The impact of 32 nearly zero energy residences on the low voltage electricity grid

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Abstract

In The Netherlands, more and more heat pumps are applied in residences. The implementation of heat pumps have an influence on the electricity grid because the heat demand of houses converse from the gas grid to the electricity grid. At local high penetration of heat pumps, the capacity of the grid in The Netherlands is expected to be local insufficient for peak demands from heat pumps. This means that the grid needs to be locally reinforced in those situations. For the new design of the electricity it is therefore important to have a good estimate on the simultaneous peak demand of the heat pumps.

In order to quantify the peak load of heat pumps on the grid, load measurements were made on the low voltage grid connected to 32 nearly zero energy residences. These measurements were compared with measurements on the low voltage grid connected to 35 conventional residences. This data analysis has shown that there are two challenges for the grid operator with nearly zero energy houses, namely: increasing peak demand due to the heat pumps and increasing feed-in due to the solar panels. The heat pump leads to a demand peak (2,7 kW) of 2.5 times the conventional peak load (1,1 kW) in a winter where the most extreme measured temperature was around -6,5 °C. Due to this higher peak demand the local electricity grid may have to be enforced.

The highest absolute peak, however, occurs in the summer/autumn where the maximum feed-in peak was 6,3 kW per residence. A conclusion can be drawn that the impact of solar panels on the grid are higher than the impact of heat pumps on the grid during the year that the measurement took place. In a different year with a colder winter the peak from heat pump is expected to be higher than measured during this winter. Currently the grid is reinforced for these energy trends. The demand peak can be reduced by demand response (e.g. controlling heat pumps) and storage systems (e.g. batteries). Next to storage systems, peak feed-in can also be reduced by (PV) curtailment. These are all new concepts that may lead to possibilities to stay within the limits of the current network, but the technical, economic and legislation feasibility still need to be determined (e.g. through pilot projects).

For heat pump installers it is important to know that they need to connect the heat pumps and solar panels symmetrical over the three phases even if the grid is reinforced. A simple action that can avoid unnecessary network problems. Next to demand response and energy storage as alternatives for grid reinforcing a collaboration of the concerned parties in the heat pump industry (e.g. heat pump producers and installers) and the grid operator would eventually lead to new heat pump designs that will be possibly more network friendly. The intention of collaboration is to cooperate in a sustainable society as grid operator and at the same time keeping the network affordable, reliable and attainable for the whole society.

Keywords: zero energy residences; heat pumps; low voltage grid

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1. Introduction

The government of the Netherlands aims to have a CO_2 reduction of 80-90% due to the signed Climate Accord of Paris. Phasing out natural gas is one of the ways to reach this goal. This means that more and more heat pumps are applied in residences for domestic heating and usage of hot water. The implementation of heat pumps have undoubtedly an influence on the electricity grid. At higher penetration rates of heat pumps, the capacity of the grid in The Netherlands is expected to be insufficient for peak demands from heat pumps. This means that the grid needs to be reinforced in those situations.

The implementation of heat pumps will play an important role in the future development of grids. Next to electrical transport, heat pumps are the most important component in the total energy demand of the households concerned. By 2020 it is estimated that approximately 0,5 million heat pumps will have been installed in the 7,7 million houses of the Netherlands [1]. As already mentioned heat pumps will have undoubtedly an influence on the grid. For Liander, largest utility company in the Netherlands, it is important to be prepared for the rapidly growing energy transition in order to keep the grid reliable, accessible and affordable at the same time. This is a quite challenging task for a grid operator. This is the reason why it is very important to know what the impact is of these challenging components on the low voltage grid. If the impact is known it enables the grid operator to take sophisticated decisions regarding the low voltage grid in order to be prepared for the rapidly growing energy transition.

Also in the Liander area residential areas with (nearly) net zero concepts are an upcoming trend. Liander has no choice than to reinforce the grid that is connected to these residences in order to manage the peak demands and feed-ins of the heat pumps and solar panels. By reinforcing the grid it is kept reliable for the residents of the nearly energy zero residences. Since these sustainable innovative projects are only growing it is important for a grid operator to be prepared for this transition. By knowing what the exact impact of these nearly zero energy residents is on the low voltage grid it gives the grid operator better insights how to be prepared for these revolutions and maybe search or develop concepts that are within the limits of the current network capacity. One way to figure out what the impact is of these nearly zero energy residents on the grid is to measure the electricity use of these households on low voltage grid.

Liander had an unique chance to measure in their own low voltage grid where these renovated nearly zero energy residences were connected and compare these measurements with low voltage grid measurements connected to conventional residences. The zero energy buildings were based on an all-electric concept due to the current law. The construction solutions of the residents imply high quality insulation of floors, roofs, windows and facades and a high-airtightness of the residences. The technical solutions imply the implementation of heat pumps, solar panels and heat recovery systems. Conventional residences are residences connected to the gas network for domestic heating, usage of hot water and cooking. The compared conventional residences in this article are the same type as the nearly zero energy residences.

2. Current electricity grid

Electric power distribution is the final stage in the delivery of electric power; it carries electricity from the transmission system to individual consumers. In order to understand the impact of the nearly zero energy residences on the grid it is important to know how the current electricity network is build up. In the Netherlands electricity is transmitted mainly through underground cables. Copper (Cu) and aluminium (Al) are the most commonly used metals in transmission wires. The cables have three phases and a zero wire. The standard 3-phase 4-wire distribution voltage level is 230V with a tolerance of 10% around this level [2]. The capacity is determined by individual load of the phases. This is why it is important to divide the load from the heat pumps and solar panels over the three phases between the residences.

The conventional electricity network in the Netherlands is designed around 1,2 – 2 kW as maximum load per residence. This value is based on the Strand-Axxelson method, a method intended for the calculation of the expected maximum load on components [2].

3. Impact of nearly zero energy buildings on the low voltage grid

The impact of nearly zero energy residences was determined through data analysis. Data analysis and interpretation were applied at the available data of the electricity usage originated from measurements at a low voltage grid cable connected to thirty two (32) nearly zero energy residences. These data were compared with the electricity usage originated from measurements at another low voltage grid connected to thirty five (35) comparable residences without heat pumps and solar panels. These conventional residences were still connected to the gas network for heating their house, usage of hot water and cooking activities. The residences are typical Dutch residences on a row with three floors and a total area of around 80m^2. They are social rented houses and inhabited by families with an order size of three to five family members. The implemented air source heat pumps have a nominal power of 1,6 kW and an electrical extra heating system of 2,0 kW. Solar panels (8,9 kWp) were installed on the roofs of each residence with an inverter of 7 kW. Since these houses are based on an all-electric concept they also make use of electricity for cooking activities and they also have an extra heat recovery system with an extra power of 1,4 kW to prevent for icing.

3.1 *Comparison of the network load of a nearly zero energy residence and reference residence*

Figure 1a shows the aggregated maximum demand and feed-in load profile per nearly zero energy residence occurred in the period October 2016 until February 2017 and the maximum load profile per conventional residence in the same period (winter profile).

It is clearly noticeable that the load of a nearly zero energy residence is higher than the load of a conventional residence. The old network capacity (1,2 – 2,0 kW per household) is not designed to capture the peak load of 2,7 kW. The peak load is probably caused by the heat pumps. The difference in electricity usage of a nearly zero energy residence and a conventional residence is around 1 – 1,6 kW for this measured winter period. The electricity usage is not equal to the maximum power (3,6 kW) of the individual heat pump. This implies that the 32 households did not have a 100% simultaneity for this measured winter. The corresponding temperature with the measured peak load of 2,7 kW was -6,5 °C [3]. This peak load was measured on the 6th of January 2017 at 18:13. The average temperature of the measured winter period was 3,8 °C. According to KNMI [4] this measured winter was mild, dry and sunny. If it gets colder than this measured winter period it is most likely that the peak load will be higher than 2,7 kW. The lowest measured temperature since 1901 in the Netherlands was -27,4 °C in January 1949 [5]. In February 2012, quite recently, a temperature of -22,8 °C was measured in the Netherlands which was the most extreme temperature of the past years 30 years [5]. These historic data of occurred Dutch temperatures implies that it is very likely that the peak load will be higher in other winters.

Furthermore, the graph shows that the highest feed-in peak was (-)3,5 kW. This peak is higher than the demand peak caused by the heat pumps for this measured winter. This feed-in peak is corresponding with a temperature of 7,0 °C [3]. This feed-in peak was measured on the 17th of February 2017 at 12:41.

Figure 1b shows the actual load profile of a nearly zero energy residence and a conventional residence on the 6th of January 2017. There was chosen for this day, because this was the day with the highest demand peak (2,7 kW) of this measured winter. Furthermore it can be seen that the feed-in peak of this day was 0,5 kW. The graph stops at 23:07 due to the missing dataset of this period (23:07-24:00).

Both graphs show that there is a little peak demand in the morning probably due to the usage of domestic hot water. The highest peak occurs in the evening probably due to the fact that most people are at home around that time and make use of the heat pumps.

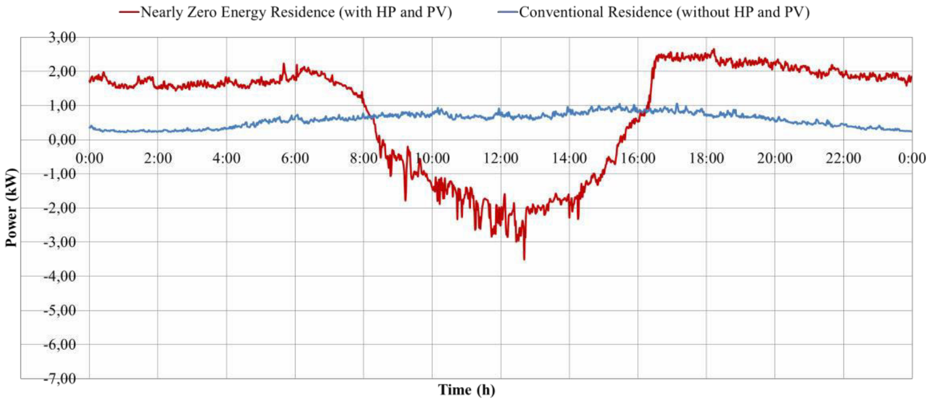

Figure 1a: Aggregated maximum demand and feed-in load profile per nearly zero energy residence occurred in the period October 2016 until February 2017 and the maximum load profile per conventional residence in the same period (winter profile).

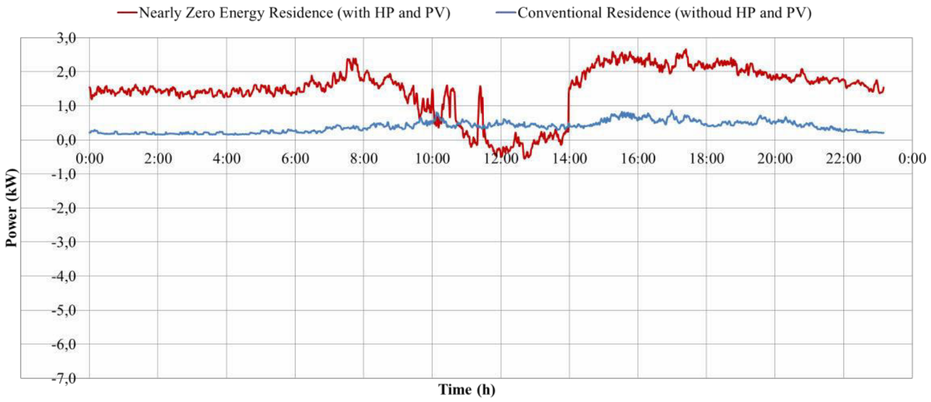

Figure 1b: Actual load profile during the 6th of January 2017 of a nearly zero energy residence and a conventional residence. During this day the peak demand from the nearly zero energy residences was 2,7 kW per residence measured at 18:13. The temperature at that moment was -6,5 ℃. The peak feed-in at this day was 0,5 kW measured at 12:44.

Figure 2 shows the aggregated maximum demand and feed-in load profile per nearly zero energy residence occurred in the months August and September 2016 and the maximum load profile per conventional residence in the same period (autumn profile). Also in the autumn it is noticeable that the network load profile of nearly zero energy residences are higher than the network load profile of conventional residences. The highest demand peak of a nearly zero energy building was 1,2 kW in the months August and September. This demand peak corresponds with a temperature of 15,6 ℃ and it occurred on the 11th of September 2017 at 18:03. The difference in electricity usage of a nearly zero energy residence and a conventional residence is around 0,1 – 0,5 kW for this measured period. It is remarkable that the difference in electricity usage is by far not equal to the nominal power (1,6 kW) of the heat pump. This was predictable due to the fact that the average temperature of the months August and September were around 17,9 ℃ [6]. According to KNMI these two months were quite warm and sunny. The heat pumps were probably only used for the usage of domestic heat water. Also in the autumn the demand peak occurs in the evening. The highest feed-in peak was (-) 6,3 kW. This feed-in peak was measured on the 5th of August 2016 at 12:33.

Figure 2b shows the actual load profile of a nearly zero energy residence and a conventional residence on the 5th of August 2016. There was chosen for this day, because this was the day with the highest feed-in peak (6,3 kW) of this measured period (August 2016/September 2016). It is also noticeable that the feed-in profile is very capricious. This capricious profile may causes voltage and current problems on the grid which is not conducive for the grid reliability. Also here the graph ends at 20:38 due to the missing data set of this period (20:38-24:00).

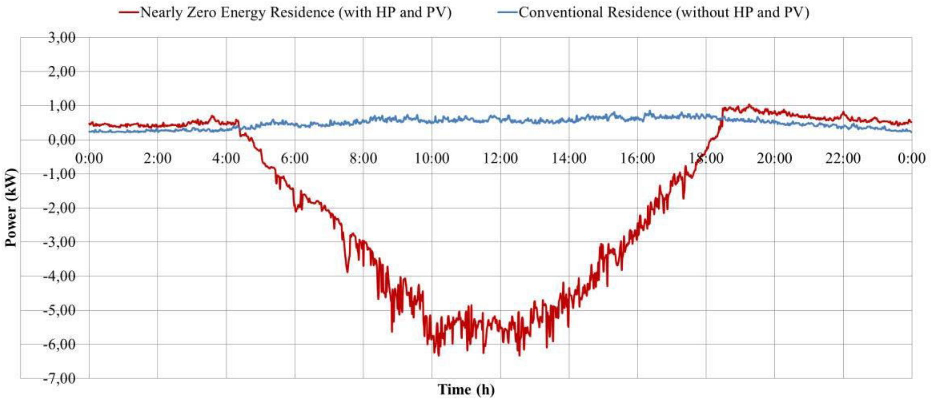

Figure 2a: Aggregated maximum demand and feed-in load profile per nearly zero energy residence occurred in the months August and September 2016 and the maximum load profile per conventional residence in the same period (autumn profile).

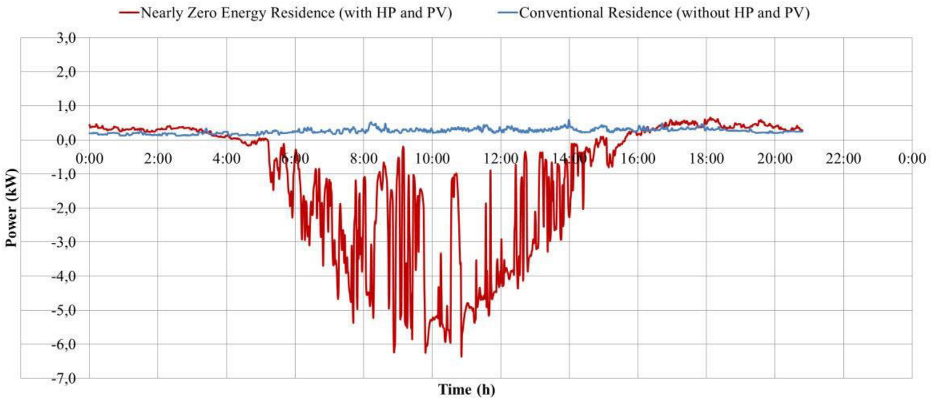

Figure 2b: Load profile during the 5th of August 2016. During this day the maximum feed-in peak of 6,3 kW per residence was measured at 12:33.

3.2 Comparison of the network load between the winter and autumn season

As predictable the demand peak (2,7 kW) of a nearly zero energy residence in the winter is higher than the demand peak (1,2 KW) of a nearly zero energy residence in the autumn. The demand peak of the winter is probably also caused to the usage of heat pumps for domestic heating while the demand peak of the summer is probably only caused by the use of the electrical devices in the house and the usage of domestic heat water delivered by the heat pumps. The feed-in peaks are also as predictable. The feed-in peak (-6,3 kW) of the autumn is higher than the feed-in peak (-3,5 kW) of the winter. In both seasons the feed-in peak is higher than demand peak. Since this conclusion is only based on the measurements of this winter where the minimum temperaturewas -7 °C it is not a statement that the feed-in peak will always be higher than the demand peak. If other winters are colder than the measured winter it is possible that the demand peak will be higher than the feed-in peak in the winter. The simultaneity of solar panels in an area is around 80% (due to the difference in location and position) which means that if the sun shines all of the solar panels are feeding towards the network due to the fact that in that time frame most of the inhabitants are not at home. The simultaneity of heat pumps is not so predictable as the simultaneity of the solar panels, because the usage of heat pumps for domestic heating and usage of domestic heat water depend mostly on the behavior of the inhabitants next to the outside temperature.

4. Possible concepts to stay within the limits of the current network with heat pumps

Currently the grid is traditionally reinforced wherever these new energy trends are implemented on neighborhood level in order to avoid network problems. A costly task for the grid operator and eventually the whole society pays for it. Alternative solutions, economic benefit still need to be determined, are demand response (e.g. controlling heat pumps) and energy storage (e.g. batteries).

4.1 Demand response and energy storage

Based on the data analysis of the measurements of the nearly zero energy residences and conventional residences it is clear that the peak demands (2,7 kW) occurred by the heat pumps are not within the limits of the current network (1,2 – 2 kW per residence). The peak load of heat pumps can only be reduced by 25% to maintain adequate comfort and the maximum peak reduction is only achievable in combination with smart/intelligent devices [7]. The peak load can be reduced by shifting loads in time. The potential peak reduction due to energy storage is dependent on system size. The buffer of the heat pump can also be used to store the energy from the PV panels. Hereby it is possible to reduce the feed-in peak by storing it as heat in the buffer of the heat pump. Enabling energetic flexibility (demand and feed-in) using smart devices is a promising development as an alternative for grid reinforcement. Next to storage systems peak feed-in can also be reduced by (PV) curtailment. Curtailment imposed by regulation is limited to 30% although higher curtailment is technically possible.

A combination of these alternative solutions is currently applied in a Liander service area (133 nearly zero energy residences) where virtual congestion is considered. Congestion is a point in the grid with too little capacity for the demand or generation behind this punt. From this pilot project Liander wants to learn how much possible flexibility there might be on the grid by controlling heat pumps and having in-home batteries in the nearly zero energy residences (these concepts are implemented and applied by a third external party). Furthermore, Liander also wants to learn how it works with the regulation side of these new concepts (e.g. giving fees for the supplied flexibility on the grid). Unfortunately no results were available yet at the moment of writing this article.

4.2 Connecting the heat pumps symmetrical over the three phases

As already mentioned in section 2 the capacity of the three different phases are determined by individual load of the phases. This is the reason why it is very important to divide the load of heat pumps and solar panels over the three phases. In one of the nearly zero energy areas of Liander the heat pumps were connected on one phase by accident. The network failed due to the overload of one of the phases. One of the phases had a current of above the 250 Ampere and the other two phases had a current of only 30 Ampere. This problem was solved by connecting the heat pumps symmetrical over the three phases. Connecting the heat pumps symmetrical over the Collaboration of heat pump industry and grid operator

Next to demand response and energy storage as alternatives for grid reinforcing a collaboration of concerned parties in the heat pump industry and the grid operator would possibly lead to new heat pump designs that are more network friendly. The intention of collaboration is to cooperate in a sustainable society as grid operator and at the same time keeping the network affordable, reliable and attainable for the whole society.

It is remarkable that the demand peak of 2,7 kW does not equals the maximum power of the heat pump. The difference in electricity usage of a nearly zero energy residence demand peak and a conventional residence demand peak is 1,6 kW. The nominal power of the heat pump is 1,6 kW. This implies that the extra electrical heating system with a power of 2,0 kW does not turn at all or not simultaneously for this measured winter where the minimum temperature was -6,5 °C. It may also be a possibility to leave this extra electrical heating system out of the design and search for other alternatives to compensate if it gets colder than this measured winter. This may be an aspect which can be taken into account in the collaboration of the heat pump producers and the grid operator.

5. Conclusions & recommendations

This data analysis has shown that there are two challenges for the grid operator, namely: increasing peak demand due to the heat pumps and increasing feed-in due to the solar panels. During the winter overload is mainly caused by demand, while in summer overload is caused by solar panels feed-in. The heat pump leads to a demand peak (2,7 kW) of 2.5 times the conventional peak load (1,1 kW) per residence in a winter where the most extreme measured temperature was around -6,5 °C. The highest absolute peak, however, occurs in the summer/autumn. The maximum feed-in peak (6,3 kW) is more than 3 times higher than the conventional peak load (1,1 kW). A conclusion can be drawn that the impact of solar panels on the grid are higher than the impact of heat pumps on the grid in the measured period. It is very important to mention that these demand profiles are from residences with an energy label A which implies high quality insulation. During cold winters the peak load of the heat pump will be higher but probably not higher than the feed-in peak in the summer/autumn. Currently the grid is reinforced for these energy trends. The demand peak caused by the heat pumps can be reduced by demand response (e.g. controlling heat pumps) and storage systems (e.g. batteries). Next to storage systems peak feed-in can be reduced by (PV) curtailment. Curtailment imposed by regulation is limited to 30% although higher curtailment is technically possible. These are all new concepts that may lead to possibilities to stay within the limits of the current network, but the technical, economic and legislation feasibility still need to be determined (e.g. through pilot projects) .

For heat pump installers it is important to know that they need to connect the heat pumps and solar panels symmetrical over the three phases even if the grid is reinforced, because the capacity of the three different phases are determined by individual load of the phases. A simple action that can avoid unnecessary network problems. Furthermore, it is a possibility to leave the extra heating system of a heat pump out of the design. A collaboration of the concerned parties in the heat pump industry (e.g. heat pump producers and installers) and the grid operator would eventually lead to new heat pump designs that will be possibly more network friendly. The intention of collaboration is to cooperate in a sustainable society as grid operator and at the same time keeping the network affordable, reliable and attainable for the whole society.

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