ANALYSIS OF NETWORK REQUIREMENTS BASED ON AN ESTIMATION OF THE FUTURE ENERGY DEMAND FOR A GERMAN METROPOLIS

Dennis UNGER
TU Dortmund University, Germany
dennis.unger@tu-dortmund.de

Lukas SPITALNY
TU Dortmund University, Germany
lukas.spitalny@tu-dortmund.de

Johanna M.A. MYRZIK
TU Dortmund University, Germany
johanna.myrzik@tu-dortmund.de

ABSTRACT

In this paper an estimation of the potentials of distributed generation units for a German metropolis is made. Therefore, deciding factors which influence the market penetration of these units are considered. In addition to technological aspects, economic aspects are taken into account.

Based on the estimated development, the impact of connecting the regarded units to the electrical power system is analysed. The loading of the network equipment and the voltage profile have to be kept within the permitted limits. The connection of a huge number of distributed generation units may increase given limits. Knowing the future development of these units is essential for distribution system operators for planning a long-term asset management.

INTRODUCTION

The aim to reduce the anthropogenic impact on global warming leads to a change in the whole energy sector. Considering the current mixture of the energy consumption it can be seen, that the supply of energy for heating purposes makes up the major part of the primary energy consumption. Over 70 % of the domestic energy demand is caused by the heating demand. Due to the fact that the household sector causes a quarter of the German primary energy consumption there is a high potential for energy saving measures [1].

German legislation has created general preconditions to accelerate the expansion of distributed and renewably energy resources and also to improve the thermal insulation for residential buildings. Thereby, conventional heating technologies with gas or oil firing systems are partially substituted by more energy efficient generation units like electrical heat pumps (HP) or micro combined heat-and-power (CHP) plants. This change results in different consequences for the electrical and the gas distribution network. Furthermore, a growing share of photovoltaic (PV) systems can be expected, which has an impact on the electrical network as well [2]. In the following, PV systems, micro CHP plants and electrical HP will be summarised to distributed generators (DG).

For the estimation of the impact on the electrical network, knowing the potentials of DG offers enhanced possibilities to distribution system operators for planning a short- and long-term asset management of the electrical network. In this paper the potential of DG is defined as the percentage of houses, in which the use of DG is reasonable based on technical, economical and sociological aspects. By estimating the potentials of DG for a German metropolis of almost 600,000 inhabitants till the year 2030, a realistic view of the development of these units can be demonstrated. Based on the estimation, the future loading of the electrical network can be investigated.

METHOD OF ANALYSIS

For the estimation of future network requirements it is important to know the development of DG in the sector of private households. Especially the share of DG for a more energy efficient thermal energy supply will increase in the future. Because of this a research method has to be evolved which considers the main factors the development of these DG units depends on. The following figure illustrates the approach of the determined analysis.

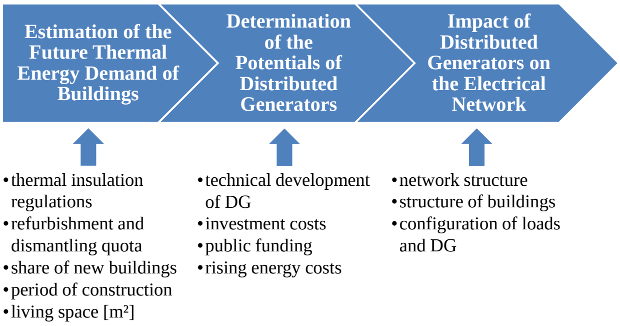

Fig. 1. Steps and input factors of the research method

The figure shows the several parts of the considered research method and their input factors. At first, the future thermal energy demand of buildings has to be estimated. This value is mainly influenced by the period of construction. For the future estimation of the thermal energy demand also insulation regulations, refurbishment and dismantling quotas have to be taken into account. Based on the thermal energy demand of buildings and the consideration of different drivers, the potentials of DG in the regarded metropolis can be determined. Finally, the impact of DG on the electrical network can be simulated. Therefore, the loading of the MV/LV transformer and the loading of the cables as well as the voltage at the terminal node are analysed.

In the following paragraphs the drivers, which have an impact on the potential of DG, are described in detail. Also the considered network structure and the configuration of the loads and generation units are shown.

Drivers

Considering the current developments and the future challenges, five main drivers, which influence the future energy demand and thus the penetration of DG, can be identified. In addition to technological and economic aspects also political, sociological and environmental aspects have strong market effects, which are described in the following.

- Technological aspects, especially the field of application, influence the penetration of DG. As this work focuses on units for domestic use, the analysis is limited to electrical HP, micro CHP plants and additionally PV systems. Also just state-of-the-art technologies are taken into account, which are established in the mass-market.
- Economic factors have a main influence on the penetration of DG. Private households will only invest in these units, if a capable payback time is reached. This is achieved, if the revenues reach the investment costs and the fuel prices within the lifetime of the unit.
- To reach climate goals energy efficient technologies have to be established. Because profitability cannot be reached without public funding, German governmental regulations improve the legal and economic conditions for investments in renewable energy resources.
- Also sociological and environmental aspects have an impact on the diffusion of DG. The attitude towards an environment-friendly life-style influences the choice of a building owner for the use of DG.

Considered Distribution Network

Based on data from Dortmunder Energie- und Wasserversorgung - Netz GmbH a typical distribution network is taken, to analyse the impact of DG on the LV network. The structure of the LV considered network is modelled. In fig. 2 a general depiction of the determined LV network structure is presented.

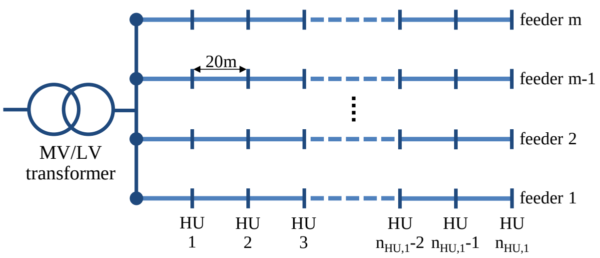

Fig. 2. General structure of the considered distribution network

The loading of one LV feeder m is dependent on the apparent power $S_{str,m}$, that results in the following formula:

$$S_{str,m} = n_{HU,m} \cdot S_{HU} \cdot g(n_{HU,m}) + S_{DU,m} \qquad (1)$$

Where $n_{HU,m}$ is the number of housing units (HU), S_{HU}=30kW [3] is the maximum network connection capacity and $S_{DU,m}$ is the apparent power of DG. Because of the stochastic behaviour of consumers, the network connection capacity results by considering the simultaneity factor $g(n_{HU,m})$ [4].

For the MV/LV transformer the loading results from the summation of the apparent power in the several LV feeders. Thereby, the simultaneity factor is adapted to the total number of HU N_{HU} supplied by the MV/LV substation:

$$S_{MV/LV\,sub} = \sum_{i=1}^{m} n_{HU,m} \cdot S_{HU} \cdot g(N_{HU}) + S_{DU,m} \qquad (2)$$

The maximum number of LV feeders is set to 6, the maximum number of single-family-houses per LV feeder is set to 24 and the maximum number of apartment buildings per feeder is set to 4. Each apartment building consists of 6 HU.

The determined power of the loads and the nominal power of the DG are summarised in table 1 depending on the calculated parameter. Additionally the displacement power factor (cos φ) is presented.

Table 1. Assumed loads and DG for load flow simulations

	P_{max}	cos φ	calculation parameter
maximum load per HU	3.5kW	0.95 ind.	voltage
	3.5kW	0.95 ind.	cable loading
	1.5kW	0.95 ind.	transformer loading
electrical HP	1.0 - 4.0kW	0.95 ind.	all parameters
micro CHP plant	1.0 - 4.0kW	1.00	all parameters
PV system	7.0kW	1.00	all parameters

Based on the represented values the load flow simulations are executed.

ESTIMATION OF THE FUTURE THERMAL ENERGY DEMAND OF BUILDINGS

Knowing the specific thermal energy demand of buildings is essential to evaluate the future heat requirement of private households. The specific thermal energy demand of buildings specifies the annual heat requirement per square meter and depends mainly on the period of construction. Rising restrictions for thermal insulation regulations and more efficient building materials have led to a lower thermal energy demand of buildings from 1977. Furthermore, regulations for energy saving and state funding lead to a continuous increase of the energy performance of existing buildings through refurbishment.

Based on the current specific thermal energy demand [5], the specific thermal energy demand in the year 2030 can be estimated by considering further parameters (see fig. 1), which affect mainly the heat demand of buildings. In detail, a refurbishment quota of 2.2% per anno, a dismantling quota of 0.15% per anno and a share of new buildings of 0.64% per anno are taken into account [6][7][8].

Fig. 3 illustrates the estimated average specific thermal energy demand in the year 2030 depending on the period of construction. Thereby, a difference between single-family-houses and apartment buildings is made because of their different heat demand characteristics.

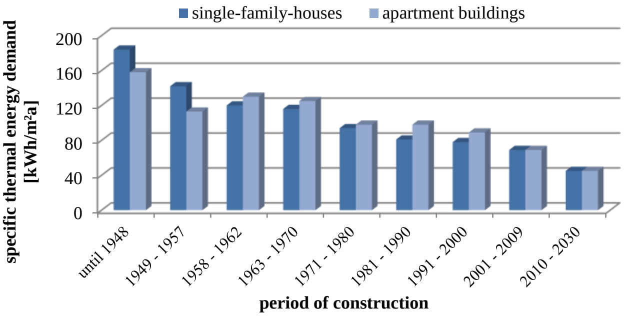

Fig. 3. Thermal energy demand of buildings in 2030

It can be seen, that the specific thermal energy demand decreases in the course of time. Differing from the assumption that the specific thermal energy demand of single-family-houses is higher than the specific thermal energy demand of apartment buildings, this correlation does not apply to the considered metropolis in all periods. This can be explained by the big share of terraced houses in the metropolis, which have a lower specific thermal energy demand than detached single-family-houses. Thus the average specific thermal energy demand decreases.

On the basis of the estimated specific thermal energy demand of the different periods of construction the annual heat requirement of the buildings can be determined. Therefore, statistic data from the department of statistics of the considered metropolis are used, which contain information about the building structure in each of the twelve districts. At first, the average living space of single-family-houses and apartment buildings is calculated for each district depending on the period of construction. Secondly, the average annual heat requirement can be calculated by the multiplication of the average living space and the determined specific thermal energy demand. Additionally, the thermal energy for the domestic hot water has to be taken into account, which can be assumed to 800 kWh per person and year. Due to the given data a number of 2.6 and 1.7 persons per HU for single-family-houses and apartment buildings, respectively, can be assigned. Furthermore, an average number of six HU per apartment building can be assumed. The estimated data will be used in the following paragraph to determine the potentials of DG.

DETERMINATION OF THE POTENTIALS OF DISTRIBUTED GENERATORS

Based on the determined annual heat requirement, the cost effectiveness of micro CHP plants and electrical HP can be investigated. Thereby, the costs of supplying thermal energy by DG are compared to a conventional gas heating systems. The calculation pays attention to the different investment costs, the rising energy prices and the run out of public funding for micro CHP plants in Germany. Fig. 4 illustrates the received potentials of use for micro CHP plants and electrical HP in the different districts of the considered metropolis. Thereby, the shown percentages indicate the share of houses in which the use of these units is reasonable based on technical, economical and sociological aspects.

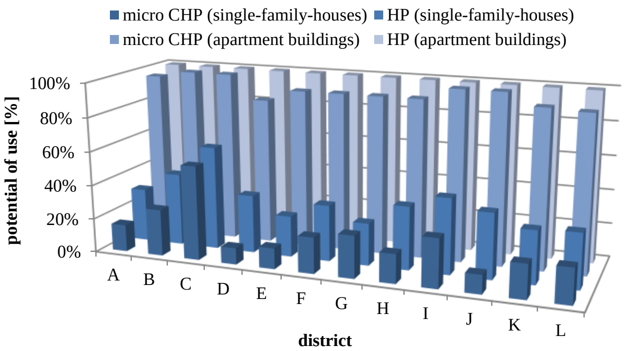

Fig. 4. Potential of use for distributed generators in 2030

It is obvious that the share of micro CHP plants and electrical HP in the area of apartment buildings is very high. Using these units in apartment buildings is economical because of the high thermal energy demand. The potential of HP in apartment buildings is near to 100%, whereas the potential of micro CHP plant is lower.

For single-family-houses the potential of DG is significant lower, but according to the apartment buildings HP have a higher potential than micro CHP plants. This is due to the lower thermal energy demand of single-family-houses which leads to a lower profitability. The different developments of DG in the several districts result from different building construction periods. Especially in single-family-houses this effect can be seen. Overall, electrical HP have a higher share compared to micro CHP plants because of significant lower investment costs.

In addition to the more energy efficient units for thermal energy supply, which were considered before, PV systems have to be regarded as well, because of their significant impact on the electrical network. Their extension of use is estimated by taking the current growth rate into account [2]. For the regarded metropolis this means that almost 24% of the houses are equipped with a PV system in the year 2030.

IMPACT OF DISTRIBUTED GENERATORS ON THE ELECTRICAL NETWORK

Connecting a huge number of DG to the electrical network affects especially the loading of the LV network. Based on the district with the maximum determined potential of DG (see fig. 4, district C), the future loading of the electrical network can be investigated. Therefore, two typical LV networks are considered, with either only single-family-houses or only apartment buildings connected to the MV/LV substation. The determined potentials of DG are scaled to the existent number of HU in these network structures. The loading of the electrical network is investigated regarding several scenarios. In these scenarios different load and generation situations are examined. The configuration of the scenarios is presented in the following table:

Table 2. Configuration of the scenarios for load flow simulations

	houshold load	electrical HP	micro CHP plant	PV system
scenario 1	x			
scenario 2	x	x		
scenario 3	x	x		x
scenario 4	x		x	
scenario 5	x		x	x
scenario 6			x	x

Based on these six scenarios the maximum loading of the LV network can be determined. Fig. 5 shows the transformer loading, the cable loading and the voltage at the terminal node depending on the scenarios, distinguishing single-family-houses and apartment buildings.

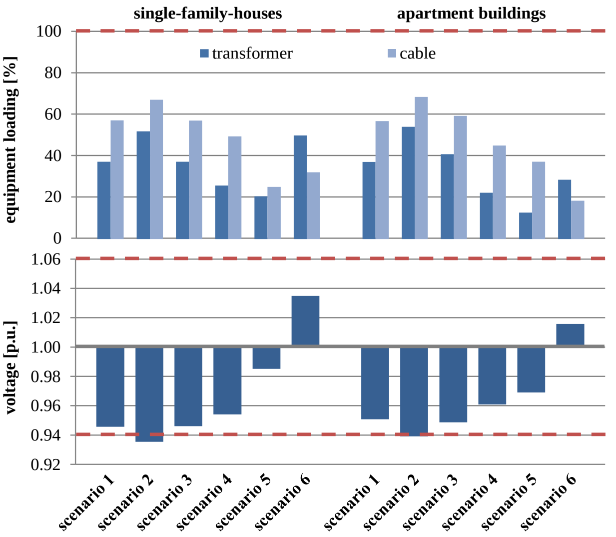

Fig. 5. Impact of distributed generators on the LV network in district C

The maximum admissible transformer loading of 100% as well as the maximum admissible loading of the cables of 100% [9] is neither exceeded in LV networks with only single-family-houses nor in LV networks with only apartment buildings. Thus, the loading of the network equipment will not exceed given limits, if the examined potentials of DG are connected to the electrical power system.

In the LV network with only single-family-houses, the lower voltage limit [10][11] is only exceeded if the examined potential of electrical HP is connected to the electrical network in addition to the regular household load. The same correlation applies to the LV network with only apartment buildings.

Furthermore, it can be seen that PV systems have an impact on the loading of the equipment and on the voltage in the electrical power system. Depending on the load flow situation PV systems can affect the voltage in the LV network positively. Considering the regular household load of single-family-houses equipped with HP, the voltage limit is not exceeded if PV systems are integrated to the LV network.

CONCLUSIONS

To increase the energy efficiency in the sector of private households, conventional thermal heating systems will be substituted by more energy efficient generation units like electrical HP or micro CHP plants. This implies a strong interconnection between thermal and electrical energy demand, which affects the electrical network. Furthermore, a growing share of PV systems (24% in 2030) has an impact on the electrical network as well. To quantify the impact on the distribution network, an estimation of the development of DG is done. For a German metropolis a realistic view of the development of these units can be demonstrated.

Regarding the estimated future development of DG, the loading of the network equipment and the voltage at the terminal node is determined. The investigation has shown that in most cases the integration of DG does not lead to an exceeding of given network limits. It can be shown that only voltage limits are exceeded, if in addition to the regular household load, electrical HP are connected to the electrical network. An overloading of the network equipment does not occur in any of the considered scenarios.

Because the development of DG depends on statistic data and a symmetrically distribution in the electrical network, the results of the load flow simulations are only initial estimations. Further investigations require more detailed data about the energy demand and real network configuration. Additionally, the impact of dynamic load and generation profiles on the load flow simulations have to be taken into account.

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