Network calculation documentation

Author: Chris Laumans;

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# Introduction

This document is intended as background information for the network calculation in the ETM. It explains the basics as well as how to test, maintain, modify, and improve the calculation. To understand and use this document some knowledge is required of GQL. In this section background of the project and some useful definitions are given.

## Background

The results of the Network Impact calculation are two charts on the front end of the model: ‘Required additional infrastructure investments’ and ‘Annual infrastructure costs’. The first chart shows the total additional investment required in the electricity grid for certain scenarios and the second shows annual costs including operation and maintenance costs and interest.

The Network Impact calculation was added to the ETM in the summer of 2010 as a project for Netbeheer Nederland. Netbeheer Nederland was interested in the calculation to support their report called ‘Net voor de toekomst’. This document was published in February 2011 and explains the so-called, network operator’s dilemma: In several future energy scenarios investments will be required in the electricity grid. Since it is impossible to predict the future the exact investments are unknown, however, network operators are faced with the dilemma that they can either invest now in an unknown outcome or wait and thereby potentially delay the energy transition they are legally required to facilitate.

The calculation was created by working in cooperation with four network operators: TenneT, Alliander, Enexis, and Stedin. Together with the network operators a model was created of the Dutch electricity grid and the necessary input parameters for the model were determined. Using this model the ETM can calculate the network impact based on the user built scenario. A basic overview of this model will be given in a following section.

Currently the Network Impact calculation in the ETM only works for the Netherlands. To date no research has been done to implement the calculation for other countries or for provinces.

## Definitions and terminology

Throughout this document several terms will be used that at first sight might not be clear to the reader. For clarity purposes these terms are explained here.

**Capacity (MVA)** –

Cables and transformers have a maximum capacity; they can only carry so much electricity at any instant. Capacity is expressed in Volt-Ampere (VA), the units for complex power. For the network calculation in the ETM, it is assumed that the complex power (MVA) is equal to the real power (MW) although in reality the complex power is slightly larger than the real power.

**Converter/Technology** –

In the ETM a converter basically means a technology. It is called a converter because it converts energy from one form to another (for example a solar panel converts solar energy into electricity). In this document the terms converter and technology are used interchangeably although there is a slight distinction. The term converter is chosen in the context of the ETM (i.e. when referring to writing queries or adding attributes) while technology is used in the context of explaining the calculation.

**(Electricity) Grid level –**

The Dutch (and other) electricity grids consist of multiple voltage levels. In reference to this the most often-encountered nomenclature for voltage levels are low, medium, and high. At the low voltage level households and small businesses are found, this voltage level is intended entirely for distribution. At the highest voltage level all central electricity production is found along with interconnections with other countries. At this highest level the electricity grid is intended solely for the transport of electricity. In between the high and low voltage levels is the found the medium voltage level which serves both the functions of transport and distribution of electricity. Decentralized electricity production is often found at the medium voltage level and sometimes is transported over long distances. Also, larger electricity consumers, such as agricultural or industrial users might be found at this level.

**(Network) Impact** –

The required network expansion is determined by finding the required network *capacity* (MVA) necessary to meet the future scenario. A higher impact therefore means a larger capacity of cables and transformers is required in a given scenario. In the ETM impact is often expressed in Euro by multiplying the required capacity by the cost coefficients (EUR/MVA) for each grid level.

**Peak load** –

Peak load refers to the maximum load that occurs in a given period of time. In the ETM four periods of time are considered: summer day, summer evening, winter day, and winter evening. Depending on the technology and how it is used, the peak load values vary for each period.

*Example*: Solar panels will have their maximum peak load during the early afternoon of a summer day. During a summer evening or a winter day solar panels might still produce electricity, but the peak load for these time periods will be lower.

For network impact calculations peak loads are of interest because cables and transformers have a maximum capacity and as long as the maximum load is lower than the available capacity no network expansion is required (i.e. the volume of energy flow over a period of time is irrelevant).

**Peak load delta** –

The change in the peak load is called the peak load delta. The network impact calculation is a comparison calculation; the required network expansion is determined by how much the peak load changes with respect to the present situation.

**Simultaneousness** –

Each technology has a certain peak load; however these peak loads do not always occur at the same time. Therefore to describe the overlap between peak loads the term simultaneousness is used. Simultaneousness is the probability that two peaks fall in the same time.

Simultaneousness has a maximum value of 100%, **although in the ETM larger values are used to reflect the results of this author’s MSc thesis** (See Appendix B for more information about this). Furthermore, in the ETM simultaneousness are defined as negative for electricity supply technologies.

*Example:*Electric vehicles have a simultaneousness of 19% in the summer and winter evening periods. This is because not everyone will charge his or her electric vehicles at the same time. Heat pumps on the other hand have a simultaneousness of nearly 100%; this is because it is certain that on a very cold day all the heat pumps in a certain area will be on at the same time.

##

# Network calculation basics

The network calculation is quite different from the other calculations in the ETM as it is a ‘power’ or ‘load’ calculation rather than an energy calculation. For this reason the calculation is contained in queries rather than as part of the graph.

In this section the theory of the calculation is explained in three parts. First, the goal of the calculation is explained. Second, it is explained how the electricity network is modelled in the ETM. Finally, an explanation of how the calculation works is given.

Using the theory presented in this chapter the next chapter will provide more details about the exact modelling of the calculation in the ETM.

## Goal of the calculation

The network calculation was implemented in the ETM to be able to calculate the required **additional investments** in the **electricity network** for **future energy technologies**. A few words of the previous sentence are important to understanding what the calculation does and the reasoning behind the calculation:

*Additional investments* – The calculation only focuses on the extra investments required due to changes in the scenario between the present and the future year. The electricity network in the Netherlands has a certain amount of room to accommodate growth of electricity demand (i.e. the available capacity of the networks is currently greater than the required capacity). In the calculation investments will be required only if the user-built scenario in the ETM exceeds this available capacity. For this reason the calculation focuses very much on the ‘delta’ between present and future in the ETM user-built scenarios.

*Electricity network* – As will be explained in the following section the electricity network consists of different voltage levels and it is of interest to consider each separately in this calculation. The calculation is focused on the electricity network and therefore will only consider electricity technologies.

*Future energy technologies –*The calculation focuses in particular on the impact of new technologies (such as electric vehicles and heat pumps) on the electricity network. The reason for doing this is that these technologies could potentially have a very large impact on the network and furthermore the impacts of these technologies are the most difficult to predict for the network operators.

The impacts of already abundant technologies such as televisions and washing machines are easier to predict, since network operators have a lot of historical data for these. As these and other similar technologies already exist in large quantities in most households and buildings, their impact on the network has already been accounted for and the focus of the calculation is on new technologies.

## Model of the electricity network

Very simply stated, the Dutch electricity grid can be seen as three voltage levels: High, medium, and low. The components of the electricity grid are cables and transformers. Electricity cables are used to transport electricity over long distances and to distribute it to the customers. Transformers are found both between and within the voltage levels.

In reality the electricity grid is a hive of interconnected cables and transformers spread throughout the country. The ETM simplifies the network and reduces it to 6 components that are linearly connected. The following figure shows a schematic of the Dutch electricity grid and the model considered by the ETM.



Figure 1: The model of the electricity grid used in the ETM is a simplified version of the actual electricity grid consisting of fewer components

The most important difference between the actual grid and the model used in the ETM is that the ETM model consists of only one component per level instead of taking into account the thousands of cables and transformers that compose the actual grid and the fact that these are geographically scattered across the country in a non-uniform way.

As can be seen in the figure the network has been simplified to two transformers and four cables. The transformers work between the different voltage levels and the cables transport and distribute the electricity. At the higher voltage levels cables mainly transport electricity (i.e. move it from point A to B). At lower voltage levels cables mainly distribute electricity (i.e. move it from one centralized point to various end points such as the households and industrial consumers). At the medium voltage level there is no clear distinction and both types of cable are found, for this reason the two types are considered in the model.

## Connection of technologies and sectors to the electricity network

The ETM model of the electricity network assumes that technologies and sectors can be connected at 4 of the 6 network levels. Where a technology or sector is found, depends on the load (power) of the sector or technology. These power demarcations are defined by the Energiekamer in a document called the “Netcode” and are summarized below along with the corresponding ETM network.

Table 1: Guidelines to determine where technologies belong in the electricity grid

|  |  |  |  |
| --- | --- | --- | --- |
| Power[[1]](#footnote-1) | Network | Description | Examples |
| < 0.3 MVA | LV network | Technologies that are used individually in households and buildings | Solar panels, micro CHP, electric vehicles, heat pumps, electric water boiler |
| 0.3 – 3 MVA | MV-distribution network | Technologies used in industry, agriculture, and collective household/building technologies | Collective CHPs and heat pumps, industry CHP, agriculture heat pump with TS, etc. |
| 3 – 50 MVA | HV/MV transformer | Decentral production technologies of max 50 MW | Wind inland and coastal, hydro river, central solar PV, etc. |
| > 50 MVA | HV network | Central production technologies | Wind offshore, coal power plants, nuclear plants, etc. |

A few important notes concerning the table above:

* No technologies or sectors are found at the MV-transport network. This network is exclusively used to transport electricity between two points therefore no users are found here.
* Some decentralized electricity production technologies, such as inland wind turbines, are found at the HV/MV transformer. In reality these are attached via a cable to the transformers, however these technologies each have their own cable with sufficient capacity and hence it is not necessary to consider these cables. For the purpose of calculating network impact it is therefore assumed that these technologies are connected directly to the transformer.
* Industry, agriculture, and the utility sectors are attached to the MV-distribution network although in reality they can be found at various voltage levels depending on the size of the users. Since in the ETM no distinction is made between, for example, large or small industry consumers it is assumed that all users are of the same type and hence found at the same level.

## Calculating network impact

The network impact is calculated for each of the six components defined in the previous sections. The investments required in extra network infrastructure are determined by considering the peak loads and the network attachment locations of new electricity technologies in the ETM.

Two calculations are used to determine the network impact. One calculation is used for the impact on the LV network up to the HV/MV transformer and a separate calculation is used for the impact on the HV network.

The reason a different calculation is used for the HV network is that the terms “available capacity” and “simultaneousness” are less applicable at this level. At the HV network level only central electricity production technologies are found, and for these network investments are unavoidable: building a new power plant requires adding network capacity.

At lower voltage levels, on the other hand, it is not necessarily the case that the addition of new technologies will require network investments. The required investments will depend on the available capacity on the network, the loads of the technologies, and the simultaneousness of the technologies. At the lower levels therefore a different calculation is used to take this into account.

#### Network impact - LV network up to HV/MV transformer

To determine the impact on the first 5 network components (the LV network up to the HV/MV transformer), the calculation assumes that the networks are connected in linear fashion and that all electricity produced or consumed at the lower levels flows to or comes from the higher levels. This implies that for each level it is necessary to consider not only the technologies found at that specific level, but also to consider the technologies at lower levels. The following figure depicts this:

 

Figure 2: The network components are connected linearly and to determine the impact at higher levels, not only is the impact due to technologies at that level taken into account, but also that of lower levels

For example, Figure 2 shows that to determine the impact on the MV-distribution network, the ETM needs to consider not only the CHPs and other technologies in the industry sector, but also the heat pumps and electric vehicles found in households at the lowest level.

What is not illustrated in Figure 2 are the simultaneousnesses and the directionality of the loads (i.e. supply or demand). In the ETM model of the electricity network the network impact is calculated for four time periods and the largest one determines the required network investment. A simple example is given in Table 2 below.

Table 2 shows an example considering four technologies: electric vehicles, solar PV panels, heat pumps and CHPs in buildings. The first three technologies are all found in households and are hence attached to the low voltage network. The buildings CHP is found at the MV-distribution network.

In the example the network impact at the MV-distribution network is determined. To do this the impact of each individual technology is determined, based on its peak load and simultaneousness during the four considered time periods. Additionally, to determine the total peak load at the MV-distribution level the simultaneousness from lower to higher voltage levels is also taken into account (in this case the simultaneousness from the LV-network to the MV/LV transformer is 70% and from the MV/LV transformer to the MV-distribution network 70% once more). A negative simultaneousness value indicates electricity production rather than consumption.

In the example several things are observed:

* The largest peak load occurs during the winter evening.
* During the summer evening and especially summer day the total peak load of the considered technologies is negative due to the solar panels.
* Low simultaneousness values work to reduce the network loads and electricity production technologies compensate for electricity consumption technologies if peaks occur simultaneously.
* If the peak load were to be determined for the LV-network instead of for the MV-distribution network, then the buildings CHPs as well as the simultaneousnesses to higher voltage levels would not be considered and the peak load in the winter evening would be even higher. (For the LV-network the load would be based on electric vehicles and heat pumps and would be 30kW\*19% + 45kW\*100% = 50.7kW)

Table 2: Example calculation to determine network peak load. All values are illustrative.

|  |
| --- |
| Maximum peak load on MV-D network |
|   | Attached to | Peak load (kW) | Simultaneousness of technology (%) | Simultaneousness to MV-D net (%) | Total peak load (kW) | Maximum peak load (kW) |
| Summer day |   |   |   |   |   | **21.8** |
| Electric vehicles | LV-net | 30 | 0% | 70%\*70% | 0.0 |
| Solar PV panels | LV-net | 15 | -100% | 70%\*70% | -7.4 |
| Heat pumps | LV-net | 100 | 0% | 70%\*70% | 0.0 |
| Buildings CHP | MV-D net | 30 | 0% | 100% | 0.0 |
|   |  |  |  |  | **-7.4** |
| Summer evening |   |   |   |   |   |
| Electric vehicles | LV-net | 30 | 19% | 70%\*70% | 2.8 |
| Solar PV panels | LV-net | 15 | -20% | 70%\*70% | -2.9 |
| Heat pumps | LV-net | 100 | 0% | 70%\*70% | 0.0 |
| Buildings CHP | MV-D net | 30 | 0% | 100% | 0.0 |
|   |  |  |  |  | **-0.1** |
| Winter day |   |   |   |   |   |
| Electric vehicles | LV-net | 30 | 0% | 70%\*70% | 0.0 |
| Solar PV panels | LV-net | 15 | -20% | 70%\*70% | -2.9 |
| Heat pumps | LV-net | 100 | 100% | 70%\*70% | 49.0 |
| Buildings CHP | MV-D net | 30 | -100% | 100% | -30.0 |
|   |  |  |  |  | **16.1** |
| Winter evening |   |   |   |   |   |
| Electric vehicles | LV-net | 30 | 19% | 70%\*70% | 2.8 |
| Solar PV panels | LV-net | 15 | 0% | 70%\*70% | 0.0 |
| Heat pumps | LV-net | 45 | 100% | 70%\*70% | 49.0 |
| Buildings CHP | MV-D net | 30 | -100% | 100% | -30.0 |
|   |   |   |   |   | **21.8** |

Once the maximum peak load has been calculated for any particular network component as illustrated in Table 2 the next step is to calculate the network impact. Calculating the network impact is done by comparing the required capacity with the available capacity. An example is given in Table 3.

Table 3: Example calculation of network impact

|  |  |
| --- | --- |
| Maximum peak load MV-D network (kW) | 21.8 |
| Available MV-D network capacity (kW) | 30.0 |
| Of which used MV-D network capacity (kW) | 18.2 |
| Required new MV-D network capacity (kW) | 21.8 + 18.2 – 30.0 = 10.0 |
| Cost coefficient of MV-D network (EUR/kW) | 5.0 |
| Required MV-D network investments (EUR) | 10.0\*5.0 = 50.0 |

The required capacity is equal to the used capacity plus capacity from new technologies (i.e. due to the calculated peak load). If the required capacity is greater than the available capacity then network investments are required. The investment costs are determined by multiplying the required new capacity by cost coefficients supplies by the grid operators.

The calculations for the other network components work in a similar manner. The only difference being the values for parameters of the networks (capacity used, capacity available, cost coefficient) and the technologies connected to the networks.

If the peak load is negative (in the case of large shares of electricity production from new technologies), the peak load will reduce the required network capacity. In such cases, network investments are required only if the total peak load is of such large magnitude that the absolute value of the newly required capacity is greater than the available capacity. The following table shows how grid expansion is needed to accommodate electricity supply rather than demand.

Table 4: Example calculation of network impact with negative peak loads

|  |  |
| --- | --- |
| Maximum peak load MV-D network (kW) | -62.2 |
| Available MV-D network capacity (kW) | 30.0 |
| Of which used MV-D network capacity (kW) | 18.2 |
| Required new MV-D network capacity (kW) | ABS(-62.2 + 18.2) – 30.0 = 14.0 |
| Cost coefficient of MV-D network (EUR/kW) | 5.0 |
| Required MV-D network investments (EUR) | 14.0\*5.0 = 70.0 |

#### Network impact – HV network

For the impact on the HV network a different method is used. The required network investments are calculated based on the newly installed centralized and decentralized electricity production capacity. Depending on the installed capacity the impact is determined with use of a few rules of thumb provided by TenneT:

* On the HV network, 1600MW can be added without requiring additional investments.
* If the newly installed capacity is higher than 1600MW, then the costs for network expansion are 20% of the installed capacity. For example: If 2000MW is installed, the network costs are 400MEuro.
* Additionally, if the total decentral capacity is larger than 30GW the costs are 25% instead 20%.
* For import and export the available capacity is 4200MW. If the total import or export is greater than this value, the extra capacity required is determined by considering interconnectors as power plants with a capacity of 400MW and a capacity factor of 62%.
* Additional costs for wind offshore are also considered. These costs are 1.2 million euro per turbine after the first 3000MW.

# Network calculation in the ETM

In the previous chapter the theory of the network calculation was explained. This chapter describes the details of how the calculation is modeled in the ETM. Four sections describe the input, calculation, output, and assumptions.

## Network calculation input

The network impact calculation requires parameters as input for the electricity network components and for the electricity technologies connected to the network.

### Required input for network components

Table 5 and Table 6 describe the required parameters for the electricity network components. The source of the parameters is listed as well as the location where the parameters are found in the ETM.

### Required input for technologies

For the technologies attached to the electricity network the following parameters are required: location attached to the network and simultaneousness values. Furthermore, an additional parameter is required, “peak load units present”, however this is calculated automatically by the InputExcel. Table 7 includes information about the parameters required and where they are found.

Table 5: Parameters of electricity network components, LV network through HV/MV transformer

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Parameter** | **Units** | **Description** | **Source** | **Input currently found in** |
| Total available capacity on network | MVA | The typical capacity per cable/transformer multiplied with an estimate of the number of cables/transformers in the country.  | Provided by network operators during project | InputExcel, sheet Network Properties |
| Total used capacity on network | MVA | The fraction of the available capacity that is occupied by the existing electricity demand.  | Provided by network operators during project | InputExcel, sheet Network Properties |
| Cost of network expansion | EUR/MVA | The costs to add new network infrastructure. This includes costs such as digging up streets to lay new cables. | Provided by network operators during project | InputExcel, sheet Network Properties |
| Simultaneousness to higher network level | % | Used to describe the effect that the simultaneousness of a technology converge to a minimum as number of users increases  | Provided by network operators and thesis Chris | InputExcel, sheet Network Properties |
| O&M costs of network | EUR/MVA/year | Costs of maintaining the electricity network per year. | Year reports of network operators | InputExcel, sheet Network Properties |
| Current annual costs of electricity and gas network | EUR/year | This parameter is not used in any calculations, it is only used for the “Annual infrastructure costs chart” | Year reports of network operators | Area data:annual\_infrastructure\_cost\_gasannual\_infrastructure\_cost\_electricity |
| Lifetime of network | Year | The lifetime of the electricity networks (40 years) | Provided by network operators during project | InputExcel, sheet Cost Other. Parameter: technical\_lifetime |
| Discount rate of network | % | Weighted average cost of capital (5.5%) | Provided by network operators during project | InputExcel, sheet Cost Other. Parameter: wacc |

Table 6: Parameters of electricity network components, HV-network

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Parameter** | **Units** | **Description** | **Source** | **Input found in** |
| Capacity buffer | MVA | Capacity which can be added to the HV-network without additional investments  | Provided by TenneT during project | Area data: capacity\_buffer\_in\_mj\_s |
| Decentral capacity buffer | MVA | Decentralized electricity capacity buffer before which costs of network investments increase | Provided by TenneT during project | Area data: capacity\_buffer\_decentral\_in\_mj\_s |
| Cost coefficient of network expansion, below decentral capacity buffer | MEur/MVA | Rule of thumb describing the investment costs as a fraction of the newly installed centralized and decentralized electricity production capacity  | Provided by TenneT during project | Query: total\_investment\_costs\_of\_hv\_net **🡨 should not be here!** |
| Cost coefficient of network expansion, above decentral capacity buffer | MEur/MVA | Rule of thumb describing the investment costs as a fraction of the newly installed decentralized electricity production capacity once the decentral capacity buffer has been reached.  | Provided by TenneT during project | Query: total\_investment\_costs\_of\_hv\_net**🡨 should not be here!** |
| Operation and maintenance costs of network | EUR/MVA/year | Costs of maintaining the electricity network per year. | TenneT year report | InputExcel, sheet Network Properties |
| Cost of network infrastructure for offshore wind turbines  | MEur/turbine | Costs of the cables for offshore wind turbines. | Provided by TenneT during project and Net voor de toekomst report | Query: yearly\_investment\_costs\_of\_hv\_net\_wind\_offshore**🡨 should not be here!** |

Table 7: Electricity technology parameters

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Parameter** | **Units** | **Description** | **Source** | **Input found in** |
| Voltage level technology is connected to | - | Electricity technologies are connected to 1 of 4 voltage levels: LV-network, MV-D network, HV/MV transformer, or HV-network.See Table 1 for more information. | Determined in cooperation with network operators and based on Netcode document | Query groups are used to define which technologies are connected where:high\_voltage\_electricity\_productionnetwork\_hv\_mv\_trafo\_convertersnetwork\_mv\_d\_net\_convertersnetwork\_lv\_net\_converters |
| Simult\_sd, Simult\_se, Simult\_wd, Simult\_we | % | Simultaneousness values for technologies during the 4 time periods. Summer and winter day and evening. | Provided by network operators during project and thesis Chris Laumans | InputExcel, sheet Peakload |
| Peak load units present | # | The peak load units present are equal to the number of units for the present year. These are calculated and nothing needs to be specified for this. |  | Calculated in InputExcel in sheet Peakload |

## Network calculation gqueries

In a previous section a description and examples were given of how the network calculation works. In the ETM the calculations are included as `gqueries` (short for ‘graph queries’). In this section the gqueries will be explained.

All the gqueries used by the network calculation are found in the following folder:

Etsource/gqueries/modules/network

Within this folder the queries are sorted into folders. The most important gqueries are found in the network\_impact\_calculations and network\_cost\_calculations folders.

Table 8: Folders with gqueries in the network calculation

|  |  |
| --- | --- |
| **Folder name** | **Description** |
| converter\_groups | Contains 4 gqueries used to define which technologies are connected to which network components. In these queries converters can be added to the calculation by adding them to the relevant query group. |
| network\_impact\_calculations | Contains 6 subfolders, one for each network component. For each network component the network impact is determined (i.e. the amount of additional capacity required per network level). Below some of these queries will be explained. |
| network\_cost\_calculations | In this folder the network impacts are converted to costs based on the cost coefficients of network expansion of the network components. |
| Popup | This folder contains some queries that check whether network investments are required which are used for the “grid investment needed” popup in the ETM interface. |
| required\_capacity\_chart | Contains queries that are currently unused but can be used for a new chart. The chart is described here: <https://github.com/dennisschoenmakers/etmodel/issues/488> |

### Network impact calculation queries

The folder network\_impact\_calculations contains 6 subfolders, one for each network component. The queries within the folders for the LV-network through the HV/MV transformer are all of a similar structure. The queries for the HV-network are different because of the different calculation method. The queries are explained below.

#### Network impact queries – LV-network through HV/MV transformer

For the LV-network up to the HV/MV transformer the queries have a similar structure. For each network component five queries are used to determine the required additional network capacity. Four queries are used to determine the impact during each of the four time periods (summer and winter day and evening), and a fifth is used to determine the maximum impact by comparing the impacts during the four time periods. An example of the logic behind the calculation was given in the previous section in Table 2. In Figure 3 below the most complex of these queries is shown followed by an explanation of the query. Figure 4 shows the fifth query that is used to determine the required additional capacity.



Figure 3: Example query, network impact on the HV/MV transformer during summer evening

Figure 3 shows the query used to calculate the impact on the HV/MV transformer during a summer evening. As has been highlighted the query consists of 5 parts. The calculation works as follows:

* **Part 1** – Calculate the network impact of technologies connected to the LV-network on the HV/MV transformer. This is done in two parts: First calculate the peak load of the technologies based on their simultaneousness and then multiply this by the simultaneousnesses of the network components between the LV-network and the HV/MV transformer (similar to what is shown in Table 2).
* **Part 2** – Calculate the network impact of technologies connected to the MV-distribution network on the HV/MV transformer. This is similar to part 1 with the exception that there are fewer network components between the MV-distribution network and the HV/MV transformer and hence fewer multiplications take place.
* **Part 3** – Calculate the network impact of technologies connected to the HV/MV transformer on the HV/MV transformer. This is again similar to the previous two parts however this last part is the impact of technologies connected to the HV/MV transformer therefore it is not necessary to multiply this by the simultaneousness values of any network components.
* **Part 4** – Calculate the total required network capacity. The total required network capacity is calculated by summing up parts 1-3 along with the current used capacity of the HV/MV network.
* **Part 5** – Take the absolute value of part 4. This is done to remove the directionality of the electricity flow. This part is done as last because it is assumed that the used network capacity is consumption. Therefore parts 1-4 are summed before the absolute value is taken instead of taking the absolute value of parts 1-3 first then adding the used capacity.

The gquery in Figure 3 shows the most complex of its type because it is the highest network level; the lower network levels (for example LV-network) will only have one or two parts instead of parts 1-3 shown above.

Three of the other queries are similar except that the parameter simult\_se is replaced with simult\_sd, simult\_we, or simult\_wd. The 5th remaining query is shown in Figure 4 and is used to determine the required additional capacity.



Figure 4: Example query, required additional capacity for the HV/MV transformer

The query in Figure 4 determined the additional capacity required. This is done by looking at the network impact during the four time periods and comparing it with the available network capacity. The query consists of two parts:

* **Part 1** – Take the maximum of five different values: The network impact during the four periods and the available network capacity. The impact during the four time periods are determined by queries similar to the one shown in Figure 3.
* **Part 2** – Subtract the available network capacity from the maximum value found in part 1. The difference between these two values is the required additional network capacity. If the network impact during the 4 time periods is lower than the available capacity, then this function will return 0 (i.e. no additional capacity required). If the network impact during one of the four time periods is larger than the available capacity, then the function will return the difference between the required and available capacity.

For the other network levels (LV-network through MV-transport network) the queries to determine the required additional capacity are similar.

#### Network impact queries – HV-network

For the HV network different queries are required because the calculation works differently. These queries are simpler than those discussed in the previous section and should be easier to understand. A description of the queries is given below:

Table 9: HV-network impact queries

|  |  |
| --- | --- |
| **Query** | **Description** |
| hv\_net\_delta\_capacity\_central | Calculates the total newly built central electricity production capacity including newly required import/export capacity.This query returns 0 if delta in capacity is negative, this is to prevent the costs calculation from returning negative infrastructure investments. |
| hv\_net\_delta\_capacity\_decentral | Calculates the total newly built decentralized electricity production capacity. |
| hv\_net\_delta\_capacity\_total | Calculates the total newly built electricity production capacity by summing the queries hv\_net\_delta\_capacity\_central and hv\_net\_delta\_capacity\_decentral |
| hv\_net\_capacity\_buffer\_decentral\_check | Checks whether the decentralized electricity production capacity is greater than the available buffer. Located in `capacity\_needed\_calculations` |
| hv\_net\_capacity\_buffer\_total\_check | Checks whether the centralized electricity production capacity is greater than the available buffer. Located in `capacity\_needed\_calculations` folder |

### Network cost queries

In the previous section it was described how the required additional capacity is calculated in gqueries. Following the calculation of the required additional capacity, the network cost queries use the results to determine the costs. There are three types of cost queries; these are similar for all six network components. The three types of cost queries are described in Table 10.

Table 10: Network cost queries

|  |  |
| --- | --- |
| **Query** | **Description** |
| Total\_investment\_costs\_of\_*<network\_component>* | Calculates the total investment costs per network component by multiplying the additional required capacity by the cost coefficient for network expansion. |
| Yearly\_investment\_costs\_of\_*<network\_component>* | Total costs calculated to yearly costs. The yearly costs consist of three parts: cost of capital, cost of depreciation, and O&M costs |
| Operational\_costs\_of\_*<network\_component>* | Calculates the O&M costs of the network components by multiplying the additional required capacity by the O&M costs coefficient. |

## Network calculation output

The output of the network calculation are two charts, both shown in Figure 5.



Figure 5: Network calculation output: Required additional infrastructure investments and annual infrastructure costs chart

The first chart, “Required additional infrastructure investments”, shows the total required investment in each of the six network components. The costs are expressed in billion Euro.

The second chart, “Annual infrastructure costs”, shows same costs but converted to costs per year and grouped per network level (high, medium, and low voltage). The costs are here again expressed in billion Euro. In addition, in this chart are also shown the current yearly costs of the electricity and gas networks for comparative purposes.

Finally, the total yearly costs of the network are also shown in the dashboard total costs.

## Network calculation assumptions

The network calculation uses some assumptions, the most important of which are documented here:

* **Directionality of the electricity flow in the current used network capacity** – As was documented in Table 5, one of the parameters required for the electricity network components is the currently used network capacity. In the network calculation in the ETM it is assumed that this capacity is always in the form of consumption at lower network levels. This implies that for the current situation electricity always flows from higher to lower voltages. This assumption is correct in almost all cases for the lowest voltage levels however at higher voltage levels (such as the HV/MV transformer level) it can become debatable and is situation specific, which is beyond the scope of how the calculation is modeled in the ETM. The directionality of the electricity flow depends on the electricity production and consumption in the neighborhood of the network. In reality the electricity grid consists of thousands of components, some of which have high shares of decentralized production while others have none.

The reason that it has been assumed that the flow is always in the form of consumption at lower levels is because this is very reasonable for the lowest voltage levels and because the quantity of decentralized electricity production in the Netherlands is significantly smaller than the electricity consumption, implying that for most cases this is a correct assumption.

The implications of this assumption are that supplying technologies have less network impact in the ETM than do electricity demand technologies. This is because any electricity supplied to the network first works to compensating the demand.

* **Electricity always flows in one direction** – Accurately modeling the direction of electricity flow is very complex and beyond the possibilities of the ETM, therefore for the network calculation it is assumed that the flow is linear and always in the same direction.

The implications of this assumption is that when for example electricity production capacity is added at the HV/MV transformer level it is impossible to know in which direction it will flow and in the ETM it is assumed to always flow to the HV-network (to the highest voltage level). In reality the electricity production at the HV/MV transformer could flow in both directions depending on where the demand is at any specific time.

As a result of this assumption possible network impact at lower levels due to activities at higher voltage levels is not taken into account.

* **Network impact of “common” technologies not included** – An assumption made at the start of the project was to take only into account the effects of “new” energy technologies on the electricity grid, technologies such as heat pumps, electric vehicles, and solar panels.

This assumption was made because the effects of these technologies are the most difficult for network operators to predict, since these technologies are new and they have quite a different behaviour than most “common” technologies. The “common” technologies, such as lighting, televisions and washing machines already exist in households in large quantities and the electricity use by such technologies is easy to describe using the existing electricity demand profiles available to network operators. The effect of these common technologies on the network has therefore been included in the ‘used capacity’ parameter defined for each network component.

The limitation of this assumption is that significant changes to the “common” scenario are not accounted for. For example, if a sector’s electricity demand increases significantly due to population growth or increased prosperity, the network impact of this is not calculated.

# Adding converters to the network calculation

It is possible to add new converter to the network calculation using the steps described below. It is assumed that the new converter is an electricity technology attached to the network and not a network component (there should no reason to change these). Furthermore, it is assumed that all non-network related converter attributes (such as efficiency and typical capacity) have already been specified for the converter. If both of these assumptions are correct the following steps can be taken to add a new converter to the network calculation.

1. In the inputExcel add the converter to the Peakload sheet by adding the converter id to the first column. The other columns in the sheet should be filled automatically based on vlookup functions using the converter id.
2. Check in particular that a value is returned in column M, “peak\_load\_units\_present”
3. Fill in values for the simult\_sd, simult\_se, simult\_wd, and simult\_we in the same sheet, columns N-Q. These values can be based on one of the following: Values obtained from experts or values of other similar technologies in the peakload sheet.
4. Check that the parameters peak\_load\_units\_present and simults are correctly passed to the other sheets.
5. Run the InputExcel export macro and the xls2yml scripts and push the data to et-source.
6. Add the converter to the relevant converter group query. This should be based on the information in Table 1.

# Testing the network calculation

**Important note**: There is no clear-cut way to test the network calculation for correctness. To be able to test the network calculation it needs to be understood and a feeling for what the expected outcomes are is a necessity. Below some results are given to help obtain a feeling of what the expected outcomes should be.

## Network calculation degradation over time

Because of the nature of the project it is undeniable that the results will slowly deviate with time from the results presented in the next section. The main reasons for the probable deviation is that the network calculation uses two types of data: data specific to the calculation and data not specific to the calculation. The data not specific to the calculation are converter attributes such as typical capacity or electrical efficiencies and these will likely be updated regularly and could change with time. On the other hand the data specific to the calculation is not easy to update and hence will likely remain the same (this type of data was mainly provided to us by the network operators based on their own case studies during the project and is therefore not easily updated). Two examples of likely deviations are given below:

* **Changing existing ETM converter attributes**: Changes to converter attributes such as the typical capacity or electrical efficiency will change the outcome of the network calculation since the calculation uses these attributes. If for example the typical capacity of a converter is increased, then it needs to be made sure that the outcome for the number of units calculation decrease accordingly to reflect this change.
* **Updating data sets and hence updating the start values for sliders**: Updating the data set might result in changes to the start values for certain sliders. This is an issue for the network calculation since the network calculation only looks at the delta between future and present and the calculation assumes that the impact of the ‘present’ is included in the attribute “network used capacity”. This attribute however is not updated along with the data set updates because it is an attribute that is not easily acquired and was provided to us by the network operators during the project. As a result it can be understood that the different components of the network calculation are not updated equally resulting in likely deviations.

## Testing procedure

Before each deploy it is suggested to test the network calculation. Although there is no protocol to test the network calculation the following procedure is recommended:

* The very first test is checking the “Required additional infrastructure investments” chart for the start scenario. This should be empty. If this is not the case the likely cause is a deviation between the peak\_load\_units\_present and the number\_of\_units for the present year. This can be tested in the GQL sandbox with the following query:

TXT\_TABLE(G(electricity\_production),key,peak\_load\_units\_present,number\_of\_units)

When testing this query simply compare the values for the two attributes and see if they deviate from one and another. If this is the case try to identify the cause within the InputExcel in the sheet Peakload.

* There are three saved scenarios that can be tested that were specifically made for the network calculation. The scenario IDs are: 3887, 3893, and 3901. These scenarios can be loaded by going to et-model.com/scenarios/<scenario\_id>. It is possible to do this on both live and beta. When testing these scenarios check the “Required additional infrastructure investments” chart for the following results:

Table 11: Expected outcomes of Required additional infrastructure investments chart of Netbeheer Nederland scenarios for testing

|  |
| --- |
| Expected results of Netbeheer Nederland scenarios (bln Euro)   |
|   | Scenario A | Scenario B | Scenario C |
| Scenario ID | 3887 | 3893 | 3901 |
| LV-networkTotal\_investment\_costs\_of\_lv\_net | 23 | 13 | 60 |
| MV/LV transformerTotal\_investment\_costs\_of\_mv\_lv\_trafo | 5 | 3 | 10 |
| MV-D networkTotal\_investment\_costs\_of\_mv\_d\_net | 2 | 2 | 5 |
| MV-T networkTotal\_investment\_costs\_of\_mv\_t\_net | 6 | 4 | 12 |
| HV/MV transformerTotal\_investment\_costs\_of\_hv\_mv\_trafo | 6 | 5 | 13 |
| HV-networkTotal\_investment\_costs\_of\_hv\_net | 15 | 6 | 13 |
| Total | 57 | 32 | 112 |

* Beyond testing the above scenarios it is also suggested to test individual sliders and their impact on the electricity network. To do this it is suggested to lock the “Required additional infrastructure investments” chart and test certain sliders. In particular household electricity demand technologies such as: Electric heaters, heat pumps, and electric vehicles. These should all have an impact on the electricity network.
* Household electricity supply technologies such as micro CHPs and solar panels have little to no network impact. Therefore to test these it is necessary to first create a network impact by building one of the previously mentioned technologies (for example electric vehicles) and then seeing if adding an electricity supply technology *reduces* the network load.
* It is most important to test electricity technologies in households however it is also suggested to test technologies attached at higher voltage levels. To do this it is best to first build some electricity demand technologies in households (such as electric heaters), these should create a network impact at all levels. Subsequently, other sectors can be tested to see if the network impact increases or decreases as expected. For example: If sufficient electric heaters are built in households to cause network impact at all levels and then wind turbines are built, then the network impact at the HV/MV transformer should decrease. Similarly, if industry or agriculture CHPs are built the impact at the MV-D levels and higher should decrease. At lower voltage levels nothing will change because the electricity only flows in one direction.
* Finally, it should be checked if the list of converters included in the network calculation is exhaustive. If any new converters have been added to the ETM that use or produce electricity (particularly if they are found in demand side of the ETM) it should be checked that they are included in the relevant converter groups query.

## Mechanical Turk

For some of the test procedures described above it is possible to create mechanical turk tests to limit the required testing by individuals. The following tests are recommended:

* Test the start scenario to make sure peak\_load\_units\_present is equal to the present value of number\_of\_units for all converters in the network calculation.
* Create mechanical turk tests of scenario IDs 3887, 3893, and 3901.
	+ The input ids and values can easily be can be taken from et-engine.com/data/latest/scenarios/<scenario id>. Using Excel or a simple script they can be translated to ruby code relatively easily.
	+ As test it is suggested to check that the results of the queries “total\_investment\_costs\_of\_<network\_component>” and make sure they are within a 10% deviation of the values presented in the above table
* Do simple checks, for example:
	+ Set electric heaters to 50% and check that “total\_investment\_costs\_of\_lv\_net” increases. Subsequently set micro CHP to 50% and check that “total\_investment\_costs\_of\_lv\_net” decreases
	+ Set electric heaters to 100% and check that “total\_investment\_costs\_of\_hv\_mv\_trafo” increases. Increase the number of inland wind turbines and check that the query decreases.
	+ Similar tests to the above can be done with other network converters as well.

# Improving the network calculation

If the network calculation were to receive a continuation project then the following recommendations are made that could improve the calculation:

* Add the effect of growth in electricity demand to the network impact. Currently increasing a slider such as electricity demand growth in households only causes a network impact at the HV-network level because of the additional required import of electricity. This however should also have an impact at lower voltage levels. A few possible solutions can be considered:
1. Letting the total used capacity on the network scale increase or decrease with changes to the electricity demand.
2. Modeling the electricity demand as technologies that are also attached to the network similar to those described in this document. If the required parameters are available the converter can be added to the appropriate network level and the calculation should work without further issues. There are two issues with this solution however: First, the converter may only have electricity input or output (having both would result in too large a network impact). Second, values for simultaneousness would need to be researched. For households an acceptable value is 14%, however for other sectors this is not known and would need to be discussed with network operators.
* Add the effect of transport of electricity in two directions. This is a very complex issue for which it is not easy to come up with a good solution. For details about this issue see the previous section on network calculation assumptions.
* Change how the HV-network impact calculation works to be consistent with the lower voltage levels. Currently 5 of the 6 network components have the same calculations while a single network component use its own rules. For the sake of consistency it could be desirable to model the HV-network similar to the lower 5 networks. This can be done by defining all the required parameters for the HV-network such that the calculation results in the same values as it currently does using the same calculation. This would imply mainly requiring values for the total available capacity on the network, the total used capacity, and the network costs of expansion. With some tweaking this should be doable.
* Automate the queries used to define which technologies are attached where. Currently the query groups defining which technologies are attached to which network levels is static meaning that if new converters are added to the ETM they are not automatically included in the network calculation. Using the guidelines provided in Table 1 it should be possible to write queries that automatically determine which converters belong on which network. There is however one issue that needs to be looked out for: The guidelines in the table divide technologies according to their power consumption and in the ETM some converters consist of multiple units (for example 1 solar panel for households according to the ETM is actually an entire block of solar panels). Therefore these types of exceptions need to be handled with.
* To allow easier automation of the queries defining where technologies are attached (previous bullet) the typical capacities of some converters should be changed to better reflect the size of one unit. In the InputExcel in sheet Peakload an example of the calculation has been provided in column S. The converters that according to that calculation are incorrectly assigned a certain network level have been highlighted in red.
* Remodify the graph to reflect where everything is attached in the network. Currently all electricity production technologies are found to the right of the HV-network. Moving certain electricity production technologies to different voltage levels in the graph or moving sectors has two possible benefits:
	+ It would solve the problem described by the previous 2 bullets. By relocating certain converters in the graph the CHILDREN( or PARENT( function could be used to identify what converters belong to which network component.
	+ With a bit of work it could also be a first step in including the network calculation in graph calculation. If everything is included in the correct place, the network impact calculations can become methods to the network converters and do not need to exist in gqueries.
* A final recommendation is to create a third chart for the network calculation showing not the investment costs but the required capacity. The queries for the chart have already been written and the chart has been described in the following ticket:

<https://github.com/dennisschoenmakers/etmodel/issues/488>

# Resources and further reading

**CE Delft, Achtergrondrapportage bij NET-document Netbeheer Nederland –**

<http://refman.et-model.com/publications/1713>

This is the background document pertaining to the Netbeheer Nederland publication “NET voor de toekomst.” Much of the work done for the network calculation is based on information in this publication. This document is more extensive than the publication itself.

**Netbeheer Nederland, Net voor de toekomst –**

<http://www.netbeheernederland.nl/Content/Files/373_320008-Rapport%20Net%20voor%20de%20Toekomst.pdf>

This is the publication that started the project. For information pertaining to the calculation described in this document it is better to consult the CE Delft document, which contains all background information of this publication.

**Laumans, C.J. Thesis: Flexibility of future energy scenarios –**

<http://refman.et-model.com/publications/1628>

This is the author’s thesis. The thesis work focuses on the electricity load profiles of future energy technologies, in particular electric vehicles and household heating technologies. Based on the results of the thesis work some of the parameters in the network calculation were adjusted.

**Laumans, C.J. Excel model of thesis work (simple) –**

<http://refman.et-model.com/publications/1714>

Simple version of Excel model built by Chris Laumans for his thesis. In the model the aggregated electricity demand profiles are shown based on the market penetrations of a few technologies (households heaters, solar panels, electric vehicles). In the simple version the number of options and technologies are limited.

**Laumans, C.J. Excel model of thesis work (extended) –**

<http://refman.et-model.com/publications/1715>

Extended version of Excel model built by Chris Laumans for his thesis. In the model the aggregated electricity demand profiles are shown based on the market penetrations of a few technologies (households heaters, solar panels, electric vehicles). The extended version contains more technologies and the calculation is spread over multiple sheets.

**Laumans, C.J. Excel documenting changes to the simultaneousness values –**

<http://refman.et-model.com/publications/1716>

This document is based on the Excel model of thesis work (simple). It uses the model to calculate the simultaneousness values such that the network impact in the ETM would be in agreement with those in the Excel model. Based on this Excel some converters received simult values greater than 1.

# Appendix A: Contacts

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Person and function | Company | Telephone | Email | Comments |
| Han Damste | Netbeheer Nederland | 026 356 947006 5337 1257 | hdamste@netbeheernederland.nl | Initiator of the project |
| John Zwaal, Hoofd Netontwikkeling | TenneT | 026 373 127406 2279 9118 | John.zwaal@tennet.eu | Very helpful in project and was quick to answer any questions concerning the high voltage level of the electricity grid.Would be willing to help in the future with any quick questions. |
| Marcel Hooijmans, Beleidsadviseur | Liander | 06 5203 4543 | Marcel.hooijmans@alliander.com | Very helpful in the project and thought along concerning how we could model the low to medium voltage levels.Would be willing to help in the future with quick questions. |
| Albert van der Molen, Senior specialist asset management  | Stedin | 088 863 312406 4635 2891 | Albert.vandermolen@stedin.net | Very helpful in project although not an expert in the electricity networks. Albert’s specialty is the gas network. |
| Danny Geldtmeijer, Innovator asset management | Enexis | 06 5271 6023 | Danny.geldtmeijer@enexis.nl | Helpful, however very busy. Questions can better be addressed at the other participants. |

# Appendix B: Simultaneousness values greater than 1

Simultaneousness values should have a value between 0 and 1, in the ETM however some values of greater than 1 are used. The reason for doing this was based on the author’s thesis work on the subject. In this appendix some considerations are given for why simultaneousness values of greater than 1 are used.

When the project was first conducted the impact of the technologies on the electricity network was in general low (for the low-voltage network in particular). This was due to how the electricity network was modeled in the ETM: The ETM uses *one* average number per network level for total available capacity and *one* average number for the used capacity. These network levels therefore represent the grid everywhere in the country and as a whole there is no capacity problem. On a case-by-case basis (i.e. per individual low voltage network) there may actually be capacity problems on many of the electricity networks, as has been shown in the author’s thesis work.

As a result of the author’s thesis work and his conclusions it was decided to modify some parameters of the network calculation to reflect more of a ‘worst case scenario’ instead of the average scenario. For this reason the simultaneousness values of some technologies were changed to reflect the network impacts that were obtained in the thesis work. The following table shows the new simultaneousness values:

Table 12: Simultaneousness values based on thesis work

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | EVs | GSHP | Electric heater | Micro CHP | Solar PV | Electric boiler | Heat pump boiler | Air conditioning |
| simult\_we | 0.98 | 3.67  | 3.13  | -0.80  |  0 | 1.14  | 1.68  | 0 |
| simult\_wd | 0.29 | 2.81  | 2.53 | -1.64  | -0.04  | 0.90  | 0.69  | 0 |
| simult\_se | 0.79 | 0.48  | 0 | -0.61  | -0.24  | 0.81  | 0.67  | 0.74  |
| simult\_sd | 0.22 | 1.96  | 0 | -0.54  | -0.74  | 0.86  | 0.35  | 2.59  |

As can be seen in the table, some simultaneousness values are greater than 1. Below some comments are given concerning this:

### Advantages

* The new values take into account the fact that the “base load” is different at different time periods. (In the ETM the ‘occupied capacity’ is a single value, and is the maximum occupied capacity, which is expected in the winter evening. During the day or the summer the occupied capacity is only a fraction of this value.)
* The new values are more accurate; previously the values was simply based on assumptions concerning the behavior of technologies while now they have been determined using modeled load profiles of the technologies. (For example, previously it was assumed that heating technologies have simultaneousnesses of 1 in the winter, whereas the new values were determined based on the load profiles of the heating technologies.)
* Being able to incur costs in the low voltage network cables is an interesting result, because the costs for cables are very high (approximately 6-10 times higher than for other network levels). Therefore users will see that it is worthwhile to take measures to avoid these costs in particular.

### Disadvantages

* The new values are more ‘theoretical’. Simultaneousness by definition should be a value between 0 and 1; clearly this is not the case anymore. The idea is still the same however, the higher the value the higher the coincidence (for example, the load of an electric heater is higher in the winter evening than in the winter day)
* These values have been calculated using the results from the author’s thesis, and therefore similar values cannot easily be obtained for other technologies.
* The results are specific to the Netherlands, and some research needs to be done to figure out how to make this applicable to other countries. (The limitation here is not on the technology side but rather on the network side concerning the available and occupied capacities).

### Alternative to this change

An alternative option would be decreasing the ‘available capacity’ and ‘occupied capacity’ values in the ETM. Like this similar results could be obtained without changing the simultaneousness values to the above ‘theoretical’ values. The disadvantage of this however is that this change would be need to be made at all network levels (middle and high voltage as well), and new cost coefficients for network expansion would be required. Data for this would need to be researched.

1. Power demarcations are taken from Energiekamer. Netcode Elektriciteit per 14 maart 2012. [Online]. Available at: <http://www.nma.nl/images/12-03-14%20NETCODE_Elektriciteit_per_14_maart_2012%2022-198164.pdf> [↑](#footnote-ref-1)