THE USE OF SMART METERS TO IMPROVE CUSTOMER LOAD MODELS

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ABSTRACT

This paper describes the use of data from smart meters at LV customers to obtain knowledge of load behaviour, load profiles and coincidence factors. These data can be used to improve load models of LV customers, which are used for calculation tools regarding planning and analysis of LV networks.
The results of calculations performed for planning and other analysis of LV networks are suspect to a large amount of uncertainty. This is because there is little knowledge of specific parameters like individual peak demand and coincidence factors which have to be used in these calculations. Most of these figures are based on best guesses, rules of thumb and a just few simultaneous measurements.
Data from smart meters can help to improve knowledge about the impact of nowadays households on the loading of LV networks. As a pilot the data from 200 smart meters was analysed. The data was obtained during the winter of 2010. Several conclusions can be drawn. The various loads during the peak don't show a normal distribution. About 20% of the connections contribute for about 50% to the peak load of a transformer and a feeder. In order to obtain proper result of LV-calculations the parameters used for expected load and coincidence factors must be adjusted.

INTRODUCTION

Modern LV networks are suspect to many changes in load and generation. Examples are the increase of home entertainment appliances, introduction of DG like PV and micro CHP, new heavy loads like heat pumps and electric vehicles. These changes have impact on the performance of the LV network and have to be taken into account by calculations performed for planning and other analysis of LV networks.
However, there is little knowledge of specific parameters like individual peak demand and coincidence factors which have to be used in these calculations. Most of these figures are based on best guesses, rules of thumb and a just few simultaneous measurements. As a result the results of calculations are suspect to a large amount of uncertainty.
The introduction of smart meters at LV customers opens the possibility to simultaneously measure the energy used in a specific time interval by a large amount of customers over a large range of time. If the time interval between the energy measurements is small, the average power used in this period can be estimated. Analysing this data can give more insight in individual and aggregated load-profiles and coincidence factors.

LV NETWORK DESIGN IN THE NETHERLANDS

LV networks in the Netherlands normally consist of underground cables. The networks have to be designed for their entire life cycle of more than thirty years. Important design criteria are the maximum current and the maximum and minimum voltages. Both voltage and current are caused by the various loads in the network. Often two extreme cases are considered. The case of maximum load and minimum generation results in the lowest voltage and the case of minimum load and maximum generation results in the highest voltage. This paper mainly deals with the case of maximum load.
When considering the load in the network it is necessary to take the coincidence factors into account. For residential loads it is often expected that they have a normal (Gaussian) distribution during the periods of maximum feeder load. Given this distribution it is possible to calculate the load for a specific number of connections.

$$Pmax_n = n \cdot \mu_1 + 3 \cdot \sigma_1 \cdot \sqrt{n}$$

Here $Pmax_n$ is the maximum load for n connections, μ_1 the average value of the loads and σ_1 the standard deviation.
In 1952 Velander [1] used this formula by relating it to the annual energy usage.

$$Pmax_n = n \cdot \alpha \cdot U_1 + \beta \cdot \sqrt{U_1 \cdot n}_1$$

Here U_1 is the annual energy use per connection for a specific group of users. The parameters α and β have to be estimated by means of measurements. This formula was used in 1975 in a Cired paper by Axelsson and Strand [2]. Therefore this equation is known as Strand-Axelsson in the Netherlands.
In 1956 Rusck [3] described a function which related the maximum load to the maximum load for a single connection.

$$Bmax_n = n * g_\infty \cdot Bmax_1 + (1 - g_\infty) \cdot Bmax_1 * \sqrt{n}$$

With:

$$g_n = g_\infty + \left(\frac{1 - g_\infty}{\sqrt{n}} \right)$$

This formula can be written as:

$$Bmax_n = n * g_n \cdot Bmax_1$$

Here g_n is the so called coincidence factor.

The parameters for α, β and g_∞ which are generally used in the Netherlands result in:

$$\mu_1 \approx \sigma_1 \approx 1\,kW$$

These values give good results for a large number of connections even on transformer level of the LV network, feeding about 200 connections. The question however is whether these equations and their point of departure are still valid for load distribution in LV feeders which in general consists of 20-60 connections. This question can be answered by analysing the data of smart meters.

DATA ANALYSIS

The data of 200 connections was investigated. The connections contained domestic loads divided over five different LV feeders. The measured data contained 15 minutes interval data over a period of two months in the winter of 2010. The smart meters don't show the exact load at a specific moment but the energy usage. By subtracting two consecutive measurements, the average load in a 15 minutes interval can be calculated. This load is expected to be the average load during this 15 minutes interval.

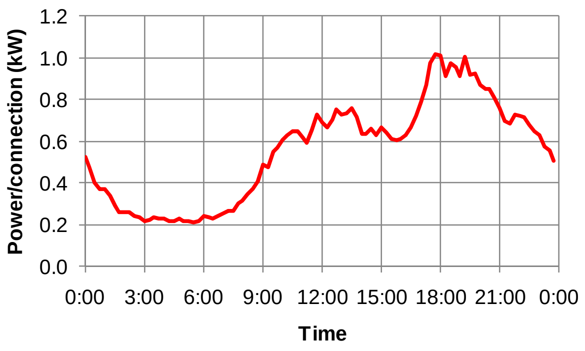

Figure 1 Load profile per connection for all connections

The aggregated load profile for all connections is shown in Figure 1. The maximum load per connection is about 1 kW. This corresponds with the value generally used in the Netherlands.

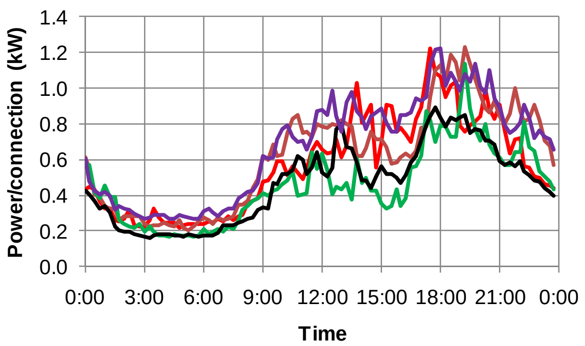

Figure 2 Load profiles per connection for the feeders

The aggregated profiles for the various feeders are shown in Figure 2. These profiles look similar in shape, although variations in magnitude are visible. All peaks occur between 17:00 and 20:00 hours. The maximum load per connection is about 1.2 kW.

The individual loads show a large variation, both in pattern as in magnitude. During the total period of measurements, the maximum individual load was about 8 kW. During the day of the aggregated peak load a maximum individual load of 7 kW occurred. In the hours around the aggregated peak the maximum individual load was 5.3 kW.

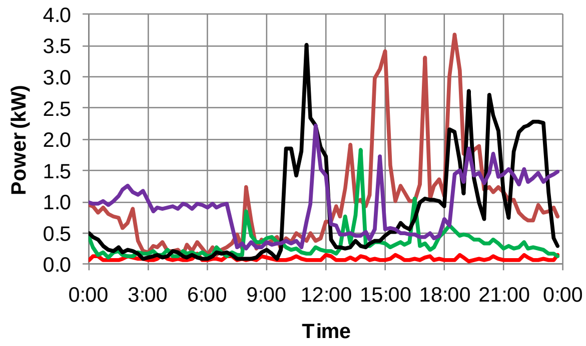

Figure 3 Individual load profiles for single phase connections

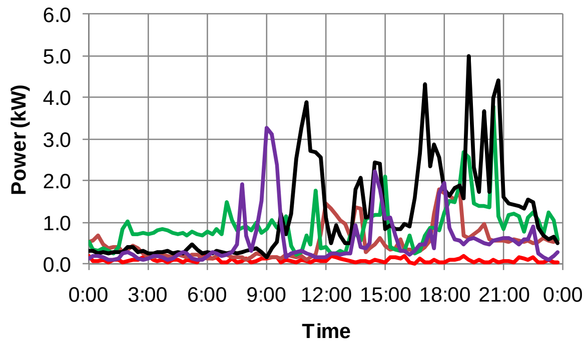

Figure 4 Individual load profiles for three phase connections

Examples of the individual load profiles over one day are shown in Figure 3 for a set of single phase and in Figure 4 for a set of 3-phase connections. From these pictures it becomes clear that there is no general individual customer profile.

ANALYSING VARIOUS LV FEEDERS

In order to get a better understanding of the behaviour of the loads various analysis were performed. The analysis was focused on the on the days with the 10 highest peaks.

Load profile

As an example the load profile for a feeder containing 49 households is shown in Figure 5. This figure shows that all ten peaks occur between 17:00 and 20:00hours. The load profile shows some difference in the time of the peaks, however the values for the peak loads just differ about 10%.

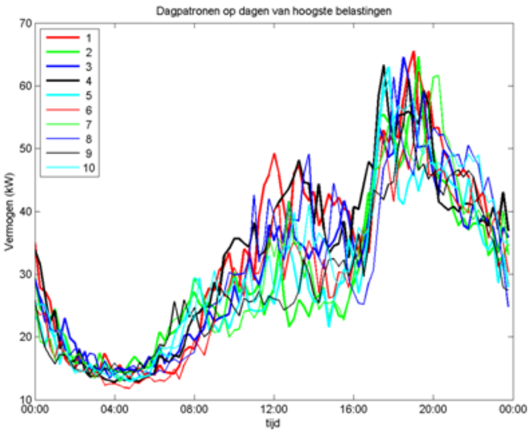

Figure 5 Load profiles for the 10 days with highest peak

Also in the other feeders the peaks occurred in the same time interval.

Individual loads

The distribution of the individual loads during the peaks in the various feeders is shown in Figure 6.

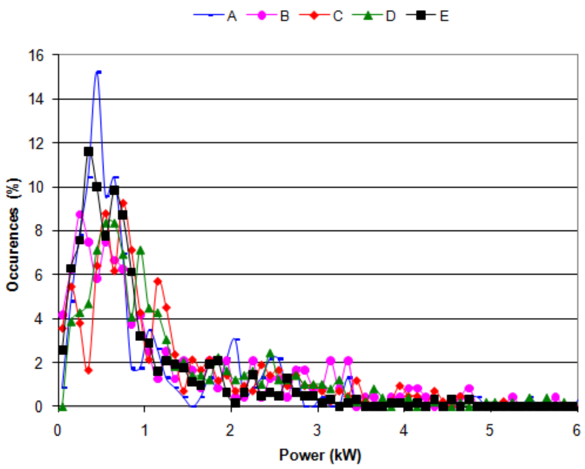

Figure 6 Distribution of load during the 10 highest peaks

From this figure it becomes clear that they don't have the expected normal distribution. A kind of normal distribution with an average value around 0.5 kW can be detected for about 80% of the loads. However about 20% of the loads lay outside this curve and show values up to 6 kW.
Figure 7 shows the contribution of the loads to the peak when the loads are sorted ascending order. This picture shows in a clear way that the 80% lowest values never cause more than half of the peak. As a result it can be concluded that half of the peak is caused by only 20% of the loads, the so called 20% group.

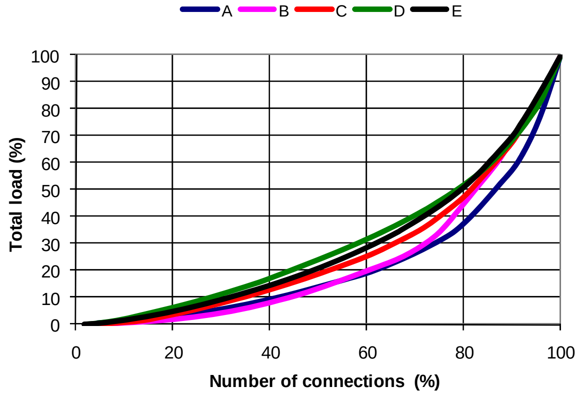

Figure 7 Contribution to the peak

It is hard to pin point specific connections which cause the peak. During the ten peaks only 7% of the loads belonged seven times or more to the 20% group and contributed significantly to the ten peaks. More than 30% never belonged to the 20% group. This is valid both for single phase and three phase connections

Maximum total load

When the loads are sorted in descending order, the maximum total load for a specific number of connections equals the sum of the sorted loads. This is shown in Figure 8 for the various feeders.

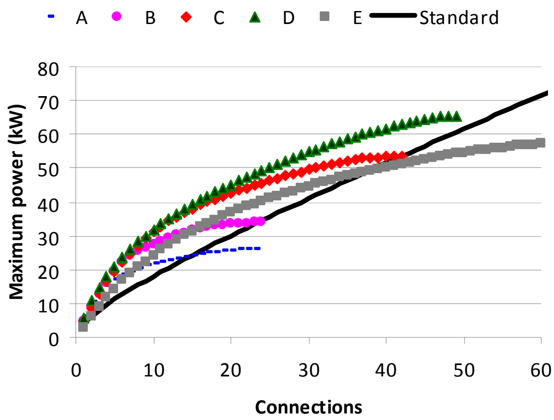

Figure 8 Maximum load

The average maximum load is shown in Figure 9. In both figures also the (average) maximum load calculated with a standard (Rusck, Velander) method is shown.
The curves from measured data differ from the standard curve. In general the measured curves show higher values than the standard curves. Also the shape of the curves differ.
The standard curve for the total load tends to a linear line with a slope of about 1 kW/connection. Therefore the standard curve for the average maximum power tends to converge to a value of 1 kW.

The total load curves for the measured data seem to converge to a specific limit value. Therefore curves for the average maximum load keep decreasing and tend to reach a value of zero for an infinite number of customers.

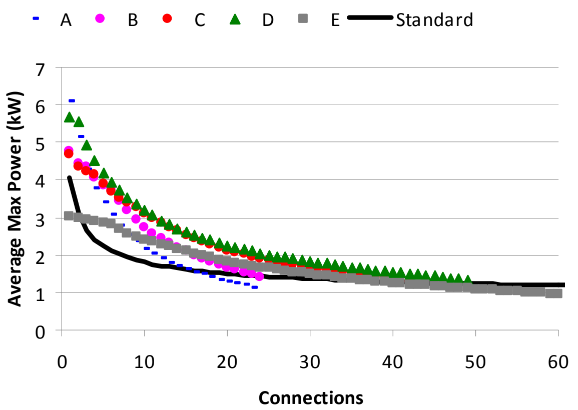

Figure 9 Average maximum load

Comparing with standard calculation methods

It is hard to find correct parameters for the Rusck and Velander formulas which correspond to the measured values. The best fit for each feeder has an average value equal to zero. These curves however result in too high loads when considering a small amount of connections and in too low total load when considering a larger number of connections like the transformer load.

If standard curves are used, the calculated load at the transformer and at the beginning of the feeder corresponds with the measured values. However the current distribution in the network differs and in general the calculated voltage drop over the feeder will be too low.

It can also be expected that the large spread in loads during the peak will result in a noticeable asymmetry in the phase currents. This will result in an increase of the voltage drop.

FUTURE RESEARCH

The next steps in the research consider the consequences for the calculations in LV networks. It has to answer the following questions:

- What are the consequences for the calculated current and voltages?
- What is the best way to model the loads. Is it possible to use Velander with adjusted parameters or are correction factors or correction functions necessary?
- Is it possible to find a calculation method based on non Gaussian distribution which can be used for both radial and meshed networks?

CONCLUSIONS

The main conclusions from analysing individual residential load data are:

- Daily peak loads in the winter occur between 17:00 and 20:00 hours. The peak load per connection is 1 kW on transformer level and around 1.2 kW on feeder level.
- During the peak 20% of the connections contribute to more than 50% of the peak. Only a very small amount of the connections always have a high contribution to the peak. More than 30% of the connections never has a large contribution to the peak.
- The distribution of the loads during the peak does not comply to the normal (Gaussian) distribution which is the base for formula's used to calculate the maximum load.
- The curves corresponding to the maximum load for a limited number of connections differs both in magnitude and shape from the theoretical curves. As a result the calculated currents and voltage drop will be too low.
- It is hard to fit the measured load values to the theoretical formula's of Rusck and Velander. Either new formula's must be developed or correction factors must be used.

ACKNOWLEDGMENTS

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