Dynamic Modelling of the Helium-cooled DEMO Fusion Power Plant with an Auxiliary Boiler in Apros

Szógrádi Márton[a], Sixten Norrman[a] and Evaldas Bubelis[b]

[a] VTT Technical Research Center of Finland Ltd., Centre of Nuclear Safety, PO Box 1000, Kivimiehentie 3, 02044 Espoo, Finland

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

Introduction

The DEMO (DEMOnstration Power Station) is a conceptual design for a future fusion power plant utilizing experience from the ITER project (see Fig. 1). As a consequence of the reactor operation the power conversion system (PCS) also follows a pulsed cycle with 2 hours full-power (burn) and 10 minutes low-power (dwell) phases. In order to maintain pulse-time conditions during dwell in the PCS an auxiliary boiler (AUXB) was connected to the water cycle in parallel with the main SG.

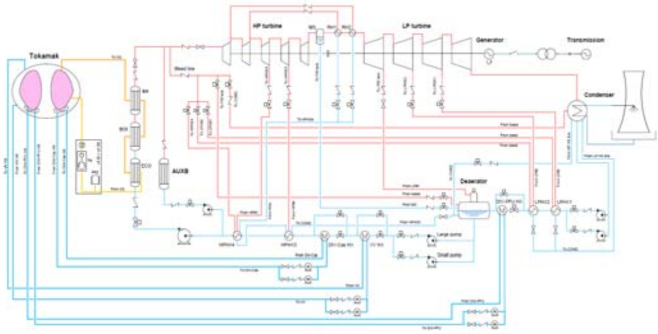

Figure 1. *Layout of the Helium-Cooled Pebble Bed Breeding Blanket (HCPB) with AUXB configuration.*

Power conversion system

Helium coolant has been utilized in order to drive the heat from the breeding blankets to the main SG supplying the turbine. The feedwater preheater system pertains water temperatures at 180-228°C i.e. the AUXB operates with similar inlet conditions as the SG (see Fig. 2.). Turbine extractions were closed during dwell phase, bleed lines from the main steam line kept the preheater heat exchangers pressurized (pulse pressure). Moreover, the bleed line kept the deaerator pressure as well at the nominal 3.6 bar.

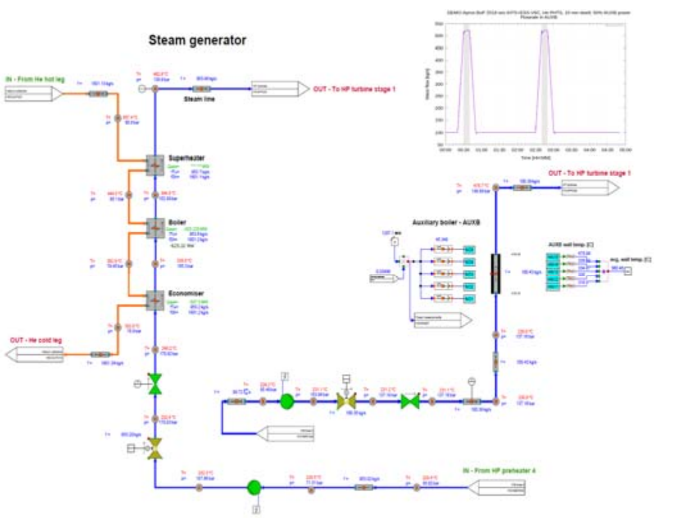

Figure 2. *Apros model of the SG, orange marks the primary He cycle while blue marks the PCS water cycle. The AUXB connects the end of the preheater line and the main steam line (MSL). The smaller graph depicts the flow rate on AUXB.*

Results

Fusion power was decreased to 1 % in 100 s during ramps, whereas in dwell the AUXB provided 50 % of the nominal heating power. The turbine was (un)loaded periodically with a slower ±5 %/min power gradient in order to minimize turbine stresses and wear. Such transient required fine tuning of control logics, respecting thermophysical constraints. Even though the pre-defined power curve was well followed during ramps, the dwell-time power output did not reach the 50 % target value (see Fig. 3). The control of the PCS required excessive pumping power, whereas the AUXB efficiency also lagged behind goal values due to feedwater temperature decrease. Nevertheless steam qualities at the high- and low-pressure inlets did not decrease below 99.3 % and 99.7 %, respectively, meaning that erosion of turbine blades was not a significant concern.

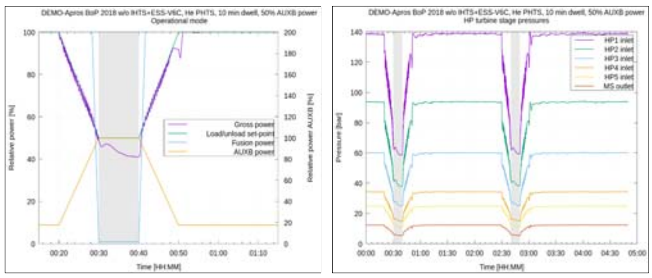

Figure 3. *Power trends (left) and high pressure stage pressures of the turbine (right) in Apros. Gray areas mark the 600 s dwell phases.*

Using fresh steam on preheaters resulted in heat-up of the shell side inducing mechanical stresses in various parts of the heat exchangers. Regarding the primary (He) cycle the compressors' shutdown did not reduce coolant velocity promptly as the low viscosity of the gas yields small hydraulic friction with pipes and compressors. This resulted in elongated heat transfer on the main SG while it was already being unloaded as AUXB ramp-up initiated. A possible solution to this problem could be a bypass line redirecting the hot gas from the SG inlet to the cold leg of the He loop.

Conclusions

- **The DEMO HCPB direct coupling configuration was modeled and analyzed with Apros**
- **Even though the control of the plant was sufficient to drive the system, target goals were not met due to excessive auxiliary power consumption and not eligible enthalpy increase on the AUXB**
- **Present configuration had only demonstrative purposes as AUXB required natural gas fuel**
- **Considering thermomechanical restrictions and feasibility other configurations e.g. DEMO HCPB BoP concept with energy storage system, showed better performance.**

Contact

Marton Szogradi
Nuclear Power Plant Behaviour
Tel. +358 40 142 4467
marton.szogradi@vtt.fi