A Smart Water Heater Thermostat

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Abstract

Before the electricity reforms and market, New Zealand had the best demand side management system in the world: ripple control of domestic water heaters. When the electricity reforms brought in a regulation that prevented the lines companies from making any return on the costs of extending, operating and maintaining the system most lines companies effectively abandoned ripple control.

Ripple control avoided expenditure on generating plant, transmission lines and distribution systems. Had it continued, New Zealand's peak demand would be 300 MW – 400 MW less than is now. In all probability, the $950 million 400 kV line would not have been needed. More would have been saved by avoiding reinforcement of other transmission and distribution systems.

With modern technology it is easy and cheap to manufacture and install smart hot water thermostats that would bring back all the benefits of ripple control – and much more.

The smart thermostat would sense water temperature and regulate the power input to the water heater as required. It would be sensitive to system frequency and would ramp down the power to the water heater if the frequency dropped below, for instance, 49.9 Hz. If the water heater was off and the frequency was high, it would inject additional power into the water heater for the few minutes needed to manage the frequency excursion.

It would be connected to the Internet via Wi-Fi so the water heating load could be controlled by the System Operator if the system was in serious trouble. The lines companies, the retailers and the consumers could also regulate demand in any way that would benefit the consumer.

Smart meters have not brought consumers any benefits that outweigh their cost. The smart water heater thermostat would cost less and bring large benefits.

The paper will show that the fragmented nature of the industry and the shortcomings of the electricity market makes it impossible for any one entity to aggregate all the benefits and so justify the expenditure on the new devices. But, unless the Electricity Authority and others make the regulatory changes necessary to allow this smart device – and maybe others – to realise their potential benefits, the consumers will be deprived of the benefits.

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Introduction

Before the electricity reforms and market, New Zealand had the best demand side management system in the world: ripple control of domestic water heaters. When the electricity reforms brought in regulations that prevented the lines companies from making any return on the costs of extending, operating and maintaining the system most lines companies effectively abandoned ripple control. They did not seem to care that this cost their consumers millions of dollars.

Ripple control avoided expenditure on generating plant, transmission lines and distribution systems. Had it continued, New Zealand's peak demand would be 300 MW – 400 MW less than is now. In all probability, the $950 million 400 kV line would not have been needed and millions more would have been saved by avoiding reinforcement of other transmission and distribution systems.

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The concept

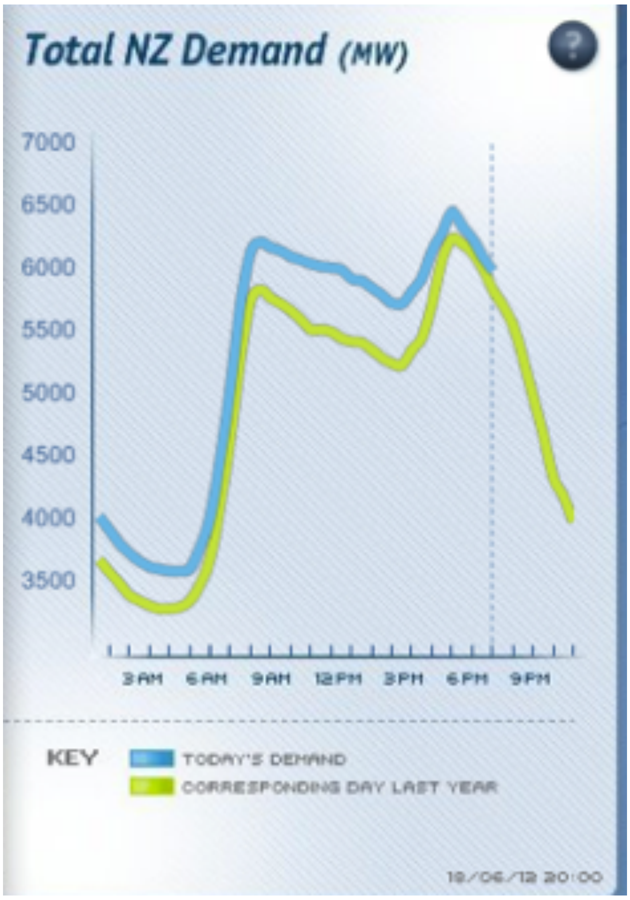
All electric water heaters have a plug in thermostat that switches the element on and off according to the water temperature. Most modern water heaters have a 3 kW element.

According to the Electricity Authority[1], water heaters used 26% of the total electricity demand of a household. For many years water heating will be a major electricity use in households and will continue to be the only one that can be regulated easily and invisibly.

New Zealand uses about 40,000 GWh per annum. 32% of this – 12.5 GHh – is domestic consumption and 3200 GWh is used for water heating. This amounts to an average water heating demand of 365 MW. There are 1,700,000 residential consumers and, at the very least, 1,250,000 of them would have electric water heaters. If they all have 2 kW elements the installed capacity would be 2500 MW. Information from Network Tasman who do use ripple control to regulate water heating demand indicates

[1] "Electricity in New Zealand" published in January 2016

that at peak times, 30% of the water heaters are switched. On this basis about 750 MW (10%) of New Zealand's current peak demand is water heating load. It is therefore safe to assume that, if all water heaters were under control, the peak demand could be reduced by at least 400 MW.



As can be seen from Figure 1, the ability to control 400 MW would effectively flatten the load curve from about 7 AM until 9 PM. As well as reducing demand, this would reduce the cost of electricity to the consumers.

At the moment water heating load is very low in the early hours of the morning and this could limit the amount of load available to be shed in the event of system disturbances. However, now that smart meters are available those that purchase electricity on the spot market have a strong inducement to make sure that their water heaters switch on only in the early hours of morning and in the middle of the day when, in general, the price is low. If this was insufficient, the system operator or the retailer could choose to switch water heaters in sequence so that, at any one time, a sufficient number of water heaters were switched on and available to mitigate frequency excursions.

To some extent, ripple control is now obsolete technology and, anyway, it would cost a lot of money to rebuild the system after years of neglect. It also has the disadvantage that, if a water heater is switched off for too long for any reason, the consumer will get cold water. It could be replaced by radio ripple control which is cheaper and better but does not offer any major technological advantages. Modern technology can produce a Wi-Fi connected, smart thermostat that can sense the temperature, control the water heater, eliminate the cold water problem and bring many other advantages.

The device

The device would be a simple plug-in replacement for an existing thermostat (Fig 2) that would retain the existing two wire connection so that it could be installed by the consumer.

There would be a temperature sensing unit in the probe communicating with the electronics occupying the space now occupied by the switch. A triac or similar device would regulate the current. If cooling was required, it could be mounted in the probe and cooled by the hot water.[2]

Once a Wi-Fi connection was established the consumer or supplier could program the device over the internet to control the water heater and to allow access by other organisations that needed to control the water heater.

The electronics would monitor system frequency by detecting voltage crossings whether or not the triac was conducting. It would also incorporate Wi-Fi and a microprocessor.

The control system would ensure that the water temperature was not allowed to drop below about 65°C unless there was a system emergency. This would eliminate the no hot water problem that is sometimes experienced with ripple control due to a faulty relay or the central controller switching the water heater off for an excessive period.

The power supply would be obtained by charging an ultra capacitor when the triac was not conducting. If it needed to be recharged when the triac was conducting, the current would be blocked for the short period needed to recharge the capacitor. This avoids the need for a neutral connection which would complicate installation.

What it could do

It could make a major contribution to frequency control, the need for spinning reserve, the management of over frequency events and substantially reduce the number of occasions when automatic under frequency load shedding was needed.

The frequency sensitive element would be arranged to modulate the power input to the water heater in proportion to the frequency deviation. Some research would be needed to determine the optimum operating band and whether or not a dead band was needed. In theory, it should be possible to have it start reducing power input at, say 49.9 or 49.95 Hz and cut the power off completely at say, 49.5 Hz. If, for instance, 100 MW of generation was lost, the frequency would drop to around 49.7 Hz and remain stable at this figure until additional generation was brought on line. This would effectively eliminate the need for fast response frequency keeping. The system is no different

[2] Triacs can operate with a junction temperature of up to 150°C.

from the load diversion governor used very successfully on many small hydro projects. Just a wee bit bigger!

In the event of a major loss of generation or a transmission line, several hundred MW of water heating load would be shed by the time the frequency reached 49.5 Hz. Load that is shed early makes a disproportionately large reduction in the magnitude of the frequency dip so it would substantially reduce the number of occasions when under frequency load shedding was needed. It would also increase the amount of load available for shedding during a frequency incident. Many people believe that it should be greater than the present 32%.

Over frequency events are also a problem in the New Zealand system. They can occur in the South Island with the DC link fails while the South Island is exporting a large amount of power to the North Island. The high inertia of the South Island hydro generators rapidly increases the frequency and, if it exceeds about 52 Hz it can cause some of the generators to trip off. In extreme cases, this leads to a system collapse because too much generation has tripped off. The smart thermostat can mitigate this problem because the control system can be arranged to switch on all the water heaters that are off. This would not cause excessive heating of the water because these incidents only last for a minute or so. But if there was any chance of a problem, the system could be set to disable itself if the water temperature rose above safe limits.

The System Operator would be able to shed load in advance if it became obvious that insufficient generation was available or that, to meet a short-term peak, expensive generation would be needed. He would also be able to shed load in regions at risk of suffering from a transmission constraint. A fringe benefit is that it would deprive generators of the ability to rack up the price!

The lines companies would be able to regulate their maximum demand to limit demand charges from Transpower – but only if the regulation that prevents them from recovering costs involved in managing their consumers loads is revoked.[3]

The retailers would be able to regulate the demand of their own consumers during times when they were purchasing electricity at a high price on the spot market.

Consumers who purchase their power on the spot market would be able to control their water heaters depending on the spot price. They could, for instance, link into a website such as Nodewatch[4] that will send a message that the spot price was high, or could be arranged to control the water heater depending on the price.

If, in the future, a tariff that reflects consumer's demand at times of system peak demand becomes available, the water heater could be arranged to always be off during

[3] I have been lobbying for this for more than 15 years with no success.

[4] Statement of conflict of interest: my son runs this website. It was initially set up to help us with the management of our hydro power station. http://www.nodewatch.co.nz/#/

the times that peak demands are expected. Alternatively, Nodewatch or some other organisation could provide signals that the system peak demand was approaching the set limit and switch off the heater.

From the consumer's point of view there would be benefits deriving from the reduction in peak demand that eliminated the need to spend money on new peaking plant. This may or may not be a benefit from the point of view of the generators!

Consumer benefit would also come from the system's ability to manage rapid drops in the output of wind farms and solar power because the smart thermostats would reduce the need for spinning reserve and mitigate price spikes. If there were a lot of water heaters controlled by spot price, the smart thermostats would switch on during periods of low price so increasing the price received by wind and solar generators when there was a surplus of energy. For instance, if the price were very low and the water heater were switched off, the system could use the opportunity to increase the amount of hot water stored by elevating the temperature set point by 5° or so.

The financial benefits

It is not easy to estimate the magnitude of the benefits but there is little doubt that they would be large.

At the moment, frequency management and spinning reserve probably cost somewhere between $20 million and $50 million. It is easy to imagine that this would be reduced by 50% or more.

There would be no direct benefit from the savings in under frequency load shedding because the cost falls on those who happen to be shed. So while it offers a real benefit to those consumers scheduled for shedding, it is difficult to establish how it should be valued or shared around.

Over frequency events do not impose a large cost so, the although the savings would be useful, they may not be all that large.

The device would virtually – maybe totally – eliminate the need to purchase interruptible load that costs something in the region of $10 million per year.

Effective management of peak demands could bring very large savings indeed. At the present peak demand price of about $100/kW, 400 MW would bring a saving of $40 million per year. There would be further savings to the consumer because the lines companies would stop over building their systems to meet unrestricted peak demand. There would also be savings from the major reduction in the need for new capacity to meet peak demands. If this is capacity is valued at $2000/kW, $800 million in capital expenditure would be saved. This, plus the reduction in the cost of operation and maintenance could amount to $100 million in annual charges.

Finally, the smart thermostats would reduce peaks in the spot price caused by the need to bring on high-priced generation during morning and evening peaks and at other times. Although this does not immediately affect people with hedges, in the long-term, hedge prices must always be higher than the average of the spot prices. It is conceivable that this would lead to a price reduction of something like 0.5 cents/kWh or $20 million per year.

In aggregate, these benefits could easily add up to as much as $200 million per year. Installing 1 million relays is likely to cost something like $400 million. The investment would be recovered in two years which is a much better recovery than is obtained from smart meters that cost about $80 per year and save about $50 per year in meter reading charges. Few of them serve any other useful purpose for the consumer.

Implementation

Under the present market regime, there seems to be no way that smart thermostats will ever be adopted. The problem is that their large overall benefit is made up from benefits from every sector of our disaggregated industry. So no single entity can capture sufficient value to make installation worthwhile. But if they did, they may choose not to implement the other features and, anyway, their investment would bring benefits to other sectors of the industry who would have no inducement to make a contribution. So the free rider problem would arise.

When I wrote to the Electricity Authority describing the smart thermostat and pointing out the implementation problems and, in particular, the need to change the regulation that stopped lines companies from recovering the costs of operating and maintaining their ripple control system the response from Carl Hansen was: "I am struggling to see a role here for the Authority." Words fail me.

It is certainly possible that if the inept regulation preventing lines companies from recovering the costs of maintaining operating and expanding their peak load control system was revoked, the lines companies might consider investing in them but it would be very difficult to sell the other benefits to other industry players. For instance, the System Operator is only likely to be interested in adopting it for frequency management if they were offered a large block of water heaters covering all of New Zealand. Which is not something a lines company can do. If the lines companies tried to cooperate to bring this about, they might be in trouble with the Commerce Commission for collusion. Similarly it is difficult to see how the System Operator could be authorised to exercise control when needed. How would the financials be handled? It does not provide any benefit for the System Operator, the benefit falls upon all consumers. But how do you arrange for all consumers to pay money to those who have installed smart thermostats?

There is one simple option that should be considered seriously. It is to have a clause in the connection agreement that states that if the consumer has a load that can be managed **to the direct benefit of the consumer without the consumer noticing**, then the consumer must make it available for control. This might seem to be somewhat

Draconian but it is much less Draconian then the present under frequency load shedding requirements where the consumer has no say in whether or not his power will be switched off following a serious frequency drop. As all consumers would benefit from the installation of smart thermostats, there is an argument for funding it via the Electricity Authority levy. Once the thermostats were installed, they would be made available to organisations who could demonstrate that the consumer would benefit directly or indirectly if their load was controlled. If this option was adopted consumers with smart thermostats would be better off than other consumers. Fair enough!

The reality is that, under the present regime, the smart thermostat will never get off the ground even though it would bring huge benefits to all consumers.

The Electricity Authority has a very strong conviction that an efficient market will, inevitably, bring maximum benefit to consumers and therefore there is no need to look at consumer benefit. Smart thermostats that will benefit the consumer rather than the industry players seem to have no place in our market. The problem is in the market, not the technology.

I believe that the fundamental flaw in our market is that it does not recognise that, to provide a reliable and economic supply, payments must be made for supplying energy (which it does) and for maintaining an adequate installed capacity to meet peak demands and dry years. If payments were made for providing adequate capacity then anything that reduced peak demands would also be rewarded.

This problem was discussed during the days of the Wholesale Electricity Market Development Group and not resolved. In fact, it seems that it has not been resolved anywhere in the world.

The simplistic answer is to set up a capacity market that pays for capacity including annual payments for capacity held in reserve for dry years. But how to determine what capacity should be paid for? For a geothermal station that runs continuously at maximum output, it appears to be its installed capacity. But what if it breaks down? Do you insist that it has sufficient reserve capacity? If every geothermal station carried its own reserve capacity, there would be far too much on the system.

If it is a wind or solar farm that produce very little during peak demand periods the answer is obvious and the outcome would, quite properly, reduce the income of wind and solar farms.

But what do you do about hydro stations? During a dry year – the critical period for our system – most of the hydro stations cannot run at full power because of lack of water. So do you arbitrarily decide that they will get half of the capacity payment? But what if they can't even meet that? You could pay them less, but that is not going to help keeping the lights on. It is a problem with no satisfactory will the answer. Worldwide, no one has reached a satisfactory solution and many power systems are now faced with the possibility of brownouts during periods of peak demand.

Conclusion

The paper has demonstrated that the smart thermostat would bring a very large benefits to the power system and to the consumer. In spite of the fact that large amounts of money are being spent on demand side management and a Smart Grid Forum has been set up to promote smart grids, there is virtually no chance of the smart thermostat being implemented in New Zealand unless changes are made to the electricity market that emphasise consumer benefit and recognise the need to regard the system as an integrated entity.

Maintaining adequate capacity for peak demands and dry years is a problem that can only be managed efficiently on a system wide basis. Something that the electricity market does not allow. If system security was managed on a systemwide basis, the smart thermostat would be a no-brainer.

The Electricity Authority has three options: continue with its present head in the sand attitude; face up to the fact that the existing market is far from perfect, imposes major risks of shortages in a dry year and denies consumers the benefits of modern technology or finance their installation via its industry levy.