Dynamic Modelling of a Solid Energy Storage Concept for pulsed operation DEMO fusion power plant (Direct Cycle)

Jaakko Ylätalo[a], Antti Teräsvirta[a], Sixten Norrman[b], Marton Szogradi[b] and Evaldas Bubelis[c]

[a] Fortum Power and Heat Oy, 02150 Espoo, Finland

[b] VTT, PO Box 1000 02044 Espoo, Finland

[c] Karlsruhe Institute of Technology (KIT), Institute for Neutron Physics and Reactor Technology Hermann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen, Germany

INTRODUCTION

The Demonstration Fusion Power Plant (DEMO) project aims to construct and successfully operate an industrial size fusion power plant. In order to succeed in this task, several challenges in the current fusion technologies have to be overcome. One key challenge is related to the pulsed operation of the Tokamak-fusion reactor. It is estimated that the tokamak reactor can run only in pulsed mode introducing challenges to conventional power conversion systems, which are commonly designed for continuous operation. The DEMO power conversion system has to be designed to manage a periodical drop in fusion heat production during the dwell period. The DEMO-project work packages Plant Level System Engineering (PMI) and Balance of Plant (BOP) aim to design a thermal- and cost-effective Primary Heat Transfer System (PHTS) and Power Conversion System (PCS) for the DEMO fusion reactor.

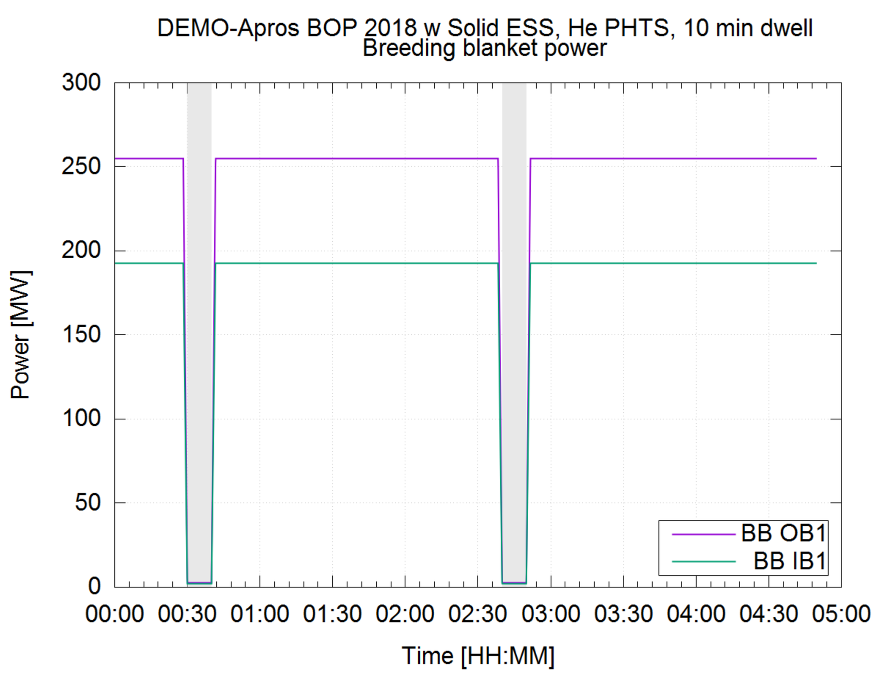

Figure 1: Pulse and dwell period thermal power in a single inboard and outboard breeding blanket section, combined pulse thermal power of tokamak 2101.7 MW

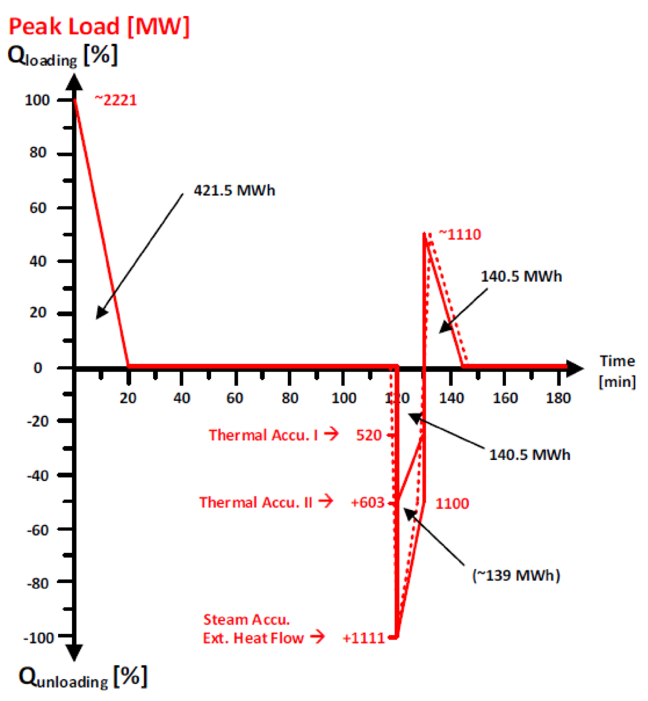

Figure 2: Evaluation of required thermal output rates of the thermal storages by Kraftanlagen Heidelberg

METHOD

- Personnel at KIT and Kraftanlagen Heidelberg performed a steady-state balance analysis of two thermal storage concepts with either external or integrated thermal storage system.
- The integral system was deemed more suitable. Evaluated sizing the thermal mass is ~2000 m^3 and the required size of the steam drum was around 230 m^3.
- The concept was used to dimension and construct a dynamic 1-D Apros model for a solid energy storage concept analyzed by VTT and Fortum. [1,2]
- In the solid energy storage concept, thermal accumulators and a steam drum are used to store heat during operation and are unloaded during the dwell period.

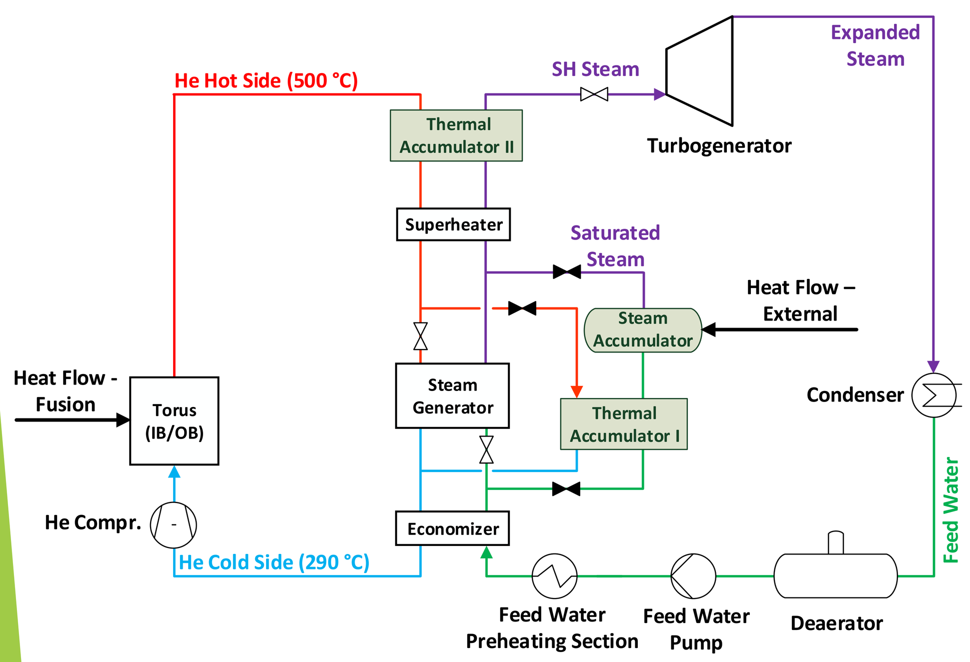

Figure 3: Integral thermal storage concept with PCS

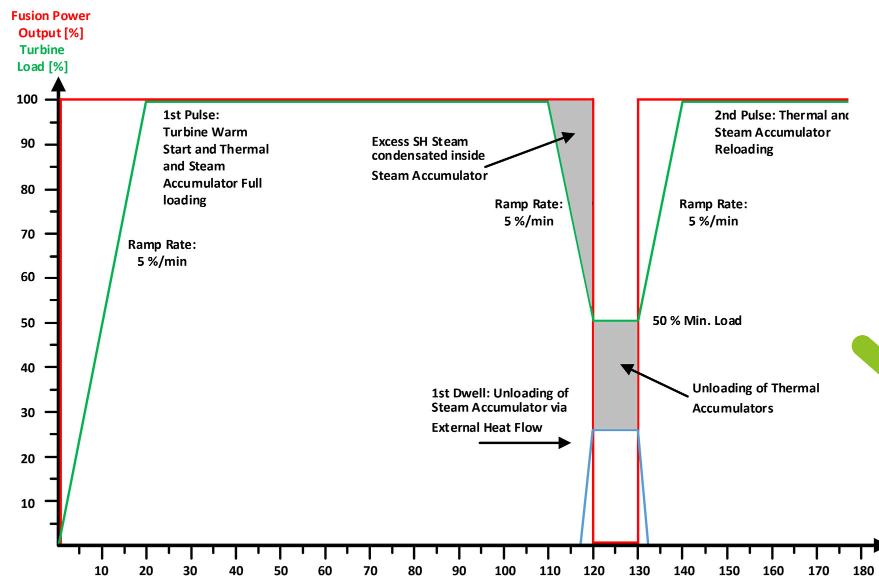

Figure 4: Turbine ramping scheme designed for the pulse-dwell operation with storage system

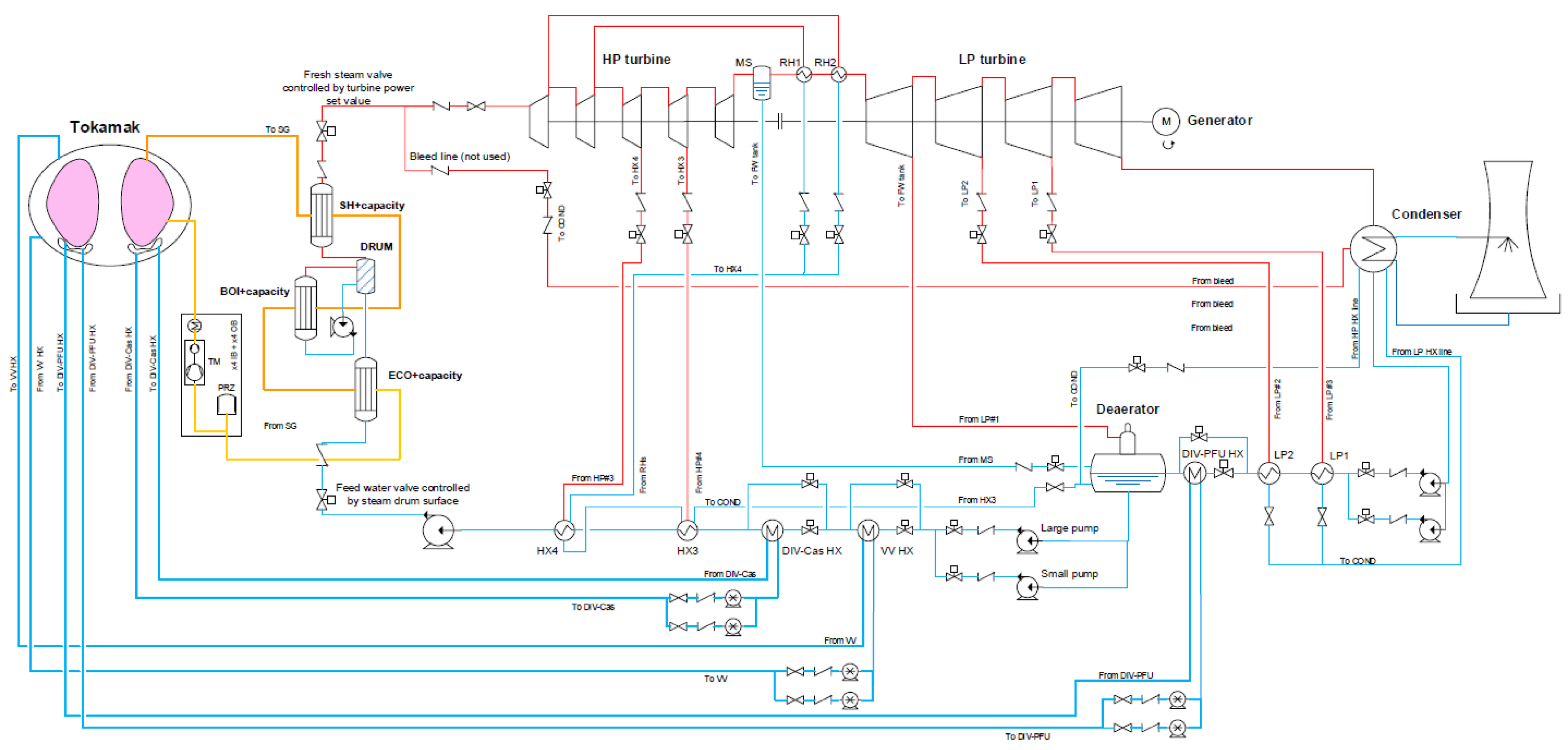

Figure 7: Final full PCS layout in the Apros model with integrated thermal storage and steam drum. All the thermal capacity is divided between economizer, boiler and superheater

RESULTS AND CONCLUSION

- The solid energy storage system succeeded in keeping turbine power around 50% during the dwell period without reducing steam quality or lowering steam temperature excessively (Figure 8, 10, 11)
- However the loading time of the thermal storages and refilling of the steam drum delay the reaching of full operation mode to 30 minutes → only 1.5 hours of full power mode during 2 hour pulse (Figure 8)
- Also, the size of the equipment was deemed to be too large as it has to be to located inside the tokamak containment building (radioactive helium contamination)
- Steam drum and steam generator equipment are subject to high pressures during turbine ramp down (Figure 9)
- The thermal storage and steam drum concept is not a feasible solution for future development of the DEMO concept

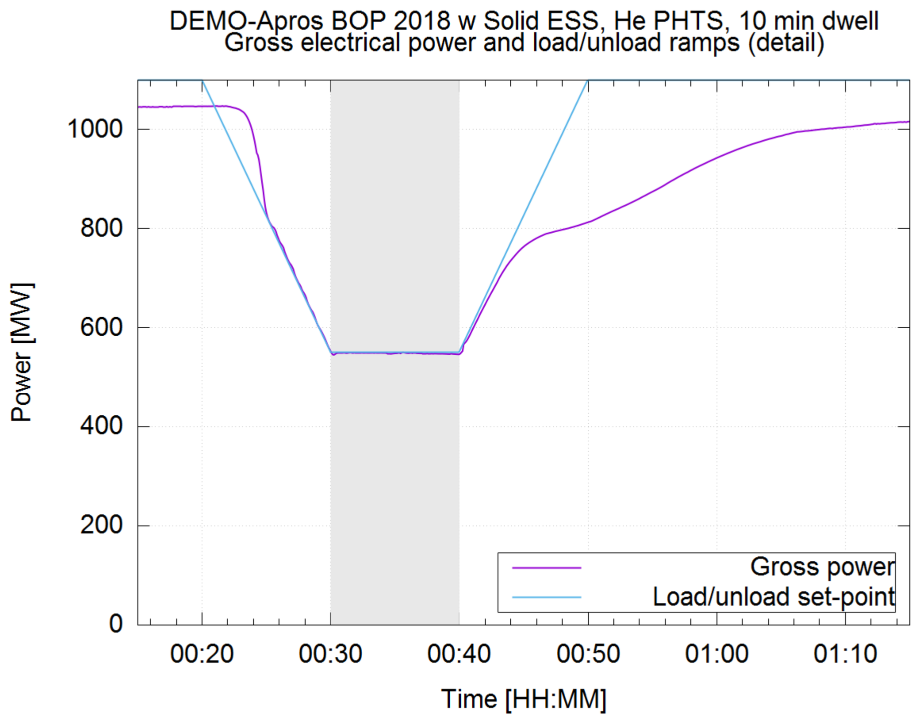

Figure 8

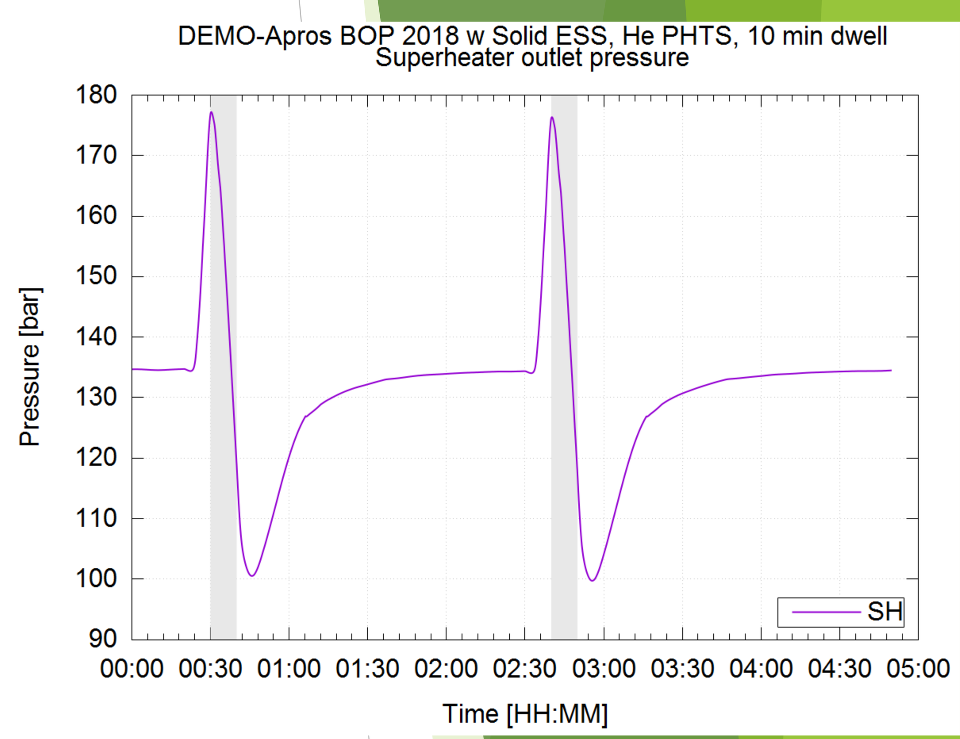

Figure 9

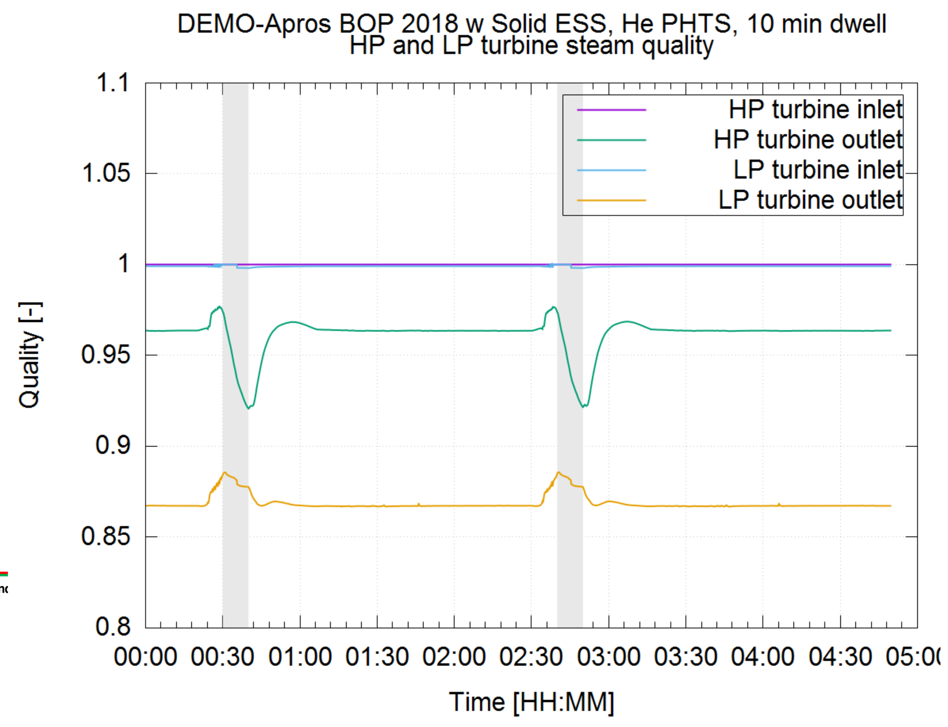

Figure 10

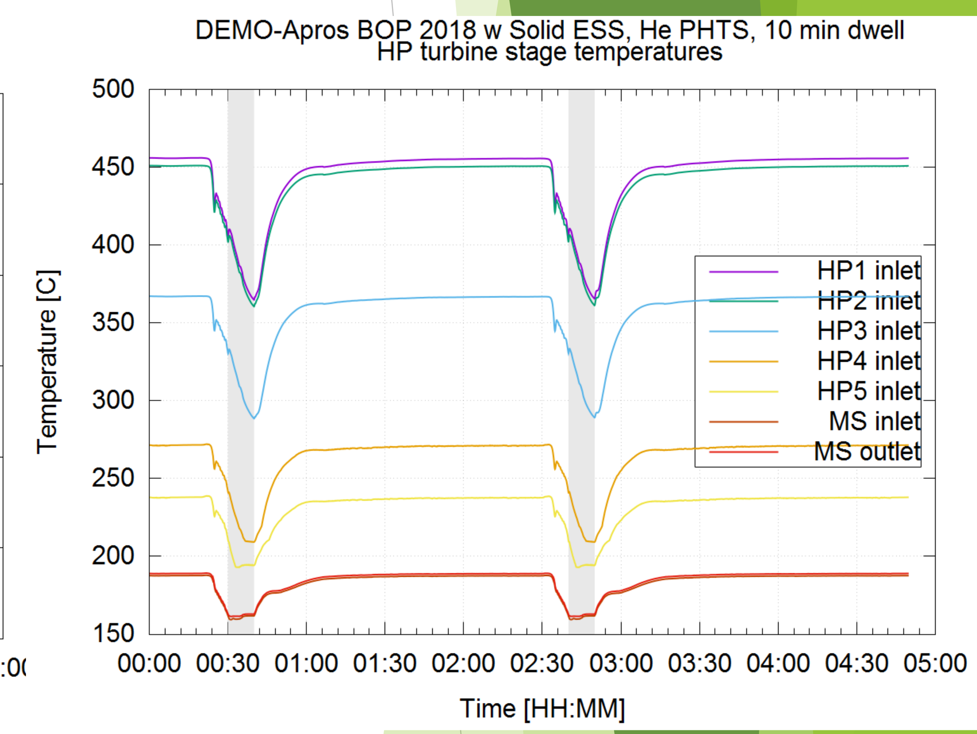

Figure 11

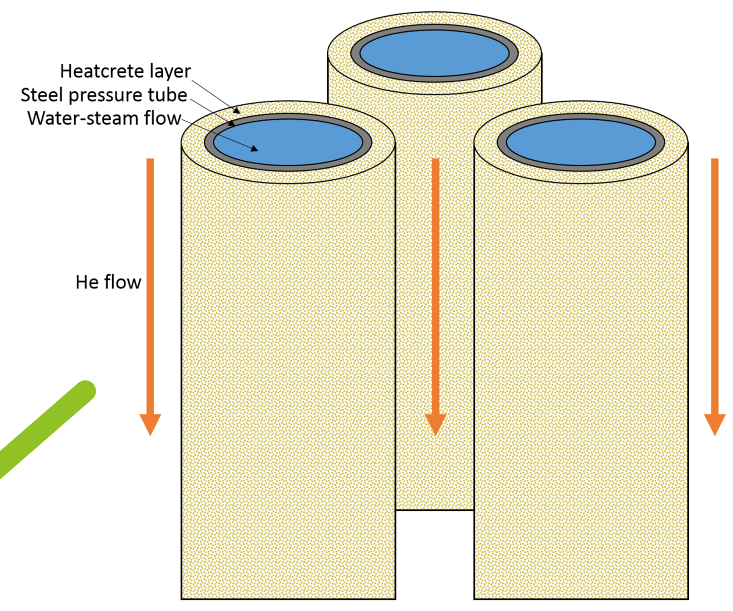

Figure 5: Distributed thermal storage solution envisioned for the steam generators

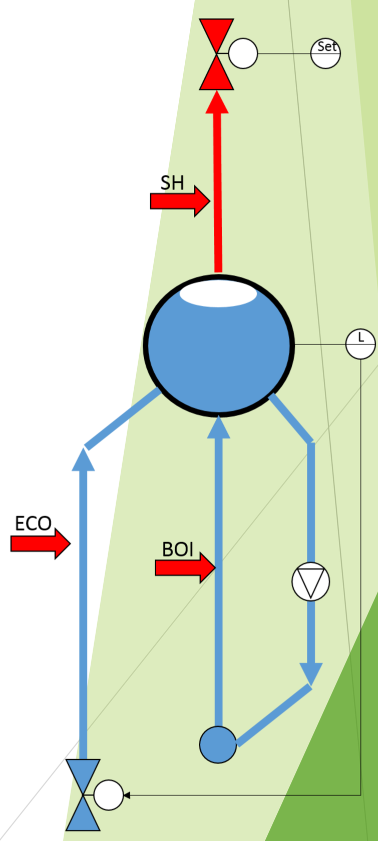

Figure 6: Steam drum arrangement used to store saturated steam during turbine ramp down

REFERENCES

[1] Apros® version 6.07.33, Espoo: http://www.apros.fi, 2018

[2] S. Kiviluoto, S.Norrman, P.Urhonen, S.Ciattaglia, Integrated System Level Simulation and Analysis of DEMO with Apros, Proceedings of Nuclear Science and Technology Symposium (NST2016)

CONTACT

Dr Jaakko Ylätalo, jaakko.ylatalo@fortum.com, mobile +358 40 7694708