DYNAMIC SIMULATION OF A VACUUM DEAERATION SYSTEM

M.F. McGarry, Technical Manager
J.D. Ulinder, Simulation Specialist
Dynamic Simulation and Advanced Control Group
Electrical & Control Systems Department
H.A. Simons Ltd., Vancouver, B.C.

J.M.F. Boisvert, Project Development Coordinator
Westcoast Power Inc.
1333 West Georgia St.
Vancouver B.C.

ABSTRACT

A dynamic simulation of the Lake Superior Power Cogeneration Plant condenser and vacuum deaeration system was completed for Nicholls-Radtke in order to verify the proposed process design and control logic design using H.A. Simons' dynamic simulation software (IDEAS™). The simulation was used to verify the innovative process concept as well as providing a method of testing the control concept for the area. Differing operating conditions were simulated, including winter peak operation and typical summer operation to provide information on the effect of upsets on the fluid level in the condensate tank. Using the dynamic model, engineers were able to verify the response of the system to a sudden turbine trip and load shed. It was found that these events would lead to a temporary level depression in the condensate tank but the boiler feedwater supply would not be interrupted.

Although no catastrophic errors were found in the process concept or the control concept, the simulation provided an assurance of what to expect once the plant is operational.

The paper discusses the fidelity of the models used, model assumptions and model limitations.

KEYWORDS

Vacuum Deaeration, Dynamic Simulation, Process Control, Engineering Design.

INTRODUCTION

Balance of plant (B.O.P.) engineering of the Lake Superior Power gas turbine combined cycle cogeneration plant was recently completed for Nicholls-Radtke, the B.O.P. turnkey contractor. The new plant, which is presently being commissioned, will supply steam to nearby St. Marys Paper while selling electrical power to the local utility, Great Lakes Power.

The plant features a Graham vacuum deaerator which uses steam from the steam turbine surface condenser to deaerate boiler make-up water under vacuum. This deaerator relies on the operation of the steam turbine. When the steam turbine is out of service an auxiliary deaerator is required to deaerate feedwater using process steam which is expanded to vacuum. Such a process design, with two vacuum deaerators had never been built or tested in operation.

Of particular concern was the behaviour of the system during a sudden turbine trip. When this occurs, the control system must effect a smooth switch over from main to auxiliary deaerator, without adversely affecting the security of steam supply to St. Marys. It was feared that during the switchover, there may be a temporary level depression in the condensate tank which could cause a condensate pump trip and subsequent loss of boiler feedwater.

Thus it was decided to model the dynamic behaviour of the condenser and vacuum systems using dynamic simulation software. The simulation would allow engineers to test the process and control system design and detect any potential operation problems, before finalization of control system design and control valve purchase.

DESCRIPTION OF THE DYNAMIC MODEL

The Lake Superior Power dynamic simulation was developed with proprietary object oriented dynamic simulation software. This software is a powerful tool which simulates physical processes, including compressible and incompressible fluid flow from first principles. It features built in correlations of the ASME steam property tables, as well as thermodynamic properties for various other substances.

The program simultaneously solves five equations to model incompressible and compressible fluid systems:

- Momentum
- Mass Continuity
- Energy Continuity
- Equation of State
- Component Mass Continuity

The LSP model is composed of various equipment models linked together by interconnection piping and controlled by valves, controllers and external boundary conditions. A printout of the LSP flowsheet is illustrated in figure 1. Each object in the flowsheet contains compiled source code modelling the physical processes governing the behaviour of the component. The user interacts with the object through a dialog box (see Figure 2). The dialog box contains input fields that allow the user to modify parameters specific to that object instance, for example a setpoint or a tuning parameter. The model includes only those elements in the condensate and vacuum system that directly impact on the dynamic behaviour of the system. It features four main pieces of equipment, interconnecting piping, control valves and process control devices.
The following is a brief description of the equipment modelled.

Steam Turbine Condenser
On the shell side, pressure is calculated based on the vapour-liquid equilibrium which is achieved as a result of energy balance in and out of the shell (steam in, vapour out, heat exchanged with cooling water, deaerated make-up to hotwell, condensate out). Heat to the cooling water is governed by an overall heat transfer coefficient. The surface condenser sub-model was verified against the Heat Exchanger Institute (HEI) Standards for Surface Condensers, in steady state operation.

Condensate Tank
The tank is modelled in the same way as the condenser shell space except that it is assumed to have no heat loss.

Vacuum Deaerators A & B
Both deaerators are also modelled using the same thermodynamic and continuity equations as the condenser shell. In addition, the deaerators include a packing model and a simulated liquid retention time. This last feature models the time lag between a sudden change in make-up flow to the deaerator and the corresponding change in deaerated out flow.

All equipment geometry including elevations of inlets and outlets were input to the model.

Piping and On/Off Valves
The interconnecting piping and manual valves which impact on the dynamic response of the system, have been modelled. Pipe diameters, equivalent lengths and friction characteristics are model inputs. Heat loss through pipes was assumed negligible.

Control Valves and Controllers
There are two relevant control valves in the system:

•Condensate tank level control valve which acts on feedwater to the deaerators
•Deaerator B pressure control which acts on steam to deaerator B.

Selection of these control valves and controller tuning constants impact on the dynamic response of the system, especially the condensate tank level control valve. Appropriate valve characteristics were selected based on flow range and noise level considerations. Flow vs valve stem position was calculated based on valve characteristics (Cv and Cg), differential pressure, density, temperature, and are corrected for critical flow. The controller tuning constants were set for fastest stable operation. These selections have been modified somewhat since finalization of design.

PROPOSED SWITCHOVER LOGIC

The simulation includes a proposed switchover sequence of events upon loss of the steam turbine. This sequence is shown schematically in Figure 3.

Most events occur immediately when the turbine trips, except for the operation of the make-up water valves which switch flow from deaerator A to B. The duration of the events is the assumed time for valve to travel from closed to fully open or vice versa. A linear ramp was assumed for valve stem position variation.

VERIFICATION OF THE MODEL

Although it was impossible to verify the results of the simulation model against actual operation, the following verifications were made:

- Steady state heat and mass continuity for various components
- Verification of equal levels in condensate tank and hotwell under steady state conditions. Verifying level equilibrium in the two tanks, provides a check of level control logic, tank geometries and elevations.
- Verification that deaerator retention time approximates Graham information.

RESULTS OF SIMULATION RUN

An example of one simulation run will be the focus of this paper, ie. a sudden turbine trip on a typical operating day.

Figure 4 represents the initial steady state condition, prior to the turbine trip. The cogeneration plant is supplying 110,000 lb/h to St. Marys Paper. The steam turbine-generator is base loaded at 25 MW. At this condition, duct burners are in operation. Once the upset occurs, the simulation models the sequence of events that would occur and the dynamic response of the system. When the turbine trips, the deaerator switchover sequence is immediately initiated. Turbine throttle steam is immediately shut off, but the turndown of the boiler feedwater flow is assumed to lag by 60 sec, due to the time to turn down duct burners, and inertia in the boiler drum. During this time, steam will be vented. Once feedwater flow has reached the un-fired condition, steam will continue to vent until the diverter valves are operated. It is assumed operation of the turbine exhaust vacuum breaker occurs after isolation of deaerator A and the condenser hotwell.

The simulation models the system response up to the conditions prior to operating the diverter valves. The results of the simulation are illustrated in Figures 5 to 10. These graphs represent the variation with time of key flows, pressures, temperatures and levels.

Figure 5 – Turbine Condenser

Approximately 10 sec after the start of the simulation run, the turbine trips. Steam flow to the condenser abruptly falls to zero and the deaerator switchover sequence is initiated. The sudden drop in steam flow causes a reduction in shell side pressure and temperature, this rapid drop causes a pressure difference between the condensate tank and hotwell with a resulting reverse flow of condensate from the condensate tank to the condenser raising the level in the hotwell.

Figure 6 – Condensate Tank

Once the turbine has tripped, the level in the condensate tank is affected by the reverse flow of condensate back to the hotwell. After the flow reversal, the rate of drainage stabilizes and the level drops very slowly. At this condition, steam is being vented since the un-fired steam generation is larger than St. Marys usage, but make-up to deaerators is limited by their design capacity, so there is a continuous drainage of condensate until the diverter valves are operated. At this rate, the tank would drain in 55 minutes.

Figure 7 – Deaerator A

When the turbine trips, the switchover logic starts isolating deaerator A from the system. Before isolation, deaerator temperature and pressure (Figure 9) are dictated by the variations in the condenser. At approximately 15 sec, the make-up valve starts to close and the deaerated flow follows with an approximate 10 sec lag.

Figure 8 – Deaerator B

When the turbine trips, switchover logic starts readying deaerator B for operation. The steam pressure control valve is immediately put in service. Temperature and pressure in deaerator B react immediately to the onset of pressure control. The vent valve to ejectors and flash steam line from the condensate tank are opened over a 5 sec period. Once make-up water is admitted to the deaerator at approximately 15 sec, pressure and temperatures start their progression towards steady state. The flow out of the deaerator lags behind the make-up flow by approximately 10 sec.

Figure 9 – Deaerator Pressures

The pressure in deaerator A, initially at steady state, starts to decrease immediately once the turbine has tripped. Deaerator B pressure initially rises above the 6.6 kPa(a) set point, and the pressure controller responds by closing the steam inlet valve. Once the make-up water valve is opened, pressure starts to slowly increase towards the setpoint.

Figure 10 – Condensate Flow
The flow through the connecting line between the condenser hotwell and condensate tank is shown on this graph as well as the condensate temperature to the condensate tank. It can be seen that from an initial steady state condition, after the turbine trips, the condensate flow from the condenser to the condensate tank becomes temporarily reversed until the isolating valve is shut.

The results of this simulation run show that deaerator switchover is accomplished with very little impact on the condensate tank level. However, condensate will slowly drain until turbine exhaust gas diverter valves are operated, due to the deaerator capacity being less than the un-fired steam generation

CONCLUSION

Dynamic simulation of the condenser vacuum system was developed using Simons IDEAS™ software. The model included all relevant equipment, valves, piping and controllers which impact on the dynamic response of the system.

The model was used to predict the system response to a turbine trip and load rejection. It was found that when the condenser pressure reacts to sudden load changes the temporary pressure imbalance between condensate tank and condenser hotwell causes a condensate flow reversal back to the hotwell. Although this has some impact on condensate tank level, it is not sufficient to jeopardize condensate pump operation.

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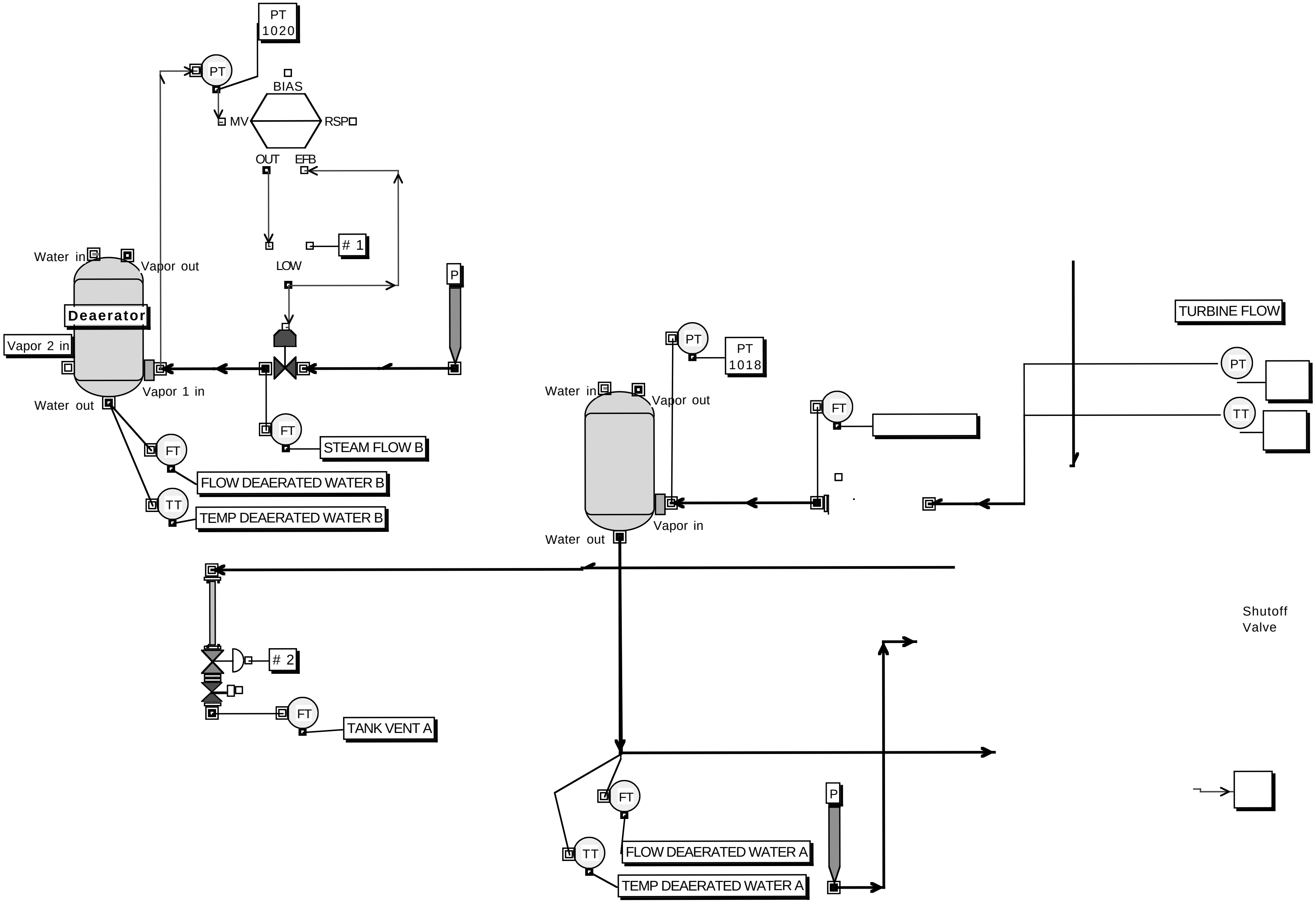
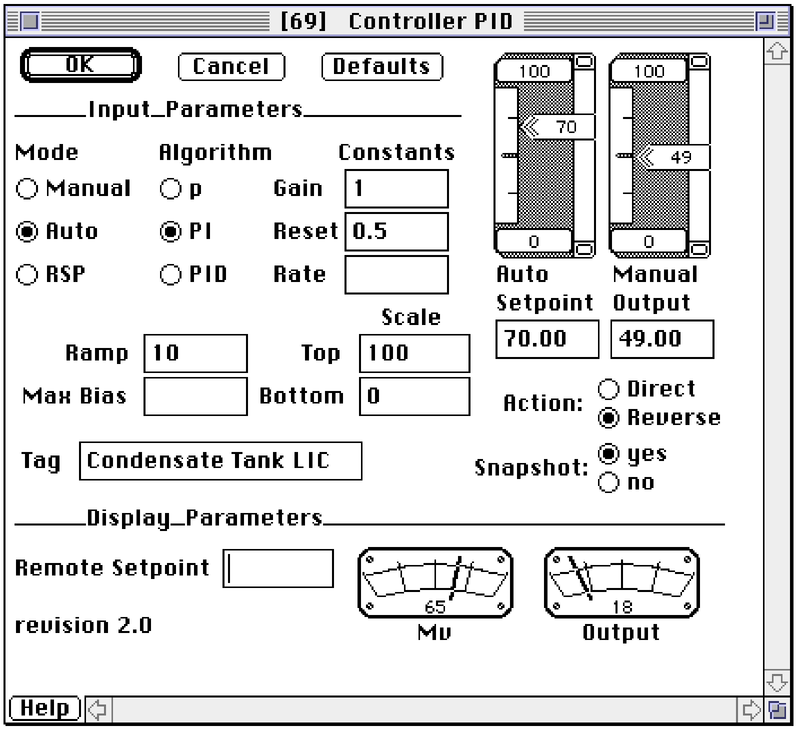


Figure 1 - A Portion of the Simulation Flowsheet



Input_Parameters

Mode	Algorithm	Constants	
○ Manual	○ p	Gain	1
● Auto	● PI	Reset	0.5
○ RSP	○ PID	Rate	

Ramp 10
Max Bias
Scale Top 100
Scale Bottom 0
Tag Condensate Tank LIC

Auto Setpoint 70.00
Manual Output 49.00

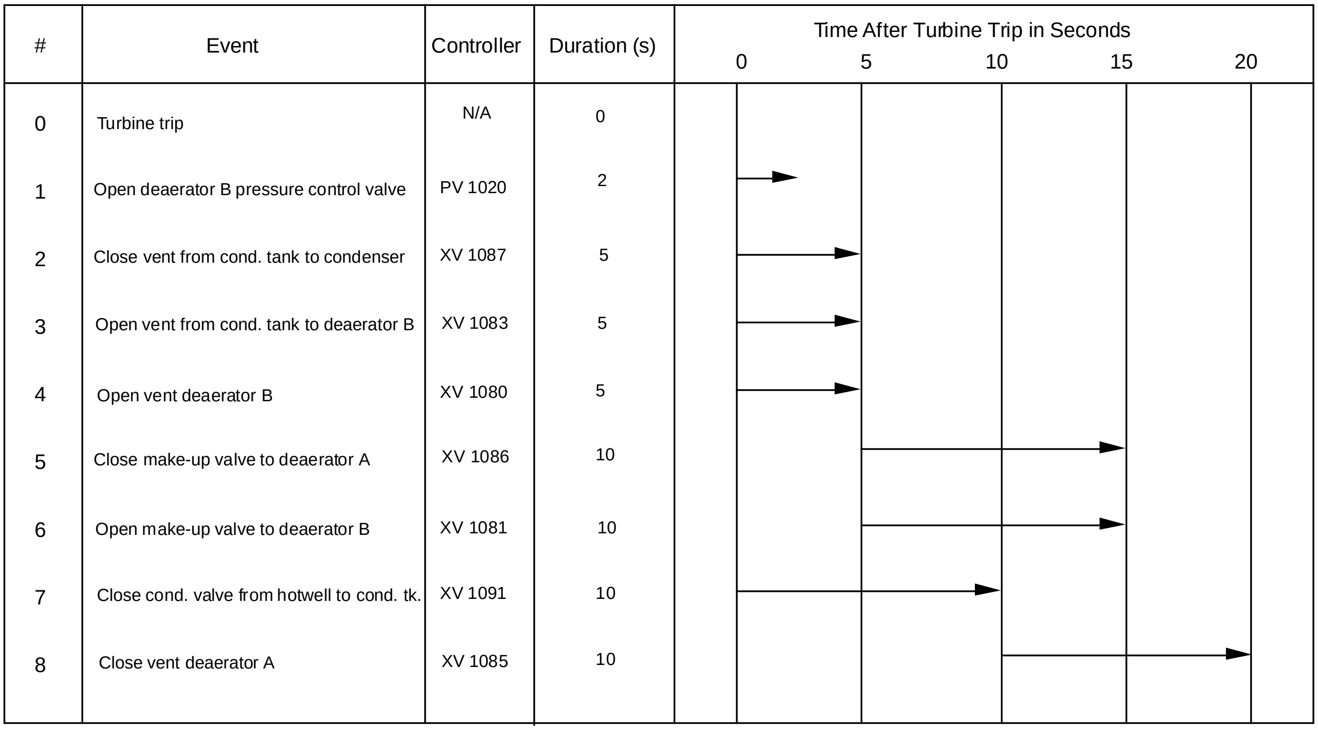
Action: ○ Direct ● Reverse
Snapshot: ● yes ○ no

Display_Parameters

Remote Setpoint
revision 2.0

Mv 65
Output 18

Figure 2 - Controller Dialog Box



#	Event	Controller	Duration (s)
0	Turbine trip	N/A	0
1	Open deaerator B pressure control valve	PV 1020	2
2	Close vent from cond. tank to condenser	XV 1087	5
3	Open vent from cond. tank to deaerator B	XV 1083	5
4	Open vent deaerator B	XV 1080	5
5	Close make-up valve to deaerator A	XV 1086	10
6	Open make-up valve to deaerator B	XV 1081	10
7	Close cond. valve from hotwell to cond. tk.	XV 1091	10
8	Close vent deaerator A	XV 1085	10

Figure 3 - Shutoff Valve Sequence

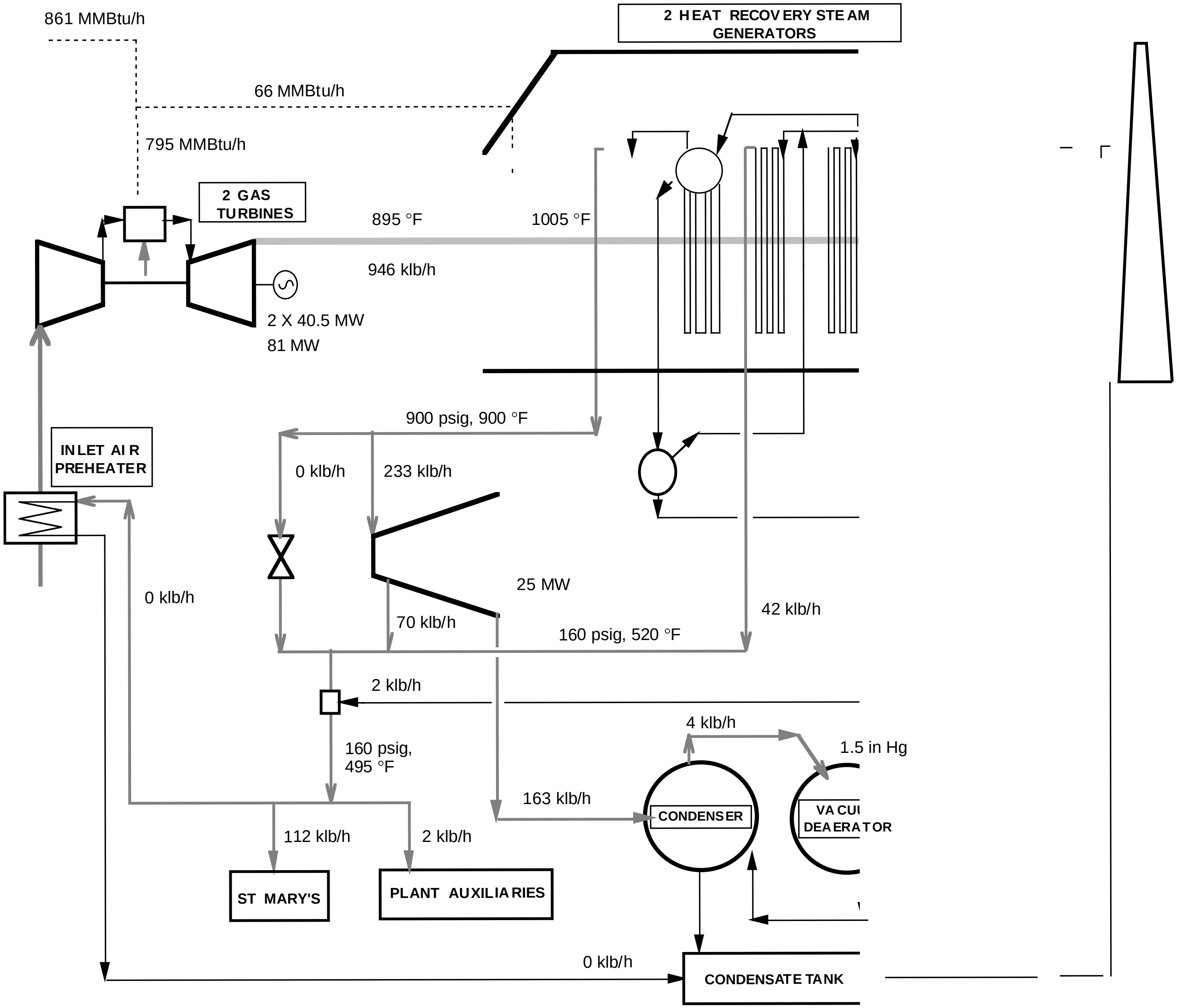


Figure 4 - Steady State Initial Conditions

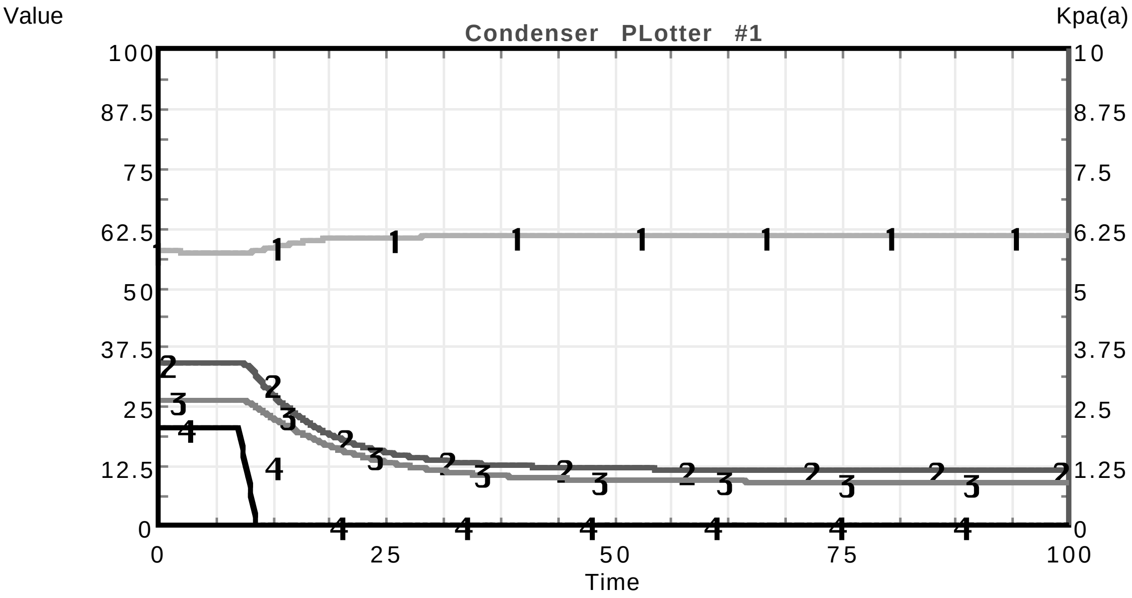


Figure 5 - Turbine Condenser

Legend	Scale
1 - Condensate hotwell level (%)	Left
2 - Vapour pressure in condenser (kPa)	Right
3 - Vapour temperature in condenser (°C)	Left
4 - Steam flow to condenser (kg/s)	Left

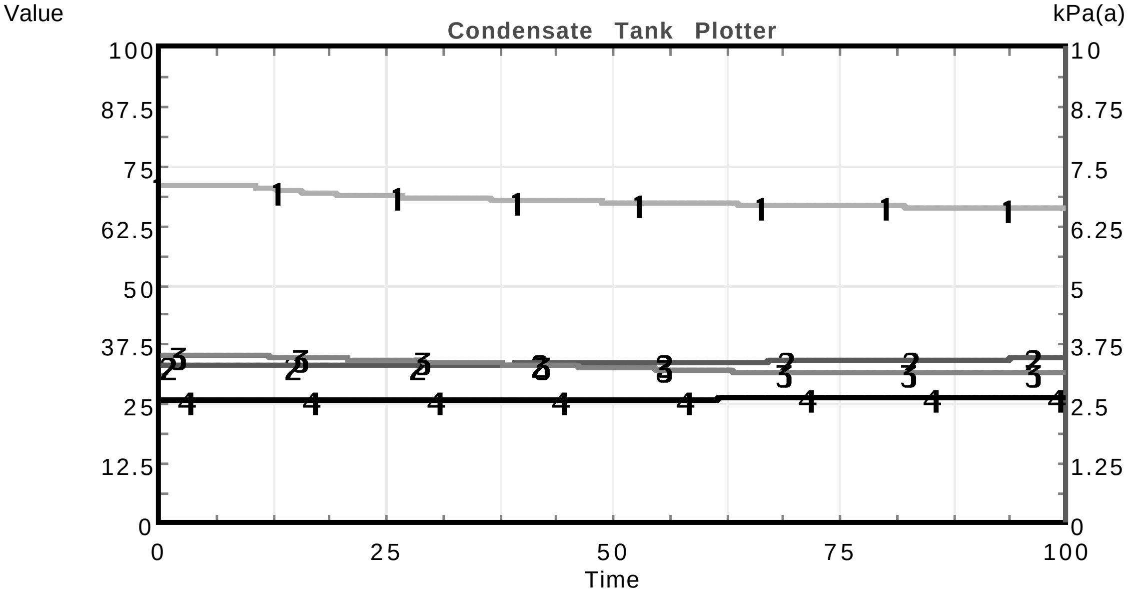


Figure 6 - Condensate Tank

Legend	Scale
1 - Condensate tank level (%)	Left
2 - Condensate tank pressure (kPa)	Right
3 - Net flow to condensate pumps (kg/s)	Left
4 - Temperature out of condensate tank (°C)	Left

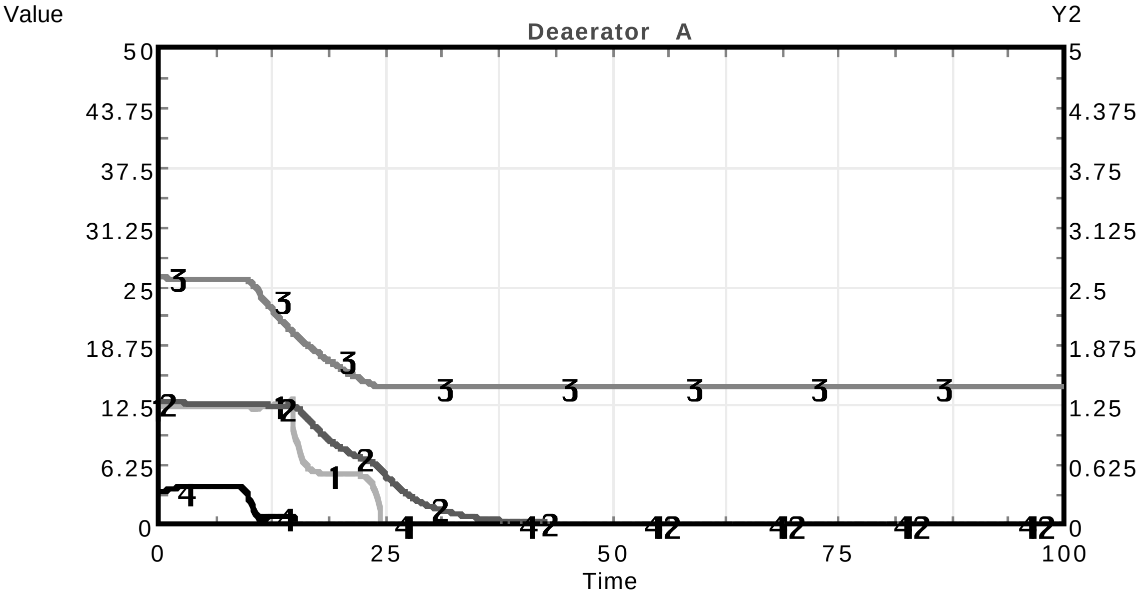


Figure 7 - Deaerator A

Legend	Scale
1 - Make-up flow to deaerator (kg/s)	Left
2 - Deaerated flow (kg/s)	Left
3 - Temperature of deaerated water (°C)	Left
4 - Steam flow to deaerator (kg/s)	Right

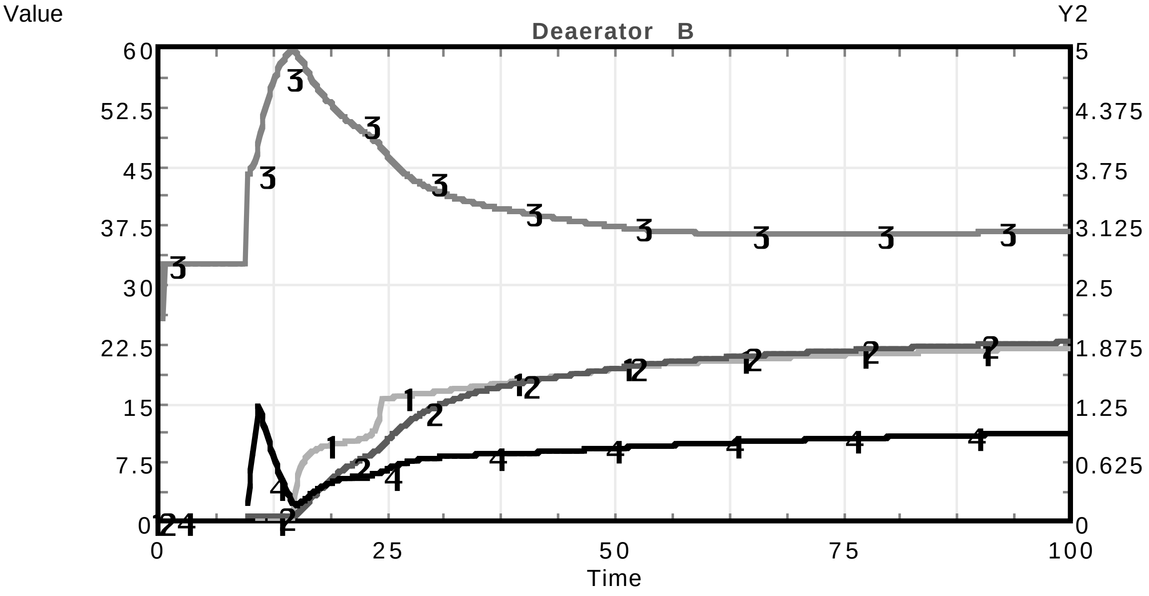


Figure 8 - Deaerator B

Legend	Scale
1 - Make-up flow to deaerator (kg/s)	Left
2 - Deaerated flow (kg/s)	Left
3 - Temperature of deaerated water (°C)	Left
4 - Steam flow to deaerator (kg/s)	Right

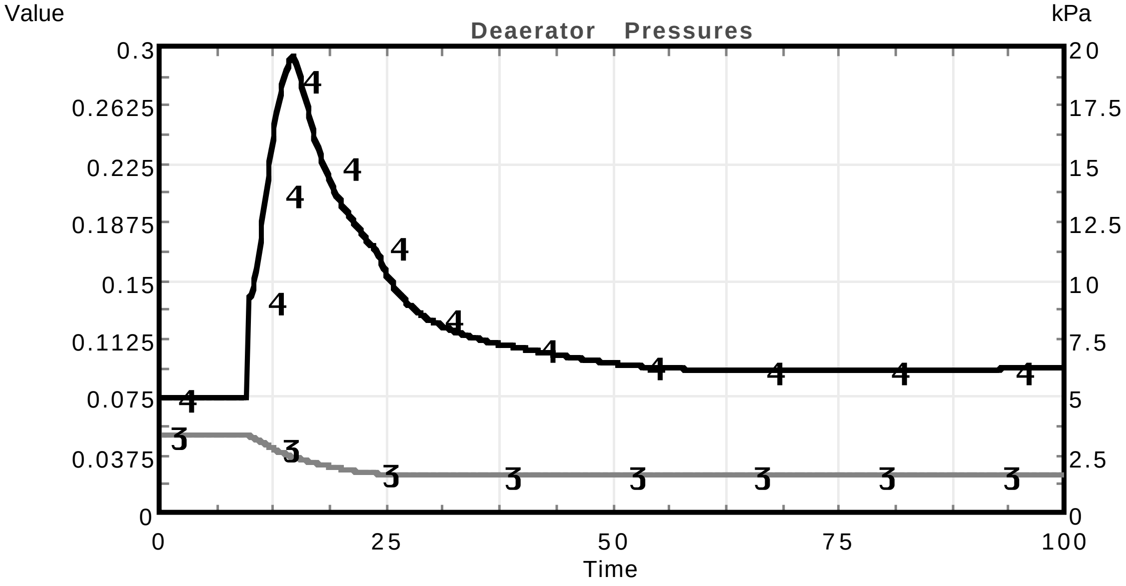


Figure 9 - Deaerator Pressures

Legend	Scale
3 - Pressure at deaerator A (kPa(a))	Right
4 - Pressure at deaerator B (kPa(a))	Right

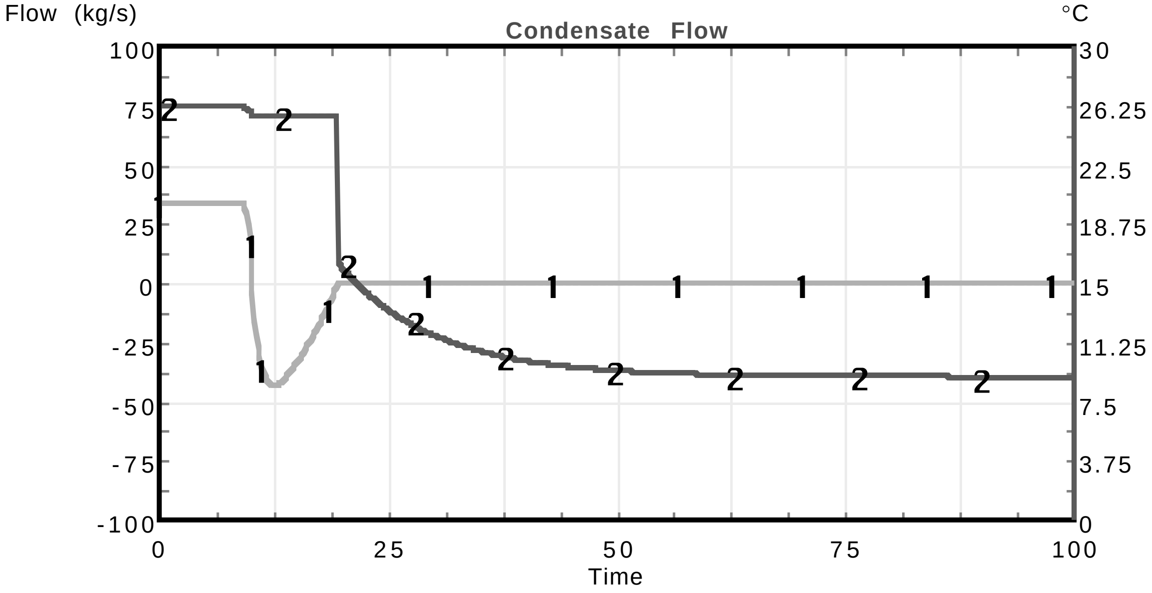


Figure 10 - Condensate Flow

Legend	Scale
1 - Condensate flow from hotwell to tank (%)	Left
2 - Condensate temperature from hotwell (°C)	Right