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Feasibility Study of nuclear-renewable hybrid energy system using MMR

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1. Introduction

Due to the expansion of renewable energy worldwide, the need for sustainability, eco-friendliness and flexibility of nuclear power plants has increased. The global power market is also growing from a centralized power market centered on large power plants to a decentralized power market, which is a small distribution network and power storage/supply system. However, due to the nature of intermittent renewable energy, a duck curve phenomenon occurs in the daily net load excluding renewable energy from total electricity demand. Duck curve shows steep ramping needs and over-generation risk. In energy grids with many renewable sources, power demand is highly variable. These power demands can negatively affect a reactor's capacity factor, resulting in significant economic losses.

As global energy is converted from coal-fired power to eco-friendly energy, the demand for eco-friendly energy supply is increasing, and the international energy paradigm is changing due to war and uncertainties in the global economy. Accordingly, a realistic power source portfolio was formed to achieve carbon neutrality in accordance with policies such as carbon neutrality, RE100, and CF100 centered on developed countries. According to the 10th power supply and demand plan, Korea has a plan to configure facilities with renewable energy (108GW), LNG (65GW), coal (27GW), and nuclear power (32GW) with the goal of securing 239GW of power generation facilities by 2036. Facilities will be expanded by extending the lifespan of nuclear power and promoting new businesses.

Accordingly, it is necessary to build a flexible energy mix through convergence with nuclear energy in order to compensate for the intermittence of rapidly growing renewable energy (solar, wind energy). A nuclear-renewable hybrid energy system (N-R HES) is a type of energy system that combines both nuclear power and renewable energy sources such as solar, wind, or geothermal power to provide electricity. In this type of system, the nuclear power plant serves as a stable baseload power source that can provide consistent electricity, while the renewable energy sources provide additional power during peak demand periods or when there is less demand for nuclear power. The combination of the two sources allows for a more stable and reliable energy supply that can help to reduce greenhouse gas emissions and meet energy demand.

2. Small Modular Reactors (SMR)

Among various reactors, small modular reactors (SMRs) are suitable for N-R HES. SMR refers to a nuclear power plant with an electrical output of 300Me or less, and is attracting worldwide attention in countries requiring distributed power and desert and island regions. SMR can be transported and installed after manufacturing and assembling as a module in a factory, and since electricity is generated as a module, it can respond to various design conditions. The advantages of these SMRs are that they have a small heat output compared to large nuclear power plants, so they are safe, and the cost and construction period are relatively short. Small-sized nuclear power plants have the advantages of small investment size, low risk in the power market, and high safety margin, ensuring inherent safety.

In a situation where renewable energy is significantly increasing, an energy mix using SMR is required according to intermittent characteristics, and SMR is emerging as an optimal energy source that meets the requirements of industry and secures safety and economy. The outlook for the global SMR business market will be 65-85GW worldwide by 2035.

The SMR market can be classified into three major categories: the first off-grid power supply market (10~20MW), the second heat/steam supply market (30~80MW), and the third coal-fired power generation alternative market (80MW~300MW). The first off-grid market is a 30 billion CAD market in 2030, and growth is expected to accelerate thereafter. There is an off-grid community using more than 70,000 diesel/gas engines globally, and small SMRs respond to small-scale electricity demand. Second, the heat/steam supply market is expected to grow continuously after reaching a market of 15 billion CAD in 2030. The third coal-fired power plant replacement market is a market of 100 billion CAD per year in 2030, and growth is expected to stagnate after that. In the long term, in the SMR market, demand for 'coal-fired power replacement' is expected to decrease, while demand for 'off-grid electricity' and 'heat/steam supply' is expected to grow steadily. After the mid-2030s, demand for small and medium-sized SMRs (10-40MW) is expected to account for more than half.

3. Micro Modular Reactor

Hyundai Engineering Co. (HEC) is currently undertaking the construction of a 5MWe demonstration plant at the site of the Chalk River National Laboratory (CNL), Canada with USNC. They are carrying out a micro modular reactor (MMR) project with the goal of commercial operation in 2026. In early 2022, HEC signed an equity investment contract with USNC and secured exclusive rights to the MMR global EPC business. The company signed an engineering and procurement contract for this project in 2022, preoccupied the initial market through participation in the project, and after supplying the first unit, expanded to European countries / combined heat and power plant / commercial power plant in polar, remote areas, mines, and off-grid.

Developed based on a modular design, MMR is transported by trailer after production in a factory, so it is easy to install quickly even in polar and remote regions. The MMR, a high-temperature gas-cooled reactor, has an outlet temperature of over 700 degrees Celsius, which is much higher than that of light water nuclear power plants. Economical hydrogen production is possible through high-temperature electrolysis (SOEC) technology using high-temperature heat.

4. Hybrid Energy System

When the schematic energy flow is expressed from the source to the end user, it is organized as shown in the following figure 1. First group ‘sources’ includes coal-fired power plant (CFPP), combined cycle power plant (CCPP), diesel engine, gas engine, wind energy, concentrated solar power(CSP), solar PV and small modular reactor, hydro and bio energy etc. The second group ‘conversion’ includes steam cycle, supercritical carbon dioxide cycle, battery, ESS, water electrolysis, and desalination technology. The third group ‘energy’ includes fresh water, electricity, process heat, ammonia, hydrogen, and oil. Final group ‘user’ may include on-grid, micro-grid, off-grid, steel mills, electric vehicles, industries, and households. For economical and efficient hybrid system and energy sector coupling, an energy demand target should be set and optimization work is required accordingly.

As an example, a hybrid system of MMR and solar energy can be combined in three ways. Tightly coupled HES is a method of maximizing energy efficiency by mixing energy sources, and thermally coupled HES can be used as needed by thermally converging energy using ESS, such as thermal energy storage(TES). The power cycle connects renewable energy and energy storage systems to produce electricity. To bridge the gap between power demand and intermittent solar energy, TES are used to store energy. During normal operation, the MMR's heat with renewable energy and ESS is centrally controlled, allowing it to respond flexibly to power demand. In addition, in the event of an accident, the controller can be used to supply various external power sources from CSP and ESS. The above two methods can be realized through the solar method. Finally, loosely coupled HES utilizes solar PV instead of CSP, so there is no interference between energies, and energy mix in the form of electricity is possible.

The goal of the hybrid system is to supply long-term stable electricity, hydrogen and process heat to micro-grids such as islands and rural towns. Solar, wind, and MMR were selected as energy sources, and sCO_2 cycle, ESS, and electrolysis technology were selected as components of the hybrid system for energy conversion. The feasibility of the energy mix for the micro-grid was evaluated by considering various factors such as market characteristics by country and region, fuel cost, discount rate, and carbon tax. Additional efforts are needed to evaluate the technical and economic characteristics of the hybrid convergence method and to find the optimal hybrid system that meets the energy demand target and linkage with the energy sector.

5. Future works

According to the future SMR market prospects, it is indispensable to respond to global carbon neutrality by combining SMR and renewable energy. Therefore, it is essential to find the most economical nuclear-renewable hybrid energy system. By confirming the technicality and economic feasibility of the nuclear-renewable hybrid energy system using MMR, we intend to establish strategies for the successful achievement of energy conversion policies. Through the development of HES technology that can be linked with various systems, it contributes to effective climate change response and securing sustainable energy sources, and it is possible to expand the application area to power generation facilities, industrial facilities, and district heating. It maximizes energy utilization by maximizing the use of heat that is wasted without being utilized in power generation facilities and minimizing loss due to energy conversion.

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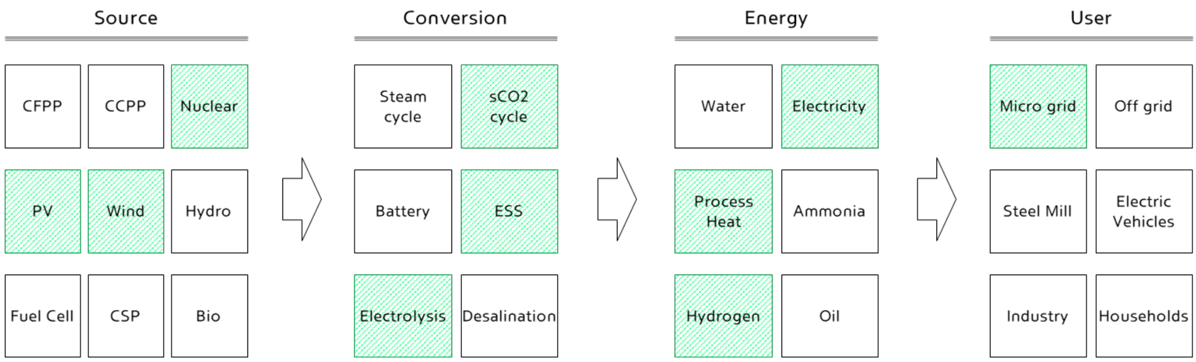

Figure 1. schematic energy flow of energy mix