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Mr. Megawatt
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What Time is It?

by Frank Todd, Manager, Thermal Performance

One of the troubles with excessive travel is trying to keep a consistent concept of time. Of course, my propensity to do my timekeeping using a wind up pocket watch is a contributing factor to my chronological distress. Time is one of those things that we presuppose. If someone tells you to meet them at 3 p.m., you look at your watch and see it is 2 p.m. and think, "I have one hour." However the actual time is 1 p.m., so when you show up at 3 p.m. and your compadre doesn't, you give him 15 minutes and drive off disgruntled for being stood up, "If only I had reset my watch when I landed in Istanbul, I would not have had the problem."

In the world of making megawatts, we also can fall prey to incorrect presuppositions. In fact, many of the problems we have uncovered in our world of thermal performance troubleshooting have been related to finding out that the issue was in the assumptions. This is a story of having two (sometimes more than two) watches and trying to figure out which is correct. (Does a person with two watches ever really know what time it is?)

So there I was at about 10,000´, going in circles around the Mondolvian international airport where the runway could not be distinguished from the piles of white cold stuff stacked up above the control tower. As we approached the runway, my fellow passengers were putting finger mark depressions on their stainless steel seat arms and I was calculating how long it would take to stop given almost no friction. There are times when my knowledge of physics can be a direct impediment to my emotional stability. The only good thing about this situation was that I would not have to worry about the brakes overheating.

Against all possible odds we did land, skid to a peaceful stop, disembarked the plane and trudged off through the snow to the terminal. I was met at the gate exit by Vichenchisku Vladirmanitnovitch (Vic), who spoke no English, and since I could not speak Mondolvian we got along great. Having been to this neck of the woods before, I was able to communicate enough to follow Vic to his 1991 Ford Fiesta which at one time was bright red (so Vic indicated) but is now a nice off red color, sort of like rust. The perfect car for a 150 kilometer journey through barely paved roads with a nice coating of ice. The drive to Outer Oershrinkinwatt Power Station (OOPS) made the airport arrival appear seamless. The probabilistic risk of sliding over the side of a mountain was well over 10-2. As we passed through the living compound enclosed by electrified razor-wire, it dawned on me why my wife insisted the insurance policy changes I made when I was at the Jersey Jungle Power Station (recounted in the October 2012 *Energy-Tech*) should stay in effect. Sort of like going from the Godfather to the KGB. (How do I get these jobs?) Already at the compound was Silas Wattenfinder (SW) our ace data crunching genius. I am not sure if SW was happy to see me or just hoping that we were doing a tag team and he could jump out of the ring. SW had already been enjoying the comforts of ice and razor wire for two days since I was delayed in Romania (another story).

The next morning, SW and I were standing in front of a panel of similarly dressed austere plant management types informing us that their hopes were high that we would solve their problem and would have all the time we needed, since a new snow storm was coming in that would shut down the airports. Apparently, their plant generation had been decreasing during the entire last operating cycle.

Their engineers (all lined up at the back of the room standing at parade rest with confident faces) had looked at the power calculation and believed that everything was fine. They wanted us to look at the rest of the plant and figure out what was wrong – a dead giveaway to look at the power calculation. Remembering the razor wire, I politely asked if I could also look into their power calculation just to satisfy my curiosity and help me with the rest of the evaluation.

OOPS is a nuclear power plant built on the CANDU model. The cycle is very much like a typical Pressurized Water Reactor (PWR) with the exception that the reheat steam drain flow is pumped to the steam generator instead of a drain tank or one of the feedwater heaters. When we looked at the various plant parameters it was clear that something was rotten in Denmark. Not wanting to feign insanity, we took the technical approach.

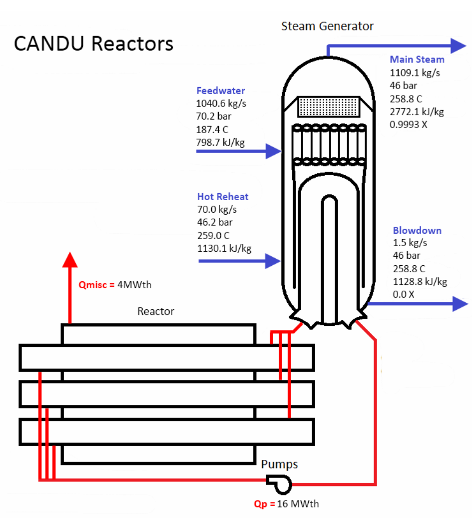

Figure 1. Typical CANDU thermal cycle

Figure 1 shows a simplified control volume for a typical CANDU thermal cycle. As you can see, we

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are tipping our hat to our metric comrades. This is where SW comes in; he is a walking unit converter.

Core thermal power is indirectly calculated using a heat balance across the steam generators and accounting for any energy credits and losses to the reactor. A typical power calculation for a CANDU reactor is:

Reactor Power = wfw (hstm - hfw) + wrh (hstm - hrh) + wbd (hbd - hfw) + Qmisc - Qp

Where:

Qmisc	=	*ambient losses*
Qp	=	*pump heat added to cycle*
wfw	=	*feedwater flow*
hstm	=	*steam enthalpy*
hfw	=	*feedwater enthalpy*
wrh	=	*reheater drain flow to the reactor*
hrh	=	*reheater drain enthalpy*
wbd	=	*blowdown mass flow rate*
hbd	=	*blowdown enthalpy*

A sample CANDU reactor power calculation using the above equations is shown in Table 1as an example.

CANDU Power Calculation

Input Data	Q_{misc} = 4 MWth Q_p = 16 MWth w_{fw} = 1040.6 kg/s h_{stm} = 2772.1 kJ/kg h_{fw} = 798.7 kJ/kg w_{rh} = 70.0 kg/s h_{rh} = 1130.1 kJ/kg w_{bd} = 1.5 kg/s h_{bd} = 1128.8 kJ/kg
Calculation	Reactor Power = w_{fw} (h_{stm} - h_{fw}) + w_{rh} (h_{stm} - h_{rh}) + w_{bd} (h_{bd} - h_{fw}) + Q_{misc} - Q_p = [1040.6 x (2772.1-798.7) + 70.0 x (2772.1-1130.1) + 1.5 x (1128.8-798.7)]/1000 + 4 – 16 = 2157 MWth

Table 1. Sample CANDU reactor power calculation

On a wild hunch, I asked them to provide me with some plant data for condenser pressure, first stage pressure and generation for the time period where they saw the decline. SW then put together a model and produced a graph showing plant generation corrected for condenser pressure.

We combined this data with the first stage pressure data and plotted them on the same chart. Core Thermal Power indicated 100 percent for the entire period of this graph. This chart told us that the decrease in plant generation was genuine and also that it had something to do with overall flow through the cycle. First Stage Pressure is the pressure measured downstream of the first stage of the High Pressure Turbine (for a turbine with a control stage). First Stage Pressure is a good indication of cycle flow; it is nearly linear with steam flow through the turbine.

As can be seen from the graph below, the decrease in first stage pressure and generation is approximately 2 percent, which is fairly significant. The loss is approximately 15MWe which, if it continues, will cost the plant almost 6 million dollars in revenue during the course of a year. One might think 6 million insignificant when compared to our federal deficit, but it can still buy quite a few Fiestas. It definitely grabbed the attention of the faces across the table.

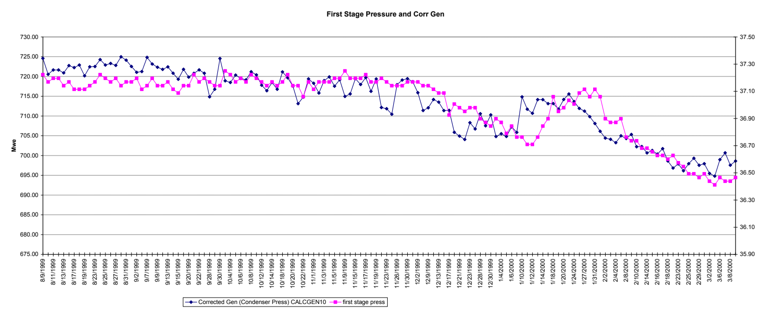

Figure 2.

The flow-passing ability of a steam turbine is given by the relationship:

$$M = k\sqrt{\frac{p}{v}}$$

Where:

M	=	steam flow lb/hr
k	=	the flow coefficient
p	=	the stage inlet pressure, psia
v	=	the stage inlet specific volume, ft^3/lb

The above relationship is a good approximation, except when turbine stage pressure ratios are substantially off-design, or the turbine is at low load. This equation also assumes area does not change. If the flow coefficient changes, then the area is changing.

If the problem was related to steam flow through the cycle, various other parameters ought to follow the same form as first-stage pressure. If we think of the turbine as a set of fixed orifices, the pressure drop across the orifices should be the same at a constant flow. If all the orifice downstream pressures change the same percentage, then it is a sure bet that flow through the cycle has changed.

As flow decreases through a steam turbine stage group, so will the pressures upstream of that group. As the entire turbine cycle is affected, so all the parameters associated with the turbine cycle are affected. The table below provides an estimate of the effect of a 1 percent change in thermal power on various parameters. Some of these parameters can be used as an alternate indication of thermal power, sort of like those radar actuated speed limit signs that blink when you're exceeding the speed limit or the cameras that conveniently mail you the ticket. Of course, these are typically alternate indications of the weight of your foot rather than your speedometer.

Alternate Indication of Power Paramter Sensitivity	1% Change
Parameter	**Power Sensitivity**
First Stage Press	0.82%
Reheat steam Flow	0.73%
Second Stage reheater Flow	-1.55%
Steam Flow	0.88%
Feed Pump Steam flow	1.34%
Condensate Flow	0.92%
Megawatts Electric	0.90%
Primary Delta T	1.00%
Feed Temperature	4.04%
Extraction Pressure	0.89%
HP Exhaust Pressure	0.97%
Condensate Flow	0.92%
Drain Flow + Condensate Flow	0.86%
Heatrate	-4.83%
Condensate Pump Current	0.92%

Table 2.

CANDU Thermal Power Calculation - Input Parameter Sensitivity	
Parameter (1% change)	**Thermal Power Sensitivity**
Feed Flow	-0.9396%
Feed Temperature	0.3859%
Reactor Steam Pressure	0.0125%
Feed Pressure	0.0013%
Steam Quality	-0.8494%
Steam Generator Blowdown Flow	-0.0566%
Steam Generator Blowdown Temperature	0.0061%
Reheater Drain Flow	0.0000%
Reheater Drain Temperature	0.0100%

Table 3.

OOPS Power Station			Station Summary	
Critical Plant Flow Parameter Comparison				
Current Statistics		**Pre**	**Post**	**% Difference**
Corrected First Stage Pressure	bara	37.22	36.46	2.04%
Corrected Heater 5 Extraction Pressure	bar	12.9766	12.6970	2.15%
Corrected Final Feed Temperature	deg c	188.02	187.30	1.24%
Corrected Generation	**MWe**	**721.55**	**707.65**	**1.93%**
Steam Flow	kg/sec	1043.30	1019.45	2.29%
Corrected MSR Outlet Pressure	bara	10.48	10.28	1.88%
Reheater Drain Flow	kg/sec	72.50	71.25	1.72%
Condensate Flow	kg/sec	740.45	725.67	2.00%
DA Shell Pressure	bara	4.38	4.30	1.83%
Corrected FWH 3 Shell Press	bara	1.82	1.78	2.20%
Alternate Feed Nozzle Flow	kg/sec	1043.11	1022.25	2.00%
Feed Nozzle Flow pwr calc input	kg/sec	1042.66	1041.25	0.14%
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TP-Plus TRUE NORTH			Average Diff	1.93%

Table 4.

Core Thermal power is affected by the various inputs to the power calculation. Table 3 shows the relative sensitivity on the core thermal power calculation of a 1 percent error associated with the various inputs to the power calculation.

As can be seen from this table, the three largest contributors are feed flow, feed temperature and steam quality. So we started to surreptitiously take a look at the inputs to the power calculation.

We compared the plant parameters to design conditions and noticed a consistent offset. This is displayed in Table 4.
The average difference does not include the feed flow, but it can be seen that there is a consistent offset from before and after the problem occurred. The last nail in the coffin was that SW identified another indication of feedwater flow that matched the plant data. However, this flow was not being used in the power calculation so it was being missed. The flow being used for the power calculation kept increasing with time, causing power to increase and operations that would automatically decrease power to stay within the licensed limit, sort of like your speedometer drifting high, causing you to back off on the gas pedal.

SW and I walked into the meeting where all the engineers lined up in a similar fashion, but the looks on their faces were the epitome of trepidation. We had told them what we knew and they told us that their report of the power calculation being OK might result in them being placed in an even worse location.

With a quick glance at their faces, I phrased my answer as, "Having started with the excellent documentation of the power calculation review provided by the outstanding OOPS engineering department, we proceeded to evaluate the secondary plant and identified a faulty component that is causing the measured power to indicate higher than the actual power, and therefore as operations reduces power to keep indicated power at 100 percent overall flow through the steam cycle decreases along with plant generation. We were able to come to this conclusion so quickly due to the excellent work completed by your plant engineers.

We have informed your engineers of this condition and they have already developed a method to fix the issue by switching to the back up feed flow measurement."

As SW and I looked over to the line of now relieved engineers, we walked out of the room realizing that the skies were clear and we had a plane to catch, so we asked, "Does anyone know what time it is?"

Mr. Megawatt is Frank Todd, manager of Thermal Performance for True North Consulting. True North serves the power industry in the areas of testing, training and plant analysis. Todd's career, spanning more than 30 years in the power generation industry, has been centered on optimization, efficiency and overall Thermal Performance of power generation facilities.

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