ANDES: Grid Capacity Planning using a Bottom-up, Profile-based Load Forecasting approach

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ABSTRACT

Liander, a Distribution Network Operator (DNO) in the Netherlands, faces potential challenges due to changing behaviour of its customers. New techniques such as electrical vehicles, solar PV and heat pumps can have a huge impact on the loads in the grid. This study evaluates ANDES, a load forecast model developed by Alliander that can make forecasts of future grid load for 40 years ahead, for multiple scenarios and from LV-feeders up to HV/MV-substations. In contrast with traditional load forecasting methods, the results of ANDES give insight into future peak loads and new load profiles due to an increased amount of EV, PV and HP in the grid. These results can be used to identify future bottlenecks in the grid and design the appropriate measures.

INTRODUCTION

Liander is one of the major Distribution Network Operators (DNO) in the Netherlands. It is responsible for the Electricity and Gas grids in roughly a third of the Netherlands and serves approximately 3 million customers. The Liander electricity grid consists of 700 HV/MV-substations, 50.000 MV-cables, 45.000 MV/LV-substations and 180.000 LV-feeders.

Traditional grid planning

Historically, the grid planning process within Liander has been relative straight forward. For the HV/MV-substations, peak load forecast are made for the coming 10 years. These forecasts take three aspects into account: the peak load of the last year, known urban developments and customer prospects and a fixed percentage of autonomous growth. For the underlying grid, such as MV-cables, MV/LV-substations and LV-cables, no forecasts are made at all, only the as-is situation is assessed.

Based on this information the grid planning process identifies current and future bottlenecks. Liander Asset Management uses a risk-based asset management method. The risk of a bottleneck is defined as a combination of the chance of occurrence of the bottleneck and the impact of the bottleneck at the occurrence. Depending on the resulting risk of the bottleneck, a decision is made whether an investment for mitigation measures is necessary.

These measures usually compromised expanding a (secondary) substation with additional transformation capacity and switchgear or to put more cables into the ground.

While most of the grid planning looks at a period of 0-5 years, it is important to have forecasts further towards the future. Typical assets lifetime in the electricity grid is 40 years of even more. To ensure the optimal grid investment can be made today, the future grid loads of at least 40 years ahead has to be taken into account. A steady rate of peak load growth seen in the Netherlands from the 1970's up to 2007 made it possible to extrapolate the yearly peak load forecasts towards the long term with acceptable results.

Need for new tools

Changes in the energy landscape however lead to the presence of new technologies in the electricity grid. For various reasons the amount of Solar Photovoltaic systems (PV), Electrical Vehicles (EV) and Heat Pumps (HP) in grid shows a steady increase and the expectation is that this growth will accelerate in the future. Traditional forecasting methods are not designed to take these changes into account. This leads to a need for new forecasting methods that take into account the effects of new applications in the grid and can show the potential changes in future peak loads.

The applications under consideration share some important aspects: they are highly dispersed, individual impact is small but they tend to have high simultaneousness and they are often grouped together. This makes it difficult to incorporate them in the traditional forecasting methods, as these have a focus on changes at the HV/MV-substations level while the changes occur at the other end of the grid, the LV-customer. At the same time this also means the load patterns in the LV-grid are bound to change. Insight into these changes is needed to assess the grid performance in a situation with high amounts of new applications.

The ANDES model

To meet this need for better forecast models that can incorporate effects from the energy transition, the ANDES-model is being developed within Alliander. ANDES stands for Advanced Net Decision Support and aims to give invaluable insight into future grid load patterns. It is an all-encompassing model that looks at the short- medium- and long-term (0-40 years ahead) from the LV-grid up to the HV-grid.

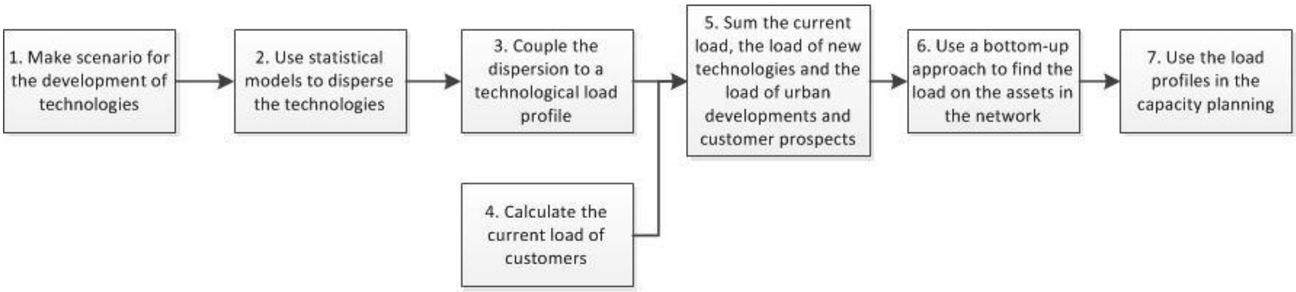

Figure 1: Overview of the ANDES-model in seven steps

METHOD

The ANDES model calculates the impact of technologies on the electricity network using a bottom-up approach. The method used is different from other energy transition impact studies in which load forecasts are made based on average linear relations and the electricity grid is treated uniformly. In contrast, the ANDES model uses the potential for specific technologies at the household level and couples this with the specific grid situation of the Liander grid.

In the ANDES model technological developments are included using predictions on household level. The main advantages of the ANDES model is that discrepancy between geographical areas are taken into account and the model is able to forecast the load on all the components in the electricity network. The large scale approach of the model leads to huge data volumes and big-data techniques, such as in-memory computing, are used to ensure the required performance.

The model can be divided in several main steps, which will be explained in more detail.

High-level Adoption Scenarios

First, scenarios are made for the adoption of electric vehicles, heat pumps and solar panels. Alliander expects that these technologies will have the largest impact on the load of the electricity network. To generate the scenarios a strategic analysis is carried out, including the regulations, the vision of the government and the incentives to buy a technology. Subsequently, S-shaped curves are generated that predict the total amount of a technology in the entire Liander-area in a specific year. For each technology a low, medium and high scenario is modelled.

Technology Dispersion

Second, the expected total amounts from the first step are used to find the penetration of a technology for each customer. External and internal socio-demographic data are coupled to the customers. The present-day location of a technology combined with the socio-demographic data is used to construct statistical models. For example, a logistic regression model calculates the probability that a household will possess a solar panel for each coming year and a regression with an arc sinus transformation is used to calculate the probability that a household will possess an electric vehicle for each coming year. Together the probability and the total amount from the S-shaped curve are used in a Monte Carlo simulation to find the penetration of a technology for each household in the scenarios in all the years.

Technology Profile Generation

In the third step, load profiles for the three technologies are generated based on measured data. More specific, sensor data is used to find an average year profile based on quarter hour values. Consequently, the customers to which a technology is allocated are coupled to an expected technological load profile.

Customer profile generation

Fourth, the ANDES model calculates a present-day load profile for every customer. For large costumers measurement data is available and this is used to generate their profile. For smaller customers, including households, an average profile is combined with the average year consumption of that specific customer to generate the load profile. The load profile of customers is based on quarter hour values.

Future profile generation

Fifth, the future load profile for each customer is generated. This new load profile is calculated by combining the current load profile with the load profile of new expected technologies. A bottom-up approach is used to connect the customers to the electricity network. A network trace, starting at the customer and ending at the HV/MV-substation, defines the whole Liander grid. The load profiles of the customers connected to a certain asset are added to each other such that an expected load profile on all the assets arises. Besides the current load and the expected load of the technologies also urban developments and customer prospects are added to the asset load profiles at the HV/MV-substation level.

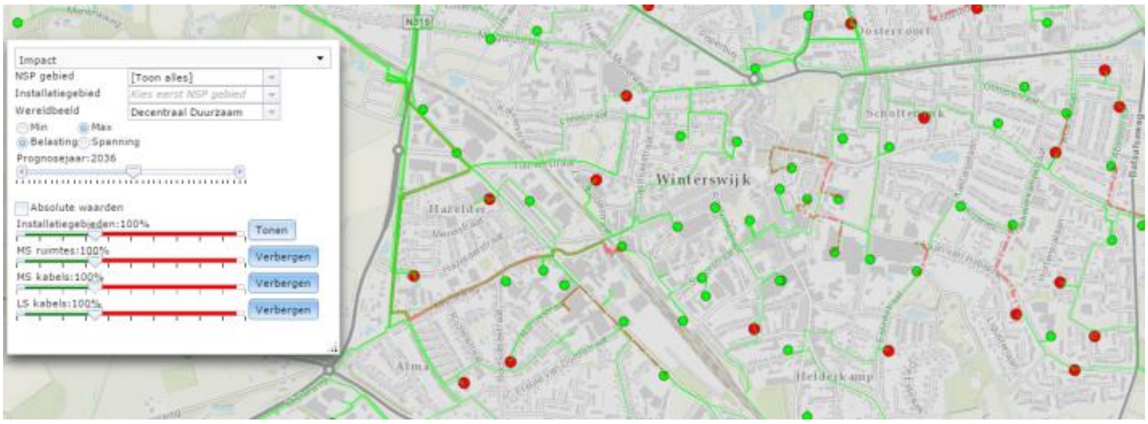

Figure 2: Snapshot of the interactive geographical visualization part of the ANDES-model. Shown are MV/LV-substation (dots) and MV-cables (lines). The color represents whether the asset is overloaded (red) in the selected year/scenario.

Result assessment and visualisation

Finally, the load profiles are used to determine congestion problems in the electricity network. More specific, the maximum and the minimum load of the yearly load profile are used and compared with the capacity of the assets. In other words, the usage and local generation of electricity are compared with the capacity of the assets. To provide easy access to the load forecast of a certain asset, an interactive, web-based, geographical interface is available.

RESULTS

The whole area of Liander is present in the model, including 700 HV/MV-substations, 50.000 MV-cables, 45.000 MV/LV-substations and 180.000 LV-feeders. The adoption of energy transition effects, such as electrical vehicles, solar PV and heat pumps, is modelled for each of the 3 million customers individually. An interactive geographical visualization has been build where the resulting loads in the grid can be assessed given a certain year and scenario. See Figure 2 for a snapshot of this visualisation. Also the change of the peak load over time can be shown for each modelled asset. These resulting load forecasts are an important part of the long term grid development plans. Based on these forecasts, the optimal route of investments can be determined for a certain energy transition scenario.

In order to identify the differences between a bottom-up approach versus the traditional approach and to evaluate the added value of the ANDES-model for Grid Capacity Planning, a standard HV/MV-substation in Winterswijk, situated in the East of The Netherlands, is considered. To do so this paper performs two kinds of comparisons, namely; a) Comparing the forecasted substation load profile from the ANDES-model with the current load profile and b) evaluate the insights of the peak load forecast.

Future load profile generation

In the traditional capacity planning approach, historical data is extrapolated to find the future peak load of an asset. Because only the peak load is used, changes in the load profile are not visible. Visualizing the present-day 15-minute load profile for a certain period (June 4th – June 8th) in figure 3 (blue line), a clear daily profile is visible. When adding the expected amount of solar panels, heat pumps and electrical vehicles expected at this substation in the years 2020 (red) and 2025 (green) and keeping the meteorological circumstances the same, we observe a clear change in the load profile. On the one

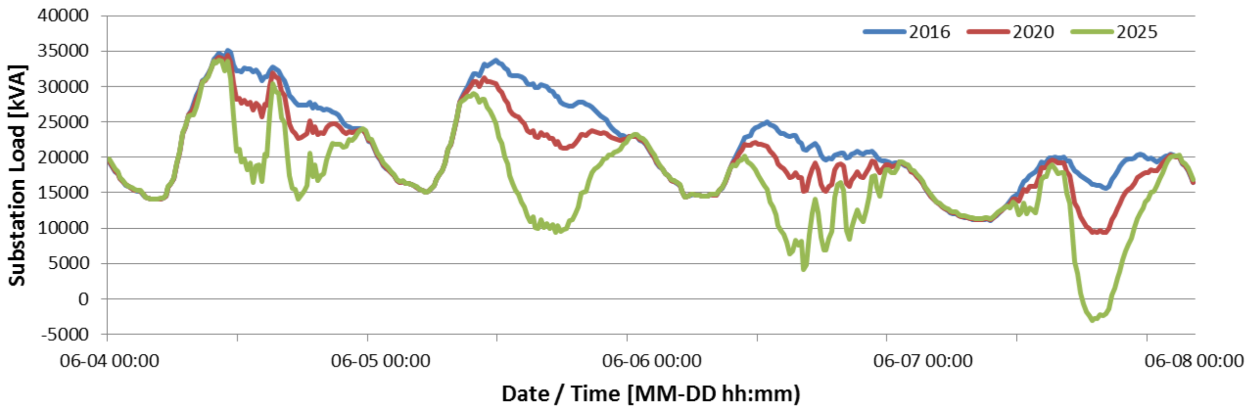

Figure 3: Example of generated load profile for HV/MV-substation Winterswijk in the years 2016, 2020 and 2025.

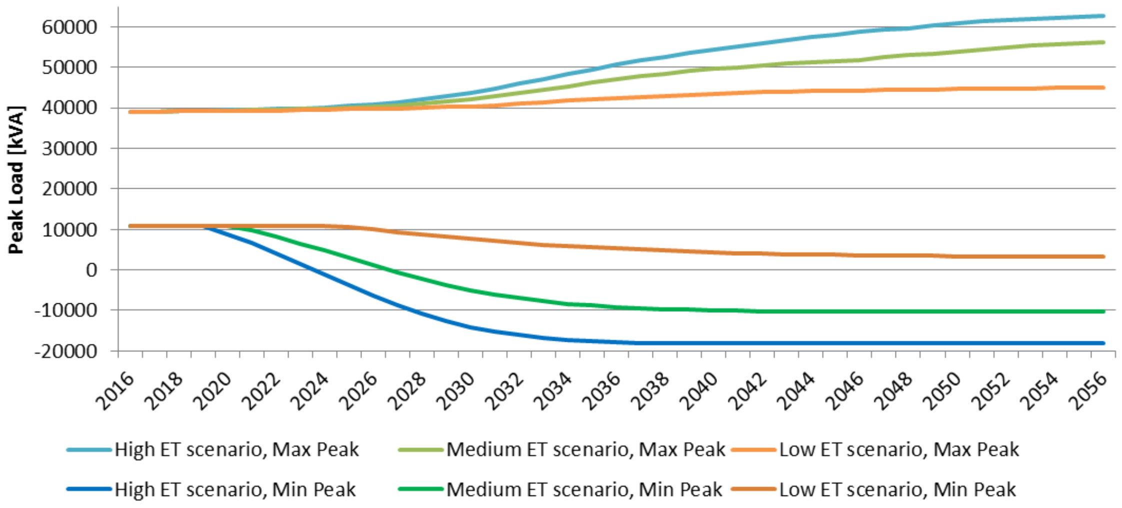

Figure 4: Forecast of the yearly maximum and minimum loads for three energy transition scenarios

hand we observe a small reduction in the maximum peak, whereas the peak moment stays the same. On the other hand, the most significant impact is visible on the minimum peak, where a sunny moment leads to a shift in the peak moment and to a surplus of locally generated energy. These are insights which cannot be derived from the traditional load forecast approach and lead to insufficient awareness of the effects of locally produced energy.

These new load profiles are also important input for the evaluation of future asset degradation. The results for HV/MV-substation Winterswijk show that the future profile is more volatile than the current profile. The larger amount of installed Solar PV leads to large load swings, even at the substation level. It can be expected this has an impact on the lifetime of the voltage regulator at the HV/MV-transformer.

Peak Load Forecast

The difference between the peak load and the total capacity of an HV/MV-substation gives information about the capacity available for urban developments and customer prospects. However, in the traditional grid planning method, effects of the energy transition on the peak load are neglected, and potential future capacity problems are overlooked.

With ANDES it is possible to evaluate the future peak loads as a result of solar panel and heat pump installations and electrical mobility. Figure 4 shows the peak load forecast for the HV/MS-substation Winterswijk, the same substation under consideration in the previous section. The forecast consists of the minimum load and maximum load occurring within each year for 40 years ahead. The results are shown for three scenarios: low, medium or high adaptation of the three energy transition technologies.

What can be observed from this figure is that regardless the scenario, the peak load at the substation will increase. Another notable insight is that the difference between the minimum and maximum load increases, resulting in larger fluctuations of the available substation load. In the medium and high scenarios, the minimum load of the substation will go into negative numbers. This means there will be moments within the year that the substation actually delivers power to the above HV-grid.

The ANDES-model generates these peak load forecasts not only at the HV/MV-substation level, but also for every MV-cable, MV/LV-substation and LV-feeder. This means that also at the lower grid levels detailed forecasts of future peak load and the impact of the energy transition are available.

The resulting forecasts can be taken into consideration within the grid planning process. Therefore they make it possible to design grid expansions suitable for a situation with a certain adaptation of electrical vehicles, solar PV and heat pumps. This will ultimately lead to better grid investment decisions.

CONCLUSION

This study shows that a bottom-up load forecasting tool like ANDES can provide new insights on the effects of the energy transition. The new approach developed for the ANDES-model is more flexible and allows detailed exploration of potential future developments like electrical vehicles, solar PV and heat pumps. Because the entire grid topology is taken into consideration, the impact of these new techniques can be evaluated at every level within the grid, from the LV-feeder up to the HV/MV-substation. Therefore it provides new understandings of the changes in typical load profiles at the LV- and MV-grid levels that were not under consideration before.

Due to the extensive temporal scope (1 to 40 year ahead) the model can be used for both short term grid planning (where new urban developments and customer prospects cause the dominant growth) as well as for long term strategical grid planning (where the energy transition effects are responsible for the dominant changes). This means that when designing grid expansions and replacements, they can be designed for their whole

lifespan of typically 40 years.
Despite a lot of potential for the outcomes of the ANDES-model is foreseen, it is still too early to conclude when this new approach will entirely replace the traditional process of grid planning. More time and experience with the results is needed to perform extensive validation and to quantify its impact.

DISCUSSION AND FURTHER RESEARCH

The aim of the ANDES-model has been to show the potential load profiles due to three energy transition effects. It presents a framework encompassing the whole Liander grid. Main focus of the early development has been to set up this framework and make it possible to generate long term forecasts based on 15-minute profiles for a large amount of assets. A result of this approach is that in some areas the model is still underdeveloped.
One import assumption is that the current household baseload (i.e. the load without EV, PV or HP) will remain constant during the period under evaluation. Further research is needed to take long term trends in household energy consumption into account in the model.
Also the grid topology is assumed to be constant in the model. This means care has to be taken when interpreting forecasted bottlenecks in the long term.
The forecast period might be longer than the remaining lifetime of the asset. Also it is not possible to model the effects of future changes in the grid. The model does have potential here though. An extension of the model could offer support while designing grid expansions and offer automated insight in the optimal investment path.
Within the current version of the model only three effects of the energy transition are under consideration. In reality it is not likely that the energy transition will be limited to the application of these three techniques. Other promising developments such as storage and demand-side management are not taken into account. On the other hand, because the model produces future load profiles at all grid levels, it can be used as input for studies of the application of storage and demand-side management.
Finally one import remark is that the model generates huge volumes of data. Because the traditional grid planning methods never had this availability, great care has to be taken how transform the vast amount of data into useful information. Especially at the LV-level where asset numbers are high (e.g. 180.000 LV-feeders), individual assessment of the results is not feasible. Clearly the grid planning process has to be adapted to the new information available.