UNLOCKING THE HIDDEN POTENTIAL OF ELECTRICITY DISTRIBUTION GRIDS

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ABSTRACT

For the grid, electric vehicles can be seen as flexible loads since they stand still for at least 90% of the time. The coupling of these flexible loads to the grid can bring advantages for the power system. However, to connect electric cars enough capacity is needed. Already existing capacity might be made available for this extra load by using the flexibility of the electric vehicles and controlling them well. This paper describes an analysis of the existing capacity of the distribution grid of Enexis B.V. which might become available for flexible loads if they are coupled to the grid in an intelligent way. The available capacity of a part of the distribution grid owned and operated by Enexis B.V. is estimated, based on measured data. Further, it is described how this capacity can be used by flexible loads. It is also briefly discussed how this can be facilitated by the introduction of the so-called ‘Mobile Smart Grid’, which includes secondary systems to control the load.

INTRODUCTION

Road transport, equipped with conventional combustion engines, is responsible for a significant share of the total of CO₂-emissions and pollutes cities with fine dust. On the opposite, electric driving is (at least locally) clean and also decreases CO₂-emissions through the high efficiency of power plants compared to combustion engines. Including all energy losses from resource to road, the efficiency of an electric car loaded with conventionally generated electricity is significantly better than efficiency of a conventional car [1-2]. Just as with a lot of other industrial processes, electricity is the ideal intermediate between the specific energy needs and the energy sources available. Besides this, electric driving brings another benefit. It adds a large flexible load to the electrical system which is advantageous. The depletion of fossil fuel reserves urges for other energy resources. However, the characteristics and especially the intermittency of many of the more renewable resources (e.g. wind power, PV) make the optimal use of these resources rather difficult and hampers their integration in the power system [3]. By connecting electric vehicles to the grid, these can be used as flexible loads to even out fluctuating infeed. This would support a high penetration of intermittent and fluctuating renewables [4-6].

The synergy between electric driving and renewables is found by coupling them through the electricity grid. Electric vehicles need to be charged and may provide storage capacity. This opens also the opportunity to transfer much more energy with the capacity of the existing grid: the hidden potential of the grid can be unlocked. When managed in an intelligent way, it is possible for the grid to cope with the extra energy consumption of electric cars and the fluctuating production of renewables in an optimised way [7].

To make this synergy possible the distribution grids
1. must have sufficient capacity for the additional electricity transport
2. and must include the required secondary systems for communication and control.

In this paper, an analysis is made of the existing capacity of the distribution grid of Enexis which might be used better with flexible loads if they are coupled to the grid in an intelligent way. First, the use of available capacity of a part of the distribution grid of Enexis is analysed, based on measured data. Included in the analysis are the medium voltage (MV) transmission and distribution cables and the MV/LV-transformers which transform the voltage from the medium voltage to the low voltage (LV) level. It is then described how this capacity can be used by flexible loads. Finally, it is briefly discussed how this can be facilitated by the introduction of the so-called ‘Mobile Smart Grid’, which includes secondary systems to control the load.

ANALYSIS USE OF AVAILABLE CAPACITY

Before analysing the use of the capacity of the distribution grid of Enexis the topology and operation of the networks are shortly described and it is put forward how the capacities of the MV-cables at Enexis are determined.

Topography and Operation of MV-Networks

The typical topology of MV-networks in The Netherlands is depicted in Figure 1. A MV-network is fed by a (regional) transmission network through a high voltage/medium voltage (HV/MV) transforming substation. Typical primary voltages of HV/MV-transformers in The Netherlands are 220 kV, 150 kV, 110 kV or 50 kV; typical secondary voltages are 25 kV, 20 kV or 10 kV. MV-transmission can be carried out either at the same voltage as MV-distribution, or at a higher voltage (e.g. MV-transmission at 20 or 10 kV and MV-distribution at 10 kV or 3 kV respectively). MV-distribution feeders are generally operated as two half rings which can be connected somewhere.
In Figure 1, MV-networks with and without MV-transmission are depicted schematically in their most straightforward form. More complex variations frequently occur, in which for instance a MV/MV-substation is connected to several other MV/MV-substations. Besides, many MV-installations at HV/MV-substations feed both MV-transmission networks and MV-distribution feeders and not all distribution feeders feature the pure ring shape. MV-transmission networks normally meet the (n-1) criterion, which means that when all (parallel) cable bundle circuits are in operation, every cable circuit in the bundle can be lost without causing an overload of any other cable and without any interruption of supply. Meeting the (n-1) criterion also facilitates maintenance, as one circuit can be taken out of service for carrying out maintenance.

**Capacities of MV-Cables**

At Enexis, the actual capacities of the cables are determined with the following formula:

\[ I_{max, equal\_loading} = I_{nom} \times P \times T \times D \]

in which \( I_{max, equal\_loading} \) is the peak current that may occur in (n-1) situations when the cables in the bundle are equally loaded. \( I_{nom} \) is the nominal cable loading. \( P \) is a correction factor for the thermal influence of parallel cables and the thermal resistance of the soil type. \( T \) is a correction for the soil temperature, which is only applied in case of MV-transmission cables. \( D \) is a factor to incorporate the thermal dynamics of the cable; this factor is determined by the loading of the cable during (n-1) situations in the grid [9]. When the cables are continuously loaded \( D=1 \) and the capacities should be corrected with the factors \( P \) and \( T \). To give an idea of the size of these factors it can be noted that at Enexis, the applied product of the factors \( P \) and \( T \) for distribution cables is 0.92 and 0.93 for XLPE and PILC-cables respectively (in normal soil).

**MV-Networks in the province Limburg**

The capacity in the distribution networks (MV-transmission and -distribution) of the province Limburg in The Netherlands is analysed. This region comprises one fifth of the total distribution networks which are operated by Enexis. In this region Enexis owns and operates 29 HV/MV-substations. No MV/MV-transformers are applied in the MV-networks, while both the transmission and distribution cables in these networks are operated on a 10 kV voltage level.

**MV-Transmission**

The average load profile of 69 MV-transmission cables in the province Limburg on the day in 2007 with the highest demand (12-12-2007) and the average capacity of these cables are shown in Figure 2. The capacity of the cables is based on the nominal cable loading \( I_{nom} \) and includes differences between Paper Insulated Lead Covered (PILC) and Cross Linked Poly Ethylene (XLPE) cables and aluminium and copper cables. To determine the capacity, it is assumed that the cables are continuously loaded, which is a conservative assumption.

The grey area in Figure 2 shows that 64% of the total capacity of the MV-transmission cables is not used in normal operation. This is mainly because of the (n-1) criterion applied in the design (when a fault occurs, a part of the capacity is needed to meet this criterion) and a conservative estimation of the simultaneity of peak loads. Moreover the networks are laid out for a foreseeable future loading. In reality the available capacity of the cables must be multiplied with the factors \( P \) and \( T \) and will be less than shown in Figure 2 where only \( I_{nom} \) is used.

**MV-Distribution**

As for the transmission cables, an average load profile and capacity of MV-distribution cables which are fed through transmission cables, are determined and shown in Figure 3. It is based on data of 147 distribution cables. Again, the
capacity of the cables is based on the nominal cable loading \( I_{nom} \), presuming continuous loading and does not include any correction factors. The grey area shows that in comparison with transmission cables an even higher percentage of the capacity is not used in normal operation. This is because the networks are mostly designed to be operated in two half rings. When a fault occurs, one part of the ring can be fed through the other side of the ring by closing a net opening (see Figure 1). Therefore, extra capacity margin is needed.

It seems that quite some capacity is available to transport extra energy in as well the transmission cables as in the distribution cables which are fed by the transmission cables, as long as no faults occur. Subsequently, it is interesting to know if the capacities of the distribution cables further in the distribution network (besides the distribution cables that are fed by the transmission cables) and the MV/LV-transformers loaded by these cables are sufficient to be loaded with extra energy. To analyse this, some loading calculations are done for one of the distribution networks in Limburg.

Three loading situations are simulated for a MV-network which is fed through a HV/MV-substation and which comprises 228 cables and 187 MV/LV-transformers. The three situations are:

1. **Normal operation.** In this case it is presumed that households have a dynamic load profile, using on the average 70% of the capacity needed for peak demand. For industry a more continuous load profile is applied.
2. **Continuous loading of cables and transformers.** The maximum load is the same as the peak load in situation 1, but in general more energy can be transported while the load is continuous over the day.
3. **Also continuous loading of cables and transformers, but in this case 50% of the extra available capacity is used, e.g. by electric vehicles.** It is assumed that the added load is equally spread over the network as the load in situation 1.

Figures 4 and 5 show that in situation 1 just in case of a few cables and transformers the peak current exceeds the nominal, continuously allowable current. Due to the relatively long thermal time constants this is currently no problem.

For situation 3, Figures 4 and 5 show that the current in 14 of the 228 cables and in 88 of the 187 transformers exceeds the nominal, continuously allowable current. Therefore, to use the surplus grid capacity as shown in Figure 2 some of these MV-cables and MV/LV-transformers must be upgraded. But particularly for MV/LV-transformers, the financial consequences of this are limited.

**MAKING USE OF THE HIDDEN POTENTIAL**

A part of the hidden potential in the existing grid can be made available for flexible loads. Electric cars are flexible, non-critical loads which may be disconnected from the network when needed. To optimally use the capacity, these loads should be coupled to the grid in an intelligent way. A concept for a control strategy to realise this is discussed in this section.

**Loading Electric Vehicles**

If flexible loads, as for example electric vehicles, could be controlled is such a way that the load is continuous throughout the day, the capacity of the grid can be used more efficiently and more energy can be transported. The electric cars can be loaded during off-peak load periods when the demand is low. In this way, the growing electricity demand can be sufficed with only a limited need for investments to expand the grid. This is in contrast with
the design of the existing grid, which is based on the peak load. In this way, flexible loads bring the opportunity to use the extra energy capacity which is already available in the existing grid.

The Mobile Smart Grid
To be able to use the hidden potential for electric vehicles and intermittent renewable energy sources while avoiding overloading, a control strategy is needed. Therefore, Enexis is planning to introduce the ‘Mobile Smart Grid’ concept. This concept includes data collection from the flexible loads, on basis of which a loading schedule can be determined taking into account customer preferences, the local grid capacity and the actual and forecasted availability of electricity. An adequate communication structure, e.g., the internet, must support the flow of information needed for intelligent charging of electric cars, i.e. adjusting the loads to the fluctuating infeed at the distribution network (decentralised generation), without the car owner experiencing any inconveniences. The loading schedules of the electric vehicles can be adjusted when more electricity becomes available or when service interruptions occur. It should also be possible to disconnect the electric vehicles in case of emergencies in the transmission network in order to prevent interruptions. In this way, the (n-1) principle of the transmission network is still guaranteed and the reliability of other customers and appliances is not affected negatively by the Mobile Smart Grid approach.

CONCLUSIONS
A closer look into the existing capacity in the grid of Enexis is described in this paper. An analysis of a part of the grid showed that 64% of the capacity in medium voltage transmission cables is available to transport extra energy and an even higher percentage is available in the medium voltage distribution cables fed by these transmission cables. It should be noted however, that the capacities are less when corrected with factors for thermal resistance of the soil, thermal influence of parallel cables and soil temperature. Also, it should be taken into account that there is some capacity planned for future loading. Still, a part of the existing capacity can be used for flexible loads without the need for investment to expand the grid.

If 50% of this existing capacity to transport energy is used, load calculations for a medium voltage distribution network showed that some cables and a larger part of the MV/LV-transformers need to be upgraded.

To use this extra available capacity for flexible loads such as electric cars, the flexible loads must be controlled well. This can be done by the ‘Mobile Smart Grid’ concept. This concept will also have the intelligence to decouple the electric vehicles to maintain the (n-1) principle.

This paper gives a first insight into the existing capacity of the distribution grid of Enexis. It seems that a hidden potential is available. To get a better insight in this hidden potential and the possibilities to use it, it will be useful to analyse the whole grid of Enexis in more depth. Besides, the Mobile Smart Grid concept must and will be developed further to be able to make optimal use of the existing capacity.

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REFERENCES