INVESTMENT STRATEGY FOR LOW VOLTAGE NETWORKS REGARDING NEW TECHNOLOGIES

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ABSTRACT

It is highly likely that electric vehicles and electric heat pumps will be introduced in new residential areas. The electricity demand of these devices is significant, causing them to have a high impact on low voltage networks. This paper focuses on low voltage networks of new residential areas and analyses investment strategies to increase the capacities of the networks needed for the new technologies. Two different strategies are compared: (1) investing now or (2) postponing the investments. It appears that investing in the capacity of the networks now is cheaper if the investments would be needed over 10 years, but postponing the investments will become a financially better choice if the investments would be needed over 20 or 30 years.

INTRODUCTION

Traditionally electrical power systems have been designed to transport energy from large production plants connected to the high-voltage networks, and distributing it to lower voltage networks. In contrast, in a power system with distributed energy resources (DERs), smaller amounts of energy are produced by numerous small, modular energy conversion units, which are often located close to the end-user.

The share of distributed generation (DG) in distribution grids increases worldwide. The drive for cleaner energy sources, the economic opportunities presented for investors in the deregulated electric industry environment and some of the potential benefits for utilities (peak-shaving, congestion alleviation, reduction of losses, better asset utilization) are contributing to this trend [1]. Grid operators have the task to facilitate this energy transition. For the transition investments are needed that should be done at the right moment and should be as optimal as possible. Usually grid investments are done for a period of at least 25 years. Therefore the need for these investments should be considered now.

This research project has been part of work of an internal project group within Enexis, a large Dutch Distribution System Operator (DSO). The group works on the validity and is updating the design guidelines for low voltage networks. One of the major research questions is whether Enexis should already take the large-scale introduction of future technologies into account in the design of the low voltage networks in the new neighborhoods. The aim of the research presented in this paper is to answer this question and to determine whether it is cheaper to invest in the low voltage grid now or later.

PROBLEM STATEMENT

As the networks are being installed for a period of at least 20 to 30 years, additional capacity which is installed now might not be needed in future, if the large-scale integration of the renewable energy technologies and the additional loads will not be realized (in the planned period). On the other hand, delaying the investments might bring the grid operator in problems in case of a sudden large-scale penetration of new technologies and this leads to higher additional costs. The advantage in the second case is that the grid operator is in possession of extra information and certainty and therefore can save on unnecessary investments. To compare the total costs of these different cases, two investment strategies are analyzed.

In *strategy 1* the networks will be designed based on the assumption of large-scale introduction of DG and new loads like electric vehicles and heat pumps. This strategy leads to higher investment costs in the beginning, but has the advantage that no further additional costs are necessary in the future. Due to the high uncertainty of the development of future technologies, investments might turn out to have been unnecessary leading to additional financial losses for the grid operator.

In *strategy 2* the investments are postponed and the networks will initially be designed just like other networks in which the large-scale penetration of the technologies is not taken into account; this means that the networks will be designed with lower capacities compared to *strategy 1*. This strategy has the advantage that there is more certainty about the investments and reduces the chances of making unnecessary investments. On the other hand, if in the future additional investments like digging, cables, transformers, are more expensive than in *strategy 1*, then the total costs might be higher. This paper considers which strategy is the optimal strategy to follow in order to keep the costs as low as possible. The exact phrasing of the main research question can be formulated as:

"Which adaptations on newly installed distribution network are needed to be able to cope with future cases and should the grid operator already invest in the low voltage grid to be able to cope with the large-scale integration of generators and loads or should these investments be postponed?"

TECHNOLOGY SCOPE

For new neighbourhoods the following technologies are expected in the future [2-5]:

- There are **electric vehicles** (EV); it is expected that an increasing number of customers will use electric vehicles.
- There are **individual heat pumps** (HP) installed; in [3] it is indicated that in a near future (2020) 80% of the dwelling in new neighbourhoods will be installed with a heat pump.
- The dwellings have **photovoltaic panels** (PV). the grid parity moment for solar panels in the Netherlands will already be achieved in 2015 [6];
- The number of installed **air-conditioners** is limited.

In order to use **micro combined heat and power boilers** (u-CHP) a gas network will be needed as it needs natural gas to deliver the heat and power. It is expected that a gas network will not be installed in new neighbourhoods as it is not economically viable anymore due to the low gas consumption.

CONSIDERED CASES

In order to set up reasonable cases for the simulations, it is important to consider the loads separated from the generators in order to determine the impact on the network. In this way, two extreme situations which can have a great impact on the grid can be considered:

1. MAX LOAD – MIN GEN
2. MIN LOAD – MAX GEN

Overview cases

The impact of a combination of technologies (only generators or loads) will be higher on the grid than when only a single technology is being considered. As a consequence, all the cases with single technology presented in Table 1, cases (1), (2), (3), (8), and (9), can be disregarded.

The chance that a customer will use heating and air-conditioning at the same time, is low. PV and u-CHP have maximum output in different seasons. Air-conditioning has less impact on the grid than heat pumps [4]. Consequently only case 4, the situation in which electric vehicles are being used in combination with heat pumps, is left. This situation is a situation with minimum generation and maximum load. In case the grid is able to cope with this case, then it can cope with all the other mentioned cases as well.

Case	*Before simplification*	*After simplification*
1)	EV	~~EV~~
2)	HP	~~HP~~
3)	AIRCO	~~AIRCO~~
4)	EV + HP	**EV + HP**
5a)	EV + AIRCO (summer)	~~EV + AIRCO~~
5b)	EV + AIRCO (winter)	~~EV + AIRCO~~
6)	EV + AIRCO + HP	~~EV + AIRCO +HP~~
7a)	HP + AIRCO (summer)	~~HP + AIRCO~~
7b)	HP + AIRCO (winter)	~~HP + AIRCO~~
8)	PV	~~PV~~
9)	u-CHP	~~u-CHP~~
10a)	PV + u-CHP (summer)	~~PV + u-CHP~~
10b)	PV + u-CHP (winter)	~~PV + u-CHP~~

Table 1: Overview cases

CASE: ELECTRIC VECHILES + HEAT PUMPS

To determine the impact of heat pumps in combination with electric vehicles the combined peak demand has been calculated. Each feeder is equipped with a certain capacity, which is called 'grid capacity' in Figure 1. By assuming that the simultaneity factor of the heat pumps is one and that they are producing heat all day on a cold winter day, the demand of the heat pumps is constant over day. This has been indicated by the green area in Figure 1.

Next to this constant power for the heat pumps each house has a certain demand for electricity use for lighting and household appliances. The blue area in Figure 1 indicates this part of the electricity consumption. This normal electricity consumption has its peaks and valleys. In general it can be stated that the peaks occur in the morning and the evening. The Strand-Axelsson method, (integrated in the simulation package GAIA [8] that is used in this research), determines the power demand values for the day and night hours and an average value based on the maximum and minimum values of the power demand.

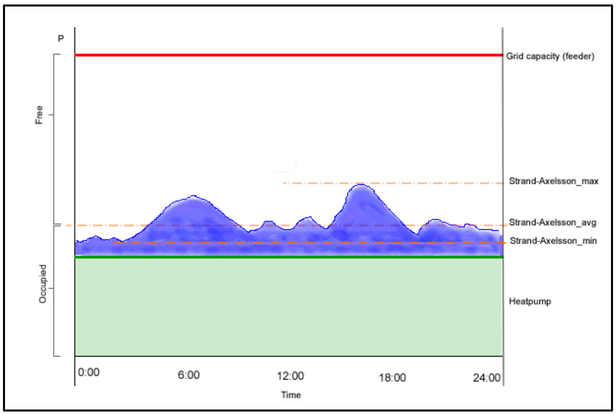

Figure 1: Modeling the demand for electric vehicles and heat pumps

Taking into account the power demand for the heat pumps and the normal electricity consumption, the capacity at a certain moment, which will be left to connect the electric vehicles, is equal to:

$$P_{electric\ vehicle} = P_{grid\ capacity} - P_{heat\ pumps} - P_{strand\text{-}axelsson\_avg}\ [kW]$$

This indicates that the load profile of electric vehicles using intelligent charging will depend on the rest of the demand. Charging the electric vehicle is only possible when there is enough capacity available on the grid, which is indicated by the white area in Figure 1. The white area is the capacity which is left after taking the power for the heat pumps and normal electricity use off from the grid capacity. This area can be used to charge the electric vehicles.

MODELLING THE NETWORK

Two different situations have been compared. The first situation is called *business as usual*; in this case no future technologies are taken into account. The second situation is the situation in which the technologies have been taken into account leading to a different network, which is called the *adapted grid*.

Business as usual

First a model grid for the neighborhood has been designed for the situation in which there would be no electric vehicles and heat pumps.

Adapted grid

If the networks would be designed just like in the *business as usual* case, this might lead to problems (capacity, voltage, current loading problems) at a certain penetration grade of the heat pumps and electric vehicles. To solve the problems in those scenarios two main different options are considered.

Option 1 – Parallel Cable

By placing a parallel cable extra capacity can be created for the area which is having the problems. In this case the existing cable in the grid will be split at the center and will be connected to the additional cable. The loads will be distributed over both feeders and this will solve the problems.

With the adapted network extra capacity is created and a situation with overcapacity caused by the heat pumps and electric vehicles is handled by the network. This option needs the investments for the additional cable that is being installed and the installation or reinforcement of the transformer. Furthermore, splitting the cable in the center leads to labor and digging costs.

A drawback of this option is that the capacity of the transformer cannot be increased infinitely due to large short circuit currents and for safety reasons. Therefore, transformers of capacities larger than 630 kVA are being avoided in practice. This puts a limitation to solving capacity problems with this option. Besides, if an additional transformer would be installed next to the existing one, this would result in a bigger medium voltage station and an extra rail for the new transformer. Therefore, a second option needs to be regarded for cases in which this first option is not possible.

Option 2 – Additional transformer

In the second option the cable is also split in the center, but instead of reinforcing the transformer an additional transformer is placed at the end of the radial networks. This would mean that there should be space for the additional transformer in the neighborhood; besides, an additional medium voltage cable will be needed for the connection of the additional transformer to higher voltage networks.

When the heat pumps and electric vehicles will be installed, the networks are shorter and the load is distributed on both sides of the split and over two transformers. This situation creates extra capacity, while at the same time reinforcements of the transformer which can lead to high short-circuit currents are being avoided.

Both options 1 and 2 can be applied in practice dependent on the topology of the medium and low voltage networks and the loads connected to the network. During the financial analysis both options have been regarded as viable options to increase network capacity.

INVESTMENT ANALYSIS

To carry out an investment analysis, first the initial costs in the *business as usual* case have been calculated. Afterwards the additional investments (digging, installation, and material costs) needed to adapt the grid are calculated. Besides the capital investments the grid losses over the years have been taken into account. Using this case the two different investment strategies are analyzed for the *adapted grid*. For *strategy 1*, the grid will be over-dimensioned from the start resulting in lower currents through the grid components. When the investments are postponed, following *strategy 2*, higher financial grid losses have to be paid due to larger currents going through the cables until the moment the investments are done.

It is expected that the digging operations and thus digging costs will be higher in the future. According to CBS (Centraal Bureau Statistiek, [7]) an increase for digging operations (labor) of 25% for each ten years can be assumed. Furthermore, when the investments in the new neighborhoods are postponed, the additional investments that should be done in the future will happen in a finished neighborhood where the cables and grid infrastructure have already been installed. This will lead to higher digging costs as it involves more digging operations. In this project it is assumed that the digging costs in the existing neighborhood is 1.5 times higher than in new neighborhoods.

In Figure 2 the red line indicates the costs when these

investments are done now (*strategy 1*). In this strategy the total costs will not change, as no other additional investments or digging are required. The blue, green and the purple line indicate the investment costs for the future if the digging costs have increased based on the linear increase of the digging costs. In those cases additional digging will be required in the future.
The pink vertical lines indicate the expected increase in digging costs following the expectations of CBS over 10, 20 and 30 years. Over 10 years a 25 % increase, and for 20 and 30 years a 50% and 75% increase have been marked.
The points A, B and C indicate the costs of *strategy 2* which should be compared with the costs of investing now (*strategy 1*, indicated by the red line). It should be noted that although point B indicates that the total costs will be as high as the costs when these investments are done immediately, postponing the investment leads to a higher certainty. Therefore, *strategy 2* is favored in this case.

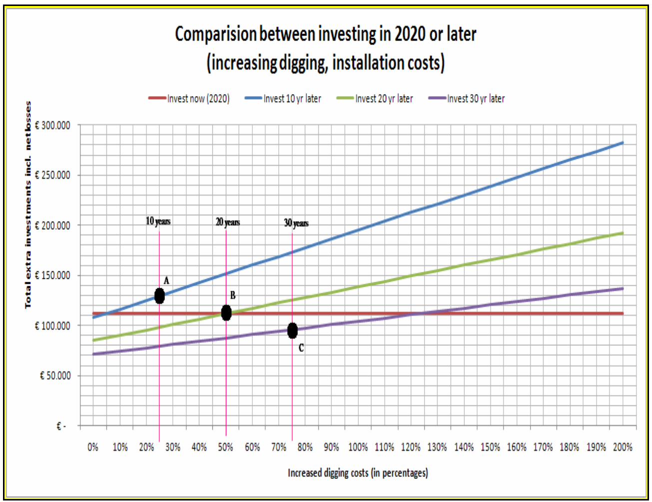

Figure 2: Comparison between different strategies

CONCLUSION

In new residential neighborhoods, the scope of this project, especially electric vehicles, photovoltaic panels and heat pumps are expected.
The demand for the electric heat pumps and the electric vehicles have a great impact on the low voltage networks. Two different situations have been compared during this project; that is, a *business as usual* network in which these technologies are not being connected and an *adapted grid* in which these technologies are connected based on different penetration levels. At a certain penetration level of the electric heat pumps and the electric vehicles, the *business as usual* network will not be sufficient to cope with the demand. Adaptations to the network will be necessary. The resulting adapted networks lead to higher investments. These investments can be done now, following *strategy 1*, in which no extra material, operation and labor costs are needed for the future. While in the case of *strategy 2*, the same investments will be done in the future, and in this case the material and labor costs are assumed to be higher.
This results in a graph in which the total investment costs for both strategies are shown for the situation of 30 dwellings. The resulting graph indicates that the results differ for the moment of postponement. In case the investments are postponed 10 years, then an increase of 5% in digging costs would make it cheaper to invest now. This situation is different in case of investing in 20 or 30 years, in which a 50% and 120% increase in digging costs will make it worthwhile to invest following *strategy 1* (invest now). Based on the assumptions from CBS, it can be stated that following *strategy 2* would be the best option if the investments would be needed over 20 or 30 years.
Now, the answer to the research question can be given based on the assumptions as made during this project. Investing now (*strategy 1*) is cheaper if the investments would be needed over just 10 years. If the investments would be needed over 20 or 30 years, then it is cheaper to postpone the investments (*strategy 2*). Taking the certainty aspect into account, it is advisable to postpone the investment to a point in which more information is available. As it is expected that the investigated penetration levels of new technologies will not be reached within the next 10 years, Enexis has decided to not profoundly change its low voltage network design guidelines. Of course, developments in the relevant areas will be followed closely in order to reevaluate this point of view when necessary.

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