Evaluating the power capability of a typical Dutch MV grid incorporating sustainable technologies

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Evaluating the Power Capability of a Dutch MV grid Incorporating Sustainable Technologies

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***Abstract*- This paper describes the power capability of a typical Dutch medium voltage (MV) distribution grid when future generation and load technologies are applied. Therefore reference networks are selected which are representative for of a larger group of networks. The application of the future technologies is simulated in these reference networks. A methodology is presented to calculate the penetration degrees for these future technologies. A sensitivity analysis is then performed on changes in the power profiles of the technologies.**

***Index Terms*--**Reference network, future technologies, capacity, medium voltage distribution grid, cable losses, penetration degree, DG

I. INTRODUCTION

The coming years the energy system is fundamentally changing while there is a shift from centralized to decentralized generation as a result of upcoming technologies. Furthermore, new types of loads may be foreseen. To figure out to what extent the grid can adopt these technologies several studies are done [1-3], mainly focussing on the low voltage grid. In this paper a case study is done to set up a methodology that gives in-depth knowledge about the power capabilities of a typical MV distribution grid. The selected cases are illustrative for the MV distribution grids of Enexis, a Dutch distribution network operator (DNO). Enexis is one of the largest DNOs in the Netherlands and owns therefore a variety of MV distribution grids.

II. REFERENCE NETWORK SELECTION

In this section a method for selecting a reference MV distribution network is described which has an average power capability for a larger group of networks. For this purpose, eight MV distribution networks that are owned by the DNO Enexis are examined. Based on geographical location, network layout and quality of data, the following eight MV network areas are selected: Helmond Zuid, Geertruidenberg, Woensdrecht, Nederweert, Valkenburg, Gasselte, Winschoten and Nijverdal.

Parameters which are expected to have an influence on the power capability are observed and compared. Earlier research already showed that the transformer capability limits the total grid capability [1].

A. *Statistical analysis of grid parameters*

The power capability of the MV distribution grid depends on different grid parameters. These are the network layout and geographical location, cable length between transformers, cable thickness, the cable and transformer loading and simultaneity factor. For the eight selected areas these parameters are statistically analysed to find out if one area is representative for the others.

The network layout of all eight selected areas is different. The number of transformers, the number of transformers per feeder and the number of cable per area vary. But also the network structure and topology are different. In Table I the variety of network layout and the geographical location are shown.

TABLE I
NUMBER OF NETWORK STRUCTURES PER FEEDER, TOTAL NUMBER OF FEEDERS AND GEOGRAPHICAL LOCATION (NORTH/SOUTH)

	radial	ring	meshed	total	location
Nederweert	0	2	8	10	s
Valkenburg	2	6	6	14	s
Helmond	22	18	4	44	s
Nijverdal	1	6	8	15	n
Gasselte	5	5	5	15	n
Winschoten	3	18	7	28	n
Woensdrecht	15	16	4	35	s
Geertruidenberg	11	36	12	59	s

To have an idea of the size and the density of the selected areas the number and length of MV distribution cables are counted. Multiple feeders connected in series between transformers are counted as one. The result in distribution of cable length between transformers is given per area in Fig. 1 using the box plot technique [9].

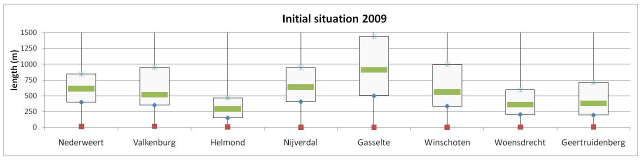

Fig. 1. Box plot of cable length between MV/LV transformer nodes

From all transformers in one area the maximum power over one year being a four year average is collected and divided by the nominal transformer power. The distribution of these initial transformer loadings is given in Fig. 2.

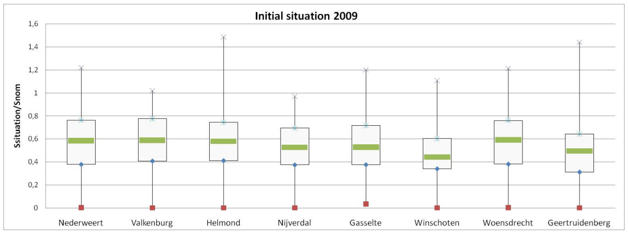

Fig. 2. Box plot of the initial transformer loading

The simultaneity factor is a grade for load activity in a neighbourhood. A low value is characteristic for a residential area and a high value, close to one, is characteristic for a business area with shops, offices or industry. This value is determined for all feeders in the different areas and the distribution is presented in Fig. 3.

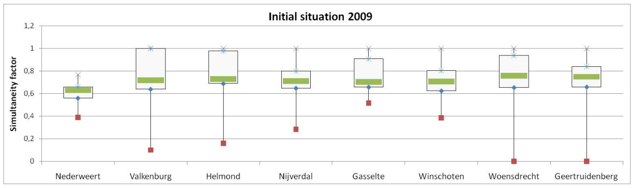

Fig. 3. Box plot of the initial simultaneity factors

Subsequently, a statistic analysis is done to compare the data given in Fig. 1-3 and to find out if areas are some how related to each other, resulting in subsets. Therefore an ANOVA (analysis of variance) is applied with a post hoc test [9] to compare the grid parameter distributions of the eight areas. It is assumed that two areas are significantly different if there is less than 5% overlap between the distributions, if not a subset is formed. From the statistic analysis it can be concluded that the distribution of the single grid parameters of all areas is comparable with each other because only one subset is formed.

B. Determining the power capability of the grid

To determine the capability for additional loading of the network areas two tests are applied. In these tests the load of all transformers behind a feeding cable is increased until this feeder becomes overloaded. The difference between both tests is the simultaneity factor which is in test one equal to the initial situation and in test two equal to one. A flow diagram of the simulation process is shown in Fig. 4.

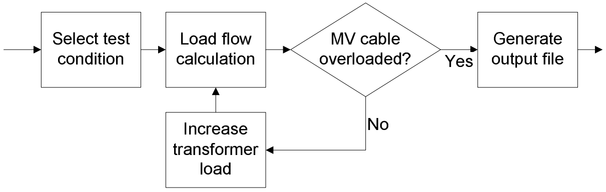

Fig. 4. Creating data for comparing the grid capability of all networks

The results of test one are shown in Fig. 5. From Fig. 5 and Table I it can be concluded that there is a visible relationship between geographical location and the mean values of the transformer loading. The requirement of the ANOVA is a normal distribution in data. It should be mentioned that Valkenburg has a relatively low number of transformers compared with the other areas and therefore a normal distribution is not reached. When an ANOVA and post hoc test is applied without taking Valkenburg into account this visible relationship is not found. Two subsets, group of data with more than 5% overlap in distribution of data, can be formed. One subset is containing Helmond plus Geertruidenberg and one subset with the other areas.

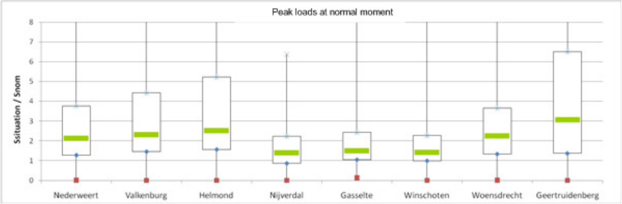

Fig. 5. Box plot of the transformer overloading for test one

In test two it is assumed that all peak loads occur at the same moment which means that the simultaneity factor becomes equal to one. The results are shown in Fig. 6. It can be concluded that the transformer loadings in Helmond and Geertruidenberg have a higher distribution grade than the transformer loadings in other areas. Again an ANOVA with post hoc is applied. The post hoc shows again that those two subsets are found, one subset contains Helmond plus Geertruidenberg, having a high grid capability, and one subset contains all other areas, having a low grid capability.

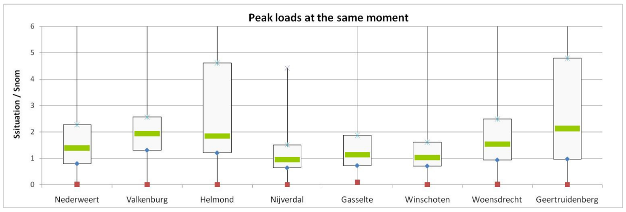

Fig. 6. Box plot of the transformer loading for test two

C. Reference grid selection

Based on the results of the capability calculation two grids are selected as being the reference networks for the low and high grid capability. The selected networks are the two outer extreme networks. This means that the networks with the highest and the lowest power capability are selected; these are Nijverdal and Helmond.

III. FUTURE TECHNOLOGY SELECTION

In this section technologies which are expected in the near future in the Netherlands and which will have an impact on the loading of the MV distribution grid components, are introduced. Each technology has its own power profile. It is assumed that the technologies are applied at the low voltage (LV) side of the transformer and are applied at multiple households. This results in the use of an average profile. For determining the grid capability only the day with the highest impact is of interest. So the profile of this day is shown. The studied technologies are: electric vehicle (EV), heat pump (HP), air-conditioning, photovoltaic panels (PV) and micro combined heat and power (μ-CHP). The selection for these technologies is based on grid impact and equal to the technologies used and described by Lumig [3], Faber [4] or Veldman [5].

The profile for a 2 kWe HP, with a backup system for peak demand, on a cold winter day is shown in Fig. 7 [3-5].

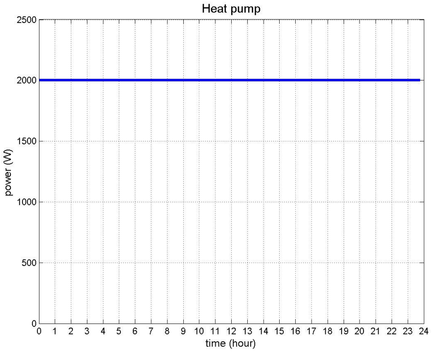

Fig. 7. Average load profile for a 2kWe HP, used on a cold winter day

The profile for an EV, with a daily average driving distance of 40 km and an efficiency of 0.22 kWh/km [6-8], resulting in a total daily energy demand of 8.8 kWh, is shown in Fig. 8.

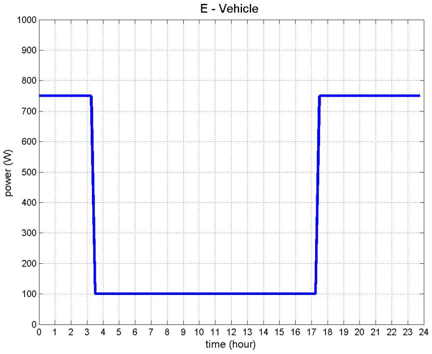

Fig. 8. Average load profile for charging an EV which drives 40 km/day

The profile for air-conditioning is based on the average power of 1.5 kWe [3] and the need for more cooling during the day than the night [4]. This profile is shown in Fig. 9.

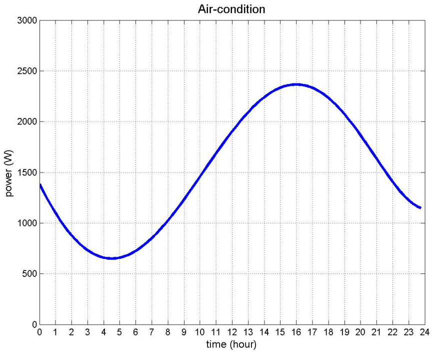

Fig. 9. Average load profile of a 1.5 kWe air-conditioner on a summer day

The profile for a 1 kWe μ-CHP is shown in Fig. 10. During the night time the μ-CHP is switching on and off.

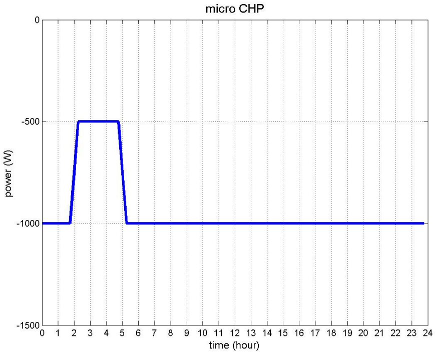

Fig. 10. Average load profile of a 1kWe μCHP [5] on a cold winter day

The profile for 10 m^2 PV panels with an efficiency of 15% is shown in Fig. 11.

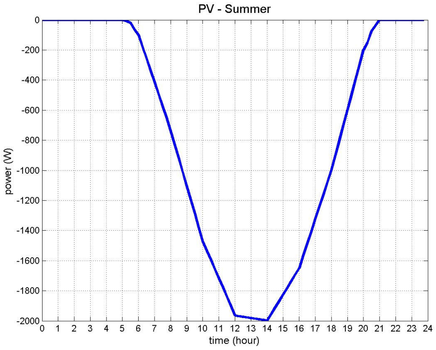

Fig. 11. Average load profile for PV (10 m^2, 15%)

IV. PENETRATION DEGREE OF FUTURE TECHNOLOGIES

To determine the penetration degree for each technology, when these technologies are applied to the reference grids, a simulation with Vision [10] is done. Only the worst case for each technology is investigated. Therefore, only the peak power for each technology, which occurs at one moment in time (time *t* in Fig. 12), is determined/calculated.

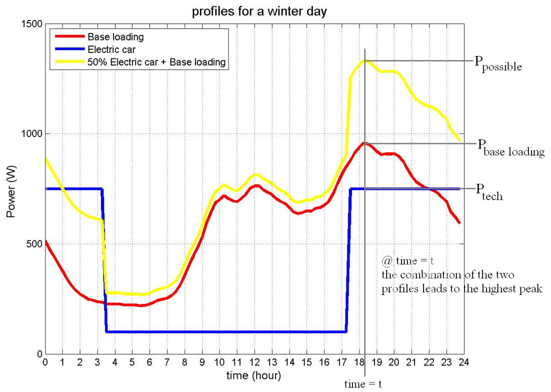

Fig. 12. An example of a load profile with EVs at 50% of the households on a winter day

In Fig. 12 the winter base load profile for one household ($P_{base\ loading}$) is combined with the load profile of charging one electrical car (P_{tech}) to the maximum possibility of the grid ($P_{possible}$). In Fig. 12 only 50% of the households can have a EV installed without changing the grid. It is assumed that behind one transformer only one type of household is connected consuming yearly 4000 kWh [3].

Table II shows the simulation results for the average allowed penetration degree of each technology for the two reference networks, if only a single technology is applied. The allowance is defined by the maximum transportable power of the MV to LV transformer, by the maximum loading of the cable to this transformer, taking into account possible reroutes as a result of an obstruction, or by the pre defined boundaries of the voltage at the end of the cable.

TABLE II
AVERAGED ALLOWED PENETRATION DEGREE

Technology	**Nijverdal**	**Helmond**
Heat pump	27 %	44 %
Electric Car	51 %	69 %
Air-conditioning	44 %	58 %
Photo Voltaic	88 %	91 %
Micro CHP	100%	98 %

From this table one can conclude that the application of µ-CHP leads to no problems in the MV distribution grid, but that the penetration of all other technologies is limited. Still, half of the households can be equipped with an EV or air-conditioning, around one third with a HP and nine out of ten houses with PV. As expected, Nijverdal has a lower power capability than Helmond. Due to this, Helmond will not further be investigated.

V. PENETRATION DEGREE OF ARBITRARY FUTURE TECHNOLOGIES

The aim of this section is to determine a methodology that gives the penetration degree for an applied technology if the power of the technology or the base loading is changed. To realize this, the results of each technology of Nijverdal are ordered for each household over the power diagram. This is possible because the numbers of households that are located behind the transformers and the penetration degree for each transformer are known. The result is shown in Fig. 13. On the left hand side the penetration degrees for distributed generation is shown and on the right hand side the penetration degrees for additional loading. Installing µ-CHP is possible for all households so only one marker is presented for it. Each marker represents a sum of transformers that can handle the same penetration degree. For example (on the right hand side) each transformer can handle the base loading of 956 W and only 5% of the households can provide a loading of almost 3000W.

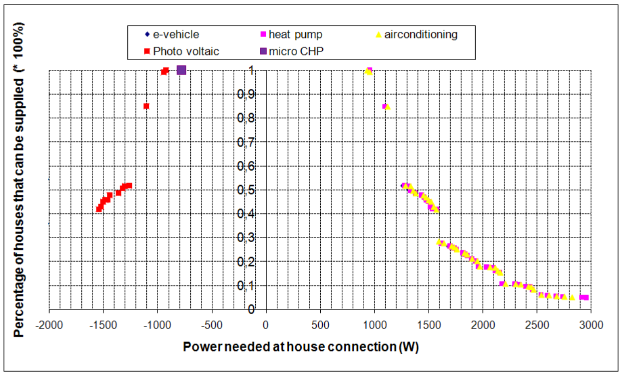

Fig. 13. The sum of $P_{base\ loading}$ and P_{tech} versus the number of houses that can be supplied

From this plot two trend lines are derived, one for additional loading and one for distributed generation. Both formulas are integrated to calculate the total power capacity. The integrated formula is divided by the required power for a certain (future) technology resulting in a formula to calculate the allowed penetration degree (α). Equation (1) gives the penetration degree for additional loading and (2) gives the penetration degree of distributed generation.

$$\alpha = \frac{3.04 \cdot 10^3 \left(e^{-0.0016 \cdot 956\,W} - e^{-0.0016 \cdot \left(P_{base\ loading} + P_{tech} \right)} \right) + 956\,W - P_{base\ loading}}{P_{tech}} \quad (1)$$

$$\alpha = \frac{2.65 \cdot 10^3 \left(e^{0.0014 \left(P_{base\ loading} + P_{tech} \right)} - e^{0.0014 \cdot 956\,W} \right) + 956\,W - P_{base\ loading}}{P_{tech}} \quad (2)$$

The value for α is equal to 1 if (3) is true.

$$\left(P_{base\ loading} + P_{technology} \right) < 956\,W \quad (3)$$

The equations are validated by additional simulations in Vision using modified power profiles. Both formulas are translated into plots to make it is easier to see the impact on the penetration degree when the base loading or the power of the applied technology is changed. The resulting plots are given in Fig. 14, for additional loading, and in Fig. 15, for distributed generation. In these figures P_{tech} and $P_{base\ loading}$ are replaced by Power of technology and Power of base loading and α is multiplied with 100%.

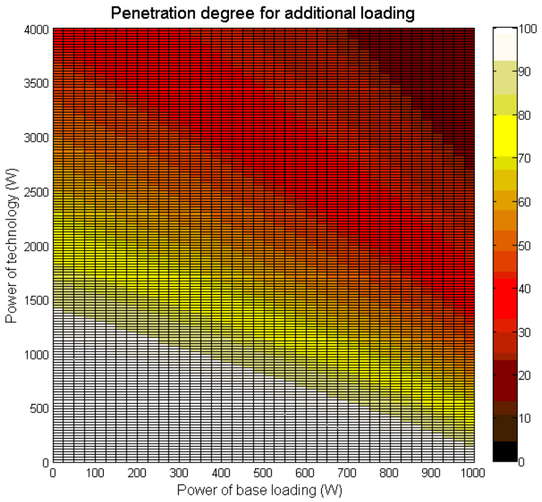

Fig. 14. A plot of a penetration degree for additional loading

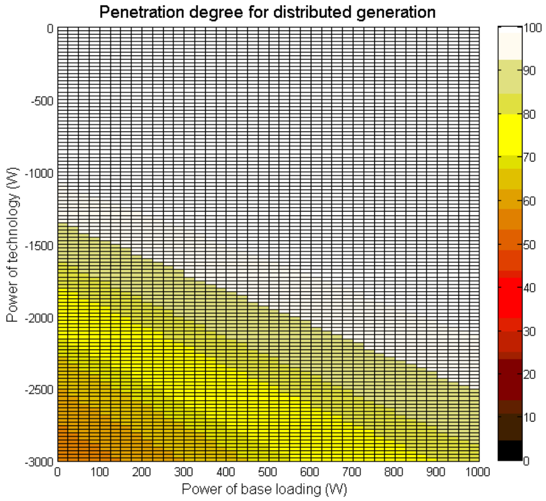

Fig. 15. A plot of a penetration degree for distributed generation

VI. SENSITIVITY ANALYSIS

To have a better understanding what will happen if a technology profile changes some adjustments in the power profiles of each technology are made. The maximum power of each technology is increased and decreased with 20% and the peak occurs five hours earlier and later then in the base case. The penetration degree is calculated using (1)-(3) and the Fig. 14 and 15. The results of the sensitivity test are shown in Table III.

TABLE III
SENSITIVITY ANALYSIS OF THE PENETRATION DEGREE

	peak power change			peak time shift		
Technology	– 20%	base case	+ 20%	- 5 hour	base case	+ 5 hour
EV	11%	0.61	-8%	0%	0.61	34%
Air condition	18%	0.48	-11%	0%	0.48	0%
HP	18%	0.32	-16%	0%	0.32	0%
PV	9%	0.90	-11%	0%	0.90	0%
µCHP	0%	1	0%	0%	1	0%

From this table one can conclude that a change in maximum power is directly related to the power capabilities of the grid, except for µ-CHP, which could already be applied without any problems. A change in peak time has only a positive effect for the penetration degree of electrical vehicles. For the EVs it is better to start charging around 22:00 instead of 17:00.

VII. CONCLUSIONS

Extensive simulations are performed to determine the power capability of a typical Dutch MV distribution grid in a nearby, more sustainable future. A sensitivity analysis is done to check the influence of changes in the power profiles of future technologies.

The penetration degree for a certain technology depends on the grid capability. For the case study two reference networks were applicable both with their own grid capability. The grid capability is not directly related to individual grid parameters. The penetration degree also depends on the required peak power. The higher the peak power is, the lower the penetration degree of that technology will be. An adjustment in time when the peak moment occurs has only impact for the EVs but leads directly to an increase of 34% of the penetration degree. Furthermore, distributed generators have less impact on the MV distribution grid than additional loading.

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