Hot Water Load Control in South Africa

Nico Beute, Johan Delport

Engineering Faculty, Cape Town Campus

Abstract

The paper investigates the development and use of ripple control for metering, street-lighting and hot water load control. The paper includes a study of the use of ripple control in South Africa to control domestic boilers remotely and evaluates how effective it is to implement demand side management for different tariff structures.

The algorithms used to control the hot water load are also investigated and recommendations are made to get optimum control with minimum interference and discomfort to the customer.

The paper also points out new trends, developments, present and future applications in controlling loads for the purpose of demand side management in the domestic sector. This will include the use of intelligent load control equipment with 2 way communication.

Introduction

In South Africa, like most other countries, the cost of electricity is determined to a great extent by the value of peak load during a year in relation to the average load. In order to reduce this ratio loads are analysed to determine which type of load contributes greatly to the peak demand. Figure 1 shows clearly that the domestic load is one of the loads that contributes greatly to the peak demand. This has been so for many years so South African suppliers and distributors of electricity have attempted for many years to control parts of the domestic load.

The hot water load of most South African households constitutes about 25 to 40% of the total load and the supply to water heaters can be interrupted for about an hour or two without inconveniencing the customer because of the thermal capacity of the water in the water heater. So there are many suppliers and distributors of electricity in South Africa who control the hot water load of individual customers.

The load factor (kWh produced times 100 divided by average net capacity times hours in year) of the South African supply authority, Eskom, who supplies about 97% of South Africa's electricity has increased from 52% to 69% over the last decade. So the ability to shift load away from the time of peak demand is becoming more and more important. [a]

The technology used to do this control has developed over many years and is still developing. As long ago as 1897, when electricity supply was still in its infancy, Messrs. Brown and Routin proposed to control two-rate meters by means of a contrasting type of current [1], [4]. In those days the load was mainly determined by lighting demand and was very peaky. Efforts were made to even it out by offering cheap rates at times of low demand. Other uses of electricity were promoted as a result. It is not intended to describe the development of ripple control, but a few of the early publications and first commercial ripple control systems are given in the following tables [1].

Table 1: The precursory of ripple control

Year of publication	Authors	Principle
1897	Brown & Rouin (France)	Presence or absence of a d.c. between active and earth of an a.c. network (the inverse for d.c. networks)
1901	Turpain & Renous (France)	'Hertzian waves' generated by Ruhmkorff inductor. Detection by iron-fillings detector (branley's coherer)

Table 2: The commercial ripple control systems

Year	Coding system	Coding sytem	Method of injection
1927	Cie des Compteurs (F) (Actadis)	One carrier frequency per command. Pulse duration 0.5 minute.	Sequential series injection into M.V. feeders.
1928	Durepaire-Perlat (F)	Rhythm of changing polarity impulses. 1 rhythm per command.	Injection between neutral and earth of L.V. networks.

The development of hot water load control in South Africa

In South Africa ripple control is used extensively to control domestic water heaters (or hot water cylinders or boilers or geysers) for demand side management by switching off the boilers at a large number of consumers for a short time during maximum demand periods. The first control of hot water cylinders started in Benoni in 1956 and Sasolburg in 1959. The main reason was to reduce the cost of electricity to the Municipalities, because of the electricity tariff applied by the electricity supply industry. Later the control of streetlights was added to the system. Previously it was done by timers and day/night sensors.

The conference "Domestic use of Electrical Energy" showed some of the earlier publications up until 1996 about work done in South Africa on hot water load control. From 1993 to 1996 There were at least 14 papers dealing with hot water load control and some of these papers are listed in the attached bibliography [5] to [10].

During 1997, Eskom did a large hot water load control research project [11] and [14]. The information gained from those notch tests was invaluable. More models could be developed and tested against the measured data [12], [13], [15] to [19]. The biggest gain from the notch test results is the after diversity demand information (the total demand of a group of appliances in normal use). This is explained in more detail in the following paragraph.

The controllable load of a municipality consists mainly of hot water storage cylinders (or geysers) that are collectively designated as the hot water load. An example of the total load and the uncontrollable or base load is shown in figure 1.

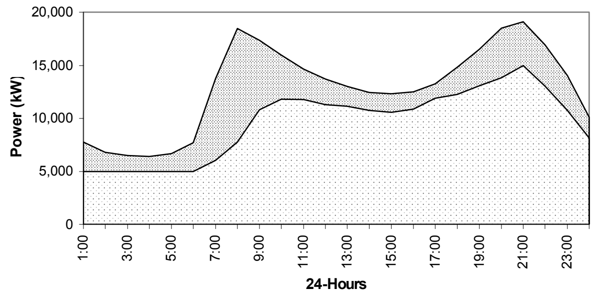

Figure 1: Total load illustrating the base load and the controllable load on top

The difference between the total load and the uncontrollable or base load in figure 1 is deemed as the controllable load (or hot water load in this case). This hot water load can be divided amongst the number of control points in order to arrive at the after-diversity demand (ADD) of the controllable hot water load as shown in figure 2.

Calculations are based on the ADD values as this allows for future load forecasting and ensures that any load that is uncontrollable at any time has no effect on the load management considerations.

The ADD graph shows that a municipality will use hot water differently during the day. The ADD graph is also unique to each municipality. Other factors, such as different consumption patterns, average element size of the hot water cylinders, outside temperature and average hot water cylinder inside temperature, will also have an influence on the graph.

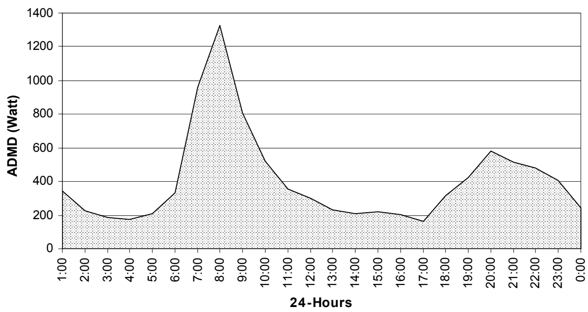

Figure 2: The ADD of the controllable load, hot water cylinders, of a municipality

This information is used to calculate the possible electricity cost saving for a municipality for a certain electricity tariff. The ADD value (per hot water cylinder) is multiplied by the number of hot water cylinders that could be controlled.
Figure 3 shows how the ADD can differ as well as what the result of a notch test looks like. The savings achieved on a R900,000 (€120 000) account per month during 2000 was in the order of R75,000 (€10 000). The tariff was a maximum demand and energy structured tariff. This was for a single customer who has many people living in university residence accommodation

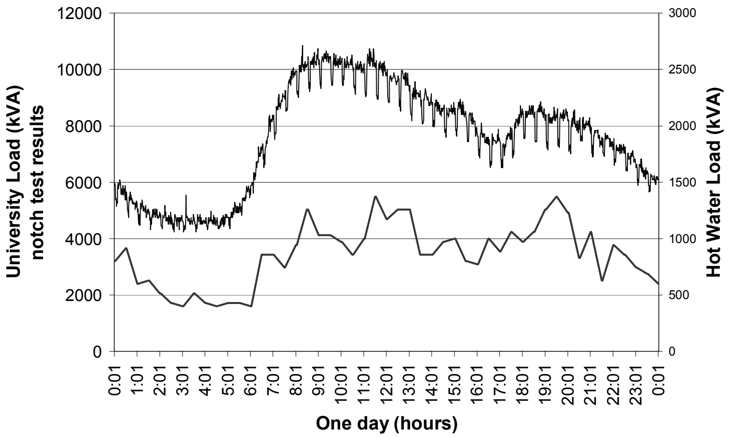

Figure 3: The notch tests and ADD of the controllable load of the University of Pretoria [21].

Using the Eskom time-of-use tariff, MegaFlex, the average saving per hot water load control switch is in the order of R 200.00 (€ 30) per year.

Current systems in South Africa

More than one hot water load control technology is used in South Africa. As previously stated, ripple control was introduced in the late 1950's. Currently ripple, radio, power line communication and combinations of radio and power line communication systems are in use. In some parts of South Africa radio technology does not work because of the demographical layout. The most common technology is ripple, but it is not necessarily financially viable for a small number of control points. Only the combined radio and power line communication technology allows for two way communication, other technologies all have only one way communication.
The highest injection voltage for ripple control is 66kV, done as a demand side management project in the Breede Valley Municipality, implemented during 2005, close to Cape Town.
Experiments have also been performed to investigate the use of free standing hot water control.[6] Fuzzy logic was used to determine the desired load pattern of hot water usage in individual households and an algorithm was developed to decrease the hot water load during peak time while minimising the possibility of users not having hot water when they wanted it. Although drift of the timing device used was considered problematic over a number of years and adjustment due to the shifting of peak periods presented a problem, the system was used very successfully in the pilot phase. Another shortcoming was the inability to respond to irregular needs due to faults in the supply chain requiring load shedding. The experience gained will prove very useful when adapting a centralised control system to suit individual customers by matching load shedding to suit the behaviour of individual customers.

Algorithms used to control the hot water load

The algorithms used to control the hot water load depend on a number of factors. Successful interventions in one municipality are not necessarily successful in other municipalities.
Normally the controlled switches will be grouped into a number of control groups, for example 20 groups. All the switches may be installed randomly. The main reason for this may be to try not to give two neighbours cold water at the same time, if the system is switching a specific group off for too long. A specific group may also be a dedicated group, for example old age homes. Those people use hot water completely different than the normal homes, so the control algorithm must take that into consideration. More examples of dedicated groupings are prisons, school hostels, hotels.

The other very important input into the control algorithm is the electricity tariff. Is the tariff a maximum demand and a single energy rate tariff, like the example of figure 3, or is it a time based energy and maximum demand tariff. The objective of the party responsible for having the control equipment installed is normally financial. So the motivation for installing the equipment is heavily influenced by the structure of the tariff. The party responsible to have the control equipment installed is normally a municipality who has to buy electricity from Eskom for resale. The structure of the tariff must be such that it motivates the municipality to improve the shape of Eskom's load curve. Another motivation for the municipality is often also to improve the shape of the load curve at any point of the network of the municipality where the municipality experiences a capacity limitation.
The reason why the maximum demand part of the tariff is so important is the recovery load. If a group is switched off for a time, then more hot water cylinders will switch on when power returns to the group than what would have been on if the power was not switched off for a time. Normally if all the switches were off for a time, the algorithm will allow the restore instruction only if the current maximum demand set point is not exceeded.
The most important point that one must remember is: Control may take place to reduce electricity cost, BUT NOT at the cost of production, in this case hot water to the customer. If a customer has cold water often, he may bypass the control in his house and the municipality will lose controllability and possible savings. Measurements have shown that during the morning and evening, when the control equipment is normally operated, approximately one third of the water heaters are switched on. Expressed in another way the average load is approximately 1 kW while the average water heater element is between 2,5 and 3 kW

The use of hot water load control to increase generation capacity

South Africa's peak demand has risen from 22 000 MW in 1990 to an expected 38The peak demand in South Africa is now very near the operating capacity of the total generating plant in the country, so South Africa is embarking on a substantial programme to increase the generating capacity. Installation of Hot water control is now planned as an alternative, cost effective way to increase generating capacity. We can also look at hot water control with another perspective. South Africa is in the process of increasing its generating capacity. Some of the options are:

- Coal power stations producing more green house gasses at a cost of R 9 000 (€1 200) per kW
- Gas fired power stations at about R 3 500 (€ 450) per kW
- Controlled Hot water cylinders at about R 2 500 (€ 350) per kW

The number of hot water cylinders in South Africa has risen from about 2 million in 1991 [20] to about 3 million now. Of these about 600 000 were controlled around the turn of the century, this gave a 360 MW saving in generating capacity [19]. Presently about 675 000 hot water cylinders are controlled. The notch tests described above show that the load which can be shed is about 1 kW per hot water cylinder during the morning peak and about 0.6 kW during the evening peak, so installing hot water load control can be compared to building a power station. The values above show that the installation of hot water load control is a cost-effective way of increasing generating capacity. Presently South African domestic customers do not have the option of a time of use customers, so the customer is not given a share of resulting savings. This has the effect that customers sometimes bypass the control equipment. Plans are in place to introduce time of use tariffs for domestic customers so that the customer can have his share of the savings. This will also counteract bypassing the control equipment.

New trends

South Africa is now experimenting with control systems having two way communication. The biggest challenge here is to obtain a cost effective technology, this applies to capital cost as well as operational cost. This technology provides the following very useful information:

- get notification of tampering,
- get hot water cylinder on / off state without doing notch tests,
- get the hot water cylinder temperature, and
- get the energy consumption of the hot water cylinder.

All these advantages will also help to make the control algorithm more customer friendly and save cost.

A need that can be ascribed to the customer is to have the hot water cylinder outlet water temperature fed back to the control switch. The switch must then have the additional intelligence, NOT to switch the hot water cylinder off, if the outlet temperature is below a certain set point. This can 'guarantee' that the customer will not have cold water.

Other controllable loads

The cost of the initial system and the load it can control determines the return on investment. The hot water cylinder is one of the largest consumers of electricity for the domestic customer, an average load of about 2.5 kW. Once the system is operational, more loads can be added. Examples are street lights, under-floor space heating and potable water pumps. These loads can then also be controlled to reduce the electrical load at peak times, thus reducing the generating capacity.
South Africa's climate is warm in summer. In the developed residential sector, a large number of houses have swimming pools. The swimming pool pump is currently under investigation to be included as a controllable load, even though the average load is only in the order of 0.75kW.

Conclusions

Hot water load control, if done properly, should be invisible to the customer. The supplier of electricity can save money, but it should never be to the discomfort of the customer.
The experience gained in South Africa with the control of hot water load over many years has put South Africa in an excellent position to use the hot water load for load shedding, without discomforting customers. The supplier and user of electricity can both benefit from cost savings that will result from this initiative. The current hot water load control systems in South Africa, can form part of the additional generating capacity that is now badly needed in South Africa as the country develops.
This development is necessary in developing countries because poverty needs to be eradicated and electricity is a commodity that is a strong catalyst to improve living standards.

References

[1] Eskom Holdings Annual Report 2005

[2] Surtees, RM 1992. The Changing shape of Eskom'd peak demand. Eskom (Internal Eskom project No 7765A017R)

[3] Kniel, R. 40 Years Ripple Control by Zellweger. Uster: Zellweger 1986.

[4] Robinson, I. Elster and Robmet – 50 years experience in ripple control. 1st Elster Demand Side Management workshop on ripple control technology, Somerset West, November 2006.

[5] Beute, N. Modelling domestic loads. Paper presented at the 1st Domestic Use of Electrical Energy Conference, Cape Town, October 1993. Paper included in the conference proceedings, page 62 - 67.

[6] Van Harmelen, GL and Lane, IE. System load impact evaluation with decentralised control. Paper presented at the 1st Domestic Use of Electrical Energy Conference, Cape Town, October 1993. Paper included in the conference proceedings, page 113 - 118.

[7] Van Tonder, JC and Lane, IE. A load model to support demand management decisions on domestic storage water heater control strategy. Paper presented at the 2nd Domestic Use of Electrical Energy Conference, Cape Town, April 1995. Paper included in the conference proceedings, page 125 - 129.

[8] Bisschoff, H, Craig, IK and Delport, GJ. On the control of a water heater. Paper presented at the 3rd Domestic Use of Electrical Energy Conference, Cape Town, April 1996. Paper included in the conference proceedings, page 1 - 3.

[9] Harley, KA and Delport, GJ. Time series analysis of the energy consumption of a domestic water heater using neural network technology. Paper presented at the 3rd Domestic Use of Electrical Energy Conference, Cape Town, April 1996. Paper included in the conference proceedings, page 10 - 13.

[10] De Wet, JG and Delport, GJ. Sun electricity water heating system. Paper presented at the 3rd Domestic Use of Electrical Energy Conference, Cape Town, April 1996. Paper included in the conference proceedings, page 14 - 17.

[11] Lourens, R, van Harmelen, GL, Delport, GJ and Forlee, C. Determination of National Water Heating Load Characteristics by a National Notch Test Program. Paper presented at

the 4th Domestic Use of Electrical Energy Conference, Cape Town, March 1997. Paper included in the conference proceedings, page 60 - 65.

[12] Van Harmelen, GL and Delport, GJ. The Quantification of Exogenous Variables for Practical Geyser Modelling in DSM Studies. Paper presented at the 4th Domestic Use of Electrical Energy Conference, Cape Town, March 1997. Paper included in the conference proceedings, page 118 - 123.

[13] Jooste, CJ, Delport, GJ and van Harmelen, GL. Water heater population behaviour under centralised control. Paper presented at the 7th Southern African Universities Power Engineering Conference, Stellenbosch, January 1998. Paper included in the conference proceedings, page 101-104.

[14] Lourens, R and Delport, GJ. Preliminary practical results and basic interpretations of modulation notch testing. Paper presented at the 7th Southern African Universities Power Engineering Conference, Stellenbosch, January 1998. Paper included in the conference proceedings, page109-112.

[15] Van Harmelen, G and van Tonder, JC. Hot water load control in the South African context: where to next ? Paper presented at the 5th International Domestic Use of Electrical Energy Conference, Cape Town, April 1998. Paper included in the conference proceedings, page 28 -32.

[16] Jooste, CJ, Delport, GJ and van Harmelen, GL Modelling load and customer impact of centralised water heater control to co-ordinate and optimise existing control resources. Paper presented at the 5th International Domestic Use of Electrical Energy Conference, Cape Town, April 1998. Paper included in the conference proceedings, page 271-274.

[17] Breakspear, D. Residential water heating systems - theoretical and real usage efficiencies. Paper presented at the 5th International Domestic Use of Electrical Energy Conference, Cape Town, April 1998. Paper included in the conference proceedings, page 241-244.

[18] Jackson, W and Sprunt, A. Micro controlled peak smoothing and energy saving geyser management system for domestic use. Paper presented at the 5th International Domestic Use of Electrical Energy Conference, Cape Town, April 1998. Paper included in the conference proceedings, page 245-250.

[19] Forlee, C. Water heating in South Africa facts & figures from the 1997 "notch testing" program. Paper presented at the 5th International Domestic Use of Electrical Energy Conference, Cape Town, April 1998. Paper included in the conference proceedings, page 265-270.

[20] Beute, N Domestic Utilisation of Electrical Grid Energy in South Africa. 1993. Dissertation for the PhD degree, Potchefstroom University for Christian Higher Education

[21] Wilken, AS and Delport, GJ. Making Money with Intelligent Hot Water Load Control. Paper presented at the pre-conference seminar: The Domestic Use of Energy at the Eastern African Power Industry Convention 2000 (eapic 2000), Kampala, Uganda, October 2000. Paper included in the conference proceedings, page 128 - 146.