Feasibility Study of Carnot Battery Systems Integrated with SMRs for Repurposing of Coal-fired Power Plants

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1. Introduction

According to the 11th Basic Plan of Long-Term Electricity Supply and Demand [1] announced by the Ministry of Trade, Industry and Energy in South Korea , all coal-fired power plants are scheduled to be decommissioned by 2050. Meanwhile, there are also plans to explore the potential utilization of coal-fired power plants to respond to the increasing power demand driven by AI, electrification and so on. Furthermore, the plan estimates the required capacity of long-duration Energy Storage System (ESS) at 23GW due to the increasing share of renewable energy. Among them, the pumped hydro storage accounts for 1.25GW, while the remaining 21.75GW has not yet been determined by 2038. Repurposing these coal-fired power plants into Carnot batteries can be the innovative approach that can comprehensively satisfy these plans. The concept of the Carnot battery is to store heat by converting excess renewable energy during the charge mode (Power to Heat, P2H), and to supply electricity from the stored heat using a power cycle during the discharge mode (Heat to Power, H2P). Therefore, repurposing coal-fired plants into Carnot battery can re-utilize these facilities and serve as a large-scale, cost-effective, long-duration ESS by leveraging the substantial stranded assets of the decommissioned plants [2]. However, a Carnot battery that relies solely on an electrical heater-based P2H system, which is a commercially mature technology, could be an inefficient process because the required heat must be supplied from electricity with low conversion efficiency. If cheap and abundant heat is used as the base heat source for the Carnot battery's P2H system, the load on the electric heater could be reduced, thereby improving the efficiency of the Carnot battery. Small Modular Reactors (SMRs) could be a solution to these limitations by serving as the base heat source. In this study, feasible layouts of Carnot battery systems integrated with SMRs will be proposed to repurpose coal-fired power plants.

2. Methods and results

2.1. The advantage of SMR Carnot battery

Since Carnot Batteries operate based on heat engines, their efficiency follows the Carnot Efficiency Principle.

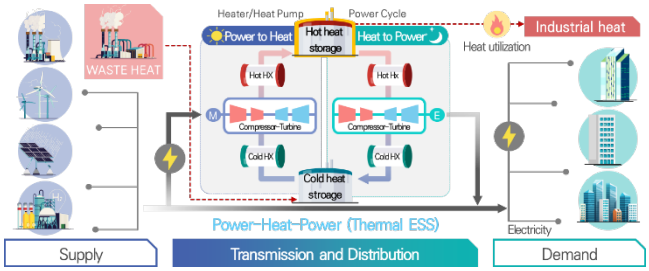

Fig. 1. Conceptual diagram of Carnot battery

In the case that a 500MW$_e$ standard coal-fired power plant is selected as the repurposing model, the required thermal power is approximately 1250MW$_{th}$ of 550℃, and the heat must be supplied only by an electric heater. Considering the heater's efficiency of 98% and cycle efficiency of 40%, the round-trip-efficiency will be around 39%.

However, if steam at 297℃ from an SMR is supplied as the base heat source to a Carnot battery, the required electric power to increase steam temperature up to 550℃ is about 312MW$_{th}$, while the residual heat from the reactor core is about 938MW$_{th}$. Therefore, Carnot battery systems integrated with an SMR have a significant advantage in terms of operation cost by reducing electricity consumption.

2.2. Layout of Carnot Battery with light water-cooled SMRs

Light water-cooled SMRs are regarded as the most technically mature reactors because they can share the value chain of large commercial nuclear power plants. However, the steam temperature of SMRs is below 300℃ due to limitations in coolant's thermal properties. Therefore, in charge mode, the steam from an SMR should be additionally heated above the coal-fired power plant's steam temperature using excess electricity through an electric heater. The steam heated by the electric heater is then stored in thermal energy storage, and in discharge mode, the coal-fired power plant extracts heat from the thermal energy storage instead of using the boiler to generate electricity. The schematic layout of Carnot batter with light water-cooled SMR is shown in Fig. 2.

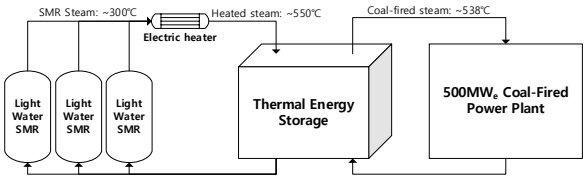

Fig. 2. Schematic layout of Carnot battery with Light Water cooled SMR

3. Conclusions

To achieve carbon neutrality, the decommissioning of coal-fired power plants is inevitable. Meanwhile, coal-fired power plants contain numerous stranded assets, such as balance-of-plant and auxiliary systems. To leverage this existing infrastructure, SMRs-a promising zero-carbon energy source-can be utilized to repurpose coal-fired power plants. However, the most technically mature light water-cooled SMRs have a limited steam temperature that does not match the requirements of coal-fired power plant turbines. Therefore, this study proposes an indirect coupling approach using thermal energy storage and an electric heater to overcome this limitation.

Acknowledgements

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