Thermal Hydraulic analysis of TES integrated PWR Cycle

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1. Introduction

The renewable energy is of great interest in the world electricity market to reduce carbon emission and alleviate global warming. The Korean government announced the 2030 energy plan in which the share of renewable energy increases to 20% by 2030 [1]. However, as the share of renewable energy in the future electric power market is expected to increase, there are some concerns about the quality and stability of the electricity supply. It is because of the intermittent nature of renewable energy sources. The unpredictable intermittent power supply of renewable energy can put a heavy burden on other power sources. A load-following operation of a nuclear power plant is proposed as a solution to this problem. However, existing nuclear load following operation such as control rod adjustment, boron concentration change, coolant temperature compensation causes a reactor thermal output deviation, which may adversely affect reactor safety and economics. In this paper, we suggest a concept that connects a thermal storage system (TES) to a secondary system of a pressurized water reactor (PWR) nuclear power plant (NPP). The TES integrated PWR type NPP can allow the load variation with less or no disturbance to the reactor core thermal output. The TES integrated nuclear power plant can save heat energy by storing thermal energy in TES, and can increase power output by using stored heat energy when it is necessary.

2. TES integrated PWR type NPP

2.1 Load-following operation

The TES integrated PWR nuclear power plant is a system for storing a part of the heat received from the steam generator by branching the mass flow of the secondary system. Then, the output of a nuclear power plant will be reduced. The TES on this system has an ad hoc power cycle to convert stored heat of TES to electricity quickly when it is needed. In this study, this the variations in the secondary side of PWR steam cycle is first focused to understand the performance changes while steam branches to TES. To analyze thermal hydraulic conditions of TES integrated NPP, we adopted KAIST-CCD which is developed for thermodynamic cycle analysis in this research. The simulation was performed for the steady-state according to the change of the steam flow to the TES.

Figure 1 shows TES connected to secondary side of PWR NPP type.

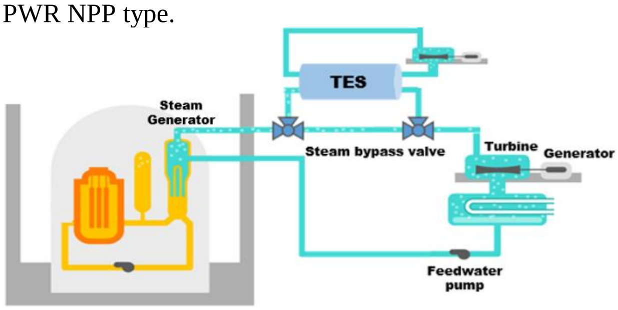

Fig. 1 The conceptual diagram of TES integrated PWR type NPP

2.2 Cycle condition

In this study, a pressurized light water reactor (PWR) type was selected for the TES integrated NPP cycle simulation. Fig. 2 shows the generic saturated steam cycle layout with multiple regenerations that combines a TES. A certain amount of the total mass flow from the steam generator divaricate to the TES. The branched flow through the TES is connected to the inlet line of reheater to merge with the main flow. The total mass flow rate is maintained at constant throughout the steam cycle. The flow rate to the HP turbine is reduced, but to LP turbine is still at constant as the branched flow to TES is increased. The steam cycle operating conditions are given in Table 1. Based on these conditions, we will analyze the amount of energy stored in the TES according to the branch flow rate, output of the HP turbine and the LP turbine, and the temperature of the feedwater on the steam generator inlet.

Table I. Cycle condition

Parameter	Value
Reactor thermal Output	3983 MWt
Electric Output	1408 MWe
Steam Generator Pressure	6.9 Mpa
Steam Generator Outlet Temperature	284°C
Condenser Pressure	5.08 kPa
Secondary cycle Mass flow rate	1925.71 kg/s
HP Turbine Efficiency	0.9
LP Turbine Efficiency	0.9
Pump Efficiency	0.85
Generator Efficiency	0.98

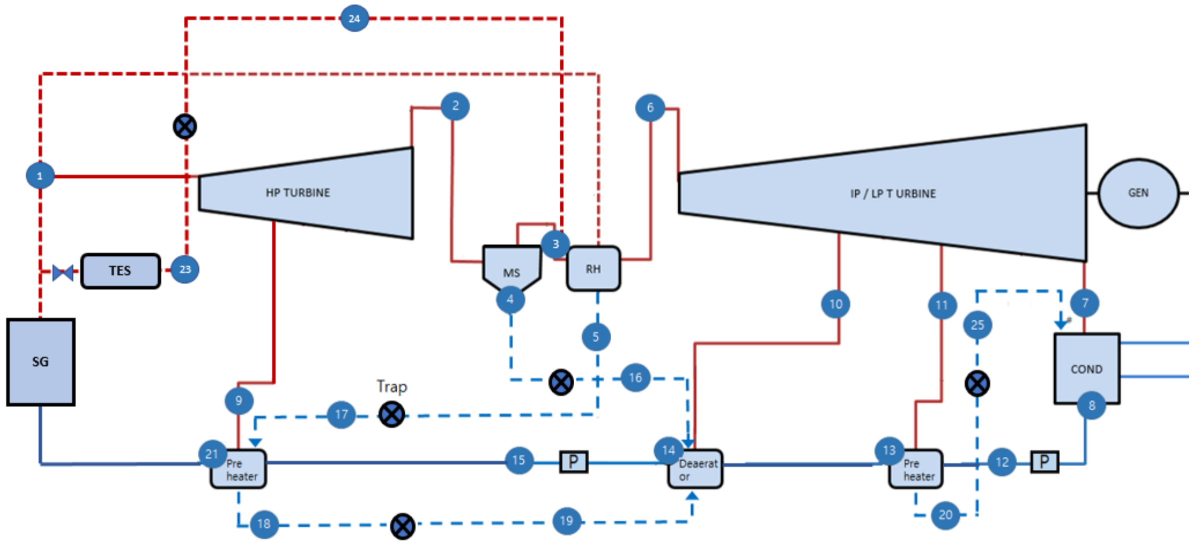

Fig. 2 Steam cycle layout of TES integrated NPP

2.3 Thermodynamic Analysis

Figure 3 shows the stored energy according to the flow rate branched to the TES. The stored heat energy is increased linearly with increasing branched flow to TES.

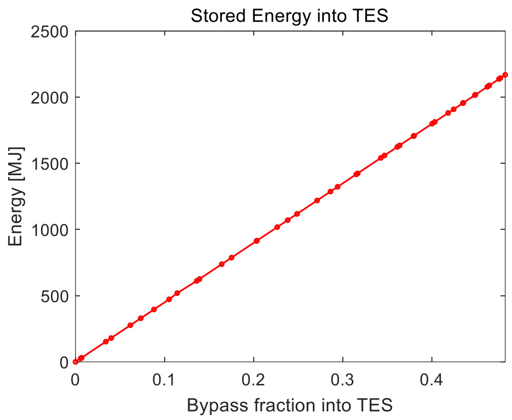

Fig 3. Simulation results of the branched flow to TES

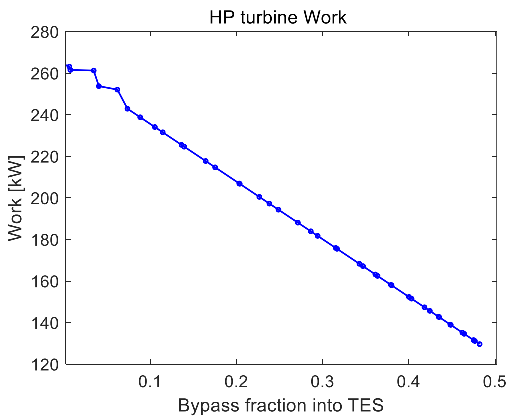

Fig. 4 High-pressure turbine work change according to branched flow to TES

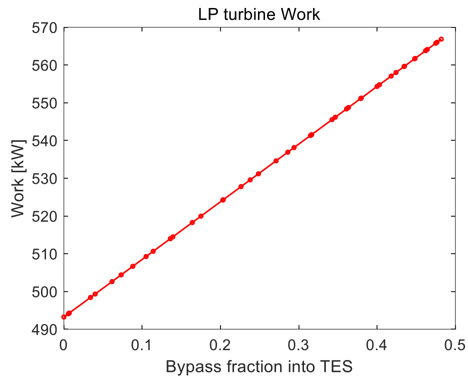

Fig. 5 Low-pressure turbine work change according to branched flow to TES

Figures 4 and 5 show the change of each turbine output. The HP turbine work is decreased as the branched flow to TES is increased since the mass flow rate through HP turbine is declined. On the other hand, the LP turbine work is increased with branched flow because the mass flow rate through LP turbine is increased with constant turbine expansion ratio.

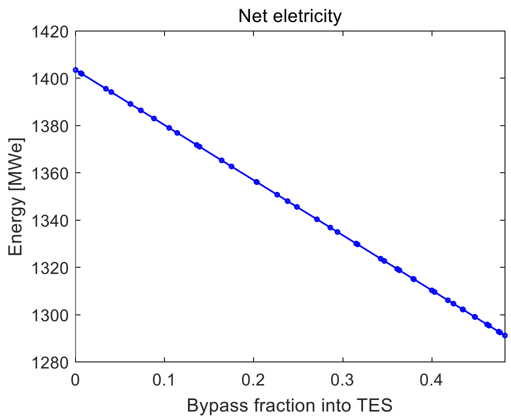

Fig. 6 Net electricity with according to branched flow to TES.

Figure 6 shows that the net electricity output decreases linearly with the branched mass flow rate. Therefore, with TES integrated NPP, the nuclear power can operate on load-following mode by branching flow rate to TES.

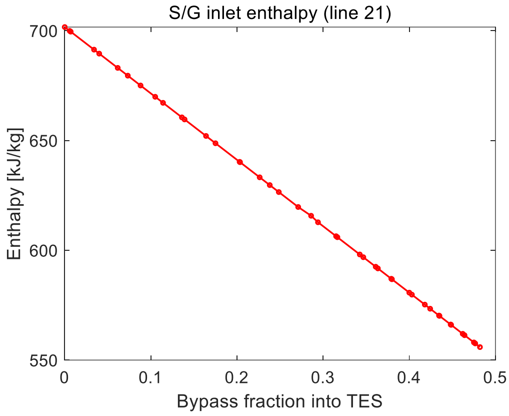

Fig. 7 Enthalpy change of steam generator inlet line according to branched flow to TES

In Figure 7, the steam generator inlet enthalpy is changed with increased branched flow to TES. It means that the temperature of the steam generator inlet is changed from 165°C to 131°C. This is because the flow rate to heat feedwater on last preheater is decreased as the branched flow to TES is increased. It can affect the primary side of nuclear power plant. Therefore, it is required to look for a way to keep the inlet temperature of the steam generator at constant on this cycle with TES.

3. Conclusions

Considering the future electricity supply situations where the share of renewable energy is increased, TES integrated NPP is proposed to ensure the quality and stability of the grid while maintaining small carbon emission footprint. TES integrated NPPs can potentially change the output of nuclear power plants without changing the reactor thermal output by adjusting the reactivity of the core. The proposed system stores some heat in TES, and then uses the stored thermal energy to increase the power output when it is needed. In this study, the stored thermal energy according to branched flow to TES is first estimated. From the simulation results, it is required to find a way to fix the condition of the steam generator inlet. An appropriate TES type for the conditions will have to be designed. In order to evaluate its load-following performance in more detail, it is necessary to study the dynamic response of the whole system as well.

ACKNOWLEDGMENT

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