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Demand side management for city districts

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ABSTRACT

The increasing installation of volatile renewable energy sources like photovoltaics and wind enforces the need for flexibility options to match the renewable generation with the demand. One of these options is Demand Side Management (DSM) in the context of building energy systems combined with thermal storage systems. This paper discusses such concepts for DSM. A method for analyzing the flexibility that is needed to maintain the stability of the electrical grid is presented followed by the restrictions that are caused by meeting the heat demand and satisfying the comfort criteria of the residents. Approaches for simultaneously fulfilling these constraints as well as matching the flexibility needs of the electrical grid and the flexibility provided by the local building energy systems are discussed. To enhance the analysis options for the shown systems, a simulation platform that covers the electrical grid simulation, the building systems' simulation and the control strategies is presented. This platform can be used to analyze different scenarios of building energy systems with different penetrations of renewable energy sources and different building types.

1. Introduction

It is widely accepted that emissions of greenhouse gases lead to climate change, carbon dioxide (CO_2) being the primary reason for this process [1,2]. Therefore, the reduction of CO_2 emissions emanating from burning fossil fuels and industrial processes is one of the goals set forth in international regulations. This goal can be reached by reducing the energy usage in general and by increasing the generation from renewable energy sources (RES) like biomass, wind and solar energy.

Currently, the demand of energy in industry, residential, transport and tertiary sectors is distributed as shown in Fig. 1. Transport and the residential sector are the largest consumers. In the residential sector, the energy consumption predominantly occurs for electrical appliances and heating purposes, therefore buildings offer great potential for improvements of energy efficiency.

This potential has also been recognized in political regulations. The Energy Performance of Buildings Directive (EPBD) [4] of the European Union for example defines limits for energy consumption of buildings. The related European standards are currently transferred to national standards and laws. In Germany for example, the transition towards a renewable energy supply is known as 'Energiewende'. As a result of these regulations, Germany has currently approximately 83 GW of installed renewable electricity generation capacity and in 2014 up to 30% of the generated electricity is expected to be renewable [5]. While this progress is in general very positive, the dynamic changes in the availability of solar and wind energy complicate the integration of RES into the power system. Already today, strong renewable generation in off peak demand phases results in local overloads of distribution grids and the requirement to curtail renewable generation.

Possible solutions to these emerging challenges in the energy generation and distribution are improvements of the existing electrical energy grid as well as the introduction of energy storage. While these measures help to secure the energy supply, they are very expensive if integrated into a centralized generation infrastructure.

Other solutions should therefore be available to generate flexibility to always match the generation and demand of energy. Inexpensive central or decentral storage technologies for energy would be a favored solution. Decentralized power generation can serve as another option as it reduces the load on the transmission network and simultaneously reduces losses for conversion and transmission.

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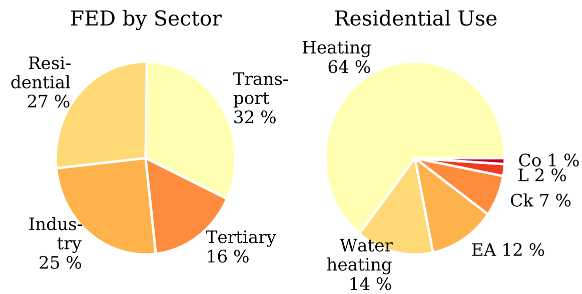

Fig. 1. Final Energy Demand and use in EU countries 2010 [3]. (Co: cooling, Ck: cooking, L: Lighting, EA: electrical appliances).

In light of the EU's plans to extend renewable energy generation to at least 55% by 2050 and an almost doubling share of electricity use [6], these difficulties will become a major problem and potentially a threat to the concept of the 'Energiewende'. To minimize the requirement for expensive back-up generation capacities and controversial extension of the power grid, it is necessary to develop concepts for matching electricity production and consumption. It is expected that Demand Side Management (DSM) will play a major role in the future energy system.

DSM is the concept of influencing consumers' energy demand in respect to the consumed amount of energy in general and the time dependent consumption behavior, with the purpose of changing the load-shape according to the concurrent availability of electricity in the grid [7]. These measures yield at both, time pattern and magnitude of the load. The concept of DSM itself is not new, one of the classical applications in the energy sector has been to ensure constant operation of inflexible base load power plants. Typical DSM methods include reducing peak loads (*peak clipping*), shifting load from on-peak to off-peak (*load-shifting*), increasing the flexibility of the load (*flexible load shape*) and reducing energy consumption in general (*strategic conservation*) [7–9].

1.1. Domestic demand side management

The most present manifestation of domestic DSM is the smart control of white goods (e.g. washing machines or dishwashers) according to availability of renewable energy. While this DSM approach is often presented in the media and usually directly related to the term 'Smart Home', it is still conceptual and can only be seen in demonstrator projects. Furthermore, only very limited amounts of energy and peak loads can be shifted through the control of domestic electrical appliances. Caused by this, the usage of thermal storage for DSM purposes offers a variety of options [10]. Heating devices, such as night storage heaters (NSH) and heat pumps (HP) are already operated according to external price or availability signals. While NSH usually have a static signal given by fixed hours with a lower nighttime electricity tariff, HP often receive dynamic signals for up to two daily shut-off periods during peak consumption periods. Such control is already available. Therefore, in future the often discussed real time pricing should be connected to heating systems in addition to electric appliances [11].

Since heating systems do not only consume electricity, but can also provide power to the grid, as for example combined heat and power (CHP) units, supply systems can offer both, positive as well as negative demand response to the grid. Both HP and CHP are potentially supplemented by Heating Rods (HR). In addition to the compensation of fluctuating electricity generation, supply systems can also react dynamically and even automatically to changes in voltage or frequency, thus stabilizing and protecting the power grid from failures. All aforementioned HVAC systems (HR, HP, NSH and CHP) are in the following named as electrical-grid coupled heat generators (EHG) while the entire system consisting of the building physics, the heat generators, storages, the distribution systems and the occupant behavior is named as building energy system (BES).

The thermal demand of buildings, however, is usually not very flexible itself and therefore requires thermal storages which allow for decoupling heat generation and demand [12]. In NSH, the storage is already integrated within the mass of ceramic bricks, while HP require water based buffer tanks to allow for flexible operation. Another option which is being analyzed is the direct usage of the buildings thermal mass to store the thermal energy [13]. This is especially promising in combination with heating systems directly connected to the buildings mass, like floor heating or concrete core activation systems [14]. Besides thermal storage options, electricity required for heating purposes could be stored in batteries, being transformed to heat when the heating demand occurs. However, our analysis has shown that due to the very high costs of batteries in comparison with thermal storages the utilization of electric storages for heating purposes will not be economic in the upcoming years [12].

1.2. Concept of dual demand side management

Matching excess or missing generation of fluctuating renewable electricity with the heat demand of buildings requires dynamic DSM control and interaction of thermal and electrical systems. Therefore, the typical DSM concept was extended towards the idea of Dual Demand Side Management (2DSM), a concept controlling electrical and thermal energy flows on the local and on the city district level in a holistic way.

The 2DSM concept aims at exploiting the entire potential of thermal storage capacities on city district level to contribute consumption and generation flexibility for the electrical grid. Furthermore, as opposed to currently implemented DSM approaches, 2DSM will also account for the current condition of the local distribution grid. Thereby, the distribution grid is monitored to ensure that line utilization and voltage will be always in the requested ranges even if local renewable generation or DSM activities are stressing the grid. The demand for flexibility in the distribution grid is discussed in Section 2 while the restrictions of the BES to offer flexibility are discussed in Section 3. If necessary, the 2DSM system will react and deviate from the intended operation scheme to protect the grid. The potential algorithms for matching flexibility demand and supply are introduced in Section 4.

In order to assess the potential of the 2DSM concept under most realistic simulated conditions, a model of a city district energy system has been implemented. The model allows for simulating different configurations of the energy system and supports the development of energy management algorithms which can be tested within a simulation environment. The parameterization of the developed model has been carried out based on an existing city district in Bottrop, Germany. To enable the simulation of a city district energy system comprising several hundreds of buildings and the corresponding energy supply infrastructure, a simulation platform had to be developed. The simulation platform enables the flexible integration of different simulators as introduced in Section 5.

2. Flexibility demand of electrical distribution grids

Operation and planning of distribution grids is undergoing a fundamental change, not only in the case of a growing number of decentralized RES with uncertain power injection, but also in terms