

LOCAL FORECASTING COULD IDENTIFY FUTURE LV BOTTLENECKS

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ABSTRACT

Part of the energy transition will take place in residential areas. In order to investigate the decisions consumers have to make in the coming decade and their consequences a forecasting model is designed. By using characteristics of the environment a mix of energy systems for a complete neighbourhood is calculated. The corresponding LV network is analysed by performing capacity calculations with the forecasted mix as input. From the case study on a typical neighbourhood it becomes clear that bottlenecks can be expected in typical LV networks in the coming decades. By using scenarios the outcomes are given for multiple projected futures.

INTRODUCTION

Following the ambition of the Dutch government to make the Netherlands more sustainable, the ‘Sociaal-Economische Raad’ (SER) states in [1] that the goal for the built environment is energy neutrality in 2050. One of the most interesting areas of the built environment is the residential area, because of its great variety of building types and owners.

Energy systems in houses will be expected to be replaced by more sustainable (including electric) systems, but the speed and location dependency of this development is yet unknown. DSO’s would like to forecast this development to support asset management decisions.

In this paper a method is proposed to forecast decisions on energy systems in residential buildings for various scenario’s, which are used to perform capacity analysis of low voltage (LV) networks. This method is tested using a case study including a real neighbourhood.

BACKGROUND

Currently DSO’s perform network planning with dated rules and standards, especially in LV distribution. The Strand-Axelsson method [2] is generally used to model residential loads, based on certain household categories. The load growth is often linearly modelled. However the emergence of PV installations and electric heat pumps undermine these rules, as they respectively introduce bidirectional power flows and increased peak loads.

Where linear load growth is historically validated and caused by factors as economic growth and an increase of electrical appliances in houses, nowadays more factors are of interest.

The decision to install new energy systems like electric heat pumps and PV installations is often based on

multiple criteria. The decision moment is estimated towards the end of the lifetime of the current energy system.

At the moment the DSO does not have insight in the time, the subject and the speed of the introduction of new energy systems in the residential area. This can cause capacity and voltage level problems in certain areas in the coming decades. An unprepared DSO would have to resort to damage control.

The presented method is able to prevent this calamitous situation by a forecasting based on various characteristics which influence the decision making on energy systems. This is done for the situation towards 2040, which ensures a definite replacement need for all energy systems in the input neighbourhood.

Electric vehicles (EV) are not included in this study as they are not part of the energy system (only as load) and the decision process for purchasing an EV differs from the process for energy systems.

In order to prevent too large uncertainties in the future projections, a scenario analysis is used to present various future scenarios.

METHOD

The foundation of the method is the presence of choice for customers. In the past, the only option for heating was a gas-fired boiler – besides the occasional district heating. For electricity the only option consisted of electricity from the grid. This has changed with the emergence of new energy systems as electric heat pumps (HP) and PV installations. This allows customers to make their own choices, which may lead to a varied mix of energy systems in a given neighbourhood.

To forecast this mix, a new method is developed. First the structure of the method is discussed, which will help to understand the logic behind the method itself.

Structure

The structure of the method can be seen in Figure 1. The top line of four blocks is the static line, with models and calculations. The bottom line can be regarded as the interaction line, where user interaction is necessary.

The input is a chosen neighbourhood in the service area of the DSO. This input consists of a list of addresses which contain characteristics about the dwelling and the owner.

This set is inputted in the forecasting model which forecasts the energy system which is most likely to be implanted in the dwelling on this address. The forecasting model will be further explained in the next section.

The forecasted neighbourhood then consists of the same list of addresses, but now including the ‘favourite’ energy system for each house, the necessary installed capacity and the changed demand values.

The network simulation file of the neighbourhood is then updated with the changed values. A so-called network load calculation is used to assess the capacity of the LV network and possible voltage levels.

As a case study a real neighbourhood (Goes-West) in the Netherlands was used to test the method.

To perform the forecasting analysis for various modes of the future, the forecasting model is executed using various scenarios. These scenarios alter characteristics as investment costs and energy prices, in order to simulate the decision process in different circumstances.

The last step is the analysis of the output of the network simulations in order to advise the asset management department on network planning.

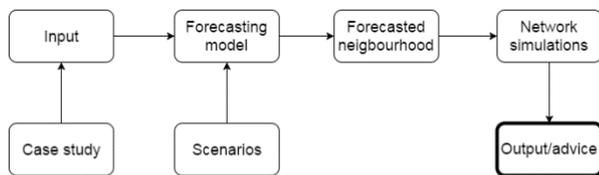


Figure 1: Structure of the used method

Forecasting model

The heart of the method is the forecasting model. The structure of this model can be seen in Figure 2.

The core of the model is a set of characteristics of the energy systems and the direct environment. Energy systems are defined as the combined heat and electricity system in the dwelling. The environment is defined as a collection of prices and taxes etcetera.

The values of these characteristics can be altered by the aforementioned scenarios to simulate different futures.

Each house (address) is also characterized, by the type of house, physical characteristics, yearly energy demands and type of owner. The values of these characteristics are used to calculate the costs and energy demand for each energy system, in the case it would be installed in this house. The calculated values are then scored using weighing factors resulting in the energy system most likely to be implemented for each scenario.

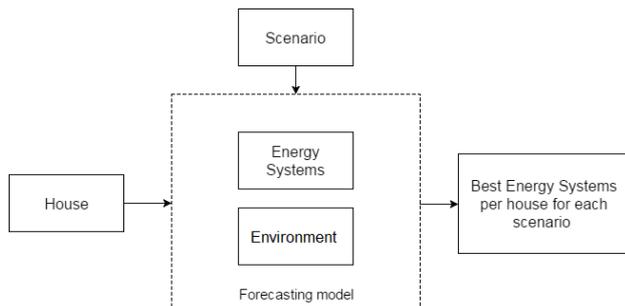


Figure 2: Structure of the forecasting model

Area & Alternatives

As mentioned earlier, the environment has to be characterized in order to use it in the forecasting model. Besides factors as prices, the energy systems and houses still have to be described.

Area

The area is the combination of houses and their owners.

Three types of owners are distinguished:

- Private owners
- Housing corporations (social rent)
- Private landlords (private rent)

The difference between these owners are represented in the weighing factors which are used to rate the energy systems.

The weighing factors and their distribution for each type of owner can be seen in Table 1. This distribution is based on the following arguments:

- Private owners are eager to save money, but may be cautious for high investment costs. They also care about the environment.
- Housing corporations are more regulated. They want to reduce costs and investments may be paid back through renters.
- Private landlords are often interested in direct cash flow, so they tend to avoid investments.

	Private owners	Housing corporations	Private rents
Net investment costs	0.2	0.1	0.4
Maintenance	0.1	0.2	0.2
Yearly savings	0.1	0.4	0.1
Yearly TOTEX	0.4	0.1	0.2
Energy use	0.1	0.1	0.1
CO₂-emissions	0.1	0.1	0

Table 1: Weighing factors for each owner

The other component in the area is the set of houses. These houses are described using the following characteristics:

- Housing type
- Physical characteristics
- Energy demand

As aforementioned, these characteristics are used for the calculations in the forecasting model.

Alternatives

The forecasting model is designed to handle all sorts of energy systems. These energy systems have to be described using the following characteristics:

- CO₂-emissions
- Applicability
- Current installed capacity

- Efficiency
- Energy savings
- Investment costs (for the owner)
- Maintenance costs
- Costs of energy (per unit)
- Fixed energy costs
- Payback period
- Lifetime
- Yearly TOTEX

As aforementioned, these characteristics are used for the calculations in the forecasting model.

In this study the three most common energy systems are incorporated in the forecasting model:

- Reference system: gas-fired boiler and electricity from the grid.
- PV only: gas-fired boiler and a PV installation to cover electricity demand.
- All-Electric: Electric heat pump, isolation and heat recovery for the heat demand. PV installation to cover the current electricity demand and the added demand by the heat installation.

Scenario analysis

The scenario analysis is a vital part to utilize the forecasting model as part of network planning. It represents various futures, where the eventual future may be a combination of the presented scenarios.

From the background description it already became clear that the main uncertainties for the DSO's are the type of energy systems being installed and the timing of this transition. This is translated into two axis for a scenario matrix:

- The matter of sustainability; the speed, state and ambition of the energy transition.
- The matter of centrality; will the energy transition take place locally or centrally?

Via this matrix, which can be seen in Figure 3, four scenarios can be distinguished. These scenarios are

described as following.

1. Local-sustainable: Sustainable energy will be generated, traded and stored locally. The government supports this with subsidies.
2. Central-sustainable: The government controls the sustainable energy, for instance by large solar and wind farms.
3. Local-not sustainable: Society will take charge, without great access to renewables. Energy corporations and demand response are examples of solutions in this scenario.
4. Central-not sustainable: The traditional situation where natural gas and centrally generated electricity from fossil fuels are supplied to customers.

These scenarios are described using four factors: Political, Economic, Socio-Cultural, Technological. The description of the scenario for each of those factors is then translated into a relative change in the values of the characteristics in the forecasting model. In this way the forecasting model performs its calculations with altered values, which may cause different outcomes for the various scenarios.

The variations of the characteristic values for the scenarios can be found in **Error! Reference source not found.** Note that the traditional scenario – scenario 4 – is used as reference scenario.

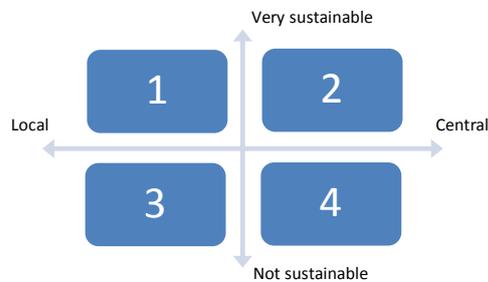


Figure 3: Four scenarios placed along the two axis

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Investment costs	-40%	0%	0%	0%
Cost of energy	Gas (grid) +30% Electricity (grid) -30%	Gas (grid) +30% Electricity (grid) -50%	Gas (grid) +40% Electricity (grid) +40%	0%
Energy demand	Electricity (ex. HP, EV) 0% Heat -30%	Electricity (ex. HP, EV) 0% Heat -20%	Electricity -5% Heat -25%	0%
CO₂-emissions	E from grid -20% G from grid 0%	E from grid -30% G from grid -10%	0%	0%
Efficiency	+20%	0%	+20%	0%
Maintenance	-10%	0%	0%	0%

Table 2: An overview of the various value alterations in the chosen scenarios

Simulations and case study

For LV network capacity analysis the network load calculation in Gaia (Phase to Phase [3]) is used. In this calculation a stochastic load flow is used by the software. The minimum and maximum voltage and the maximum current amplitudes are calculated for two situations.

The first situation is the afternoon situation, which represents minimal load, maximal generation and maximal supply voltage. The second situation is the evening situation, which represents maximal load, minimal generation.

Minimal generation is defined here as 0%, representing no PV generation due to the absence of sun. Minimal load is defined as 20%, an estimate of the minimal load of residential connections during the afternoon. This is based on the standard profiles for this connection category.

In order to simulate the results for the period from 2015 to 2040 the results of the forecasting model are multiplied with a relative penetration rate. In this way the energy transition is simulated, instead of an instantaneous change. The relative penetration rate (<1) is given by the following S-curve:

$$f(x) = \frac{L}{1 + e^{-k(x-x_0)}}$$

With:

- L : the maximum value, which is 1 here – representing 100%. The 100% relative penetration rate represents the situation in 2040.
- k : the steepness of the S-curve, which is adaptable and now chosen at 0.35.
- x_0 : the x-value of the midpoint of the curve. As there is 25 years between 2015 and 2040, $x_0=12.5$
- x : the time in years, starting at 2015.

The outcomes of the forecasting model for the capacities and energy use of the new energy systems are multiplied by the relative penetration rate for every five years.

The case study is performed on a test neighbourhood in the Netherlands. The used neighbourhood is Goes-West in the city of Goes, Zeeland. Goes-West consists of a mix of stacked houses, terraced housing and separate houses. Also all different types of owners are represented. In total approximately 1300 addresses, 1500 cable sections and 11 transformers are included. Energy data of the addresses is supplied by the responsible DSO.

RESULTS

For four scenarios and six moments in time the mix of preferable energy systems and their consequences on the LV network are calculated and simulated. The results are categorised in six types of bottlenecks:

- Overloaded cables in the evening situation
- Overloaded cables in the afternoon situation
- Overvoltages in the evening situation
- Overvoltages in the afternoon situation
- Undervoltages in the evening situation
- Undervoltages in the afternoon
- Overloaded transformers in the evening situation
- Overloaded cables in the evening situation

The results are visualized in both a numerical and a geographical way. For scenario 1 – the most progressive scenario – these numerical results are shown in Figure 4 and Figure 5. Not surprisingly, the most progressive scenario – in terms of local electrification – results in the most forecasted bottlenecks. Also the amount of the conservative Reference systems installed is only in 14% of the households, where the maximum is 59% for scenario 2. This confirms a correlation between a progressive scenario and the dominance of ‘new’ energy systems.

An example of the geographical visualization of the bottlenecks can be seen in Figure 6. Here, the forecasted situation in 2040 for scenario 1 is visualized. An orange-coloured connection represents an overvoltage, where blue represents an undervoltage. Orange-coloured cables and transformers mean that they are overloaded.

From the geographical visualization it becomes clear that there are certain parts of the grid which contain a relatively high number of bottlenecks. Therefore these areas are considered as hotspots. In this case study, the hotspots are often areas with an old (and low capacity) infrastructure in combination with a relatively high forecasted penetration rate of ‘new’ energy systems as electric heat pumps and PV. Another hotspot in this case study is a part of the neighbourhood which consists of large, separate houses. This causes the forecasted installations implemented in these houses to be relatively big, resulting in large electricity flows.

The results vary for the different scenarios, both in total number of bottlenecks and number of hotspots. The scenario analysis simulates a different environment, which results in altered decision-making.

From the case study it can be concluded that for this neighbourhood structural bottlenecks can be expected in the future. In these hotspot locations the probability of electric energy systems being installed is relatively high. The age and capacity of the network components are reinforcing factors of this process. This is useful information for DSO’s with comparable neighbourhoods, which exist throughout the Netherlands.

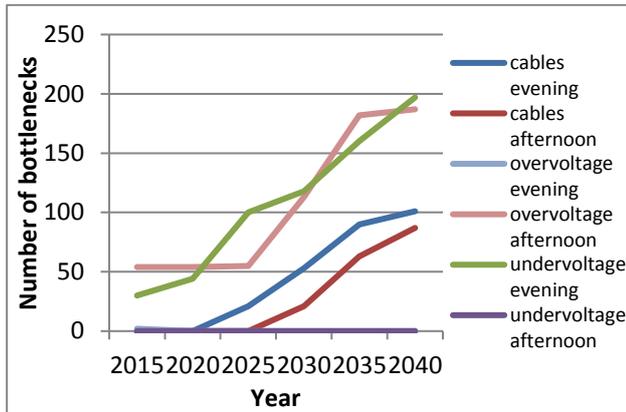


Figure 4: Overview of cable overloads and over- and undervoltages over time in scenario 1

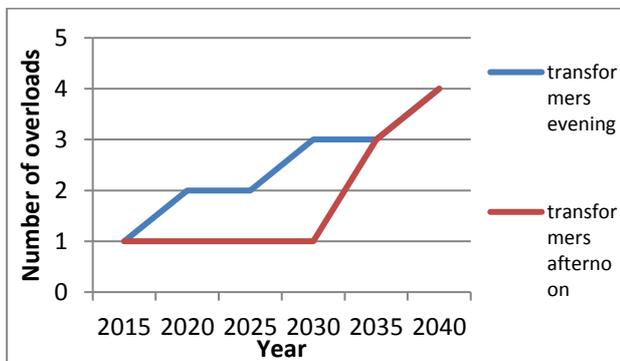


Figure 5: Overview of transformer overloads over time in scenario 1. There is one transformer overloaded from the start due to modelling inaccuracies.

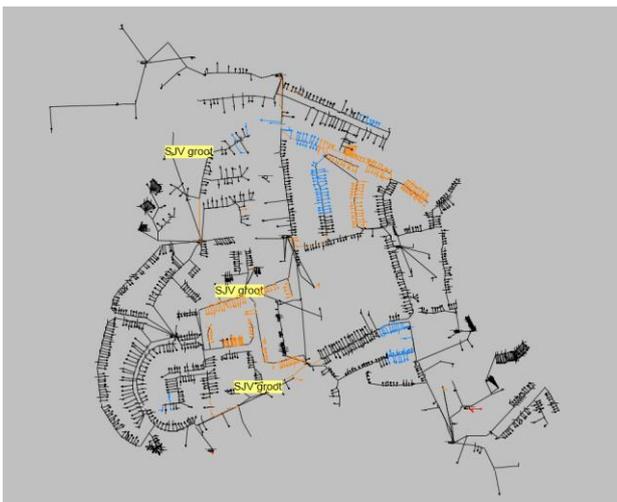


Figure 6: The LV grid and forecasted bottlenecks in Goes-West in 2040 for scenario 1

CONCLUSION

The goal of this study was to investigate future energy systems decisions of residential consumers and their consequences for the DSO. A method was designed to

forecast the decision made by consumers based on a scenario analysis which represents a changing environment. To demonstrate the impact of these decisions, network capacity calculations are performed and the results are visualized.

As the future of the energy transition remains uncertain, the scenario analysis provides a framework that covers the area of realistic futures. By using four scenarios, sensitivity issues are avoided, because the different scenarios represent variations in the projected future.

By using weighing factors with underlying arguments, the motivation of consumers is simulated. However, much is unknown about this motivation, so further research would be advised.

A time period larger than the renewal period of the energy systems was chosen, which shows that other systems than the traditional system become attractive to owners. By forecasting the decisions and simulating their impact on the LV grid, it becomes clear that bottlenecks may be expected in typical Dutch neighbourhoods. This especially holds towards the end of the next two decades. Only the assumption of a stagnation of the current number of PV and heat pump installations would ensure the absence of capacity bottlenecks.

From the case study it follows that bottlenecks are likely to occur in certain hotspots, characteristic for a high concentration of electric energy systems and often an old infrastructure with limited capacity.

Further research would include the motivations of consumers regarding energy system decisions. Also the scale of the study could be enlarged, for instance by including a larger area and the MV level. This would enable analysis of the capacity of (parts of) MV networks. A last improvement would be the inclusion of other energy systems, but also the modelling of solutions as demand side management.

All in all it was shown that a method which forecasts the future energy use and production in residential areas and uses that forecast to do network capacity analysis is valuable for the DSO. By structurally assessing uncertainties in a scenario analysis, a robust way of advising the network planning is achieved.

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