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Flexibility assessment of a pool of residential micro combined heat and power systems

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ABSTRACT

This paper presents a simulation study to explore the flexibility of a pool of residential combined heat and power plants (cogeneration systems) coupled with thermal storages. Flexibility is identified by sending daily trigger signals (ON and OFF) of various signal lengths to a pool of 60 micro cogeneration systems over the course of one year. A randomization approach is used in order to reflect realistic system sizing based on commercially available components. Each system operates individually based on its thermal demand. The response of the pool to the external signals is evaluated. Flexibility is characterized by flexible power, flexible energy and pool regeneration time. Results show that both signal types can potentially activate a significant amount of flexible power and energy. The flexibility is highly dependent on the ambient temperature and the signal duration.

1. Introduction

In the traditional energy distribution system central power plants feed electricity into the grid at high voltage levels. Typical consumers are located on low voltage. The existing power grids are planned and constructed for the optimal use of the unidirectional power flow from the producer towards the consumer. Requirements for this centralized system changed within the last decade [1]. A growing share of renewable energy that is generated by decentralized devices is fed into the grid [2]. In Germany for example, the share of renewable generation was as high as 38.3% of the total generated electricity in 2017.[1] Local distributed renewable energy systems usually feed into the grid at low voltage levels. Such drastic changes imply increased utilization of advanced concepts and control systems to enable flexible demand through demand response technologies and proper system integration [3]. Power-to-heat and the co-generation of heat and electric power (Combined Heat and Power plants, CHP) are both well known technological concepts for heating and cooling of residential buildings. Heat Pumps are the most prominent technology used in single family houses. From 2010 to 2015 approximately 800.000 electrically driven heat pump units have been sold in the European Union (EU21) per year [4], adding up to more than 7.5 million units. CHPs with a nominal electric power output of around 5 kW (μCHP) combined with thermal storages are more suitable to be installed in residential multi-family buildings [5]. It has been shown that these systems can be operated to provide flexibility to the power system and help the transition towards a high share of renewable electricity and heat supply [6]. Several objectives have been considered to influence the operation of single units or a pool of aggregated units. In [7], time-variable electricity tariffs were used to motivate system friendly behavior. In [8], the contribution of μCHPs to stabilizing the frequency in local distribution grids by controlling the CHPs' electricity output in response to significant fluctuations in system frequency was discussed. When equipping a building with a μCHP, a model with a suitable thermal power is chosen. By means of the buildings historical thermal demand, the sizing of the μCHP is selected so that the unit has a high full load runtime. Runtimes between 4.000 and 5.000 h per year are common [9]. While this sizing strategy optimizes the individual usage of the μCHP for the single prosumer, a high obligatory runtime diminishes the flexibility that the unit can potentially provide to the energy system.

With ongoing decentralization in the modern energy system, distributed energy resources have the potential to not only deliver the valuable electricity services that have traditionally been provided by centralized generating units, but also new services enabled by their distributed nature [10]. For system planners and operators, a key question is how much flexibility is available in their grid and how can it

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[1] https://www.energy-charts.de, accessed on 12th Feb 2018.

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be triggered. The reaction of a pool of μCHPs in a distribution grid to a given signal at a given time has to be approximated in order to be able to design control strategies and demand response schemes. In this paper, this question is addressed by modeling a pool of residential μCHPs. The pool's reaction to external broad-casted control signals is analyzed. A method to study and characterize the potential flexibility the pool can provide is presented. Flexibility parameters are identified and analyzed. The technological focus of this study is on residential μCHP units planned for multi-family buildings and used for the preparation of domestic hot water (DHW) and for space heating (SH).

1.1. View on flexibility

Demand-side management, involving energy efficiency, demand response, and distributed generation, is an efficient and effective way to improve the resilience of the energy system via changing the profile of power demand and generation of a spatially confined power system [11]. In the context of demand-side management, the applied view on flexibility is such a system's ability to modify its energy generation and consumption in response to external signals [12]. Adapting the definition of D.Fischer et al. in [13], the flexibility of a pool of distributed generation units is investigated by the parameters: amount of power change, shifted energy and pool regeneration time.

1.2. Previous work

An overview on μCHP technologies operated in combination with renewable sources is given in [14]. After detailed discussion on up-to date technologies, the authors conclude that CHPs in combination with thermal storages are an efficient way to introduce higher shares of renewables in both residential and industrial environments. On individual household level, most studies on μCHPs focus on optimal system sizing and design, efficiency and operation control. Sizing of a hybrid solar μCHP system for the household sector was optimized in [15]. The authors focused on the importance of optimal sizing of renewable microgeneration systems. They found that optimal sizing enhances savings in dwelling sector applications. Predictive and non-predictive control strategies have been used to align CHP operation with on-site generated renewable energy. In [16] an economic dispatch of a micro gas turbine is considered for smart grid integration. An optimization model is developed for solving the problem of integrating the turbine into the grid based on varying economic drivers. A probabilistic framework based on a scenario method for microgrid management was set up in [17]. Operational cost are reduced by time-of-use rates of demand response programs. In [18], the authors propose a combined control algorithm for PV-CHP hybrid systems. The algorithm combines a model predictive control and a rule-based control to correct setpoints for incorrect PV and load forecast. A metaheuristic modelling approach was introduced in [5]. The approach relieves the complexity of the scheduling compared to other methods like linear programming. The authors evaluate their combined heat and power scheduling in a hypothetical building to serve the electrical and thermal loads driven by the occupants' comfort requirements.

The target of aggregator level controls, in contrast to individual household level approaches, is to modify the operation of a pool of devices in order to fulfill a certain goal in the context of the electricity system. A possible goal could be the provision and commercialization of the pools' flexibility. In a case study that focuses on wind power integration as a specific use case with optimal system knowledge, [19] shows that the power system can potentially benefit from flexible operation of pools of decentralized generation units and highlights the seasonal characteristics of their load shifting availability. In [20], the authors use pools of CHPs in combination with enlarged thermal storages to maximize the integration of renewable generation into the energy system. Virtual power plants composed of μCHPs amongst other technologies were analyzed to optimize bidding strategies for aggregators on electricity markets in [21].

Generally, when controlling pools of distributed units, there exist centralized and decentralized approaches [10]. In a decentralized approach, the field devices receive information (e.g. electricity prices) and optimize their behavior individually according to that external signal. In a central approach, operational planning is done in a central place and all operational decisions and individual set points are transmitted to the field devices.

A central question for any kind of load control and flexibility provision is which information is available as feedback for the aggregator to do operational decisions. This information could range from only metered power up to high resolution storage sensor values. Multiple studies analyze flexibility provision by distributed devices: [22] find that currently, there is no valuable insight into how much flexibility a specific building or a cluster of buildings may offer. Their study gives an overview over the theoretical approaches and existing indicators to evaluate this flexibility. In [23] a dynamic flexibility function for buildings and districts is proposed. In contrast to a static flexibility output at every time step, a flexibility index describes to which extent a building is capable to respond to the grids need for flexibility. In a study focussing on multi market bidding strategies for demand side flexibility aggregators in electricity markets, [24] find that the challenge is to allocate volumes to the different markets in an optimal way. They propose a methodology for optimal bidding for a exibility aggregator participating in sequential markets.

1.3. Presented work

While previous studies on μCHPs provide valuable proof that the systems can be used for load shifting and demonstrate advanced control approaches, most are demonstrated on the level of individual systems and only a few analyze the behavior and the potentials of a pool of single systems in a spatially confined system like a distribution grid. Studies on aggregators show a rather theoretical approach or focus on the optimal selling strategies for flexibility. Considering a pool of μCHPs, there are points that have not yet been sufficiently analyzed, which are addressed in this paper:

- Realistic single unit implementation for a pool of μCHPs including system characteristics like efficiency, storage size and CHP sizing.
- Definition of parameters to evaluate the flexibility of a pool of residential CHPs accessible by external trigger signals.
- Analysis of the characteristic response of a pool of μCHPs to external trigger signals.

This paper presents a methodology to model a pool of residential μCHPs that combines stochastic bottom-up energy demand models with a randomized system sizing based on commercially available components. Furthermore, it evaluates the pool's flexibility. Within the pool, each unit operates on its own accord. Broadcast signals to influence the pool behavior are sent to all unit models.

2. Methods

Fig. 1 shows the method used in this paper to simulate the reaction of a pool of μCHPs to an external trigger signal and to evaluate the pools flexibility parameter. The individual levels are described further in the following.

2.1. Single unit models

The single unit models in the pool consist of a single- or multi-family household thermal-electrical load profile, a μCHP system and a defined reaction of said system to external trigger signals.

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