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THE IMPROVEMENTS TO PRESENT LOAD CURVE AND NETWORK CALCULATION

Contents

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1 Introduction

The aim of this study is to find new ways to improve network calculation and present solutions we can apply with improved calculation. The aim is to fully utilize the possibilities that AMR data enables. Accurate calculation is the key to correct investments and to more accurate simulations which is important for the development of whole industry.

In this study network calculation was improved on several different levels. Temperatures' effect on electricity consumption was studied and model to simulate electricity consumption on different temperatures was created. The load curve selection and creation was completely redone in way were the customer's actual consumption becomes the only criterion for curve selection. New methods to calculate the probable peak power of the year was created and loss calculations were improved to include deviation's effect. New method using transformers ageing as a criterion whether the transformer should be changed was created in fashion that enabled the usage of load curves and one that correctly included the effect of deviation. The optimizing on-load tap charger on transformers was studied as an alternative against network strengthening to improve the voltage of the customers.

2 Temperature effects on electricity consumption

2.1 Data

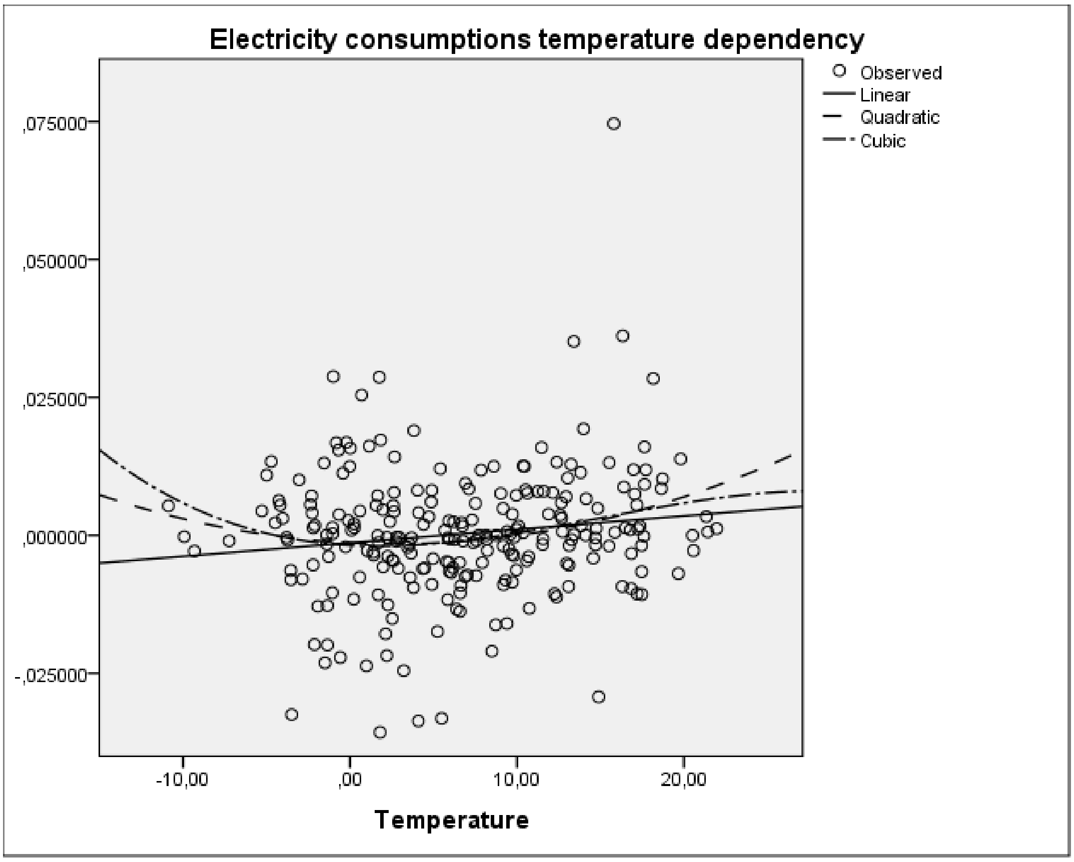
Few years of hourly measured temperature data was collected from several weather stations. Some data was missing and those hours were replaced with temperature of previous hour. For longer periods, missing temperature data was taken from other weather station near the one with missing data. In some stations data was measured 3 times in an hour and in those cases average of each hour was calculated and used in this study. But overall data was quite good and reliable. And the missing data points will not most likely cause any notable errors on calculation.

2.2 Preliminary estimation for delay of temperature dependency on electricity consumption

It was known that temperature effects consumption with some kind of delay. Last 24 hour temperature average was found to be the best estimation of delay. Although delay might very well be dependent on temperature itself or it might be different on different hours of year. Though that kind of assumption would have made the examination unnecessary difficult creating too many variables. So for initial estimation the average of last 24 hours temperature was chosen. After the temperatures effect on electricity consumption is understood better, the best delay for different hours of year and for different customer groups should be studied.

2.3 Initial SPSS analysis

Initial SPSS analysis revealed that the temperature correlation of electricity consumption of detached households with electric heating is partly logarithmic and partly directly dependent on temperature of the moment and partly linearly dependent on change of temperature. The deviation was found to be quite high and the temperature dependency was not all easily discoverable and the temperature dependency seems to differ quite a lot with different customers, even if the customers otherwise consumed electricity in similar pattern. There seems to be a need for creating individual temperature dependency coefficients for each customer. In chart bellow x-axis is temperature in Celsius and y-axis is consumptions difference from 2-week assumption consumption of that hour. This is explained later in chapter 1.5.2.



As we can see from the chart the variation is very high but there is dependency between temperature and consumption.

2.4 The Usage of index-model in revealing temperature dependency

2.4.1 Presumptions

New model to reveal temperature dependency was created. Customer's consumption figures were aligned with the temperature figures from the nearest weather station. The average of last 24 hours temperature was calculated for each hour of the year.

Those figures where later on used in calculations. Using 2-week index assumption meaning that equivalent hours of same 2-week periods workdays were assumed to have equal values and the difference is assumed to be caused by the difference in temperature. Weekends were left outside of inspection because the temperature dependency is different in weekends than in weekdays so own correction coefficients would have been needed for both and that would have made the inspection harder than it needed to be.

Different coefficients were made for cooling and warming. The limit where the cooling ends and warming starts was discovered with SPSS analysis to be around +16 °C. That +16 °C temperature was found to be a realistic limit for cooling and warming in Finland. Although the limit might be different for each customer in this study limit for cooling and warming was set to that +16 °C and in further study that limit was found to be quite reasonable.

The temperature correction is only dependent on change in temperature and on the temperature where the change happens, meaning that same correction coefficients can be used in every month of the year. Temperature coefficients were found to be completely different for different hours of the day.

2.4.2 Calculations

To calculate temperature correction coefficients, first we needed to create load curve from customer's data using 2-week index principle and after that calculate the difference of the equivalent consumption and load curve values, which is assumed to be caused by the difference in temperature. Using same method for last 24 hour average temperatures new index model like temperatures were formed and reduced from the actual 24 hour average of each hour and that difference was assumed to be the cause for difference in consumptions. Now for those figures were tried to be explained with fitting different kinds of curves. The temperature dependency was discovered to be at least 3 degree equation and some logarithmic dependency especially in case of households with electric heating. The cooling was discovered not to be strongly dependent on the temperature where it happens when the temperature is over the +16°C limit. Though it is possible that in very high temperatures the dependency starts to be exponentially dependent on in what temperature cooling is taking place. But at least with this inspection no exponentially dependency for cooling was found.

2.4.3 Temperature coefficients

The temperature dependency was assumed to be dependent on the temperature of the hour in question, constant term and the natural logarithm of the temperature of the hour in Kelvin degrees. The change in consumption caused by the temperature for warming is:

$$\Delta P = \Delta T \times P_i \times (a \ln(T_i) + bT_i + c)$$

Then program to search for the best coefficients for each hourly measured consumer in Fortum networks was created and that code was implemented on curve selection program that was later created. The model was found to improve calculations and in consequence found useful. The results were sometimes quite surprising. For example, with office buildings relatively strong temperature dependency for warming was discovered although they have no electric heating a part of few exceptions. Number of possible explanations was found one of them being that the temperature is depended of the time of the year obviously and electric consumption of office buildings may very well be dependent on the time of year. For example, in summer there are less people in offices because of the summer holidays and therefore less electric consumption. Revealing the correction coefficients takes quite a lot calculating power from computers so when dealing with hundreds of thousands of customers some kind of limit how accurately the temperature dependency is needed needs to be established. Though the code is really optimized, calculating correction coefficients for entire Fortum network takes time but not too much when considering that those correction coefficients need to be calculated only once for each customer so the calculating speed is not an issue. After heavily optimizing the code was made possible to calculate correction coefficients for all customers with relatively good accuracy and it takes only a few days for the computers to calculate. However, if the need for model where the delay or the temperature limit is dependent on something, the complexity of the calculation increases quite a lot and the calculation time might become an issue.

2.4.4 Ideal model

Another model to examine the temperature dependency was also created to examine the potential for temperature correction. The assumption was that consecutive years' equivalent hours are the same and the difference comes from difference in temperature. Similar kind search for temperature dependency coefficients was done. The point where the model explains as much as possible of the difference in consumptions can be considered as some kind of limit how good the model can be found with these assumptions. These coefficients could also work as correction coefficients for customer but this model requires a lot more data and was found to be inferior in comparison with the other models explained in chapter 1.5.3. But this model is useful when testing different kinds of assumptions for example for delay or for the limit. Even after testing with several different assumptions the average of last 24 hours temperature was found to be the best. For example when trying average of last 12 hours temperature the explanation factor drop down from 14.59 to 14,11. Although those numbers do not themselves mean anything they are comparable with each other. Noteworthy is that the temperature which is used in calculations does not necessarily need to be average of any sort. It can very well be about anything that can be calculated from temperature figures.

2.4.5 Results

Temperature correction model was tested on pilot area where all the customers had hourly measured consumption data. The model significantly improved the peak power estimations. In addition, the possibility to choose correct temperature correction for each customer from existing data was studied but for now it was not found useful. After optimizing code, program was able to determine correction coefficients for a customer in approximately 3 seconds which is acceptable time when keeping in mind that these coefficients only have to be made once for each customer.

2.4.6 Criticism

The model only needs one-year data to create temperature correction coefficients. It also means that if the correction coefficients have been made from one year's data the models work only between the temperatures that were recorded on that year. For example, if the lowest temperature of the year was only -20°C, the model does not say anything what happens to the electricity consumption if consumption is tried to be changed to represent what consumption would be if the temperature were under -40 °C. While this model uses the same assumptions that are used in 2-week index model, it also suffers from same problems as in 2-week index model. On the other hand, it is not a big issue because those assumptions have to be made anyway. Also currently the delay is assumed to be the same for every hour of the year which might not be the optimal assumption. This model does not separate effects that might affect on electricity consumption that are dependent on temperature like the length of a day. Increasing amount of variables naturally increases the explanation factor but it also makes them harder to distinguish while they often correlate with each other.

2.5 Future applications

Despite how much the new curve selection method and better peak power calculation improves PowerGrid calculations the results are just the best estimate of the year 2008 consumption. If we want to know how high the electricity consumption is on a very cold year we need separate program to forecast electricity consumption in that kind of year. Also program to forecast electricity consumption based on weather forecasts is possible and quite easy to create just by modifying the model that normalizes consumption figures. In future it may even be possible to separate different loads which would make understanding the temperatures effect on electricity consumption a lot easier and improve the forecasting abilities dramatically.

3 Peak power calculation

3.1 Theory

Traditionally the peak power of several similar consumer types is calculated with equation, which is bellow. A fault in the calculation is that the probability is only calculated for one random hour, whereas it is not related to the peak power probability during a year at all. Also there is an inner conflict in this model, since it assumes that variation factor is constant and deviation is linearly dependent on yearly consumption. In addition, when summing different customers together, it is assumed that their deviations are equal which is impossible if the consumptions are different. This fact is thoroughly explained in VTT project report "Kuormitustutkimus 2003" and in fact the deviations are only slightly dependent on each other and to actually to calculate anything it is crucial to assume that deviations are not depended on each other.

$$P_{max} = n \times \overline{P} + z_a \times \sqrt{n} \times \sigma$$

Where

n is the number of customers

$\overline{P}$ is the net power of that hour

z_a is coefficient, which corresponds exceeding probability of variable a from standard deviation

σ is dispersion

The network calculation program PowerGrid does not either calculate the peak power mathematically right, so a method to make the results more exact was created by using standard deviation, which density function is:

$$G(x) = \left(\frac{1}{\sigma(x) \times \sqrt{2\pi}} \times e^{\frac{-(A-P(x))^2}{2(\sigma(x))^2}} \right)$$

The peak power of a customer should be calculated from standard deviation:

$$F(x) = \prod_{x=1}^{8760} \left(1 - \frac{1-\Phi\left(\frac{A-P(x)}{\sigma(x)}\right)}{2} \right)$$

In equation above F(x) is the probability that a customer does not exceed the power limit A. When F(x) = 0,5, A is the peak power (P_{max}) of a year. In equations $\sigma(x)$ is the dispersion of the hour x and $P(x)$ is active power in hour x. Two different customers' consumptions should always be summed together as in equations bellow.

$$P_{sum}(x) = P_1(x) + P_2(x) + \cdots + P_n(x)$$

Where

$P_{sum}(x)$ is the sum of customers' mean powers during hour x

$P_n(x)$ is the mean power of a customer during hour x

In equation above the values of active power of each hour are summed. The dispersion curves are summed quadratically for each hour of a year.

$$\sigma_{sum}(x) = \sqrt{[\sigma_1(x)]^2 + [\sigma_2(x)]^2 + \cdots + [\sigma_n(x)]^2}$$

Where

$\sigma_{sum}(x)$ is the square root of quadratic sum of customers' consumption's dispersion during hour x

$\sigma_n(x)$ is the nth customer's consumption's dispersion during hour x.

The combined power and dispersion curves are processed as if they were only one customer. PowerGrid doesn't directly support this kind of calculations but with clever selection of dispersion this problem can be solved.

4 Load curve selection

4.1 Target

The aim is to choose the load curves in the way that stresses the correctness of the factors that are most important to the DSO is the ability to predict peak power. Also the groups created by this new curve selection are interesting because by understanding why some customers that seem outwards similar consume electricity in different patterns. DSO might be able to affect on those patterns and change them to be more optimal for the grid. Also better understanding how much electricity consumption patterns might vary with seemingly similar customers is important when designing new electricity network.

4.2 Principles of curve selection

In the past, the load curve selection has been based on consumer groups but there is no need for that anymore. It is clear that the load curve selection should only be based on customer's actual consumption. There is no reason why to do it otherwise because curve selection from actual consumption gives always the best calculation results. But the selection based on consumption is not a trivial task because not all the hours are equaly important for DSO. The most important thing for DSO in network calculation is the ability to predict peak power as accurately as possible. The grid is designed for certain peak power and also transformer aging and losses are highly connected to peak power and other hours when electricity consumption is high. Therefore in curve selection those hours should also be stressed. It is noteworthy that the load curve that is mathematically closest to the data is not necessary the best curve for customer when we keep the interests of DSO in mind because not all hours are equally important. Therefore the target is to select load curves stressing compatibility of those hours that are the most important for DSO.

4.3 Curve selection

When the load curves no longer represent any predefined customer group the content of load curves loses all meaning as well. Meaning that it is no longer a question of whether better curves are needed. It becomes a question of selecting the right one for each customer. It no longer matters whether the curve has been made from actual data or made with random generator if there is a customer which this curve represents well enough it is a good curve. Only the curves that no customer is closest to are useless. Of course the amount of curves has to be kept under some kinds of limits so that the network calculations would not be slowed down unnecessarily, so the limit when to create new curve has to be chosen wisely.

To calculate the best curve for a customer, first the customer's consumption figures was needed to be changed to represent the consumption in year 2008. Then 2-week indexes were made from customer's consumption figures. Then those indexes were compared with the existing curve indexes stressing those hours when consumption is highest with the customer's indexes and exiting load curve's indexes. Compatibility of deviation and probable peak hour of the year were also added to the compatibility factor. And the curve, which compatibility factor is the lowest is chosen for the customer's new load curve. If none of the curves' compatibility factors is low enough, new load curve is formed from customer's data, assuming that some criteria for the creation of new load curve are fulfilled.

4.4 Curve selection for substations

It is also possible to give every substation own load curve in order to quicken the network calculations. The selection can be made exactly the same way as with one customer. Instead of using customer's consumption the substations consumption is used in curve selection program. Also to understand what kind of substations we have is important, because it helps to understand where the small scale production should be implemented. It also helps to predict probable peak hour of substation and by using the temperature correction program we can find temperature dependency of substations electricity consumption and this way we can predict what kind the consumption would be for example in a very cold year. Also just by looking how well, for example, load curve that has mostly apartments under it represents substation's consumption, we can determine how much apartments there are in that substation network. With the method described in this study it does not matter how many customers or appliances are used for the curve selection. For example, the method for modeling single light bulb's consumption is identical to the method modeling electricity consumption of Finland. Therefore, this method can be exploited while designing new electricity network.

4.5 Results

Program to automatically select the best load curve for each customer was made and it was discovered to be fast enough to be used for all customers. Optimized curve selection should be done twice, because during the first selection, new curves will be made for those customers, which consumption does not fit to none of the existing curves well enough. Curve selection was made for the entire electricity consumption of Finland and the curve that fitted for Finnish consumption was one that is also quite often used to model big shopping centers and big office buildings. The deviation was naturally quite small with the whole Finnish electricity consumption and the deviation compatibility was not very good between existing curve and Finland's consumption. Temperature corrections for Finland's consumption cannot be made, because Finland is very vast and temperatures vary inside of it a lot. Whereas, for example, in substation level temperature corrections can be made easily to simulate consumption in different kinds of temperatures. So in order to simulate whole Finland's electricity consumption in different temperatures the temperature correction has to be made for every substation separately and then combine those powers with method explained in chapter 2.

5 Improvements to the loss calculations

Presently, in loss calculation the deviation of load curves is ignored which should not be the case, because losses are quadratically dependent on power. Hence, the probable value of losses is dependent on deviation of power. So there is a need for a method to calculate losses with deviation.

Therefore, new program to calculate losses with different power values was created. In this program the results were stressed with standard deviation density function and the middle point of this function is the most probable loss value.

6 Improvements for transformer calculations

6.1 Present transformer calculations

At present the criterion has been that if transformer is 5 consecutive hours in overload it should be changed to bigger size. But transformers can very well be short times on overload it only increases their aging factor by some amount. But, this is not at all necessary and in fact the present method to calculate the 5 consecutive hours is incorrect. It should be calculated with the formula bellow:

$$F(x) = \left(1 - \frac{1 - \Phi\left(\frac{P_{N.max} - P(x)}{\sigma(x)}\right)}{2}\right)$$

$$G(x) = \prod_{x=1}^{8760} 1 - [1 - F(x)] \times [1 - F(x+1)] \times [1 - F(x+2)] \times [1 - F(x+3)]$$

Where G(x) is the probability of 5 consecutive hours in overload and $P_{N.max}$ is the transformer's rated nominal power. But as stated before, this method should not be used as criteria for whether or not transformed should be changed.

6.2 Transformers aging and hot spot calculations

The best way to determine when transformers should be changed to bigger size is to research their aging factor. This can be calculated from formula bellow:

$$F_{AA} = e^{\frac{B}{\theta_{h,r}+273} - \frac{B}{\theta_h+273}}$$

There are several ways to determine hot spot and top oil temperatures and the method does not affect on the aging factor determination. A relatively simple hot spot temperature model is used in this study:

$$\theta_h = \theta_A + \Delta\theta_{to} + \Delta\theta_h$$

$$\theta_{to} = \Delta\theta_{to,r}\left(\frac{1 + R \times K^2}{1 + R}\right)^n$$

$$\Delta\theta_h = H \times g \times K^{2m}$$

$$K = \frac{I}{I_r}$$

$$F_{AA} = e^{\frac{B}{\theta_{h,r}+273} - \frac{B}{\theta_A + \Delta\theta_{to,r}\left(\frac{1+R\times K^2}{1+R}\right)^n + H\times g\times K^{2m} + 273}}$$

Symbol	Parameter	Default value
m	Winding exponent	0.8
n	Oil exponent	0.8/0.9
R	Noload/Full load loss	3.2
τ_w	Winding time constant	0.08
τ_{to}	Oil time constant	3.0
θ_k	temp. factor for resistance	$234.5/225^0C$
$\theta_a r$	Rated ambient temp.	30^0C
$\theta_{h,r}$	Rated hot-spot temp.	$110/95^0C$
$\theta_{w,r}$	Rated avg. wnd. temp.	$65/55^0C$
$\theta_{ao,r}$	Rated avg. oil temp.	60.5^0C
$\theta_{wo,r}$	Rated oil temp at hot-spot	75^0C
$\theta_{bo,r}$	Rated bottom oil temp.	46^0C
$\theta_{tdo,r}$	Rated temp. of existing duct oil	75^0C
$\Delta\theta_{h,r}$	Hot-spot rise over top oil	25^0C
$\Delta\theta_{h,r}$	Rated hot-spot rise over top oil	25^0C
$\Delta\theta_{ha,r}$	Rated hot-spot rise over ambient	80^0C
$\Delta\theta_{to,r}$	Rated top oil rise over ambient	55^0C

6.3 Including deviation in aging calculations

To be able to calculate aging with load curves, some modifications to previous equation has to be made because the deviation increases the probable aging rate. Because the powers are exponential and therefore the deviations are also exponential and therefore the most probable value increases. Deviation's effect on ageing is quite complex and can only be solved numerically. Therefore new program to calculate ageing with different power values was created. The results were stressed with standard deviation density function and the middle point of this function is the most probable ageing rate. Noteworthy is that the uncertainty of this kind of calculation is quite high and that this kind of calculation reveals only what is the most likely aging rate. Deviation is now quite complex equation and it is not identical to both directions. However, even if this kind of calculation contains a lot of inaccuracies it is still by far the best way to determine the time when transformers should be changed. But whenever possible actual power values should be used in previous equation, but it is good to keep in mind that the hourly consumptions are averages of that hour's consumption and therefore flattened and therefore the actual ageing is higher than calculated. The actual ageing can be solved by either measuring power in shorter intervals or assuming the deviation inside on hour to be something and using it and method described earlier to reveal the actual ageing rate.

6.4 Maximum age of a transformer

This kind of calculations only reveal how much transformer ages in comparison with transformer that is in rated nominal power. Therefore the actual maximum age of a transformer should be investigated. After that the actual ageing is discovered, then more accurate cost estimates when to change transformers can be made. It is useful to find which kind of transformers should be installed to different kinds of areas. Also by including outside temperature measurement to ageing calculations it becomes easier to determine is it better to select a pole transformer because it would get benefits during winter with better cooling.

7 Optimizing voltage ratios for transformers

A program to optimize voltage ration of transformers was created. Program exploits the improved loss calculation program described in chapter 4. First losses during peak hour are calculated. Then the voltage is calculated to every hour of the year to every customer in secondary substation with formula bellow:

$$U_{customer}(a) = b_2\left(b_1 \times U_{substa.} - \frac{P_{substa.net}(a)}{b_2^2 \times P_{substa.net}(\max)} \times (U_{sub.sta} - U_{sec.substa.})\right) - \frac{P_{sec.substa.net}(a)}{b_1^2 \times P_{sec.substa.net}(\max)} \times (U_{sec.substa} - U_{customer\ during\ load\ peak})$$

Where:

$U_{customer}(a)$ = Customer's voltage during hour a

b_2= Primary substations secondary voltage/20500 V

b_1= Secondary substations secondary voltage/230 V

$U_{substa.} = \frac{230\ V \times substations\ secondary\ voltage}{20500V}$

$P_{substa.net}(a)$ = Substation networks power during hour a, which is modified with loss calculation program to include deviation.

$P_{substa.net}(\max)$ = Substation networks maximum power during a year which is modified with loss calculation program to include deviation.

$P_{sec.substa.net}(a)$ = Secondary substation networks power during hour a, which is modified with loss calculation program to include deviation.

$P_{sec.substa.net}(\max)$ = Secondary substation networks maximum power during a year which is modified with loss calculation program to include deviation.

$U_{sec.substa}$= Secondary substations voltage during load peak

$U_{customer\ during\ load\ peak}$= Customers voltage during load peak

Now program raises b values so that the average voltage of all customers is 230 V. After that if there are customers which voltage drops during any hour of the year bellow 207 V program still raises b values until there is none. After that if there is a customer which voltage of any hour surpasses 257 V limit b values are reduced until there is no customer over the 253 V limit.

Program raises first $b_1$value and when reaching 1,05 limit, that is the limit where to we can adjust our transformers in secondary substations. After that it starts to raise b_2 value. At the moment it only raises b_2 value to 1,1 because then we can be certain that there won't be any customers who's voltage surpasses the 253 V limit. Then the b values minus one times hundred is how many percentages voltage should be raised by modifying voltage ration on substations and secondary substations.

There is huge potential in modifying voltage ratios. Program was able to increase almost all customers' voltage over the 207 V limit. For example in one test case one of the customer's voltage was initially only 190 V during the peak hour. After the modifying voltage ratio the voltage rose above the 207 V limit, while b_1 was 1,04 and b_2 was 1,03. The highest voltage of the year for any customer was 244 V meaning this kind of modification could very well take place.

Modifying voltage ratios is very cheap alternative for the strengthening the network. So it should be done whenever possible to avoid unnecessary investments. Voltage ratio modifications in secondary substations always need interruption in electricity transmission. So, whenever there is a planned interruption in electricity transmission in secondary substations. The optimal voltage ratios should be calculated and set to the transformer.

8 Pilot examination

8.1 The goal of the pilot

The goal of this pilot is to forecast as accurately as possible the peak powers in year 2010 in pilot area using consumption data from 2008-2009 and temperature data of 2008-2010. The results are compared against the present PowerGrid calculations and previous year's peak powers. Transformer changes that could be avoided with better calculations are economical benefits that this new improved calculation brings.

8.2 Calculations

First, the customers' consumption in 2009 were normalized to represent consumption in 2008 then load curve indexes were formed from that data and those indexes were compared with present load curves and then the best one was chosen. In this pilot test the compatibility limit was set quite low so quite many new load curves were formed because one of the present ones fitted good enough. Then these indexes are transformed into 2009 consumption figures by multiplying them with their 2009 yearly energy consumption. After that temperature correction into 2010 consumption figures were made and the probable peak power of every customer was calculated and these peak powers were compared against actual peak powers in year 2010.

8.3 Results

8.3.1 Keilaniemi

A case study was performed in Keilaniemi with 2009 consumption figures. In the study was noticed that the peak powers estimated with PowerGrid program with old index-series differed 23,5 % of actual values, whereas the standard error of values estimated with temperature correction model was only 9,7 %. In conclusion, the new method is about 2,5 times more accurate than the PowerGrid program's present results. The standard error was 11,1 % when presuming that the peak powers are equal to the previous year's peak powers but it is noteworthy that this kind of methods prediction accuracy is reduced when combining different customers' consumptions together. Present PowerGrids calculation results are in fact even more incorrect because in this inspection PowerGrid was allowed to use 2010's actual energy consumptions. Whereas, this new method forecasted electricity consumption of every hour of the year is based on temperature data and after that the new index model method was applied in order to predict the peak powers of the year. Also PowerGrid's present results are supposed to represent the 95% exceeding probability, when in fact the results were significantly too low even to represent 50% exceeding probability.

8.4 Direct consumption forecasting from AMR data

For comparison, direct consumption forecasting was also studied. 2009 consumptions were changed with temperature correction to represent consumption in 2010 and the peak powers from those corrected models were assumed to be peak powers in year 2010. This was done to prove that direct peak power forecasting is not the best way to predict future consumptions.

This method gives relatively good results when the peak power of only one customer is calculated. Its prediction capabilities reduce dramatically when trying to predict several customers' consumptions' peak power. Whereas, in index model the predicting capabilities increase, when the amount of customers increases.

Directly predicting peak powers with temperature correction is inferior to the method presented in this study even in a case of one customer. The reason is that with index model one can use 2-week assumption, which allows usage of standard deviation, whereas mere peak power of previous year reveal nothing but the peak power. It does not reveal what the probable value of the peak power would have been. In reality actual peak power and predicted value of peak power always vary a bit and this variation is the reason why direct consumption forecasting is inferior to the model presented in this study.

9 Future possibilities for load modeling

In future new load curves can be used as a tool to design new electricity network. Network planner only needs to choose right area curve for the new area or test it with several different area curves and choose correct transformer size and the best possible cables and other components. Area curve is a load curve for a certain area. With temperature correction, network can be sized correctly to withstand even the coldest of weathers. For pole transformers ambient temperature is almost exactly the same as the outside temperature. The ambient temperature affects on the ageing of transformer even during summers when electricity consumption is lower than in winter. Some transformers might age too fast because the ambient temperature is higher than the rated ambient temperature. Therefore, the temperature is also higher than expected without including outside temperature into the calculations, thereby it also crucial to inspect if the high ambient temperatures might cause some pole transformers to age too fast.

In future by examining which load curve would fit best for certain substation we can determine where we should implement small scale production and energy storages. Temperature correction can also be used to determine how the climate change will in long run effect electricity consumption in Finland. By determining how much it increases temperature variation and average temperature. Although the average temperature does not increase significantly in 30 years that is the average time span of network investments. The temperature variation increases as climate change progresses and at the same time extreme weather cautions increase and the network has to hold even the most extreme weather cautions.

Load curve selection can also be used to give personalized energy saving tips to the customers by inspection how they consume electricity in contrast to their neighbors. Also the price elasticity of electricity consumption can be studied with exactly same principles used in temperature correction. This can be used to design optimal tariffs for the grid.

In future power in secondary substations should be measured to improve the ageing calculations. It would also be useful in testing different ways to model customers, which electricity consumption is complex, for example greenhouses. Because assumptions that are used in index model namely the 2-week assumption apply very badly with greenhouses, so they need completely different kind of method to model their consumption. It should include the lighting of a day and it should not rely so heavily on the 2-week assumption.

The reactive power compatibility should be included as one of the factors when selecting load curve. Also, it would be useful to examine how much different kind of compatibilities should be stressed to find the optimal way to stress these factors in order to find the selecting procedure that serves DSO's interest the most.

In future it would also be possible to create a program to design new electricity network with just approximate amount of customers and their consumer groups and approximate yearly consumptions. Program would examine what kind of load curves there are under each consumer group and choose the most difficult ones for the grid. Then most of those curves would be used to determine the worst possible consumption for the network in that area and the network then should be sized withstand that kind of consumption. That would be the most optimal way to size network. This way the cost of under and over sizing network would be minimized. Selecting the worst load curves for the grid is quite difficult but one way around it would be just to calculate network with all the possible load curve combinations.

In future one of things that should be investigated is how the increment of substations secondary voltage reduces the ageing rate of transformers and how that can be exploited in real networks. Also the economical benefits for the possibility to actively modification in secondary substations' secondary voltage should be investigated. The initial investigation suggests that there is a lot of potential for active modification in secondary substations' secondary voltage.