Modelling Future Residential Load Profiles

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ABSTRACT:
Due to several developments the future electricity demand of residential consumers will change and they will also start to generate electricity. Differences may exist between individual consumers connected to the grid, e.g. one household may choose for a micro combined heat and power (CHP) boiler and the other for a heat pump in combination with solar panels. This variation between consumers and the differentiation over time of the profiles of future residential load elements cannot be satisfactorily modelled by current approaches for the goal of network planning and analysis. In this paper an approach to model the profiles of future residential load elements is proposed. The application of micro-CHP boilers, heat pumps, photovoltaic panels and electric vehicles are the considered technologies. It is illustrated how these individual elements of the future residential load can be modelled and subsequently combined to construct the total aggregated load profile for a group of households.

INTRODUCTION
Due to the transition to a more sustainable energy supply, decentralised electricity generation and technologies that realise a more efficient use of energy sources take a growing share in the electric power supply. Although these technologies may reduce the overall use of energy, they can lead to a growing demand for electricity. For example, the demand for electricity for heat pumps and especially electric vehicles would, although saving fossil fuels, mean a substantial additional load for the electricity distribution grids. On the other hand household consumers start to produce energy themselves by the application of photovoltaic panels or combined heat and power production, and in that case need less electricity from the public grid. However, renewable sources such as solar energy are variable so that consumers may still need to be fully supplied by the grid at peak moments.
From the above, it can be concluded that future load profiles of individual household consumers will differ more and be less predictable than nowadays. Existing standard load profiles will therefore no longer be sufficient for a reliable representation of the future electricity distribution needs.
The goal of this paper is to find a way to model the different elements of future residential demand (and generation). Subsequently, the resulting profiles can be combined and used for load flow calculations to support network planning and analysis of distribution grids. The most important changes which are expected at the customer side are studied. For each of these changes it is described how their profiles can be determined for the goal of network planning. Individual elements of the residential load can then be combined to construct the total aggregated load profile for a group of households. The paper ends with conclusions and a view on future work in which the modelling approach as proposed in this paper can be applied.

Expected Developments at Households
Future distribution needs are affected by new technologies which change both demand and supply of electricity at the household level. In this paper the focus will be on the future residential load in the Netherlands. However, since developments in the Netherlands are similar to developments in other developed countries, the results are wider applicable. Based on governmental goals and expectations of specialists from the industry and research institutes, the following developments in the supply and demand of electricity at the household level are expected in the Netherlands for the coming 20 years (Ministry of Housing, Spatial Planning and the Environment, 2007; Kema, 2002; Platform Duurzame Elektriciteitsvoorziening, 2008):

- Demand growth of normal electricity use.
- The application of new technologies for heating: micro-CHP boilers and heat pumps.
- Generation of electricity by photovoltaic panels.
- The adoption of electric vehicles.

Modelling the Residential Load Profile

These developments for future residential load elements all have different characteristics in size, in time when they produce or consume electricity and the variability of use. Because of these differences, these elements must be modelled separately and individually. In this section a way to model the different elements of the residential load profile is proposed. These different parts resemble load or generation profiles for individual households. However, while the goal for modelling is network planning, the focus is not on perfectly simulating every individual household with its own specific characteristics, but to be able to model aggregated load profiles of some hundred households connected to the grid.

Normal Electricity Use

For the aggregated load of normal electricity use of residential electricity consumers, normalised curves are used. With these normalised curves the average demand curves of a number of households can be defined if the annual energy demand is known. For the Netherlands normalised day curves for residential consumers are available for all days of the year(1). These curves are based on data of 400 households.
In Fig. 1 the average load curves for a residential customer with an annual electricity demand of 3400 kWh (equals the average electricity demand in the Netherlands) are shown for four different days over the year. This normalised curve can be adjusted and the average annual demand can be increased (or decreased) to model future demand which is subject to changes caused by e.g. demand side management or economic growth.

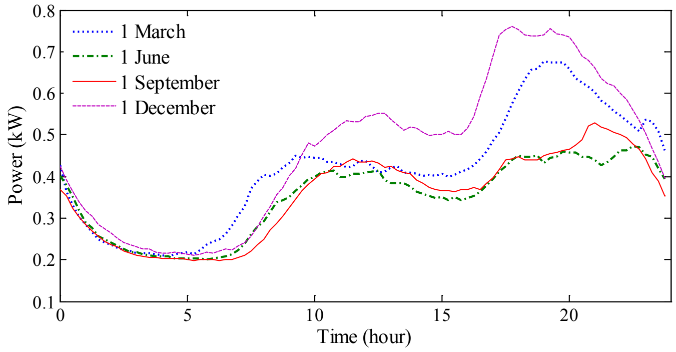

Fig. 1: Daily load profiles for normal electricity use for a household with an annual electricity demand of 3400 kWh

Micro-CHP Boilers and Heat Pumps

Just as for electricity, normalised curves are available for the gas demand of residential consumers. These gas demand profiles are divided in two parts: a part which is independent of the ambient temperature (presenting the gas used for tap water heating) and a part which is dependent of the ambient temperature (presenting the gas used for space heating). With the annual gas demand per residential consumer and a given outside temperature, the heat demand profiles can be determined for every day in the year. In Fig. 2 three heat demand profiles for space heating are shown. If the heat demand profiles are known, the electricity generation profiles for micro-CHP boilers and electricity demand profiles for heat pumps can be modelled if the specifications of the applied systems are known. How these profiles can be constructed is demonstrated by the examples below.

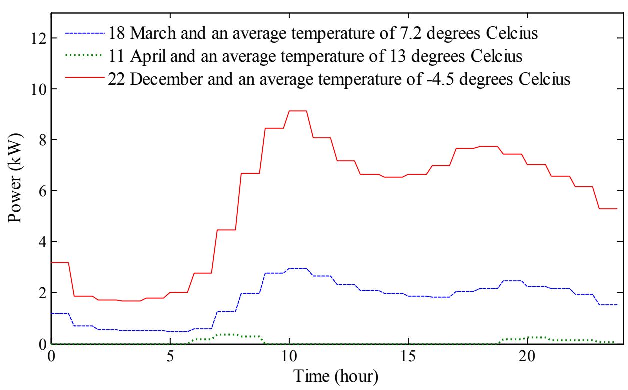

Figure 2: Daily heat demand profiles for space heating for a household with an annual gas demand of 12.500 kWh

1These profiles are composed by the Dutch branch organisation EnergieNed and available for Dutch energy suppliers and network operators.

Distribution network operator Enexis is taking part in a pilot where micro-CHP boilers of the brand REMEHA are applied. The boiler has the following specifications:

- The electric power output is 1 kW and the thermal power output is 5.5 kW. The thermal power is designed to be less than the power at peak demand to maximise the operation hours of the micro-CHP boiler; an auxiliary burner is used for supplementary heating in these cases.
- The micro-CHP boiler is used for space and tap water heating and follows the heat demand. In case there is no demand for space heating, no tap water is heated by the micro-CHP. The auxiliary burner is then used for tap water heating.

The heat demand profiles for space and tap water heating as presented in Fig. 2 and the above specifications are used to model the generation profiles for the micro-CHP. The modelled generation profiles for one micro-CHP boiler on a day in spring and on a cold winter day are shown in Fig. 3. The most interesting observation from this figure is that the micro-CHP boiler will generate no electricity in summer and will almost continuously generate electricity on winter days. For network planning particularly these extremes are of interest.

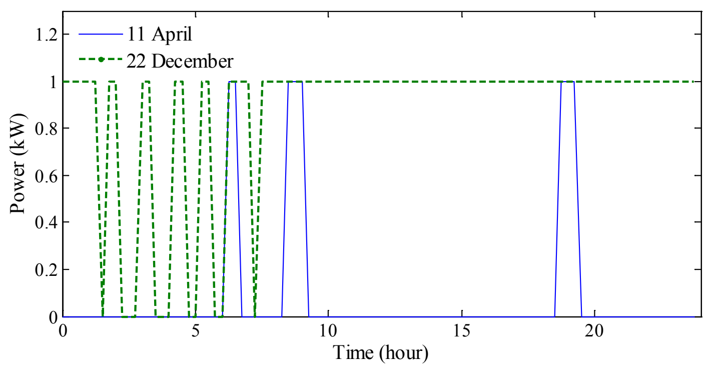

Fig. 3: Daily generation profiles for a micro-CHP boiler with an electric power output of 1 kW

Examples of demand profiles for heat pumps are modelled for three different sizes of heat pumps. The specifications of the heat pumps are chosen as follows:

- The power of the compressors of the heat pumps are 1.4 (type 1), 1.6 (type 2) or 2.0 kW (type 3). This power includes the power of additional electronics and they all have a resistive element with a power of 6.0 kW for extra heating at peak moments.
- All heat pumps have a coefficient of performance (COP) value of 4.
- The heat pumps are used for space heating only.

With the heat demand profiles presented in Fig. 2 for space heating and these characteristics for the three types of heat pumps load profiles are modelled. For a day with a heat demand as on 22 December these profiles are illustrated in Fig. 4.

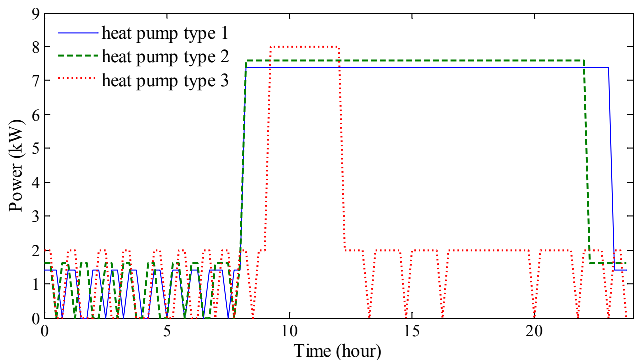

Fig. 4: Daily load profiles for three types of heat pumps on a cold winter day

As can be seen in this figure, especially the extra element for heating at peak moments can cause a high load on cold days. These heat pumps are not used for cooling, so in summer they are not used at all. The load profiles for these heat pumps are thus very different for summer and winter days.

Photovoltaic Panels

For a group of houses with solar panels the efficiencies of the solar cells can be averaged and the total area of the panels can be summed up. These factors can subsequently be applied to the maximum irradiance pattern to create an

aggregated generation profile of the total of solar panels.
For example, for solar panels with an efficiency of 14% and five square meters, the maximum power output for a day in July is shown in Fig. 5.

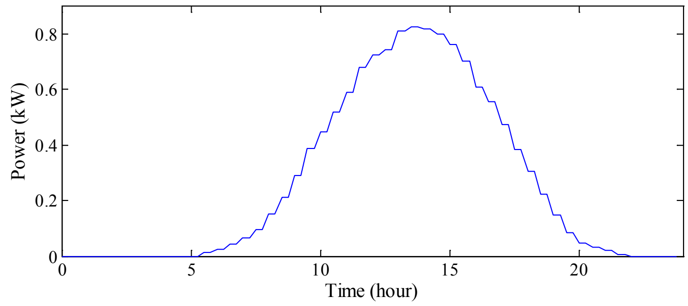

Fig. 5: The profile of the maximum electricity generation of 5 m^2 solar panel on the longest day in July

Electrical vehicles
Given an average car user profile, the maximum distance driven per day and the conversion efficiency of the battery of the electric vehicles (EVs), the electricity demand for the car can be determined. For example, an average distance of 20 km per car driver and an efficiency of 0.2 kWh/km result in an average demand profile that equals profile A in Figure 6. However, the car can be charged during the time it is connected to the grid and the charging process can be adjusted to the availability of electricity and grid capacity.
In the case demonstrated here, it is assumed that all cars will be charged at the home connection and people do not have the possibility to charge their car at other locations. The chosen charging strategy is to charge all cars somewhere between 23.00 and 7.00 hours when they are at home and connected to the grid. In that case, the electricity demand profile for one car may look like profile B as presented in Figure 6. While it is a flexible, not time critical load, there are many degrees of freedom for the charging process and therefore, taking into account the other elements of the total residential load, the charging process may be varied over time to use this flexibility to spread the total load.

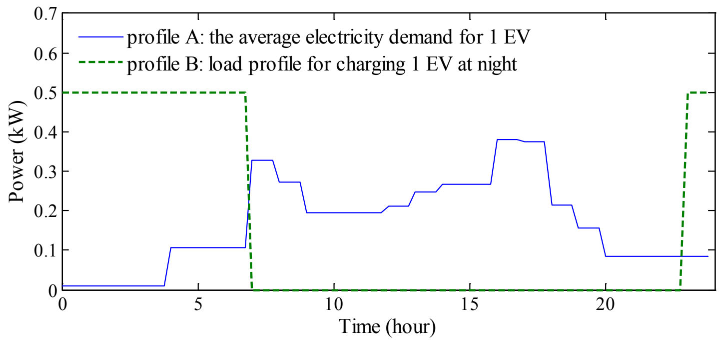

Fig. 6: Load profiles for charging an electric vehicle

Combining the Profile Elements

So far, the different elements for future residential electricity demand and generation have been discussed separately. For network planning it is of interest to model groups of consumers and different penetration grades of the different technologies. This can be done by combining the load and generation elements.
As an illustration, two combinations of the individual load elements as presented in this paper are chosen. A case of 800 households is used with penetration grades of the technologies as presented in Table I.
In Fig. 7 the profiles of these two combinations are shown for a sunny summer day, when there is no space heating, and for a cloudy, cold winter day when all micro-CHP boilers and heat pumps are operating on their maximum. Also the normal electricity use, without any new load elements, is shown for comparison.

Table I: Penetration Grades of the Residential Load Elements for a Case with 800 Households

	households with normal electricity use	houses with 5 m² solar panel	electric vehicles	heat pumps[(1)]	micro-CHP boilers
combination 1	800	400	100	125	200
combination 2	800	100	400	-	200

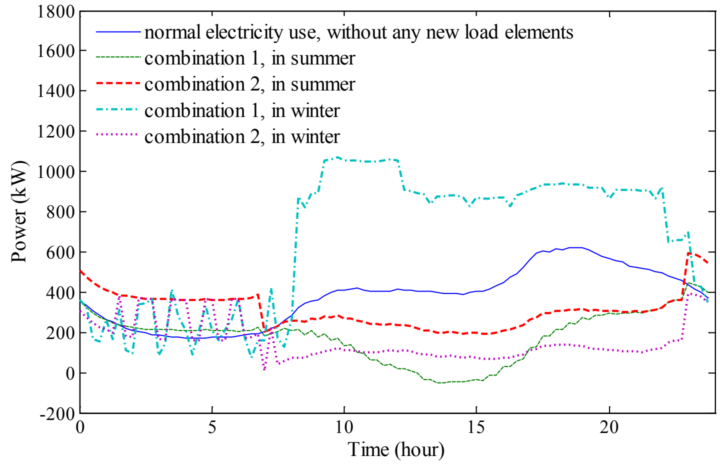

Fig. 7: Daily load profiles for different combinations of residential load elements

Conclusions and Future Work

Current load models are not satisfactory as they do not take into account the variation between consumers and the variation over time to assess the capacity need of the distribution grids for future demand, including decentralised generation of electricity in residential areas.

The most important developments which change the load profile at household level are the application of new technologies like micro-CHP boilers, heat pumps, photovoltaic panels and electric vehicles. The load or generation profiles of these elements should be separately modelled, because their peaks occur at different moments during the day and they have different characteristics to take into account. The load profile of electric vehicles is subject to many degrees of freedom, since it is a flexible load and the car can be charged at various times of the day. Therefore, for intelligent charging, the profile of the electric vehicle will depend on the rest of the demand.

By modelling the profiles of the different elements, the contribution of the future residential load elements for various penetration grades can be studied by combining the profiles. This gives insight in the impact of these developments on the total aggregated residential load profile. Different days in the year were studied, since the maximum of the elements occur at different times of the year. For network planning, the worst case situations, which are often in summer or winter, are of most interest.

The next step will be to use the total residential load profile based on the studied elements and to see how the grid can cope with this new aggregated load, to investigate the benefits of demand side management and to determine how many electrical vehicles can be charged with the remaining grid capacity, if any.

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(Footnotes)

1 *There are a total of 125 heat pumps: 25 with a 2.0 kW compressor, 50 with 1.4 kW compressor and 50 with a 1.6 kW compressor*