decade. This competition is particularly fierce in the development of Small Modular Reactors (SMRs), which serve as a pivotal component of next-generation nuclear power.

As of 2022, more than 80 countries are actively engaged in the development of SMRs. Recently, driven by imperatives such as carbon neutrality, energy security, and safety, competition among nations to advance SMR technology has escalated. This competition aims to preemptively address the replacement of aging thermal power plants and large nuclear facilities. Consequently, considerable attention has been directed towards the development of 'independent SMR reactors' as part of the 110 national initiatives in Korea.

Replacing coal boilers in aging thermal power plants with SMRs is expected to yield significant economic benefits and substantially reduce carbon emissions. In the case of Poland, it has been estimated that the initial capital required for the installation of SMRs would decrease by approximately 28-35%, and the Levelized Cost of Electricity (LCOE) would decrease by about 9%-28% [1]. Furthermore, if global retrofit decarbonization of thermal power plants were undertaken, it is estimated that 200 billion tons of CO2 emissions could be reduced [1].

As SMR development advances in Korea, it's crucial to assess it in the local context by analyzing the distribution of thermal power plants. This study aims to identify the best candidates for decarbonization using SMRs, consolidating relevant data and proposing future steps based on available SMR steam temperature analysis.

2. Methods and Results

The study is based on publicly available data from the Korea Electricity Exchange [2], Electric Power Statistics Information System [3], and Repowerscore [4]. Data for 91 thermal and Cogeneration Heat and Power (CHP) plants of 30MWe or more installed in mainland South Korea were analyzed. Small power plants installed on islands off the coast of South Korea were not included in this analysis. The number of plants and their capacities were estimated on a standalone unit basis.

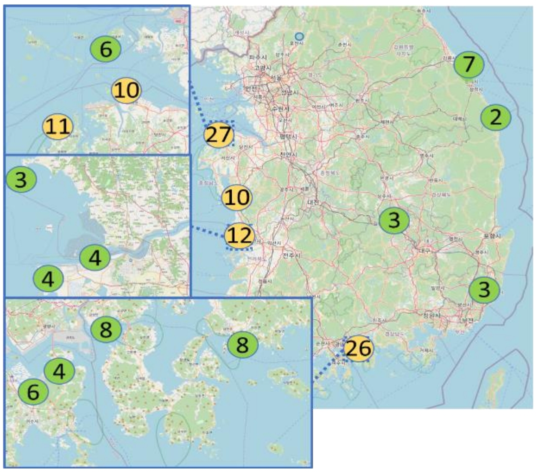

Figure 1 Location of domestic coal plants

As shown in figure 1, most coal-fired power plants in South Korea are situated along the coast, benefitting from their proximity to water bodies for cooling purposes. However, there are four coal power plants located inland: Pocheon, Gumi CHP, and two Gimcheon CHP units. Notably, Pocheon Power Plant and Gumi Power Plant are strategically positioned near Pocheon Stream and Nakdong River, respectively, facilitating the supply of cooling water. Additionally, the two cogeneration units in Gimcheon, each with an output of 30 MWe, appear capable of meeting the cooling water requirements of the industrial park's water supply system. This abundance of cooling water supply in domestic coal power plants suggests favorable conditions for considering coal repowering with nuclear energy.

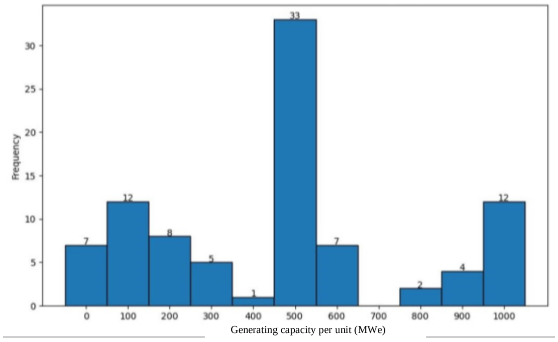

Figure 2 Overall distribution of generating capacity

The overall distribution of capacity per unit for domestic coal plants is shown in figure 2. In terms of standalone units, plants with an output of 500 MWe make up the largest share, with 33 out of the total 91 units. However, given the wide range of power outputs, from less than 100 MWe to 1000 MWe, other metrics are needed to effectively select target plants.

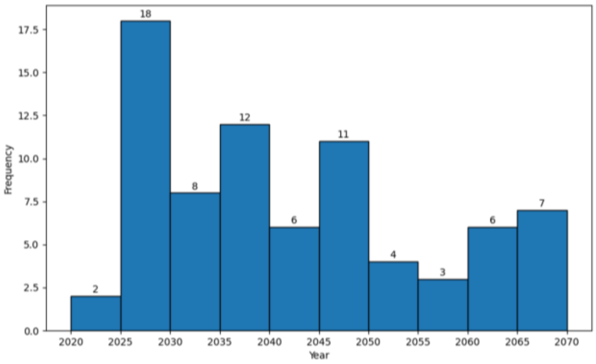

Figure 3 Distribution of planned retirement day

Figure 3 displays the expected retirement dates of coal plants after 2023. Among the 91 existing units, 77 are anticipated to retire after 2023, while 14 have already been retired. In selecting the placement of the targeted coal plants, consideration will be given to the fact that more than half of the 77 units are expected to retire by 2040. Therefore, a comprehensive review of their generating capacity through 2040 will be undertaken.

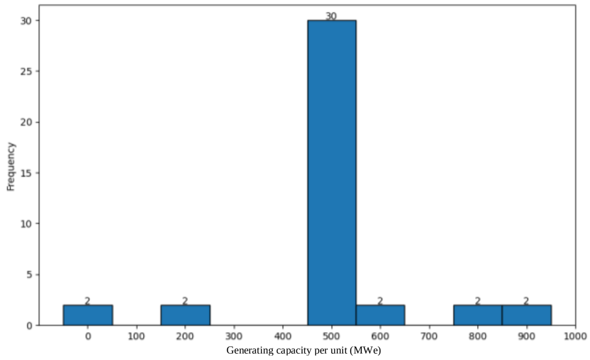

Figure 4 Distribution of capacity retired until 2040

Figure 4 displays the capacity distribution of thermal power plants scheduled for retirement by 2040. It is evident that the largest number of plants falls within the 500 MWe class, with 33 units. This indicates that the highest demand for decarbonization and repowering with SMRs is expected for plants in the 500 MWe class due to their retirement.

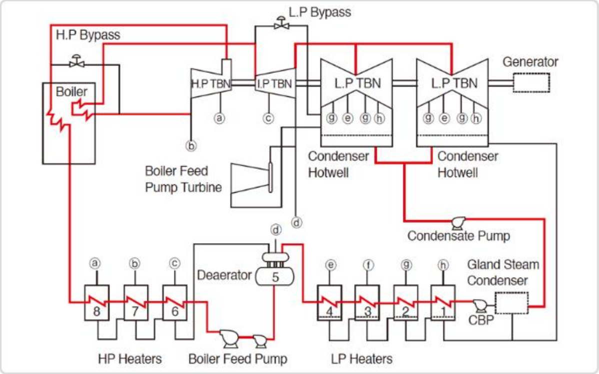

Figure 5 Layout of standard Korea 500MWe coal power plant [5]

Table 1 Steam pressure and temperature of Korea 500MWe coal power plant [5]

Location	Pressure (MPa)	Temperature (℃)
HP Inlet	24.233	537.80
HP 1st stage Outlet	6.314	341.06
HP Outlet	3.958	281.66
IP Inlet	3.601	537.80
IP 1st stage Outlet	1.528	416.67
IP Outlet	0.841	334.80
LP Inlet	0.841	334.80
LP 1st stage Outlet	6.636E-2	84.40
LP 2nd stage Outlet	2.459E-2	64.62
LP Outlet	5.982E-3	33.18

Figure 5 and Table 1 depict the temperature and pressure of steam as a function of layout and location for a 500 MWe thermal power plant. The data presented above can provide an initial insight into the conditions that will need to be considered when the heat source of a coal-fired power plant is replaced with SMRs in the future. When considering repowering with SMRs, the boiler portion illustrated in Figure 5 would be replaced with SMRs, providing heat from the SMRs to the steam cycle. Depending on the conditions of the steam from the SMRs, it is anticipated that all or some of the turbines in that layout could be reused. These conditions will also affect the economic evaluation of the repowering process [1].

Table 2 Steam temperature and pressure of SMRs

	Temperature (℃)	Pressure (MPa)	Type
Xe-100	565 [6]	16.5 [7]	HTGR
NuScale	306.67 [8]	3.35 [8]	PWR
SMART*	296.4 [9]	5.2 [9]	PWR
MMR	660 [10]	3~6 [10]	HTGR

***In case of SMART HP turbine inlet temperature and pressure were accessible**

Table 2 displays the steam temperature and pressure conditions for currently available SMRs. The four SMRs within the scope are X energy's Xe-100, NuScale, KAERI's SMART, and Ultra Safe Nuclear's Micro Modular Reactor (MMR). Overall, it is observed that the high-temperature gas reactors (HTGRs) have higher temperature and pressure conditions than the SMRs of the pressurized water reactor (PWR) type.

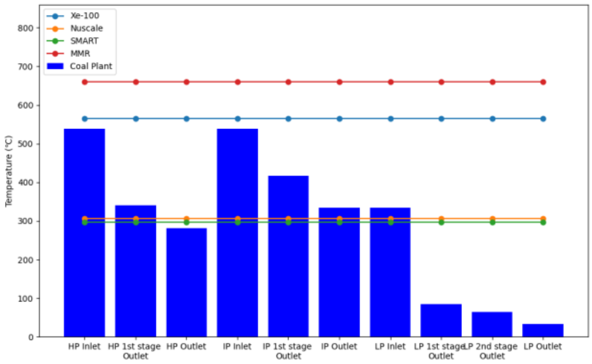

Figure 6 Steam outlet temperature of SMRs and coal plant temperature depending on location

Figure 6 displays a bar graph depicting the temperature as a function of location in the steam cycle of a thermal power plant, as indicated in Table 1. Each individual solid line represents the steam temperature for each type of SMR, as specified in Table 2. During the process of replacing the heat source with SMRs, some temperature changes may occur due to potential differences in the design of the steam generator compared to conventional steam generators. However, it is not anticipated that these temperature changes will be significant. Therefore, for PWR-type SMRs like NuScale and SMART, it is expected that the temperature conditions of the second stage of the high-pressure (HP) turbine and the low-pressure (LP) turbine will be met. Conversely, for HTGRs such as Xe-100 and MMR, it is anticipated that all stages from the HP turbine to the LP turbine will be usable due to the high steam.

3. Conclusions

The study revealed that more than half of the country's 77 operating coal-fired power plants are expected to retire by 2040. The largest number of plants scheduled for retirement by 2040 are in the 500 MWe class, indicating high demand for decarbonization and repowering with small modular reactors (SMRs). Integrating a small modular reactor (SMR) as a replacement heat source for a coal-fired power plant requires consideration of the steam conditions for integration into the existing steam cycle. Depending on the steam conditions of the SMR, the existing turbine can be reused, impacting the economics of the repowering process. In summary, the specific steam conditions of SMRs play a crucial role in determining compatibility with existing turbines and the overall feasibility of the repowering. Therefore, it is expected that factors such as the steam temperature of SMRs should be prioritized for the repowering of aging thermal power plants with SMRs, followed by further optimization to maximize economic benefits.

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