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Impact of HWC DSM on voltage conditions and the choice of load parameters for feeder design

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SUMMARY

An extensive load research program, known as the NRS Load Research Project, was conducted between 1994 and 2005 in South Africa. It produced a large volume of domestic customer load data based on a 5-minute sampling period. From this data source statistically-based load models were derived, and are used in a probabilistic design procedure for the sizing of LV feeders. The statistical description used is a Beta probability density function. While this approach has received nation-wide approval in South Africa, it does not include the effects of peak-load reduction through the use of hot-water cylinder (HWC) switching.

In this paper we investigate the impact of HWC DSM on the voltage performance of a LV feeder and the how it affects the choice of load parameters for design. It describes a procedure for using load data for a community with HWC, but without DSM, and then predicts the effect it would have on the characteristic loads once the HWCs are restored, subsequent to load-levelling.

KEYWORDS

Probabilistic load modelling, LV distribution

OVERVIEW

Towards the end of the 1980s a significantly large proportion of the South African population had not yet experienced the benefits of electricity in their homes. A concerted drive was launched under the banner of “Electricity for All” to redress this problem, and became the National Electrification Programme. This necessitated the accelerated planning, design and construction of new electrification networks. An obvious, but often misunderstood, component of the design of LV distribution circuits is knowledge of the design loads. To address this issue an extensive load research programme was launched under the auspices of the National Rationalization of Standards (NRS) organization. A suitable data logger had been designed and constructed to collect 5-minute load current samples from selected sites [1]. These data were analyzed in some detail and a statistical description in the form of a Beta pdf was found to best represent the loads at the interval of system maximum demand [2].

A probabilistic design procedure was then formulated to use the characteristic Beta parameters (α , β and C) from the load research data. This method was thoroughly tested using Monte Carlo simulations and found to be superior to previous methods used in South Africa [3]. It was then included in the South African design standard, NRS:034-1 [4]. Subsequent work has identified an approximate relationship between the after diversity maximum demand and the beta parameters of the loads [5]. However, because the emphasis of the electrification being carried out in South Africa was on the lower end of the consumer scale, DSM using hot water cylinders (HWC) was not monitored and is not included in the analysis so far. Currently the demand has outstripped the supply in South Africa and DSM is again a topic of importance. A pertinent question needing answers is: ‘how will voltage conditions be affected by HWC-DSM and how would the load parameters change?’ This paper suggests a procedure for analyzing the problem using the NRS load research data.

METHOD TO EXTRACT EFFECT OF HWC-DSM

Using Excel the method was briefly the following:

1. Three economic classes of customer were chosen from the data that would include hot water cylinders.
2. The sample sizes were greater than 45 each, ensuring statistical significance.
3. Each data set was analyzed between midnight and 05:00 in the morning to identify the kind of loads active at this time. The reasoning was to determine a period of time in which HWCs would operate under the control of thermostats.
4. We assumed that HWCs would have ratings of either 2 kW or 3 kW – corresponding to load currents of 8.7 Amps and 13 Amps respectively.
5. Next, a filter was set to identify these two load magnitudes using nested IF statements in Excel spreadsheets.
6. We excluded from the data set any customers whose appliance usage had a more frequent pattern of larger loads. These we identified as air conditioners or thermostatically controlled space heating. Call the truncated dataset FILTERED SET.
7. We identify the system peak from FILTERED SET by averaging the load currents of all the customers at each 5-minute interval. The maximum value of these mean values corresponds to the interval at which the ADMD occurs, t_w .
8. We then recorded the size of the HWC for each customer in amps in FILTERED SET.
9. Next we apply DSM to the FILTERED SET for an interval that included the system peak period, t_w . This was typically between 18:00 and 20:00.
10. DSM is applied by subtracting the HWC (i.e. HWC switched off) load current from the customer’s load current, provided the load current was larger than the HWC load. If the load current magnitude was less than that customer’s HWC size, the load current was left unaltered.
11. It was further assumed that all the HWC loads would be restored simultaneously. This produces cold-load load pickup at the end of the DSM period, t_c (say 20:00). It is simulated by adding the associated HWC load to each customer’s load current.

12. The load prediction ends at this point because we do not know how long they will remain switched on, pending usage, but it should be sufficient to produce a planning model.

RESULTS FOR HWC DSM ANALYSIS

Results are shown for one of the three cases analyzed, the procedure being the same for each. Figure 1 shows the load profile as measured on the day in which system maximum demand occurred. It shows (a) the mean load current and (b) the mean plus one standard deviation current as functions of time for a group of customers belonging to a similar class. No DSM interventions are included in this graph. It is evident from the graphs that the maximum demand for this group of customers occurs at about 19:00 (t_w). The graphs further suggest that peak lopping, if applied using DSM, would occur between 18:00 and 20:00.

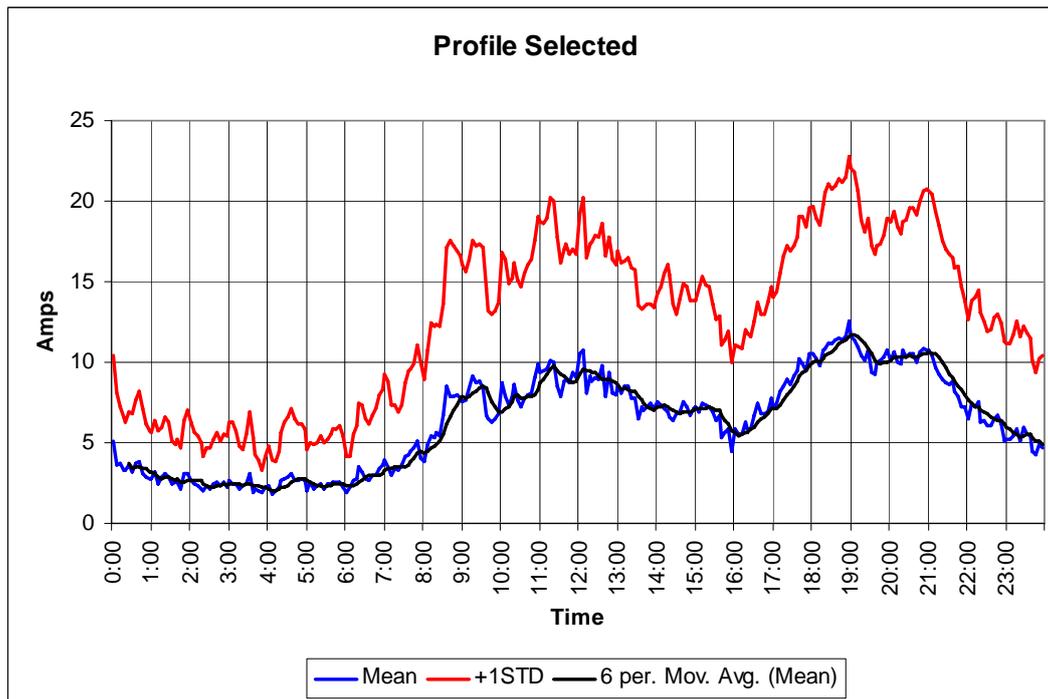


Figure 1 Daily profile for Residential group – without HWC DSM

Figure 2 shows the simulated HWC usage for the period from 00:00 to 05:00. This corresponds to steps 4 to 6 in the procedure described. It should be noted that each HWC type identified is tagged to that individual customer. This allows us to simulate the effect of switching each one on and off. To simulate the effect of HWC-DSM each customer's HWC (be it 2kW or 3kW) is switched off at 18:00. This is done by the subtraction steps, 8 to 10.

Finally, the HWCs are restored at 20:00 by adding the respective HWC load current to each customer's load at 20:00. It is assumed that the thermostats would be in the 'switch-on' position after the two-hour rest. This of course results in a cold-load pick-up condition that raises the demand load current for both customer and system.

In this typical South African scenario the effect of cold load pick-up is significant. It would result in higher voltage drop in the feeder feeding the customers. The change in characteristic load parameters at the interval, t_c , and the resultant impact on voltage drop calculations is discussed in the next section.

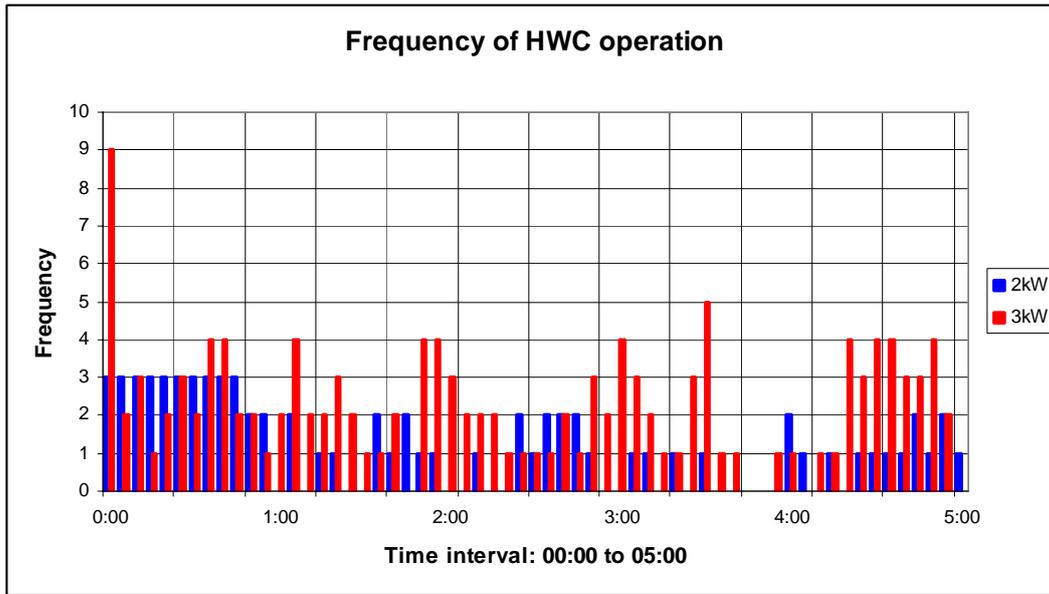


Figure 2 Estimated frequency of operation of HWCs during stand-by period

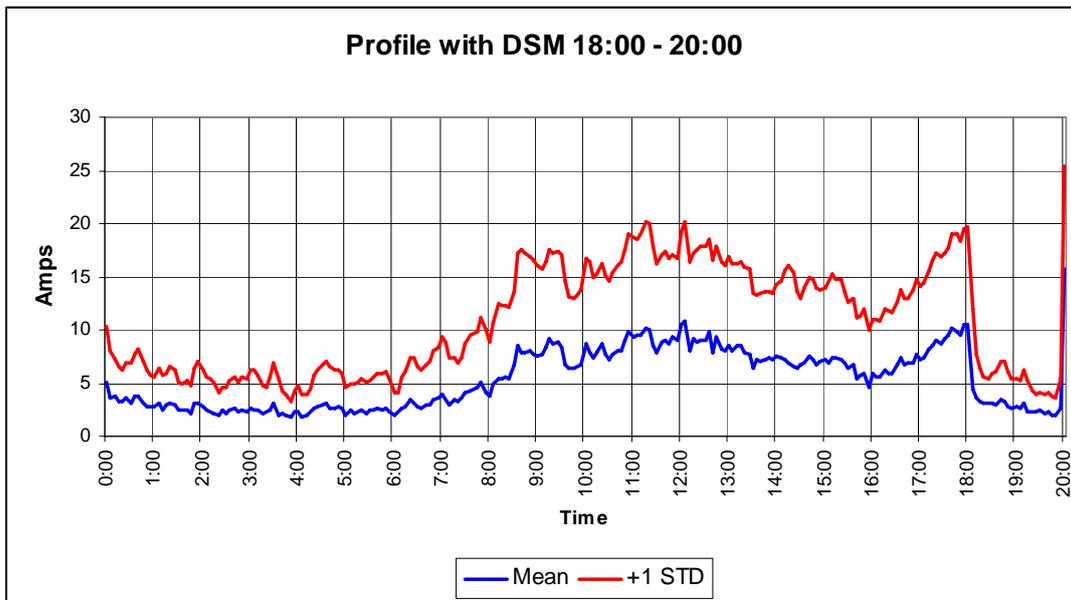


Figure 3 Profiles with HWC DSM from 18:00 to 20:00

EFFECTS ON LOAD PARAMETERS AND VOLTAGE DROP CALCULATIONS

On average the ADMD at cold load pick-up was 30% higher than the ADMD at the time of the community peak, t_w . Further, the ratios between standard deviations and means (known as the coefficient of variation) for the two instants are on average 0.5 and 0.8 respectively. From this information we can estimate the Beta parameters of the load currents at the instant of cold load pick-up. Following this reasoning the Beta parameters were calculated for the time intervals: t_s , t_w and t_e .

To illustrate the impact on voltage drop performance at these various time intervals, an example was chosen where four customers were fed by a single-phase, 100 m, 35 mm² cable. The Herman-Beta method was then used to calculate the voltage drop at a 10% risk value. The results are shown in table 1.

Table 1 Results of analysis for HWC - DSM

	Mean	STD	+1 STD	Alpha	Beta	CB	V-Drop
Cold Load Pickup at 20:00, t_c	15.669	9.673	25.342	1.914	7.86	80	6.68
Load at 18:00 (No DSM), t_s	10.551	9.089	19.640	1.038	6.83	80	5.04
Load at 20:00 (No DSM)	10.066	8.618	18.684	1.067	7.41	80	4.80
Maximum Demand, t_w	12.524	10.190	22.714	1.118	6.02	80	5.86

It is clear from the results of the case illustrated that the voltage conditions are aggravated by the application of HWC-DSM. The calculated voltage drop at maximum demand (t_w), without DSM is 5.86%, while the voltage drop at the end of the DSM intervention is 6.68%. This represents a percentage increase of voltage drop in the feeder cable of approximately 14%. Also, the mean current increased from 12.52 Amps to 15.67 Amps per customer. This is an increase of about 25%. Because the diversity among customers is reduced when all the HWCs are switched on, the ratio of standard deviation to mean changes from 0.81 to 0.62.

CONCLUSIONS AND RECOMMENDATIONS

This analytical procedure was conducted on a relatively small data base at the time due to difficulties in accessibility. A more comprehensive study would be beneficial in the future once the load research data base has been transformed into a more usable format. Based on the study of the limited sample, it was recommended that the following design approach be adopted by a utility. When HWC-DSM might be applied to a LV distribution network in the future, the design procedure should be:

Estimate the beta parameters at cold load pick-up from:

- Mean load amps, $\mu = 1.25 \times \text{ADMD (amps)}$
- Standard deviation, $\sigma = 0.6 \times \mu$
- Use μ and σ with the circuit breaker size or a standard value of C, to calculate α , β and C. The formulae for conversion are available in Annex B of [4] and in [5]
- Use these parameters in the Herman-Beta method for calculating voltage drop.

ACKNOWLEDGEMENT

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REFERENCES

- [1] R Herman & C T Gaunt, "Measurement and representation of maximum demand for individual and grouped domestic consumers including constraints", CIRED, April 1991, Liege, Belgium.
- [2] R. Herman & J.J. Kritzing, "The statistical description of grouped domestic electrical load currents", *Electric Power Systems Research*, 27 (1993) 43 – 48.
- [3] R. Herman & S.W. Heunis "A General Probabilistic Voltage Drop Calculation Method for L.V. Distribution networks based on a Beta p.d.f. Load Model", *Electric Power Systems Research*, 46 (1) (1998) pp 45 – 49.
- [4] SANS 507-1 / NRS:034-1:2007: *Electricity distribution - Guidelines for the provision of electricity distribution networks in residential areas: Part 1: Planning and design of distribution networks*. Standards South Africa, Pretoria. Available at (April 2009) [http://www.nrs.eskom.co.za/nrs/Specifications/NRS%20034-1%20\(0.4\).pdf](http://www.nrs.eskom.co.za/nrs/Specifications/NRS%20034-1%20(0.4).pdf)
- [5] R. Herman & CT Gaunt, "A Practical Probabilistic Design Procedure for LV Residential Distribution Systems", *IEEE Trans on Power Delivery*, 2008.