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PERFORMANCE ANALYSIS OF SMR PLANT WITH STEAM HEATING FOR MULTI-PURPOSE APPLICATIONS

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1. Introduction

❖ **SMR and Secondary System**

- SMRs: (1) reactors with electrical output of 300 or less. (2) simpler and smaller than conventional plants, reducing equipment, size and cost.
- Secondary system: design of the steam cycle is crucial for enhancing SMR economic viability.

❖ **Plant Thermal Performance Modeling and PEPSE Software**

- Heat balance: one of the important indicators showing plant output and thermal performance.
- PEPSE(Performance Evaluation of Power System Efficiencies): a software program for modeling the steady state performance of thermodynamic systems.

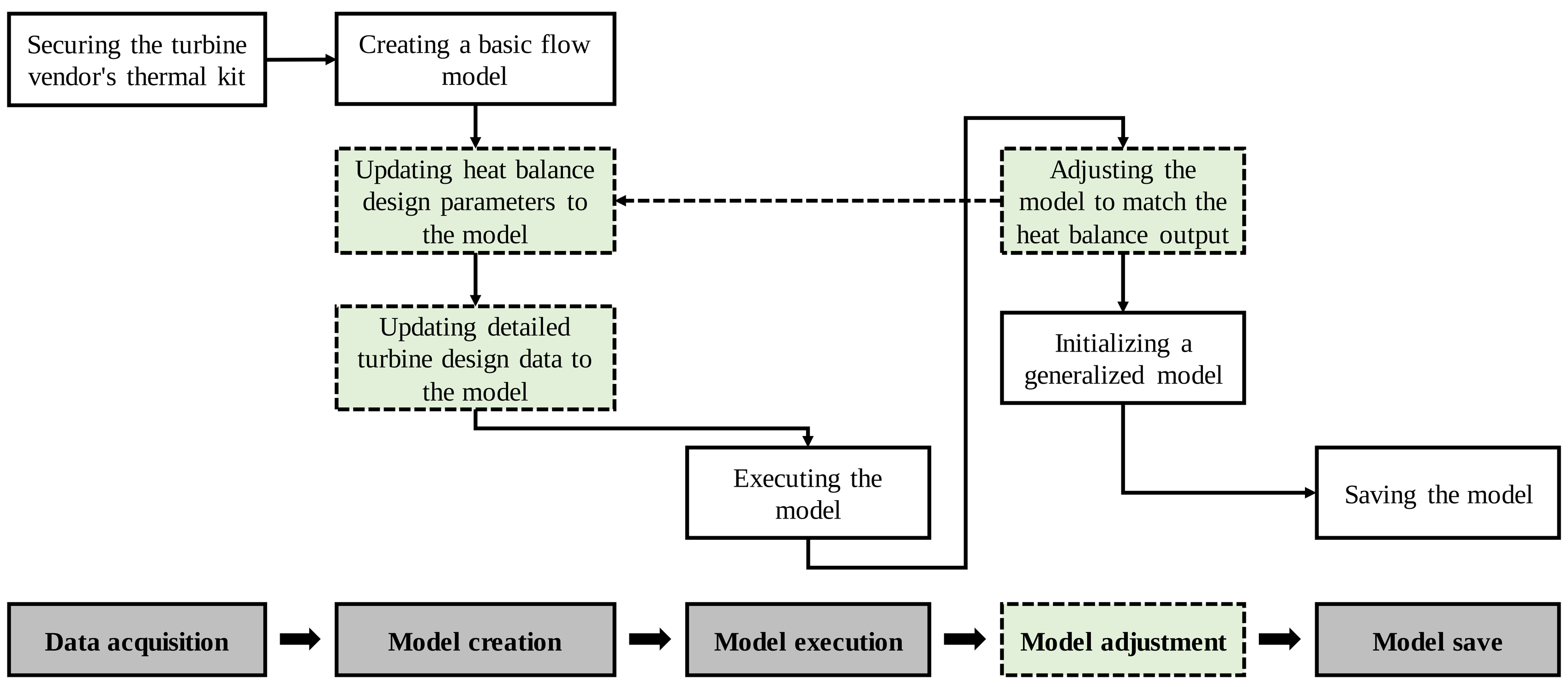

FIG. 1. Schematic development sequence of a heat balance thermal performance model.

2. SMR plant heat balance and analysis

❖ **Developing Baseline Model**

- The valve wide open (VWO) condition of the baseline model was constructed.
- The fluid flow, design variable values, etc., under the VWO condition were adjusted to satisfy the 100% rated output (150 MW) design condition.
- In a similar way, models for partial loads (75%, 50% and 25%) were created.

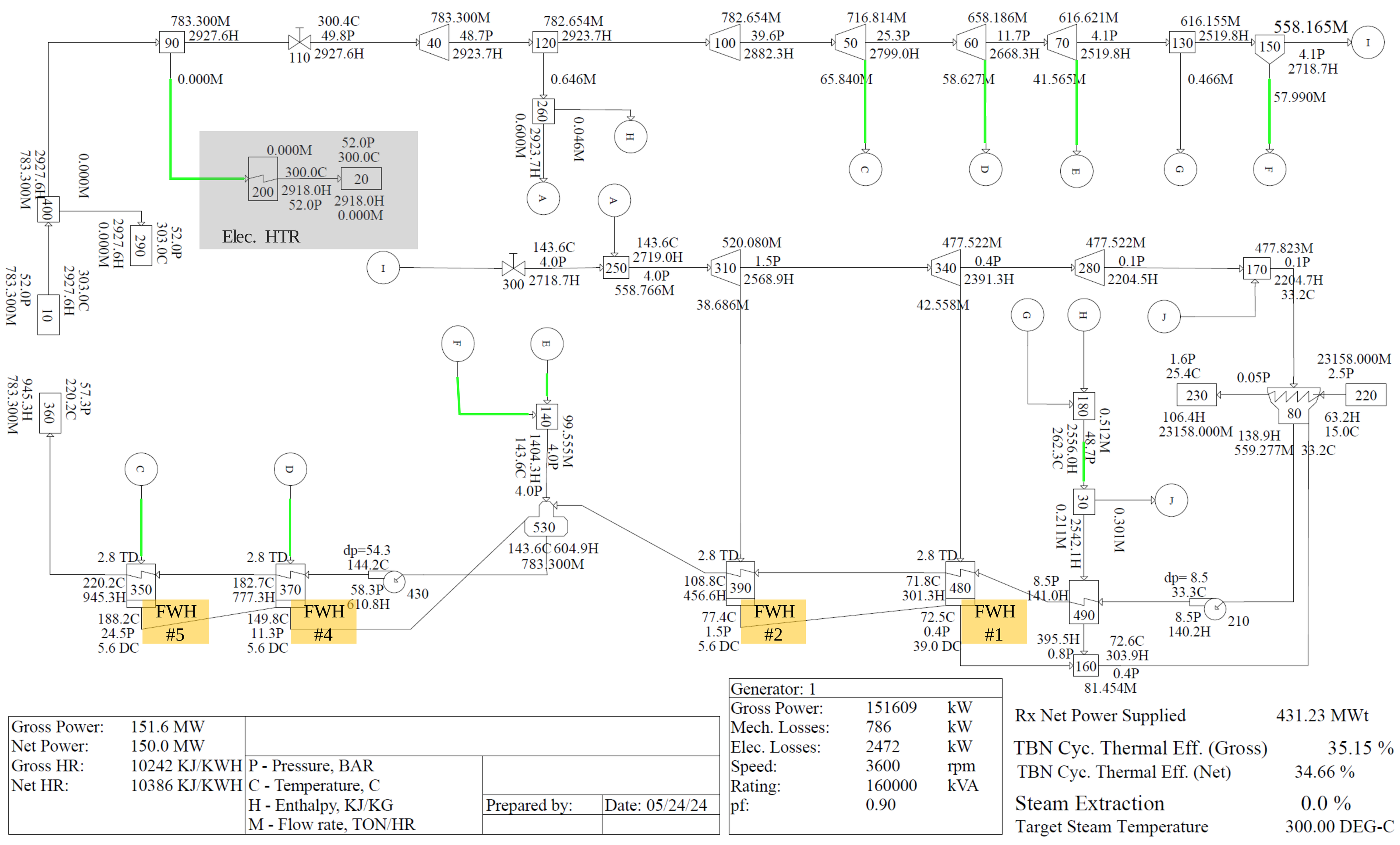

FIG. 2. PEPSE heat balance model (100% rated power, no electric heater operation)

❖ **Analysis of Plant Performance (Changes in operations cases)**

- Case 1-1 to 1-5: VWO, 100%, 75%, 50%, 25%
- Case 2-1 to 2-3: FWH out-of-service excluding the final FWH (#5)
- Case 3-1 to 3-3: FWH out-of-service including the final FWH (#5)

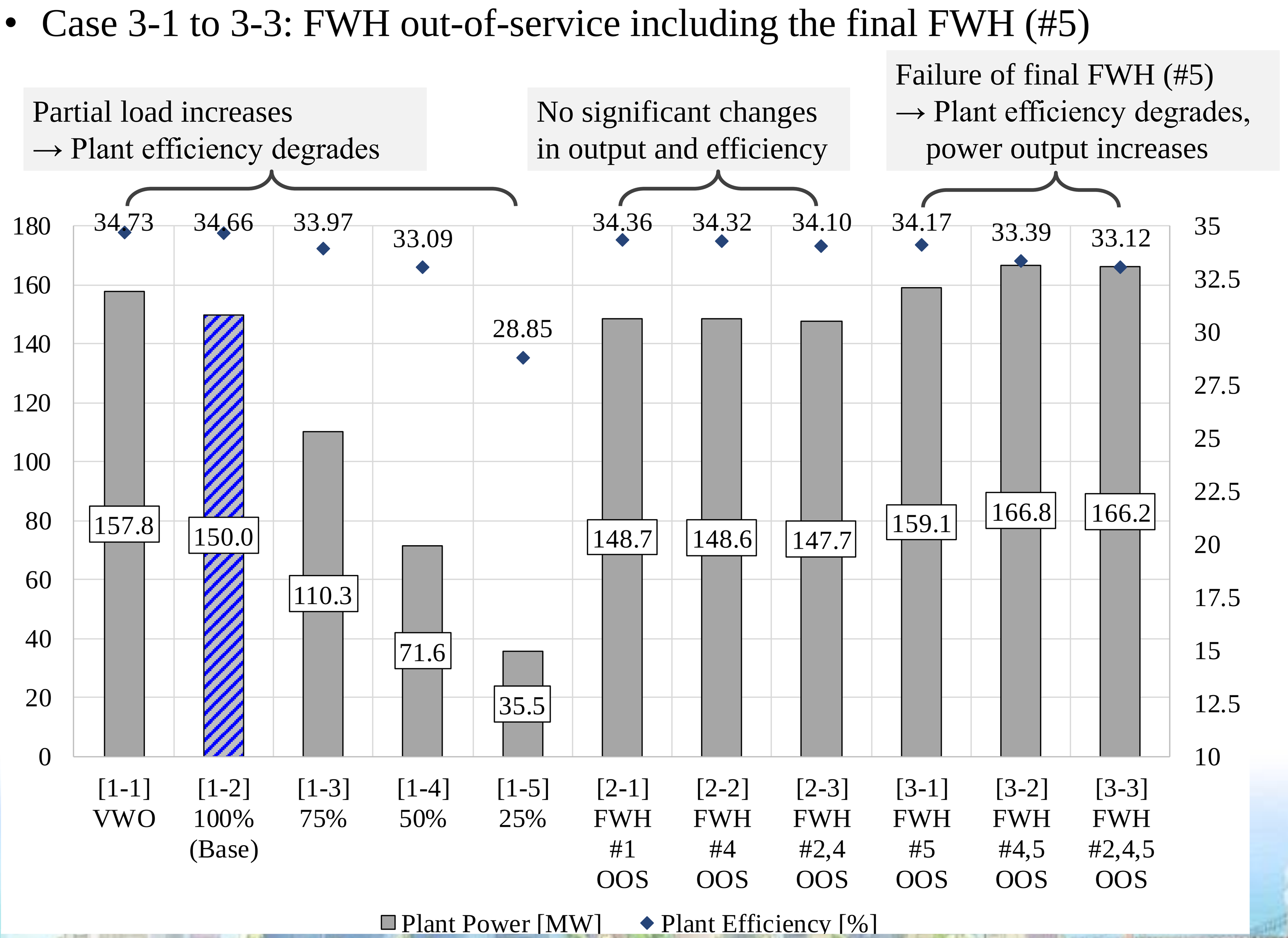

FIG. 3. Comparison of plant performance simulation results by design conditions

❖ **Steam heating for multi-purpose utilization**

Table 1. Multi-purpose nuclear steam utilization

Nuclear Steam Utilizations		Operating temperature (°C)	Applications
1.Hydrogen production	Low-temperature electrolysis	Room temperature – 90	Alkaline, PEM
	High-temperature electrolysis	700 – 1,000	SOEC
2. Desalination	Low-temperature desalination	Room temperature	RO
	High-temperature desalination	35 – 120	MSF, MED
3. Coal to nuclear	Subcritical steam cycle	538	
	Supercritical (SC) steam cycle	600	
	Ultra-supercritical (USC) steam cycle	610	
4. Process heat	District heat	Below main steam temperature (Depends on requirements)	

Table 2. Various Methods for obtaining high-temperature steam

Classification	Method
1. Hydrogen combustion	Steam heating by a hydrogen combustor. Securing superheated steam as a final by-product through hydrogen and oxygen combustion ($2H_2 + O_2 \rightarrow 2H_2O$).
2. Steam compressor	Steam heating by multi-stage steam compressors (temperature increase during compression of superheated steam to high pressure).
3. High-temperature heat pump	Steam heating by indirect heat transfer through the heat pump.
4. Electric heater	Steam heating by electric heater.

- Steam at various operating temperature can be obtained depending on the applications.
  - For a lower steam temperature than the main steam
    : Through an energy cascading method (e.g., simple HX, heat dissipation, etc.).
  - For a higher steam temperature than the main steam
    : Additional energy (e.g., heat, electricity, etc.) must be added.

- **Research Scope**: High-temperature steam above 300 °C with electric heater.
  - Ratio of steam extraction from main steam line (%): 0, 2, 4, 6, 8, 10.
  - Target steam temperature value (ºC): 300, 440, 580, 720, 860, 1000.

❖ **Analysis of Plant Performance (Changes in target steam rate and temperature)**

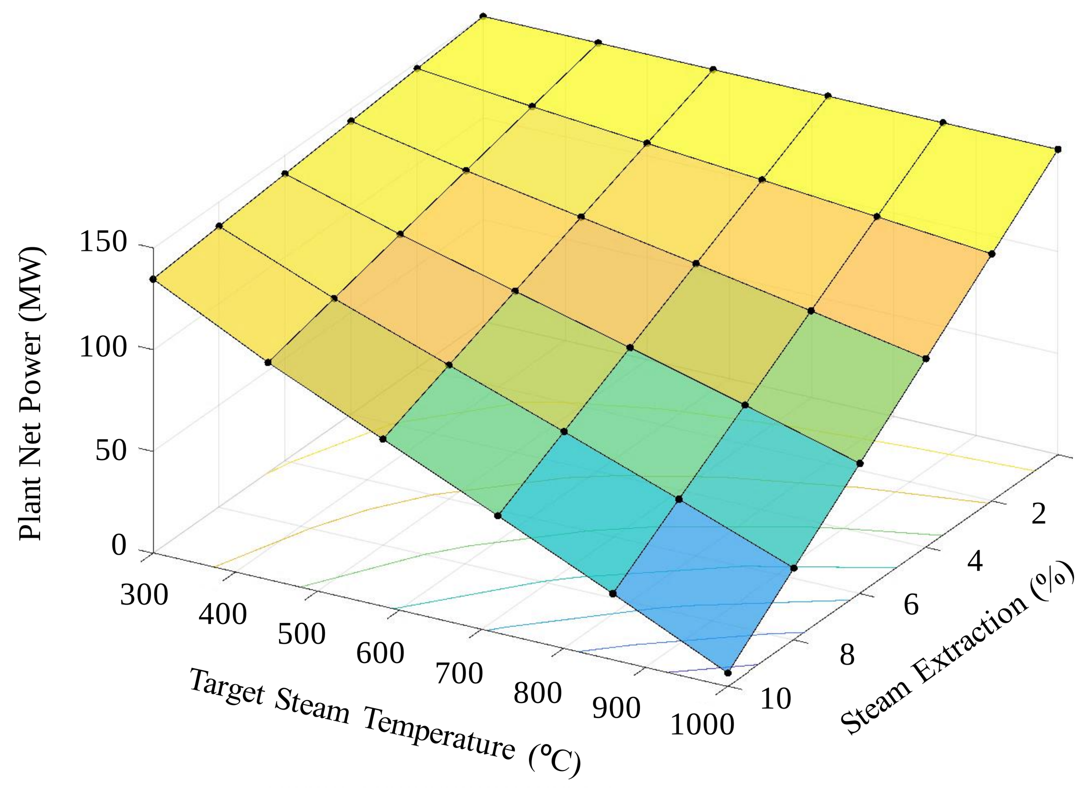

FIG. 5. Plant electrical output depending on the amount of extracted steam and target steam temperature.

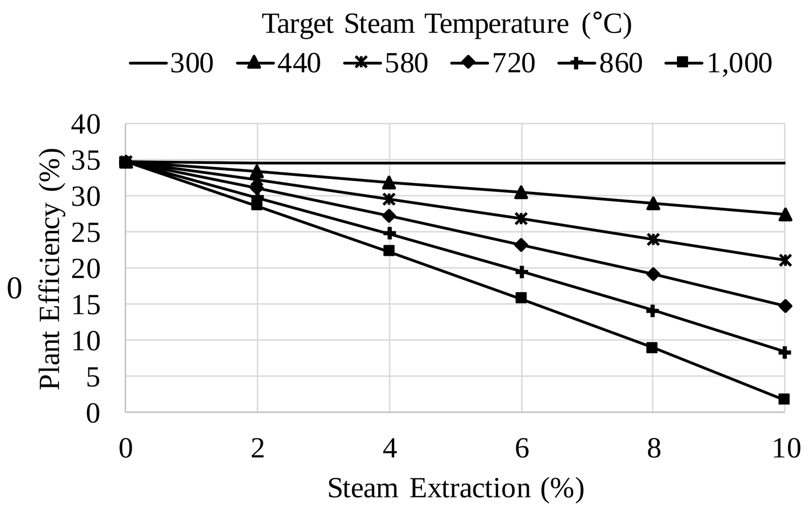

FIG. 6. Plant efficiency depending on the amount of extracted steam, and target steam temperature.

(a) **Partial load operation:** As the steam flow to the turbine inlet decreases due to higher extraction at the turbine front end, plant electrical output decreases.

(b) **Increased target steam temperature:** Higher target steam temperatures increase the electricity demand of the electric heater, further deducing plant output.

(c) **Optimization for 150 MW**: The turbine model is optimized for 150 MW-class output, so performance (especially efficiency) sharply declines when operating outside this optimal point.

(d) **At 300ºC target temperature:** When the target steam temperature matches the extracted steam temperature (300ºC), plant output still decreases with more steam extraction, but efficiency remains relatively stable due to the very small load value required by the electric heater.

3. Conclusion

❖ **A 150 MW-class SMR plant heat balance cycle was modeled using PEPSE** to analyze plant performance based on secondary system design and configuration.

❖ **A model was developed to raise the main steam temperature from 300ºC using an electric heater** for multi-purpose applications**.**

❖ Key findings from performance simulations:

(a) Plant performance decreases sharply with increased partial load operation.
(b) Absence of a regenerative cycle can improve plant output but reduce overall efficiency.
(c) Heating extracted main steam with an electric heater lowers both plant output and efficiency as extraction rate and target temperature increase.

❖ Future research is needed to optimize plant models for different conditions and to explore non-electric applications like hydrogen production and process heat.

❖ Detailed site-specific environmental data (temperature, cooling waterflow flow rate, ambient conditions) are required for precise plant performance simulations.

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