ELECTRICITY DEMAND PROFILE FOR RESIDENTIAL CUSTOMER 2030

Juha HAAKANA, Jouni HAAPANIEMI, Jukka LASSILA, Jarmo PARTANEN
LUT University – Finland
juha.haakana@lut.fi

Raimo HÄRMÄ
Kymenlaakson Sähköverkko Oy – Finland
raimo.harma@ksoy.fi

Matti RYHÄNEN
Savon Voima Verkko Oy – Finland
matti.ryhanen@savonvoima.fi

ABSTRACT

This paper describes a methodology to estimate electricity demand of the residential customers in the future. The methodology takes into account electric vehicles, photovoltaic solar power systems and heat pumps replacing or supporting the main heating system of the buildings. Moreover, the paper shows some examples of the future electricity demand curve with and without the estimated changes in electricity demand.

INTRODUCTION

Electricity demand is changing meaning that today's customer's electricity demand profile does not match with the profile of year 2030. At present, the photovoltaic (PV) power generation and electric vehicles (EVs) are not the mainstream in Finland, but they are coming more and more popular every year. For instance, present traffic scenarios [1] show that in 2030 the residents will have huge amount of electric vehicles (EVs) even today they are rare. The other changes in electricity demand occur due to changes in the heating systems of the buildings, demand response activities, and new pricing elements in electricity distribution.

Changes in the electricity demand should be seen in advance so that they can be taken into account in the electricity distribution network planning. This concerns especially the cases, where the renovation of the network is carried out in the next few years, when the rising trend in electricity demand may not be seen in the statistics of the previous years. This is a valid challenge, for instance, in the Finnish electricity distribution system, where the existing infrastructure will be widely replaced with the new one within the next 10 years because of the tight supply security requirement. It drives major part of the rural area distribution system operators to renew significant part of their electricity distribution networks meaning that the estimation of the future electricity demand should be accurate.

The basis of the electricity demand forecast in the electricity customer level is the profiling of the present customers. The profiling of the customers can be based on the initial electricity demand profiles or new electricity profiles. A challenge with the existing load profiles for different customer types is that they can be relatively old or the customer does not fit with the load profiles. Thus, it can be reasonable to determine complete new electricity demand profiles. The new profiles can be formed based on the customer measured AMR (automatic meter reading) data, which today contain hourly measured data from each customer points. The load profiling can be carried out, for instance, by using clustering method. In this study the profiling is based on the K-means clustering process described in the diploma work [2].

The paper presents a methodology to create new electricity profiles for residential customer types comprising daytime and nighttime electricity users.

DATA IN THE ANALYSES

The analysis requires significant amount of data. In this study, the data is hourly measured electricity consumption from several years from 10 800 electricity customers, which are mostly residential customers. The data is gathered from four Finnish distribution system operators: Kymenlaakson Sähköverkko Oy, Savon Voimaverkko Oy, PKS Sähkönsiirto Oy and Järvi-Suomen Energia Oy. The electricity consumption data is combined with the building information data that is gathered from the Finnish Population Registry Centre [3]. This provides more information in support of customer classification and thus the future electricity demand can be better estimated. In addition a proportion of the electricity customers have been interviewed to understand the changes in the electricity demand in the future. For instance, in the interviews have been asked questions related to heating system of the house, future renovation plans of the buildings and willingness to install PV systems.

METHODOLOGY TO DEFINE FUTURE ELECTRICITY DEMAND

The future load profiles consist of the present load profiles and the estimated load profiles for the load changes such as charging of EV. Thus, another important step in the future load profile estimation is to use suitable models to indicate occurring load changes and to focus these on the customers, which likely have these changes in their electricity consumption behavior.

The future load profile estimation process is described with the following steps:

1. Definition of the initial electricity demand profiles
2. Study of the background information affecting electricity demand such as building database and customer interviews (information of heating system, size of building, building type)
3. Allocation of EVs, PVs and heat pumps for customers
4. Definition of load profiles for EVs, PVs and heat pumps
5. Definition of the future electricity demand profile for the customers

Figure 1 presents an example of the load profile estimation with the indicated changes in future electricity demand.

Profiling of the present electricity demand

As profiles of the present electricity demand of the customers can be used present electricity load curves of the customers based on the older studies or the load profiles can be generated using the measured AMR data. In this study we have used the AMR data based method, where the new demand curves are generated using the K-Means clustering method [2]. Before the clustering the data has been preclassified so that the nighttime electricity users have been classified as one group as well as the leisure time electricity users. The leisure time electricity users are determined so that they are having zero consumptions at least 25% of the hours of the selected time period.

After the preclassification all the groups are clustered independently. In the clustering process the load curves with similar shape are located in the same categories. Thus, for instance, the electricity users having high temperature dependency can be separated from the users who has no dependency.

The load profiles have been divided to 2-week indices and 24 hours indices for working day, Saturday and Sunday for all the 2-week periods. The profiles have 27 two-week periods, where the last period consists of few days at the end of the year.

Customer specific electricity demand curve is determined using the index-curves (2-week indices and daytime hourly indices), which are multiplied with annual energy consumption. The possible temperature correction can be carried out for the index-curves.

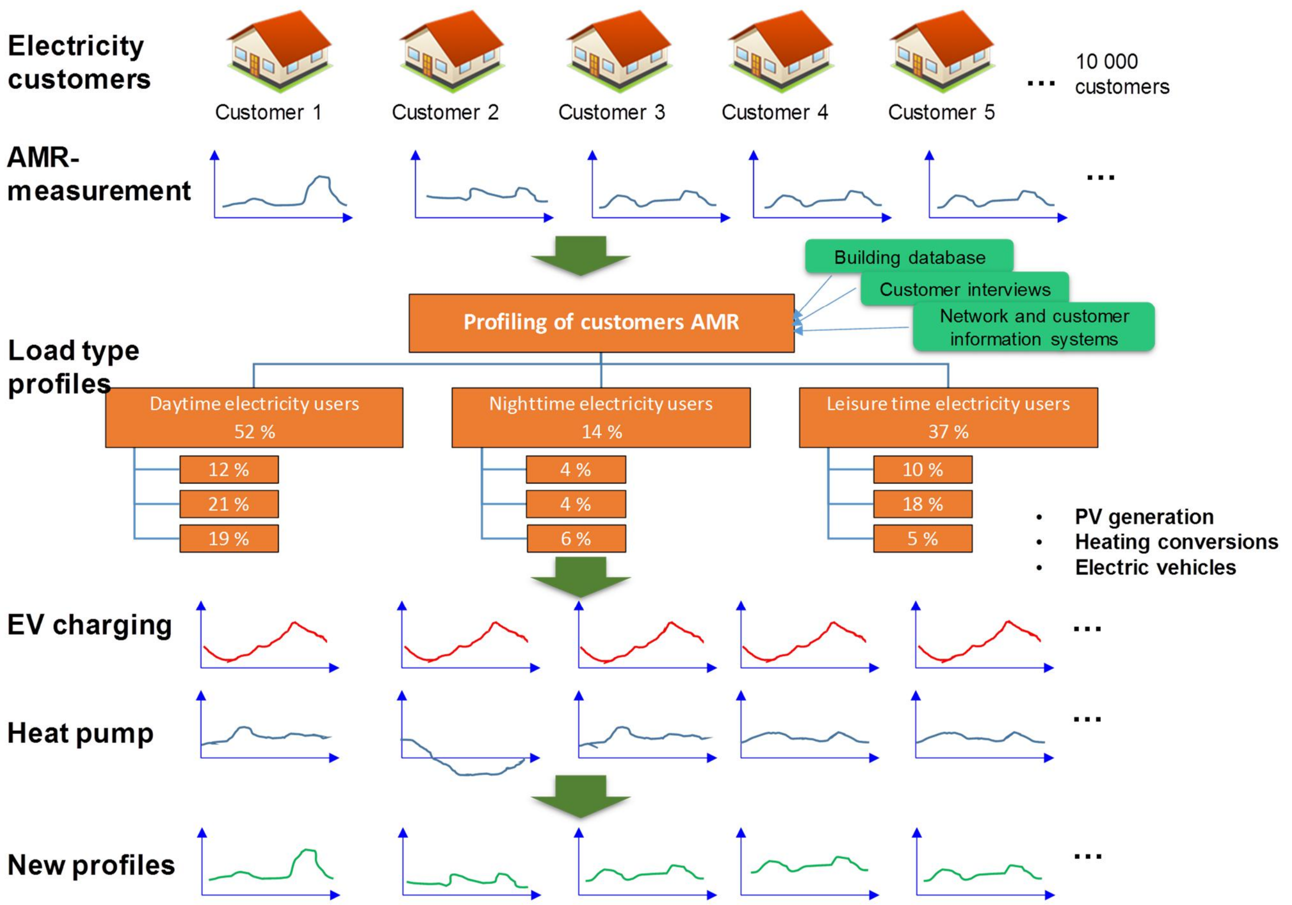

Figure 1. An electricity customer future load profile estimation process.

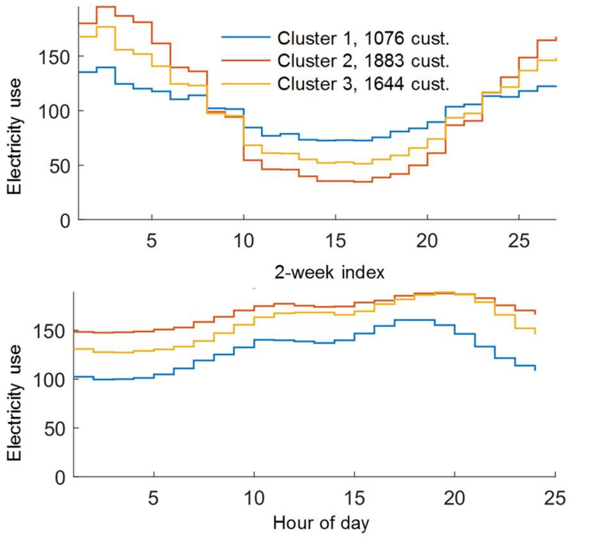

Figure 2. Electricity demand profiles (2-week indices) and hourly indices of an example day at the wintertime of the three customer groups using electricity mainly at the daytime.

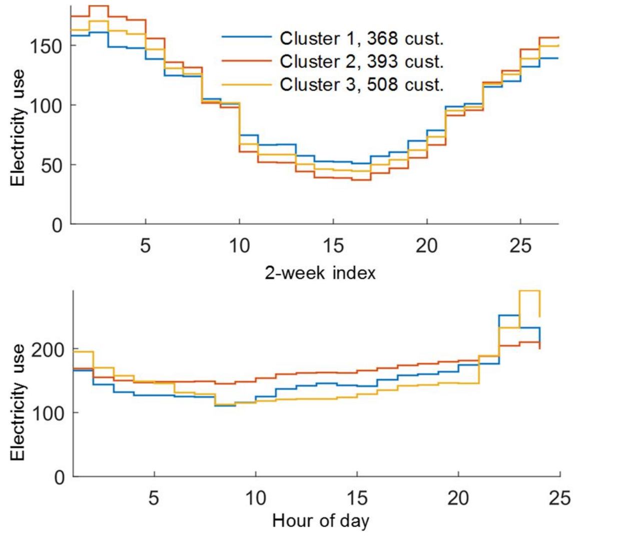

Figure 3. Electricity demand profiles (2-week indices) and hourly indices of an example day at the wintertime of the three customer groups using electricity mainly at the nighttime.

Clustering process divides customers to several load profile types. For instance, there are six electricity demand profiles for residential customers. Three profiles for the customers using electricity mainly at the daytime as well as three profiles for the customers using considerably electricity at the nighttime hours between 22:00–06:00.

Daytime electricity users

Figure 2 shows 2-week electricity demand indices and hourly indices of an example day at the wintertime for the daytime electricity users. It can be seen that cluster 2 has the most significant temperature dependency of the selected three clusters. This means that at the wintertime the electricity demand is at relatively high level compared with the summer time electricity demand.

Nighttime electricity users

Figure 3 shows 2-week electricity demand indices and hourly indices of an example day at the wintertime for the nighttime electricity users. It can be seen that cluster 2 has the most significant temperature dependency of the selected three clusters. Also the customers in cluster 2 seem to use electricity more smoothly during the day so that in the evening after 22:00 do not exist similar consumption peak as in the other two clusters.

Recognition of the customers having EVs, PVs and heat pumps

Allocation of the changes in electricity demand such as EVs, PVs and heat pumps on the likely customers is a challenging task. We have used customer interviews and building database to determine the customers having most probable installation of PV, purchase of EV or heat pump. For instance the building database describes that what is the heating system of the building. Hereby the effects of the new loads can be allocated on the correct network components.

Present heating systems have significant role in the allocation of the changes in electricity demand. An example of the electric loads between the customers with different heating system types is presented in Figure 4. It shows the mean load profiles of direct electric heating, full load capacity ground source heat pump system and partial load capacity ground source heat pump system. The main finding of the figure is that GSHP either full load or partial load capacity decrease electricity demand compared with direct electricity heating system.

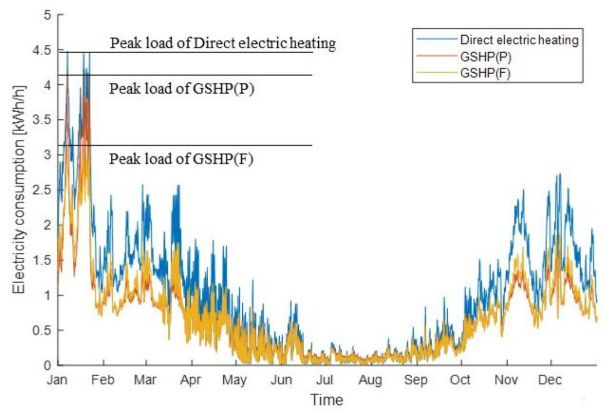

Figure 4. Annual electricity-based heating loads for households with different main heating systems (direct electric heating, full load capacity GSHP, partial load capacity GSHP). The curves are generated from the data of the year 2016 from 10 000 electricity consumption places [4].

In the study [5] has been assessed the proportions of Finnish building stock having a heat pump either a ground source heat pump (GSHP) or an air source heat pump (ASHP) in 2030. Table 1 presents the forecasted changes in the main heating systems of Finnish households between 2016 and 2030 meaning that the present main heating system is replaced by a GSHP. These proportions have been used to focus GSHPs on the residential electricity customers. For instance, in Finnish scale, the number of oil heating systems decrease by 108 000. This means that 58% of the present oil heating systems are replaced by GSHPs.

Table 1. Forecasted changes in the main heating systems of households between 2016 and 2030 in Finland [5].

Heating system	Year 2016 [pcs]	Year 2030 [pcs]	Change 2016-2030 [pcs]	[%]
District heating	62 983	62 983	0	0 %
Natural gas heating	22 638	13 638	-9 000	-40 %
Direct electric heating	387 255	378 255	-9 000	-2 %
Electric storage heating	90 048	45 048	-45 000	-50 %
Oil heating	184 985	76 985	-108 000	-58 %
Wood heating	235 079	226 079	-9 000	-4 %
Ground source heating	120 000	300 000	180 000	150 %

Definition of the profiles for changes in electricity demand

The changes in electricity demand between year 2019 and 2030 have been modelled by using the estimated EV charging profiles, PV generation profiles and effects of heating system conversions on electricity demand.

Charging of EVs

The charging of an electric vehicle can be a significant increase in the customers load. There are some key questions, which determine the effect of charging on the electricity demand. At first it is important to know where the EVs are likely charged: at homes or EV charging stations. In this study we have focused mostly on rural area electricity distribution meaning that customers are typically having enough space and three-phase charging possibility to arrange home charging. Thus, the home charging is more likely. Another question is that what is the charging power and is the charger 1-phase or 3-phase device. The third question is; in which time the charging is carried out. Here we have used a charging curve for 3-phase charger with 10 kW power. The timing of the charging in the used load profiles is based on the national travel survey assuming that EV owners charge their cars after they have arrived home. Thus, controllod EV charging is not included in the examples of the study. Figure 5 presents an example of home charging with 10 kW charger with 30 kWh battery for an average EV owner in the summertime working day. The charging curve indicates that typically persons arrives home between 16:00 and 20:00 that cumulate charging peak to evening hours.

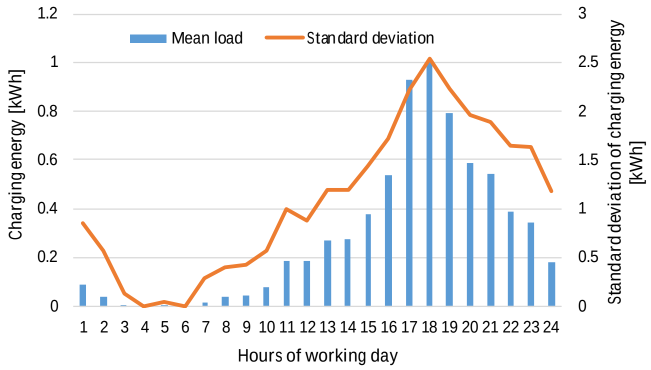

Figure 5. Electric vehicle charging curve (summertime). The energy capacity of the EV battery is 30 kWh and the charging power is 10 kW [6].

Modelling of PV generation

Photovoltaic generation is modelled using pvlib-python functions [7]. The generation has been focused in the Finnish circumstances assuming that in the wintertime between December and February snow covers the panels, and thus, the generation is blocked. A general normal distributed PV generation curve is presented in Figure 6.

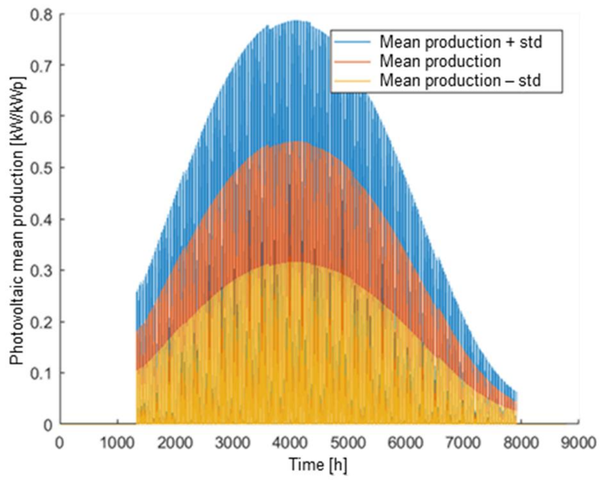

Figure 6. PV generation curve for Finnish circumstances.

Modelling of heating system change

In case of heat pumps it is important to know the current heating system of the buildings. Heat pumps may affect load profile various ways depending on the using behavior of the heat pump and the present heating system, which can be replaced or supported with the heat pump. If a heat pump replaces a present direct electricity based heating system, electricity demand typically decreases. On the other hand, if the heat pump replaces an oil-based heating system, the electricity demand increases. To be able to estimate the effect of the heating system conversion on the electricity demand, the initial heating system has to be known as well as the initial electricity demand profile. Modelling of the heating systems is described more accurately in [4].

RESULTS

As a result of the study is the methodology to estimate the electricity demand profile for a residential customer in year 2030. The demand profile consists of factors: the present electricity demand profile, possible EV charging profile, possible heating system modification and possible PV generation profile. Thus, the result demand profile for the customer is a combination of all the factors.

Figure 7 and Figure 8 illustrate present load profile with the estimated electricity demand profile of year 2030 for an example customer belonging to cluster 3 of the daytime customers using mainly electricity at the daytime. The figures illustrate the expectation value of electricity demand. Thus, the deviation of the demand is not included in the figures. The annual electricity consumption of the customer is today 11 300 kWh/a. For the customer is modelled EV charging with 10 kW charger, 5 kW PV system.

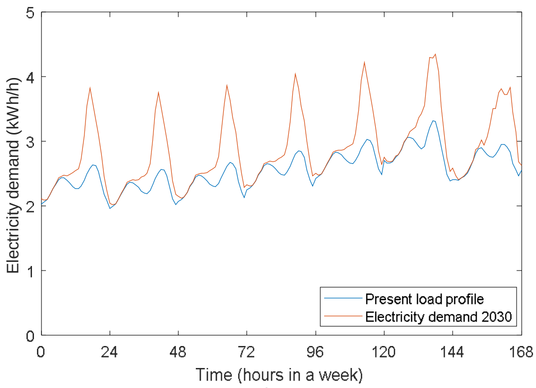

Figure 7. Electricity demand of a daytime customer in a winter week in the middle of January.

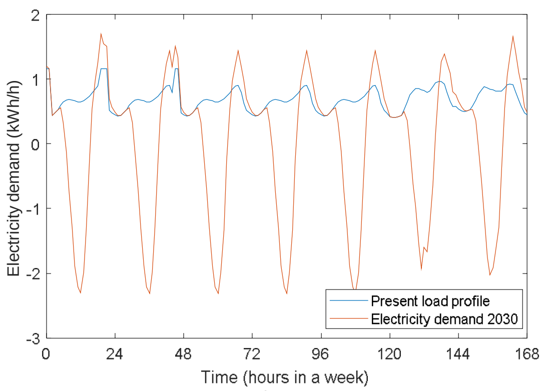

Figure 8. Electricity demand of a daytime customer in a summer week in the middle of June.

From the figures it can be observed that EV charging increases peak power demand of the customer especially at the wintertime, when the charging is not controlled. At summer the PV generation seems to compensate EV charging and several hours in the day customer cannot use the produced electricity meaning that it will be supplied to public grid. However, we have to remind that this is an example of a single customer meaning that all the customers has their own profile. Nevertheless, the observations support the idea that in the future the peak powers of the customers may increase at the same time, when delivered energy may reduce due to new PV systems and more efficient energy use.

CONCLUSIONS

This paper presents a methodology to estimate electricity demand profiles for residential customers taking into account the effects of EVs, PV systems and heat pumps on the electricity demand. The methodology consists of few primary steps: definition of the initial electricity demand profiles, definition of the customers having EVs, PV systems and heat pumps, definition of effects of EVs, PV systems and heat pumps on electricity demand and finally the definition of the electricity demand profile for the residential customers in the future.

REFERENCES

[1] Liikenne ja viestintäministeriö 2018, "Carbon-free transport by 2045 – Paths to an emission- free future Interim report by the Transport Climate Policy working group", *Hiiletön liikenne 2045 – polkuja päästöttömään tulevaisuuteen, Liikenteen ilmastopolitiikan työryhmän väliraportti* (in Finnish)

[2] S. Viljakainen, 2017, "Power customer classification and load forecasting with electricity consumption data," *Sähkönkäyttäjien luokittelu ja sähkönkäytön ennustaminen sähkönkulutustietojen avulla,* (in Finnish), Master's thesis, Lappeenranta University of Technology

[3] Population Register Centre of Finland, http://vrk.fi/en/frontpage

[4] J. Haakana, J. Haapaniemi, J. Lassila, J. Partanen, H. Niska and A. Rautiainen, "Effects of Electric Vehicles and Heat Pumps on Long-Term Electricity Consumption Scenarios for Rural Areas in the Nordic Environment," *2018 15th International Conference on the European Energy Market (EEM)*, Lodz, 2018, pp. 1–5.

[5] Gaia Consulting, "Effects of heat pumps on electrical loads," *Lämpöpumppujen vaikutukset sähkötehon tarpeeseen* (in Finnish), Report, 2016.

[6] A. Rautiainen, S. Repo, P. Järventausta, A. Mutanen, K. Vuorilehto, and K. Jalkanen, "Statistical Charging Load Modeling of PHEVs in Electricity Distribution Networks Using National Travel Survey Data," *IEEE Trans. Smart Grid*, vol. 3, no. 4, pp. 1650–1659, Dec. 2012.

[7] William F. Holmgren, Clifford W. Hansen, and Mark A. Mikofski. "Pvlib python: a python package for modeling solar energy systems." Journal of Open Source Software, 3(29), 884, (2018).