Compensating for Renewables: SMR Capability for Load Following

SMR NUCLEAR TECHNOLOGY

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Nuclear power plants and the electricity grid system

Nuclear power plants (NPPs) have traditionally provided baseload power. This is because their output is not weather dependent, the fuel cost is relatively low and there was no requirement for load following. Nuclear and coal continue to provide most of the baseload in electricity power systems; some coal, hydro and gas turbines also provide intermediate, load balancing and peaking capacity.

For countries with a high proportion of nuclear power, particularly France, NPPs have always had to have the capability to reduce their output. For a reactor which shuts down to refuel, the load following ability is related to the time since the last refuelling. After refuelling, the ability of the reactor to change load is at its highest, decreasing particularly near the end of the cycle when the fuel has been 'burnt-up' and the excess reactivity required for a quick load change is at its lowest level. In France, the refuelling of reactors is scheduled so that sufficient reactors are available for load following.

With nuclear power, there will always be some trade-off between maintaining flexible operation and optimizing fuel cycle economics. To maximise the fuel use, some knowledge about how the plant will operate is required before the core is designed and the reactor refuelled.

With the increase of weather-dependent renewable energy sources, e.g. wind and solar, connected to electricity grid systems, the increasing expectation is that power plants of all types on a system should be able to compensate for the variations in output from renewables (although who should pay for this service is a matter of ongoing debate).

There are several ways in which modern nuclear power plants can work with renewables:

- Adjusting the reactor output to meet the load requirement (typically reactors can be adjusted to produce an output of between 20% and 100% of their rated output):

- Maintaining the reactor power and dumping some of the steam directly to the turbine condenser, bypassing the turbine (this enables a quick drop in power output, followed by an adjustment to the reactor output);
- Maintaining the reactor power and using some of the steam or electricity for desalination;
- Maintaining the reactor power and using some of the electricity for a pumped storage hydroelectric facility;
- Maintaining the reactor power and storing surplus heat in molten salt or graphite for electricity production at peak times; and
- Maintaining the reactor power and using some of the electricity to charge MW capacity batteries for electricity production at peak times.

For any electricity supply system that includes generation from variable output renewable energy technologies, the operating flexibility required from other generation plants to compensate comes at a cost. Each of the above options has its own engineering and cost implications over and above steady state operations.

Modern SMRs are designed particularly to incorporate load following capabilities. The smaller size of the reactor enables more flexible operation. Also a multi-module SMR power plant can schedule module refuelling times so that output and load following capability is always available.

Examples of SMRs with Load Following Capabilities

Westinghouse (USA)

The Westinghouse SMR reactor is an integral PWR (Pressurised Water Reactor) with a rated net output of greater than 225 MWe. The normal power range is 20 – 100% of full power. There are two operating regimes:

- **Daily load follow at 5%/min**
  The power is ramped down to as low as 20% and remains at the reduced power for some fixed amount of time (typically 2 to 12 hours) and then ramps back to full power. Such manoeuvres are assumed to occur once per day to address reduced power demands and can occur every day for up to approximately 90% of the operating cycle length. Power changes are achieved using banks of grey (low worth) control rods.

- **Continuous load follow of +/- 10% at 2%/min**
  This regime provides frequency control to the grid system by adjusting power typically between 90-100% of rated full power to follow variations in grid demand.

As is usual for PWRs, soluble boron is used to compensate for fuel burnup. As fuel is used, the reactivity reduces and the amount of soluble boron in the primary cooling system is reduced to restore the reactivity to the required level. Use of grey control rods for load following reduces the frequency of soluble boron changes to approximately once per week.

NuScale (USA)

The NuScale SMR module is an integral PWR connected to a conventional steam turbine generator with an output of 50 MWe. Up to 12 modules can be accommodated in one power plant to provide a gross output of 600 MWe (net output 570 MWe). Each reactor module is connected to its own steam turbine generator.

The NuScale plant is specifically designed to accommodate load changes in three ways:

- For a 12 x 50 MW module plant, taking one module offline reduces the output by 8%. A module can be returned to service in a few hours from a hot shutdown.
- Each module is able to independently vary its output by 40%/hour. A 12 module plant has 12 independent degrees of freedom by modulating the output of each module.
- Each module has a 100% turbine bypass. The module can be maintained at full power and all the steam dumped to the condenser enabling a fast load change.

The Utah Associated Municipal Power Systems (UAMPS) are working with NuScale for the deployment of the first NuScale plant within the UAMPS area, possibly on the Idaho National Laboratory reservation. The 57 MWe Horse Butte wind farm is in this area, and an analysis has been carried out of the integration of a NuScale plant with this windfarm, using actual wind farm generation data [1}.

B&W mPower (USA)

The mPower SMR module is an integral pressurised water reactor (PWR) connected to a conventional steam turbine generator with an output of 180 MWe.

The power plant is offered as a two module 360 MWe output twin pack. The 100% bypass from the steam turbine inlet to the turbine condenser enables immediate load following by dumping steam directly to the condenser, thus reducing the electrical output quickly. The reactor power can then be adjusted at 10%/min over a range of 20-100% power levels to enable the reactor output to match the demand. Unlike many other PWRs, the mPower reactor has a control rod in every fuel assembly which enables quick and flexible reactor power control.

The SMRs being developed now are specifically designed to accommodate working with the variable output from renewables. We consider them very suitable for deployment in the evolving Australian grid system.

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Reference

[1] D.T.Ingersoll, C.Colbert, Z.Houghton, R.Snuggerud, J.W.Gaston and M.Empey, "*Can Nuclear Power and Renewables be Friends?*", Proceedings of ICAPP 2015, May 03-06, 2015, paper 15555