MODELLING APPROACH TO ASSESS THE IMPACT OF HEAT AND ELECTRICITY STORAGE ON DISTRIBUTION SYSTEMS

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ABSTRACT

Based on a simulation model for the analysis of heat pumps, dispersed units for combined heat and power generation and renewable energy sources a tool has been designed which calculates optimal operation strategies for these units placed in distribution networks together with storage systems by applying generation and load management. At the same time the influence of additional electrical and thermal storage systems is analysed using different objective functions

INTRODUCTION

A strong decentralisation of the energy supply is expected to occur in Germany in the course of the coming years, especially due to the encouragement by the policy framework which sets subsidies for renewable energy sources and for combined heat and power generation. As a result of the growing share of renewable energy sources with their inherent volatility and uncontrollability of generation in the future there will be more points in time at which generation and load do not match each. Therefore, action is needed in order to balance the influence of fluctuating renewable energy sources and to ensure an uninterrupted power supply.
The integration of energy storage systems into the existing electricity networks is an important component in order to realize the projected expansion of renewable energy sources and at the same time ensure the security of supply. In addition, smart grids should automatically compensate for over- and undersupply. The use of thermal energy storages offers the possibility to align the operation of heat pumps and cogeneration units with the electricity demand in the network without endangering the security and stability of the heat supply.

MODELING OF PLANTS

The decentralized conversion technologies are mainly connected close to the loads in the respective distribution networks at a low voltage level. The individual units in a grid area are usually operating independent of each other. Systems of combined heat and power (CHP) work mostly in heat driven mode, which means that their operation depends on the local heat demands. To investigate the influence of increasing decentralized energy provision in the existing networks and in order to perform an economic and ecologic analysis, a bottom-up modelling of the various decentralized conversion technologies is necessary to account for the stochastic operating behaviour. The focus of this model is to develop stochastic load and generation profiles for individual decentralized systems. Furthermore, the use of thermal and electrical storage technologies in intelligent distribution networks is examined under different operating strategies. The technologies considered are combined heat and power plants, heat pumps and, additionally for each facility, a thermal tank to avoid the undesirable clock operation of the systems. Furthermore, renewable energy converters and electrical storage systems are included.

CHP units

The rated power of the cogeneration facility is set in the model to a reasonable level with respect to the heat demand in the building assuming dual-mode operation. In addition, a peak load boiler is included for each plant to support CHP on the coldest days of the year. As input parameters the model uses a heat load profile. Depending on building type, year of construction and rehabilitation a practical supplement is added [1].

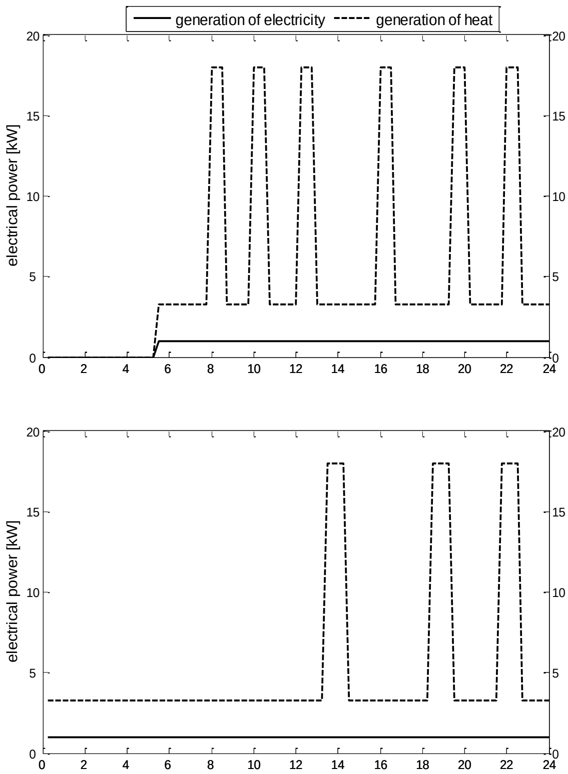

Figure 1 Synthetic production profiles for CHP (example)

Each CHP plant is either turned on or turned off at each time interval of the day according to the local heat demand and the condition of the existing thermal storage. Since the state of the thermal storage and heating demands of the individual objects differ from each other, the output of the model comprises a stochastic production profile for each day of the year. In Figure 1, for example, the production profiles (electricity and heat) of two cogeneration plants for a house on a winter day (here: November, 13th) is presented. The electrical rated power is 1 kW while the thermal rated power equals 3.25 kW. The stochastic behaviour of individual plants can be seen in the figure: While one of the CHPs (upper panel) is turned on at 5 a.m., the other one (lower panel) is in operation all day. The peaks in the thermal profiles indicate the use of the peak load boiler.

Heat pumps

Like the cogeneration plants, the electric heat pumps also run heat-operated in the model and turn on and off stochastically. The main differences in comparison to the cogeneration technology are that the heat pump operation leads to load profiles instead of electrical production profiles and that the efficiency of the heat pumps depends on the temperature differences between heat source and sink. This means that the electrical power needed in relation to the requested amount of heat not only depends on whether water is heated for direct use (higher temperature) or for the heating system (lower temperature), but also on the heat source and its temperature level.

Renewable energy sources

The renewable energy sources considered in the model are photovoltaic (PV) generators and small wind turbines. In the following modeling, PV (rated power 3kW-8kW) is assumed to be installed only on the roof of residential buildings while the small wind turbines can be installed either on roofs or in the back yard (rated power 1kW-10kW). In contrast to cogeneration and heat pumps these technologies can not adjust to the energy demand as their output depends on the weather conditions. Therefore, in addition to the technical parameters (such as efficiency, roof area, building height, rotor diameter, etc.) the model considers the weather data of the examined region in the appropriate resolution in order to calculate generation profiles.

Storage systems

A range of technologies is able to store thermal energy. However, using today's knowledge only systems based on sensible heat storage which store thermal energy directly by heating up the storage media are economically feasible. At temperatures which are typical for domestic heating the typical technical solution would be an insulated water reservoir. Compared to other materials like concrete or sand the high thermal capacity of water (1.17 Wh/(kg*K)) leads to a sufficiently compact design. Latent heat storage systems using phase change materials or systems based on reversible chemical processes are not included in the model because of their high costs and limited availability on the market. However, they can be easily added to the model by using new parameters for costs, losses and operation behaviour.
Today pumped hydro plants are commonly used to store electrical energy. However, they are highly dependent on the topology of the landscape and inflexible in their size. Therefore they cannot be seen as the preferred technology for the application in distribution networks. Hence, the electrical energy storage systems in this assessment are limited to different types of battery storages with individual investment costs, efficiency and standby losses.

OPTIMISATION OF THE OPERATION

The modeled generation profiles represent the heat driven operation of CHP units. Consequently the operation hours depend on the demand of thermal energy by the object to be supplied. In this uninfluenced operation mode, the generated electricity is fed into the distribution network without taking the current demand for electricity into account. Combined with additional local electricity generation (e.g. from photovoltaic) a situation can be reached in which the surplus of energy endangers the stable operation of the electric power grid.
By the introduction of thermal energy storages it is possible to shift the operating hours of the CHP units to time intervals with insufficient generation (see figure 2) because the heat storage guarantees that the demand of thermal energy is met at any time.

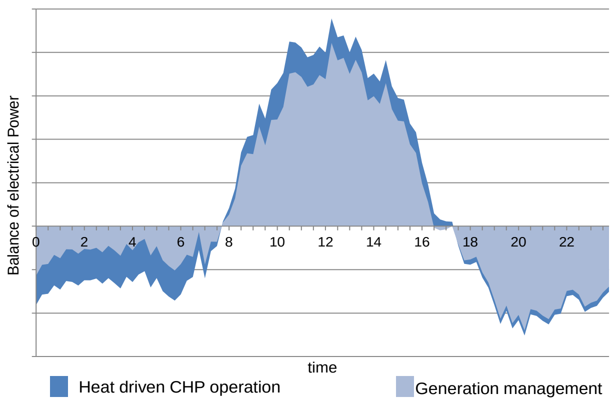

Figure 2 Intelligent operation control of CHP units

This optimisation can be carried out by using the objective of a distribution system with a high degree of autarky. This means in this case that the distribution network is almost independent of the transmission network and is mainly supplied by local generation from renewable energy sources and CHP.

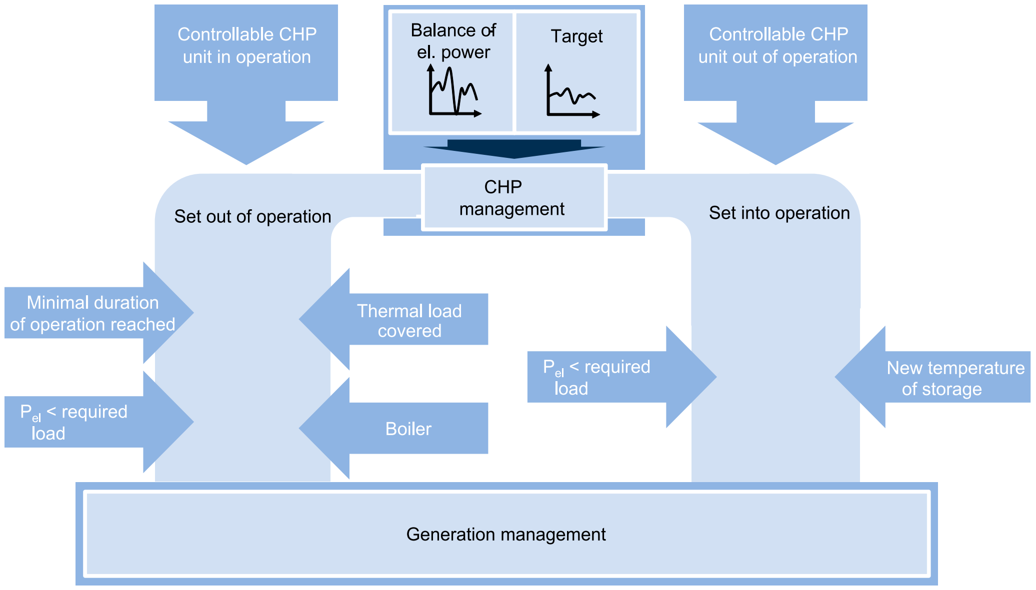

Figure 3 Generation management for CHP units

A second approach for the examination is the harmonisation of power flows. The objective function aims to reduce the maximum load of the assets in order to reduce transmission losses. Apart from the different objective functions both approaches are based on the implementation of a generation management for CHP units and a load management for heat pumps, respectively.
For load and generation management the model uses a time resolution of 15 minutes. In the following the approach for CHP units is described: Firstly, based on the temperature of the heat storage, the current heat demand and a number of technical parameters it is checked whether the current condition of the CHP unit necessitates changes to the current state of operation. A projection for the heat demand of the following 24 hours is used to prevent the unit from working in a mode with on-off-cycles as they reduce its durability. If deemed beneficial a change in the state of operation will be done. The constraints are shown in the simplified figure 3.
The approach for heat pumps follows the same principles while different technical parameters have to be taken into account and the objective of the controlling is inverted as a heat pump represents an electrical load. The battery storage is then used to balance the remaining deviation from the objective value, for example to enhance the electrical autarky.

EXEMPLARY RESULTS

The developed model has been used for the assessment of an exemplary supply area with 102 private households. In the network area examined the local electricity generation from CHP (56%), photovoltaic (36%) and wind energy (8%) matches approximately the annual energy demand of 300 MWh. However, there are seasonal differences between generation and demand of roughly 20%. In order to compare production costs of the specific technologies as well, life spans and costs have been assumed according to [2].

Autarkic operation

The analysis shows that a combined operation of CHP units and thermal storage systems within an intelligent distribution network can reach similar grades of autarky up to a specific level at much lower costs as compared to the installation of battery storage. Firstly, the advantage of heat storages rises faster with lower additional costs. However, there is always a point of saturation where additional heat storage yields no further benefits.

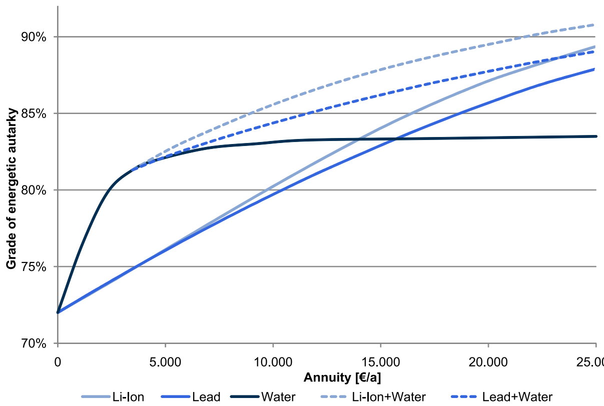

Figure 4 Autarky of the system using different storage technologies

An example for the relationship between costs and autarky is shown in figure 4. It displays the results for the supply area described above using today's costs and life spans for battery storage systems. A scenario analysis has been carried out which showed that for any generation mix there is always a region in which heat storages are superior to batteries when considering the ratio of cost- to autarky increase. The combined operation of electrical and thermal storage (dashed lines) allows higher grades of autarky at lower costs compared to the sole operation of battery storages. It shall be noted that the costs only represent additional costs for storage systems but no investment or operation costs for the generation units.

Homogenisation of power flows

Whereas the objective of autarky aims to bring the load balance down to zero, the target value becomes variable with the objective of power flow harmonisation. For the supply area described above a forecast of generation and load has been done with a resolution of 15 minutes. The mean value of the load balance is then the target value for load and generation management. This relationship is shown in figure 5 for a selected week. The target value became time dependent and rose slowly during the week from a starting point of -18 kW. Small fluctuations in the load balance can be almost fully balanced by the storage technologies whereas a high disequilibrium cannot be balanced like in the case of the operation strategy "autarky". As a result the analysis of the assets shows that the loads on lines and secondary substations are significantly lower than in the unaffected operation.

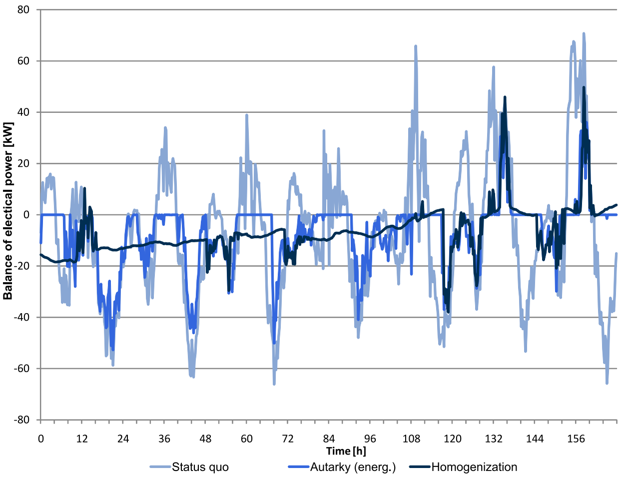

Figure 5 load balance of the system in a selected week

CONCLUSION AND OUTLOOK

In a first step the introduced approach allows simulating the operating behaviour of dispersed energy conversion units and the influence of a significant number of these units on the distribution networks. Second, a generation and load management has been implemented in order to control the load balance of the supply area according to the chosen objective function. Therefore the operation of thermal and electrical energy storages has been included.
In the future the model shall be linked to an optimisation tool for designing the setup of the heat and electricity supply in a specific area. Using local generation based on renewable and fossil energy sources a supply area can be autarkic for some period of time. For this purpose the objective function for load and generation management could be changed in a way that the energy exchange with the transmission grid becomes dependent on the electricity prices on the wholesale markets in order to generate additional income towards the distribution grid.

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