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# Preliminary study of steam cycle layout and modeling for SMR application

Jae Jun Lee [a], Won Woong Lee [a], Jinsu Kwon [a], Jeong Ik Lee [a*]
[a]*Department of Nuclear and Quantum engineering, Korea Advanced Institute of Science and Technology (KAIST)*
*291 Daehak-ro, (373-1, Guseong-dong), Yuseong-gu, Daejeon 34141, Republic of KOREA*
[*]*Corresponding author: jeongiklee@kaist.ac.kr*

## 1. Introduction

Until recently, a lot of small modular reactor (SMR) concepts such as NuScale, mPower and SMART have been developed and proposed. These reactors have specific features like natural circulation, advanced passive safety system.

Center for Autonomous Small Modular Reactor Research (CASMRR) has been researching Autonomous Transportable On-demand reactor Module (ATOM). ATOM has some features such as soluble boron free, passive safety system that utilizes air cooled natural circulation, automatic load following algorithm, development of fuel and structural materials and so on. The final goal of the research is to develop and verify key technologies enabling a naturally-safe and autonomous operation. In this project, since ATOM is still in the conceptual design stage, SMART is first chosen as the reference reactor to test various control algorithms and design changes.

As a part of the project, a simulation platform is being constructed for thermal hydraulic analysis of the system at steady and transient states and evaluation of thermal margin. Also, this platform will be used for constructing database for autonomous operation. In this paper, some processes for building the platform are introduced. The layout of steam cycle for ATOM is designed using KAIST-CCD, which is an in-house code for the cycle design. The cycle is modeled for simulating the reactor power plant system using MARS-KS.

## 2. Methods

The primary system of ATOM is being designed conceptually. The electric output of ATOM is the same with SMART which is 100MWe. By using MARS-KS, operational conditions of the primary system is calculated for the steady state.

Table I: ATOM's primary operating condition.

| | ATOM(100MWe) |
|---|---|
| Core thermal power [MWth] | 330 |
| Core mass flow rate [kg/s] | 1557 |
| Operating pressure [MPa} | 15 |
| Core inlet Temperature **[℃]** | 270 |
| Core outlet Temperature [°C] | 312 |
| MDNBR | 3.4 |

In this paper, to design a steam cycle of ATOM, the power conversion system data of SMART that have same power are used without scaling. General plant data of SMART power conversion system are shown in table II. From the heat balance, SG outlet temp is estimated to be 290℃.

Table II: General Plant Data of SMART's BOP. [2]

| | Value |
|---|---|
| Total heat from SG [MWth] | 330 |
| Mass flow rate at SG [Kg/s] | 160.8 |
| SG Inlet temp [℃] | 200 |
| HP turbine Pressure [MPa] | 5.2 |

### *2.1. Cycle Layout Design*

Steam Rankine cycle is considered for a power conversion system for a ATOM. By using KAIST-Closed Cycle Design code (in-house cycle code) with REFPROP (NIST database), the cycle process flow diagram is designed. KAIST-CCD code is written in MATLAB and directly connected to the NIST REFPROP database. Considered steam cycle has been descriped in the previous reference [3] and these some operating conditions are given in Table III. The code proceeds by connecting the components sequentially. Through all the processes, optimized component values are found. In other words, once the table III design parameters are provided, then, the code returns the optimized cycle through iteration for each variable. The cycle layout is shown in Figure 3 .

Table III: Design parameters for cycle analysis

| | |
|---|---|
| Secondary side pressure drop [kPa] | 119 |
| Turbine inlet Temperature [℃] | 290.5 |
| Condenser outlet Temperature [℃] | 32 |
| Turbine efficiency | 0.9 |
| Compressor efficiency | 0.85 |
| Heat exchanger effectiveness | 0.92 |
| Generator efficiency | 0.98 |

### *2.2. Nodalization of BOP*

Figure 4 shows a nodalization of the BOP cycle. Steam generator is first modeled with the time dependent volume as a boundary. All pumps are also first modeled as the time dependent volumes because there is no specific data of them. There are four heat structures for heat exchangers.

HP turbine consists of 2 separate stages and LP turbine consists of 3 separate stages. It is noted that the stage modeled in MARS-KS does not correspond to the real turbine stage. It is just a segment separating turbine internals for steam separation section for the feed water heating. Each turbine was followed by a volume for steam extraction except LP turbine last stage

## 3. Simulation and Results

The simulation results is table IV.

Table IV: Set point and Results.

| | Set point | Simulation | Error (%) |
|---|---|---|---|
| SG outlet temperature[℃] | 290.5 | 296.75 | 2.1 |
| SG outlet pressure [MPa] | 5.2002 | 4.64 | 10.8 |
| Turbine side flow rate[Kg/s] | 145.2463 | 145.79 | 0.4 |
| Condenser inlet temperature[℃] | 37.30 | 37.7 | 1.1 |
| Condenser inlet pressure[MPa] | 0.0063 | 0.0067 | 6.3 |

Figure 1 and 2 are HP, LP turbine power when simulate separately like red dot line in figure 4.

## 4. Summary and Further Work

The conceptual power conversion cycle is modeled using MARS-KS. The platform is constructed with the conceptual diagram only. To improve and fill the lack of information, additional design work will be followed and the model will be updated with more details. The more accurate and specific data will be presented during the conference.

The prepared platform will be used to generate large amount of data which is used for training machine for autonomous control in the future.

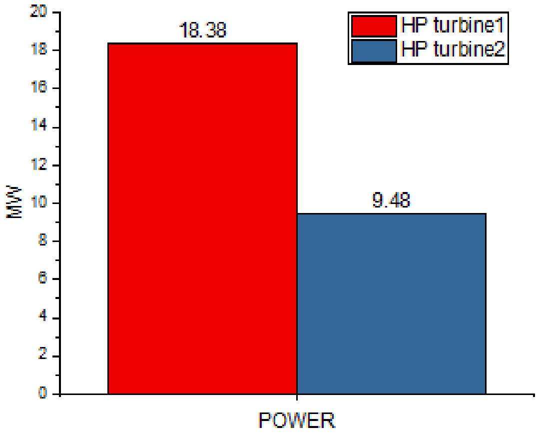

Fig.1. HP turbines power.

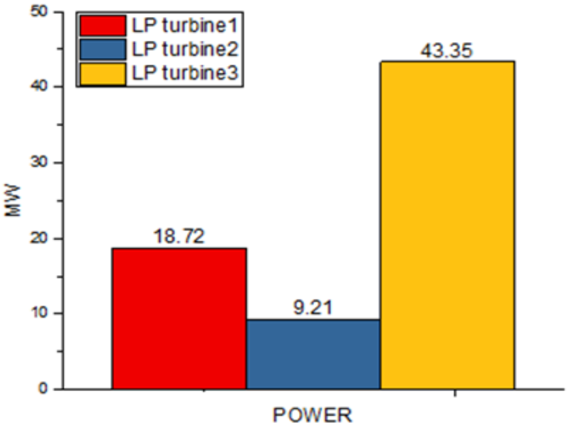

Fig.2. LP turbines power.

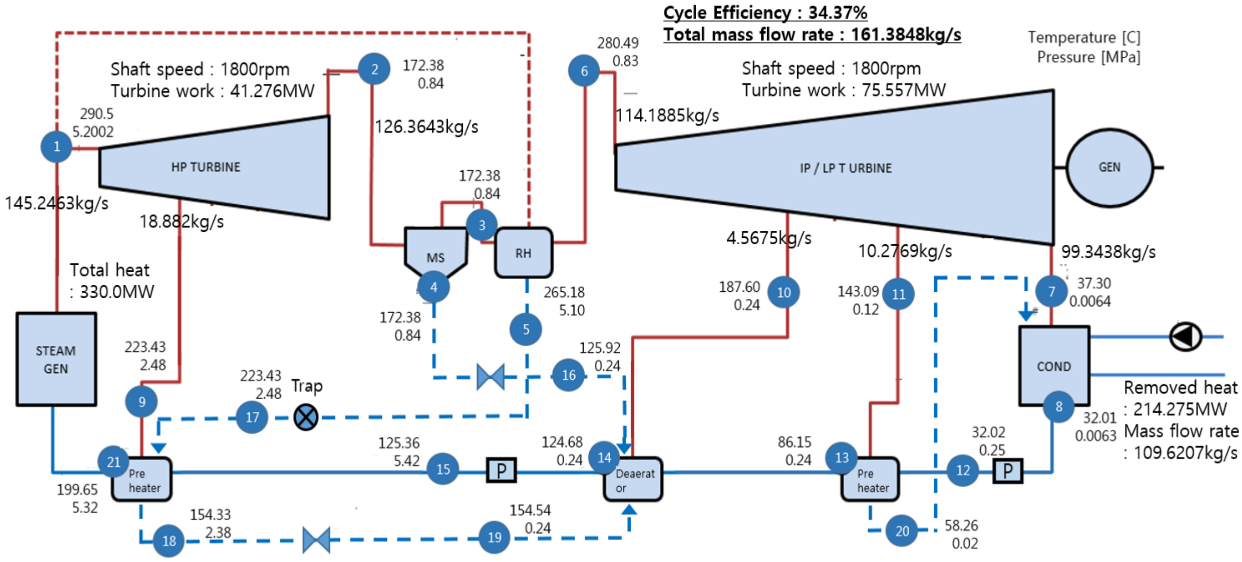

Fig. 3. Cycle process flow diagram. [

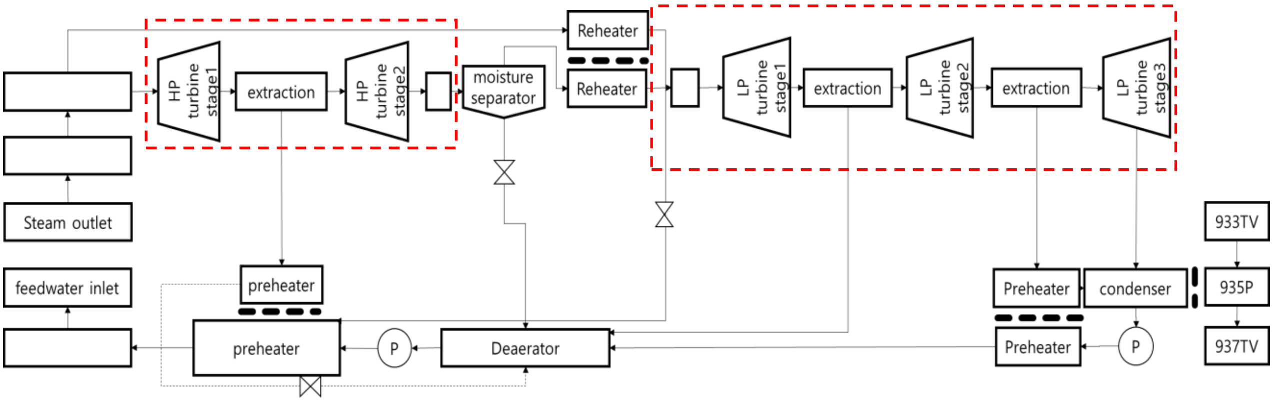

Fig.4. Nodalization.

## ACKNOWLEDGEMENT

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## REFERENCES

[1] KAERI, “MARS CODE MANUAL”, KAERI/TR-2811/2004, 2009
[2] “Status report 77 - System-Integrated Modular Advanced Reactor (SMART)”, 2011
[3] Kwon, Jinsu, et al. “Comparison the steam Rankine cycle with the supercritical CO2 Brayton cycle as a power conversion system for water-cooled SMR.” American Nuclear Society, 2016
[4] Han-Ok Kang, et al “Thermal-hydraulic Design of a Printed-Circuit Steam Generator for Integral Reactor”, Journal of Fluid Machinery 17(6), 2014.12, 77-83 (7 pages).