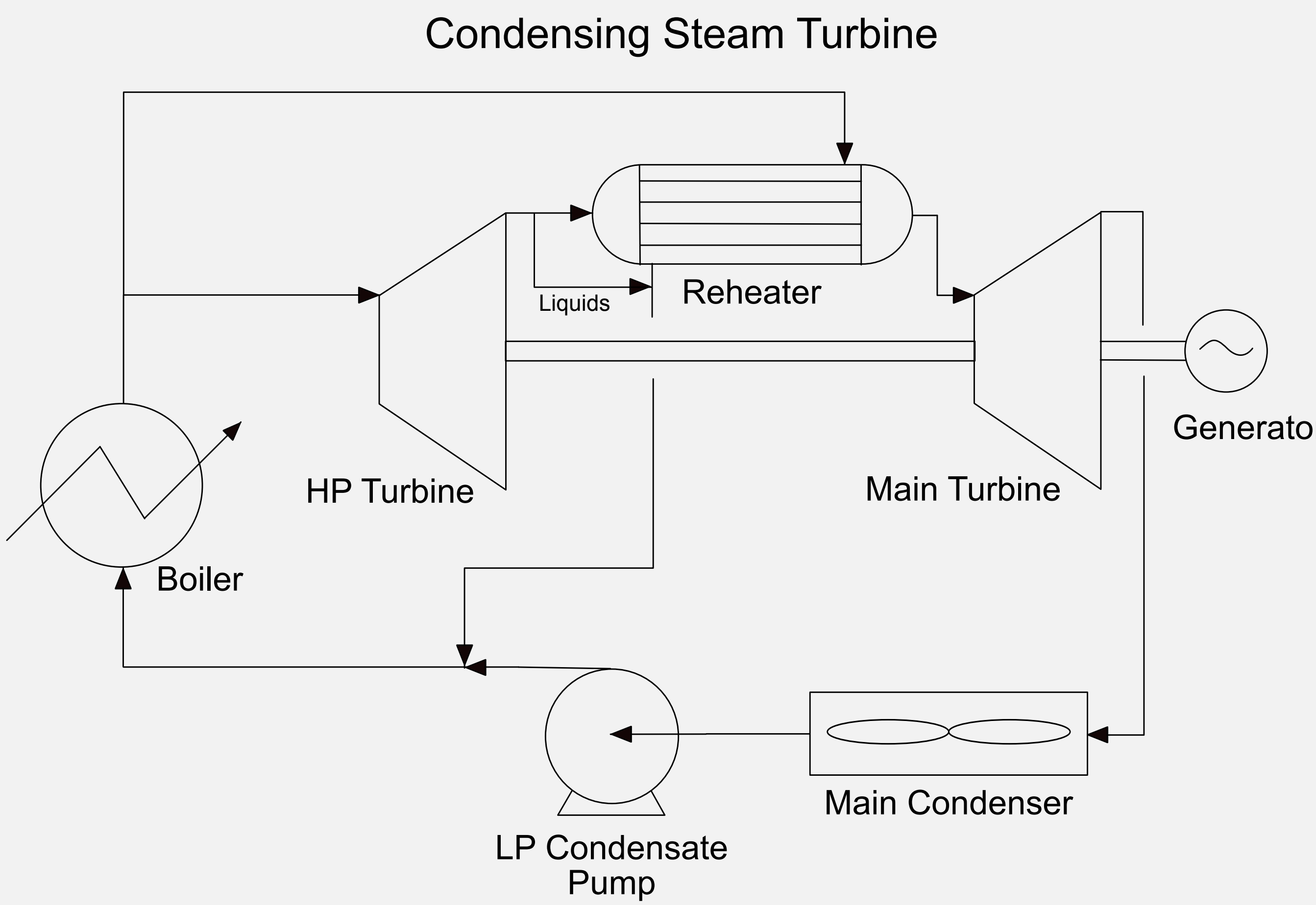
Condensing Steam Turbine

This is a model of a simplified condensing steam turbine system for a power plant. Power generating turbines in chemical and industrial plants often only expand the high pressure steam to a lower pressure steam that is useful in other processes. Electical utilities strive to maximize the electricity generated and so use the steam condenser to reduce the turbine outlet pressure to the lowest possible value, well below atmospheric pressure.

The diagram below represents the process used here:



High pressure steam is produced in boiler utilizing the energy of some sort of combustion, solar heating or nuclear reaction. A portion of this (**HPTInlet**) is sent to a high pressure turbine and is expanded to an intermediate pressure and of course generates power.

A second portion of the high pressure steam (**RHHotIn**) is used in a reheater to raise the temperature of the vapour portion of the high pressure turbine exhaust to 250 C. This reheated steam (**MSTInlet**) is fed to the main turbine (**MainTurbine**) and the exhaust is condensed with ambient air to 40 degC, resulting in a very low pressure.

The condensate is then pumped back up to the high pressure and mixed with the steam from the heating side of the reheater and the liquids formed in the high pressure turbine to become the boiler feed.

This is a gross simplification for not only did I ignore all pressure drops, but a real system would probably have a complicated systems of feed heaters utilizing steam draws from intermediate parts of the turbine. I omitted these for simplicity and because in truth I really have no idea how they are implemented. 😀

Calculations

It is a pretty straight forward process, but there are some interesting heat balances used to get flows etc.

The feed to the high pressure turbine is represented by **HPTInlet** and it is specified with arbitrary T and P values of 300 degC and 6000 mPa, which were inspired by some random Internet browsing. I will come back to how the flow is calculated in a bit.

The high pressure turbine, **HPTurbine** lets the pressure down to 1000 mPa and then reheats the vapour portion of the exhaust to 250 degC to become the feed, **MSTInlet** to the main steam turbine **MainTurbine**.

The calculation of the flow for **MSTInlet** is a bit tricky and I had to dust off some rusty but fortunately basic algebra skills to come up with the formula. I assume that we know how much power we want to generate and want to back calculate the flows from that. This would be a simple heat balance if it weren't for the liquid being removed from the high pressure turbine outlet, with only the vapour going to **MSTInlet**.

The energy generated will be the sum of the high pressure and main turbines and is described by:

$$\mathbf{E = (Hoh - Hih)Hf + (Moh - Mih)MF}$$

where:

E = the desired power produced - I assumed a princely 1000 mW, divided by a 0.95 efficiency for the generator.
Hoh = the enthalpy of the outlet of the high pressure turbine (**HPTurbine.h**)
Hih = the enthalpy of the inlet of the high pressure turbine (**HPTInlet.h**
Hf = the flow rate to the high pressure turbine (**HPTInlet.f**)
Moh = the enthalpy of the outlet of the main turbine (**MainTurbine.h**)
Mih = the enthalpy of the inlet to the main turbine (**MSTInlet.h**)
MF = the flow rate to the main turbine, which will be Hf minus the liquid produced in the turbine. This is what we want to solve for.

The expander models will calculate the outlet enthalpy even if the flow rates aren't known, so the only unknowns are the two feeds, and:

$$\mathbf{Mf = Hf * Hoq}$$

where **Hoq** is the vapour fraction of the high pressure turbine outlet fluid (**HPTurbine.outfluid.q**). Combining and rearranging gives:

$$\mathbf{E*Hq / (Hoh - Hin + (Moh - Mih)Hq)}$$

or in Minionese:

HPTurbine.outfluid.q * 1000 mw
/
(
(
HPTInlet.h - HPTurbine.h
+ (MSTInlet.h - MainTurbine.h)
*** HPTurbine.outfluid.q**
) * .95
)

Going back to the flow of **HPTInlet**, it is **Mf/Hq** or

MSTInlet.f / HPTurbine.outfluid.q

The hot side feed to the reheater is represented by **RHHotIn**, which has all the same properties as **HPTInlet** except for the flow rate, which is determined by another, but simpler, heat balance. The duty of the reheater will simply be the heat flow of the cold side outlet (**MSTInlet.hflow**) minus that of the inlet (**HPTurbine.outfluid.v.hflow**).

The flow rate of the hot side will then be that duty divided by the difference in hot side outlet and inlet enthalpies.

A compressor model is pressed into service as the condensate pump **CondPump** (the thermodynamics doesn't care) and a three feed mixer model **CondMixer** combines the pumped condensate, the reheater hot side outlet and the liquids from the high pressure turbine into the boiler feed **BoilerInlet**.

Finally an expression **OverallBalance** is added that does a material balance around the entire system. This should equate to near zero or something isn't right. As it come up with a tiny fraction of a watt, it is more than close enough.

Inlet to high pressure turbine
Boiler out

HPTInlet

Label	Unit	B
q	Fraction	-1.00000
t	degC	300.00
p	kPa	6000.00
f	kmol/h	260388.08
h	kJ/kmol	51983.79
s	kJ/kmol-K	109.36
dmolar	kmol/m^3	1.53
mwt	kg/kmol	18.01527

x	Fraction	1.00000
massf	kg/h	4690961.06354
hflow	W	3.759989e+9

The main boiler duty

BoilerDuty	3667.24 mW

Condensate mixer outlet and boiler pump inlet

BoilerInlet

Label	Unit	B
q	Fraction	-1.00000
t	degC	70.65
p	kPa	1000.00
f	kmol/h	283058.16
h	kJ/kmol	5342.94
s	kJ/kmol-K	17.34
dmolar	kmol/m^3	54.28
mwt	kg/kmol	18.01527
x	Fraction	1.00000
massf	kg/h	5099368.58259
hflow	W	4.201005e+8

HP steam to reheater
Also boiler out

RHHotIn

Label	Unit	B
q	Fraction	-1.00000
t	degC	300.00
p	kPa	6000.00
f	kmol/h	22670.08
h	kJ/kmol	51983.79
s	kJ/kmol-K	109.36
dmolar	kmol/m^3	1.53
mwt	kg/kmol	18.01527

x	Fraction	1.00000
massf	kg/h	408407.51905
hflow	W	3.273546e+8

HP steam leaving reheater

RHHotOut

Label	Unit	B
q	Fraction	-1.00000
t	degC	260.00
p	kPa	6000.00
f	kmol/h	22670.08
h	kJ/kmol	20442.75
s	kJ/kmol-K	51.91
dmolar	kmol/m^3	43.59
mwt	kg/kmol	18.01527
x	Fraction	1.00000
massf	kg/h	408407.51905
hflow	W	1.287330e+8

Inlet to Main Steam Turbine
Reheated LP Turbine out

MSTInlet

Label	Unit	B
q	Fraction	-1.00000
t	degC	250.00
p	kPa	1000.00
f	kmol/h	239080.49
h	kJ/kmol	53021.14
s	kJ/kmol-K	124.78
dmolar	kmol/m^3	0.24
mwt	kg/kmol	18.01527
x	Fraction	1.00000
massf	kg/h	4307099.05350
hflow	W	3.521200e+9

Sanity check heat balance

OverallBalance	8.656271e-8 mW

Assume 95% efficiency for electricity generation

ePower	1000.00 mW

Condensate from main condenser

MainCondOut

Label	Unit	B	V	L
q	Fraction	0.00000	1.00000	0.00000
t	degC	40.00	40.00	40.00
p	kPa	7.38	7.38	7.38
f	kmol/h	239080.49	0.00	239080.49
h	kJ/kmol	3018.15	46362.48	3018.15
s	kJ/kmol-K	10.31	148.73	10.31
dmolar	kmol/m^3	55.07	0.00	55.07
mwt	kg/kmol	18.01527	18.01527	18.01527
x	Fraction	1.00000	1.00000	1.00000
massf	kg/h	4307099.05350	0.00000	4307099.05350
hflow	W	2.004393e+8	0.00000	2.004393e+8

MainCondDuty	2624.23 mW

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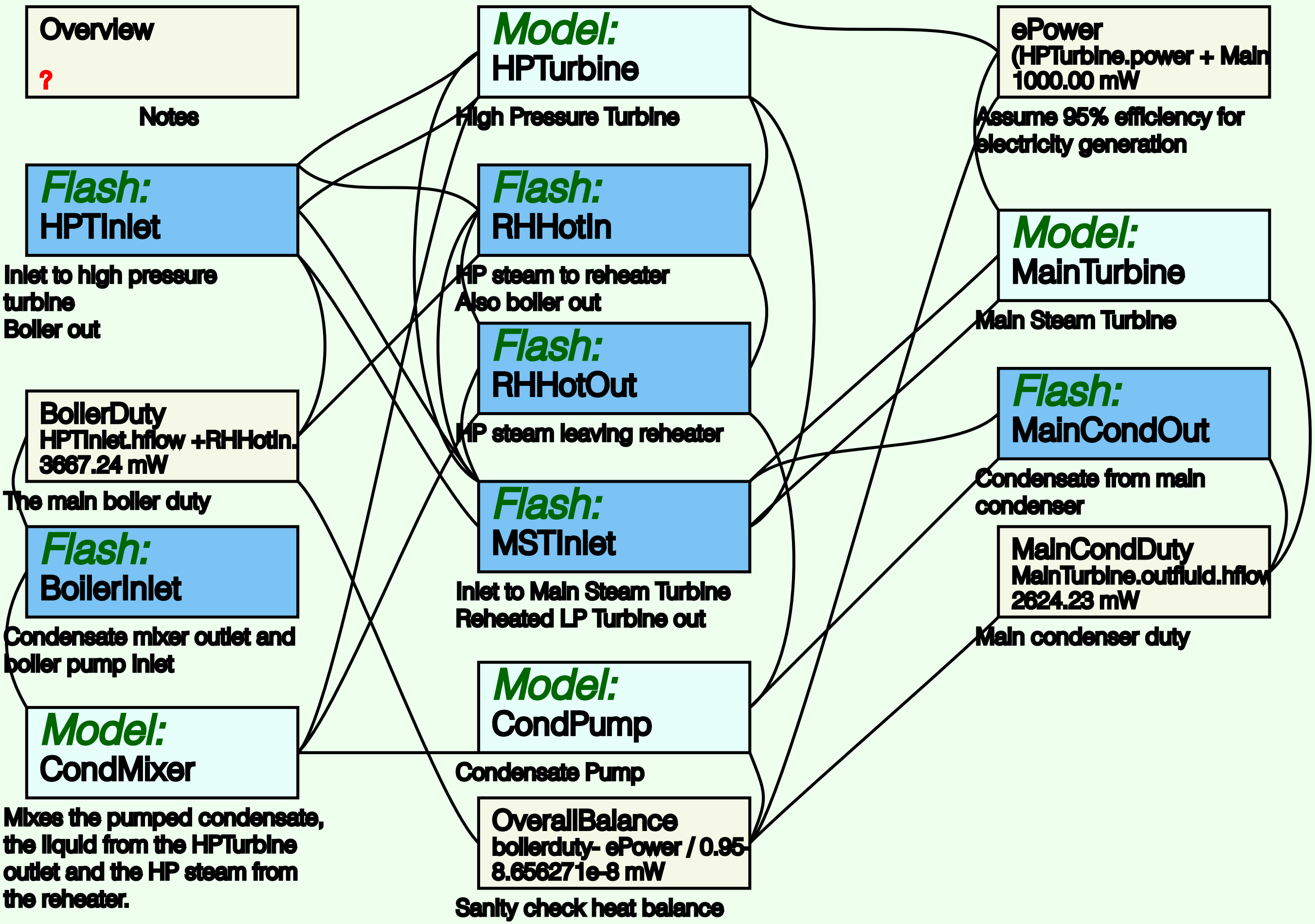

Info Sessions Console Undo Redo Units