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Thermodynamic Analysis of Hydrogen Production Integrated Pressurized Water Reactor

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Introduction

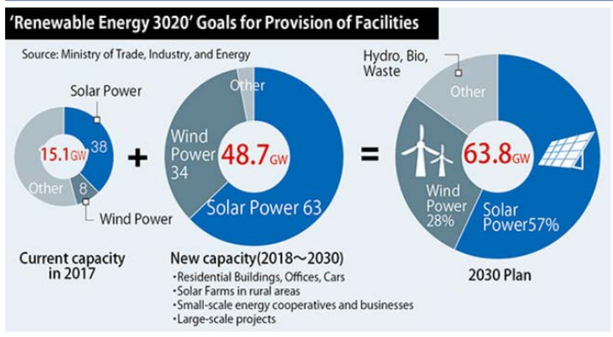

Fig. 1. Renewable energy 3020 goals

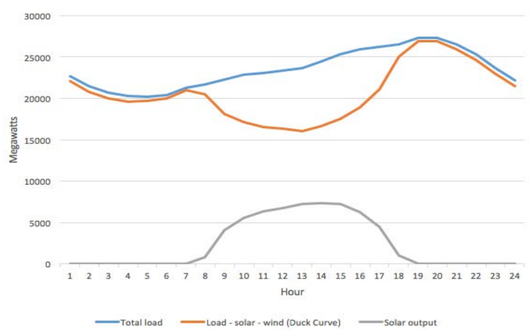

Fig. 2. Duck curve

- The increase in the proportion of renewable energy will inevitably cause an increase in demand for energy storage system(ESS).
- Among several ESSs, interest in hydrogen energy storage is increasing.
- In this study, the layout of hydrogen production integrated PWR is suggested and the off-design operation of the PWR secondary side due to hydrogen production are analyzed thermodynamically.

Hydrogen production using secondary side steam

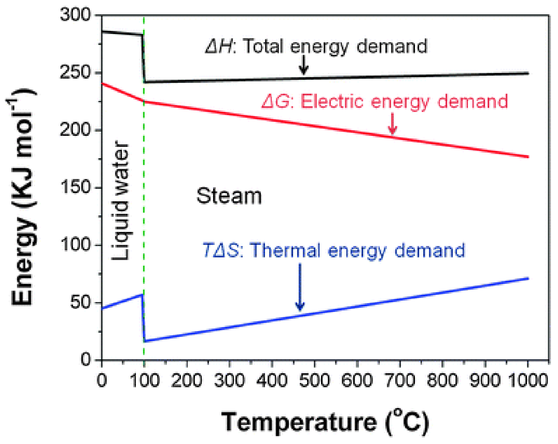

Fig. 3. Electric, thermal and total energy demand for H_2O electrolysis as a function of temperature

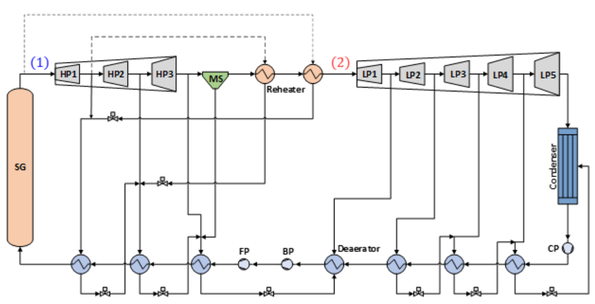

Fig. 4. Typical PWR secondary side

- As shown in Fig. 3, the basic principle of high temperature steam electrolysis(HTSE) using PWR is to reduce the amount of electrical energy required to decompose water molecules by supplying thermal energy.
- Since the PWR can produce steam, it has the advantage of supplying both steam and electricity required for HTSE.

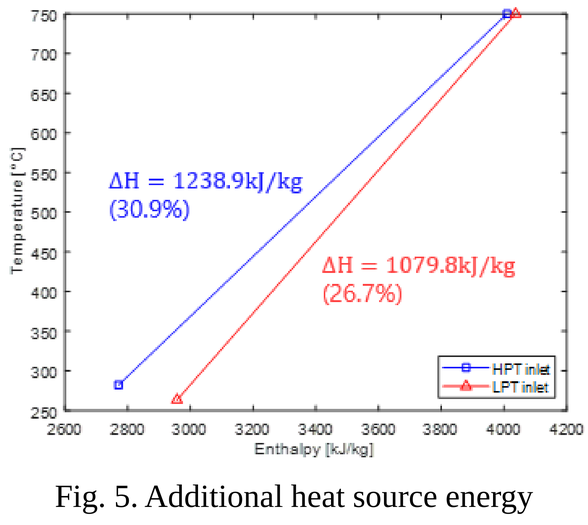

Fig. 5. Additional heat source energy

Table I. HPT and LPT inlet conditions of typical PWR

	HPT	LPT
Temperature [°C]	282.21	263.36
Pressure [MPa]	6.63	1.44

- As shown in Fig. 5, about 30% of the additional heat is required, that is, about 70% of the total heating energy is contained in the steam produced in the PWR.

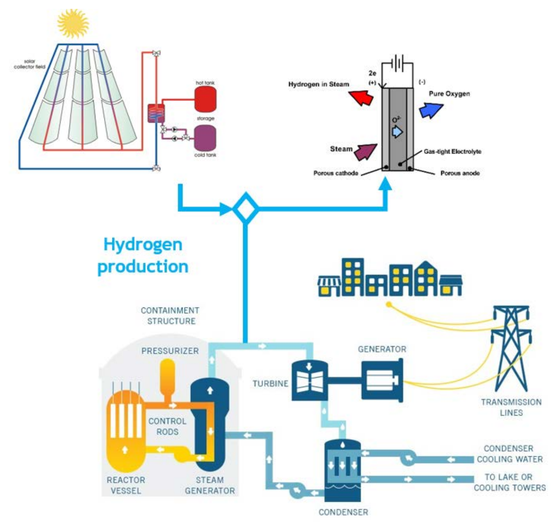

Fig. 6. Solar thermal energy as additional heat source

- In this study, solar thermal energy is recommended as an additional heat source for HTSE.
- Solar thermal energy stores energy in the form of thermal energy, so it is easy to supply heat for hydrogen production.

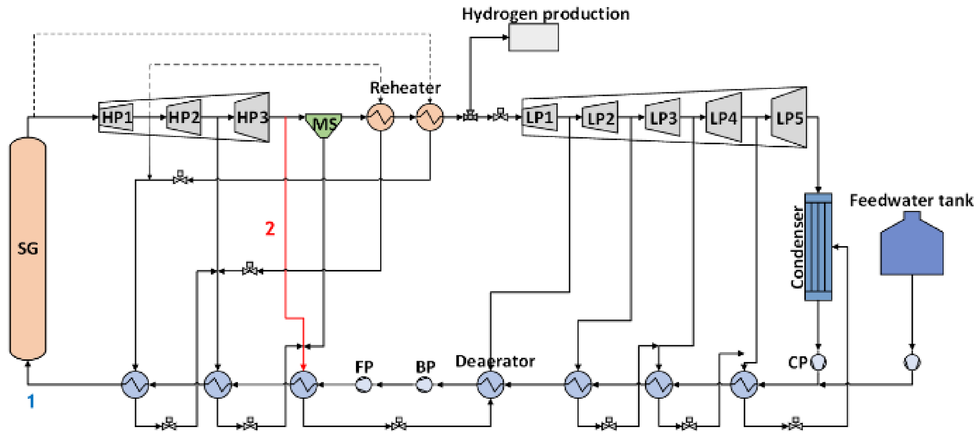

Fig. 7. Hydrogen production integrated PWR(HP-PWR) layout

- After the steam for hydrogen production is branched, it does not return to the secondary side, so additional mass flow rate must be injected near the condenser.
- The temperature of point 1 can be controlled by HPT outlet (2) branch flow.

Off-design operation of HP-PWR

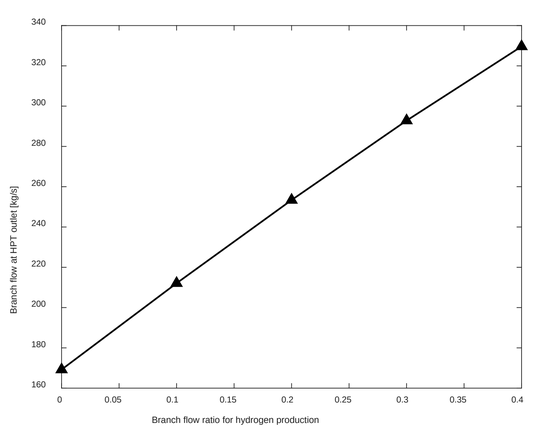

Fig. 8. Branch flow at HPT outlet change

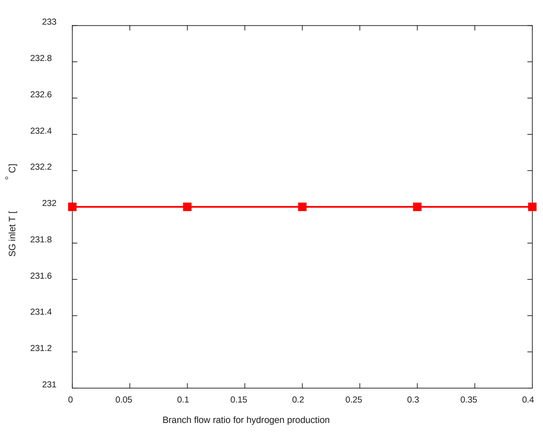

Fig. 9. SG inlet temperature change

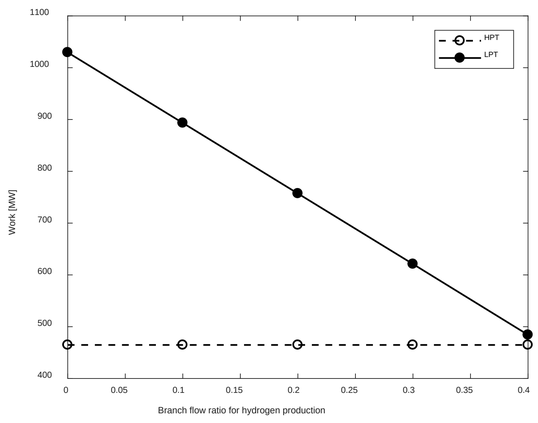

Fig. 10. HPT and LPT works change

- Constant volumetric flow rate model and Ray`s semi-empirical equation are used for turbines and ε-NTU methods is used for feedwater heaters.

$$= \frac{Branch\ flow\ ratio}{\frac{Branch\ flow\ for\ hydrogen\ production}{LPT\ inlet\ flow\ rate\ (On-design)}}$$

Conclusions and Further works

- As a solution to solve the difficulties of PWR caused by the increase in renewable energy, a layout of HP-PWR is proposed.
- The secondary side steam has enough energy for HTSE and the additional heat is received from solar thermal energy.
- Hydrogen production will result in PWR work loss.
- There must be a power generation technology by utilizing the produced hydrogen that can compensate for PWR work loss.