ECO-EFFICIENCY ASSESSMENT OF DISPERSED POWER GENERATION IN DISTRIBUTION ENERGY NETWORKS

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ABSTRACT

It is assumed that future power grids will be modified with more decentralized, renewable power supply systems. The integration of the so called dispersed generation (DG) brings up challenges which may have further impacts on structure and organization of today's power grids. No final conclusion can be provided, so far, in which areas and under which preconditions such as power flow densities, choice of place to install, generation efficiency and optimal ratings etc., these systems should be installed and could be efficiently operated with minimum environmental impacts. In this paper, the power supply in distribution networks is analyzed under ecological conditions based on future power generation scenarios up to 2030. In doing so, the impacts of grids with DG provided by combined heat and power units (CHP) will be compared with a power supply scenario without DG. Following another approach, distributed energy storage devices (ESD) will be installed close to the loads and the consequences on the load flow and environmental impacts will be quantified.

INTRODUCTION

The public power supply in Germany and the EU face major challenges that might have effects on the structure development of today's power grids. The liberalization of European energy markets, the ongoing regulation and the implementation of climate protection strategies are some of the tendencies. Furthermore the discussion about the phasing out of nuclear energy and the grid integration of renewable energy systems are still ongoing.

In future power supply scenarios it is assumed that DG will increase significantly. It is not clear under which conditions DG units have advantages compared to today‘s large power plants. Additionally, it is necessary to evaluate whether the integration of renewable, decentralized power systems provides a sustainable character of power grids with minimized environmental impacts or if contrary effects occur, e.g. the need to provide either additional reserve power or energy storage devices for fluctuating generation.

Future power supply scenarios for Germany

If changes in operative strategies of DG installations and the utilization of energy storage systems as additional degrees of freedom positively influence the technical eco-efficiency of future distribution networks is still an open issue. It is vital to analyze which future power supply scenarios could be realistic. Therefore, future trends for peak load and power demand in the different sectors households, trade and commerce and industry are analyzed. Following the results of studies about Germany's future power supply [2], [3] four possible scenarios seem to be realizable.

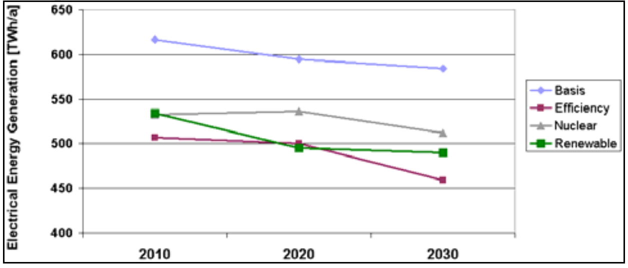

Figure 1: Electrical energy generation in Germany between 2010 and 2030 (four scenarios)

Figure 1 shows the trend of electrical energy generation in Germany between 2010 and 2030. In addition to the basis scenario which represents the current trends in power supply, an efficiency scenario with higher efficiency in power generation and energy usage, a nuclear scenario with new nuclear power plants and a renewable scenario based on a large amount of power by renewable energy sources can be identified. Obviously, all considered scenarios expect a decrease of the electrical energy demand considering population shrinkage until 2030 as well.

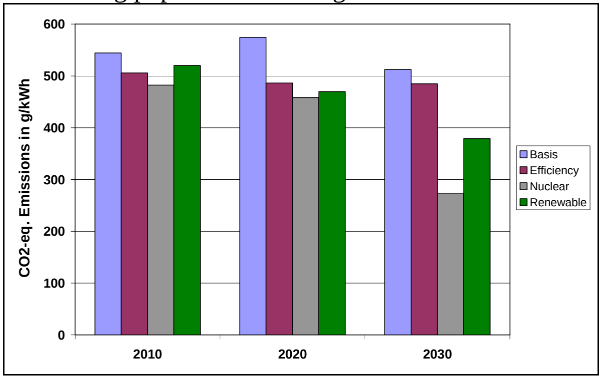

Figure 2: CO_2-eq. emissions [g/kWh] in various scenarios.

Figure 2 shows exemplary the specific emissions in [CO_2-eq./kWh] of the electrical energy mix in Germany based on the four trend scenarios with decreasing emissions.

Power generation trend of the efficiency scenario

Figure 3 shows the shares of different energy carriers in power generation between 2010 and 2030 for the efficiency scenario. Equally to the basis scenario the discontinuation of nuclear power plants in the efficiency scenario will be compensated by additional gas power plants and a moderate expansion of wind power plants. The share of power by coal fired power plants is about approximately 40%. In 2030 additional imports of electrical energy based on renewable sources are considered.

The possible penetration in 2030 of CHP units for DG is quite different comparing the scenarios. Both efficiency and renewable scenario contain an expected proportion of about 30% electrical energy from distributed CHP plants, mainly caused by a higher use of gas (including gas out of biomass).

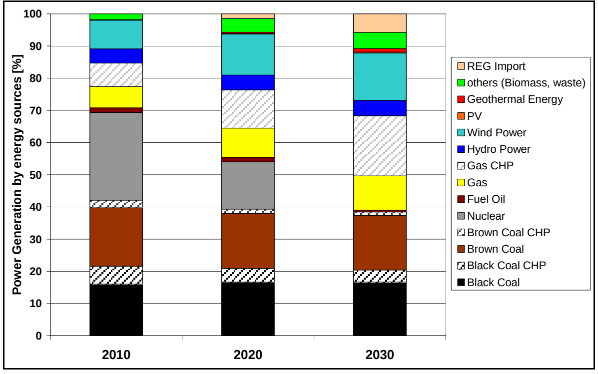

Figure 3: Power generation in efficiency scenario [%]

In the following study case the efficiency scenario is chosen as basis for the simulations because it seems to be the most realistic scenario for the future power supply in Germany.

Study case: DG with CHP units in a distribution network

In this study case distributed CHP systems and ESD are integrated into a distribution network on medium voltage level. Table 1 shows the basic parameters of the analyzed distribution network.

Parameter	Unit
Voltage Level	10 kV
Annual power consumption	100 GWh
Net length	50 km

Table 1: Local power grid parameters

The penetration factor (DG_{CHP}) of installed CHP units is assumed to 30% in the efficiency scenario with:

$$DG_{CHP} = \frac{(E_{in,CHP})}{(E_{in,CHP} + E_{in,HV})}$$

($E_{in,CHP}$= absolute electrical energy generated by CHP, $E_{in,HV}$=absolute electrical energy fed in by overlay system)
The power output of the installed CHP units is changed for different variants as shown in table 2. All CHP units are operating 5.000h/a based on generation profiles and were placed close to loads with equal or higher power demand.

Variant	Output Power of CHP Units
“NO DG”	0
“SMALL”	5 – 200 kW motor CHPs
“MEDIUM”	0,5 – 1 MW motor CHPs
“BIG”	6 MW gas turbine
“NO DG + Stor”	No CHPs but installed ESDs

Table 2: Output Power of CHP units by variants

Integration and layout of energy storage devices in distribution networks

The theoretical integration of ESDs into power flow calculations is impeded by the additional degree of freedom at each spot in the system with connection to an ESD. Since the load profiles used in this investigation are known entirely, there is no uncertainty about the evolution of the energy storage content given, the operational strategy is defined. That means that a sustainable strategy for any of the 24-hours-cycles does exist. Therefore, if the applied operating strategy aims at equalizing the energy contents at the beginning and the end of each standard profile, there must be, for arbitrarily complex ESD loss functions, a pair of a minimum necessary ESD capacity and a new load profile consisting of the sum of the load and the ESD terminal power profile. For the presented investigations, the resulting profile was assumed to be constant, resulting in minimum network losses. The problem of dimensioning ESDs by eliminating the aspect of finding the correct operation strategy is hence solved. Figure 4 shows the result for the 24-h-cycle of a typical standard profile. The resulting, constant line flow in the presence of an ESD is indicated with a dashed blue line and is higher than the mean of the load alone, due the ESD losses. The energy charge state reaches the starting value in the end of the 24-h-period, while having reached its minimum value in between.

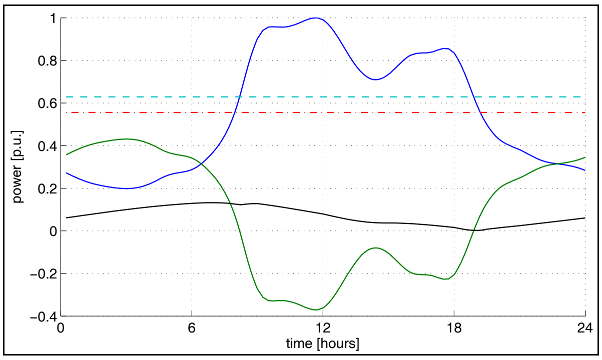

Figure 4: System layout of ESD for a standard load profile.

A concluding remark needs to be made regarding the validity of energy storage calculations with time series. The procedure explained above is of value based on the knowledge of the entire load profile, i.e. the power values of the 24-h-cycle. Only in this way, it is possible to find a deterministic relation between a given load time series and the storage design. If the time series was the product of a stochastic process, the same procedure would be applicable, a procedure that has been used generously in the literature. However, since this time series is only one realization of an underlying stochastic process, the correct result can in fact not be a deterministic value for e.g. the necessary storage capacity, but rather only another probabilistic result. This basic fallacy of understanding has been followed upon in the literature for quite some time. For an analysis of this problem, see [4]. The solution proposition in this paper relies entirely on the statistical relevance of the chosen load time series. The character of this strong simplification needs to be emphasized for the reader.

Results of the eco-efficient assessment with and without energy storage devices

Figure 5 shows that power losses on the medium voltage level can be reduced with DG. In this figure the power losses of the “NO DG” variant are set to 100%. Based on 101 GWh/a electrical energy fed in the distribution network by the overlay 110kV system the power losses on cables and overhead lines are in the range of approximately 1%. Comparing the results, the minimum power losses can be expected in the variant “SMALL” because here the output power of each CHP is always lower than the demand of the consumers at each node where the CHP systems were installed. Contrary effects can be detected in the variant “BIG”, because of power recovery into the overlaying 110 kV system by the 6 MW CHP unit.
The variant “NO DG + Stor” shows that the integration of energy storage devices can lead to reduced power losses. In comparison to the variant “NO DG”, the power losses in the distribution network can be reduced by approximately 5%. The internal power losses of the ESD differ by the system layout and technology, the place and total amount of installations. First calculations show that the internal power losses of the ESD can be below 1% of the amount of electrical energy fed in the distribution network by the overlay system.

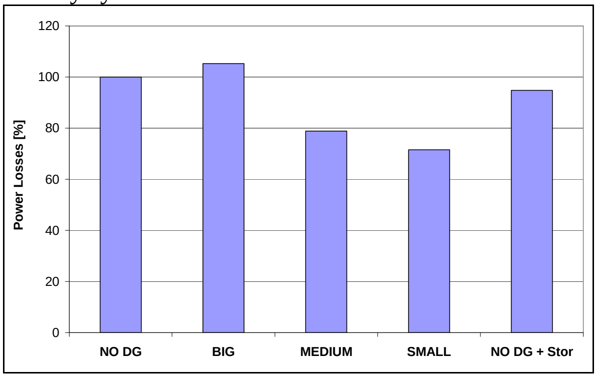

Figure 5: Power Losses by variants

It is obvious that the amount of electrical energy fed into the distribution network by the overlay system can be reduced by DG as presented in figure 6. In this figure the amount of electrical energy in the distribution network in the “NO DG” variant is set to 100%. All other values are referred to this value.

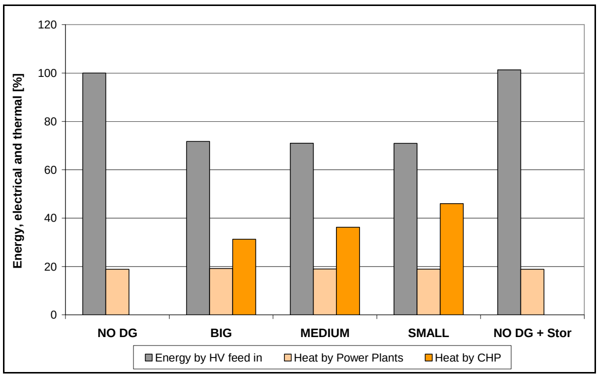

Figure 6: Energy flows (electrical and thermal)

Depending on system layout of the CHP (variation of the CHP power output level) an increased heat output for smaller CHP units can be achieved. The system layout of the CHP units in the “SMALL” variant (5 – 200kW) are optimized on increased heat output instead of power output against the power output optimized units in the “MEDIUM” and “BIG” variants. The variant “NO DG + Stor” has an increased electrical energy demand because of internal energy losses by the ESDs.

Environmental impacts of the variants

The environmental impacts of the variants are shown in the following figures. The results are focused on global warming emissions (GWP) measured in CO_2-equivalents relating to power generation. Beside the power generation the additional heat output of the CHP is included in the specific emissions shown in the next figures by giving credits based on allocation. Figure 7 shows the specific emissions in CO_2-eq./kWh of the local electrical energy mix (per kWh). DG here can lead to lower specific emissions depending on the variant.

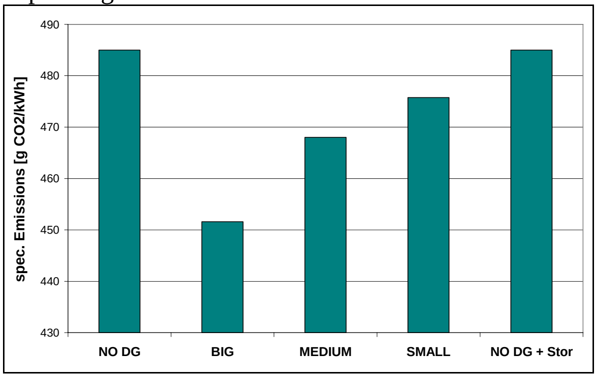

Figure 7: Specific emissions of the local electrical energy mix by variants

In the variant “BIG” the specific emissions can be reduced up to approximately 7% in comparison with the “NO DG” variant because of the high system efficiency (electricity and heat generation) of the gas turbine. The specific emissions of the “NO DG + Stor” variant is equal to the

"NO DG" variant. Here, all electrical energy has the specific emissions of the electrical energy mix fed by the overlay system with 485 g CO_2/kWh.
The emissions of power generation and the manufacturing of the units (CHP and power plants) including power losses measured in CO_2-eq./a are shown in figure 8.

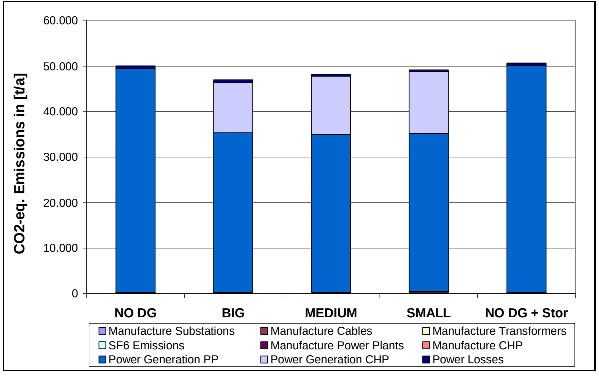

Figure 8: CO_2-Emissions by power generation and manufacture

Obviously, power generation has the largest influence regarding this impact category. Beside this impact the influence of manufacturing of CHPs, power plants, transformers, substations and power losses as well can be neglected. The variant "BIG" with one big gas turbine in the local power grid has the minimal annual emissions caused by its high power generation efficiency and its small material demand per installed power capacity. Disregarding the emissions caused by power generation the influence of the component manufacture and power losses can be seen in figure 9. Power losses lead to the highest amount of emissions in this diagram.
However, it becomes clear that an increased amount of installed small CHP units may result in negative effects on the overall emissions regarding power losses and manufacture.

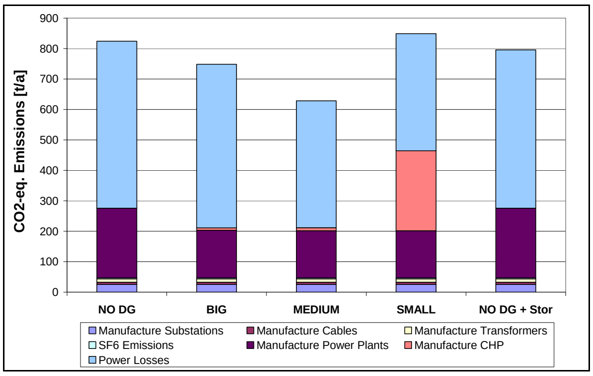

Figure 9: CO_2-Emissions by manufacture and power losses

In a variant with very small CHPs (1-3kW_{el}) installed in each one-family house the impacts of manufacturing will highly increase and could become a more relevant parameter at the system level.
Since energy storage technologies are not available at large scale yet, information sources such as [5] provide sufficient information on the relation between certain technologies and their respective resource utilization.

Conclusions and Outlook

The presented results show the potential of reduced power losses in distributed networks with DG. To achieve this aim the output power of the installed CHPs has to be dimensioned in dependence on the local power and heat demand of the consumer.
The ESD sizing assessment described above allows for the determination of a minimum necessary ESD capacity with respect to a given profile and a specific loss mechanism. EPSs can reduce the power losses as well but the internal system losses may not be neglected.
Considering the environmental aspects it can be noticed that DG with CHP can lead to lower specific emissions of the local electrical energy mix. The higher system efficiency of CHPs against large condensation power plants, which are optimized on power generation, make CHP an available option for a sustainable decentralized energy supply in future. But it is quite uncertain whether the consumer heat demand is high enough in the future which is mandatory for the usage of CHP in distribution networks. New passive houses and low energy buildings will reduce the end user heat demand in the future. This could reduce the high system efficiency of distributed CHP systems when the heat is not used and lead to higher specific emissions of such systems as mentioned here.
Sophisticated multi-parameter simulations and optimization procedures will be necessary to evaluate possible „Brake-Even-Points", above which DG and ESDs are useful to obtain sustainably operated future distribution networks.

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