COMPARISON OF FUTURE ENERGY SUPPLY SCENARIOS WITH DISPERSED GENERATION IN DISTRIBUTION NETWORKS

Thomas SMOLKA  
RWTH Aachen – Germany  
smolka@ifht.rwth-aachen.de

Thomas Dederichs  
RWTH Aachen – Germany  
dederichs@ifht.rwth-aachen.de

Prof. Dr. Armin SCHNETTLER  
RWTH Aachen – Germany  
schnettler@ifht.rwth-aachen.de

Bernhard SCHOWE-VON DER BRELIE  
FGH Mannheim e.V. – Germany  
Bernhard.schowe@fgh-ma.de

ABSTRACT

The massive integration of dispersed generation of combined heat and power units (CHP units) brings up challenges for today’s distribution networks that they not have been planned for. However, it is not yet fully understood in which areas and under which precondition, CHP units shall be installed and could be efficiently operated with minimum environmental impacts. In this paper an analysis of different energy supply scenarios for different distribution networks in Germany in 2030 evaluating the environmental impacts and the effects on grid planning is presented. Based on a comparison of these scenarios recommendations are given in which areas and under which preconditions a local heat and power supply with CHP units is more environmental friendly compared to centralized power generation in large power plants combined with conventional heating systems.

INTRODUCTION

Environmental protection and the efficient utilization of natural resources is the main aim of a sustainable energy supply assuring availability of energy with taking economical aspects into account. For ensuring a sustainable energy supply for the end-user the components of future power grids, high efficient dispersed generation units and optimized distribution networks with minimized losses and emissions are necessary. Until now these technologies are often optimized only in one of the following sustainable criteria:

- Best Economical Value
- Highest technical Efficiency

Additionally, there is a need to evaluate whether the massive integration of dispersed generation units (wind, biomass, photovoltaic) provides a more environmental friendly energy supply or if it involves contrary effects, e.g. the need to provide either additional reserve power or energy storage devices for fluctuating generation. Thus, as an important step towards a reliable and economical and ecological optimized future power supply, it is vital to develop new energy supply scenarios that meet the future energy demand in distribution networks with reduced heat consumption and a higher electricity demand caused by new e-mobility applications and a higher penetration of consumer electronics. First the trends in power and heat consumption in Germany until 2030 have to be analyzed.

TRENDS IN ENERGY CONSUMPTION AND GENERATION IN GERMANY

The overall trend of electricity consumption from 2000 to 2030 in Germany can be estimated as nearly constant by analyzing the sectors industry, private households, trade and commerce and transportation as shown in figure 1.

![Figure 1: Trend of Electricity Consumption in Germany](image)

Possible increases in electricity consumption caused by a higher use of air conditioning and information and communication technologies will be compensated by higher energy efficiency.

In contrast to, the overall heat demand up to 2030 will reduced significantly. In the sector private households the heat demand will be reduced up to 20% while the heat demand in the trade and commerce sector could be downsized up to 30% due to better insulation of private and business houses, as shown in figure 2.
Based on the possible trends in energy consumption three possible scenarios in electricity generation can be described. The reference case would be a trend development in electricity generation based on the status-quo following the most likely environmental - political parameters. By extending the operating time of the existing nuclear power plants and assumed a high integration of renewable in the future the “best case” scenario can be described. The “worst case” scenario under ecological aspects for Germany would be a reduced development of electricity generation by renewable energy combined with a high amount of new coal fired power plants which would lead to the highest specific CO2-equi. emissions of the future electrical energy mix in Germany as shown in figure 3.

By a variation of the influencing parameters and simulation of each scenario in the implemented system model in the material and energy flow software Umberto the environmental impacts of each scenario can be calculated. Table 1 presents the analytical framework of the scenario analysis. For a detailed analysis of the model see [3].

Table 1: Analytical Framework of the scenario analysis
The scenario analysis is done for two different distribution networks described in table 2.

<table>
<thead>
<tr>
<th>Distribution Network</th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Region</td>
<td>Urban</td>
<td>Rural</td>
</tr>
<tr>
<td>Voltage Level [kV]</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Share of households [%]</td>
<td>0.63</td>
<td>0.66</td>
</tr>
<tr>
<td>Share of Trade an Commerce [%]</td>
<td>0.37</td>
<td>0.34</td>
</tr>
<tr>
<td>Peak Load [MW]</td>
<td>26.6</td>
<td>33.7</td>
</tr>
<tr>
<td>Electrical Energy Demand [GWh/a]</td>
<td>46.8</td>
<td>44.1</td>
</tr>
<tr>
<td>Heat Demand [GWh/a]</td>
<td>165.3</td>
<td>179.9</td>
</tr>
<tr>
<td>Heat to Power Ratio (HPR)</td>
<td>3.5</td>
<td>4.1</td>
</tr>
</tbody>
</table>

Table 2: Figures of the considered distribution networks

The scenarios with CHP units are divided in three variants, all dimensioned on the local heat demand:
- **CHP Decentralized**: The CHP units are installed in each household (1-50kW).
- **CHP Local Heating**: Each CHP unit powers the underlying network of a medium voltage transformer (50-1000kW).
- **CHP District Heating**: Only a few CHP units are installed in the medium voltage network including a heat supply by using a district heating system (1-10MW).

**EXEMPLARY RESULTS**

**Exemplary Results for the urban network (A)**

The specific emissions in heat and electrical energy mix show the results of the scenario analysis of CHP integration in the urban distribution network in figure 5.

![Figure 5: Specific Emissions of the different scenarios in the urban distribution network (A) with HPR 3:1](image)

The dominant scenarios are P2 (CHP with district heating) with lowest electrical energy mix and heat mix emissions and P3. The scenario with no CHP units installed (P1) has the lowest specific electrical energy mix emissions but higher heat mix emissions due to the use of conventional heating systems instead of heat out of high efficient cogeneration units. It is obvious that the scenarios with small CHP installed in each household have ecological disadvantages compared to CHP units in a larger power range which have a higher electrical coefficient efficiency.

The overall installed CHP capacity in the distribution network lies below the maximum grid load in most of the considered scenarios. The installation of fuel cells with a higher electrical coefficient than motor CHP units lead for a HPR 3:1 and 4:1 to a - the maximum grid load exceeding - installed overall capacity as shown in figure 6. In these scenarios it has to be analyzed if local network transformer or other components get overloaded in peak load times and have to be replaced.

![Figure 6: Installed CHP capacity in the urban distribution network (A)](image)

**Exemplary Results for the rural network (B)**

The ecological impacts of the scenario analysis in a rural network show differing results compared to the urban network. The dominant scenario with lowest electrical energy mix and heat mix emissions is a scenario with no CHP units installed. Caused by a high amount of one-family houses a proportion of 74% electrical heat pumps were installed in this scenario. Combined with the lowest electrical energy mix of 380g CO₂-equivalent/kWh this scenario has the lowest overall emissions as shown in figure 7.
Figure 7: Specific Emissions of the different scenarios in the rural distribution network (B) with HPR 3:1

The overall installed CHP capacity exceeds the maximum grid load in the scenarios with fuel cells for HPR 3:1 and 4:1 and in the CHP district heating scenario with 4:1. Here it has to be analyzed if local network transformers or other components (cables etc.) get overloaded in peak load times and have to be replaced.

Figure 8: Installed CHP capacity in the urban distribution network (A)

SUMMARY AND OUTLOOK

Different scenarios of CHP integration (decentralized, local and district heating with CHP units) have been analyzed and compared to a centralized power supply with conventional local heating systems. The integration scenarios are specified varying the identified influencing factors of the power generation mix of centralized power plants, the structure of conventional heating systems (heating mix), the fuel mix and the local heat-to-power ratio in distribution networks. Due to the evaluation method developed it is possible to evaluate and compare multitude decentralized energy supply scenarios considering ecological and technical circumstances. These are then compared to an energy supply following the reference development without dispersed generation. In highly populated areas a CHP-integration should be realized in combination with local or district heating networks. Integration of decentralised CHP units into medium or highly populated areas shows a higher CO2-reduction potential compared to an optimization of present large power plants on the system level. Decentralized generation units with a high electrical efficiency are necessary if assessing a significant reduction in heat demand in future scenarios. Assuming a CHP unit dimensioning on the local heat demand – as today’s customary – leads to an installed capacity which is much higher than the maximum electrical load. Here, feed in power in the overlaying system is likely to occur during light load times. This variation requires dimensioning of the CHP units according to the local power demand. Additional integration of electric consumer loads such as heat pumps, electrical air-conditioning or electric vehicles can be an opportunity to reduce generation into the overlaying system. Fuel cells do not have any ecological advantage compared to CHP units equipped with internal combustion using standardized natural gas. Only using hydrogen as one of all renewable sources that cannot be integrated into the energy supply system (e.g. surplus funds of wind energy) leads to ecological advantages.

The integration of dispersed generation with CHP units is a local implemented method reducing green house gases and increasing energy efficiency in distribution networks. In addition to the promotion of CHP integration in distribution networks a national strategy has to be implemented in order to achieve the targets of the formulated environmental production by reducing the consumers’ energy demand and improving the electrical energy mix of the overlaying system.

REFERENCES

