Smart Grids: Fact or Fiction?

A Discussion of Smart Grids in New Zealand

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1. Introduction

The term ‘smart grid’ is used extensively today, even though there are diverse opinions on what it means. Common definitions focus on communications, sensing and control, with less clarity regarding the ‘smart’ actions the technology could enable. All power networks include sensing and control technology to some extent, and the key questions should not be about what constitutes a ‘smart grid’, but what challenges our transmission and distribution industry are facing, and how modern digital technology can be used to help in addressing these challenges. In this paper we first examine the influences on transmission and distribution companies in the electricity sector that have led to, and are leading to imperatives for change. Secondly we look at what innovative technologies and ideas are being employed in New Zealand’s power transmission and distribution systems, and which are likely to be used in the future in response to the imperatives for change. Next we briefly comment on comparisons between electricity and telecommunications (which has undergone radical change in the last 20-30 years). The paper concludes with a summary of new developments, a discussion of the term ‘smart grid’ in the New Zealand context, and areas where New Zealand might improve its performance in the utilisation of new technology.

The main conclusion from the paper is that ‘smart grid’ is a very broad term that refers to almost any number of new technologies in the grid, some that have been in existence for many years, and others that are being implemented now. There is certainly scope for application of new technology in distribution and transmission networks that has arisen from advances in semiconductor technology and computing. Although the term ‘smart grid’ is useful in generally referring to the modernisation of the grid and a variety of new technologies being used in it, it is not so useful when referring to a specific technology or technique.

2. Influences on the Electricity Sector

The electricity industry is and has always been an asset intensive industry. The cost of generation stations, transmission lines to connect generators to regions, and distribution lines to take power to homes and businesses, amount to a considerable investment across a number of owners – the estimated book value of NZ plant and equipment assets employed in generation is in the order of NZ$16B and the assets employed in transmission and distribution is in the order of NZ$14B[1]. It is not surprising that electricity companies strive to optimise the use of their assets, and thereby generate a greater return on their investment.

In the regulatory environment in New Zealand, where for the majority of distribution network companies their ability to increase prices is partly regulated according to the reliability of the electricity supply they provide [1], there is an incentive to provide greater reliability, as well as optimise asset use. In the transmission network, the regulatory environment requires Transpower to seek non-transmission solutions when considering major capital projects (for example, to defer building new transmission assets) [2]. It also provides strong signals to the System Operator to operate the power system with security of supply as one of its primary considerations [3]. Finally, in the wholesale electricity market, the selection of which stations generate power is based on cost minimisation, as well as minimisation of losses in the transmission network, and minimisation of the cost of reserve generation required for supply security [4]. Requirements to reduce operating costs and provide high reliability are important in the electricity industry, which is a cost to the New Zealand economy, and thus contributes to New Zealand's ability to continue to export and survive in the global marketplace.

2.1 The Changing Electricity Environment

Cost minimisation and regulatory pressures lead to imperatives for electricity transmission and distribution companies, which this paper divides into two categories: cost and reliability. More recently a new set of factors have emerged, which are shaping the environment for electricity companies, and which require a response from them. Some of these factors are listed in the table below, which lead to a third imperative on electricity transmission and distribution companies: flexibility.

[1] Generation assets were obtained from the Statement of Financial Position, plant and equipment non-current asset line, of the 2012 annual reports of the privately owned or publically listed generators, and from the Government's financial statements [19] for the state owned generators. Transmission assets were also obtained from the Government's financial statements, and distribution assets were obtained from the Commerce Commission's Electricity Distributors' Performance report [1].

Factor	Description
Decreasing cost of renewable energy	Wind energy is now economic, and the cost of photovoltaic (P.V.) panels has reached about NZ$1 per Watt, which is making it more attractive to the homeowner. [2] Equipment to inject power into the grid has reduced in price substantially, making P.V. even more affordable. Geothermal generation developments are progressing [5]. Greater wind generation will cause greater variability of generation supply, and greater domestic P.V. penetration will also cause more variability and give rise to technical challenges in distribution networks related to protection, safety, network capacity, and power quality.
Changing use of electricity	The last 15 years has seen an influx of heat-pumps into New Zealand homes and businesses, which, together with increasing irrigation, have contributed to a higher peak demand in the summer [6]. The nature of the heat pump load depends to a large extent on their manufacturer and age. Some appear as inductive loads, which together with the many other industrial induction motor loads require support of the voltage [7], [8]. Gas for water heating and space heating has also made in-roads, displacing electric water heating as a source of demand response.[3] In the future electric vehicles may increase in number, potentially contributing to the evening peak, but also providing a greater resource for demand response. Home automation may make some appliances in homes more able to respond to signals to reduce demand (through price for example). More efficient appliances and lighting technology (such as LED technology) will provide scope for lowering electricity consumption and greater participation in demand response. Users of electricity are also demanding greater reliability, especially in the light of high profile failures and shortages that have occurred in the past. This is heightened by the need for competitiveness as more pressure comes on the manufacturing sector. To complicate this, there is an on-going focus on cost of electricity.
Greenhouse gas reduction imperative	The need to reduce greenhouse gas emissions should make fossil fuel use more expensive. The New Zealand Energy Strategy (NZES) actively promotes the use of renewables to reduce CO_2 emission [9]. Increased renewables in the network will have implications for cost and require greater flexibility. New Zealand is unique in that it already generates most of its electricity from renewable sources, and the bulk of this generation is hydro, with comparatively less thermal generation in its power system than countries such as Australia, the USA, and European countries. New Zealand has little international experience to draw on in assessing the implications of adding more renewable generation, and has a unique opportunity to share or export its experience as the rest of the world strives to generate more from renewables.

[2] This is based on one of the author's recent experience of purchasing PV panels.
[3] Demand response is generically used in this paper to mean the reduction of demand in the short-run (hours) to some signal. The signal might be direct control by a distribution network company (traditionally ripple control in New Zealand) or it might be control by a home automation system in response to a high price (something very new to New Zealand with little uptake to date). Demand response might also refer to short periods of demand reduction by large industry, by for example moving production from times of high electricity price to times of lower electricity price.

Resource consent barriers to building new generation and transmission	It is now very difficult to develop any significant generation or transmission investment due to resource consent challenges. This places greater demands on existing infrastructure which must be managed.
Natural disasters	Continuation or rapid restoration of supply after faults or natural disasters is crucial to recovery. Disasters such as the Australian bushfires and the Christchurch earthquakes are placing more emphasis on liability of distribution companies, the need for safe and reliable distribution, and rapid location and repair of faults or identification and resolution of faults before they cause issues. Consequently there is increased pressure on cost, a clear focus on reliability, and emphasis on flexible systems.
Ownership of electricity assets and relationship with the customer	While ownership of distribution in New Zealand has always been spread among about 24 companies, in the last 15 years the change of ownership of retail from distribution companies to mainly generators, combined with contestability for consumers, has complicated industry relationships and relationships with the customer. For example, there have always been multiple reasons for demand response obtained from customers (energy cost reduction through capacity management, transmission capacity management, distribution capacity management, and instantaneous reserve for supply security). However there are now multiple companies with different ownership who each have specific uses for demand response. Coordinating these different, and potentially conflicting, goals is now a challenge, creating an imperative for greater flexibility.

3. Responding to the Changing Environment in New Zealand

The paper has discussed the influences on the electricity sector and the changing environment, both of which give rise to imperatives of cost, reliability, and flexibility. This section discusses what the New Zealand electricity industry has done, and is doing to respond to these.

3.1 Cost Imperative

Demand response has been used for many years by the electricity industry to shift demand from times of peak demand to times of low demand. New Zealand has led the world since the 1940s to 1970s with ripple control of hot water heating [10], [11], which has been very successful in improving the utilisation of generation, transmission, and distribution assets. Improved utilisation is achieved by shifting demand at peak times to off-peak times, through direct control of the water heating load, and associated controlled load tariffs. In this respect, parts of New Zealand's grid have been smart for decades.

With the disaggregation of the electricity industry, separation of retail and distribution, and ownership of the various entities in the industry resting with numerous different companies, signals for water-heating control became mixed and anecdotally it is now used less in some areas. Water-heating could be used to respond to energy prices, optimise use of the distribution network, control maximum demand to manage transmission utilisation, or for the reserve market (the various uses of demand response are covered in more detail in reference [12]. References [13] and [14] also cover the use of ripple control of water heating, and other appliances, to provide demand response). In some distribution networks it is used successfully, while in other areas it is not.

Dynamic rating is another tool that can improve capacity utilisation of assets, to 'work the assets harder' by changing the rating of a plant as weather conditions change. For example, a line might be able to be rated at a higher capacity in the winter when it is colder, and thereby meet the winter peak. This requires monitoring of the local weather at the transmission line, and feeding this information into an algorithm that calculates the new line rating. Transpower is exploring this approach to lift grid performance within the next ten years [15]. A similar method can be applied to cables and transformers, through short-time overload of their capacity when conditions are suitable. Gathering and responding to this information falls under the smart grid definition.

3.2 Reliability

When an outage occurs, distribution companies and/or retailers have relied on customers contacting them to report the outage. Some smart meters have a 'last gasp' feature that can automatically report the loss of power. In turn the distribution company, with appropriate systems to collate and visualise this information, can rapidly respond to an outage and pinpoint the fault. Such functionality falls into the category of a smart grid application. An issue in New Zealand is that smart meters are not being rolled out uniformly, meaning that not all smart meters have this feature built in, or to achieve equivalent functionality requires a different approach.

Clearly it is preferable to avoid faults before they occur, as the economic impact on customers and distribution companies is severe. On-line condition monitoring of assets such as transformers, can provide early warning of equipment failure, which in turn can deliver better supply reliability as well as optimise asset utilisation by possibly enabling assets to be used for longer. On-line condition monitoring requires data acquisition and signal processing to acquire and sift through data produced by large numbers of devices. Such technology has been researched and used in New Zealand for many years, and is very much a smart grid approach.

Finding faults before they occur is not usually possible, hence minimising their impact, and rapid location of them before they re-occur is important. Some distribution companies have deployed ground fault neutraliser (GFN) technology that allows a line to stay in service when a line-to-ground fault occurs. This employs power electronic control that injects a neutral current that cancels the fault current, and allows supply to be maintained. However it is still necessary to find a fault, even if its consequences have temporarily been reduced. Faults might range from a 'downed line', to a tree brushing against a line, debris caught in an insulator, or a faulty insulator. Finding a fault on a long distribution line can be very time consuming and expensive. Finding a fault with electronic sensing equipment would provide dividends in reducing operating cost and improving reliability.

When a fault does occur, the power system must be protected. Generation, transmission, and distribution networks employ increasingly sophisticated protection equipment and methodologies to ensure appropriate isolation and protection of faulted areas, and thereby minimise the cost impacts of faults.

A power grid is a complex system of interconnected generators, lines, and loads that transfers huge amounts of energy continuously. Stability of the system, both in the steady state (normal operation) and transient state (should there be a disturbance such as a generator tripping) is paramount to reliability of supply. In New Zealand the System Operator constantly coordinates both energy supply across the grid and security on the grid. This involves, in part, continuous analysis of security ahead of time, and assessment of risks. The systems that perform this analysis are complex computer systems that rely on vast amounts of data collected from across the grid, sophisticated load forecasting, and incorporate advanced transient modelling. Off-line computer simulation is also constantly taking place, to investigate the impact of changing the grid, and to find better ways of delivering a secure supply.

The grid is run by computer systems, and part of ensuring supply reliability involves protecting the computer systems, ensuring for example appropriate resiliency to loss of systems and data, as well as ensuring cyber security – protecting them from outside malicious interference.

3.3 Flexibility

Building a new transmission asset is expensive and time consuming, and risks stranding of the asset if conditions that require it change in the future (for example, generation location changes, load in the area reduces, or new generation is built). To complicate this, it has been impossible to add to transmission capacity marginally, meaning investments are large 'chunky' investments that require substantial financing. Demand response, already discussed, does effectively enable deferral of new transmission, by smaller marginal increments of capacity, enabling transmission and distribution companies to respond more flexibly and rapidly to changing load.[4] However demand response is not always adequate (for example the transmission reinforcement is for voltage support reasons). Transpower has implemented ways of reinforcing transmission in smaller capacity increments, thereby more nimbly deferring large investments. An example of this is their use of static VAR compensators (SVCs) and static compensators (STATCOMs) to support voltage and thereby defer

[4] Demand response can be procured in much smaller increments than a full transmission line, with more procured as load increases.

upgrading transmission.[5] Their use also enables a more flexible response to changing demand and generation patterns and improves power quality by maintaining a better voltage profile. An example is the rapid stabilisation of the voltage in the Canterbury region after the 4 September 2010 earthquake [15].

As mentioned earlier, demand response has been used in New Zealand for some time. It has been suggested that there is also a large untapped resource for demand response, from appliances in homes and small businesses. This has been difficult to utilise, due to inability to control appliances, no home automation, and poor communication to homes. However with an increasing number of homes connected to Internet, and with smart meters and their associated communications infrastructure, appliance manufacturers are starting to include interfaces in their appliances to enable them to be turned on or off at certain times. Such control might happen automatically, after a homeowner has selected a more economic power option. This might be augmented by smart metering and the provision of time of use tariffs. Uptake of electric vehicles might also supplement the demand management resource, by using the stored electrical energy within the vehicle to supply some of the building's demand at certain time. Battery degradation and the consequent a reduction in the vehicle's lifetime due to increased battery cycling is likely to make this unattractive for vehicle owners. The parameters of this degradation are being investigated by the authors at present. Such a demand response resource gives greater flexibility to respond to changing demand, and possibly even changing renewable generation. Demand response from homes and small businesses is an aspect of smart grids being investigated by the authors and co-investigators in the GREEN Grid project.

One way of providing effective demand management from a house or building is generation from within the home. The most commonly talked about form is solar electricity, generated by photovoltaic panels, and injected into the grid with an inverter. This is leading to major changes for distribution companies, who in countries such as Australia and some European countries have experienced a reversal of power flow within certain parts of their network [16] and [17]. This form of highly embedded generation requires great care with network protection, sizing, and safety, and is another aspect of smart grids being investigated by the authors and co-investigators in the GREEN Grid project.

[5] A static VAR compensator is *power electronic* device that injects a form of power known as reactive power, which is consumed by loads such as electric motors (common amongst all heat pumps). The need for reactive power support is typically higher at the end of a long transmission line, and is required to maintain the voltage at the far end of the transmission line. Reactive power can be produced by a generator, however it may not always be available from a generator, and costs money to procure (because the generator must 'back off' producing energy). An SVC is a more economical alternative, in some situations, improves power quality, defers investment, and provides a faster and more flexible option for network reinforcement.

4. Technology and Electricity

The electricity industry has often been compared with the telecommunications industry, and accused of being a laggard given the fundamental shift in services offered in the telecommunications industry. Furthermore, the accusation has been levelled at the electricity grid (in the USA) that it "…still runs on century-old technology." [18] While one of the key principles of modern day electricity does date back to the late 19th century, there have been substantial advances around this principle.[6] It is also worth noting that the key principles of some of our modern day telecommunications were (also) discovered in the late 19th century (for example, Marconi's (arguably Hertz's, made useful by Marconi) discovery of radio through accelerating electrons in a conductor), Maxwell's equations that describe light (used in fibre optics and wireless) and telephone that was delivered to homes via a twisted pair of wires, and deployed widely in NZ in the mid-1900s, is used today to deliver broadband Internet to most urban NZ homes.

What has enabled the advances in telecommunications described above, overlaid on older technology, are the amazing advances in semiconductor technology and micro-electronics in the last fifty years. These advances are generally attributed to increasing density of micro-chips, and advances in manufacturing and mass production. The practical outcome of these advances has been an ever decreasing size of electronic device with greater functionality. Combined with mass production, it has led to very powerful and inexpensive devices available to most individuals. The examples are obvious in the telecommunications and computing industries; the *smart* phone (one million times the memory of a state of the art 1980s computer and considerably smaller), the tablet, and more powerful laptops. However the electricity industry has benefited from these also. For example, the smart meter with remote reading capability is only possible through advances in micro-electronics and manufacturing, and greater computing power and storage have enabled the distribution and utility companies to capture vast amounts of information from their networks.

On the larger scale, in high voltage networks, modern power electronics, also a benefactor of the semiconductor industry, has led, for example, to more efficient HVdc transmission over long distances, and to greater flexibility in configuring the grid to respond to load growth and changing generation patterns.[7] One way in which this flexibility is achieved is through deployment of STATCOMs and SVCs, used to support voltage level. Advances in computing have also facilitated more in-depth understanding of the transmission network and its interaction with loads and generators. Behind the scenes there is a considerable amount of study undertaken in this area, by Transpower for example.

In some respects it is not possible to compare the power industry with telecommunications. The grid in the power industry is about transporting large amounts of power and energy efficiently and securely. The telecommunications network is about transporting large volumes of data rapidly (bandwidth) with reliability and connectivity. The telecommunications industry has advanced (for the reasons already explained) to be able to deliver greater bandwidth over existing and smaller assets. However, by its very nature, delivery of large amounts of power requires bigger assets – either larger conductors to carry greater current, or higher voltages to carry less current (and thereby reduce losses). Higher voltage requires greater separation of conductor from the ground and transmission

[6] The principles of electromagnetics (Michael Faraday 's discovery of electromagnetics), which were utilised in Nikola Tesla's idea that alternating current, linked in frequency to the speed of the rotating machinery that generates it, can be transformed to a higher voltage to enable more efficient transmission over long distance.

[7] HVdc refers to high voltage direct current, such as that used in the Benmore-Haywards inter-island link.

towers, which requires larger structures. The two industries are both advancing, but they have differences.

5. Summary and Conclusion

This paper has discussed changes to the New Zealand electricity environment and the imperatives resulting from those changes. Following that it has summarised a number of initiatives taking place in the electricity industry to deal with the imperatives, all of which are applications of new technology or new approaches to building and operating electrical power systems. The term 'smart grid' is a broad term that could refer to any number of these. In summary the following can be classed as examples of smart grid applications:

- Demand response to improve asset utilisation and to defer transmission and distribution investment.
- Home automation, increasing the amount of demand response, giving consumers ability to interact with the power system.
- Dynamic rating to optimise the capacity of a transmission asset, such as a transmission line or cable, and thereby reduce costs.
- Improved fault reporting and location and deployment of technology to reduce fault outages, and thereby provider greater reliability.
- Intelligent protection of generation, transmission, and distribution networks.
- On line condition monitoring to extend asset lifetimes and improve reliability.
- Use of STATCOMS and SVCs to flexibly and rapidly augment transmission capacity, and thereby defer investment.
- Computing applications that process the vast quantities of data acquired by new devices and turn it into useable information for the operator.
- Real-time security analysis of the grid to ensure reliability of supply.

Many of these applications are already in use in New Zealand, making the grid smart already. Examples in the distribution network include WEL Network's active use of smart meters to narrow down the location of network faults and provide time-of-use charges, and the upper South Island load controller to coordinate ripple control demand response from five distribution companies. However approaches vary by distribution company, leaving room for improvement. Some areas where improvement could be gained are:

- Dealing with multiple ownership, and therefore multiple, potentially competing, needs for demand response. The aim of this should be to simplify the decision of a consumer whether to provide demand response and to better understand its value.
- Improve technology in customers' premises (e.g. building automation systems in small-medium businesses and home automation systems in homes), as well as appliances that interface to home automation systems. In turn this could lead to more demand response.
- Develop applications for analysing data; there is a huge amount of data collected from the grid, but not all of it is converted into information. Computing applications could analyse the data to provide information on the condition of, and operation of, assets in the grid.
- Develop cost effective fault location to reliably and quickly locate faults in the distribution network in particular, and thereby reduce operating cost.
- Utilise smart meters more extensively to provide such features as fault reporting and location, and use them to implement time-of-use tariffs, in order to change electricity consumption behaviour and thereby better utilise assets.
- Address the non-uniform smart meter rollout across all distribution networks.

A number of the areas where New Zealand could improve also have implications in terms of innovation and development of new industries in New Zealand.

We return to the question posed in the paper's title: "Smart grids: fact or fiction?" and conclude that 'smart grid' is a convenient term to refer to any number of new technologies or operational approaches in electrical power systems, but not very specific, and therefore potentially misleading. We also conclude that there is a substantial amount of new technology and thought being applied to power systems in NZ already, but that there is scope to improve this. Some of this new technology derives from advances in semiconductor technology, and includes power electronics and computing. There is a substantial amount of data collected from the grid, with scope to improve algorithms to use that data and provide operators with better information about the grid.

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