USING LOAD RESEARCH DATA TO ASSESS DEMAND SIDE MANAGEMENT INTERVENTIONS

C. Doyle(1), C.T. Gaunt(2), R. Herman(2)

(1) Chalmers University of Technology, Sweden (2) University of Cape Town, South Africa

ABSTRACT

The Southern African NRS Load Research (LR) project was established in 1994 with the aim of providing design parameters to guide the National Electrification Programme (NEP) [1]. Socio-demographic data and over 75 million (5-minute averaged) load readings from domestic customers at 40 sites have been collected, representative of all residential customer types in South Africa, i.e. rural and urban with low, middle and high household income. The electrification of so many new customers under the NEP has had a major impact on the national system load, such that electricity demand will outstrip peak generation capacity by 2007. To relieve the situation many demand side management (DSM) initiatives are being implemented to try to modify the system load profile. It is difficult to select the optimum DSM method for a distribution area without first knowing more about appliance ownership and usage of each customer type and the associated load profile. The data available in the NRS LR database has been analysed to determine the characteristics of each customer type and uses this information to assess the impact of various DSM interventions.
Keywords: DSM, residential, load models, data mining, distribution

INTRODUCTION

The South African "Electricity-For-All" programme has achieved great success since its inception in 1991. Over 4 million households in South Africa were electrified and the aim is to electrify the remaining 3.5 million households by 2012. The load profile of a residential customer is peaky in nature with a pronounced peak in the morning between 07h00 and 09h00 and another in the evening between 18h00 and 20h00 (Figure 1).

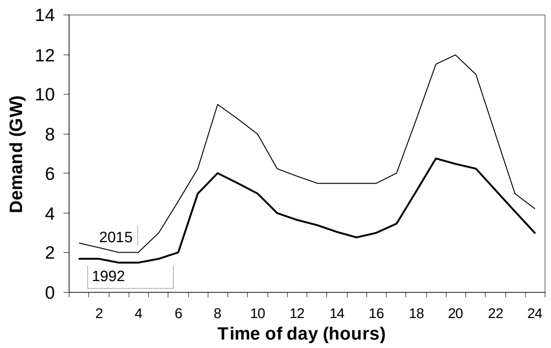

Figure 1 South African domestic load profile [2]

The addition of all these residential customers with this type of load profile has had a significant effect on the national system load profile. The load factor (average load/peak load) has declined over the last few years and the system peak has moved from the morning to the evening. The percentage contribution of residential load to the system peak has increased, which has pushed up energy consumption and cost during peak periods. These changes in the system load profile and the fact that the growing electricity demand will outstrip existing national peak supply capacity by 2007, have led to many demand side management (DSM) initiatives being implemented, to try and modify the load profile.

Most DSM programmes in South Africa are aimed at reducing the system demand at peak times because of the capacity constraints. With this type of focus, the effect on the transmission and distribution network can be overlooked, which can result in overloading lines and transformers. On the other hand, if a DSM method is successfully implemented it can benefit the transmission and distribution system by enabling the deferral of upgrades to lines and equipment. DSM programmes also need to ensure that the end user is not inconvenienced. The objective then is to implement DSM interventions in such a way that all players derive some benefit.

Accurate assessment of DSM interventions depends largely on the data available to give a complete picture of the impact. Real customer data is irreplaceable, but can be expensive to collect. The NRS Load Research (LR) project was established in 1994 to collect electrical load and socio-demographic data from domestic consumers. This data was successfully used to devise new design parameters that reduced the National Electrification Programme (NEP) costs. The research currently being carried out, investigates the possibility of using the data already in the NRS LR database to assess Residential DSM (RDSM) interventions. Since the data has already been collected for other purposes the associated cost is negligible. In fact, if the data can be used in the future for DSM assessment this database will prove to be a valuable investment. The database provides a unique insight into the load profiles, appliance ownership and usage of residential customers, which can vary widely depending on customer type i.e. rural and urban with low, middle and high household income. This paper illustrates the extent of the data available and how it can lend itself to aiding in the assessment of DSM interventions.

DSM INTERVENTIONS

The profile manipulations that are mainly used in residential design and operation are peak clipping, load shifting and strategic conservation.

- Peak clipping reduces energy consumption at the time of the daily peak.
- Load shifting, is the moving of load from the time of peak to times when energy consumption is low.
- Strategic conservation involves reducing the entire energy load.

The DSM interventions discussed in this paper include measures that have been tried and tested in South Africa to reduce the residential load and also measures that have yet to be fully tested in the South African context.

Hot Water Cylinder Control

A typical hot water cylinder (HWC) is rated at 3kW. Without control it will operate in a continuous cycle based on upper and lower thermostat settings, adding a significant amount to the household load. The fact that hot water in storage cylinders does not need to be heated and used at the same time, provides an opportunity to control the energy supply to the HWCs, and thus to lower the demand at peak times. Ripple control sends a signal to the HWC through the mains to operate by a defined algorithm. The algorithm design dictates how and when the HWC will function and thus in turn how the load profile will be effected, i.e. peak clipping, load shifting or strategic conservation.

Circuit Breaker Tariff

The capacity of a residential customer to contribute to the system maximum demand is limited by installing a low circuit breaker rating. Customers choose from a range of ratings, for example 20A, 30A or 60A. In order for circuit breaker tariff to be successful in reducing demand, customers must be encouraged to choose a circuit breaker rating low enough to restrict their appliance usage at peak times. To do this, utilities can offer incentives in the form of a lower monthly basic charge or kWh cost or a combination of both, as the circuit breaker rating decreases. Customers can then choose the best option for themselves based on their own financial situation. If they choose a low value circuit breaker, they must plan their use of electricity in such a way that they do not trip the circuit breaker. Circuit breaker tariffs fall into the category of strategic conservation.

Energy Control Unit

An energy control unit (ECU) is a simple method that could be used to control the load. This device can be connected to enable the shedding of non-essential loads such as HWCs or under floor heating. The stove and HWC are the high current appliances in a mid- to high-income household that are used most frequently. The ECU could be connected so that when the stove is turned on, the supply to the HWC is cut off. By virtue of the sizes of these appliances and their regular use, this device could provide a good opportunity to reduce the demand at peak times through load shifting.

Time of Use Tariff

A lower tariff is set for off-peak times, thus encouraging customers to shift load from peak times to off-peak times. The major challenges with implementing a domestic customer time of use (TOU) tariff in South Africa in the past were the high cost of retrofitting meters and the education of customers to enable them to respond to TOU tariffs. The future in metering in South Africa now lies in prepayment meters, due to their effectiveness in revenue collection. Over 4 million households are connected to the prepayment system and utilities are encouraging customers with credit meters to convert to the prepayment system.

The current tariff used with prepayment metering is a single rate energy based tariff. Before prepayment meters can be used for TOU based DSM there are some technical specifications that must be met, e.g. the meter must be able to deal with complex tariffs and incorporate a clock that can be reset to correct for drift. If the present meters can be adapted, they could provide an effective way to implement DSM. They already have several features that make them an attractive device for this application, including an interface that enables customers to track their energy usage more easily. If customers have a better understanding and a simple means of tracking their energy usage there is a higher possibility that a TOU tariff would be successful in reducing the demand.

Conservation Voltage Reduction

Conservation voltage reduction (CVR) is a technique that is really only used when there is a severe power shortage. For example, it was implemented in Chile in 1999 when an extreme dryspell in the nation severely curtailed generating capacity at the hydroelectric facilities [3] and in California in the summer of 2001 to help alleviate its energy crisis [4]. Although CVR is mainly used in emergency situations, some utilities have investigated using it as a method of reducing the demand on the system during normal operation, with estimates of a 1% reduction in load for every 1% drop in voltage [5]. If used only at peak times, CVR falls into the category of peak clipping. If it is used for an extended period, it falls into the category of strategic conservation.

The voltage is reduced at the medium voltage busbars (South Africa: 132kV/11kV) by means of adjusting the set point of on-load tap changers. The reduction in voltage reduces the demand on the system, if the load is made up of mainly constant impedance loads. Domestic customer loads can be characterised by the way they respond to changes in voltage. There are three different load characteristics – constant impedance, constant current and constant power.

LOAD DATABASE CHARACTERISTICS

Since 1994, the NRS load database has collected socio-demographic data and over 75 million (5-minute averaged) load readings from domestic customers in 40 different communities, representative of all customer types in South Africa.

Load data

A minimum of 60 households is sampled at each site to meet sampling criteria. Measurements are sampled at 2-second intervals and averaged over 5 minutes using a 16-channel data logger. One of the channels is used to record a phase-neutral voltage. Internal clocks synchronise the loggers. The stored data on the logger is downloaded every month and checked for errors before being uploaded onto the database. The loggers are usually moved to a new site after two years.

Socio-demographic data

Each customer surveyed was asked a range of questions relating to income and education level of occupants, construction of house, water source, appliances owned, appliance usage, cooking habits and the electricity supply. A survey was also completed for each site that recorded site-specific information, e.g. distance from nearest town or city.

Storing and retrieving data

The database has grown significantly in size over the years requiring the development of a relational database and software application tools to store and analyse the load and socio-demographic data. Microsoft Sequel Server was selected as a database framework because of its compatibility with other software and its ability to handle the type of queries endemic to load data. Once the data has been uploaded to the database it is again checked for errors. Suspect data is tagged so that it can be excluded from analysis. Microsoft Access is used as an interface to query and view the data. Once the required data has been retrieved, it can be copied into Excel or a statistics package for analysis.

ANALYSIS

To assess the effect of residential DSM interventions on the national system demand or on a particular utility demand, a residential load profile needs to be generated appropriate for each case. Certain socio-demographic information also needs to be collected, for example in the case of HWC control the number of households with a HWC is needed.

The socio-demographic information that was collected and stored in the load database is conducive to the assessment of the DSM interventions already described in this paper.

- The information is available as to whether or not a customer has a HWC and 3- or 4-plate stove, which can be used in the assessment of HWC control and ECUs.
- The circuit breaker rating of each household has been recorded. Customers on low and high circuit breaker ratings can then be selected to investigate if current limiting is an effective way of reducing peak demand.
- The voltage measurements can be used to investigate the suitability of implementing voltage regulation.

Using this socio-demographic information in conjunction with the current measurements allows profiles to be generated for each customer type.

Classification of customers

The classification of customers, as set out in NRS 034, has been used [6]. This classification is based on the Living Standards Measure (LSM). The LSM is frequently used in South Africa to classify market segments.

RESULTS

Hot Water Cylinder Control

A lot is already known about the effect of HWC control on the South African system, as it has been studied extensively by Eskom and the municipalities. Eskom's RDSM programme focuses on this method, as it appears to be the RDSM method that can have the greatest impact on reducing the system peak. As mentioned previously, the collection of load data is timely and expensive. Therefore assessment of HWC control has been based on substation load measurements lasting a couple of weeks [7]. The load database can complement the work already completed, as it has two to three years worth of end user load recordings from sites that have implemented HWC control. Figure 2 shows the average household winter weekday of one site in the database for 1998 and 1999.

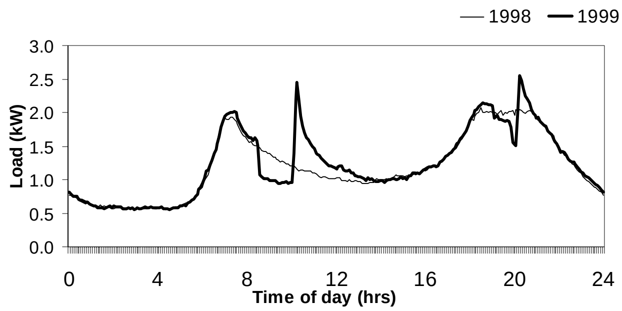

Figure 2 Average winter weekday per customer

This is a high-income (LSM 9) site that has 100% HWC penetration, with an average of 1.5 HWCs per household. The load profiles indicate that in 1999 HWC control was operated by the distributor in response to the TOU tariff set by the supplier. Implementing HWC control in this way achieved a reduction in the peak period demand of 0.25 to 0.4kW per customer. The survey data can be used, along with information available on the percentage of population in each LSM category [8] and the electrified household data [9] to estimate the saving on total system demand. If all HWC were controlled in this way, the possible saving on total system demand is calculated to be between 0.65GW and 1GW. The benefit to a utility can be estimated similarly using the number of customers and the % of customers in each LSM category. This method of HWC control achieves the objective of reducing the national system demand and the distributor benefits financially due to TOU tariff. However the 1999 profile illustrates the impact of cold load pick-up on demand once the cylinders are switched back on. The load data available for this site has shown that the cold load pick up consistently exceeds the 'normal' site peak load, which could result in the overloading of lines and transformers. Obviously this cold load pick up could be managed effectively by returning the HWCs to the system over a longer period of time.

Circuit Breaker Tariff

The majority of South African households have a circuit breaker rating of 20A or 60A. Two sites were selected to investigate the impact of a low circuit breaker rating. The first site was a low-income site (LSM 1-2) where households had a circuit breaker rating of 20A installed. A high evening peak and a load factor of approximately 0.4 are characteristic of low-income households. The objective of installing a low circuit breaker rating would be to reduce the demand at peak times and improve the load factor. Of the 64 households that were analysed, 83% never went above 15A. Only 5% of the remaining households used over 15A for more than 10 minutes a week. Evidently the 20A circuit breaker is not low enough in this situation to encourage customers to modify their appliance usage and reduce the demand at peak times, and is thus redundant as a short-term DSM measure. The year on year growth in the community indicates that it will be some years before this device will become effective.

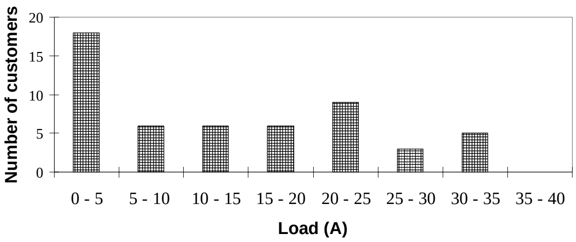

Figure 3 Customer loads at maximum demand

The second site to be analysed was a high-income site where customers had 35A circuit breakers installed. A histogram of customer loads at maximum demand is shown in Figure 3. High-income communities with a 60A circuit breaker rating do not have the same distribution. The histograms of these 60A communities decrease gradually as the load increases and few customers operate close to their circuit breaker limit, compared with the clumping of 35A customers around their limit. This suggests that in this situation the circuit breaker tariff has been effective at curtailing the customer usage at peak times.

Energy Control Unit

The survey data was extracted to find the percentage customers per LSM group that have a stove and HWC (Table 1). A high proportion of households have both a stove and a HWC, which suggests a large load shifting potential. However, previous research findings [10] have shown that the system maximum demand is highly dependent on the diversity of individual customer maximum demand. ECUs limit individual maximum demand but they also change the customer diversity, resulting in no significant change to the system demand. The maximum change in system demand that could be expected is a shift of load by 10 to 15 minutes. As a system DSM measure it would be ineffective.

Table 1

Consumer Class	Living Standard Measure (LSM)	% HWC/ household	% households with stove & HWC
Rural Village/Settlement	LSM 1 & 2	0%	0%
Rural or Informal Settlement	LSM 3 & 4	0 - 10%	0 - 10%
Township area	LSM 5 & 6	10 - 80%	10 - 75%
Urban residential I	LSM7	80 - 100%	75 - 100%
Urban residential II	LSM8	95 - 150%	75 - 100%
Urban townhouses	LSM9	95 - 150%	90 - 100%
Urban Multistorey	LSM10	95 - 200%	90 - 100%

Time of Use Tariff

Figure 4 shows a conservative estimate of the proportion of the total system load that is made up of customers with prepayment meters. This prepayment load profile was modelled using load profile, LSM and number of electrified household data. The contribution of these customers to the morning and evening peak is 1.3GW and 2.5GW respectively. When a domestic TOU tariff was tested in Durban the customers responded by reducing their peak demand by 20% [11]. If a similar reduction was achieved with all prepayment meter customers a saving of 0.26GW and 0.5GW on the morning and evening peaks respectively could be achieved. This may provide an allowance to increase the reserve margin, but to fully understand if this saving is significant, a full financial analysis would need to be completed.

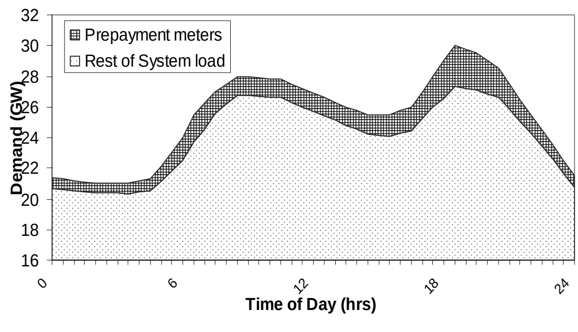

Figure 4 Prepayment meter load as a proportion of total system load

Conservation Voltage Reduction

To deduce if CVR would be an effective method in reducing the residential demand, the domestic customer load characteristic must be determined, i.e. whether the domestic load is made up of mainly impedance, current or power loads. This can be illustrated by examining the effect of voltage adjustment. A site was selected where a voltage increase had been applied site-wide of 10V, which corresponds to a 4.5% increase. The current increased across the site as a result, which is indicative of impedance loads. It is difficult to determine the exact increase because of the continuously varying magnitude of the domestic load and the response may vary for various types of communities. Since the domestic customer load appears to consist mainly of impedance loads, a reduction in demand could be achieved by reducing the voltage. However, before CVR can be implemented the present voltage levels must be examined. If the voltage level in some areas is already very low, it may not be possible to reduce it further. The voltages for different rural and urban sites were extracted from the database. As suspected, due to the long feeder distances, rural areas were operating with a wider voltage range than urban areas and have a lower minimum voltage level, in some cases as low as 160V. Installing capacitors or voltage-regulating devices in rural areas may be effective solutions in preventing excessive voltage drop.

CONCLUSION

From the above analysis HWC control and CVR appear to be the most effective in reducing residential demand. HWC control can only be implemented for customers in LSM categories 5-10, as the majority of customers in LSM 1-4 do not possess a HWC. Distributors must be aware when implementing HWC control that the cold load pick up could stress the distribution network. CVR could be successfully introduced in urban areas, but some precautions against excessively low voltage levels must be taken before it can be implemented in rural areas. Tariff approaches appear to have an intermediate impact and their future is dependent on metering technology and devices being developed. The ECU would only succeed in shifting the load by a very small period and thus would be an ineffective DSM measure.

The assessment of DSM interventions completed here was based on data extracted from the NRS LR database, together with LSM and electrification figures. If combined with substation data and other DSM site analysis, it could be a very powerful tool indeed.

REFERENCES

1. Dekenah, M., Gaunt, C.T., "Design Parameters for Electrification", Proc. Domestic Use of Electrical Energy Conference, Cape Technikon, Cape Town, South Africa, 1998. Text available at: http://www.ctech.ac.za/conf/due/SOURCE/Web/Dekenah1/Dekenah1.html

2. Boyle, S. "DSM progress and lessons in the global context", Energy Policy, v 24, n 4, pp. 345 – 359, April 1996

3. "New round of power rationing announced", Chile Information Project – "Santiago Times" – Political, Environment, Human Rights, Economic News, March 31, 1999. Text available at: http://ssdc.ucsd.edu/news/chip/h99/chip.19990331.html

4. Wilson, T.L., "Energy conservation with voltage reduction-fact or fantasy", Proc. 46th Rural Electric Power Conference, Colorado Springs, Colorado, pp. C3-1-6, May 5 –7 2002

5. McCarthy, C., Roberts, S., "The CAPS Program, Capacitor application for peak shaving", The Line, pp. 7-9, May 2000.

6. NRS 034-1:1999 "Electricity Distribution – Guidelines for the provision of electrical distribution networks in residential areas", Edition 3.1, 1999

7. van der Walt, S., "Geyser control as a DSM tool for Tshwane Metro", Energize, pp. 12-15, Sept 2003.

8. Living Standards Measure, South African Advertising Research Foundation. Available at: www.saarf.co.za

9. "Lighting up South Africa 2003", National Electricity Regulator, Republic of South Africa, pp. 10, 2003.

10. Gaunt, C.T., Herman, T., Dekenah, M., Sellick, R.L., Heunis, S.W., "Data collection, load modelling and probabilistic analysis for LV domestic electrification, CIRED '99 Proc. 15th International Conference on Electricity Distribution, Nice, France, June 1-4 1999. (CD-ROM)

11. Wienand, R.F., Reuben, R.C., "Domestic Time of Use tariff: The Durban Experience", Proc. Domestic Use of Electrical Energy Conference, Cape Technikon, Cape Town, South Africa, pp 46-52, 1999.

AUTHOR'S ADDRESS

The authors can be contacted at

Department of Electrical Engineering,
University of Cape Town,
Private Bag,
Rondebosch,
7701,
South Africa

email: ciara@etek.chalmers.se; ctg@eng.uct.ac.za