WIND FARMING AND THE AUSTRALIAN ELECTRICITY SYSTEM

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This document is a detailed briefing paper discussing how wind energy integrates with the Australian Electricity System. This paper was prepared as background information for the preparation of a fact sheet for dissemination to the general public. As a result this document, any related documents (listed below) and the fact sheet itself attempts to be as non-technical as possible and sometimes goes to great pains to explain what may appear to be quite obvious to someone intimately involved in either wind energy or the operation and planning of the electricity industry.

However, as is often the case, such attempts may unintentionally oversimplify the issue or present information in a distorted way. We may also have made errors or omissions in the preparation of this document. Please do not hesitate to forward any suggested changes or additions to this document to Grant Flynn at Sustainable Energy Australia (Grant@SustainableEnergyAustralia.com.au).

Where possible footnotes have been provided within the text to allow the reader to consult the source article directly.

This document should be read in conjunction with the following sub-documents;

- Glossary of Australian Wind Energy Terms (19 Pages)
- The Australian Coal Industry and Coal Fired Electricity Generation (32 pages)
- Steam Turbine Engines (36 pages)
- Gas Turbine Engines (20 pages)
- Electricity Supply System (16 pages)
- Photo Voltaic Cells (7 pages)
- Electrical Transformers and Electrical Energy Storage (17 pages)

This document has also been distilled into a very brief fact sheet of just 2 pages which will be able to be downloaded from the AusWEA: Australian Wind Energy Association web site at www.auswea.com.au.

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SOURCES OF INFORMATION

- Wind Energy Conversion Systems
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SUMMARY

How the Australian Electricity System Works

The electricity system on the eastern seaboard of Australia is operated as a single interconnected system called the National Electricity Market (NEM) and supplies the bulk of Australia's population. Electricity supply to the Northern Territory and Western Australia is achieved through the operation of a number of small, remote grids - apart from the South West Interconnect System (SWIS) supplying the south west tip of Western Australia including Perth.

The NEM is a complex system but essentially consists of generator operators, transmission system providers, distribution system providers and retailers. Transmission and distribution relate to the transport of the electricity through power lines across the network; the transmission network being very high voltage and long distance transport between terminal stations and the distribution network being the lower voltage power lines that distribute the power from the terminal stations down to the customers' premises. The generator operators generate the electricity and the retailers negotiate the supply of electricity from the generator operators, through the transmission and distribution networks to their customers' premises.

The whole system is managed by the system operator - the National Electricity Market Management Company (NEMMCO). NEMMCO is responsible for ensuring the system is stable secure and operated as cost-effectively as possible. NEMMCO manages the supply of electricity through a cycle of bidding and dispatch that repeats every half hour. NEMMCO receives bids from generators as to what volume of electricity they can provide and at what price they will charge for it. The bids are then arranged in a stack with the cheapest at the bottom and most expensive at the top. NEMMCO will then dispatch the electricity generation from the bottom of the stack until the demand for electricity has been satisfied. The highest price dispatched is the price for all the electricity in the half hour.

NEMMCO has a sophisticated monitoring system that allows it to track the level of demand for electricity, the generators supplying the demand and the transmission and distribution networks transporting the electricity. As you might imagine the level of demand for electricity fluctuates all the time but with the assistance of the monitoring system, a lot of experience and the assistance of the market participants they can generally respond to very dramatic changes in supply and demand.

This control of the system is achieved in numerous ways (called ancillary services) of which the two important ones are reserve capacity and frequency control ancillary services (FCAS). NEMMCO maintains a level of reserve capacity (about 5% of system total capacity) to ensure that the system stability can be maintained even if a major generator fails in a period of extreme load (usually a series of very hot, summer days). NEMMCO also manages FCAS (also called *load-following* or *spinning reserve*) to respond to the second-by-second variations in demand for electricity.

The amount of generation required for reserve capacity and FCAS are determined through calculations based on a trade off between system reliability and cost effectiveness. It would be unacceptable to the community to have repeated power failures so we maintain capacity to be held in reserve and for FCAS. However, it would be far to costly to have complete redundancy, even though this would provide excellent reliability. Hence there is a trade-off between system reliability and cost.

NEMMCO also provides forecasts to the market so that participants can make preparations to increase or reduce the supply and demand of electricity so as to maintain overall system stability. These forecasts range out to a few minutes to hours and even out as far as ten years ahead.

The forecasts covering a couple of hours are called pre-dispatch forecasts and help generators make reasonable bids for electricity based on expectations of demand and availability of other generators on the system. Beyond this, NEMMCO issues Projected Assessments of System Adequacy (PASA), which try to assist in the management and scheduling of maintenance and so on. The PASA are prepared in various time frames. Finally there is the Statement of Opportunities (SOO) which looks 10 years ahead and is aimed at providing information to participants in regard to the need for capital investment – i.e. new generators, transmission lines, interconnectors, etc.

It is important to point out that electricity does not flow like the post or e-mail, in that it does not have addresses on each electron telling it which customer to go to. The physical movement of electricity will be quite different to the financial transactions with which it is associated. Electricity will take the path of least resistance and be consumed by the nearest load, even though the financial transaction may indicate the electricity was sold to someone in another state altogether.

The easiest way to visualize the system is to imagine that all the electricity that is generated flows into a pool (hence the name used in the NEM). Your retailer buys electricity from the pool in sufficient quantities to meet the demand of all its customers and the losses associated with the transmission and distribution of that electricity. When a retailer purchases electricity off-market to meet a specific need of its customers (e.g. to meet a demand for GreenPower™) it will simply ensure that the generator puts enough of the right type of electricity into the pool to meet the amount of electricity it takes out of the pool. This is why we do not need to re-wire our homes when we change retailer or purchase specific electricity products like GreenPower™.

Currently our electricity system is dominated by a centralized system of very large, thermal power stations with a network of power lines radiating out from the power stations to each customer. These power lines incur losses which can be quite significant (over 10%) especially when the customer is a long way from the generator. A distributed generator is one which is located within the network and away from the central hub of generators. Distributed generation has the advantage that it generates electricity where it is consumed and so can dramatically reduce the losses associated with transport of the electricity.

In the centralised system the location of the central generator hub has been determined by the location of the fuel source – large reserves of cheap brown and black coal - and most Australian electricity generators are mouth-of-mine, coal-fired steam driven turbine generators.

How Does Wind Farming Interact with the Australian Electricity System

Not all generators sell their electricity through the market explained above. It is not uncommon for a generator and retailer to enter into a contractual arrangement for the supply of electricity according to a fixed price schedule over extended periods of time. Such trading of electricity is called "off-market" trading. However NEMMCO needs to know about it so that it can manage the flow of electricity through the system. The most effective way of doing this is via "the pool" (i.e. dispatch system).

The off-market trades are simply bid into the pool at zero dollars which ensures that they are located at the bottom of the stack and are guaranteed to be dispatched by NEMMCO. Generators that bid in this way are called "price-takers" because they will essentially take whatever price is set by the pool (their price has already been set in the contract with the retailer so they don't care about pool price).

To date all the wind farms in Australia have relied on the financial security provided by a long-term, off-market contract with one or more retailers. Consequently they operate as price-takers and their entire output is sold directly into the grid to which they are connected (not all of them are on the NEM or SWIS).

Wind farms are located - just like coal-fired power stations - according to the availability of their fuel resource (i.e. the wind). Consequently they appear as distributed generators in our coal dominated system. This means wind farms have the advantage of reducing transport losses of the system. However, it also imposes a problem on the wind farm developer; how to connect to the grid. It is often very expensive to inject large quantities of power into the edges of the system.

All the wind farms built in Australia so far can also be classified as “embedded generators”. An embedded generator is one which the output is sold only into the distribution system in which it is connected and does not travel out through the transmission system. Essentially it means that the output of the generator is “small enough”, relative to the local demand, to be consumed by that local demand for electricity. It is important to remember here that some of our “local” distribution systems can be quite large and cover hundreds of thousands square kilometres and service tens of thousands of customers.

To reduce the relative cost of the projects, some of the wind farms proposed for construction over the next couple of years are quite large and because of this will need to be connected directly into the transmission system. These wind farms will operate like traditional generators in our system.

Does Wind Energy Really Displace Coal Fired Generation?

Wind farms operate as price-takers in the NEM pool and so are located on the bottom of the dispatch stack. Their inclusion at the bottom of the stack will mean that more generation at the top of the stack - so called “marginal generation” - will not be dispatched by NEMMCO. So wind energy will displace the marginal generator, but which is the marginal generator?

The marginal generator changes according to the time of day, day of the week and even the season and is also different within each of the interconnected jurisdictions of the NEM. The output of a wind farm will also change, according to how the wind blows at each particular time of day, day of the week and season. So determining exactly which generator will be displace by wind energy at any given time and by how much requires relatively complex predictive models. However we can make a few assumptions and get a good estimate of the marginal generator’s identity.

Firstly we know that hydro electric generators that are run-of-river or on-irrigate systems will also operate as price takers and will not be marginalised. Furthermore, large hydro schemes such as the Snowy Mountain Hydro are unlikely to be affected (or at worst, the timing of their generation will be shifted). The remaining 90% of Australian electricity generation comes from fossil fuels and of this about 90% is derived from coal fired generators. So, all things being equal, a coal fired power station has the greatest chance of being the marginal generator and being displaced.

For Pacific Hydro’s Portland Wind Energy Project the Environment Effects Statement actually included the complex calculations required to assess the marginal generators to be displaced and took into account the expected change in generation technologies over the 20+ year life of the project. At the start of operation the marginal generator would be brown coal 80% of the time, black coal 19% and gas 1% of the time. Based on an expectation of increased interconnection between states and changes in fuel usage by 2010 it changes to; brown coal 50% of the time, black coal 40% and gas 10% - still 90% coal fired and still 100% fossil fuels.

Do Wind Farms Need Backup from Coal Fired Generators?

There is a common misconception that a coal fired generator needs to be burning away on standby, just in case the wind stops blowing. This is not true. If it were true then, taking this argument to its logical conclusion, we would have a back up coal fired generator for every generator on the system, even for the coal fired generators, just in case they failed too! Conversely there is also a misconception that because wind energy capacity is so small compared to the total system size that their output will be largely invisible to the system and therefore cost free. This is not true either.

As discussed above NEMMCO operate a level of reserve capacity (about 5% of total system capacity) just in case there is an unexpected failure of a large power station in a time of extreme load. They also operate FCAS capacity to match the supply to the constantly varying level of load.

While wind energy can account for a significant level of the supply to specific distribution areas (e.g. Albany wind farm supplies up to 70% of Albany's demand) it still accounts for a very small amount of Australia's total system supply capacity (about 0.3%). Consequently wind energy has no direct impact on the level of capacity reserve required by NEMMCO and the fluctuations of a wind plant in output are covered solely by the FCAS capacity.

The level of FCAS capacity held on standby is determined through experience of demand (load predictions) and the expectation of overall system reliability. Different generators make different contributions to system reliability according to their technology. In planning the levels of FCAS reserve to have ready, there are several ways to look at the effective capacity of generation plant. In regulated markets, the term "capacity credit" is often used to describe the level of contribution to system capacity that a generator makes. Capacity credit estimates of wind power plants help generating companies, utility planners, and other decision-makers evaluate this intermittent resource in the context of other types of power plants.

Most studies of actual wind projects show that the planning capacity credit for wind is in the order of 20% to 40% and closely correlated to the capacity factor of the wind farm[i]. This makes some sense as the capacity factor of a generator driven by the wind is most significantly determined by the wind regime (because their reliability and availabilities are so high). The more often the wind is available the higher the capacity factor and so the higher the capacity credit.

Some Technical Terms Explained

Watts and Watt-hours

Energy is measured in Joules. The rate of delivery of energy, or power, is measured in Watts (or Joules per second). Because we use a lot of energy and also to make calculations a bit easier for us all, the electricity industry uses the term watt-hour for energy. A watt-hour is equivalent to the amount of energy delivered in one hour at the rate of one Watt. It is equivalent to 3,600 Joules (1 J x 3600 secs in 60 minutes).

We also use prefixes to reduce the number of zeros we need to write down. A kilowatt-hour (kWh) is a thousand watt-hours just like a kilometre (km) is a thousand metres. A megawatt (MW) is a million watts, like a megalitre (ML) is a million litres.

CAPACITY

The capacity of a generator is the maximum power it can deliver under normal conditions and is measured in Watts or for large electricity generators in MW. The terms “nameplate capacity” and “rated capacity” are sometimes used and are interchangeable. Installed capacity refers to the total output of a number of generators. For example Loy Yang power station has four generators, each with a capacity of 500 MW to give it an installed capacity of 2,000 MW.

CAPACITY FACTOR

Capacity factor is a measure (usually expressed as a percentage) of the output of the actual generator compared to the output of a perfect generator of the same capacity - i.e. one that is able to operate at full capacity all of the time.

$$CapacityFactor = \frac{ActualEnergyOutput(Wh)}{RatedPowerCapacity(W) \times Time(h)}$$

Measuring a power station’s capacity factor takes into account all the losses and other factors that affect the total output of the power station. Things that will affect the power station’s capacity factor include;

- Fuel availability (wind in the case of a wind farm)
- Generator reliability and availability
- Grid reliability and availability
- Electrical losses between generator and the “front gate” (e.g. transformer losses)

EFFICIENCY

Efficiency is a measure of the ability of a system to convert an input to an output. It is simply the quotient of the output of the system and the input of the system;

$$Efficiency = \frac{Output}{Input}$$

It is usually expressed as a percentage or as a co-efficient (i.e. a fraction) and is sometimes called the coefficient of power (C_p) or coefficient of energy (C_e).

In complex systems such as electricity generators it is important that comparisons of efficiency are made of the same level of conversion and of relevant conversions. For example it is wrong to compare the boiler efficiency (energy in coal to energy in steam) of one generator against the generator efficiency (steam to electricity) of another; nor would it be correct to compare the fuel efficiency (litres of fuel per kilometre) of a petrol driven car to that of an electric car that uses no petrol!

RELIABILITY

Reliability is a measure of how long a period of time occurs between failures of the machine and/or how long those failures last. In the former case it is a measure of time (i.e. days, weeks, months or years between failures) but in the later it is expressed as the percentage of the time that the machine is not able to operate because of an unscheduled requirement for maintenance or failure.

AVAILABILITY

Availability describes how much of the time the generator is available to operate. It is generally expressed as a percentage of the year. This does not mean it actually operates, simply that it is ready to operate. Availability takes into account the reliability of a machine as well as how long it is shut down for servicing. In other words it takes into account its scheduled as well as its unscheduled maintenance. For example a machine may have

100% reliability (i.e. it never fails) but have a low availability because service crews are always performing scheduled maintenance.

UTILISATION

Utilisation is a measure of how often the machine operates and is expressed either in hours or as a percentage of the measurement period (e.g. a year). A generator is deemed to be being utilised regardless of the capacity at which it operates – i.e. even if it is only outputting just 0.1% of its rated capacity it is still considered as being utilised.

How Do Wind Farms Compare With Other Generation Technologies

Modern utility scale wind turbine generators are constructed using very high quality materials and are designed for very low maintenance regimes. As a consequence they have very high reliabilities (usually in excess of 99%) and all the major components of a wind turbine generator (blades, drive shafts, generators, etc) are guaranteed for the life of the machine – generally 20 years or more.

Wind turbine generators also have very high availabilities (usually in excess of 95%). Like all large complex machines there are often more problems in the first few months of operation as the machines "bed-in" and availability may be a bit lower (94 to 96%). Once this initial period has past the availability will generally exceed 97% and most of the better manufacturers will provide commercial guarantees of at least this level of availability for the life of the machine.

The very high reliabilities and availabilities of wind turbine generators means that the utilisation of the wind turbine will depend upon the wind regime in which it is located and the way it interacts with the electricity system. In Australia all wind farms currently operate as "price-takers" and their output is utilised whenever the generator is available to operate. So for Australian wind generators their utilisation is essentially determined by the wind regime in which they are located.

A wind generator will not operate in very low wind speeds (less than 10 km/h) or very high wind speeds (more than 90 to 100 km/h). Developers generally locate wind farms in very good wind regimes with strong and consistent winds rarely outside this range - the very low electricity prices in Australia drive them to this. Consequently utilisation rates are generally in excess of 95% and closely match availability rates (e.g. Codrington Wind Farm has a utilisation factor of over 97%).

How does this compare to other generation technologies? There are many generator technologies in use in the Australian electricity system and the generators are used in a variety of ways. However some basic figures will provide some indication of their operation.

The bulk of our electricity generators are steam-driven, turbine generators supplied with steam derived from black or brown coal-fired boilers or gas-fired boilers. There are of course quite a few generators that are driven by hydraulic (water) turbines and a small number of generators that are driven by either open cycle or combined cycle gas turbines.

All of these machines tend to have very high reliabilities, usually well in excess of 90%. Hydro electric systems tend to have the highest reliabilities at or above 99% whereas coal is a little lower at 96% to 97%[ii]. Gas turbines can be quite variable - according to the type of fuel they use.

The availability of power stations varies considerably. While black coal-fired power stations tend to have availabilities in the order of 90% to 92% brown coal-fired power stations can be as low as 80% to 85%. The main problem with brown coal is that, because of the type of boiler used and fuel quality differences, boilers need more scheduled maintenance time for ash and slag cleaning, etc. The availability of hydro generation can also be quite variable but typically ranges between 80% and 90%[iii].

With very large power stations (especially those operated as base load stations) the availability levels can vary quite dramatically from year to year. For example the table below shows the reasons for loss of availability (LOA) of Victoria's coal fired power stations. As can be seen some of the outages occur only after a few years operation so long term averages need to be used.

Description	Typical frequency	Typical duration	Typical LOA	Content of outage
Major outages (Full inspection)	Every 4 years	4-8 weeks	2-4 %	Planned major repairs
Minor outages	Yearly or six monthly	3-5 days	1%	Critical planned inspections and repairs
Boiler clean(This type of outage is required only by brown coal boilers)	Determined by fouling in boiler- 3-6 months	2 days	1%	Heat transfer surfaces cleaned. Inspections may be possible in some areas. Always happens at beginning of minor and major outages.
Forced outage	Random event	2-3 days	2-8%	Repair the failure and inspect other equipment at immediate risk
		TOTAL	**6-14%**	

The utilisation of traditional generators will depend upon how they operate within the electricity system. Plant that are operated so as to supply the base load demand will generally have their utilisation limited only by their availability (85% to 95%) and will typically operate at full rated capacity at all times. Consequently their capacity factor will be very high (close to availability).

However many plants are only operated during periods of intermediate load demand or only when the load demand reaches peak levels. Consequently their utilisation will be much lower (in some cases less than 10%). While the cost of operating peaking plant is very high (because they operate so little of the time) the pool price of electricity during peak demand periods is very high allowing recovery of their costs.

It is a common misconception that wind turbines are inefficient in converting the energy of the wind into electricity. This is not true. There is a theoretical limit to how much energy can be taken from the wind and it is about 59%. Basically a turbine extracts momentum from a moving fluid stream. If any more momentum was extracted, the fluid would slow down so much the turbine rotor could not keep turning.

Currently, the maximum efficiency (or Power coefficient - C_p) obtainable with a modern, large-scale, wind turbine generator is roughly 47%[iv]. Blade design is very important factor affecting C_p and there can be significant variations between different machines allowing for optimisation for different wind regimes. Before a wind farm is constructed there is a lot of modelling undertaken to determine which machine best suits the wind regime at a proposed wind farm site.

It is important to remember that a wind turbine generator does not always operate at this peak efficiency – nor would we want it too! The energy in the wind is proportional to the cube of the wind speed - as wind speed increases slightly the amount of energy available in that wind increases dramatically. As the energy in the wind exceeds our ability to convert it to electricity (i.e. as it exceeds the capacity of the electrical generator) we purposely "spill" energy from the rotor blades. We achieve this "spilling" by reducing the efficiency of the rotor blades so that the amount of energy it captures matches the capacity of the electrical generator.

A wind turbine generator with a rated capacity of 1.5 MW typically has rotor diameter of 64 metres. At wind speeds of 30 ms^{-1} the rotor is receiving energy at the rate of about 213 MW and we clearly do not want the turbine to still be 45% efficient. Otherwise we would have to have a generator capable of generating 96MW just for the rare occasions (typically only 8 hours or less a year) that the wind blows at these extreme speeds.

The situation for more traditional forms of generation is quite different. In a coal or gas-fired generator, or in a storage hydro-electric system, the delivery of the “fuel” can be carefully regulated and the machine is able to be operated at its maximum efficiency. This is not always true for gas turbines (whether operated in an open or closed cycle) or diesel generators. For these machines the efficiency is maximized at close to rated capacity and the efficiency drops off dramatically (especially for gas turbines) at power levels below about 90% of rated capacity. A wind turbine, by its nature has to deal with a fluctuating fuel source.

With the above in mind, and remembering to compare the ratio of energy out to the energy in over the entire system, we can look at the peak efficiencies of different generating technologies.

For Australian black coal-fired generators (mainly in NSW and QLD) the overall system efficiency ranges between 32% and 38% with most around the 35% level (e.g. Tarong at 35% and Stanwell at 35.6%[v]). For brown coal-fired power stations the efficiency is about 26%[vi]. The lower efficiency for brown coal fired stations is mainly because the coal has moisture contents in excess of 60% compared to the 12% moisture in the black coals of NSW and Qld.

An open-cycle gas turbine will have a plant efficiency of about 25% to 35% depending upon the compressor and turbine efficiencies. However modern combined cycle gas turbines (CCGT) can have efficiencies approaching 45%[vii]. This however does not take into account the energy spent extracting, refining, transporting and storing the gas before it is burnt. It is worth noting here that Combined Heat and Power (CHP) systems – where low grade heat is also used as an output - can have overall thermal efficiencies in the order of 90%.

Photovoltaic cells can have peak efficiencies approaching 37% when used in conjunction with concentrators and sun tracking equipment[viii]. Photosynthesis, the process by which plants convert sunshine to the chemical energy of their biomass, has a theoretical maximum of 26% but even in high yield crops like sugar cane it is as low as 2.6% and much lower in food crops like wheat and barley[ix].

So the system efficiency of wind turbine generators is not that different to other generation technologies. Perhaps the key difference to fossil fuels like coal, gas and petroleum products is that the “fuel” being used (i.e. the wind) is renewable, free and has no noxious gaseous emissions.

There is also a perception that the rated capacity of wind is too small to be of any consequence. Typically electricity generators tend to have rated capacities of

- Coal or gas fired steam Turbines - hundreds of mega watts (up to thousands)
- Gas Turbines – tens of megawatts (up to hundreds)
- Large Hydro Turbines – tens of megawatts up to thousands
- Large Wind – tens of megawatts (up to hundreds of megawatts)
- Mini Hydro Turbines – hundreds of kilowatts (up to a few megawatts)
- Mini Wind – tens of kilowatts (up to a megawatt)
- Biomass – tens of kilowatts (up to tens of mega watts)
- Solar Thermal - tens of kilowatts (up to tens of mega watts)
- Photovoltaic – hundreds of watts (up to tens of kilowatts)

The rated capacity of a generation facility is of little consequence except in terms of the ability of the plant to take advantage of economies of scale. Having a single large plant can help reduce the capital costs associated with the construction of the plant and can also reduce the number of staff and the operating expenditure required to operate it. However, if all our generators were so very large then it reduces the reliability (or increases the cost to maintain a level of reliability) of the overall system. If we had just one super-large, “cost effective” generator in each state we would actually be worse off. If that single generator ever failed our whole electricity system would blackout. Even in the actual system, if one of the four 500MW generators at Loy Yang shut down unexpectedly, it has massive implications on the system stability. This is why NEMMCO maintains at least 500MW of capacity reserve in the Victorian jurisdiction – just in case one of the Loy Yang generators fails.

In the end it becomes a trade off between the “cost-effectiveness” of large generation and the cost burden of maintaining large capacity reserves.

Forecasting Wind Energy - Is It Unpredictable?

Electricity can only be generated by a wind turbine generator when the wind blows. Wind energy is therefore often mischaracterized as an unpredictable source. It is more correctly described as an intermittent resource. Because of its intermittent nature, a wind farm does indeed present unique challenges to system-scheduling operations. However, constraints on wind farm output are not unique and each generation technology has distinct characteristics and presents operators with challenges that must be overcome. Wind is simply a new one with which system operators in Australia have had little experience to date.

Weather measurements and weather forecasting are very important for wind energy because it affects the initial locating decision and ultimately the operation of the wind farm. There are two broad phases of meteorology involved in wind farming – development phase wind monitoring (to determine where to put the wind farm and predict how much energy it will produce) and operational phase wind forecasting (to predict when and at what capacity a wind farm will operate.

The computer modeling used in the development phase has evolved over a long period of time and can now provide remarkably accurate predictions of energy outputs of wind farms with only 1% to 2% error over the long term. This is like climate data, we know the average rainfall but we will still have drought years and wet years.

Operational forecasting is a much newer concept and is like the four day weather forecast we are familiar with on television. Short-term micro-scale forecasting is not unusual and is already used in other industries quite successfully. Even though wind power output can be highly variable, it can be predicted with a reasonable degree of accuracy. Meteorological models (using weather data from satellites and surface measurements) can be used to produce hourly wind forecasts for the next one to two days. Persistence models predict the output of a wind farm two hours ahead.

Utility operations occur over several time scales and it is important to realize that, even without wind plant, utilities have tremendous variability to contend with. By being able to predict the output of a wind farm ahead of time, it can increase the benefits and reduce the dis-benefits of the interaction between the wind farm and the electricity system. Despite the stochastic nature of wind power fluctuations, the magnitudes and rates of wind power changes caused by wind speed variations are seldom extreme, nor are they totally random. Their values are bounded in narrow ranges.

The variability of wind power decreases as the number of wind turbines in a wind farm increases and the distances between turbines increase. This is because the turbines are exposed to different winds across the site. To the electricity system a geographical diversity of wind farm locations can also significantly reduce the variability of wind farm output because of the different weather patterns each of the wind farms are exposed to.

MAIN DOCUMENT

An overview of basic electricity concepts

This section will explain in fairly simple terms some of the basic concepts involved in the electricity system. How the main Australian electricity system operates and how it is managed is described in the next section "The National Electricity Market – an Overview".

Watts and Watt-Hours Explained

In many wind farming brochures you will continually see reference to terms like kilowatt hours and mega watt hours and megawatts, and how many average houses to which this is equivalent. But what do these terms really mean and are they accurate?

The first part to get out of the way is the prefixes used on these terms like "kilo", "mega" and "giga". These are simply multiplier so that we don't have to worry about writing down lots of zeros in numbers. For example we would not want to write the travel distance between Melbourne and Sydney as 998,267 metres rather as 998 **kilo**metres (or thousands of metres). The same is used with all the other measures. Melbourne's water storage capacities are measured in **mega**litres (or millions of litres). Likewise with electrical units of measure we use the same prefixes to indicate multiples of the unit.

The prefixes are standardised around the world under the "Système International d'Unités" (or SI Units) as adopted at the general conference on weights and measures for the coherent system of metric units.

Fraction	Prefix	Symbol	Multiple	Prefix	Symbol
10^{-1} or $\frac{1}{10}$	deci	D	10	deca	da
10^{-2} or $\frac{1}{100}$	centi	C	10^{2} or 100	hecto	h
10^{-3} or $\frac{1}{1,000}$	milli	M	10^{3} or 1,000	kilo	k
10^{-6} or $\frac{1}{1,000,000}$	micro	M	10^{6} or 1,000,000	mega	M
10^{-9}	nano	N	10^{9}	giga	G
10^{-12}	pico	P	10^{12}	tera	T
10^{-15}	femto	F	10^{15}	peta	P
10^{-18}	atto	A	10^{18}	exa	E

Energy is measured in Joules (for those of you still trapped in the pre-metric dark ages it is analogous to calories or ergs). A Watt is the measure of power (horsepower in the old system) or the rate of delivery of energy. One Watt is equal to one Joule per second.

To make this a bit easier to visualise we can relate the flow of energy to the flow of water. The water itself is equivalent to the energy (Joules to Litres) and the power is equivalent to the rate of flow of the water (Watts to Litres per second).

Unfortunately a Joule is not much energy by our day-to-day human standards. So if we were to measure electrical energy used in our houses in this way we would be measuring our daily energy consumption in megajoules (gas bills show your energy consumption in megajoules). Furthermore it makes it a bit complicated to work out electrical energy consumption if we used Joules all the time.

The electricity industry has adopted a simple measure called the watt-hour as a unit of energy (this is not the case for gas supply). A watt-hour is the amount of energy that flows in one hour if allowed to flow at the rate of one watt. Back to the water analogy this is the same as "how much water flows into the bucket in one hour if we allow it to flow at a one litre per second". Typically our electricity bills are measured in kilowatt-hours or thousands of watt-hours. A watt-hour is equal to 3600Joules (i.e. 1J x 3600 seconds in 60 minutes). A kilowatthour is simply a thousand watthours or 3,6000,000 Joules or 3.6 megajoules.

This makes it relatively easy to work out how much energy is being used in electrical systems. If we have a motor that uses energy at the rate of one kilowatt (i.e. a kilowatt motor) and run it for an hour we have used one kilowatt hour of energy. Likewise if we have a 500 watt motor and run it for 2 hours we have used a kilowatt hour of energy.

Consumption and Demand

We need to keep both the amount of energy (kilowatt-hours) and the rate of flow of that energy (kilowatts) in mind when thinking about electricity. The kettle in my kitchen uses power at the rate of 2.4 kW while my desk lamp uses power at the rate of 20 watts. It takes my kettle 2 minutes to boil the water I put in it, and I boil it twice a day so it uses 160 watt-hours of energy a day. My desk lamp burns for 8 hours a day so it too uses 160 watt-hours of energy a day. However the kettle makes a much greater demand for energy than the lamp.

This greater demand means that the wires in my house need to be bigger (like the water pipe needs to be bigger) to cope with this larger rate of flow of energy and more generation capacity (or water pump capacity) needs to be ready to supply that demand. So to operate electricity supply system effectively your utility not only needs to know how much electrical energy you are likely to use in a given period but also the peak demand rate at which you will consume it.

Of course, as the system gets bigger and bigger and more and more people connect to it, the operation of the system becomes much more complex. My neighbour does not wait for me to have boiled my kettle before boiling his. In fact most of us wake up at about the same time and all want to boil our kettle and operate our toasters, lights, etc at about the same time. This can mean that residential areas can have significant power demands for some periods of the day, even though their overall energy consumption is relatively low.

Likewise, all the office buildings and factories start up at about the same time of day. This leads to a fluctuation in demand throughout the day. Over time, a pattern forms and the utility companies can now make a fairly good predictions of how much energy they need to deliver and at what rate at any given time of the day.

The demand for electricity doesn't just vary according to the time of day, it also depends upon which day of the week it is (weekends and public holidays have different supply needs), what season it is and what the temperature is. In recent times the increased use of air-conditioning systems has meant our typical suburban energy demand profile has changed. Traditionally winter has been the time for peak energy demand, but now summer demands are outstripping winter demands.

Distribution and Transmission

The electricity is delivered from the generator to our homes by the electricity network. The network is divided into two main parts – transmission and distribution. The transmission system is that part of the system used for the delivery (or transmission) of large volumes of electricity to specific nodes within the network. The distribution system is that part of the system used for delivery (or distribution) of electricity from the transmission nodes down to each customer's premises.

This is analogous to the roadway system. The transmission system is equivalent to the freeways and highways while the distribution system is equivalent to the small feeder roads, suburban streets and country tracks. In the road network the highways and freeways tend to have more lanes and divided roadways to cope with a greater flow. They also tend to have higher speed limits to increase the total flow rate of traffic. Smaller suburban roads tend to get progressively narrower and have slower speed limits.

Likewise in the electricity network the transmission system tends to have very big power cables at very high voltages while the distribution system has progressively smaller cables and lower voltages. The substations and pole mounted switchgear can be thought of as intersections (at least in simple terms).

Of course in very densely populated areas (like inner city suburbs) there is a large demand so some of their roads are bigger and have moderately higher speed limits. The same happens in the electricity system. To get lots of energy from one part of the distribution system to another we use "sub-transmission" lines that have larger cables and higher voltages than the rest of the distribution system but still not as high as in the transmission system.

The transmission and distribution systems are controlled and managed by different organisation but, like the whole electricity system, they are seamlessly integrated so that normal electricity consumers don't have to think about them too much – unless something goes wrong!

Warm and hot summer days can complicate matters for the transmission and distribution system. Powerlines tend to work less effectively as the temperature increases and so they are not able to carry as much electricity on warmer days. This can make the delivery of electricity on hot summer days particularly problematic. We tend to use more electricity and at higher rates as the temperature increases and at the same time the ability of the system to deliver that electricity from the generator to our homes is also reduced.

Rain after long dry periods can also cause problems for the electricity network, just like it does on our roads. During the dry period dust builds up on insulators and when we finally get rain it can sometimes be so light that a mud forms over the insulators allowing the electricity to leak out of the wires. This can lead to short circuits and results in pole fires and equipment failures.

Lightning and wind storms can also cause problems. Wind storms can bring trees across powerlines causing blockages in the system (just like a tree across the road). Lightning is even more problematic in that it contains so much energy that it is like hundreds of run-away freight trains and can cause massive damage to the system.

Just as we can have motor vehicle accidents and signal failures on the road network we can also have equipment failures on the electricity network. Both cause massive problems that can cascade down the system and even lead to complete system failure (gridlock). Sometimes even seemingly trivial problems can escalate into big problems. One person lightly applying their brakes on a freeway in peak hour can very quickly degenerate into a parking lot.

Balancing Supply and Demand

While the transmission and distribution companies look after the delivery of the electricity and direct it through the electricity network from the generator to our homes, it is the electricity retailer that negotiates the purchase of bulk electricity from the generator and its sale to individual customers.

Provided that the network is able to cope with the level of demand this should be a fairly simple task right? The answer is no. It is in fact a very complex task.

For a start, the network can't always cope with the demand. In suburban areas we perhaps don't see too many problems, but in some country areas where the distribution cables are very long and tenuous there can be real problems. In some areas you could tell when the neighbours were milking or using arc welders because your lights would dim and flicker. This is because the dairying equipment and welders have a high demand for energy and the network simply couldn't cope.

To use our roadway analogy it is like a dusty country road. If one car goes along it every now and then it is OK, they have clear vision but if lots of cars are going down it one after another in quick succession then the dust becomes blinding and the cars must (or at least should!) slow down, affecting everyone along the road.

We can overcome the problems of supply interruption by having very strong power lines and multiple levels of redundancy. We could go to the point that our supply is never interrupted. However this would be very expensive and so we compromise to reduce cost.

Another significant problem to overcome in balancing supply and demand is that traditional coal-fired generators cannot respond instantaneously to changes in demand. They work by burning coal to heat water into steam and the steam is used to drive a turbine which turns an electricity generator. If we suddenly double the demand for electricity we need lots more steam but it necessarily takes a certain period of time to generate that extra steam. The period of time taken to bring some of the larger coal-fired generators on line can be several hours or even days.

In fact this is why in some cases we can have different tariffs for electricity in the so called near-peak and off–peak periods. This is an “economic signal” being sent by the generator via your retailer to you saying, “Please use your electricity at night time when no one else wants it, so I can keep my coal-fired generator ticking over during the night in preparation for tomorrow morning’s peak in demand.” This helps smooth out the energy demand so that there is a “steady” level of demand present all the time with peaks and troughs over it.

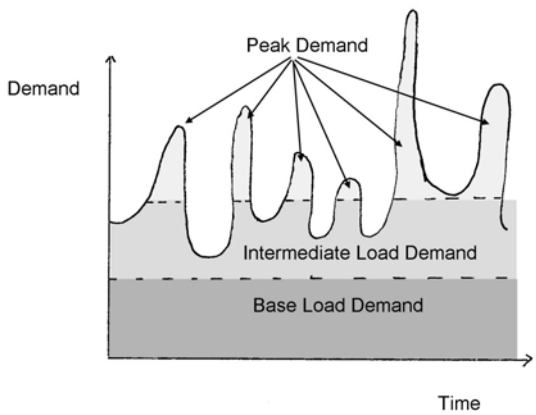


Figure 1 A Contrived Demand Curve

This steady demand is called base load and the generators that we use to provide this plant are called base load generators. To supply the demand in the periods of higher demand we have some generators that only operate during these periods of higher demand. These are generally called intermediate plant. In extreme conditions when demand becomes extreme (or peaks) we use generators called peak generating plant or peaking plant. These generators operate only under periods of extreme demand.

It would be possible for us to have a “limitless” power supply by having numerous generators on standby just in case we need them. Of course this is far too expensive and again we compromise to reduce cost to manageable levels.

The next section provides a more detailed description of how the Australian electricity system operates (at least on the Eastern Seaboard).

The National Electricity Market – An Overview[1]

INTRODUCTION

Over the past 200 years, society has become increasingly reliant on energy to function and develop. Electrical energy is the most common form of energy used because of the ease with which it can be transported and converted to heat and light, and used to power machines.

The electricity production and supply industry plays a significant role in the Australian economy and the industry has undergone significant reform and deregulation over recent years. A national electricity market has been created to increase efficiency in the industry through competition and is expected to deliver substantial benefits to the energy dependant public.

In Australia, most of our electricity is produced from coal in a process where coal (chemical energy) is burnt to heat water and produce steam (thermal energy). This steam is forced under great pressure through a turbine (kinetic energy) that turns a generator to produce electricity (electrical energy). In a similar way, hydro-electricity converts the kinetic energy of falling water to electrical energy and wind turbine generators convert the kinetic energy of the wind to electrical energy.

THE NEM

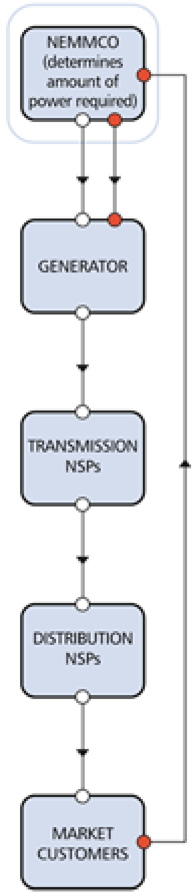
The National Electricity Market (NEM) has been operating since December 1998 and one of its key objectives is to promote competition at each stage of the electricity production and supply chain.

The NEM supplies electricity to over 7.7 million Australian customers on an interconnected national grid that runs through Queensland, New South Wales, the Australian Capital Territory, Victoria and South Australia. Approximately $8 billion of energy is traded through the NEM each year.

The National Electricity Market Management Company Limited (NEMMCO) operates a wholesale market for trading electricity between generators and electricity retailers within the NEM. This means that all the electricity output from generators is pooled, and then scheduled to meet electricity demand.

This pool system has been adopted to reflect two particular aspects of electricity generation and use. Firstly, electricity cannot be stored for future use; therefore supply must always be responsive to variations in demand. Secondly, it is not possible to distinguish which generator produced the electricity consumed by a particular customer.

In the centrally-coordinated dispatch process, NEMMCO continually works to balance electricity supply and demand requirements by scheduling generators to produce sufficient electricity to meet customer demand. Generator operators compete by providing offers and bids for supplying energy to NEMMCO. These bids are comprised of prices and associated quantities the generators are willing to schedule in the dispatch



Electricity Market Physical and Financial Flows

[1] For more detail please refer to the web site of the National Electricity Market Management Company (NEMMCO) at http://www.nemco.com.au

process. NEMMCO issues demand instructions and schedules generators based upon these bids.

The spot market is the whole process whereby prices for electricity are set and then settled. Generators are paid for the electricity they sell to the pool, and retailers and wholesale end-users pay for the electricity they use from the pool.

In general, all electricity must be traded through the spot market and NEMMCO calculates the spot price using the price offers and bids for each half-hour period during the trading day. The spot price is the clearing price to match supply with demand.

The electricity pool is not a physical location; rather it is a set of rules and procedures managed by NEMMCO in conjunction with generators, retailers and Network Service Providers (NSPs). NEMMCO matches the generating capacity declared available by scheduled generators against its forecast of demand to determine whether sufficient capacity is available to meet the peak demand each day, as well as providing sufficient reserves to handle potential failures in either the generators or the transmission networks.

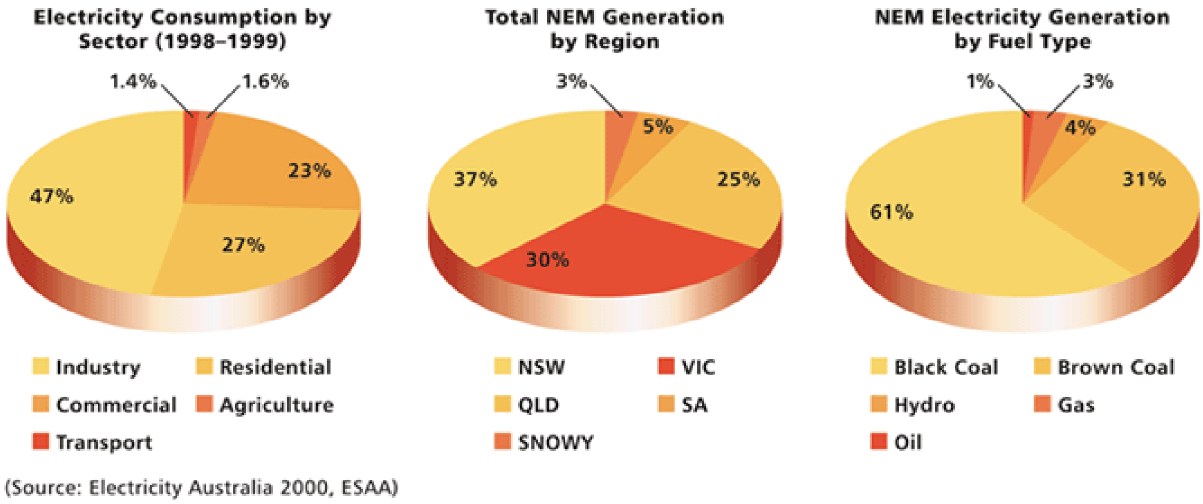


Figure 2 Electricity Supply and Consumption in 2000

The rules by which the market operates are set out in the National Electricity Code (or “The Code”) and these rules are administered by the National Electricity Code Authority (NECA). The Code also defines technical requirements for the electricity networks, generating plant, and customer connection equipment to ensure that electricity delivered to the customer meets prescribed standards.

Under The Code, NEMCO is responsible for the day-to-day operation and administration of both the power system and the wholesale spot market. NEMMCO operates on a self-funding, break-even basis. The five State governments are NEMMCO's shareholders, and each government appoints a director to make up the NEMMCO Board.

MARKET PARTICIPANTS

The NEM comprises more than 70 registered participants who fall into six categories based on the role they perform in the market. Some participants fill more than a single role within the NEM and therefore belong to more than one category (for instance, a participant may be registered as both a generator and a market customer).

The categories are:

- Generators
- Distribution Network Service Providers (DNSPs)
- Market Customers (electricity retailers and large end-use customers)
- Transmission Network Service Providers (TNSPs)
- Market Network Service Providers (MNSPs)
- Traders

GENERATORS

Generator operators produce and sell electricity. Australia relies almost entirely on fossil fuels - namely coal, oil and gas - for electricity production. Hydro-electricity plants operate in Tasmania and the Snowy River region, and there are significant gas-powered stations in South Australia. The generators may be privately or publicly owned.

Generators are classified into four categories according to their capability and their obligation to participant in the NEM:

Market generator – is a generator whose entire output is sold through NEMMCO's spot market.

Non-market generator – is a generator whose entire output is sold directly to a local retailer or customer outside the spot market system.

Scheduled generator – is an individual or group of generators with a capacity rating over 30 megawatts, and whose output is scheduled by NEMMCO's dispatch instructions.

Non-scheduled generator – is an individual or group of generators (generally with a capacity rating of less than 30 megawatts) whose output is not scheduled by NEMMCO's dispatch instructions.

NETWORK SERVICE PROVIDERS

Electricity is transported along the power grid on wires made up of many separately owned networks. Historically, each State developed its own transmission network and linked it to another State's system via a large transmission line called an interconnector.

Access to the electricity grid is provided by Network Service Providers (NSPs) who own, control and/or operate the transmission or distribution systems. The networks must be maintained and operated securely and in a manner that provides open access to participants who trade in the NEM and to smaller operators who trade directly with local retailers.

Network elements are sometimes out-of-service for maintenance purposes and because this has the potential to affect the power system security, all significant outages must be carefully planned by the NSPs and scheduled with NEMMCO.

There are three categories of NSP:

Transmission Network Service Providers (TNSPs): TNSPs operate the networks that carry electricity between generators and distribution networks. TNSPs advise NEMMCO of the capacity of their transmission assets so they can be operated without being overloaded.

Distribution Network Service Providers (DNSPs): DNSPs operate a network of low voltage substations and wires that transport electricity from distribution centres to end-use customers. DNSPs also provide technical services such as construction of overhead and underground power lines, regular inspection of equipment, maintenance and street lighting.

Market Network Service Providers (MNSPs): MNSPs are entrepreneurial interconnectors who obtain revenue from trading in the wholesale NEM. MNSPs interconnect two price regions within the market and offer their capacity to transport power into the market through a bidding process similar to that used by generator operators. Currently there is only one MNSP operating in the NEM. It is called Directlink, and links New South Wales and Queensland.

ELECTRICITY RETAILERS

There are a number of electricity retailers operating in each region in the NEM. Retailers purchase electricity either through the spot market or from local generators who commit to sell their entire output to them. The electricity purchased is packaged and then sold on to end-use customers.

Some retailers only buy and sell electricity, others also operate distribution networks.

Retailers can also purchase energy direct from generators through a financial instrument called a "hedge contract" which effectively reduces their risk exposure against pricing outcomes (refer Financial Risk Management section).

MARKET CUSTOMERS

Market customers include both electricity retailers and end-use customers who purchase directly from the NEM.

In terms of the wholesale market, in the old State-regulated system, all customers were franchised customers (i.e. one who purchases electricity from a designated vendor at a regulated price). Since deregulation began, the NEM has implemented a process whereby all customers have a choice of electricity supplier called "contestability".

In the area of retail trade, contestability means that customers may elect to buy their electricity from either the wholesale or the retail market. Those who elect to purchase directly from the wholesale market will need to register with NEMMCO as market customers.

TRADERS

Traders essentially buy electricity on the wholesale market and on-sell it to other wholesale customers rather than use it themselves.

THE SPOT MARKET

Wholesale trading in electricity is conducted as a spot market. The spot market allows instantaneous matching of supply against demand, and plays a significant role in the economy in providing secure and reliable generation, transmission and supply of energy.

Generators offer to supply the market with different amounts of energy at particular prices. From all offers submitted, NEMMCO selects the generators required to produce power and at what times throughout the day, based on the most cost-efficient supply solution to meet specific demand. Generators can change their bids or submit re-bids according to a set of bidding rules.

Dispatch instructions are then sent to each generator at five-minute intervals to schedule the amount of power to be produced. Demand for electricity varies from State to State and throughout the day. Prices are calculated for dispatch intervals in each region. The six dispatch prices calculated during each half-hour period are averaged to determine the spot price. This spot price is used as the basis for billing participants within the NEM for all energy traded.

A maximum spot price is set under the Code. This price cap is the maximum level at which generators can bid in the market. It is also the price automatically triggered when NEMMCO directs NSPs to interrupt customer supply (or shed load) in order to regain balance in the system. In this situation the spot price is referred to as the "Value of the Lost Load" (VoLL).

Inter-Regional Trade

The NEM is currently comprised of five interconnected electrical regions. These basically follow State boundaries. The Australian Capital Territory is, however, incorporated in New South Wales and the Snowy is also a region. Each region contains a regional reference node, which may be a major load centre such as a city, or a major generation centre, such as the power plants in the Snowy region.

The regional reference node is where the Regional Reference Price (RRP), also called the regional spot price, is set.

The RRP is based on the bids and takes into account the constraints of interconnector capacities between the regions and energy transmission and distribution losses.

Interconnectors

The transmission lines that connect and transport power between adjacent electrical regions on the national electricity grid are called interconnectors. Power is transmitted between regions to meet energy demands that are higher than local generators can provide, or when the price of electricity in an adjoining region is low enough to displace the local supply.

The scheduling of generators to meet demand across the interconnected power system will sometimes be constrained by the physical transfer capacity of the interconnecting links between the regions. When the limit of an interconnection link is reached, NEMMCO schedules the most cost-efficient sources of supply from within the region to meet the remaining demand.

For example, if prices are very low in Victoria and high in South Australia, up to 500 megawatts of electricity can be exported to South Australia across the interconnector. Once this limit is reached, the system will then use the lowest priced generators in South Australia to meet the outstanding consumer demand.

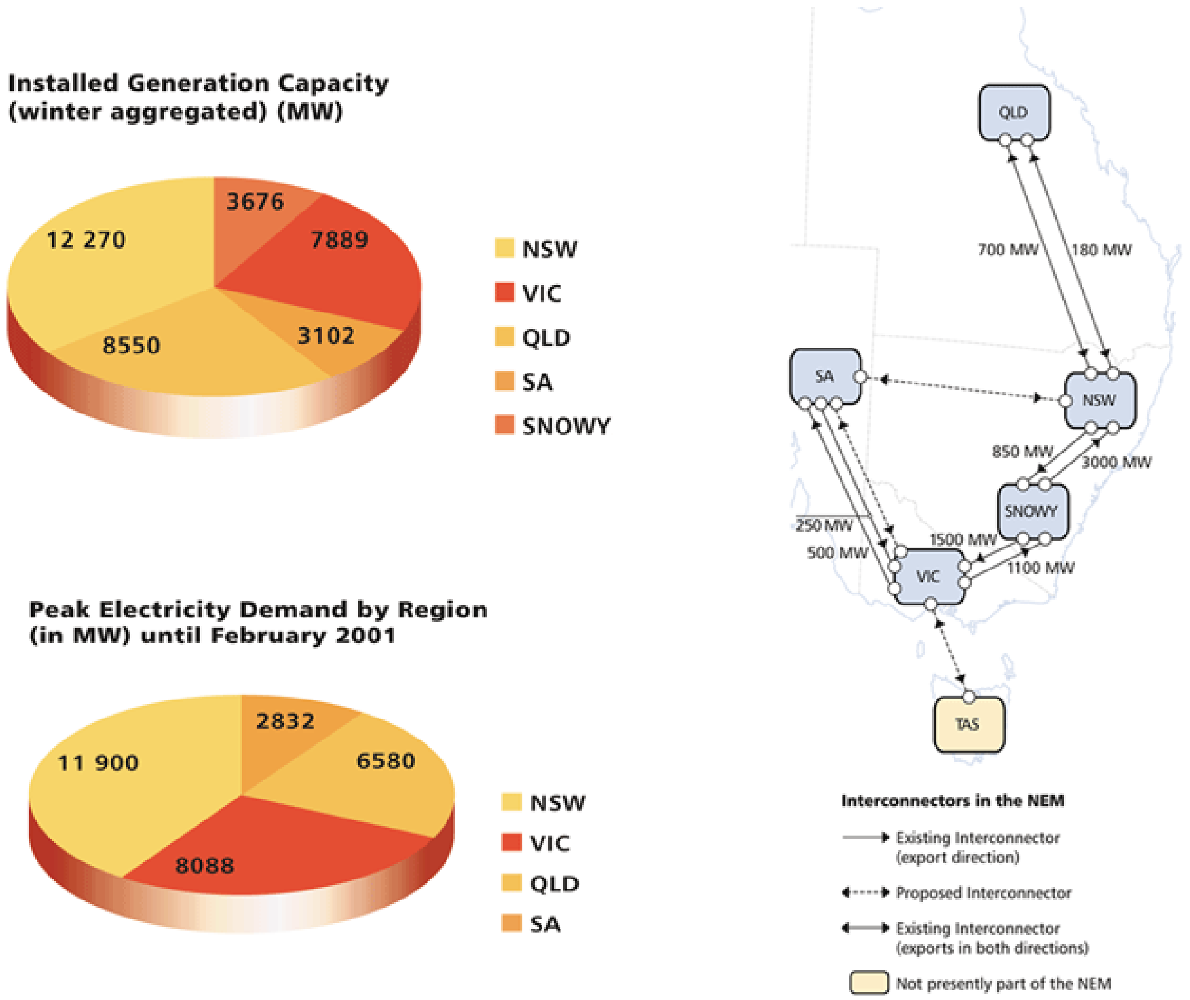


Figure 3 Electricity Consumption, Generation and Interconnection in 2001

REGULATED AND UNREGULATED INTERCONNECTORS

Under the NEM the regulation of interconnection assets is handed to the Australian Competition and Consumer Commission (ACCC).

Regulated interconnectors receive a fixed rate of return that takes into account the value of their asset base. The amount of this return is determined by the ACCC and reviewed every five years.

Unregulated or entrepreneurial interconnectors (MNSPs), rely on trading in the wholesale market to derive their revenue. Unlike regulated interconnectors, they may also enter into financial contracts (refer Financial Risk Management).

New proposals for interconnection must meet a regulatory test in order to be considered regulated assets and be assured of a fixed level of income. Currently this test is determined by the ACCC and applied by NEMMCO.

LOSS OF ENERGY IN THE SYSTEM

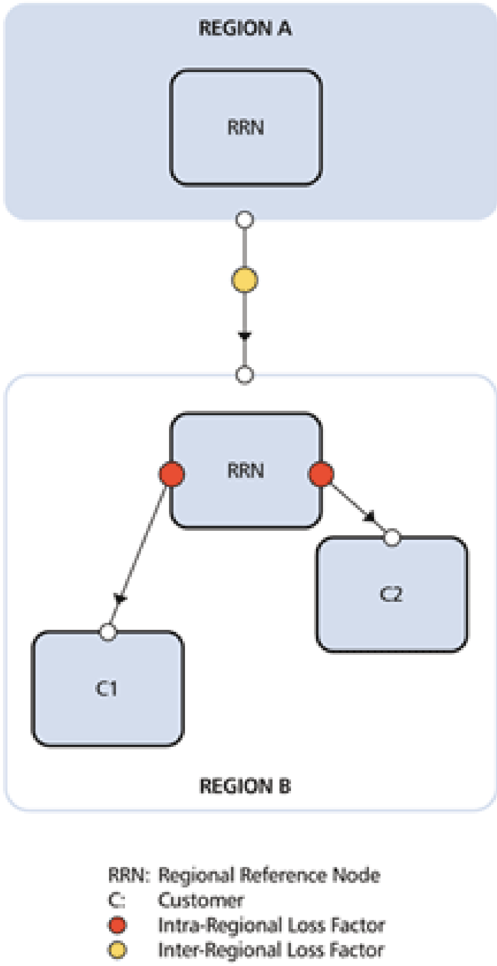
As electricity flows through the grid, energy is lost in the transmission and distribution lines due to the electrical resistance of these lines. Electrical losses account for about 10% of the electricity transported between power stations and customers.

This means that if a customer requires 9 MW of electricity, a generator will need to produce 10 MW of energy to meet this demand. This loss factor is considered in price calculations provided to generator operators and customers.

Power is lost through heating of the conductors of both the transmission and distribution lines as electricity is transported to load sites.

Loss factors, which represent the impact of network losses on spot prices, are calculated for each region. The regional loss factor is calculated by using an average loss factor fixed for 12 months, and used in calculations during the scheduling and settlement processes.

Intra-regional loss factors must likewise be factored into calculations for energy transported from generators to a market customer's connection point.



Loss of Energy in the System

Electricity losses occur between regions and within regions. Losses between regions are called inter-regional loss factors. For example, to ensure 90 MW of energy is supplied to Region B, 100 MW of electricity will need to be exported from Region A.

Intra-regional losses occur between the regional reference node (RRN load centre) and the customer connection point. (Customer C1 would require more energy to be imported to receive the same supply as customer C2, as C2 is closer to the RRN.)

Market Forecasts

It is necessary fro NEMMCO to identify limitations or constraints on supply as far in advance as possible. This enables other participants to respond to potential shortfalls by re-bidding their own generating capacity.

Pre-Dispatch Forecasting

Pre-dispatch is a short-term forecast of market activities. It is used to estimate price and demand for the next trading day and energy flow across the interconnectors. Generators must notify NEMMCO either of the maximum volume of electricity they are able to supply or in the case of fixed loads, the amount of energy they require for consumption. This information is then collated to estimate total regional capability, thereby enabling NEMMCO to assess potential supply shortages.

Projected Assessment Of System Adequacy

NEMMCO also monitors the future adequacy of generating capacity based on plant availability information. This is supplied by generators against forecast electricity demand. These projections are called Projected Assessments of System Adequacy (PASA) and assist generator operators to plan maintenance and NEMMCO in scheduling electricity production.

NEMMCO produces two PASA forecasts to account for the fluctuations in the demand for electricity supply;

- Short Term PASA (ST PASA): a seven day forecast updated every two hours, and
- Medium Term PASA (MT PASA): a two year forecast updates each week.

Statement Of Opportunities

Each year NEMMCO publishes a Statement of Opportunities (SOO) which predicts market trends for the following 10 years. The SOO outlines the system capability, and supply and demand forecasts for each jurisdiction in the NEM.

Specifically, the SOO includes:

- forecasts of electrical energy usage,
- details about generator capabilities,
- NEMMCO's assessment of the adequacy of energy supplies to meet demand,
- inter-regional transmission capabilities for exchange of energy between NEM regions,
- forecasts of ancillary service requirements to ensure secure operation of the system, and
- a summary of initiatives and proposed projects.

Bidding and Dispatch System

As part of the NEM, scheduled generators are required to submit offers to the market indicating the volume of electricity they are prepared to produce for a specific price. There are three types of bids:

- **Daily bids:** must be received before 12:30pm on the day before supply is required.
- **Re-bids:** are submitted after 12:30pm and can be received until approximately five minutes prior to dispatch. Only the availability details can be changed in a re-bid; price cannot be changed.
- **Default bids** are back-up bids in case daily bids are not submitted. These bids are of a "commercial-in-confidence" nature.

Scheduling Generators

Scheduling is the process that balances supply and demand in the market. It also prioritises dispatch based on cost-efficiency of supply. NEMMCO uses the bids from generator operators to determine which generators will dispatch into the market, at what time and at what volume.

Energy offers are stacked in order of rising price until consumer demand is met. As energy demand increases, more expensive generators are accepted into production. The scheduling of generators may be constrained by the capacity of the interconnectors between the regions.

When this occurs, higher price generators within the region will be called on to meet this demand. This is one reason for the variation in the spot price of electricity between regions.

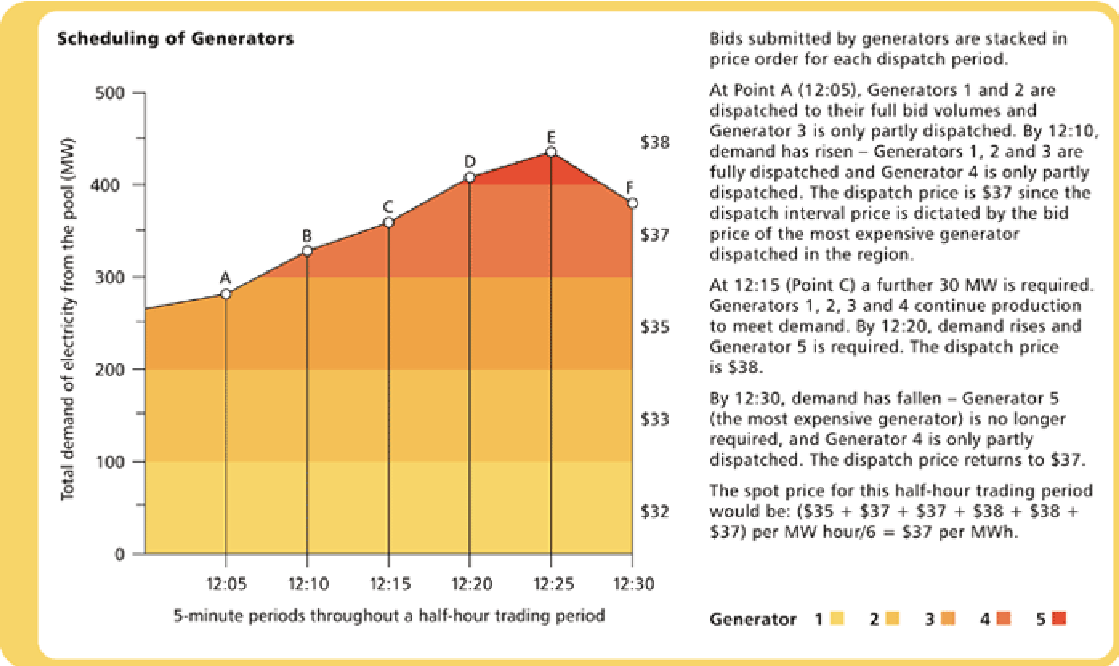


Figure 4 Scheduling of Generation in the NEM

DISPATCH

The spot market's trading day is a 24-hour period commencing at 4:00am Eastern Standard Time. Dispatch instructions are issued at 5-minute intervals and the price and demand data for each dispatch interval is averaged over each half-hour period for 48 trading intervals (24 hours) each market day.

The dispatch price represents the marginal cost of supply in each dispatch interval and is generally the offer price for the highest bid generator brought into production. Other factors, including available interconnector capacity, system load, plant outages, frequency control, voltage control, testing and transmission outages, can also impact on the dispatch price.

METERING

All market participants are required to install equipment to record electricity consumption. Metering is usually managed by local NSPs using Metering Data Agents (MDAs). These MDAs measure the amount of electricity supplied or purchased, validate the data, apply distribution loss factors, and forward the data to NEMMCO for use in calculating wholesale settlement accounts.

SETTLEMENT

Settlement is the process of determining financial payments, billing and settling of amounts payable and receivable for electricity sold to and purchased from the pool. NEMMCO issues weekly accounts to all market participants.

Under the Code, NEMMCO has a prudential responsibility to the market to ensure the trading risks relating to the solvency of market participants and their ability to trade are monitored and managed.

- **Generator settlement:**
  Settlement price = energy produced x spot price x transmission loss factor
- **Market customer settlement:**
  Settlement price = energy consumed x spot price x transmission loss factor

ANCILLARY SERVICES

NEMMCO is responsible under the Code for ensuring that the power system is operated in a safe, secure and reliable manner. In order to fulfil this obligation, NEMMCO controls the key technical characteristics of the system. These include frequency, voltage, network loading and system re-start capabilities.

Variations in frequency or voltage can cause damage to generation equipment and industrial, commercial and domestic machinery, and create safety concerns. Ancillary services are used to maintain this balance and further protection systems are in place to correct disturbances quickly.

NEMMCO purchases these services under ancillary service agreements. An example is the frequency control used to prevent frequency deviations when the balance between demand and supply in the power system is disrupted.

The following functions are managed by ancillary services:

- **Automatic Generation Control** - enables a generating unit to respond to signals from the NEMMCO to correct system frequency and prevent overloading of network elements.
- **Governor Control** - enables a generating unit's controller to correct the system frequency within a six or sixty-second time-frame.
- **Load Shedding** - enables the automatic disconnection of load in response to an extreme frequency deviation within a six to sixty second time-frame, in order to prevent overload.
- **Rapid Generator Unit Loading** - enables a generator to automatically reduce generation in order to preserve stability under certain situations.
- **Reactive Power** - enables a generator to control system voltage by the generation or absorption of reactive power.
- **System Re-start** - enables a generator to supply the transmission system following a complete system failure.

Payments for ancillary services are broken down into payments for availability, enabling usage and compensation for the provision of the services. Costs for the services are currently allocated between market customers and generators.

FINANCIAL RISK MANAGEMENT

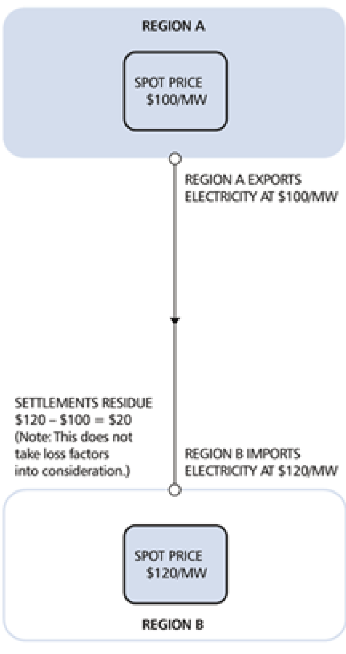
There is a financial risk associated with the operation of the National Electricity Market. NEMMCO is responsible for the prudential operation of the NEM.

SETTLEMENT RESIDUE AUCTION

For each region of the NEM, the Regional Reference Price (RRP) is determined by a range of factors including supply and demand, the physical limitations of transporting electricity and transmission and distribution loss factors. This means that there may be significant differences in the RRPs of the trading regions. The difference between the price of energy generated in one region and the price of that energy once it has been transmitted to another is called the Inter-Regional Settlement Residue (IRSR).

IRSR arises in the NEM because the amount required to be paid by market customers to NEMMCO, in respect of spot market transactions, will generally differ from the amount required to be paid by NEMMCO to generators for those transactions. By making the settlement residue available to the market place, the risks of trading between regions can be better managed.

The Settlement Residue Auctions (SRAs) are intended to improve the efficiency of the NEM by promoting inter-regional trade. Only registered generators, market customers and traders are able to participate in these auctions (i.e. TNSPs are not permitted to participate).



Settlements Residue

FINANCIAL (HEDGE) CONTRACTS

A hedge contract is a financial instrument used to manage the risk created by price volatility in the market. Buyers and sellers of electricity may enter into long or short-term contracts that set an agreed price for electricity outside the spot market and without the involvement of NEMMCO.

The basic form of contract may be a bilateral hedge where two parties agree to exchange cash against the spot price. In a two-way hedge contract, generators pay retailers the premium price when the spot price is above the contracted price. If the spot price is below the contracted price, retailers pay generators the amount of the discount.

A one-way hedge contract manages the risk of high pool prices while allowing wholesale buyers to take advantage of low prices. When the pool price exceeds a certain level, generators pay retailers the difference between the pool price and an agreed amount for the contracted amount of electricity.

Hedge contracts only affect the financial settlement of accounts and do not affect the operation of the power system in balancing supply and demand in the pool. Therefore they are not regulated under the Code.

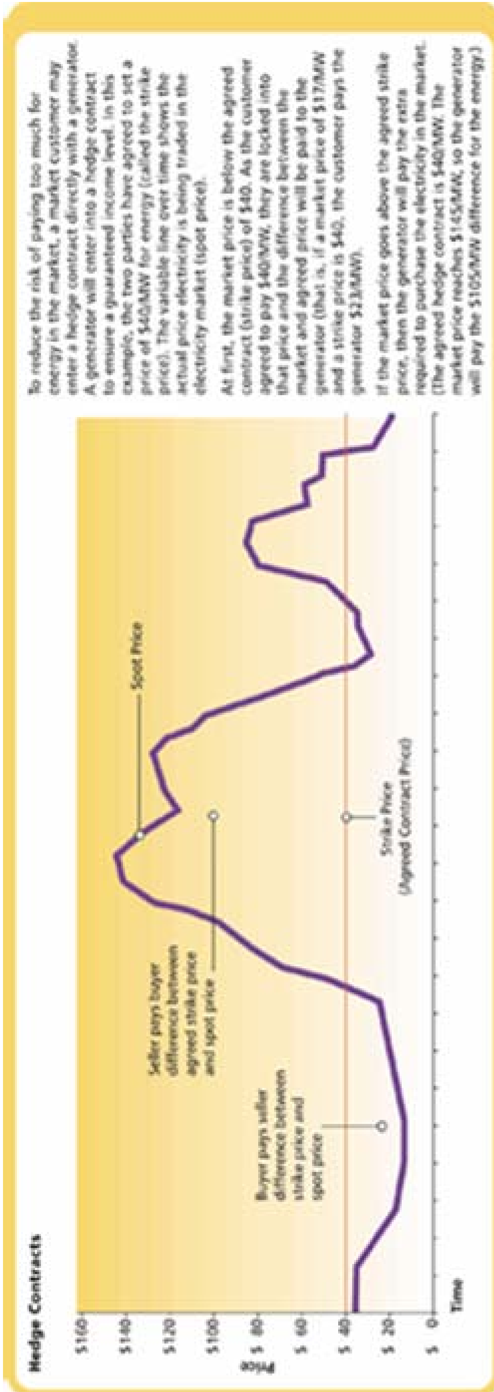
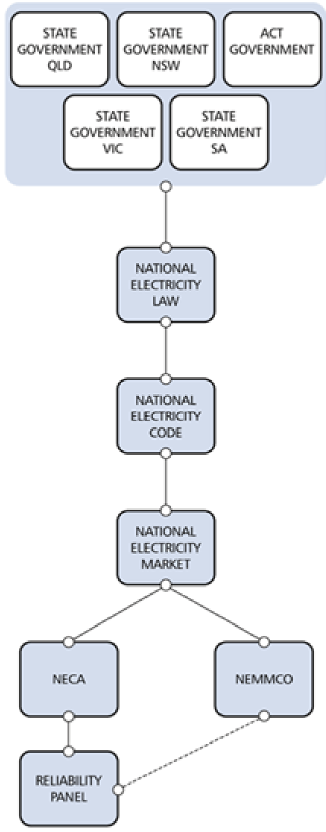


Figure 5 Hedge Contracts in the NEM

REGULATORY ARRANGEMENTS



Regulatory Framework – National Electricity Market

Because of the importance of a secure energy supply system to the good order of society and stability of our modern economy, the electricity supply industry is closely controlled and regulated by a variety of agencies.

- **The National Electricity Code Administrator (NECA)** administers and enforces the Code. NECA also monitors and reports on Code compliance, manages changes to the Code, establishes procedures for dispute resolution and establishes consultative and reporting procedures.
- **The Reliability Panel** determines power system security and reliability standards. It also provides guidelines for NEMMCO's exercise of its power to issue directions in connection with maintaining or re-establishing the power system in a reliable operating state; and enter into contracts for the provision of reserves.
- **The Australian Competition and Consumer Commission (ACCC)** administers the Trade Practices Act, approves changes to the Code, and sets pricing for transmission services.
- **The Australian Securities and Investment Commission (ASIC)** regulates financial instruments, which are used by participants in managing their risk in the NEM.

In addition, some regulations remain under the authority of the State Governments. Specific responsibility and regulatory arrangements differ between States but may include responsibility to:

- Regulate pricing for distribution network access
- Set timetable and process for deregulation
- Prevent misuses of monopoly power
- Enforce safety and environmental standard
- Set distribution and retail licence conditions

The major State Regulatory Bodies include:

- Office of Energy, Department of Treasury (QLD)
- Queensland Competition Authority (QLD)
- Independent Pricing and Regulatory Tribunal - IPART(NSW)
- Department of Urban Services (ACT)
- Essential Services Commission (VIC)
- Office of the Chief Electrical Inspector (VIC)
- Electricity Supply Industry Planning Council (SA) - ESIPCSA
- SA Independent Industry Regulator (SA)
- Technical Regulator (SA)

How Does Green Power™ Get To My House?

Electricity is supplied from a common grid network, with generation coming from a range of power stations. When you purchase your electricity from your electricity retailer (i.e. you turn on the switch) you have no control over how the flow of electrons is routed through the system. This is not a bad thing. If you had to worry about the routing of electricity through our national grid each time you wanted to turn on a light we would not be able to cope!

In fact, it is not possible to track the flow of a unit of electricity. All mains electricity is purchased from the electricity pool (the bulk of which comes from coal-fired power stations). Every unit of energy purchased by Green Power™ customers however will be supplied into the grid from a renewable source and one less unit of energy will come from coal-fired stations. No changes to cabling or power poles are required.[2]

So when you buy Green Power™, an amount of renewable electricity equivalent to your consumption is fed into the grid eliminating that amount of coal derived power. That means your electricity will be exactly the same as before, but your purchase directly reduces the greenhouse emissions. The collective purchasing by Green Power™ customers represents a significant benefit to the environment.

Is It Guaranteed Green?

Electricity retailers use a variety of brand names to identify their renewable energy schemes. When you see the Green Power™ logo on an electricity scheme, it means that it has been approved by the National Green Power™ Accreditation Steering Group.

A National Accreditation Program has been developed to ensure that Green Power™ offered by electricity suppliers is generated from approved renewable energy sources. Green Power™ products sold by accredited electricity retailers are rigorously monitored under a National Green Power™ Accreditation Program, administered by government energy agencies in all states and territories.

An accredited Green Power™ product is one where the generation source:

- results in greenhouse gas emission reductions
- has nett environmental benefits
- is based primarily on a renewable energy source

"Primarily" means that more than half of the electricity output can be attributed to a renewable source, but only the renewable part can be counted as Green Power™. This is to allow for co-firing of generators, where the renewable fuel makes a significant contribution to the power output.

A generation source that could cause significant environmental or cultural damage, even if considered renewable, will not be approved. For instance, major flooding hydro projects would not be approved.

Accredited Green Power™ retailers must submit regular reports to ensure that sufficient approved renewable energy has been purchased. Revenue from the schemes must be independently audited and retailers themselves must purchase Green Power™ for their own purposes. Retailers must commit to the development of new renewable generation and source a minimum of 80% of their Green Power™ from 'new' renewable sources. This acts as an incentive for a viable renewable energy industry in Australia. Under the national

[2] from www.greenpower.com.au

accreditation program, a 'new' generation source is one commissioned after 1 January 1997.[3]

[3] From www.seav.vic.gov.au

How do Wind Farms form a part of the Electricity System

The “fuel source” and generation technology are not relevant to NEMMCO in terms of the way the generation is dispatched to the pool. Once the energy reaches the pool, it is controlled by NEMMCO and distributed throughout the system according to the needs of system – i.e. to ensure system stability and satisfy demand.

The electricity retailers simply buy enough electricity from the pool to satisfy the needs of their customers and to account for the losses in the transmission and distribution system. Once in the pool the retailer has no way of knowing where the electricity came from.

While most electricity is traded in this way not all electricity is traded through the pool. In some cases a large customer (e.g. an aluminium smelter) or an electricity retailer will purchase electricity from a specific generator according to a contractual arrangement between the two parties. Such trades are called “off – market” trades.

For the good operation of the electricity system NEMMCO needs to control the flow of energy from generator and on to the retailer even if the trade is “off-market”. The most efficient way to do this is via the National Electricity Market pool. In the case of off-market trades, the generator will operate as a “price-taker”. In other words the generator output is bid into the electricity pool at $0/MWh so that they are guaranteed to be dispatched by NEMMCO.

The revenue derived from these “off-market” trades is later transferred to the retailer to compensate them for the cost of “purchasing” electricity from the pool that they have already purchased (i.e. to neutralise the “trade” in the pool).

Even in these off-market trades the retailer is not able to track specific energy flows through the system. They simply know that an amount of energy was put into the pool by their contracted generator and that they have taken a corresponding amount of energy out of the pool.

The actual flows of electricity in the National Electricity Market (or any interconnected grid) can be quite different to the financial flows with which they are associated. For example it is quite possible for a retailer to purchase electricity in Queensland to supply a customer’s demand in South Australia. However the physical electricity may not even make it out of Queensland because it will be consumed by another load in Queensland. However the retailer (and so the customer) must pay for the losses involved in transferring the energy across the electricity network.

So far in Australia all wind farms have opted to sell their electricity via long term contracts to specific electricity retailers either to satisfy the retailer’s need for accredited Green Power or to satisfy the retailer’s need for Renewable Energy Certificates. In other words the wind energy is sold via “off-market” trades.

The output of very small wind turbines may not even make it to the grid. Wind turbines are often connected to stand alone power systems (SAPS) that are not connected to the electricity grid and so the energy must be used immediately by the system or stored in batteries for later use. SAPS allow people to avoid the cost of connecting the electricity grid, which can sometimes be prohibitively high.

In recent times, grid-inter-tied systems have been permitted on electricity grids. In this case the wind turbine is connected to the generator owner’s house or workplace and supplies their own needs. If more energy is being produced than can be used on in own premises at a given time, then the extra energy is exported to the grid. If the turbine cannot keep up with the demand at a given time, then extra energy is imported from the grid. Such systems can operate using a net metering system (where electricity is bought from and sold to the gird at the same price) or dual metering system (where electricity is bought and sold at different prices - generally with a higher purchase price than sale price).

In these small grid-inter-tied systems the output is generally so small that no effect is seen beyond the local distribution point. It is essentially just like the customer turning all their lights off or (if they are exporting power) like their neighbour turning their lights off as well.

When there are very few of these systems in a specific distribution area and the generating capacity of the systems themselves are very small, the impact of their operation does not emerge beyond the typical fluctuations of demand.

This is analogous with the installation of domestic air conditioning systems. If only one house in the distribution system operates an air conditioner, you hardly notice the difference. However if everyone installs an air conditioning system then it can completely change the load profile of the area and make system management quite complicated.

To date grid-inter-tied systems have not been taken up sufficiently in Australia to have any obvious impact on the load profile of distribution systems. In other countries, where electricity prices are much higher, the use of building integrated photo-voltaic systems and grid-inter-tied wind or hydro systems (amongst many other initiatives) has seen changes in the demand profile. Residential areas can essentially become small electricity generators (compared to electrical loads) during the day when the production exceeds the local consumption.

As the output of wind turbines - or wind farms - becomes larger, the impact on the distribution system changes. As at the end of 2003 all the wind farms in Australia operate as “embedded” generators. An embedded generator is one in which the electrical output is sold within the local distribution network to which it is connected and satisfies (either partially or completely) the need of the retailer’s own customers within that part of the network.

It is essentially like a very large version of the domestic grid-inter-tied system. The Codrington wind farm in south west Victoria is connected to the power line that supplies the electricity to Portland and its surrounding districts. This power comes from the Koroit zone sub station (NB: the aluminium smelter has its own separate supply). When the wind farm is able to generate enough energy to meet the demand for electricity in Portland, no energy needs to be delivered from Koroit. As far as the system at Koroit is concerned, it is as if everyone in Portland turned their power off. If the demand exceeds the output of the wind farm the short fall is delivered from Koroit in the traditional way. When the output of the wind farm exceeds the needs of Portland, as is often the case, energy actually flows “backwards” up the system to Koroit. This extra energy is then used to supply customers fed directly from the Koroit sub station and in this case the “up-stream” terminal station, located at Terang, simply sees a further reduction in demand at Koroit.

A significant challenge for wind farm developers is paying for the technical upgrades and augmentation of the grid so that they can connect their wind farm to the system. For example at Codrington the grid needed to be augmented so that it could cope with the maximum output of the wind farm (which at times would have otherwise exceeded the capacity of the power line) and the zone sub-stations had to be altered so that they would be able to cope with reverse power flows.

While it may not be obvious, an important part of a traditional centralised electricity system is that energy flows only in one direction. With the advent of distributed generation we need to be able to allow electricity flows in both directions.

Making such changes to the electricity system costs money. Traditionally in the environment of government owned and operated, vertically integrated, monopolies a new electricity generator had such upgrades provided to it and such costs were not associated with the generator. Today the environment is very different and a generator or customer must pay for any upgrades required for connection to the National Electricity Grid. These costs can represent a significant part of the cost of the project.

Some of the wind farms proposed for construction in the future have very large capacities (compared to the electricity grid to which they will be connected) and will not be embedded generators. Instead they will be connected to the transmission system at very high voltages and their output will be sold to retailers across the country, essentially in the same way that large fossil fuel generators operate now. In doing so the wind farm operator is able to take advantage of economies of scale both in the construction of the wind farm itself and also in regard to the costs of connection of the wind farm to the electricity grid.

ARE THERE ANY TRANSMISSION LOSS SAVINGS FROM WIND FARMS

One of the advantages of distributed generation is that it brings the generator closer to the load and the energy does not have to travel as far through power lines. This in turn means that the losses associated with the transport of the energy can be significantly reduced.

These losses occur in all powerlines weather they be very high voltage transmission lines or the local distribution lines or even the power cables in your own home. The losses associated with the transmission and distribution of electricity can be quite significant. On average the transmission and distribution losses consume between 10% and 15% of the electricity that we generate. In some areas, especially those that are a long way from the centralised generators, the losses can be even higher.

The rate of loss is related to the flow of energy in a line and the resistance to flow of the line. To reduce the losses associated with the transport of a given amount of energy we can either reduce the rate of flow or reduce the resistance.

We can reduce the rate of flow of electricity (current) by increasing the voltage of the electricity. This is why we use quite high voltages (e.g. 500,000 Volts) in long transmission lines. The other way to reduce transport losses is to increase the size of the conductor so that its resistance is reduced (like using a bigger pipe).

It is worth noting that the resistance to the flow of electricity in metal wires increases with temperature. This is why power lines have reduced capacities during summer months. Consequently carrying capacities are generally calculated for summer periods.

Both loss reduction strategies are quite expensive to undertake: a larger conductor costs a lot more to manufacture, is much heavier to hold up on poles and catches more wind; higher voltages need to be quite high off the ground (50m or more) and are much more difficult to handle and so are more expensive to insulate, switch and transform.

Distributed generation can be a cost effective alternative to simply putting in more and bigger poles and wires.

For example a wind farm on the Yorke Peninsular in South Australia would be able to generate electricity for local consumption. While the energy generated is less than the local energy consumption the amount of energy that has to be brought from Torrens

Island or Port Augusta is significantly reduced and the amount of energy lost during its transport over the several hundred kilometre trip would be reduced. Once the level of generation matches the local consumption the transmission losses are eliminated because no energy needs to be imported to the local area. As generation levels exceed local consumption the energy begins to flow back out into the grid and there will be losses associated with that flow. However these losses will still be smaller than without the wind farm until the wind farm generation exceeds local consumption by so much that the region is exporting more energy than it would otherwise have been importing.

Another way that a distributed generator such as a wind farm can reduce losses is through the augmentation required to connect it to the grid. Sometimes the power lines need to have new conductors installed to be able to cope with the amount of energy coming from the generator. The new power lines and other associated equipment will be more efficient and so losses will be further reduced.

DOES A WIND FARM REALLY DISPLACE COAL GENERATION

Wind farms reduce the amount of energy required in a particular distribution area in two ways. Firstly there is the actual energy that they produce that supplies the local loads and secondly there is the reduction in transport losses that would otherwise have been incurred in delivering energy from the centralised power system.

While it is quite reasonable to assume that the generation from the wind farm would displace generation from the dirtiest and least efficient of our traditional generators, this may not necessarily be the case at all times.

The dispatch of generation into the national electricity grid is adjusted every 5 minutes by NEMMCO. The way NEMMCO determine which generators to dispatch is by a bidding system. The generators are ordered according to the sale price that they bid, from least to most expensive and NEMMCO begins by dispatching the least expensive and works through the list until the needs of the system are met. Once the needs of the system are met the remaining generators are not dispatched so if your price is too high then you may not be dispatched (be allowed to generate) at all for a particular period. The last generators to be dispatched are called marginal generators (they are on the margin).

To date wind farms in Australia have all been “price takers” and bid at zero dollars all the time. This means they are essentially guaranteed to be dispatched. Whatever capacity they are able to offer to the system will no longer need to come from another generator and the point in the stack of generators at which NEMMCO will stop dispatching moves a little lower. In other words, wind farms displace the more expensive marginal generators.

There is no driver within the system to encourage NEMMCO to dispatch cleaner or more efficient generation technologies. NEMMCO’s primary responsibility is system security and stability and then to run the system as cheaply as possible (none of which are easy tasks!). They are not responsible for the emissions from the generators, or how safely they operate, or how socially desirable they may be. NEMMCO has no way of influencing the operation of the electricity system except through price.

Fossil-fuel generators are able to dump their emissions in our atmosphere for free, so the cost to us as a community is externalised from the operation of the power station and is not included in the price of their bids to NEMMCO. So NEMMCO has no way of giving any preference to renewable energy or any low emission technologies that may be more desirable than traditional fossil fuel technology, unless its price is lower.

So which marginal generators are displaced by a new wind farm? The marginal generator varies according to the load on the system, bidding behaviour of other market participants, new electricity inter-connectors between states and generator additions and subtractions from the market in the intervening time. However approximately 90% of our electricity generation comes from the burning of fossil fuels and over 90% of that fossil fuelled derived electricity is from burning coal. Consequently it is a safe bet that the wind farm will be displacing coal fired generation at least some of the time.

It is possible to calculate the order in which generators would logically be dispatched in the market, and to compare this 'stack' of generators against the load-duration curve projected by NEMMCO. Such a calculation was done by Sinclair Knight Merz for Pacific Hydro's Portland Wind Energy Project Environment Effect Statement. For more detailed explanation you should refer to that document.

Essentially the stack of generators has local coal-fired generators (the cheapest) at the bottom, inter-state coal-fired generators further up and the more expensive local gas-fired generators at the top. Additional wind generation would appear on the 'stack' at the very bottom, since wind generation has a very low variable operating costs and is generally going to operate as a price-taker and be bid at zero anyway.

It is not anticipated that the operation of a wind project would ever displace hydroelectric generation (such as Snowy Mountains Hydro). This is because hydroelectric facilities are either run-of-river (where the hydro facility will operate without consideration of other generators in the electricity market – i.e. act as a "price-taker"), or storage dam facilities where at most the presence of other renewable energy generators will only move the hydro generation from one time to another without reducing the overall amount of hydro electricity generated.

Each extra wind generator would lift the 'stack' up such that for every 1 MWh of wind generation provided at the bottom of the stack, 1MWh of the marginal generator's output (i.e. the generator that is represented by the point where the 'stack' matches the load-duration curve at the hour in question) is displaced. This marginal generator does not generate the 1MWh that it otherwise would have generated and does not emit the greenhouse gas emissions that it would have emitted in generating the 1MWh. Since the wind generator does not create any greenhouse gas emissions in generating its 1MWh, the emission of greenhouse gasses from the marginal generator at this time is entirely saved for each and every MWh provided by the wind generators.

For the Portland Wind Energy Project the calculations showed that in the year 2010 (as an example) that the marginal generator would be, brown coal power stations for approximately 50% of the time, NSW black coal power stations for approximately an additional 40% of the year and gas fuelled power stations for the remainder of the time. The calculation results are shown in Table 1

Year	Brown coal %	Black coal %	Gas %	Average emissions factor
2001	80%	19%	1%	1.5
2002	80%	19%	1%	1.5
2003	78%	20%	2%	1.4
2004	75%	23%	2%	1.4
2005	70%	27%	3%	1.4
2006	67%	29%	4%	1.4
2007	63%	32%	5%	1.3
2008	59%	35%	6%	1.3
2009	56%	37%	7%	1.3
2010+	50%	40%	10%	1.2
Average (20 years)			**1.3**	

Table 1 Marginal Generation Displacement by Portland Wind Energy Project[4]

[4] Portland Wind Energy Project: Environment Effects Statement and Planning Report, Supplemental Volume A. 2001

The average emissions factor is determined by aggregating the typical greenhouse gas emissions for each of the technologies. These typical levels are shown in Table 2.

It is of note that not only do the older brown coal-fired plants have a higher expected cost of generation, but they also have a higher greenhouse gas emission rate compared to newer brown coal-fired plants. So, to the extent that the Wind Farm displaces brown coal fired generation, it can be expected that this displaced brown coal-fired generation would be the higher emitting, older plants.

Technology	Typical greenhouse gas emissions T/MWh CO_2
Brown coal	From 1.2 (newer plants) to 1.6 (older plants)
Black coal	0.93
Gas	0.53

Table 2 Typical greenhouse gas emissions rates for each technology[5]

IS WIND POWER BASE LOAD POWER

Wind power, along with a number of other distributed generation technologies does not conform to the traditional definitions of generation used in a centralised system. A base load power station is one which provides power to meet a consistent level of demand. This consistent level provides the base of the demand profile (see Figure 1) and so is called the base load. Generators that provide the supply to meet base load are called base load generators. Loads in excess of the base load are called intermediate loads and the very peak of the load curve is called peak loads.

In a centralised system with very large generators it is important that the characteristics of different generators are matched to the loads that they supply. For example it may take a large coal fired power station a few days to come on line after a complete shutdown so these generators are scheduled and are not allowed to shut down without giving prior notice to the system operator (NEMMCO).

Even changing the output of a large coal fired power station in response to a change in load may take several hours. Consequently intermediate plants are operated in the system. These plants are only operated when the load is expected to exceed base load levels. They are able to respond to changes in load more quickly but because of this and also because they operate only for short periods, they are more expensive to operate.

Finally, the very short duration peaks in the load are met by peaking plant. These generators are generally able to come on line extremely quickly and can respond to changes in load very rapidly. Such peaking plants are not used very often at all and so are even more expensive to operate and maintain in proportion to their total output.

The above is a simplified view of the system as many generators may operate differently at different times of the year. For example a peaking plant may actually operate continuously during extended periods of increased demand (e.g. hot summer weather) and actually be supplying intermediate loads.

For a wind farm this sort of labelling is nonsense. The wind farm will operate whenever the wind blows and its output is not scheduled to meet any particular load expectations. Wind power (especially embedded generation) should be thought of as a reduction in load rather than in terms of supplying base-load, intermediate-load or peak-load generation. This circumstance is not specific to wind energy. There are many other generators within the NEM that operate in this way.

[5] Portland Wind Energy Project: Environment Effects Statement and Planning Report, Supplemental Volume A. 2001

IS FOSSIL FUEL REQUIRED TO BACK UP WIND

It is a common misconception that a coal fired generator needs to be burning away on standby just in case the wind stops blowing. If this were true then, taking this argument to its logical conclusion, we would have a back up coal fired generator for every generator on the system. We would even need backup for the coal fired generators in case they failed!

It is true that the system operator (NEMMCO) manages a certain amount of reserve capacity so that it can manage changes in load or supply beyond their forecast expectations. However the level of reserve capacity is not equivalent to 100% of the system capacity! To have complete system redundancy would simply be too expensive.

There are two main issues here – Frequency Control Ancillary Services (FCAS) and Capacity Reserve. FCAS is what used to be called "spinning reserve" or "load-following" and describes scheduled generation capacity with very fast response time that is able to follow the small changes in level of demand in real time.

Capacity reserves are the amount by which the available generation exceeds the demand for electricity. These reserves are intended to maintain a balance between supply and demand even during situations where a reduction in generation capability has occurred. This means that customer load may continue to be supplied even though a generator has failed. If this was not the case then, especially during extreme conditions, it may be necessary for customer load to be reduced through load shedding until a balance between supply and demand is restored. Summer periods are generally the periods of lowest capacity reserve[6] simply because demand tends to be so high.

Capacity reserve differs from FCAS in three important respects. First, it occurs over longer time intervals than does FCAS, five minutes or more rather than minute to minute. Secondly the capacity reserve patterns of individual customers are highly correlated with each other, whereas the FCAS patterns are largely uncorrelated. Thirdly capacity reserve changes are often predictable (e.g. because of the weather dependence of many loads) and have similar day-to-day patterns; this phenomenon yields stable and predictable diurnal load shapes.[7]

To make matters even more complicated capacity reserve can be assessed in an operational sense (making sure there is excess capacity in real time) or in a planning sense (will we have sufficient reserve capacity in an hour's, a day's, a week's, a month's, a year's or a decade's time). Determining operational capacity reserve and ensuring it is adequate is a moderately complex task but essentially involves measuring the load and measuring the amount of generation available. By assessing operational capacity reserve we can assess the accuracy of our planning capacity reserve and change our schedule of generator dispatching accordingly. Determining planning capacity reserve is much more complicated but is very important in maintaining system security.

It is important to link this concept of planning capacity reserve to operational capacity reserve. Planning capacity reserve is the value given to a generating plant over a long time horizon, and is typically in the context of utility generation planning, and is the topic addressed here. Operational capacity reserve is the capacity value that could be specified in a transaction between utilities. Over the long run, we would expect that the average operational capacity reserves would approach the long-term value.

NEMMCO is responsible to maintain adequate capacity reserve to ensure system security and keeps the national electricity market informed of capacity reserve through its forecasts. If NEMMCO feels that there is not enough capacity reserve then it notifies the market of the deficiency and if possible allows market forces to correct the deficiency. As a matter of last resort NEMMCO may issue reliability directives to either instruct a scheduled generator to delay some maintenance or alert a scheduled load to curtail its consumption for a short period.

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[6] Management of Capacity Reserves, NEMCO System Operations Planning and Performance. Version 1.2 25 Sep 2003.
[7] Of Wind Farms With Bulk-Power Operations And Markets. Eric Hirst Sep 2001 Project for Sustainable FERC Energy Policy.

The amount of capacity reserve is only a small fraction (<10%) of the overall system capacity and is a measure of the risk assessment of the system. The minimum reserve capacity at the moment is set at about 1,800 MW while the overall system capacity is about 40,000 MW. Demand is predicted into the future and capacity is assessed to see if it will be adequate to cover an extreme level of demand where there is only a 10% probability of exceedence. This extreme load is generally going to occur in summer when there is a prolonged period of temperatures exceeding 35°C. It also assumes that such a condition occurs at the same time across the entire network and extra supply is not available from other jurisdictions. The reserve margin must also allow for an unscheduled outage of a large generation unit in each jurisdiction to occur during a period of extreme load.[8].

Each generator is assessed by NEMMCO to determine how much the system can rely upon its capacity being on-line when required. This calculation is performed as a part of the Project Assessment of System Adequacy (PASA) forecasts and takes into account the reliability (forced outage rate), capacity factor and schedule of maintenance of generators to determine the adequacy of the system.

Because generator capabilities vary according to fuel type and the method used to produce electricity, it is helpful to use a measure of capacity that can be applied to all types of plants. For example, the capacity value of a 100MW coal-fired plant might be equivalent to a 75MW oil-fired plant. A 300MW wind farm might provide the same capacity measure as the 100MW coal plant.

Integration of wind into the electricity system is qualitatively different to that of other types of generators because wind output depends on whether - when, and how hard the wind blows. Compared to conventional generators, wind's output is relatively less controllable, less predictable and more variable. Because of these characteristics and because electric-system operators have little experience with wind facilities, considerable disagreement exists about the costs of integrating wind into electrical systems.

On the one hand, wind advocates suggest that the small size of most wind farms implies that their output will be largely invisible (and therefore cost free) to a large electric system. On the other hand, some utilities suggest that every unscheduled megawatt movement of a wind farm must be offset, megawatt for megawatt, by some other resource, generally at high cost. Neither perspective is correct, nor is either perspective informed by actual operational data and analysis.[9]

There are several ways to look at the effective capacity of wind power plants. In regulated markets, the term "capacity credit" is often used to describe the level of conventional capacity that a wind plant could replace.[10]

Capacity credit estimates of wind power plants help generating companies, utility planners, and other decision-makers evaluate this intermittent resource in the context of other types of power plants. Capacity credit is the level of conventional generation that can be replaced with wind generation. To perform such an analysis, it is important to define the way in which one type of resource can be substituted for another. Most analysts prefer basing such a trade-off on a reliability measure.

A common measure of system reliability is loss-of-load expectation (LOLE). The LOLE is an indication of the statistically expected number of times within a given time period that the system could not provide for customer load. If a given level of wind-generating capacity can be substituted for conventional capacity, holding the reliability level constant, then we can obtain a measure of wind plant capacity credit.[11]

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[8] Statement of Opportunities 2003. NEMCO.
[9] Interactions Of Wind Farms With Bulk-Power Operations And Markets. Eric Hirst Sep 2001 Project for Sustainable FERC Energy Policy.
[10] Factors Relevant to Incorporating Wind Power Plants into the Generating Mix in Restructured Electricity Markets. Michael R. Milligan National Wind Technology Center National Renewable Energy Laboratory
[11] Modelling Utility-Scale Wind Power Plants Part 2: Capacity Credit Michael R. Milligan. NREL 2002

The energy value of wind power plants is highly dependent on the utility system in which it operates, the wind turbine performance characteristics, and the on-site wind regime. Because the wind power displaces power generated by marginal units, the value of power displaced will vary throughout the day. During low-load periods, a marginal generator typically has a lower fuel cost than during the system peak. Therefore, the timing of the wind power has an important influence on the value of energy that is displaced. Wind sites that are highly correlated with load will have a higher energy displacement value because higher-cost energy is displaced during the peak period.

One way to assess this is to calculate the reliability measure of choice (e.g. Loss Of Load Probability or LOLP) and compare the results with and without the generator of interest. Another approach involves converting to a megawatt quantity by increasing the peak load until the reliability matches the base case (excluding the generator of interest). This quantity, called the effective load-carrying capability (ELCC), is well known and has been widely used for many years. ELCC has traditionally been called a measure of capacity credit. To evaluate competing power plant options, one can calculate the ELCC of each plant.

Another related approach is to compare an intermittent power plant, such as wind, to its closest competitor (say, a gas plant). The evaluation strategy works like this. For a given size gas plant, calculate the system reliability for the generating system, including the gas plant. Record the system reliability attained by the calculations. Then remove the gas plant, substituting increasing penetrations of wind capacity until the reliability measure equals the system reliability in the gas plant case. Once this equality has been achieved, the rated capacity in MW of the wind plant is reliability-equivalent to the gas plant.

ELCC can be calculated for a wind power plant, using the same basic technique as for conventional power generators. Because wind power plants can only operate when the wind blows, the ELCC must be calculated so periods of lull are also taken into account. The most accurate way to do this is to use actual hourly chronological wind power output and hourly chronological load data. Because wind speed can vary significantly from year to year and from hour to hour, capacity credit estimates that are based on a single year (or less) of data and modelled without taking this variation into account may not be credible.[12]

Most studies of actual wind projects show that the planning capacity credit for wind is in the order of 20% to 40% and closely correlated to the capacity factor of the wind farm[13]. This makes some sense as the capacity factor of a generator driven by the wind is most significantly determined by the wind regime in which it operates (because their reliability and availabilities are so high). The more often and harder the wind blows the higher the capacity factor and the higher the capacity credit.

As is true for all loads and resources, the wind output is aggregated with all the other resources and loads to analyse the net effects of wind on the power system. Aggregation is a powerful mechanism used by the electricity industry to lower costs to all consumers. Such aggregation means that the system operator need not offset wind output on a megawatt-for-megawatt basis. Rather, all the operator need do, when unscheduled wind output appears on its system, is maintain its average reliability performance at the same level it would have without the wind resource.[14]

[12] Interactions Of Wind Farms With Bulk-Power Operations And Markets. Eric Hirst Sep 2001 Project for Sustainable FERC Energy Policy
[13] Californian Energy Commission. RPS Integration Analysis Workshop 12 Sep 2003
[14] Interactions Of Wind Farms With Bulk-Power Operations And Markets. Eric Hirst Sep 2001 Project for Sustainable FERC Energy Policy.

BENEFITS FROM A DIVERSITY OF WIND SITES

Several studies have examined the issue of geographically dispersed wind sites and the potential smoothing benefit on aggregate wind power output. The principle behind this benefit is that lulls in the wind tend to be more pronounced locally than over a wide geographic area. Building wind capacity at different locations may help reduce the problems caused by the intermittency of the wind resource. All of these studies found that the geographic spread of wind generators provides a smoothing benefit when wind output is aggregated. Although measurement techniques were different in each of these studies, the results appear to be robust across time scales ranging from minutes to hours.[15]

CHANGES IN CAPACITY RESERVE DUE TO INCLUSION OF WIND

As the systems capacity is increased a larger capacity reserve needs to be implemented because there is greater risk that more than one generator will fail during a peak load period. An issue raised because of the intermittent nature of wind resources is that the overall capacity reserve of the system needs to be increased by a disproportionate amount because the wind farm's output may disappear at any time without notice. In fact the amount of extra capacity reserve that is required in the system because of the inclusion of a wind farm is generally very low. The very worst case scenario analysed results in a reserve allocation that is less than 6% of the installed wind capacity, and the annual average reserve allocation is less than 1% of the wind-plant-rated capacity in all cases. [16]

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[15] Kahn, E. "The Reliability of Distributed Wind Generators," Electric Power Systems Research. Vol 2. 1979. Elsevier Sequoia. Lausanne, Switzerland.
Grubb, M., "The Integration of Renewable Electricity Sources," Energy Policy, September 1991. pp. 670-688.
Milligan, M., and Artig, R., "Optimal Site Selection and Sizing of Distributed Utility-Scale Wind Power Plants." Proceedings of the 1998 International Conference of the International Association for Energy Economics; May 13-16, 1998; Quebec City, Canada: International Association for Energy Economics: Cleveland, Ohio, USA; pp. 313-322.
Ernst, B., Analysis of Wind Power Ancillary Services Characteristics with German 250-MW Wind Data. 1999. NREL/TP-500-26969. Golden, Colorado: National Renewable Energy Laboratory.
Milligan, M., and Factor, T., "Optimizing the Geographic Distribution of Wind Plants in Iowa for Maximum Economic Benefit and Reliability." Journal of Wind Engineering 24, No. 4. 2000

[16] A Chronological Reliability Model Incorporating Wind Forecasts to Assess Wind Plant Reserve Allocation. Michael Milligan NREL 2002

Forecasting of wind farm output

Forecasts of the weather are important to us all – even if only to complain about how "wrong" the Bureau got the forecast! Climatic measurements and weather forecasting is very important for wind energy because it affects the location and ultimate operation of the wind farm.

Wind power can only be generated when the wind blows. Often mischaracterized as an unpredictable resource, the intermittent nature of a wind power plant does indeed present unique challenges to system-scheduling operations. Constraints on wind power plants are not unique, however, because each technology has distinct characteristics and presents operators with challenges that must be overcome.

It is important to understand that there are two broad phases of meteorology involved in wind farming – development phase wind monitoring and operational phase wind forecasting.

Development Phase Wind Monitoring

Prior to the construction of a wind farm a developer will make detailed measurements of the wind speed and direction at various heights above ground and may even measure temperature and air pressure on site too. All of these factors are very important to the determination of the energy in the wind. Wind speed is the most important factor because of the cube relationship between wind speed and energy. Complex computer models can then be used to determine how the wind flows across a wind farm site within a few kilometres of the monitoring mast. These models can be used to optimise the location of the wind turbines and determine what energy will be produced.

Just as important as the on site measurements are long term measurements of wind speed and direction at nearby reference stations. These reference stations are usually Bureau of Meteorology weather stations and are used to determine if the particular year(s) of on-site measurement were done in a particularly calm or windy year or just a typical year. By combining together the on-site and reference station data we can determine long term (20 to 30 year) predictions of energy output of the wind farm.

Unfortunately the equipment used in reference stations is less than optimal because of the difference of accuracy required for weather forecasting and wind energy measurements. Further complications are added by reference stations not necessarily being located in open areas where the wind monitoring is clear of the interference caused by obstacles etc. The Bureau does not have sufficient funds to install or maintain enough weather stations for weather forecasting let alone wind energy prediction modelling, so the location of the reference station may not always be ideal for proper correlation of the long term data to the short-term on-site data.

Despite these limitations the computer modelling can provide remarkably accurate predictions of energy outputs of wind farms with only 1 to 2% error over the long term.

These models are able to tell us the average annual energy output, the likely range of output from year to year, which months will have higher output than others and even the variation of energy output from hour to hour within a particular month of the year. However, these are predictions of the long term averages and are no different to the climate data provided by the Bureau.

The Bureau of Meteorology is able to provide us with detailed climate data (e.g. temperature, humidity, wind speed, rainfall, cloudiness, etc) so that we can see that Melbourne is cooler than Cairns but has less rain and rainy days than Sydney or that September is much windier in Hobart than April and Hobart is generally far windier than Alice Springs.

The wind energy predictions described so far are equivalent to the Bureau's climate data and are useful to wind farmers (just as the Bureau's climate data is to traditional farmers) in that they can help determine whether an area is suitable for a "crop" or not and when the best "growing" seasons are.

OPERATIONAL PHASE WIND FORECASTING

As the number of wind farms increases and the total rated capacity and energy output increase, their integration into the electricity system becomes more problematic. We will want to know not just that the wind farm will output a certain amount of energy over a year but also exactly how much energy it will produce between 9am and 10 am tomorrow.

This sort of prediction is analogous to the Bureau's weather forecasts and a great deal of work is being done to improve the ability of wind farm operators to predict their output.

Such forecasting can be helpful in scheduling maintenance on wind turbines (much better to do this in calm weather rather than windy weather) but is becoming increasingly important for the integration of the wind farm into the electricity system. This is because the forecasts will mean that the wind farm can be more heavily relied upon by system operators to provide a certain level of generation capacity.

As with the weather forecasts that we see on television or in newspapers, the further into the future we try to predict the less accurate our prediction is. Trying to predict the weather past about 4 days is generally little more than an educated guess.

While it is tempting to discount the reliability of weather forecasting - because "the Bureau never gets it right" - we need to keep in mind that weather is a very complex process and that there are many levels of weather forecasting. Trying to determine the exact temperature in each street or laneway right across the country at any given moment in time is very, very difficult. However we can improve our accuracy if we reduce the area for which we are trying to forecast and how far forward we wish to forecast (i.e. by reducing the forecast index in both space and time).

Short-term micro-scale forecasting is not unusual. Mining and smelting operations often have sophisticated weather modelling and forecasting for their local precinct so that they can better monitor and control the movement of dust or fumes. These predictions can be very accurate and the operation of the facility can be altered according to the forecast.

The same short-term micro-scale forecasting can be done for wind farms. A computer model can be used to determine the correlation between the large synoptic flows of air across the region to wind speeds across the wind farm site which may only be a few square kilometres. Detailed measurements of wind speed and direction on the site can be used to improve the predictive power of the forecasting models over time and through the use of fussy logic it is able to become relatively accurate within a short period of time. Once the wind speed and direction are know it is a relatively "simple" task to convert this into the output of the wind farm.

FORECASTING OUTPUT AIDS INTEGRATION INTO ELECTRICITY SYSTEM

Even though wind power output can be highly variable, it can be predicted with a reasonable degree of accuracy in the 1-hour-ahead time scale. Once the forecast error distribution can be estimated, it is possible to calculate the risk posed by wind forecast errors relative to the risk of other power plant outages. Using standard reliability calculations and a variation of the reserve allocation calculations, the reserve allocation to wind power plants is a small percentage of the wind plant rated capacity[17].

A wind resource that cannot be counted on for capacity has a minimal contribution to system reliability. An accurate forecast allows the utility to count on wind capacity and reduce costs without violating reliability constraints[18].

[17] A Chronological Reliability Model Incorporating Wind Forecasts To Assess Wind Plant Reserve Allocation. Michael R. Milligan, National Wind Technology Center National Renewable Energy Laboratory May 2002
[18] Modelling Utility-Scale Wind Power Plants Part 2: Capacity Credit Michael R. Milligan. NREL 2002

While here in Australia the total wind generation forms only a tiny fraction of the total generation (about 0.25%) in some parts of the network there is significant penetration of wind energy (e.g. in western Victoria where Pacific Hydro's Codrington and Challicum Hills wind farms provide a significant amount of the total energy). Consequently this forecasting of wind energy will soon become very important to utilities here in Australia.

Utility operations occur over several time scales. Generator (or supply) regulation is the fast response of generators to changes in load from minute to minute. Over longer periods, such as 10 minutes to a few hours, generators must be controlled so that longer trends in load can be accommodated. As more wind power plants are added to the electrical supply, there is more interest in the impact that these plants have on utility operations.

It is important to realize that even without wind plant, utilities have tremendous variability to contend with. Loads vary from day to day, hour to hour, and minute to minute. Utility operators have different procedures for handling these variations, and the existing portfolio of generating resources is divided unto units that can quickly respond to changing conditions and units that run at a more or less constant output. When analysing load data, utilities can take advantage of the statistical correlation between loads, which can be high in the load following time frame and low during the regulation time frame. System operation does not require running all generators at a flat output. Instead, the mix of units must respond so that the total generation balances the total load, with a small error component.

Load forecast errors and wind forecast errors are largely uncorrelated[19].

The impact of wind energy on the electricity system can be assessed over various time scales, ranging from regulation (seconds to minutes), load following (10 minutes to a few hours), and unit commitment (many hours to days). It is possible to predict the output of a wind farm from a few minutes to a couple of days ahead and these predictions can be periodically updated giving a "sliding window" effect on the forecasts. Generally the system operators wish to know what the output will be for the next one to two hours and what it will be in the next 12 to 48 hours. Meteorological models (using weather data from satellites and surface measurements) can be used to produce hourly wind forecasts for the next one to two days. Models that predict the output of a wind farm two hours ahead are called persistence models.[20]

Although the technology mix in each electrical control area is unique, basic system-scheduling methods are similar. An hourly load forecast is calculated, and resources are scheduled on an hourly basis so that expected demand plus a reserve margin are met. In cases of unanticipated generator outage or higher-than-expected load, a sufficient reserve margin protects against outages. When resources are scheduled for the day ahead, all known data are taken into account. For example, if a two-unit coal plant is undergoing repairs on one of its boilers, that unit won't be scheduled. All units that can reasonably be expected to generate (given market or other dispatch rules and procedures) are scheduled, subject to demand and generator cost or price.

If a wind farm is part of the power supply, it can participate in the same way. All known data are taken into account so that the wind farm can be scheduled on an hourly basis for the day ahead. Although mechanical availability is also relevant to wind farms, a few turbines that are out of service in a large wind farm won't significantly impair the wind farm's output. The main issue facing the wind farm operator is the accuracy of the wind forecast for the scheduling period. The best available forecast should be used to schedule the wind resource, just as the best available information is taken into account to schedule a conventional generator. In both cases, there may be financial penalties associated with a generator's inability to meet its scheduled output, and unanticipated excess generation may not produce profitable sales.

Wind does indeed have an impact on load following requirements and imbalance. The magnitude of these impacts increases nonlinearly with wind penetration. The increase in load following requirements is a fraction of wind farm rated capacity and can be analysed statistically. Similarly, the impact of wind on imbalances is noticeable, but it ranges from just more than 1% at low penetrations (5% penetration) up to about 4% at a high penetration (22%).

[19] Wind Power Plants and System Operation in the Hourly Time Domain M. Milligan. NREL May 2003
[20] Interactions Of Wind Farms With Bulk-Power Operations And Markets. Eric Hirst Sep 2001 Project for Sustainable FERC Energy Policy.

IS FORECASTING ACCURATE

The accuracy of wind forecasts will depend upon how well we know the site, to what resolution we wish to forecast output and how far forward we wish to forecast. Figure 6 shows a comparison of an hour ahead forecast over a one week period performed at a wind farm in USA.

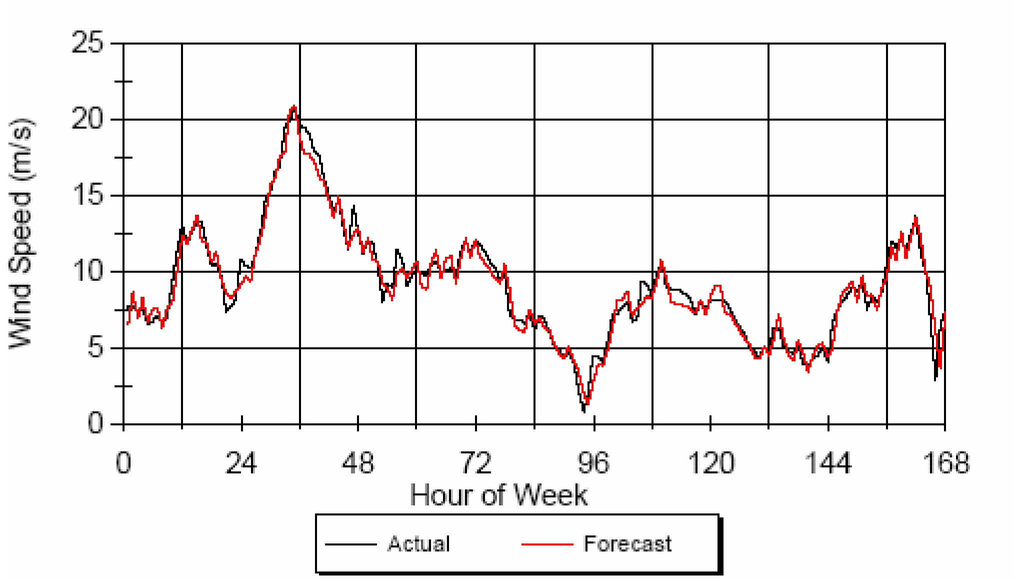

Figure 6 Comparison of Forecast to Actual Output at Estherville Wind Farm USA[21]

IMPLICATIONS OF GEOGRAPHICAL DIVERSITY ON OUTPUT FORECASTING ACCURACY

The main purpose of these models is to provide grid operators with the best information available so that conventional power generators can be scheduled as efficiently and as cost-effectively as possible. One of the important ancillary services is capacity reserve, which involves scheduling additional capacity to guard against shortfalls. A reserve allocation scheme using 1-hour forecasts results in a small allocation of system reserve relative to the rated capacity of the wind farm. This reserve allocation is even smaller when geographically dispersed wind sites are used instead of a large single site. Geographically dispersed sites significantly reduce the reserve burden. This combination of sites has approximately the same effect on the reserve allocation as a 50% improvement in forecasting accuracy. These results further support the development of geographically dispersed wind sites to mitigate the effects of unknown variability on aggregate wind power output.[22].

Studies have been performed by NREL on the actual performance of large diverse wind farms in the USA[23]. Wind farm output was monitored second-by-second at wind farms in Minnesota and Iowa at Lake Benton II (138 x Zond 750 kW turbines = 103.5MW), Storm Lake (262 x Zond 750 kW = 196.5 MW) and a series of smaller wind farms around Buffalo Ridge (220 MW).

Despite the stochastic nature of wind power fluctuations, the magnitudes and rates of wind power changes caused by wind speed variations are seldom extreme, nor are they totally random. Their values are bounded in narrow ranges. Power output data also show significant spatial diversities within a large wind power plant[24].

Their values are bounded in narrow ranges. For example, 94.5% of minute-by-minute power level changes are within a range of only 2.8% of the total installed capacity. Second-by-second power level changes are even smaller (98% are within 0.9% of the total installed capacity). The rates of sustained power changes are also relatively small, with 99% of all apparent ramping rates of a 100+ MW wind power plant within ±220 kW/s. The wind power production shows distinctive seasonal patterns, but these values remain relatively constant throughout the year.

[21] A Chronological Reliability Model Incorporating Wind Forecasts To Assess Wind Plant Reserve Allocation. Michael R. Milligan, National Wind Technology Center National Renewable Energy Laboratory May 2002

[22] A Chronological Reliability Model Incorporating Wind Forecasts To Assess Wind Plant Reserve Allocation. Michael R. Milligan, National Wind Technology Center National Renewable Energy Laboratory May 2002

[23] Short-Term Power Fluctuations Of Large Wind Power Plants. Yih-huei Wan (NREL) and Demy Bucaneg, Jr. (Enron Wind). NREL Jan 2002

[24] Short-Term Power Fluctuations Of Large Wind Power Plants. Yih-huei Wan (NREL) and Demy Bucaneg, Jr. (Enron Wind). NREL Jan 2002

The wind power plant output data show clearly the effect of aggregating many wind turbines. The variability of wind power decreases as the number of wind turbines in a wind power plant increases and the distances between turbines increase.

To the utility system, large wind power plants are not really random burdens. The narrow range of power level step changes provides a lot of information with which system operators can make short-term predictions of wind power. Large swings of wind power do occur, but those infrequent large changes (caused by wind speed changes) are always related to well-defined weather events, most of which can be accurately predicted in advance.

The data also offer encouraging evidence that accurate wind power forecasting is feasible. They clearly show that when one power production pattern appears at one wind farm, an almost identical pattern can later reappear at another wind farm, even hundreds of kilometres away. The time delay corresponds to the wind speed and direction. Correlation analysis of two power data streams confirms the observed time-delayed pattern repetition[25].

[25] Short-Term Power Fluctuations Of Large Wind Power Plants. Yih-huei Wan (NREL) and Demy Bucaneg, Jr. (Enron Wind). NREL Jan 2002

What does efficiency mean? Are wind turbines inefficient?

Efficiency is a measure of the ability of a system to convert an input to an output (e.g. energy, power). It is simply the quotient of the output of the system and the input of the system;

$$Efficiency = \frac{Output}{Input}$$

Efficiency is essentially used as a measure of the losses within a system and is usually expressed as a percentage. Because it is a comparison of an input and an output of the same type (e.g. energy out compared to energy in) it has no units.

Sometimes the term efficiency can be less rigorously (i.e. incorrectly) used to compare inputs and outputs of different types, such as the number of times to hit a nail with a hammer before it is sent completely home into the piece of timber (hits per nail). The correct term for this sort of comparison is *effectiveness* and it should not be confused or interchanged with *efficiency*. Note that the two can be combined using the term efficacious (i.e. efficient and effective).

Efficiency of any system may be measured between many different points within a complex system and it is easy to get very confused about which two points in the system we are talking about. This can also make comparison of two different systems very confusing if we do not compare the same two points in each system or worse yet try to compare irrelevant parts of a system.

Let us take the common motorcar as an example. We could look at the overall effectiveness of the car by looking at how much fuel is required to move the car a single kilometre (L/km). We could also (perhaps more correctly) look at how much energy is required to extract the necessary amount of crude oil buried in the ground, refine it to petrol and deliver it to the car to get it to move a single kilometre having taken into account the amount of energy required to construct the car in the first place. Both of these are worthwhile measures of effectiveness but are of completely different scales and should not be compared against each other (except perhaps to show how different they are).

Within the system (i.e. the car) we can look at the efficiency of the engine in its conversion of the chemical energy of the fuel into kinetic energy in the rotation of the drive shaft. We could also look at the efficiency of the gearbox in converting the high-speed rotation of the drive shaft into the lower speed rotation of the wheels. We could also look at the overall efficiency of the car at converting the chemical energy of the fuel into the kinetic energy of the car as it travels down the road.

This is all fine because we are comparing inputs and outputs of the same type (energy in this case). The problem occurs if we try to compare the efficiency of two cars but don't use the same measure of efficiency of each. For example if we compare the efficiency of conversion of fuel energy into drive shaft rotational energy in the first car with the efficiency of conversion of fuel energy to car motion energy in the second car then we have completely ignored the losses in the first car associated with the drive train transmission, aerodynamics, etc. Its not a fair comparison.

It is crucially important that efficiencies at the same points within a system are compared if the comparison is to be of any value at all.

Sometimes the two systems we wish to compare don't have similar points for comparison. Try comparing the fuel efficiency of a car with a petrol motor against a car with an electric motor - the driver of the electric car will still have all of the petrol left at the end of the test! Clearly this would not be a fair comparison.

So the important message with efficiency is to ensure that the measure of efficiency is a reasonable comparison between the two systems and that the way it is calculated is the same for each system.

WHAT IS THE EFFICIENCY OF WTG AND A WIND FARM?

As we now know there are many points at which we can measure the efficiency of any system. For a wind turbine the easiest measure of efficiency is to compare the energy that is available in the wind that impacts on its rotor to the electrical energy sent out at the terminals at the base of the wind turbine. In this way we can encompass the entire system losses in a single measure.

There is a theoretical limit to the amount of energy a wind turbine can extract from the wind. The limit is about 59% (16/27) and can be proved using Betz Theorem. However it is perhaps easier to understand if explained in simple terms rather than as a mathematical proof.

The wind turbine converts the kinetic energy of the wind (the energy of the motion of the air) into mechanical energy of the spinning drive shaft and then converts this into electrical energy using a generator. Because it takes the kinetic energy out of the wind the wind must be moving more slowly downwind of the wind turbine than it is upwind of the wind turbine. If our wind turbine had perfect, 100% efficiency then it would take all the energy out of the wind to convert into electricity. This means the "wind" would have no kinetic energy downwind of the wind turbine – i.e. motionless air. This clearly cannot happen because we need that air to get out of the way to let more wind hit the rotor so we can keep on generating more electricity. So there has to be some energy left in the wind so that the parcel of air will move away downwind of the wind turbine and let more wind into the machine.

Currently, the maximum efficiency (or Power coefficient - C_p) obtainable with a modern, large-scale wind turbine is roughly 47%[26]; this occurs when the rotor blade's tip speed is between five and six times the free-stream wind velocity (called tip speed ratio). For a given rotor rotational speed, the tip speed ratio drops rapidly as the wind velocity decreases. Consequently it is possible for a variable speed machine to maintain its peak efficiency over a much wider range of free-stream wind speeds because it can slow down (or speed up) the rate of rotation of the blade tips. Of course blade design is very important, and there can be significant variations between different machines which can be optimised for different wind speeds.

For small domestic machines the efficiency is not so high and their peak efficiency ranges from 20% to 35% depending upon the machine. The smaller machines simply don't have the size to allow for the precision blade design and the cost of such design would make these small machines cost prohibitive.

It is important to remember that the machine does not always operate at this peak efficiency. In fact we don't even want it too!

The energy in the wind is proportional to the cube of the wind speed. So as the wind speed increases slightly the energy in that wind increases dramatically. As the energy in the wind exceeds our ability to convert it to electricity (i.e. it is more than the capacity of the electrical generator) we purposely "spill" energy from the rotor blades (i.e. reduce the efficiency of the machine) so that the amount of energy it captures matches the capacity of the electrical generator.

Consider a 1.5 MW capacity generator which typically with have a rotor diameter of 64 metres. At wind speeds of 30 ms^{-1}, the rotor is receiving energy at the rate of about

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[26] Encyclopaedia Britannica 2003

213MW. We clearly do not want the turbine to be operating at 45% efficiency otherwise we would need to have a generator capable of generating 96MW. This is a massive machine and cannot be justified for the rare occasions that the wind blows at these extreme speeds.

In practice we make a compromise and "tune" the machine so that it operates at peak efficiency at those wind speeds that are most likely to occur. This can be done through changes to blade design, blade pitch or speed of rotation.

This is not the whole story though. We generally consider a wind farm rather than a single wind turbine. The above discussion only considers the efficiency of the machine to its output terminals. This will take into account the transmission losses of the drive train, the electricity required to operate the computerised controller, the yaw motors, lights, etc. However, there are a number of other components within the wind farm that will slightly reduce the overall efficiency of the system. These include losses associated with the transformers at each wind turbine, the losses of the cables of the collector network, the losses of the main transformer at the point at which the wind farm connects to the electricity grid and the power needed to operate monitoring equipment and the switchyard.

The meter by which the electricity is sold is usually mounted on the high voltage side of the main transformer so wind farm developers will take these losses into consideration in their predictions of energy output – they are interested in what they can sell which depends upon the "farm gate" meter.

While the losses of these component parts will vary from one wind farm to another transformers are generally 99% efficient or better and the cables are generally sized to ensure that the efficiency of the collector network is about 98%. Unfortunately these losses are compounding and so the overall electrical system efficiency (i.e. from the wind turbine generator output terminal to the "farm gate" may fall to about 96% to 97%. This would mean that the overall system peak efficiency would drop from its 45 - 47% down to about 43 – 45 %.

Of course wind energy has the advantage that the wind is free and renewable, so comparisons of the different measures of efficiency are relatively moot beyond the issue of the cost per unit of energy. The wind turbine will cost a certain amount of money to develop, install and operate. However the more efficient the turbine is the more energy (and therefore more revenue) it will produce so developers are always looking for more efficient machines – providing they don't impact the cost per unit of energy.

As an aside the main cost in a wind farm is servicing the debt incurred in its initial capital cost - so interest rates have a more important impact on the cost effectiveness of wind energy than the efficiency of the individual wind turbines.

How Does Wind Compare To Other Technologies' Efficiency?

Over the centuries, a wide array of devices and systems has been developed for the transformation of energy from forms provided by nature to forms that can be used by humans. Some of these energy converters are quite simple. The early windmills, for example, transformed the kinetic energy of wind into mechanical energy for pumping water and grinding grain.

Other energy-conversion systems are decidedly more complex, particularly those that take raw energy from fossil fuels and nuclear fuels to generate electrical power. Systems of this kind require multiple steps or processes in which energy undergoes a whole series of transformations through various intermediate forms.

Many of the energy converters widely used today involve the transformation of thermal energy into electrical energy. The efficiency of such systems is, however, subject to fundamental limitations, as dictated by the laws of thermodynamics and other scientific principles.

In contrast to this, considerable attention has been devoted in recent years to certain direct energy-conversion devices, notably solar cells and fuel cells, which bypass the intermediate step of conversion to heat energy in electrical power generation.

Energy can exist in many forms within a system and may be converted from one form to another within the constraint of the conservation law. These different forms include gravitational, kinetic, thermal, elastic, electrical, chemical, radiant, nuclear, and mass energy. Although the total amount of energy in an isolated system remains unchanged, there may be a great difference in the quality of different forms of energy within the system.

Many forms of energy, in theory, can be transformed completely into work or into other forms of energy. This is true for mechanical energy and electrical energy. The random motions of constituent parts of a material associated with thermal energy, however, represent energy that is not available completely for conversion into directed energy.

Energy Efficiency of Coal Fired Power Stations

Coal fired power stations are quite complex systems that involve several steps, including extraction, cleaning, transport, combustion, steam generation ,electricity generation and waste handling.

The energy efficiency of coal fired power stations varies from station to station depending upon the technologies used in each step of the process and upon the ease of access to and quality of fuel that they use.

It is important that we understand the efficiency statistics that we use. For example many of the boiler systems used in power stations have thermal efficiencies of over 80% however this is only part of the system. To quote this figure would be like quoting the transmission efficiency of a wind turbine's drive train (>98%) – it simply ignores most of the system.

Black coal-fired power stations (e.g. in NSW and Queensland) will have overall efficiencies of between 32% and 38%. For example the Tarong Power Station, which is one of the few power stations to publish its performance data, has an overall efficiency of 35.2%. This is mainly because they are able to use relatively dry black coal as their fuel source (moisture content of less than 15%).

Brown coal-fired power stations in Victoria have much lower overall efficiencies. The four main brown coal fired power stations do not publish their performance data, however it can be inferred from the amount of coal they mine and the amount of electricity produced. Based on publicly available data shown in the table below they have an overall efficiency of about 26%.

<table>
<tr><td>Station</td><td>Coal Consumed</td><td>Electrical Energy</td></tr>
<tr><td>Loy Yang A</td><td rowspan="2">31 Mega Tonnes</td><td rowspan="3">≈ 36 Tera Watt Hours</td></tr>
<tr><td>Loy Yang B</td></tr>
<tr><td>Yallourn W</td><td>18 Mega Tonnes</td></tr>
<tr><td>Hazelwood</td><td>18 Mega Tonnes</td><td>≈ 12 Tera Watt Hours</td></tr>
<tr><td>Total</td><td>67 Mega Tonnes[27]</td><td>48.465 Tera Watt Hours[28]</td></tr>
</table>

[27] The calorific value of the brown coal was assumed to be 10 mega joules per kilogram to give a total of 670 peta joules.
[28] This is equivalent to a total of 174 peta joules

Table 3 Consumption and Energy Production of Victorian Brown Coal Fired Geenrators

This reduced efficiency (compared to say Tarong) is mainly because of the very high moisture contents of the coal in the Latrobe Valley (generally above 60%).

Energy Efficiency of Gas Turbines

As for coal-fired power stations the efficiency of the plant will depend upon the technology used and the fuel source.

An open-cycle, gas turbine will have a plant efficiency of about 25% to 35% depending upon the compressor and turbine efficiencies. However modern combined-cycle, gas turbines (CCGT) can have much higher efficiencies. The combine cycle plant uses the cogeneration principle to produce power from a gas turbine linked to a steam turbine. The exhaust gases retain enough heat to raise steam to drive a turbo-generator. Because of its higher operating temperatures, the overall thermal efficiency of the combined cycle plant can approach 45%[29].

Another approach is to use a combine cycle gas turbine in a co-generation or combined heat and power (CHP) system. This is where the combined-cycle, gas turbine and steam driven turbo-generator are located at a facility where low-grade heat is also required. This allows the use of low-pressure steam and heat that cannot be economically used for electricity generation to be used as a heat source for an industrial process. In this way the overall thermal efficiency of the plant can reach as high as 90%, however this is perhaps an unfair comparison of technologies as the outputs are different.

Energy Efficiency of Photovoltaic Systems

Photovoltaic systems are an attractive alternative to fossil or fissile fuels for the generation of electricity. Sunlight is free, it does not use up an irreplaceable resource, and its conversion to electricity is non-polluting. In fact, photovoltaic systems are now in use where power lines from utility grids are either not possible or do not exist, as in outer space or remote, non-urban locations.

The barrier to widespread use of sunlight to generate electricity is the cost of photovoltaic systems. The application of materials science is essential in efforts to lower the cost to levels that can compete with those for fossil or fissile fuels.

In the early part of the 20th century the first true photovoltaic cells (using selenium and gold) were developed but they transformed less than 1% of the absorbed light energy into electrical energy.

By the 1930's both selenium and copper oxide were being employed in light-sensitive devices, however they still had energy-conversion efficiencies of less than 1%.

By the 1940's the silicon photovoltaic cell had emerged and was capable of 6% energy conversion efficiency when used in direct sunlight and by the late 1980's this had improved such that fabrication of cells with efficiencies of more than 20% was possible. Today, with the help of concentrators and sun tracking devices, it is possible to achieve efficiencies of as much as 37%[30].

This does not take into account the losses involved in transferring the electrical energy from the photovoltaic cell to the grid and overall system efficiencies can be significantly lower than this value.

Unfortunately the biggest limitation on terrestrial use of photovoltaic cells is that the energy source (direct sunlight) is not always available. For example in Melbourne the sun shines at an equivalent of about 4.5 peak solar hours per day.

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[29] From SA Government's Energy SA web site http://www.energy.sa.gov.au/pages/conventional/resources_use/coal/using_coal.htm
[30] Encyclopaedia Britannica 2003

ENERGY EFFICIENCY OF PHOTOSYNTHESIS[31]

The energy efficiency of photosynthesis is the ratio of the energy stored to the energy of light absorbed. The chemical energy stored is the difference between that contained in gaseous oxygen and organic compound products and the energy of water, carbon dioxide, and other reactants. The amount of energy stored can only be estimated because many products are formed, and these vary with the plant species and environmental conditions.

Light can be described as a wave of particles known as photons; these are units of energy, or light quanta. The energy of light varies inversely with the length of the photon waves; that is, the shorter the wavelength, the greater the energy content. Blue light has a shorter wavelength and therefore more energy than red light. The part of the solar spectrum used by plants has an estimated mean wavelength of 570 nanometres; and can therefore also be estimated.

The estimated maximum energy efficiency of photosynthesis is 26%. However the actual percentage of solar energy stored by plants is much less than this theoretical maximum. An agricultural crop in which the biomass (total dry weight) stores as much as 1% of total solar energy received on an annual area - wide basis is exceptional, although a few cases of higher yields (perhaps as much as 3.5% in sugarcane) are reported.

There are several reasons for this difference between the predicted maximum efficiency of photosynthesis and the actual energy stored in biomass. First, more than half of the incident sunlight is composed of wavelengths too long to be absorbed, while some of the remainder is reflected or lost to the leaves. Consequently, plants can at best absorb only about 34% of the incident sunlight.

Second, plants must carry out a variety of physiological processes in such non-photosynthetic tissues as roots and stems; these processes, as well as cellular respiration in all parts of the plant, use up stored energy.

Third, rates of photosynthesis in bright sunlight sometimes exceed the needs of the plants, resulting in the formation of excess sugars and starch. When this happens, the regulatory mechanisms of the plant slow down the process of photosynthesis, allowing more absorbed sunlight to go unused.

Fourth, in many plants, the process of photorespiration wastes energy.

Finally, the growing season may last only a few months of the year; sunlight received during other seasons is not used.

Furthermore, it should be noted that if only agricultural products (e.g., seeds, fruits, and tubers, rather than total biomass) are considered as the end product of the energy conversion process of photosynthesis, the efficiency falls even further.

So the efficiency of photosynthesis is very low. However none of us would consider it as a waste of time – given that most forms of life on the planet are totally dependent upon it!

[31] Encyclopaedia Britannica 2003

What does rated capacity mean?

The rated capacity of an electrical generator is the maximum power it is able to generate in its normal operation. It is expressed in Watts (or a multiple thereof). The term is synonymous with “name plate rating”.

A group of generators connected together will combine their capacity in an additive way. For example four generators each with a rated capacity of 500 mega watts will have a total rated capacity of 2,000 mega watts. In the same way a wind farm with ten wind turbine generators, each with a rated capacity of 1.5 megawatts, will have a rated capacity of 15 megawatts.

WHAT IS THE RATED CAPACITY OF WTG

The rated capacity of wind turbines can vary from a few watts to millions of watts depending upon the area swept by their rotor and the size of the electrical generator used in the machine.

The maximum size of modern, large-scale, series production, wind turbine generators has been growing steadily over recent years. This has come about mainly through advances in materials science, which has allowed machines to be scaled up.

In 2003 a typical wind turbine generator for use in an on-shore wind farm will have a rated capacity of between 1 and 2 mega watts while machines of up to 5 megawatts have been proposed for offshore installations.

HOW DOES WTG COMPARE TO OTHER TECHNOLOGIES IN TERMS OF RATED CAPACITY

Compared to other traditional electricity generators, wind turbines have quite small rated capacities. However they can be connected together in a wind farm to provide much greater capacities.

Very large generators can be connected to coal-fired turbines. Single machines of up to 1,300 mega watts have been installed. However for the most part, a series of machines are used in combination (e.g. four 350 MW machines at the Stanwell and Tarong Power Stations in Qld or the four 500MW machines at Loy Yang A in Victoria).

They can also be much smaller machines, such as the four 30 MW coal fired generators at Callide A Power Station in Qld.

Hydro-electric turbines can be quite variable in size from only a few watts up to more than a thousand megawatts in a single machine. Generally it is sized according to the resource available and is only limited by the characteristics of the materials used in its construction.

Typically electricity generators tend to have rated capacities of

- Coal or gas fired steam Turbines - hundreds of mega watts (up to thousands)
- Gas Turbines – tens of megawatts (up to hundreds)
- Large Hydro Turbines – tens of megawatts up to thousands
- Mini Hydro Turbines – hundreds of kilowatts (up to a few megawatts)
- Large Wind – tens of megawatts (up to hundreds of megawatts)
- Mini Wind – tens of kilowatts (up to a megawatt)
- Biomass – tens of kilowatts (up to tens of mega watts)
- Solar Thermal - tens of kilowatts (up to tens of mega watts)
- Photovoltaic – hundreds of watts (up to tens of kilowatts)

The rated capacity of a generation facility is of little consequence except in terms of the ability of the plant to take advantage of economies of scale. Having a single large plant can help reduce the capital costs associated with the construction of the plant and can also reduce the expenditure and the number of staff required to operate it.

This has been the main driver behind the establishment of our centralised electricity supply system in western societies. Large plants are established at the “mouth-of-mine” and huge electrical transmission systems are used to transport the energy to loads. This is fine, but this approach does have a downside and significant risks associated with it.

The major downside is the losses associated with the transmission system. By having the generation source a long way from the load centres, quite a lot of electricity is lost in the wires. By using very high voltages (e.g. 500,000 Volts) we can reduce these losses but on average the Australian electricity transmission system looses more than 10% of its generation in transmission losses. This means that the generators have to generate more than we consume so as to make up for these losses.

Some of the risks associated with large generation plant include the risk of a single plant failure disrupting large parts of the system. Imagine if we had only one generator in all of Australia. If this machine failed or had to be shut down for maintenance then no one would have any electricity. We help alleviate this risk by having multiple machines and in recent times by having a more interconnected electricity system (i.e. links between states). However, with only a few very large plant on the network, it can become very difficult to maintain system stability if even one machine goes off line unexpectedly. The greater the number of machines the less is the risk, because we would need multiple simultaneous failures to have the same problem.

A consequence of this is that system operators need to keep large machines on standby just in case we do have a failure. This imposes a cost on the whole network. The situation is worsened if the standby machines have long lead times and are required to be on idle and ready to go. The larger the machines on the system, the larger the machine(s) that will be need to be held on standby to make up for any unexpected failures.

Consequently, to say a generator is not useful, simply because it is “small”, is nonsense.

What does capacity factor mean?

No electricity generator operates at full rated capacity all of the time. There will always be a period of time when it needs to be serviced or when the electricity system does not require it to operate at its full rated capacity. The measure of a generator’s operational output compared to its theoretical ability to operate continuously at full rated capacity is called capacity factor and is usually expressed as a percentage.

As is the case with any statistic, it is important that there is a proper understanding of how capacity factor is calculated so we can be sure that any comparison between different plant are reasonable and made on a fair basis. Capacity factor is conventionally measured over an entire year (i.e. 8,760 hours) using the following formula;

$$CapacityFactor = \frac{ActualEnergyOutput(Wh)}{RatedPowerCapacity(W) \times Time(h)} \times 100$$

Consider a five-megawatt generator that operates for eight months of the year (6,080 hours) at full rated capacity (i.e. is generating at five megawatts) but for the remainder of the year (2,680 hours) only operates at 80% of its capacity (i.e. is generating at four megawatts). Over the whole year it will actually produce a total of (5MW x 6,080h = 30,400 MWh) plus (4MW x 2,680h = 10,720 MWh) or a total of 41,120MWh. So its capacity factor could be calculated as follows

$$
\begin{aligned}
CapacityFactor &= \frac{ActualEnergyOutput(Wh)}{RatedPowerCapacity(W) \times Time(h)} \times 100 \\
&= \frac{(5 \times 6080) + (4 \times 2680)}{5 \times 8760} \times 100 \\
&= \frac{41120}{43800} \times 100 \\
&= 93.9\%
\end{aligned}
$$

In reality, generators do not operate in this simple way. Their output will vary from day-to-day and within each day according to the requirements of the load they are servicing. The capacity factor will be determined by comparing the generators actual output with the theoretical output of continuous operation at full rated capacity.

Just like efficiency, capacity factor can be determined at a lot of different points along the system. The best measure of capacity factor for a generator is to measure the output from the generator's terminals compared to its theoretical maximum output. Likewise the best measure of capacity factor for a power station (e.g. Loy Yang A or Toora Wind Farm) is to measure the amount of energy leaving the power station's "front gate" and compare this to the theoretical output of the station.

Measuring a power station's capacity factor in this way, will take into account all the losses and other factors that affect the total output of the power station. Things that will affect the power station's capacity factor include;

- Fuel availability
- Generator reliability and availability
- Grid reliability and availability
- Electrical losses between generator and the "front gate" (including transformer losses)
- Internal consumption (e.g. lighting, control systems, etc)

By taking all these losses and factors into account when measuring the capacity factor it is reasonable to use the term Net Capacity Factor (as opposed to the Gross Capacity Factor which merely looks at the generator terminals).

Predicting Capacity Factor

Predictions of capacity factor are a little bit more problematic in that they may need to be further discounted to allow for the generator operating below expected performance. Large electrical generators cannot be tested before they are purchased and manufacturers will provide guarantees of performance to the purchaser. A manufacturer may only guarantee that the generator will perform to within 97% of its expected output for a given fuel input. In such cases the actual output will be discounted (to 97%) to allow for this potential loss.

Capacity factor is not always a very good measure of the usefulness or effectiveness of a generator. It does not always tell us anything beyond the figure itself. It does not tell us how often the machine will operate or what would provide an equivalent outcome. Some quite large generators only operate for a small number of hours a year and yet they are critical to the operation of the electricity system. Their capacity factors are extremely low.

Consider a 200 MW generator with a capacity factor of just 1%. This means that the generator only produced 17,520 MWh in the year as compared to the 1,752,000 MWh it could have provided if operating at rated capacity all the time. It might be tempting to say that we could replace that generator with one of say 4 MW and operate it with a capacity factor of 50%, however this may completely miss the importance of the generator. If the generator is a peaking generator then it may only operate for a hundred or so hours in a whole year but when it does, it must be able to deliver power at the rate of 200 MW to assist in maintaining system stability. At only 4MW the entire system might begin to collapse and load shedding (blackouts) may be required.

Likewise some generators will have lower capacity factors because of fuel constraints. Generators that are fuelled by bagasse (the cane trash from a sugar refinery) may only operate during cane harvesting time because the bagasse cannot be stored for extended periods beyond the end of the harvest season. This low capacity factor is not a poor reflection on the generator, merely a consequence of the intermittent resource upon which it relies. It is still a very effective use of the bagasse resource.

Comparing Capacity Factor, Reliability, Availability and Utilization

It is timely to compare capacity factor with other terms that are used to describe the operation of a generator, namely reliability, availability and utilisation.

Reliability is a measure of how long a period of time occurs between failures of the machine or how long those failures last. In the former case it is a measure of time (i.e. days, weeks, months or years between failures) but in the later it is expressed as a percentage of the time the machine is not able to operate because of a failure.

Availability describes how much of the time the generator is available to operate. It is generally expressed as a percentage of the year. This does not mean it actually operates, simply that it is ready to operate. Availability takes into account the reliability of a machine as well as how long it is shut down for servicing. In other words it takes into account its scheduled outages as well as its unscheduled outages. For example, a machine may have 100% reliability (i.e. it never fails) but have quite a low availability because service crews are always required to preform scheduled maintenance.

It is important not to confuse this “mechanical availability” of a generator (from the wind farm operator’s point of view) with its readiness to provide electricity to the grid (from the grid operator’s point of view).

Utilisation is a measure of how often the machine operates and is expressed either in hours or as a percentage of a year. A generator is deemed as being utilised regardless of the capacity at which it operates – i.e. even if it is only outputting 0.1% of its rated capacity, that time is still considered to be utilised.

To illustrate the variance in each of these terms consider a 1 mega watt generator with the following operational profile over a 210 hour period.

Hours	Status	reason
10	shutdown	unexpected fault
10	operating (100%)	Demand high
5	shut down	scheduled maintenance
20	operating(50%)	demand low
5	shut down	no fuel, generator OK
10	operating (25%)	demand low
1	shut down	grid failure, generator OK
39	operating (40%)	demand low
90	operating (100%)	demand high
10	shutdown	scheduled maintenance
10	Shutdown	No demand

During the 200 hour period the machine has;

- Operated for a total of 169 hours (so utilization is 80.47%).
- Output a total of 128.1 MWh (so capacity factor is 61.00%).
- Had 10 hours of unscheduled maintenance (so reliability is 95.24%).
- Been ready to operate for a total of 175 hours (so availability is 83.33%).
- In a position to deliver energy to the grid for 179 hours (so readiness is 85.24%)

What Is The Capacity Factor, Reliability, Availability and Utilisation Of Wind Turbine Generators And Wind Farms?

From the previous discussion it will be clear that the biggest influence on a wind farm's capacity factor will be its "fuel availability" – i.e. how hard and often the wind blows. Sometimes capacity factor is erroneously used as a de facto measure of how energetic a wind regime is. Such use of capacity factor is only valid if the same wind turbine generator is used at each site. Some turbines produce much more energy than others (e.g. variable speed, pitch controlled machine compared to constant speed, stall controlled machine) so just by changing the turbine generator the capacity factor will change for the same site.

The capacity factor values for wind farms in Australia vary quite widely, but the capacity factors for all wind farms around the world will generally fall within the range of between 20% and 50% (see Table 4 for actual Australia values). Currently the wind farms with the highest capacity factors in the world are located in New Zealand - Poll Hill wind turbine and Tararua Wind Farm - both with overall annual net capacity factors in excess of 50%.

Wind farm site	Total rated Capacity (MW)	Number of Generators	Capacity Factor
Codrington (VIC)	18.2	14	35.0%
Windy Hill (QLD)	12.0	20	28.5%
Blayney (NSW)	9.9	15	19.6%
Crookwell (NSW)	4.8	8	20.0%
10 Mile Lagoon (WA)	2.0	9	32.0%

Table 4 Comparison of Capacity Factors of some Australian Wind Farms[32]

[32] Portland Wind Energy Project Environmental Effects Statement. Pacific Hydro Limited 2002.

It is difficult to determine what capacity factor might be deemed acceptable to a wind farm developer. Generally they will want as high a capacity factor as possible but in the end it comes down to the price per unit of energy sold that is required to recover costs and earn the desired level of profit.

In circumstances where electricity costs more, a lower capacity factor will be acceptable to the developer. For example, in almost any country around the world electricity prices are higher than here in Australia, so it is likely that lower capacity factors will be deemed acceptable. Even here in Australia there are places such as King Island or the remote grids of Western Australia where electricity prices are very high (and are subsequently heavily subsidised by state governments to make them affordable). Consequently lower capacity factors may be acceptable. (NB King Island and south western WA are exposed to consistently strong winds and the wind farms here are blessed with high capacity factors, making the use of wind energy very sensible).

Wind turbines, and consequently wind farms, have very high reliability and availability. Typically wind turbines have reliabilities of 99% or more and most often it is above 99.8%. Availabilities are generally in excess of 95% and most often will be around 97% to 99%.

The availability of wind farms (like all generators) tend to be lower in the early part of their life (during the first six to twelve months) as the machines bed in. During this period the availability may be as low as 95% but once the machine passes this period they routinely exhibit availabilities in excess of 99%. Most manufacturers will make financial guarantees that the availability of their wind turbines will be in excess of 97%.

Utilisation of wind turbines, and consequently wind farms, will vary according to the wind regime in which they are placed and to a lesser extent the grid to which they are connected. Because of their high reliability and availability it is the lack of "fuel" (i.e. suitable wind speed) which is the main restraint on their utilisation.

For most wind farms in Australia the utilisation is excess of 90% and for many it is in excess of 97%. The times when the machine is available to generate but is not utilised relates to periods when the wind speed is too low to justify operation of the machine (usually less than $3ms^{-1}$ or 12 km/hr) or when the wind speed is too high and the machine needs to be shut down to protect it from damage (usually greater than $25ms^{-1}$ or 90km/hr). These wind speeds are generally quite rare at most wind farm sites. This is especially the case in Australia where electricity prices are so low that developers search for very windy sites to ensure that their project will be economically successful.

Another circumstance to affect utilisation is grid failure. The wind farm cannot operate if the section of the grid to which it is connected fails. Generally most wind farms will be connected to relatively robust parts of the grid (or the grid is made that way as a part of the grid augmentation), however it can occasionally impose significant restraints on the utilisation of the wind farm.

How Does This Compare To Other Technologies?

As can be imagined, the fuel supply to mouth-of-mine coal-fired power stations is not constrained except in rare and exceptional circumstances such as equipment failure or industrial action. In fact these generators are so important to our system security that specific reference is made to them in legislation to prevent any industrial action that would limit their operation.

Capacity factors of large coal fired power stations that are used as base-load, scheduled generators tend to be quite high and are limited more by their availability and to a lesser extent by their utilisation factors. In other words they are run at full capacity whenever they are ready to generate.

Table 5 shows the capacity factor of a number of Victoria's brown coal-fired, base load generator power stations. While these figures are a little out of date, the "recent" figures from 1999 are a good indication of the capacity factors of base load power stations. The improvement during the 1990's was mainly due to increases in availability of these power stations.

Power station	**Capacity Factor %**	
	1989 – 91 (3 year average)	"Recent" (1999)
Loy Yang (A)	85.0	96.4 (1st half 99)
Yallourn (W)	69.7	91.6 (98/99)*
Hazelwood	56.7	89.4 (7 months 99)

Table 5 Some power station capacity factors[33]

Australian power stations have achieved significant improvement in their availability in recent years. The best publicly available data is the summary provided by the ESAA (1998). In 1995/6 the average availability factor for Australia was 89.1% while for 96/97 the availability had improved to 90.9%. The forced outage factor had reduced from 3.0 to 1.7 (see Table 6[34])

State	**Availability factor %**		**Forced outage factor %**		**Planned outage factor %**	
	95/96	**96/97**	**95/96**	**96/97**	**95/96**	**96/97**
NSW	92.0	92.1	3.0	1.6	5.0	6.3
Vic	83.0	91.3	4.0	2.1	12.7	6.6
Qld	90.2	93.1	3.2	1.5	6.6	5.4
SA	89.2	87.9	3.4	N/A	7.4	N/A
WA	90.8	89.7	2.3	3.5	6.9	6.8
Tas	93.5	82.1	0.7	0.2	5.8	17.7
SMHEA	85.5	90.7	1.1	1.4	13.4	8.0
NT	N/A	N/A	N/A	N/A	N/A	N/A
Australia	89.1	90.9	3.0	1.7	7.9	7.2

Table 6 Generation Availability from Electricity Australia 1998

Description	**Typical frequency**	**Typical duration**	**Typical LOA**	**Content of outage**
Major outages (Full inspection)	Every 4 years	4-8 weeks	2-4 %	Planned major repairs
Minor outages	Yearly or six monthly	3-5 days	1%	Critical planned inspections and repairs
Boiler clean(This type of outage is required only by brown coal boilers)	Determined by fouling in boiler- 3-6 months	2 days	1%	Heat transfer surfaces cleaned. Inspections may be possible in some areas. Always happens at beginning of minor and major outages.
Forced outage	Random event	2-3 days	2-8%	Repair the failure and inspect other equipment at immediate risk
TOTAL			6-14%	

Table 7 Causes of Loss of Availability for Coal Fired Power Stations in Victoria[35]

Prior to privatisation, the capacity factor for the large coal-fired power stations were very close to the availability factor because of the way the system was run. These stations were considered to be "high on the order of merit" and difficult to start up and were generally loaded as soon as they were available.

Loy Yang A, between 1989 and 1991, averaged an availability of 85%. In 1998 Loy Yang A achieved an availability of 97.4%. This is actually close to the absolute possible value of the station (see Table 7) and was aided by there being no long planned outage in that

33 From The Performance Of Victoria's Privatized Power Stations ,John W H Price, Mechanical Engineering Department, Monash University. Proceedings of the Australian Institute of Energy National Conference 1999

34 From The Performance Of Victoria's Privatized Power Stations ,John W H Price, Mechanical Engineering Department, Monash University. Proceedings of the Australian Institute of Energy National Conference 1999

35 The historical availability figures for Victorian power stations from the period of government ownership prior to any privatisation are given in the SECV 1990/1 Annual report (SECV 1991). More recent data for the individual power stations is available from company newsletters.

year. The average which Loy Yang A can achieve is about 95%. Even so this change is significant and it is like adding another 200 MW to the station.

Hazelwood, between 1989 and 1991, averaged availability of 56.7% which is a very poor figure. Hazelwood had suffered persistent long term problems with reliability and in fact 1989-91were actually better than previous years. For most of its life the station struggled with availability between 48% and 60% (SECV report 1991). There had been only two occasions, in 1974 and 1991, lasting only a few weeks on each occasion, when all 8 boilers had been simultaneously in operation.

In 1998 (to November) an availability of 82.7% was achieved (Hazelwood 1998). This change is, on its own, like having a new power station of over 400 MW on the grid.

The reliability, availability, capacity factor and utilization of power stations that are not operated as base load generators (i.e. intermediate and peaking plant) is significantly different. They also operate using different fuels and different technologies.

Mica Creek Power Station[36] consists of gas and waste heat powered steam and gas turbine generators ranging in age from 40 to 4 years with combined capacity of 325 MW. The total consumption is of 18PJ of gas and 2.7 GL of water per year to produce 2 TWh of electricity. So overall efficiency is approximately 20%.

Swanbank Power Station[37] consists of black coal (1Mtonne), diesel oil (4ML) and natural gas (5PJ) firing gas and steam turbines with a total rated capacity of 1356 MW to produce approximately 3 TWh of electricity. So overall efficiency is approximately 25%.

[36] Mica Creek Power Station Facts June 2001 CS Energy
[37] Swanbank Power Station Facts June 2001. CS Energy.

Is Energy Efficiency a More Effective Approach to GHG Emission Reductions?

The problem of accelerated climate change from the emission of greenhouse gasses is a very serious one and there is no “magic bullet” solution to the problem of reducing our greenhouse gas emissions. Greenhouse gasses such as carbon dioxide remain in the atmosphere for at least 50 years so the effect of the gasses we emit today will be with us for at least another half century - even if we were to totally eliminate all greenhouse gas emissions today!

To combat the problem of dangerous climate change, it has been suggested that we need to immediately reduce our emissions to a level 50% below the 1990 level of emissions. This is a huge change, and to date the global community, and more specifically the Australian community, have done little more than slow the growth in emissions let alone reduce them.

Reducing our greenhouse gas emissions will require a variety of approaches in all walks of life. The use of electricity is a major contributor to Australia’s greenhouse gas emissions and represents approximately 45% of our total greenhouse gas emissions. Clearly it is a significant target for reductions.

Unfortunately the level of emissions from electricity generation is currently increasing rather than reducing. This is mainly because of increased consumption of electricity. Electricity underpins our modern society and to simply try and do without electricity is not a valid choice. However we can do a lot in terms of being more prudent in our use of electricity (e.g. through energy efficiency) our operation of the electricity system (e.g. through demand side management) and the way in which we generate electricity (e.g. fuel switching from the dirtiest of fuels to cleaner “fuels” including renewable resources).

To think that any one approach to greenhouse gas reductions in the electricity industry sector is better than another is to misunderstand the enormity of the task with which we are faced! Our long term goal over the next few generations will be to eliminate greenhouse gas emissions. In the medium term we must do all we can to reduce our emission levels in whatever way we can.

Penetration Level

The penetration level is a measure (usually expressed as a percentage) of the relative amount of wind turbine generating capacity in an otherwise conventional electrical supply system. This is the quotient of wind generating output divided by the system's total consumption.

In some European countries there have been times when wind penetration levels have exceeded 100% because the wind energy was able to be exported through an inter-connector into another system.

In Australia the penetration level of wind energy is currently at about 0.25%. However in some parts of the network there is significant penetration of wind energy. In Western Australia Western Power's Albany Wind Farm has a maximum penetration of approximately 0.6% because of the relatively small size of the south western interconnected system. However, within the Albany region itself the penetration is much higher (70 to 75%). Even in the National Electricity grid that supplies the eastern seaboard, penetration levels can be high in some parts of the network such as in western Victoria where Pacific Hydro's Codrington and Challicum Hills wind farms provide a significant amount of the total energy.

In small and isolated utility systems there is usually a limit to the penetration level of wind allowed on the system. This is because wind turbines are set up as "parallel generators" (as are many other generators). These "parallel generators" need the utility system to "tell them" what sort of electricity to produce (voltage and frequency). Without getting too bogged down in technical explanations, a wind turbine looks to the grid it is connected to, and generates more of whatever it sees (in terms of frequency and voltage). This is fine when the utility system's other "pace-setting" generators are of a size and output well in excess of that of the wind turbines. If the penetration level gets too high then the message from the pace-setters becomes too weak and the system can become unstable.

Another problem in small isolated systems is that if there is a sudden drop in wind or sudden increase in load, then it may not be possible to respond quickly enough to the change using wind alone. Traditionally the answer has been to have a diesel generator on standby acting as spinning reserve to provide during these periods when wind is not enough alone (essentially acting as FCAS and capacity reserve). This is not a specific requirement of wind/diesel systems. Even a pure diesel system would need another generator to be on standby.

Unfortunately diesel generators do not operate very efficiently on idle. Sometimes this has lead to the seemingly ludicrous situation where the wind turbines are shut down, despite the wind being present, so that the diesel engine can operate at optimal output, thereby improving its efficiency and reducing maintenance costs.

Despite these limitations, penetration levels of 15% to 20% are not unusual. Methods are being developed here in Australia (and elsewhere in the world) to overcome this problem through energy storage systems and special pace-setting wind turbines. For example the Denham Wind/Diesel/Storage System allows the wind turbines to penetrate up to 70% through the use of sophisticated control equipment and a fly wheel. As a further example Hydro Tasmania's Huxley Hill Wind Farm (King Island) has a Vanadium RedOx battery which also allows for significant penetration levels.

The Australian Antarctic Division hopes to develop a hydrogen economy at its Antarctic bases so as to do away with diesel fuels altogether.

[i] Californian Energy Commission. RPS Integration Analysis Workshop 12 Sep 2003

[ii] The Performance Of Victoria's Privatized Power Stations ,John W H Price, Mechanical Engineering Department, Monash University. Proceedings of the Australian Institute of Energy National Conference 1999

[iii] The Performance Of Victoria's Privatized Power Stations ,John W H Price, Mechanical Engineering Department, Monash University. Proceedings of the Australian Institute of Energy National Conference 1999

[iv] Encyclopaedia Britannica 2003 and Personal Correspondence with Dr. M Bechly of Garrad Hassan Pacific Pty Ltd

[v] Respective company annual reports for 2000/2001.

[vi] Derived from information from various company reports and web sites for the year 2000/2001 giving a total coal consumption of 67 megatonnes with an assumed average calorific value of 10 kilojoules per gram to give a total electricity output of 48.465 terrawatt-hours. The calculation excludes losses associated with parasitic loads (e.g. operation of coal dredgers and other mining and power station plant and equipment) and so is expected to slightly overstate the system efficiency.

vii From SA Government's Energy SA web site http://www.energy.sa.gov.au/pages/conventional/resources_use/coal/using_coal.htm

[viii] Encyclopaedia Britannica 2003.

[ix] Encyclopaedia Britannica 2003