Ontario's Candus Can Be More Flexible than Natural Gas-Fired Generation and Hydro Generation

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There is a widely held belief that commercial nuclear-electric plants are only capable of baseload operation when in fact they can be more flexible than a natural gas-fired generating station. This belief has led the Ontario government to restrict nuclear generation to 50 percent of total demand, in its Long-Term Energy Plan, to avoid more surplus baseload generation (SBG). It may also have provided some of the rationale for the expansion of wind/gas generation. In France nuclear meets nearly 80 percent of the electricity demand so the output of nuclear units has to be changed throughout the day to match the load on the grid, load-following. In Ontario the nuclear units operate baseload but units at Bruce B can be held at reduced output overnight when demand on the grid is low, load-cycling.

The Independent Electricity System Operator (IESO) has stated that in general coal-fired units can be dispatched down to 20 percent of full output, and combined cycle gas turbine (CCGT) units down to 70 percent even though they can operate at lower power outputs. Generating units are dispatched by the IESO, that is, sent instructions to raise or lower electrical output, at five minute intervals day and night. If units are operating below their dispatchable power range they will not be able to respond to the dispatch instruction in the time allowed. This means that a hot coal-fired unit is more flexible than a CCGT unit in meeting a variable demand on the grid. Hydro is technically very flexible but suffers from water management regulatory restrictions. New nuclear build in Ontario will be highly manoeuvrable with a dispatchable power range wider than gas or coal and could even have dispatching preference over hydro. See Appendix which describes the operation of the Ontario grid.

In order to be available to help restore the grid after a grid blackout or get back on line after a loss of load all CANDUs (except Bruce A) are capable of quickly reducing reactor power to 60 percent of full power, holding at reduced power, and then returning more slowly to full power using their adjuster rods. The unit electrical output would be held to around 6 percent full power, just enough to supply the plant's auxiliary services load, with the reactor held at around 60% full power and steam bypassed around the turbine to the condenser. Pickering A and B do not have steam bypass to the condenser but bypass steam to atmosphere. The reactors using bypass to condenser can remain at 60 percent full power indefinitely until the grid or load are re-established. In this so called "poison prevent" mode the already hot turbine can then be quickly brought up to 60 percent power to feed the grid causing the bypass valves to close and the slower return to 100 percent power output can then begin. During the 2003 August blackout in Ontario and the north-eastern U.S. some units at Bruce B and Darlington were put in this mode. For various reasons, Bruce A and Pickering A and B units are shutdown after a grid blackout.

All the Ontario CANDUs were designed for baseload operation. Darlington and Bruce B also included the capability for some load-cycling using reactor power changes, without using turbine steam bypass. They were not designed for load-following. In the past some domestic units and off-shore units did accumulate considerable good experience with load-cycling, with some deep

power reductions, but not on a continuous daily basis. For example back in the 1980s several of the Bruce B units experienced nine months of load-cycling including deep (down to 60 percent full power, or lower) and shallow reactor power reductions. Analytical studies based on results of in-reactor testing at the Chalk River Laboratories showed that the reactor fuel could withstand daily and weekly load-cycling. Since then, for various reasons, the Bruce and Darlington units have been restricted to baseload operation and are not allowed to vary reactor power for load following or for load cycling although Bruce B is allowed to reduce unit electrical output by bypassing steam that would otherwise go through the turbine. Slow reactor power changes can be made as part of normal operation. Reactor power reductions to around 60 percent of full power combined with steam bypass, poison prevent mode, is still allowed at Bruce B and Darlington for unanticipated events such as a loss of load or grid blackout. For the way that Ontario's nuclear units interact with the grid see Reference 1.

Since the steam bypass system in the present nuclear units was not designed for the frequent use necessary to alleviate SBG this system should be made more robust as part of the upcoming refurbishment of Bruce and Darlington. Such a system could then provide a degree of load following as well as load cycling, automatic generation control (AGC- see Appendix) and a dispatchable power range better than a CCGT, depending on the design of the steam bypass system. Steam bypass system design and its advantages for units undergoing refurbishment is described in Reference 2. If all the present Ontario units were refurbished to have the same, or better, steam bypass capability as Bruce B, and if many new manoeuvrable units were built, this would go a long way to reducing Ontario's dependence on precarious gas-fired generation that is subject to future gas price escalation and availability concerns - see Reference 3.

Bruce B units have frequently dropped around 300 MW overnight, using steam bypass, to alleviate periods of SBG. Reactor power is kept constant at full power, around 822 MW. The power down, and later power up, takes up to two hours using a steam bypass system that was not originally designed for this kind of use. This means each unit can provide 300 MW of dispatchable power with electrical output held at 63 percent of full power. On occasion units have dropped over 440 MW to operate at 46 percent of full electrical output. On one early 2011 November weekend, according to an IESO Generator Output and Capability Report, one of the units even reduced reactor power to 385 MW and with steam bypass brought the electrical output down to 208 MW, which is around 25 percent of full power. Under these circumstances this is better than the 70 percent dispatchable limit of the CCGTs. However, for operational reasons to reduce the risk of a unit forced outage, Bruce Power presently prefers to make one big power move, say 300 MW, rather than a series of smaller, say 80 MW, power reductions during any SBG period, which restricts dispatchability somewhat in comparison with CCGTs. SBG is exacerbated by self-scheduling wind generation and since the existing wind generation projects have priority access to the grid it means that nuclear has to be powered down or even shutdown to accommodate wind if hydro and gas generation have been already reduced to must-run power levels. Wind generation has the potential of making the grid less reliable - see Reference 4. There will be around 8,000 nameplate MW of wind on the grid by 2018, in the belief that it will reduce the greenhouse gas emissions from the gas-fired generation that is replacing coal. Significant reductions are unlikely - see Reference 5. Although it can be done, dispatching clean low cost nuclear, and hydro, to integrate wind makes no technical, environmental or economic sense.

For new CANDU build, whether ACR-1000 or EC6, up to 100 percent steam bypass combined with a reactor power that can be varied if necessary, anywhere between 100 percent and 60 percent full power, would be used to vary unit electrical output down to zero if required, at high up and down load ramping rates. This will provide dispatchable load-following, load-cycling, and AGC capability, with a dispatchable power range much greater than that of CCGTs and coal. Overnight load-cycling would be done by varying reactor power with little if any steam bypass. Although the energy in the bypassed steam is being wasted, at least at present, CANDU fuel costs are very low. Even so, operating the plant regularly at less than full power, whether by reactor power changes or by steam bypass, will reduce the capacity factor and increase the unit cost of electricity generated.

The loading rate of a CCGT unit is set by temperature transients in the thick walled components of the heat recovery steam generator and the rest of the steam side, typically for today's plants up to 5 percent full power per minute. The loading rate of a CANDU unit using steam bypass would be set by turbine metal temperatures, typically up to 10 percent full power per minute with relatively low temperature nuclear steam. This is also better than the maximum 5 percent per minute load ramping rate that the EPR and AP1000 can achieve, and this not over all of their fuel cycle. The hydro stations are extremely flexible and can load at high ramp rates when available. However there can be restrictions on the operation of stored water hydro units due to water management regulations, environmental concerns, and from public safety concerns around the dams because of sudden variations in water levels. All this could reduce the flexibility of some of the hydro generation to respond to dispatches at high ramp rates, so in some circumstances dispatching nuclear units using steam bypass could be a much better option for the grid operator.

France provides a precedent for load-following and load-cycling in Ontario. France has been producing nearly 80 percent of its electricity from its nuclear fleet for many years with the balance coming from hydro and fossil fuels in about equal amounts. France has 58 pressurized light water reactor units on line so the national grid controller can select units that have been recently refueled and have high reserve reactivity so have the flexibility to provide dispatchable load-following, load-cycling, and AGC. Power is varied by so called "grey" control rods and boron use is minimized. Steam bypass is not used for these operations. When units are around 65 percent through their 18 to 24 month fuel cycle they play a diminishing part in load-following and when 90 percent through their fuel cycle they are restricted to baseload operation. CANDU flexibility is not affected by fuel burn-up limitations since it is refueled on-line.

Nuclear is not a one trick pony.

Appendix - How the Ontario power grid works

As of mid 2011 the Ontario grid consisted of 11,446 MW of nuclear with 1,500 MW more refurbished generation to come on line in 2012, 4,484 MW of coal-fired generation, 9,549 MW of gas and oil-fired generation mostly combined cycle gas turbine (CCGT) but includes the rarely used 2,140 MW oil/gas-fired Lennox thermal units, 7,947 MW of hydro-electric base,

intermediate and peak generation, and 1,334 nameplate MW of wind generation. The grid consists of many generating stations located throughout the province feeding consumers through a network of high voltage transmission lines, transformers, switchgear, and low voltage distribution lines to major consumers including local utilities. Electricity cannot be stored in large amounts so generation and demand has to be kept in balance at all times. If demand exceeds supply all the generators on the grid slow down and the normal grid frequency of 60 Hertz (reversals per second of alternating current) will drop. All electric motors working off the grid would similarly slow down. If supply exceeds demand the frequency will increase. It is the job of the Independent Electricity System Operator (IESO) to ensure that these frequency swings keep within very tight tolerances. It does this by dispatching hydro, coal and CCGT (hardly any simple cycle gas generation) at five minute intervals, not necessarily the same generator, to move power up or down. In the morning the power moves would generally be in an upward direction and in the evening in a downward direction but there can also be small reversals in the general trend. This is called load-following (load-cycling refers to powering down units overnight when demand is low). This brings the grid into a rough balance. In order to bring the frequency into its narrow operating band around 60 Hertz the IESO automatically controls the output of a very small number of selected generators that have the capability to continuously and rapidly vary their output over a seconds to minutes time scale. These are some hydro units at Niagara Falls and, in the past, some coal-fired units. This is called Automatic Generation Control (AGC).

The second to minutes supply/demand variations on the grid, including the erratic fluctuations of wind, are smoothed out by the rotational kinetic energy of the many generators on the grid, by the hydro and fossil turbine-generators on the grid changing their output by normal speed governor action over a limited range (called primary frequency control), and by AGC (called secondary frequency control, normally automatic but can also be done manually). Primary control limits the frequency deviation caused by changes in supply and demand, and secondary control restores the frequency to normal by removing the frequency deviation, or offset, by changing the setpoint of the speed governor of the generating unit(s) on AGC. Nuclear units presently do not take part in frequency control. The current AGC regulation service requirement from the IESO is for at least plus or minus 100 megawatts at a ramp rate of 50 megawatts per minute but this may be changed to allow other generators to supply this service. The designated unit(s) that is on AGC service is kept in its desired operating range by dispatching hydro, coal and combined cycle gas generation at five minute intervals. This dispatching allows for the normal daily demand changes (load-following), including the intermittency of wind. Since valuable hydro is fully committed, gas or coal generation is used to cater for wind intermittency. As well as frequency, voltage levels at points on the grid also have to be maintained but that will not be discussed here.

References and Links– Next Page

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