Electricity Generation, Transmission and Distribution: what does the future hold?

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Introduction

New technologies coming on stream in generation, transmission, distribution and changing load characteristics will present challenges and opportunities for the future.

Opinions on what will actually happen vary widely largely because people have different views on the future of renewable energy technologies such as wind and solar power and on the safety of nuclear power stations. To complicate matters further, many people believe that distributed generation is the way of the future while others believe that large fossil fuel and nuclear power stations will continue to provide a cheap and reliable source of electricity for many years to come.

Generation

Most large power systems rely on low cost power from coal and natural gas fired power stations. Coal-fired stations are usually close to the mine but gas-fired stations have more flexibility in siting. The world has huge resources of fossil fuels so there is no reason why this should not continue into the foreseeable future.

Modern supercritical coal fired power stations are clean and efficient. Stack gas cleanup removes the environmentally damaging soot, sulphur dioxide and nitrogen oxides emitted by older stations leaving ash disposal as the only significant environmental effect. The world resources of low-cost coal are sufficient for more than 200 years so fuel supply is not a constraint.

World resources of methane are huge. Proven conventional and shale gas reserves will last for more than 50 years and more will be found. But the really enormous resource is “clathrates" – a mixture of methane and ice found off most continental shelves that could supply our gas needs for the foreseeable future.

Gas-fired generation technology has settled on highly efficient combined cycle units often with the steam and gas turbines on a single shaft. They are inherently clean because they emit only water vapour and carbon dioxide and, as technology develops, lower and lower levels of nitrogen oxides.

Recently, many much less efficient open cycle gas turbines have been installed on power systems because they are best suited to respond to the unpredictable and rapidly changing outputs of wind and solar farms. It can be strongly argued that the owners of wind and solar farms should pay the extra cost of generating power from these less efficient gas turbines.

Nuclear power is a major source of low-cost electricity and currently provides about 20% of electricity. There is a virtually unlimited amount of uranium and thorium[1] available. Operating experience over the last 50 years or more shows that it is, by far, the safest major form of power generation. Nuclear stations have very long lives and many are more than 40 years old. Many have had their lives extended and are licensed to operate for 60 years: lives of 80 or even 100 years are possible.

Even though existing nuclear power stations have proved to be very safe, extensive work is now being done on generation three and four reactors that should be cheaper, more efficient, and even safer. In most cases safety is being ensured by making them simpler and less reliant on emergency power supplies and complicated standby equipment.

A new development in the nuclear field is Small Modular Reactors (SMRs). These are factory built sealed modular units that can be transported to the power station site and the modules connected up to provide a generating unit that can operate without refuelling for 10 to 20 years. In most cases, the units are buried in the ground for safety and convenience. When refuelling is needed the reactor unit is replaced with a new one and the old unit returned to the factory for recycling. Outputs range from 25 MW to 300 MW so they can do everything from replacing diesel generators in isolated communities to providing several thousand MW from a number of units on a single site. Many people believe that they will be cheaper and faster to build than 1200 MW+ units built on site. In spite of the fact that the technology is well proven in submarines, aircraft carriers icebreakers and the like the regulatory hurdles are still enormous. If, by some miracle, the regulators can be persuaded to license a design and then not require regulatory intervention for every individual installation, their future should be bright.

The major problem with nuclear power is a widespread belief that any radiation from nuclear power stations is dangerous in the short and long term. Regulatory authorities have adopted a radiation model that assumes that there is no safe level of radiation. They have ignored evidence from people exposed to radiation at Chernobyl, Hiroshima and at places with high levels of natural radiation such as Ramsar in Iran where, according to the radiation model, death rates should have been very much higher than actually occurred. Studies of radiation exposure tells us that radiation levels 200 - 1000 times higher than that allowed for nuclear power stations are perfectly safe. According to the United Nations Committee on the Effects of Atomic Radiation no one has, or will, die of radiation from Fukushima. No harmful effects were found in any of the 200,000 people in the region around the power station. But 750 or more died as a result of forced evacuations from areas with safe levels of radiation.

[1] Thorium, which is three times as abundant as uranium, can be used for power generation in molten salt reactors with extremely high burnup rates.

There is widespread fear of nuclear waste because it takes many thousands of years for the radiation levels to reduce to the levels experienced in a uranium mine. But what everybody should be concentrating on is that it takes less than 1000 years for the radiation levels to reduce to a level that is known to be safe. Shielding against radiation is not difficult and, with shielding, it is safe to be within 2 m of a flask of high-level nuclear waste that would kill a person in a few minutes if they stood alongside it.[2]

If realistic and safe radiation limits were applied to the stations and waste disposal public acceptance would be much greater and there would be a very substantial reduction in the cost of nuclear power.

In some countries, hydropower and can also play a major part in power generation. In Africa, for instance the hydro power potential is huge – 40,000 MW from the Congo alone. But it has a greater environmental impact than nuclear power and, in many countries, insufficient attention is paid to dam safety. The risk of a catastrophic failure of a large dam is surprisingly high and, I believe, the hydropower industry is not taking this sufficiently seriously.

Another substantial source in some countries is geothermal power from subterranean fields of water and steam. Most geothermal stations provide reliable and relatively cheap electricity but the steam fields can have a life of less than 100 years.

For many years great hopes have existed for wind and solar power with regular promises that they will soon be cheaper than conventional power generation. At the moment wind and solar power are expensive compared to the options. Wind power costs about $US2200/kW[3] and solar power about $US3800/kW. Their capacity factors in New Zealand are around 35% and 15% respectively. Both require backup capacity that is usually provided by inefficient and expensive open cycle gas turbines that add at least $1000/kW to the cost of wind and solar power. A nuclear power station costing about $12,000/kW would generate at the same cost as wind power. The figure for solar power is $30,000/kW.

The major problem with them is that they are intermittent and, to a large extent, unpredictable. This means that conventional generation must be provided to cope with sudden changes in their output and for meeting peak demands when the sun is not shining and the wind is not blowing. The problem of intermittency is illustrated by a comprehensive study of wind power in the UK that revealed that annual power output would:

- exceed 90 % of capacity for only 17 hours
- exceed 80 % of capacity for 163 hours
- be below 20 % of capacity for 20 weeks
- be below 10 % of capacity for 9 weeks

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[2] I did exactly this at Sellafield a few years ago!

[3] http://www.eia.gov/forecasts/capitalcost/

In what other technology would you install 1000 MW of capacity and be happy with a maximum effective output of 80%?

The guaranteed output was 2%. For solar power, the guaranteed output is zero.

Germany has 35,000 MW of solar power operating at a capacity factor of 8% and generating nothing during winter evening peak demand periods. Much of the surplus generated by the solar panels in summer is exported at prices far below the subsidies paid to the owners of the solar panels.

A few years ago I analysed a typical isolated system with a demand of 10,000 MW supplied by wind power and by pumped storage hydro. The total installed capacity of wind and pumped storage needed to provide a continuous supply was 51,000 MW - 31,000 MW of wind power and 20,000 MW of pumped storage hydro! Using nuclear and pumped storage hydro an installed capacity of 11,900 MW was all that was needed.

Convincing evidence that wind and solar power are expensive and uneconomic is given by its developers who insist that the construction of new wind and solar facilities will stop if guaranteed twenty-year subsidies are terminated. Roll on the day!

Transmission

The need to limit currents to manageable levels means that high voltages are needed to transmit large amounts of power for long distances. Except in special circumstances, alternating current has been used because transformers are a simple and economical solution to the problem of converting the low voltage power produced by generators to the high-voltage power needed for transmission and to bring it down to distribution voltages at the receiving station. The technology is well proven and has not changed significantly for many years.

Since the 1960s high voltage direct current has been used for undersea cables where AC cables cannot be used because of high charging currents and, more recently, for long distance point-to-point transmission using overhead lines. Its advantages are a substantial reduction in the cost of the line – two conductors rather than three – elimination of the skin effect and elimination of the problems associated with reactive power flows. It's one disadvantage is the high cost of the terminal equipment but, as technology advances, the cost is reducing steadily.

Direct current has not yet been used for interconnected networks because, until recently, there have been no circuit breakers capable of breaking high DC currents at high voltages.[4] In 2012, ABB made a technological breakthrough when they developed a

[4] AC circuit breakers break the current flow at a current zero. Their main problem is re-establishing sufficient voltage withstand across the opening contacts to prevent re-strike. DC circuit breakers have to break the current flow.

hybrid circuit breaker that combined a mechanical switch that normally carried the current with a solid-state switch in parallel. When there is a need to switch off the current the mechanical switch opens and transfers the current to the solid-state switch which is able to break the current.

There seems to be little doubt that, in a few years, we will begin to see large-scale interconnected networks using high-voltage (>400kV) DC. In the short term, it is likely that existing high-voltage grids will be reinforced with DC links and, in the longer term, we may even see 220 kV+ AC grid systems covering large areas converted to DC. This will substantially increase transmission capacity, eliminate reactive power transfer problems and reduce losses.

About 20 years ago ECNZ seriously considered extending one pole of the DC line up to Auckland using one of the existing 220 kV AC lines. There is a high possibility that the 400 kV line will one day operate at something like +/-350 kV DC rather than 400 kV AC.

About 20 years ago the then CEO of Transpower believed that distributed generation was the way of the future and that Transpower would never need to build another transmission line. He was convinced that small gas-fired generators scattered around the system and providing combined heat and power would supersede large central power stations. It didn't happen – and for reasons that, to most people, were very obvious. New Zealand paid a very heavy price for his mistaken belief because we had to reinforce the system in great haste and at high cost after he left.

The recent trend in many countries has been the construction of wind and solar farms in remote areas that need hundreds of miles of new transmission lines transmitting power with a very low capacity factor and, often, at times when the system does not need it. So we can conclude that when distributed generation finally arrived it needed more, not fewer, transmission lines!

Distribution

Distribution technology has barely changed in the last 100 years. Sub transmission systems distribute power to zone substations where it is transformed to medium voltage in the 6.6 to 33 kV range to distribution transformers that, in most countries, distribute power to about 200 domestic consumers at 230/400 V. Countries with systems based on US practice distribute at 110/220 V and a distribution transformer usually supplies 4 - 10 consumers.

The 230/400 V system has stood the test of time and could continue providing power as it always has into the foreseeable future. The 110/220 V system already has serious problems because of the high number of transformers and the high electricity demands from air conditioning and, more recently, heating using heat pumps.

However, as more and more domestic appliances use direct current or frequency converters it is possible to contemplate a change to distributing at a DC voltage in the 300 to 600 V range. This would supply large loads and could be converted to a suitable DC voltage – perhaps +/- 24 V DC to run small appliances, lighting, and electronic equipment. Alternatively, 3 phase 660 V AC could be used up and down streets with individual transformers each house.

The widespread adoption of electric cars and domestic solar power could force major and expensive changes on the distribution system. Whether or not it will happen is open to debate because both technologies depend on the continuation of large subsidies. If governments finally realise that these subsidies are very expensive and that the ostensible reason for providing them – fighting climate change – is no longer an issue, the industries will collapse.

It was predicted that there would be 1 million electric cars in the USA by the end of 2015: The actual figure was 308,000 and the rate of uptake is falling off. Last year 3.7 million light vehicles were sold in the USA.

If the number of electric cars exceeds say, 20% of the total, then the (typically) 10 kW of extra load they place on the grid during battery charging will become significant. If they travel 40 miles per day, it would double household electricity consumption and this would require major and expensive reinforcement of the distribution system. While there is a widespread belief that they will always be recharged in the early hours of the morning, a significant number of people will choose to charge it as soon as they get home – either because they do not care about the extra cost or they are going out in the evening. In systems with a 110/220 V system, a 25% uptake of electric cars could force the replacement of huge numbers of distribution transformers and the installation of larger cables. The cost would be high and it would be imposed on all consumers.

It is often claimed that electric car batteries could be used to support the grid during peak demand periods. The cost of battery storage is high because, for instance, a typical battery stores 24 kWh, costs $15,000 and lasts for about 1000 charge/discharge cycles. The cost of one charge/discharge cycle is $15 or 80 cents/kWh – three times the cost of power from the grid! The obvious solution is to stop subsidising the cause – the fluctuating output from expensive wind and solar farms.

My assessment is that the number of electric cars is not likely to increase as predicted because they are a solution in search of a problem and rely entirely on government subsidies that are based on the belief that man-made carbon dioxide causes dangerous global warming. Governments also ignore the fact that at more than $1000 per tonne it is a remarkably expensive way of reducing carbon dioxide emissions. Nuclear power stations can do it for nothing!

Domestic solar power is expensive – about $NZ4000/kW for capacity factor of around 15% – and heavily subsidised. In the UK solar power reduces carbon dioxide emissions at a cost of around $200 per tonne. (Carbon credits can be purchased on the open market for about $4 per tonne.) In New Zealand the cost must be a lot higher because it generates most energy in the summertime when demand is low and, often, there is surplus hydropower available because many hydropower schemes must discharge a minimum flow for environmental reasons.

If domestic solar power continues to be subsidised and a lot more is installed, we will soon be in a situation that is now quite common in Australia where many installations export power into the grid between the hours of 9 AM and 3 PM and can cause an unacceptable rise in the voltage of the distribution system. If this export is large enough to reverse the power flow in a medium voltage feeder there can be major problems with voltage control in the medium voltage distribution system that are very expensive to resolve. To mitigate these problems Australian regulations require that the solar panels must shut down if the voltage becomes dangerously high. New Zealand would probably have to do the same.

New technologies succeed because they offer substantial advantages in cost and convenience over existing technologies. If they do need subsidies, it is only during the research and development stage.

History tells us that when governments pick winners they are nearly always wrong. It is almost certain that this is the case with electric cars, wind power and solar power.

Smart grids

"Smart grids" are often regarded as a wonderful collection of new technologies that will revolutionise the electricity industry. This is not necessarily so.

Grid systems have always been smart using the best available technology at the time. This arose from necessity because something as complex as an integrated power system has to be very smart to isolate faulty sections and minimise the chance of a total blackout.

“Smart grids” usually refers to systems with smart metering and very complex monitoring and control systems to manage the effect of solar and wind power feeding into distribution systems to stop them causing serious problems with voltage and power flow.

All smart meters can communicate with a central point to report on power consumption. The main advantage of this is that it results in savings of $10-20 per year in meter reading. Other advantages are that it gives lines companies better information on the loading of lines and transformers and allows consumers to see what their electricity consumption and power price is at any time. It is widely believed that smart meters can also control the consumers load. In practice, this does not happen because new technology is needed in individual appliances so that they can respond when the price is high. There do not appear to be products - or even agreed standards - for this and, it appears, distributors and retailers prefer to sell more power and, to a large extent, consumers do not care.

"Smart grids" are also promoted as a solution to the problems generated by domestic solar installations. The promoters envisage a system where vast amounts of information are exchanged and complex optimising programs adjust the system to match the current situation. This is a complex and expensive exercise that is needed only because of the existence of expensive and ineffective solar power that we would be better off without. So, once again, it is a solution in search of a problem. Or, putting it another way, a solution to a problem that, in a rational world, would never have existed. (Issues of system security from hacking are now becoming apparent.)

Demand side management

"Demand-side management" is the current buzzword for what used to be called peak load control. Since the 1930s New Zealand has used insulated storage water heaters to manage peak demand. In the 1950s ripple control that sent signals over the mains to switch water heaters on and off became virtually universal. This system was probably the best in the world and it could hold New Zealand's load virtually constant between 8 AM and 8 PM on peak demand days. Unfortunately the regulations associated with the electricity market removed the incentives lines companies had to manage peak demand and now the upper South Island alone act against their own commercial interests and engage in large-scale peak demand control. On a peak demand day they are able to hold the demand constant from 7 AM to 10:30 PM. Without it the 220 kV lines from Christchurch to Nelson would have needed a very expensive upgrade. If the lines companies in the upper North Island had also acted in the consumer's interest the billion-dollar 400 kV line would not have been needed.

Various incentives have been dreamed up to promote demand-side management but, compared to ripple control, they are expensive, difficult to administer and relatively ineffective.

There is an expectation that if consumers are exposed to spot prices they will reduce their demands as the price goes up. This has not happened to a great extent for the simple reason that electing to pay spot prices rather than purchase a hedge gives a very useful reduction in overall power costs so most industrial and commercial users choose to maintain production during high-price periods knowing that, overall, they are still winning.

The sad part about all this is that there are technologies available that are very smart and could lead to large savings for consumers. For instance, many existing ripple control relays have frequency sensitive elements. If they were set to switch off water heaters, refrigeration plant, and even air conditioning plants for a short period when the frequency dropped it could easily save the need for something like 200 MW of spinning reserve. But nobody has explored this option because, it seems, it would be difficult to set up within the structure of our existing electricity market.

Modern technology has brought us radio ripple control that uses low-frequency radio waves that can control one relay, all relays or anything in between. Three transmitting stations could serve the whole of New Zealand. There appears to be no way of implementing it in New Zealand under the present electricity market structure. Such is progress!

So what does the future hold?

It is now obvious that the $2 trillion or more that has already been spent on new renewable energy technologies has brought a very small return in carbon dioxide reduction, a very large increase in electricity prices and an increased risk of shortages. As firms manufacturing wind turbines and solar cells seem to be losing money, the chances are that enthusiasm for these technologies will die away. However, we can expect that the developers who are profiting from the huge subsidies that they have attracted will fight tooth and nail to stay on the gravy train.

If, as many people expect, the world soon starts to cool and more and more people conclude that dangerous man-made global warming is probably the biggest hoax in the history of world then there is a reasonable chance that the prejudice against fossil fuel generation will slowly decline. If, on the other hand, temperatures continue to stay virtually constant or even increase a bit, it becomes difficult to predict what might happen and when.

Although nuclear power is substantially safer than any other power generation technology it will be very difficult to persuade people that low levels of nuclear radiation are harmless. One of the problems is that the nuclear industry regulators respond to every minor radiation problem with more and more safety precautions so perpetuating public belief in the dangers of radiation. No one has, or will, die of radiation from Fukushima but nearly 1000 people died from panic driven evacuations from areas with safe levels of radiation: this seems to have escaped notice of the decision-makers and the public.

But, in spite of all this, public acceptance of nuclear power is slowly increasing and the advent of small modular nuclear reactors could help nuclear power provide a cheap, clean, safe, and environmentally friendly supply of all the energy we will need for the foreseeable future.

We can be confident that the use of DC transmission will steadily expand into connected EHV networks.

The future of distribution systems depends, to a large extent, on future take-up of domestic solar installations. Given its high cost, the problems it causes on the system and the high cost of CO_2 reduction, common sense will indicate that it will soon die. But common sense is not all that likely to prevail and is there are many people whose profits, jobs, and power rely on a belief in dangerous man-made global warming: they will not give up without a major fight.

I predict that, in 25 years time:

- *the world will be using even more fossil fuels*
- *mining for clathrates will be well underway*

- *nuclear power will be expanding*
- *interconnected high voltage DC networks will be emerging,*
- *distribution systems will be much the same as they are now,*
- *new renewable energy technologies will have fallen out of favour*
- *the more exotic aspects of smart grids will be forgotten.*