Notes on Wind Energy

How do wind turbines generate electricity?

A wind turbine works the opposite of a fan. Instead of using electricity to make wind like a fan, wind turbines use wind to make electricity.

“Wind turns the blades of a rotor (between 10 and 25 turns per minute), a source of mechanical energy. The rotor then turns a generator which transforms the mechanical energy into electricity. An electric motor orientates the nacelle so that its rotor is positioned facing into the wind. Each turbine is made up of a mast of between 20 and 100 m according to the power of the machines. The mast supports the rotor, usually equipped with three blades, and the nacelle which contains the generator and electrical and mechanical back-up.

The power of modern turbines is over 3 MW on land [typically 2-3 megawatts or MW in Australia]. Wind turbines are designed for wind speeds of between 14 and 90 km/h. Above that, a braking mechanism automatically stops the turbine for the safety of the equipment and to minimise wear and tear. Modern wind turbines supply their nominal power at around 50 km/h.”


Falling Price and Increased Capacity of Wind Generation Equipment

The price of wind energy (and large scale solar) has steadily fallen in recent years. As of May 2017, the lowest long term price for a Power Purchase Agreement (PPA) for wind energy in Australia was for less than $60 per MWh (6 cents per kWh). This graph copied from Origin Energy indicates the rapid fall in PPA prices for large scale wind and solar.

Because of the significant fall in the long-term cost of energy from wind farms, the rate of installing wind farms in Australia has increased significantly in recent years. The Clean Energy Council’s “Clean Energy Australia Report 2015” reported that “the contribution of both wind and solar power grew by just over 20 per cent in 2015” and “over 8000 MW of wind energy and 2500 MW of solar power projects are under construction or have planning approval”.

Challenges of wind energy

The challenges of integrating wind into the National Electricity Market were underlined in the “system black” event that occurred in South Australia on 28 Sept 2016. No electricity could be supplied via the National Electricity Market (NEM) network to customers in South Australia. It should be noted that supply was maintained to all towns in the far north and west of the state supplied by small isolated grids.
The system black was triggered by the loss of three transmission lines (blown over by several different tornadoes) that resulted in all generators in SA and the Interconnectors between SA and the eastern states, being taken off line. The two most significant causes of the system black were the destruction of significant numbers of pylons on various transmission lines plus inconsistent and conservative protection setting on the wind farms that resulted in low resilience to faults before they tripped off the NEM grid. In their analysis of the system black event the Australian Energy Market Operator (AEMO) noted the need for Regulators and electricity market players to meet the technical challenges of transiting to a mix of generators with reduced inertia and lower passive resilience to faults.

The Australian Energy Market Commission (AEMC) has made similar comments noting the NEM has been weakened by the rapid take-up of wind and solar generation and the retirement of conventional gas and coal fired generators.

Difference between Synchronous and Non-synchronous Generators

Typically wind and solar are termed non-synchronous generators while conventional gas and coal fired generators are termed synchronous. The synchronous gas fired generators (SA no longer has any coal fired generators) are able to support a critical element of the electricity supply known as frequency (nominally 50 cycles per sec or 50 Hz). When a fault occurs because synchronous generators have inherent inertia in the turbine and generator that keeps them spinning at the required speed for a few seconds. During these few seconds auto protection systems in the distribution network can then turn off sufficient customers so output from the remaining generators still generating post the fault; matches the remaining load on the grid.

Non-synchronous generators such as wind and solar PV generators follow the frequency of the grid they are supplying. If there is a fault and the frequency falls, they simply follow the fall rather than attempting to maintain the frequency at the required 50 Hz. This results in the system having less time to recover from sudden equipment failure before various protection systems trip both generators and loads off to protect them from under frequency that can cause serious damage.

Mechanisms to support Grid Frequency

Under normal circumstances the interconnectors between SA and Victoria support frequency following a major fault. Because Victoria (and NSW) still predominantly have synchronous coal fired generators, they can provide inertia and hence frequency support. Back in Sept 2016, however, the interconnectors also tripped off due to over current (they became overloaded trying to pick up the lost generation capacity in SA) and hence were not able to support the SA grid frequency.

It is possible to design wind turbines so that they provide what has been termed “synthetic inertia” and act like synchronous generators, ie utilise the inertia in their spinning blades to support the grid frequency post a major fault. Most wind turbines installed in Australia are however not designed to operate this way. Governments and Regulators are actively considering whether future wind turbines will be required to provide frequency support. See further discussion below.

In the interim the AEMC is proposing to require each state's transmission network operators to provide and maintain a defined level of inertia at all times. In states with low inertia, such as South Australia, the transmission companies may need to install new equipment to meet these minimum
inertia levels. Services to provide this inertia could include large-scale, grid connected batteries capable of providing fast frequency support response.

Peter Farley in ReNew Economy, 12 May 2017, argued that “while the inertia of turbines [coal or gas fired] is large, it is only useful as a store of energy if you can use it. Most of the energy stored in a rotating turbo-generator is unavailable because …. even if a 1Hz short term deviation [ie drop in rotational speed of 2%] is allowed it is still only 4% of the system inertia”. More inertia than this is available in the spinning turbine and generator but only this tiny amount can be extracted because the overall grid cannot tolerate more than about a 2% drop in rotational speed. Farley says “given that only 4% maximum is available as inertia services it means that a 250MW generator can compensate about…… 6 MW for 5 seconds. A 10MW battery system can provide 10MW for 40-200 minutes”. A large battery system has a greater capacity to support the grid after a major fault, for a much longer period than one 250 MW turbine.

As with gas fired steam turbines, wind turbines, with additional electronic controls, can give up the inertia in their spinning blades to support the frequency of the grid. Farley says that “a key advantage of modern wind (and hydro) turbines is that they can be variable speed machines so they can give up perhaps 10% of their mechanical rotational energy while still maintaining electrical frequency”. Because wind turbines feed power to the grid via an electronic controller known as an inverter, they can reduce their rotational speed (as the kinetic energy is given up to support the grid) while maintaining their output at the required frequency (50 Hz).