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# Corrective receding horizon scheduling of flexible distributed multi-energy microgrids

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## HIGHLIGHTS

- Defining optimal configuration between centralized and distributed MEM configurations.
- Flexibility of MEM increases with consideration of additional energy vectors.
- Annual operational costs are independent of the model approximations (e.g. MEM unit efficiency modelling).
- Significant errors occur if approximations are used for MEM daily operation analyses.

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## ABSTRACT

The goal of the paper is to provide a comprehensive operational flexibility evaluation of different Multi-energy Microgrid (MEM) options. This is done by incorporating Mixed Integer Liner Programming (MILP) model for annual simulations and expanding it with Receding Horizon Model Predictive Control (RH-MPC) algorithm for short term daily operational analyses. The model optimizes flows of various energy vectors: heat, fossil fuels (natural gas), cooling and electricity, coordinating different microgrid elements with the goal of serving final consumer needs and actively participating in energy markets.

The second novelty of the work is in the approach to multi-energy operational flexibility assessment, capturing different technologies, MEM configurations and different modelling concepts. When MEM is connected to the upstream power system its flexibility manifests as capability to alleviate variability and uncertainty in local production of RES and demand. On the other hand, when operating isolated from the rest of the system, the main flexibility indicator is minimum waste of energy while ensuring the satisfaction of all demand needs (electrical and heating/cooling). Following on this, multiple MEM configurations have been analyzed, showing different levels of available flexibility and capability to follow scheduled day-ahead exchange with the rest of the system, but also different amounts of wasted/curtailed energy in off-grid mode. Additionally, detailed analyses are performed concerning algorithm approximations which are often introduced in MEM modelling, such as efficiency of generation units. While these approximations have smaller impact on annual operational flexibility assessment (the difference is around 2–5% in terms of total cost), the result clearly show their significant impact on daily operational flexibility estimates.



## 1. Introduction

### 1.1. Introduction and motivation

Integration of renewable energy sources today is largely driven by incentives [1] and general goal of the European Union to increase the share of zero emission generation [2]. However, passive integration of these sources close to the consumers might result in significant over investments driven by needed improvements on the distribution grid level [3,4]. In addition, the idea and design of all renewable energy system (RES) [5] and global energy policy [6] should be put hand in hand with the latest strategic goal announced in Europe; at least 50% of energy production should be in the hands of final consumers [7]. This also means that a significant share of operational flexibility, alleviating above mentioned issues, will come from the distribution level through integration of technologies capable of responding to different price

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signal. Evaluating the potential flexibility benefits of different technologies in the distribution level microgrids provides a valuable step towards a successful integration of renewable energy sources that will complement the low carbon technologies on a larger scale [8].

Microgrid is defined as a set of consumers, distributed generation and energy storages coordinated with the aim of achieving reliable supply for final consumers and exchanging predefined energy with the rest of distribution system through a point of common coupling (PCC) [9]. Scheduling microgrid operation is subject to imperfect forecasting of local RES or demand, however if these imbalances are compensated on the local level microgrids become flexible nodes capable of providing multiple flexibility services to the upstream system thus enabling larger integration of RES [10,11] (Fig. 1). Aggregating consumers of different energy vectors (electricity, gas, cooling) and distributed multi-generation sources on the same location with coupled centralized control is the main advantage of a multi-energy microgrid (MEM) concept.

Power system flexibility is becoming a key characteristic in answering the increasing share of variable generation. Technically, it can be defined as the ability to respond to changes in demand/generation equilibrium [12]. In economic sense, the flexibility can be defined as the capability of a single market subject to quickly adjust to most current market situation and follow the scheduled plan of exchange [13]. All power systems inherently have a certain flexibility level; with increase of unpredictable and variability RES these values are much higher. Lack of system flexibility can be manifested in frequency deviations which can lead to load shedding, deviations from contracted exchanges, wind curtailment, higher price volatility. The current system flexibility requirements are mostly based on deterministic calculation which increases the system costs and does not include variables that stretch through several time periods (intertemporal constraints) [14].

Traditionally all the imbalance between the production and consumption had to be compensated by centralized unit, however with the advent of new technologies (μCHP, electric vehicles, flexible demand, electric heat pumps etc.) new flexibility potential can be unlocked on the local, distribution level [15–17]. Concepts of a virtual power plants and microgrids (e.g. [18,19]) are well known, yet there is still a lack of integral approach to all energy vector assessment on a microgrid level, particularly in terms of interaction between the MEM and the rest of the system. This paper tackles the operational aspects also providing some valuable inputs for planning, optimal sizing of microgrid elements [20] and business cases [21].

### 1.2. Current research

While integration of batteries and electric vehicles is widely researched for their capability to provide these flexibility services [22], it is equally important, if not more, to unlock the already existing flexibility in the distribution level energy systems. In this context multi-energy systems (MES) [23] and multi-energy microgrids (MEM) become increasingly relevant by coupling different units and shifting between energy vectors. Such systems have the capability of providing required services for the consumer without diminishing the comfort of final users and, on the other hand, to provide response to system requirements on different and multiple time frames [24,25]. Several research papers have shown significant benefits by means of adaptive dispatch and coordination of multi-energy systems in active distribution networks [26].

In order to utilize provision of price driven services from multi-energy entities such as MEM, or other flexible units at the distribution side, they need to be aggregated into a single entity since such market participation increases both market visibility, capability to compete in multiple market and, correspondingly, their benefits [27]. Aggregation in the concept of virtual power plants (VPP) is usually composed of conventional and renewable energy units (RES) [28,29]. The inability to forecast RES generation of the VPP defines participation of such units in the market, where flexible units such as storage are put in service of minimizing the level of variability and uncertainty announced ahead of realization of production [30,31]. Recent research focuses on robust or risk-based bidding strategies to overcome these issues [32], however such approach can lead to conservative solutions and non-optimal operating points. It is interesting to notice that already single MEM unit can be regarded as VPPs, since they are usually composed of several units coupled together [33]. Cooperation of these units results in both economic savings and environment impact reduction compared to separate production [34]. When grouping different multi-energy units the value of multiple energy vector shifting becomes even more highlighted [35].

On a microgrid level the local heat and cooling demands are more or less predictable and do not contribute significantly to uncertainty and variability; unlike local RES production. In addition, heat and cooling have a significant amount of inertia

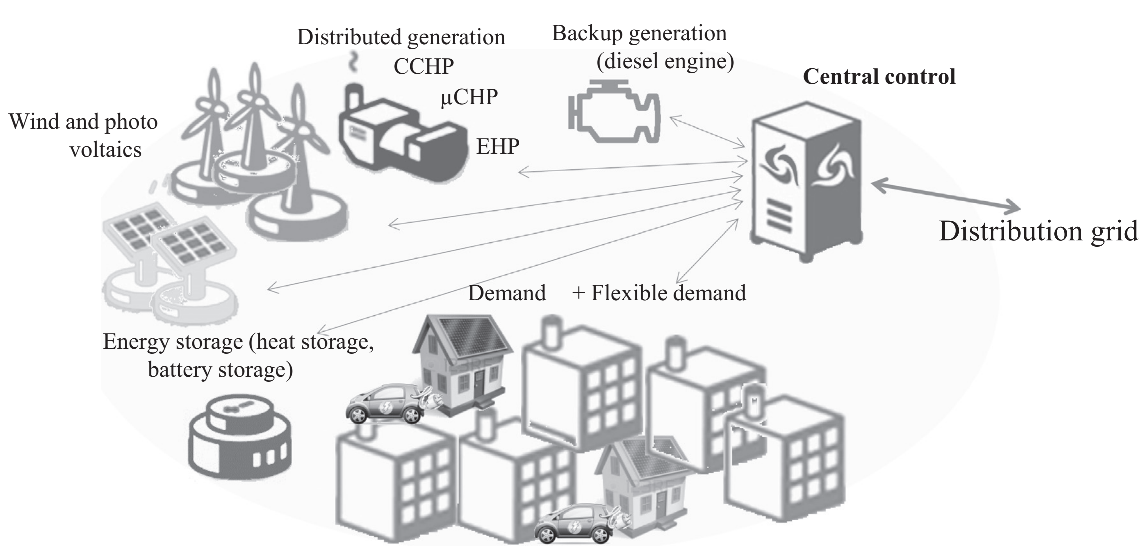


**Fig. 1.** Microgrid elements and the potential of connection of a multi-energy microgrid as a flexible multi-energy node through a PCC.

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