Proposal for simulator contest

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1 Introduction

It is about time to initiate a major comparison between power plant simulators. For this reason, this exercise has been created. It has been a major concern that the model should reflect a real power plant without details having only little influence on the final results. On the other hand, realistic details with some influence should be present.

The power plant modelled is the Avedøreværket unit 1 (AVV 1) located on the southern outskirts of Copenhagen. The data for this exercise has most generously been provided by the owner Energi E2, the Danish power producer located on Zealand, and they originate mainly from the original tender material. The plant was commissioned in 1991.

2 Plant description

AVV 1 is a pulverized coal fired combined heat and power (CHP) plant with a nominal net power in condensation mode of 250 MW_{el}. The net efficiency is 42% including the power used for flue gas cleaning. The plant has a catalytic $DeNO_x$ unit and a wet gypsum producing $DeSO_x$ unit. In full back pressure mode the plant can produce 212 MW_{el} and 330 MJ/s heat for district heating (100°C/ 50°C) with a total energy utilization of 92%.

The plant operates at supercritical conditions at full load. Live steam data at full load at the steam turbine inlet are: 240 bar, 540°Cand with reheat to 540°C. Spray water is taken from the feed pump and sprayed into the reheater in order to control the reheat exit temperature in near full load conditions. The boiler is a once through coal fired Benson boiler with a Benson minimum load at 40%.

The turbine has a high pressure cylinder (HP), one single intermediate pressure cylinder (IP 1), one double (un-symmetric butterfly) intermediate pressure cylinder (IP 2) and one double (unsymmetric butterfly) low pressure cylinder (LP). This design, including the number and locations of steam extractions for feed water and condensate preheating and the size of the LP turbine, has been optimized for many operating hours with a high district heating production.

The condenser is conventional with tubes in a church window arrangement and it uses sea water (design inlet temperature is 10°C) for cooling. In full back pressure mode there is a small mass flow of steam through the LP-turbine to the condenser with the purpose of cooling the LP turbine. The flow is approximately 0,8 kg/s for each of the LP-turbines.

The plant has one turbine driven main feed pump (FWPT). The steam is taken from the hot reheat line and the exhaust is split between the first condensate heater (CH1) and the first district heater (DH1), depending on the district heating load.

3 Design Case

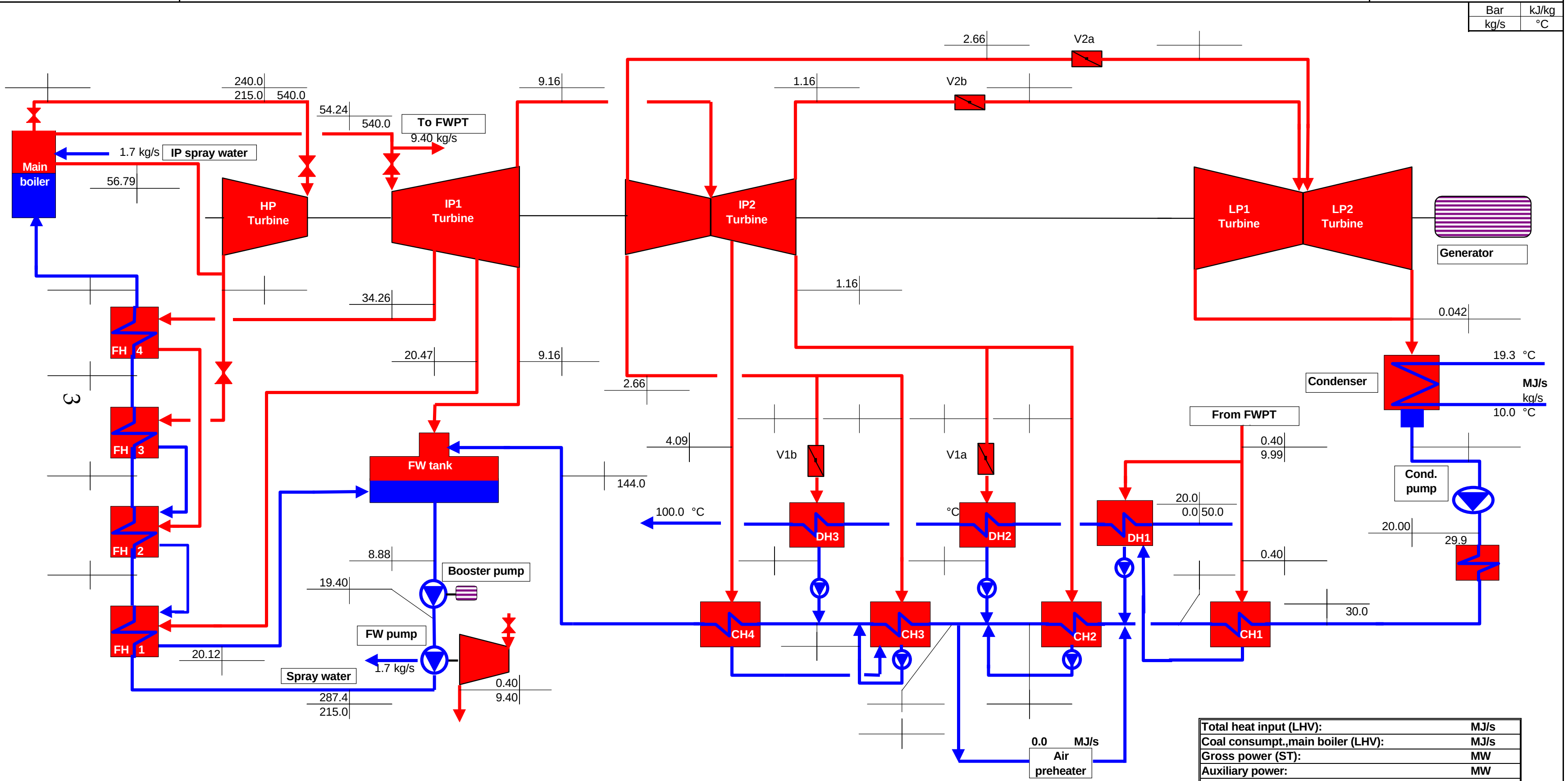
A process flow sheet for the plant is shown in figure 1. An EXCEL version is down-loadable from the ECOS2003 homepage (www.ecos2003.dtu.dk). All relevant pressures and temperatures for determining the 100% condensing operation mode are given in the flow sheet. In the flow sheet, red lines indicate steam and blue lines indicate liquid water.

In 100% condensing operation mode the gross output of the turbine is 261.5 MW and the auxiliary power con-sumption is 11.5 MW. The corresponding live steam flow is 215 kg/s at 240 bar and 540°Cat the HP turbine inlet.

The following nominal turbine isentropic efficiencies can be assumed:

AVV1

ENERGI E2	Simulation program:	Boiler load:	Departm: Proces
			Initials: ceh
			Date: 21.06.2002
	Calculation by:	Date:	Draw nr:



Total heat input (LHV):	MJ/s
Coal consumpt.,main boiler (LHV):	MJ/s
Gross power (ST):	MW
Auxiliary power:	MW
Net. power:	MW
District heat:	MJ/s
Net. electrical effiency coal (LHV):	%
Net. thermal effiency (LHV):	%

HP:	88%	
IP1	92%	
IP2:	93%	
LP1-2:	91%	(without exhaust loss, which is 44 kJ/kg)
FPT:	82%	
Generator efficiency:	98.7%	
Boiler efficiency:	94%	

The other pumps (assumede isentropic efficiency equal to 80%) are with elctrical drives and the power is included in the auxillary consumption.

The TTD - Terminal Temperature Difference (temperature difference between the saturation temperature of the steam and the feed water or condensate outlet) for the feed water and condensate preheaters (FHx and CHx) and the district heaters (DHx) can be assumed to be 2°C. The DTD - Drain Temperature Diference (temperature difference between condensate outlet and feed water inlet) for feed water heaters (FHx) can be estimated to be 15°C. The desuperheater (FH4) rises the feed water temperature 5°C.

The pressure drop (in % of extraction steam pressure) in the steam extraction lines to the preheaters can be assumed to have the following values:

LP-PH1	3%
LP-PH2	3%
LP-PH3	1.6%
LP-PH4	0.3%
Deaerator (FW Tank)	3%
HP-PH1	1.7%
HP-PH2	0%
HP-PH3	0.3%
HP-PH4	1%

For the design case the mass flow ratio of steam to LP1 is 50.2% compared to the total flow of steam to LP1 and LP2. The flow ratio varies during off-design operation, but the information can be used for determining the swallowing capacities of the LP1/LP2 turbine parts.

The pressure drop in the valves V1 and V2 when fully opened can be neglected.

4 Off-design operation

The feed pump is speed controlled and the isentropic efficiency as a function of the main steam flow is shown in figure 2.

The live steam temperature is 540°Cbetween 40-100% live steam flow (boiler load).

The hot reheat temperature is constant 540°Cbetween 80-100% boiler load. Below 80% boiler load the hot reheat temperature decreases linearly to 500°Cat 40% boiler load.

The reheat spray water mass flow is decreasing from 1.7 kg/s to 0 kg/s when the boiler load varies from 100% to 80%. The plant is operated in sliding pressure operation mode with fully open turbine valves between 40% and 100% boiler load.

The auxilliary power consumption during part load operation can be considered a linear function of live steam flow:

$$\text{aux. power [kW]} = 50 \cdot \text{live steam flow [kg/s]} + 500. \quad (1)$$

5 Exercise 1

Calibrate the simulator on the above design point conditions (100% boiler load). Then reduce the load of the plant to 40% - still in condensing mode. Make the complete heat balances (pressure, entalpy, mass flow, temperature at all connecting points) for the following boiler loads:

LOAD	100%	80%	60%	40%
Net Power				

For each 5% point print/plot the net plant efficiency and the cooling water mass flow versus the load. If possible, make an exergy analysis of the plant at each boiler load. Assume the cooling water inlet temperature (10°C) to be the reference temperature.

6 Exercise 2

The production of district heating is achieved by increasing the district heating water flow while operating the two set of valves V1 and V2 in order to maintain 100°Csupply temperature. In condensing mode, the valves V1 are closed and V2 are fully opened. At first, V1a is opened to admit steam to the condensing district heating heat

Fig.4.2.9

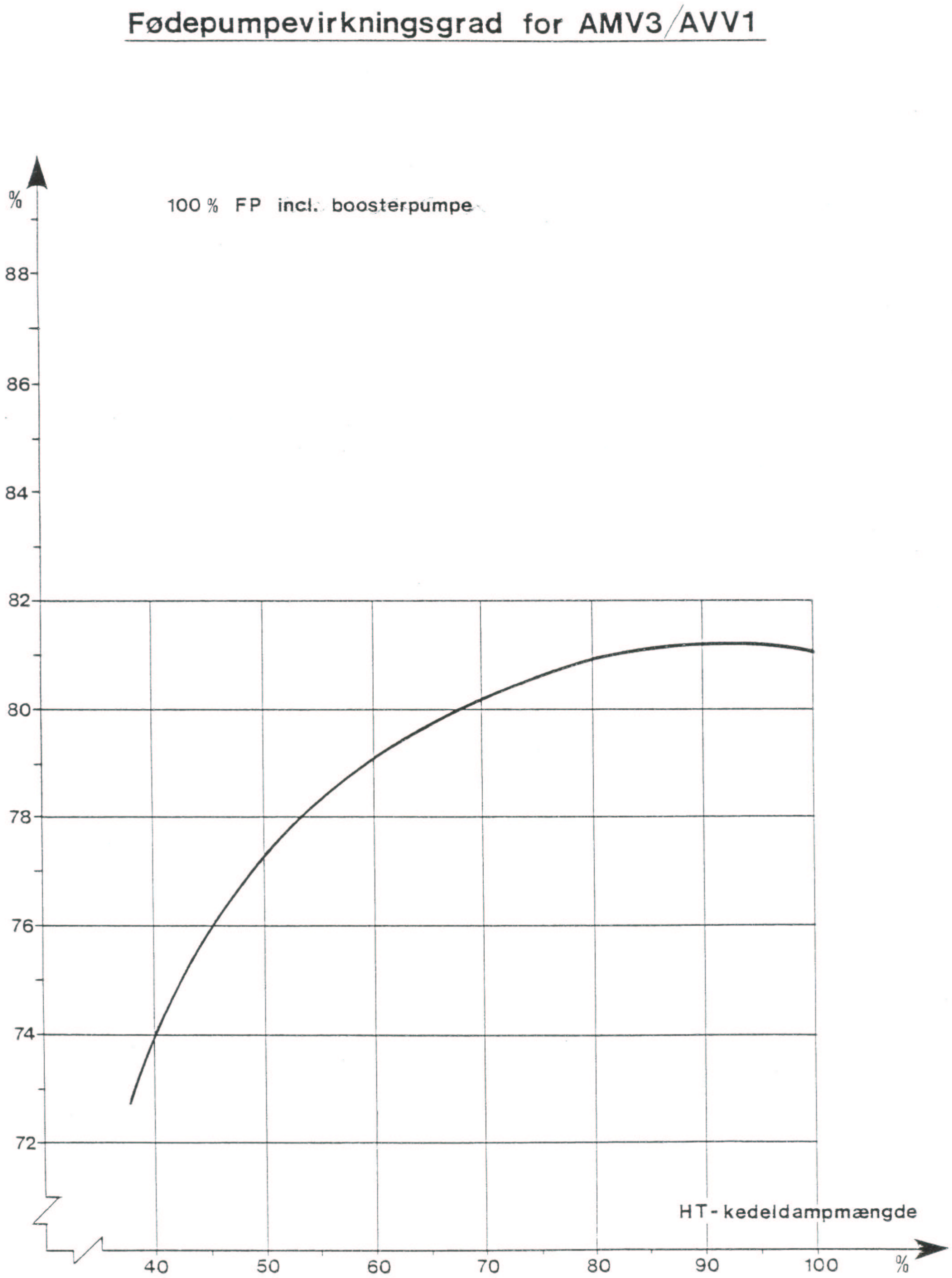


Figure 2: Feedwater Pump Efficiency

exchangers. When V1a is fully opened, V1b is opened. When both valves V1 are fully opened, the valves V2a/b will be closed in parallel in order to increase the production of district heating and back pressure operation is achieved when the valves V2 are almost fully closed ($<$ 1% of the main steam flow).

For all four of the above boiler load points, simulate the plant in order to obtain iso-load (iso-fuel) lines in a P–Q diagram (P is the electric power and Q is the district heating power). With 50°C/100°Cdistrict heating return/supply temperatures the following district heating load cases are wanted:

1. 50 MJ/s
2. 100 MJ/s
3. 165 MJ/s
4. No-loss point, i.e. the valves V1 and V2 are all fully open.
5. 250 MJ/s
6. "Back-pressure", i.e. the valves V1a/b are fully open and the valves V2a/b are almost fully closed.

The slope of an iso-fuel line is called the C_v value (lost power per produced unit of heat). Calculate the C_v values above and below the no-loss line (point 4 at different boiler loads).

In order to illustrate the influence of the district heating temperatures only at 100% boiler load, add to the above P-Q- diagram the line obtained by running the following cases with 65°C/110°Cdistrict heating return/supply temperatures:

7. 100 MJ/s
8. No-loss point, i.e. the valves V1 and V2 are all fully open.
9. 250 MJ/s
10. "Back-pressure", i.e. the valves V1a/b are fully open and the valves V2a/b are almost fully closed.

A complete heat balance for case 6 at 100% boiler load is wanted.