A NOVEL LONG-TERM FORECASTING PROCESS FOR ELECTRICITY DISTRIBUTION BUSINESS

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ABSTRACT

The long-term planning of the electricity distribution networks is a current topic, since large-scale distribution network investments will be done in the future. In this development process, long-term forecasts of power and energy demand are in a crucial role. At the same time, the way of using electricity have changed and will change radically in the future. In addition, implementation of smart metering provides more information of consumption and new possibilities to model electrical loads. The present forecasting methodologies are not necessary optimal, because the operational environment of the electricity distribution business is changing significantly. Therefore, a novel long-term forecasting process for electricity distribution is needed. A new forecasting process offers opportunities to adapt operational environment changes for Distribution System Operators (DSO).

INTRODUCTION

As a consequence of the increasing reliability demands and remarkable storms, caused by climate change, large-scale distribution network investments is a current topic in electricity distribution worldwide. In Finland, new electricity market act sets the limits for maximum interruption times (6 hours in urban area and 36 hours in rural area) in Finland. Distribution networks have to be planned so that these limits are met in year 2028. [1] This sets requirements for the long-term planning of the electricity distribution networks. Here, long-term electricity load forecasting plays a central role.

Electrical loads have traditionally consisted of similar type of end-use. However, it seems that there are significant structural changes in electricity end-use at the moment. For instance, electricity consumption in lighting has decreased remarkably. [2] Here, energy efficiency have probably had a major role. Significant changes in electricity end-use may occur also in the future. There will be technologies, such as micro generation and electric vehicles, which will change electricity end-use radically in the future. Also urbanization and other structural changes in society have influence on electricity consumption. Eventually, all the above mentioned issues will cause notable changes for electrical energy and power demand in distribution networks.

Another important change is related to the amount of data, which is increasing all the time. One of the most significant data source is Automatic Meter Readings (AMR), which provide more accurate and up-to-date consumption information. This data enable, for instance, more accurate customer classification, which can be utilised in the long-term load forecasting process.

Electricity consumption has typically increased over the several decades, and energy consumption has traditionally been flat and predictable. Energy consumption forecasts together with loads models have been applied to forecast network loads. However, electrical energy consumption trend and load models are changing. Therefore, the present forecasting methods do not work in an optimal way, and new forecasting methods are needed. Electricity distribution environment needs and provides new characteristics for long-term electricity distribution planning. In this paper, a novel forecasting process for estimating the future power and energy demand in electricity distribution is presented. In this forecasting process, the impacts of structural changes in customer side, such as the increasing amount of distributed energy resources (DER), are taken into account and novel data sources (e.g. AMR) are utilised. Different methods, such as spatial analyses, clustering, end-use modelling, scenarios and simulations, are applied in the forecasting process. The results of the paper indicate how to forecast future energy and power in distribution networks and what kind of methods in forecasting process are needed. Distribution System Operators (DSO) can apply this tool for the future load forecasting process during the long-term network and business planning.

LOAD TRENDS AND MODELING

Changes in energy systems will have impacts on electricity consumption. For instance, energy efficiency will alter electricity consumption patterns and it will have remarkable effects on network loads. Some of the energy efficiency actions decrease electricity consumption, such as lighting. On the other hand, some energy efficiency actions, such as installation of the ground-source heat pump into oil heating detached house, increase electricity consumption. In addition, future technologies, such as electric vehicles, micro generation, energy storages and demand response, will have significant impacts on network loads. These new loads and small-scale production will alter the electricity end-use patterns. Load patterns will change dramatically, which decreases the accuracy of the traditional load modelling and forecasting methods. For instance, a residential customer's load curve may involve negative values during summer time because of micro generation.

In Finland, load modelling have traditionally been based on Velander's formula and load models. [3], [4] Load models are over 20 years old, and many changes in electricity consumption have occurred during that time. For instance, air conditioning has increased abundantly over the last years. [2] However, more accurate load forecasts and analysis can be made in the future. AMR data can provide new methods to model electricity consumption. Almost every customer has a smart meter in Finland at present. [5] Smart meters provide hourly based information of the customer's electricity consumption. This data will play a key role in load modelling and long-term load forecasting.

Basically, the amount of different kind of data have increased remarkably. The trend may continue in the future, and more accurate data, such as device group specific load data, can be available. These changes are revolutionizing the load forecasting process. Changing electricity end-use patterns and the increasing amount of data create a need to develop load forecasting process. The future loads cannot be forecast by applying only one load forecasting method, such as econometric modelling. Hence, a novel long-term load forecasting process is needed.

LONG-TERM LOAD FORECASTING

Long-term load forecasting in electricity distribution networks is usually made for a period from ten years to 40 years ahead. Annual electrical energy and the highest mean hourly powers in distribution networks are the most significant subjects of forecasting. Mean hourly powers are used in the forecasting process, because AMR data are hourly based and forecasting is traditionally based on hourly resolution.

The first step in the forecasting process is to select research area and time period for the forecast. Loads have to be forecasted spatially, that changes in various areas can be analysed. Research area can be e.g. district in the urban area or region of the municipality in the rural areas. The case area has to be defined so, that the number of customers would not be too high or low, and all data can be manageable and available. Decision of the time period in the forecasting process is also important, because various changes in consumption behaviour may occur in separate time periods. For instance, the number of EVs will definitely be different in 2030 compared with 2050. The great number of data and a multi-phased forecasting process create requirements for the forecasting system. Therefore, the forecasting process involves several methodologies. Here is pointed out some basic methods, which are required for the forecasting process.

Electrical loads are location dependent, which means that load forecasts have to be modelled spatially. Long-term load forecasting begins normally from the spatial research of the case area. In addition, electrical load forecasting requires customers' consumption data from the case area. AMR data provide new tools to classify customers in the case area more accurately compared with earlier methods. For this purpose, clustering methods are excellent tools.

When customer clustering have been made, creating the forecasts can be started. Scenario based approach is the most suitable method for estimating the changes in the case area in the future. For instance, volumes and characteristic consumptions are typically forecasted based on scenario method. However, the forecast results are strongly dependent on applied parameters. The effects of the scenarios have to be modelled into the case area. Simulation method provides an approach to model the future loads in the research area.

NOVEL FORECASTING PROCESS

Long-term electricity load forecasting is a multi-phase process. Basically, electrical loads can be forecasted by applying traditional long-term load forecasting methods. However, the effects of the future energy technologies have to be forecasted separately. This is based on the fact that the future technologies may have radical effects on electricity end-use, which cannot be modelled in a traditional way. Electricity end-use without future technologies (traditional electricity usage) will not necessary incur challenges into the distribution network or business. However, new loads and variable production create requirements for more accurate load forecasts. This paper presents a novel long-term load forecasting model, which takes into consideration the structural changes in operational environment. Fig. 1 presents the simplified model of this forecasting process.

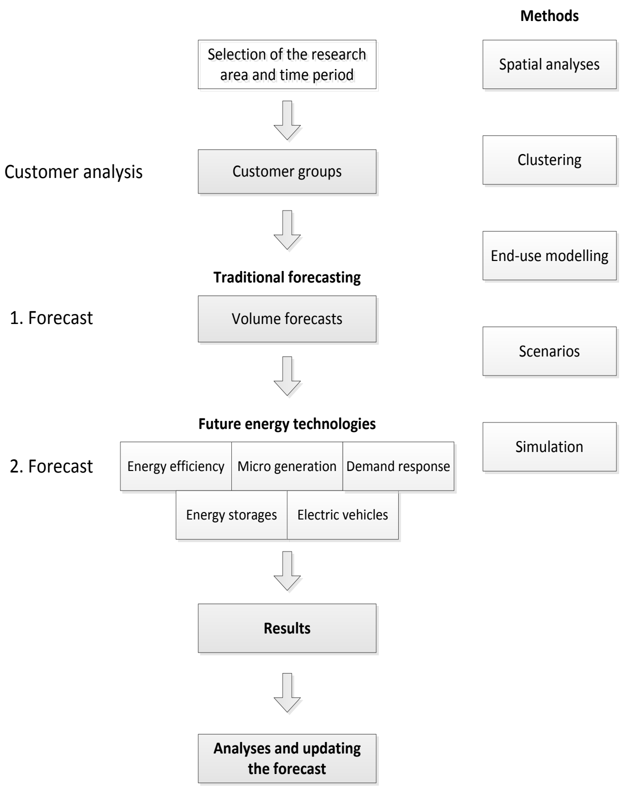

Figure 1. Structure of the novel long-term load forecasting process for electricity distribution.

The structure of the forecasting process consists of customer analysis, the first-stage and the second-stage forecasts. Customer analysis creates the base on the present load patterns in the case area. The first-stage forecast is a traditional long-term forecast, where volume and consumption forecasts are in a key role. The second-stage of the process takes into consideration the effects of the future technologies on the case area.

Customer analysis

The research area defines the customers, which are included in the forecasting process. At the same, customer analysis acts as a starting point for the forecasting process. The customer analysis involves AMR data processing, customer grouping, clustering and analysing of the temperature dependency. Finally, the characteristic load curves for different customer categories can be formed and those will be used in forecasts.

AMR data processing

Smart metering offers totally new consumption information of the customers. Previously, only customer's annual energy consumption was available. Nowadays consumption data can be obtained from the each hour of the year. The number of customers in the area and the time period under study determines the amount of AMR data. AMR data provides new opportunities to model customers' consumption and electrical loads in different areas. Moreover, AMR data enables hourly-based load forecasts. The main requirements for the smart metering data are that data are valid and do not include errors. If the data include clear errors and erroneous values, those measurements have to be removed from the data, or an approximate of more suitable values are needed. AMR data analysis have to be also based on time stamps.

Combining the information to the research area of different data systems with the AMR data and DSO's other data systems have to be carried out. It is advisable to pay attention to the collection and development of data. The customer data can be supplemented by e.g. building and heating type information from other data registers. For example, municipality register can provide information of the buildings' surface areas.

Customer classification

In the long-term forecasting it is advisable to know the type and number of the customers in the research area. Therefore, customer grouping plays a key role in the forecasting process. The greatest benefit in customer classification is that a similar analysis can be made for the same type of customers. For example, the customers who lives in detached houses with direct electric heating, can be modelled with the similar load analysis in the whole research area. Customer classification has mainly been based on national-level models in Finland. These SENER load profiles include numerous customer groups and precise classifications. [3] However, not all the DSOs necessarily use these load models.

The same types of customers have typically similar load curves. However, there may be large variations in loads between the same types of customers. Moreover, there are remarkable differences between customer groups. The load forecasts have to be made separately for these customer categories, because the load patterns differ significantly from each other. By clustering the AMR data it is possible to produce typical load profiles for each customer group. The customers can be divided into customer groups reliably by clustering methods. On the other hand, clustering method can be used in customer identification as well. K-means and ISODATA methods are probably the most popular methods to cluster customers. [6], [7] Clustering methods can provide better customer classification results compared with traditional load models. [8]

After customer analysis, the characteristic load curves for each customer group can be formed. The characteristic load curves are reasonable to use in load forecasting process, because those make load modelling easier and more reliable.

Temperature dependency

There are weather elements, such as wind and solar radiation, which have impacts on the electric loads. The outdoor temperature dependency is a significant factor, because the electric heating demand is depending on it. On the other hand, the electric cooling demand is also depending on outdoor temperature. Therefore, outdoor temperature is usually taken into consideration in load modelling calculations. Changes in heating systems will have impacts on electrical heating demand in the future. For instance, heat pumps may increase or decrease electricity consumption in the existing buildings. Furthermore, the increasing amount of air conditioning will grow electricity demand during summer time. Thereby, the outdoor temperature is an important element in load forecasting process. Outdoor temperature dependent electrical loads have to be classified, that it is possible to analyse, how these loads will develop in the future.

First-stage forecast

Basically, the first-stage forecast is a traditional forecast with AMR data. Scenarios in the first-stage forecast are based on the volumes and electricity consumption predictions. AMR data offer new opportunities to develop the traditional load forecasting process. In addition, lot of other data are needed. It is important to collect data from the DSO's internal and external data systems and make the data eligible for the research area. DSO's external data systems may include e.g. municipal, provincial or national systems. Defining and applying the internal and external data efficiently may bring benefits to the forecasting process.

The future electricity consumption consist of two elements: from the consumption of the present customers and from the consumption of the new customer points. Electricity consumption of the present customers have been quite similar over several years. However, electricity consumption of the present customers may alter in the future because of future energy technologies. Instead, the load profiles of the new customers can be totally different compared with the existing customers. Therefore, the consumption of the present and new customers have to be forecasted separately.

Basically, the present consumption can change, if the number of customers alter or the customers' electricity end-use change. Information of the building stock and customers' electricity end-use provide a good starting point for the forecast. The total consumption of the certain customer groups can be calculated by multiplying the number of the customers by the characteristic consumption. The total electricity consumption in the research area can be calculated by summing the consumptions of the customer groups. [4] The present and historical electricity consumption data of each customer groups are needed for the present customers' consumption analysis in the case area. Also information of the social factors in the case area are needed. Structural changes, e.g. urbanization, aging and structure of livelihood, have impacts on electricity consumption. The data of the structural changes have to be taken into account in scenarios. This data is commonly available from DSO's external data systems.

New customer points are logical to model separately from the existing buildings. For example, energy consumption in new detached houses can be totally different in the future compared to consumption of this day. For instance, electricity consumption in heating can be significantly lower in the new low energy houses. Thereby, when forecasting consumption of the new customer points, especially building and heating types have to be taken into account. Information of the new and planned buildings can be obtained from landscape and town plans.

Second-stage forecast

The second-stage in the forecasting process is based on the future energy technologies. Future energy technologies (energy efficiency, electric vehicles, energy storages, demand response and micro generation) will have different kind of effects on energy and power. For instance, energy storages can decrease peak powers and electric vehicles may increase peak powers. The effects of these technologies have to be forecasted in the forecasting system. Fig. 2 presents the presumable changes in electricity end-use in the future. [9]

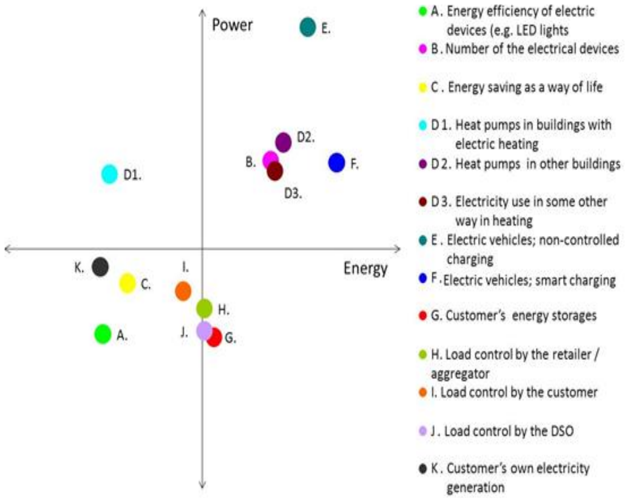

Figure 2. Possible changes in electricity end-use. [9]

Future energy technologies have to be forecasted separately from each other, because the impacts on electrical loads are variable. The effects of the future energy technologies on electrical loads are mainly dependent on the capacity of the technology and the number of the technology in the research area. The effects are also dependent on time of use and location in the case area. However, the suitable parameters for the forecast have to be estimated. The impacts of the future technologies in the case area can be simulated by using end-use modelling. The end-use models of the technologies can be created by measurements. There have to be also made scenarios of the amount of the energy technologies in the different time periods. Technologies will take place in different time periods, which are challenging to forecast. The scenarios can be based on national or international trends of the future technologies. These trends have to be modelled for the case area. Applying simulation method, the forecasts can be finally modelled into the case area.

DISCUSSION

There will be new energy technologies in the future, which require new load modelling and forecasting tools. These will have remarkable effects on electrical loads, which cannot be modelled in a traditional way. The increasing amount of data, especially smart metering, can revolutionize traditional load forecasting process. Lot of data will be needed for the long-term forecasting process, and the role of data will increase in the future. DSO's AMR database is the main data sources in forecasting process. However, DSO's external data systems may provide supplement information of the research area. As a result, this paper suggests a novel forecasting process for electricity distribution. The novel forecasting process involves different methodologies, which are spatial analysis, clustering, scenario, end-use modelling and simulation methods.

In the novel forecasting process, annual energy consumption can be forecasted from the load forecasts, which are based on hourly powers. Annual energy consumption is important, because it effects on DSO's revenue. Distribution network planning, in turn, is based on the highest hourly powers. In this way, network planning has also effects on distribution business. Fig. 3 presents the novel long-term load forecasting process for electricity distribution business.

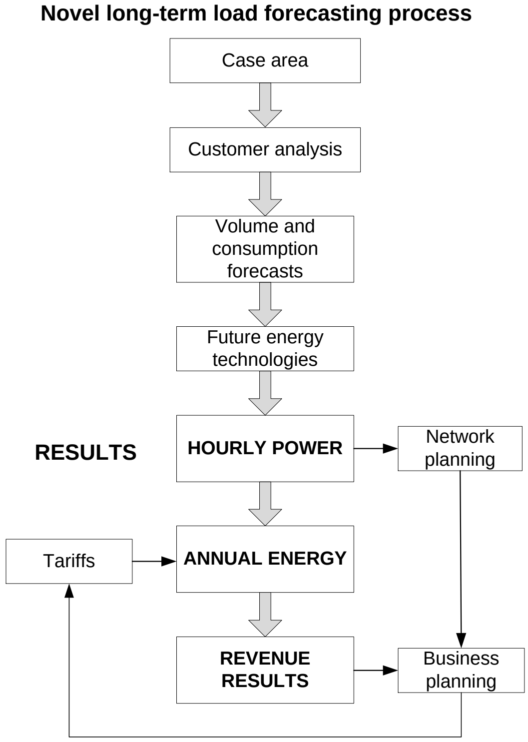

Figure 3. Novel long-term load forecasting process.

The shape and level of the load patterns in distribution networks may change dramatically in the future because of future energy technologies. For instance, customer's load curve can be negative during summer time due to micro generation production. However, the load changes are always dependent on the case area, and changes are challenging to approximate in advance.

CONCLUSIONS

Remarkable network investments in electricity distribution will be made in the near future. Therefore, the role of the long-term network planning is growing significantly at the present. Long-term load forecasting will need new tools, because of significant changes in electricity end-use. The effect is, that traditional load models are changing. In addition, smart metering provides more accurate consumption data to model and forecast loads.

The main conclusion is that, the long-term load forecasting will change. Earlier, load forecasts were mainly based on energy consumption. In the future, energy consumption forecasts in electricity distribution can be based on power forecasts. Altogether, load changes will have effects on electricity distribution business. Energy results together with DSO's tariffs determines the impacts on DSO's revenue. In this way, it is possible to estimate the impacts of load changes on electricity distribution business.

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