METHOD TO SCAN THE LOW VOLTAGE NETWORK FLEXIBILITY TO ADAPT TO FUTURE DEVELOPMENTS

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ABSTRACT

It is expected, that new technologies in load and generation (PV, EV and heat pumps) may cause power quality and grid operating problems, especially in LV grids. However, without additional information, it is still not clear which problems will occur; as well as when and where (geographically) they will take place. This paper provides a method to gain a good insight in the distribution network adaptability for these future developments. The method makes use of in-house available data to perform grid calculation. Further it classifies and visualises the calculated results. This will help the grid planners and operators to define the necessary measures needed to prevent and mitigate expected power quality (PQ) and other network problems.

INTRODUCTION

As one of the distribution system operators in The Netherlands, Alliander has the responsibility to facilitate the transition towards more distributed generation and new types of loads, e.g. solar panels (PV), electric vehicles (EV), and heat pumps (HP). The grid, which was designed several decades ago, was not designed for these new generations and loads. Therefore, problems are expected to occur, especially in the LV network. However, it is still not clear as to what, where, and when these problems would occur.

It is therefore important to have an insight in the network condition, not only for the daily operation at this moment but also for investment purposes in the future. Especially, the asset management department needs to know how flexible the network is to adapt to different scenarios of the energy transition so that the necessary measures can be taken in due time. This is specifically concerning several aspects, such as flicker, safety, voltage level, and component loading.

To simulate the impact of future scenarios and also to assess the present situation, Alliander needs to have a realistic and predictive model of the LV network. Subsequently, to determine whether the present situation complies with the network code and whether the future scenarios will cause a problem, the simulation results have to be classified.

LOW VOLTAGE NETWORK DESIGN AND MAINTENANCE

At this moment, an extension of the LV network takes place when there is a new installation, e.g. of a new building or a new residential area. A grid planner will then model this new installation in Gaia, a LV network design and simulation software. In addition to that, a grid planner has to calculate the grid impedance at the customer's point of connection (PoC) when the customer reports a complaint regarding the voltage quality.

An overview of the current process is shown in Fig. 1. Asset and customer data such as the cable parameters are exported from the GISdatabase, called Netwerk Registratie GIS (NRG) in Alliander, through an external application such as ArcGIS or WebGIS.

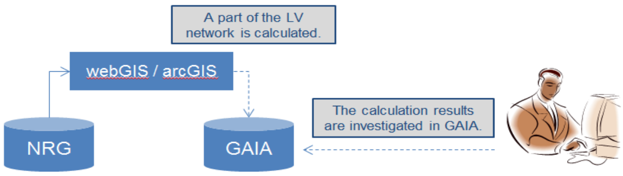

Figure 1Currently used method for LV grid calculations

All of this is performed manually for every installation – which is labour intensive. With the distributed generations and loads still expected to grow in the coming years [1], the labour hour for the calculations with regards to new installations or complaints will only increase. Take for example the PV technology.

PV technology

The voltage level at PV panels PoC is determined by the current it produces and the grid impedance at that point. If the grid impedance is high, the voltage level may exceed the limit specified by the grid code. This especially happens if PV is connected at the end of the cable which either is relatively long or has a small conductor diameter. Usually the solutions to this problem are a new transformer setpoint, a bigger cable, or a dedicated cable – which is costly. By identifying possible problematic areas timely, Alliander can proactively take necessary precautions, including making necessary arrangements with the customers. For example, peak shaving of the PV production, downscaling of the PV capacity, or another configuration of the grid. In this way, customer complaints or dissatisfaction – and the cost resulting from them- can be prevented.

GRID CALCULATION

To reduce the labour work and cost, the method presented here deploys automatic export from NRG to Gaia. Gaia will then perform calculations on the network model:

- Load flow: to obtain the voltage level at PoC and the current (loading) of each component,
- Flicker: to obtain the grid impedance at PoC,
- Safety: to obtain the touch voltage and disconnection time at PoC.

The result of the classification is visualised on a geographical map and in reports to assist a grid planner in preparing grid extension plan. Figure 2 and 3 depict this process.

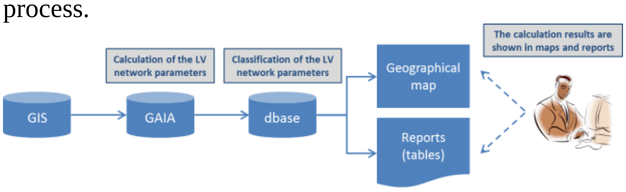

Figure 2 Developed method for LV grid calculations and impact analysis

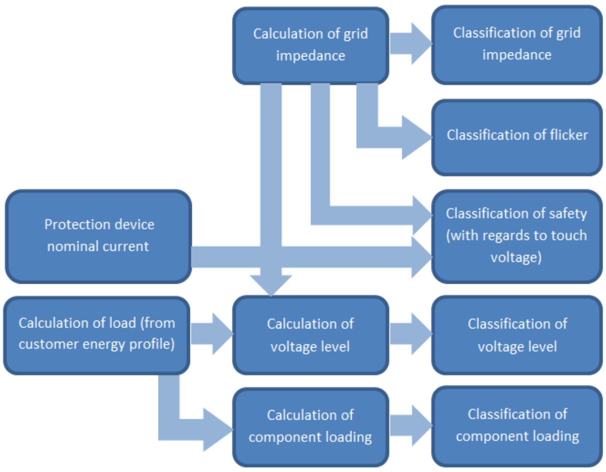

Figure 3 Calculation and classification of different aspects

Export to Gaia

All components data and geographical information, such as cable length, cable cross section, cable type, transformer nominal power and X and Y coordinates, are stored in NRG. The export from NRG to Gaia will use this information to model the network. Gaia can represent a network in two ways: a single line diagram and a geographical layout, as shown in Fig. 4 and 5, respectively [2]. Each node in the single line diagram represents a customer.

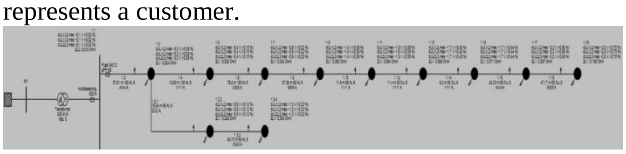

Figure 4 Single line diagram in Gaia

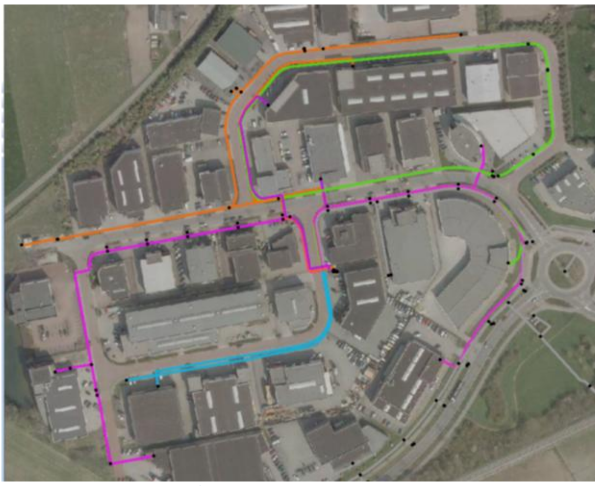

Figure 5 Projection of the network on the map

Modelling of customer loads

One of the novel things of this approach is that the information about the load does not have to come from measurements. In this method, the load is obtained from the customer energy usage profile which is then aggregated on the cable and transformer level to obtain the cable and transformer loading, respectively.

Each customer has a total annual energy usage which is recorded in Alliander's database. The customers are grouped into 10 different categories based on their connection type and their energy usage pattern. For each category, there is an average 15-minutes load profile which can be scaled according to the annual energy usage of each customer. These average profiles are available from the Energie Data Services Nederland (EDSN) and can be applied to any electricity connection in The Netherlands [3].

Figure 6 shows the comparison between the transformer loading profile, calculated using the EDSN average profile, and the actual measurement of that station. The data shown in the graph is taken from 11 to 12 Oct 2014 for a transformer with 391 customers. It shows that the calculated profile matches the measurement quite well and this means that the EDSN profile can be used for load estimation and simulation of future scenarios too.

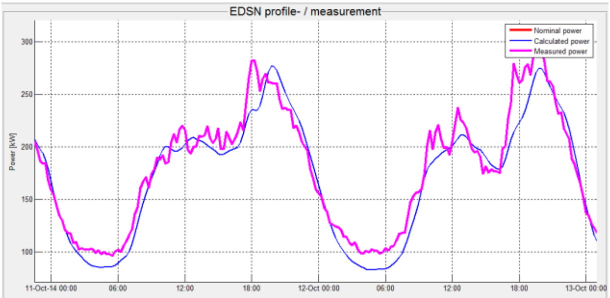

Figure 6 Comparison of EDSN profile and measurement

The calculation of load is performed for present situation and for future scenarios, with the integration of PV, EV, and HP. The increase of the customer load is also taken into account.

For every technology, there are three different scenarios of their growth: maximum growth, most likely and minimum growth. The combinations of different technologies are simulated. With these calculations, the component loading can be estimated for a few years ahead and it can be estimated when and which component might be overloaded or when high loading will result in too much voltage drop or rise. When this information becomes available, the asset management department can make necessary plans.

Load flow calculation

The load flow calculation will yield the loading of each component and the voltage level at each PoC. Since the load is changing with the integration of new technologies, the voltage level is also calculated for every year with different scenarios of the future developments. In this way, it can be predicted when and which customer might have a problem with voltage level.

Flicker calculation

The flicker phenomenon (fast voltage variation) is dependent on the inrush current and the grid impedance at the PoC. The Dutch grid code specifies that 283 mΩ is the maximum grid impedance at the PoC to ensure that in the situation with an inrush current of 32 A the flicker level at that PoC will still be within the allowable limit (P_{lt} ≤1 for 95% and ≤5 for 100% of the time for a measurement period of one week) [4].
By performing flicker calculations in Gaia, the grid impedance and the voltage variation of every PoC is calculated.

Safety calculation

In the event of a phase to earth fault, a voltage difference originates between the protective earth (PE) and the “far-off ground”. As a consequence of this, a current could run through the body of a person working with a grounded piece of equipment at that moment. The voltage between the person and “far-off ground” is called “touch voltage”.
The touch voltage is calculated in Gaia when performing phase to earth fault simulation. Gaia will determine whether a PoC is “safe” or not. In this model, it is desired to have the information; not only on whether the PoC is safe, but also on how critical it is to replace the existing protection devices, in case the PoC is not safe.
Therefore, the safety aspect is classified based on the grid impedance and the protection device (fuse) nominal current. The impedance is calculated already in the flicker calculation and the fuse nominal current is available from the registration in NRG.

CLASSIFICATION OF THE NETWORK

For the classification, three categories with three different colours and statuses are defined. By using three categories, a distinction can be made between LV grids that are OK (green), Critical (orange) or NOT OK (red) for that specific parameter. For the parameters flicker, loading and voltage level, the category Critical means it is still within the limits. However, it is already critical and in the (near) future it could pose a risk. For the safety parameter, the category Critical is above the accepted limit. However, the level of the risk is lower than the NOT OK category.
The classification is based on international standards and company requirements. Some aspects which are specified in the grid code, e.g. the voltage level, might be classified differently here. That is because the limits presented here have the emphasis on the investment plan and on the mitigation of customer complaints. Furthermore, the calculations are performed with certain assumptions and the results are not perfect. Therefore, the classification should leave a margin for this error too. The limits presented here are stricter than the grid code. They have, however, been discussed and approved by different departments in Alliander. Further, these limits can be adjusted in the course of time.
One important thing to remember is that the classification will help to give indication of the grid situation. They are not to be taken directly as the base of investment plans. If an area is classified as OK then there is nothing to be done. Since the limit is already stricter than normally, one can be sure that the possible problems are already covered in this classification. When an area is classified as NOT OK then the grid planners should take a deeper look at the area to investigate the possible problem better.

Classification of flicker

An example of the classification limits with regards to flicker is shown in Table 1. For the lower classification value, the reference impedance of 283mΩ from the IEC 61000-3-3 standard is used [5]. An impedance value equal to or below 283mΩ does not mean there will not be any flicker problems. However, if there is a flicker problem, it is more likely that the solution has to be made by the customer and not by the DSO.

Table 1 Classification margins regarding flicker

Value	Classification
Z ≤ 283mΩ	OK
283mΩ < Z ≤ 523mΩ	Critical
Z > 523mΩ	NOT OK

Classification of loading

For the loading aspect, the classification limits apply to the maximum or peak value of the cable and transformer year load profile. The logic behind it is that if the component is classified as OK even under the maximum loading, it can be expected that no problem should arise under normal loading condition.

Classification of voltage level

The grid code sets the voltage level limits at the PoC at ±10% of the nominal voltage 230V [6]. This includes

Table 2 Classification limits regarding touch voltage (safety)

Values	100A	125A	160A	200A	250A
t < 5s & Uf< 66V	Z ≤ 346mΩ	Z ≤ 278mΩ	Z ≤ 234mΩ	Z ≤ 189mΩ	Z ≤ 148mΩ
5s ≤ t < 15s & Uf ≥ 66V	346mΩ < Z ≤ 412mΩ	278mΩ < Z ≤ 328mΩ	234mΩ < Z ≤ 281mΩ	189mΩ < Z ≤ 225mΩ	148mΩ < Z ≤ 186mΩ
t ≥ 15s & Uf ≥ 66V	Z > 412mΩ	Z > 328mΩ	Z > 281mΩ	Z > 225mΩ	Z > 186mΩ

thus the voltage variation in the HV and MV network. With the assumption that the voltage variation in the HV and MV network will not exceed ±3.5%, the classification limit values of voltage variation at the PoC are set at ±6.5%. Taking into account the error resulting from the load model deployed to calculate the customer load profile, the limits are set at ±5%.

Classification of safety

An example of the classification limits with regards to touch voltage is shown in Table 2. The safety aspect is classified on the basis of the grid impedance at that node. The values of the maximum impedance are determined by the fuse at the beginning of the cable and the time needed to fuse to break the short circuit.

Geographical map

When the parameters of each of the distribution transformer and its outgoing feeders have been calculated in Gaia, the results are presented on a geographical map. This map provides a straightforward vision as to which areas require extra attention and further investigation. An example of such map is shown in Fig. 7.

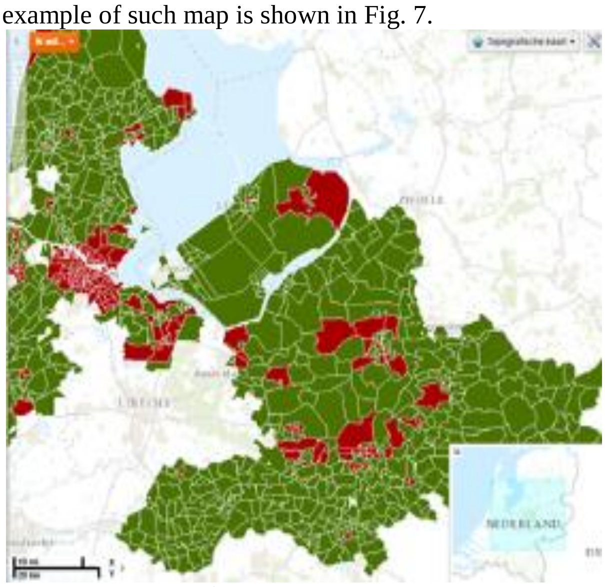

Figure 7An example of the geographical map showing problematic areas

The Netherlands is divided into postcode areas with 6 digits code. The number of digits shows the size of the area, i.e. a 4-digits postcode area (PC4) is greater than a 6-digits postcode area (PC6). This map is based on PC4 area because it provides adequate information without too much detail. Normally a 6-digits postcode covers an area as big as a street. The PC6 areas can be aggregated to PC5 areas and similarly the PC5 areas can be further aggregated to PC4 areas.

Each distribution transformer feeds one or more PC6 areas. When a distribution transformer or one of its outgoing cables is classified as NOT OK (red), the PC6 area to which it belongs will then be represented as red too. Subsequently, the PC5 area will be highlighted with red if one of its PC6 areas is highlighted in red. The same aggregation applies to PC5 to PC4 area.

RESULTS

As a proof-of-concept, 7 distribution transformers were selected from different regions to be modelled and calculated in Gaia. One of them, Nieuwe Tijningen, is shown here. This transformer station has 7 outgoing cables whose IDs are shown in Fig. 8 to Fig. 10.

From Fig. 8 it can be seen that all LV cables of Nieuwe Tijningen are classified as OK regarding flicker. All impedances are lower than 283mΩ so no problem regarding flicker is expected in this network.

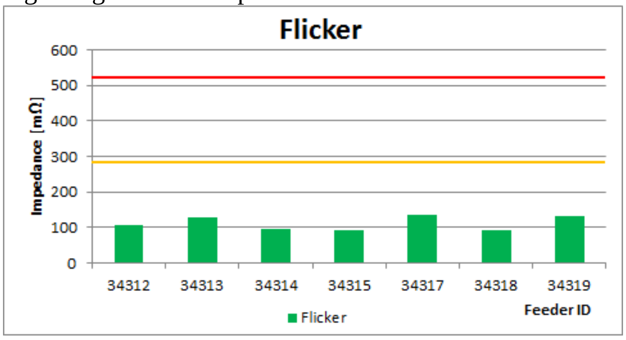

Figure 8 Results and classification of flicker

For the loading aspect, not only the cables but also the transformer is considered, denoted as DS (Distribution Station) in Fig. 9. The figure shows that the LV cables of Nieuwe Tijningen have a relatively low loading except for feeder number 34317. This cable is loaded for more than 70% and is therefore classified as critical.

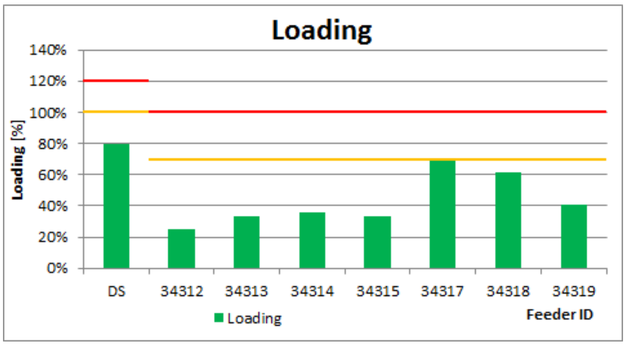

Figure 9 Results and classification of loading

Figure 10 shows the maximum voltage drop/rise from all nodes on each cable. It can be seen that none of the cables maximum voltage level exceeds the limits. The highest voltage drop occurs in feeder 34317 which can be explained by the fact that this feeder has the largest impedance and the highest loading.

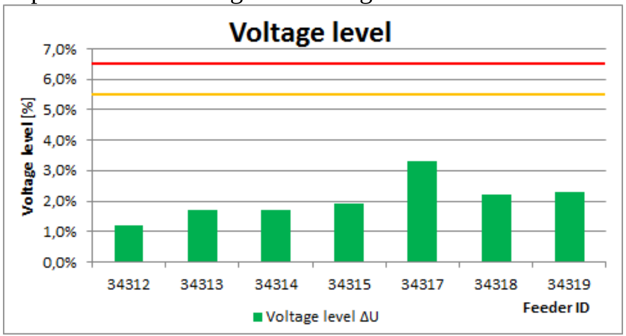

Figure 10 Results and classification of voltage level

CONCLUSION

This paper introduces a novel approach to assess the LV network flexibility to adapt to new technologies. As the technology around distributed generation and load advances, it is really important to have the possibility to check the flexibility and limits of the LV-network. This method shows that such assessment can be performed by deploying data that are already available within the organisation. This process can yearly check the changes of the total LV-network. With this insight, Alliander is in control of its grid and can be more flexible and effective in her investment plan – considering the new technologies. Furthermore, the calculations and results are available for other purposes across different departments. Thus, it increases the efficiency and synergy between departments.

In this paper, the algorithms behind the process and the results have been reported. Future development will include the automation of the process and the improvement of data quality issue.

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