Investigation of different thermodynamic cycles for Nuclear Power Plants.

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Summary

Nuclear Power Plants (NPPs) play major role in today's electricity production. There are different types of power-conversion sides for NPPs. Most of them are based on the Rankine cycle. In this paper steam-cycle arrangements for CANDU, Sodium-cooled Fast Reactor (SFR) and Pressurized Water Reactor (PWR) are investigated and compared. Thermodynamic layouts, T-S diagrams and thermodynamic efficiencies of corresponding cycles are investigated and presented.

1. Introduction

All steam-cycle arrangements for CANDU, PWR and SFR are based on the Subcritical Rankine cycle, however they have different parameters at the exit of the steam-generator and at inlet to the turbine. Major parameters of the cycles are presented in the Table 1. For the CANDU we consider a 584 MW_{el} unit, for PWR we consider VVER-1000 NPP while for SFR we consider one of the most efficient NPPs nowadays – BN 600.

Table 1. Major parameters of the cycles [1,2,3]

Parameter	CANDU	PWR	SFR
Turbine inlet temperature, °C	251	274	505
Turbine inlet pressure, MPa	4.03	5.88	14.2
Reheat	By the extraction from the steam generator	By the extraction from the steam generator	By the secondary-side sodium

2.1 CANDU steam-cycle arrangement

The corresponding layout of the 600 MW_{el} CANDU reactor is presented below in Figure 1.

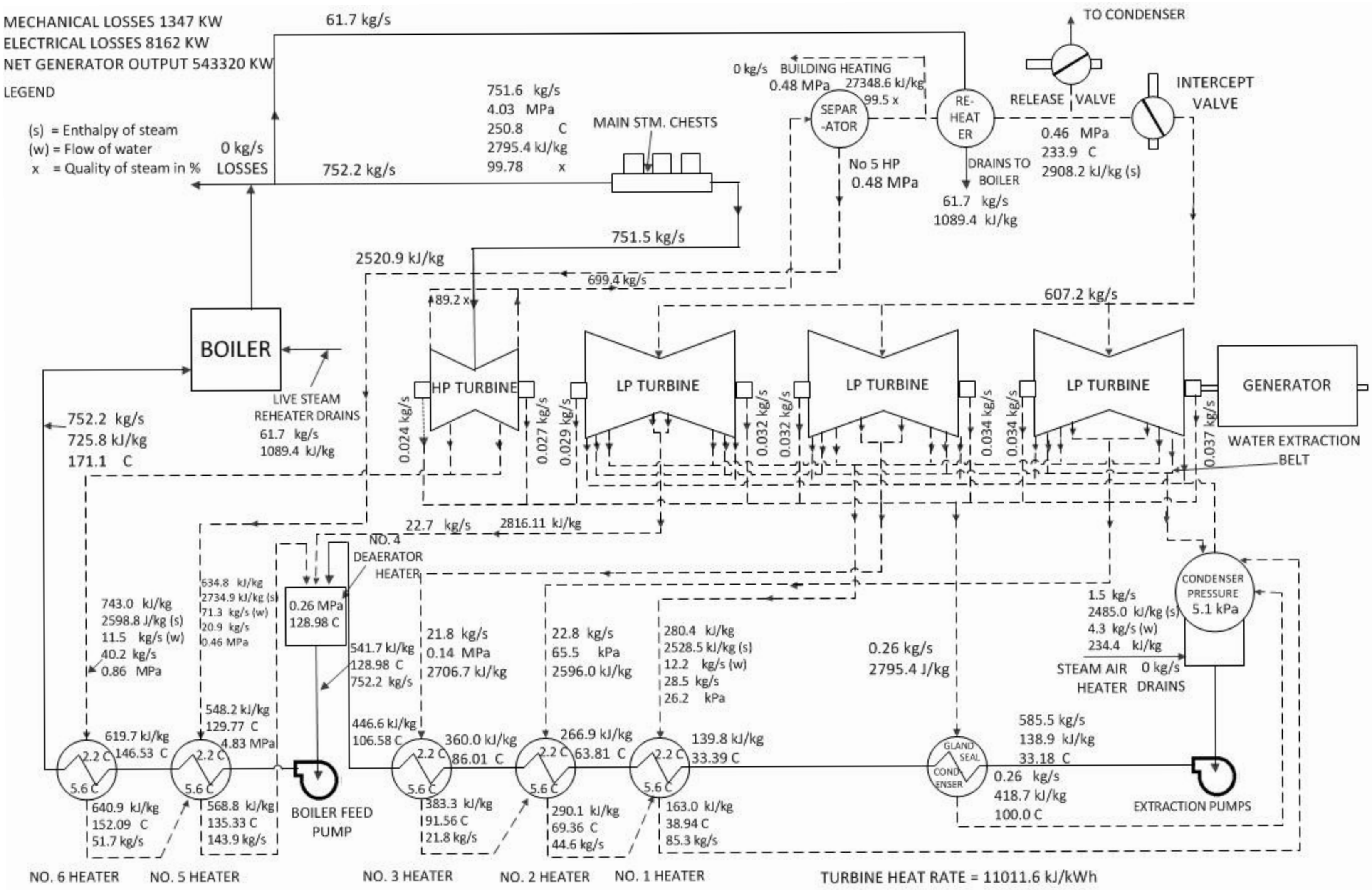

Figure 1. Detailed layout of the 584 MW_{el} CANDU Nuclear Power Plant (adapted from [1]).

2.2 PWR steam-cycle arrangement

The corresponding layout of the 1000 MW$_{el}$ VVER-1000 reactor is presented in Figure 2 below.

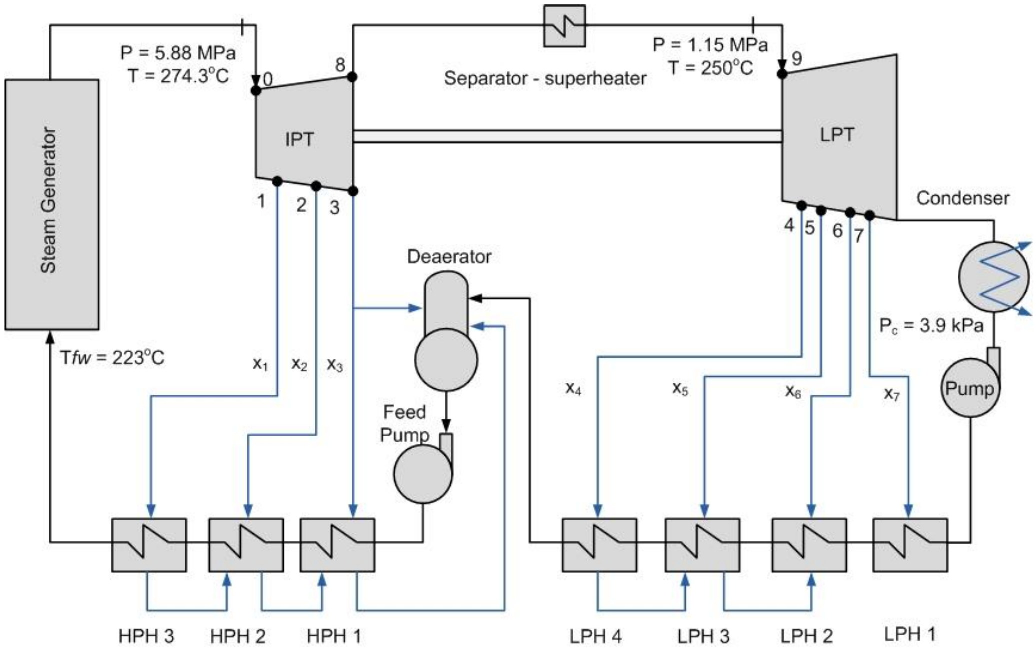

Figure 2. Thermodynamic layout of the 1000 MWel VVER-1000 pressurized water reactor [2,3].

2.3 SFR steam-cycle arrangement

The corresponding layout of the 600 MW$_{el}$ BN-600 reactor is presented below in Figure 3.

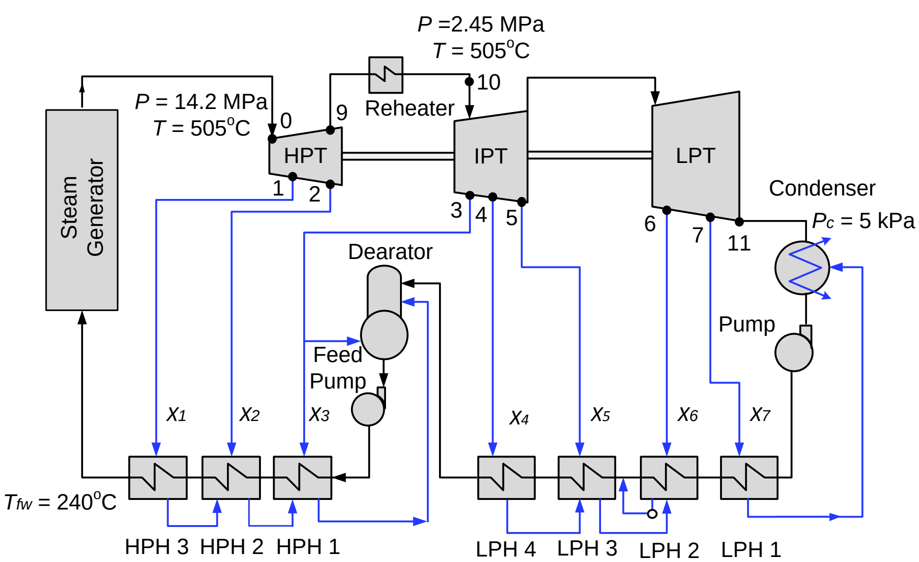

Figure 3. Thermodynamic layout of the 600 MWel BN-600 Fast Reactor [2,3].

3. Analysis

T-S diagram for the corresponding cycles in shown below.

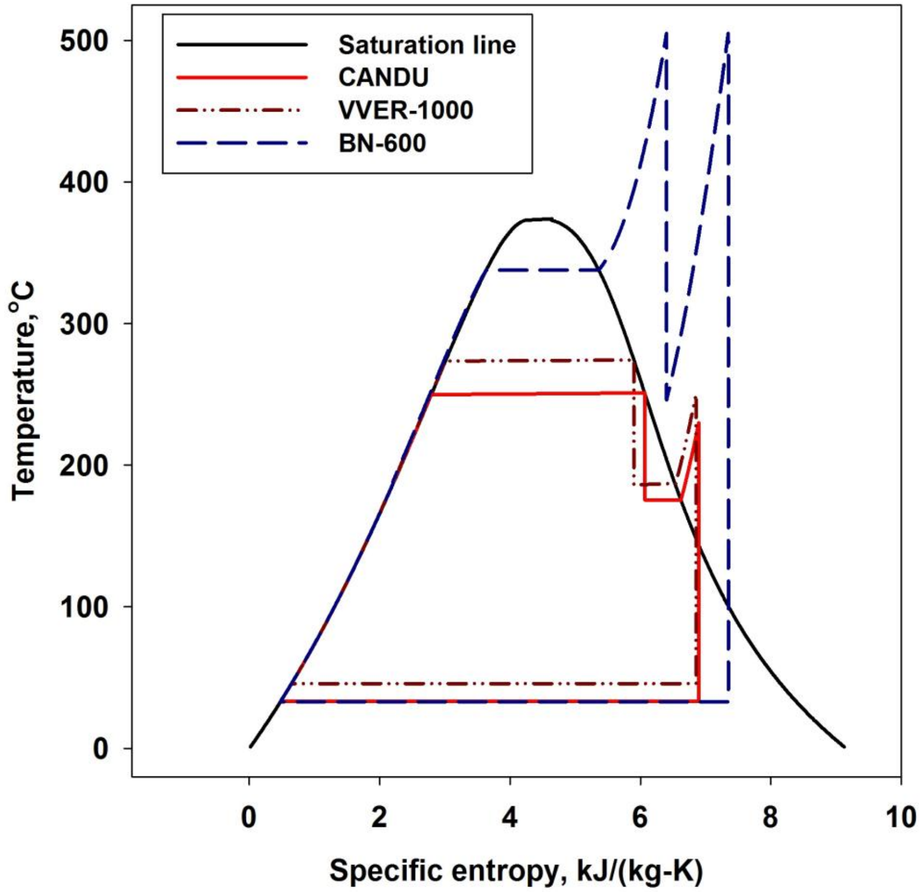

Figure 4. T-S diagrams for CANDU, VVER-1000 and BN-600 turbine cycles.

Cycle efficiencies of the considering cycles are presented in the table below.

Table 2. Efficiencies of the considered cycles and the corresponding NPPs

Parameter	CANDU	VVER-1000	BN-600
Thermal Efficiency of the turbine cycle	32.5 % [1]	~ 35 % [2]	49.1 % *
Thermal Efficiency of the NPP	29.1 % [1]	32 % [2]	40 % [3]

* Was calculated for an idealized cycle in [4].

Though T-S diagram for CANDU and VVER-1000 don't differ significantly, still there is a 9% increase in overall thermal efficiency if the steam generator exit temperature increased by 20 degrees. Regarding the BN-600 we can see that steam parameters at the turbine inlet are approximately the same as at the outlet of PWR core. Therefore, PWR could potentially reach efficiencies of 40-42% if direct cycle could be implemented.

4. Conclusion

Comparison of thermodynamic cycles of three types of NPPS showed that implementation of steam reheat by the coolant (as in BN-600) rather than by partially extracted working fluid (as in CANDU and VVER-1000) allows a drastic increase of the cycle thermal efficiency. As for the case of CANDU, were the core consists of individual channels, nuclear steam reheat may be implemented by passing high pressure turbine exhaust through a part of channels.

5. References

[1] Pickering generation station. Design description, 1969. Report prepared by Atomic Energy of Canada Limited.

[2] Grigor'ev, V.A. and Zorin, V.M., Editors, 1988. Thermal and Nuclear Power Plants. Handbook, (In Russian), 2nd edition, Energoatomizdat Publishing House, Moscow, Russia, 625 pages.

[3] Margulova, T.Ch., 1995. Nuclear Power Plants (in Russian). Izdat Publishing House, Moscow, Russia, 289 pages.

[4] Dragunov, A., Saltanov, Eu., Bedenko, S. and Pioro, I., 2012. A Feasibility Study on Various Power–Conversion Cycles for a Sodium–Cooled Fast Reactor, Proceedings of the 20th International Conference on Nuclear Engineering (ICONE–20), July 30 ‑ August 3, Anaheim, California, USA, Paper #55130, 10 pages.