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Modeling and optimization of distributed energy resources microgrids

Keywords: microgrid, optimization, modelling

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Extended abstract. Microgrids are electricity distribution systems containing loads and distributed energy resources, such as distributed generators, storage devices, and controllable loads. Microgrids can be operated either while the system is connected to the main power grid or while the system is islanded (off-grid).

The paper will present early results from modelling and optimization of the operation of a case system, which is under construction at Lempäälä, in Marjamäki industrial and commercial area. Marjamäki grid will consists of 4 MW solar power plant, total of 8.4 MW gas engines for CHP production, two 65 kW fuel cells, 2.4 MW/1.6 MWh (charge and discharge power/capacity) electrical energy storage system, heat and cooling storages, smart buildings having their own generation resources and demand response functionalities, and intelligent grid automation and management systems. The microgrid has a medium voltage connection to the grid of the local distribution system operator (DSO), and its own gas and district heating networks.

The intelligent microgrid environment aims to cost efficient utilization of all resources available at the energy community consisting of the members connected to the microgrid. Key features are energy conservation and promotion of circular economy through energy networks. An important topic is the creation of incentives for investments in community-friendly energy solutions. The energy community perspective should be promoted by optimizing the network performance so that community costs are minimized when members' costs are minimized instead of individual player focused local optimization.

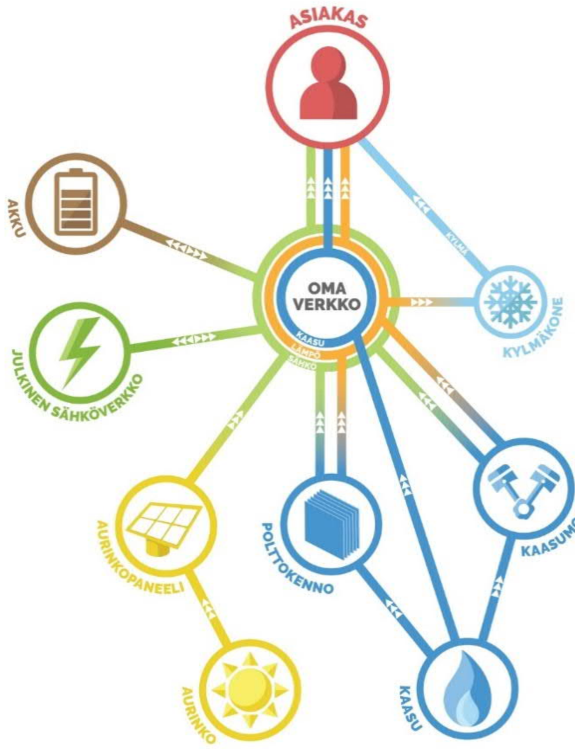

Figure 1. Structure of the Marjamäki microgrid.

Microgrid Model.

The operation of the microgrid system is studied with a dynamic simulation model. The model consists of power flows between consumer and producer nodes and the grid connection with the DSO network. Consumption and production data is provided with hourly-based time series data. System formulation is carried out by General Algebraic Modelling Systems GAMS as well as optimization of operation costs as a function of electricity price in spot market and own generation potentials. The model variables are

- power flow from/to DSO grid
- power flow between microgrid and battery energy storage (BES)
- charge level of BES
- cost of grid electricity
- cost of generation by fuel cells
- cost of generation by gas engines

The case study is calculated based on hourly data from year 2017 including

- Nordpool Elspot Day ahead price [€/MWh]
- electric power consumption at microgrid area [MWh/h]
- heating power consumption [MWh/h]
- solar intensity rate
    - measured from the roof of the Electrical Engineering building at Hervanta Campus, Tampere

System operation related boundary conditions are

- Allowed battery charge level 30 – 90%
- upper limits for generation and battery charging/discharging capacities
- battery charge level at the beginning and the end of the optimized day
    - 24 h net use equal to zero

Model equations

- momentary power balance between consumption and production
- battery dynamics (calculation of battery charge level)
- cost function, minimize the sum of operation and purchasing costs

Optimization results

Figures 2 and 3 show the optimization results from two 48 hours periods on the January 24.-25. and on the July 18.-19. 2017. The optimization problem is to minimize the supply costs of electric energy by the active use of the battery storage. During both periods, the fuel cells were operated at full capacity and gas engines were operated according to the heat load (CHP generation). Solar PV generation capacity is calculated according to the measured solar irradiation data. Yellow bar on positive power side indicates discharging and negative bar charging of the battery storage (direction of power flow from battery to microgrid). During the January period, the gas engines are intensively used for heat production and solar PV generation capacity is minor, especially on 25.1. During the period on July, solar PV generation is more intensive, but the heat load and thus the gas engine generation is negligible.

Figures 4 and 5 show histograms and duration curves of load and generation levels calculated from year 2017 data. On the first row of Figure 4, two first histograms show electricity and heat load distributions. The third histogram is the generation capacity of fuel cells, which is constant 65 kW all through.

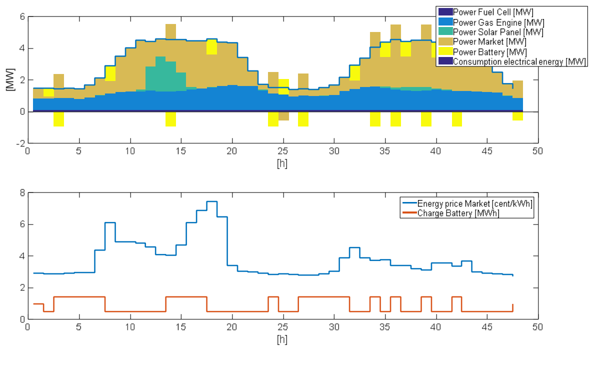

Figure 2. Optimization of supply cost of electric energy on 24.-25.1.2017.

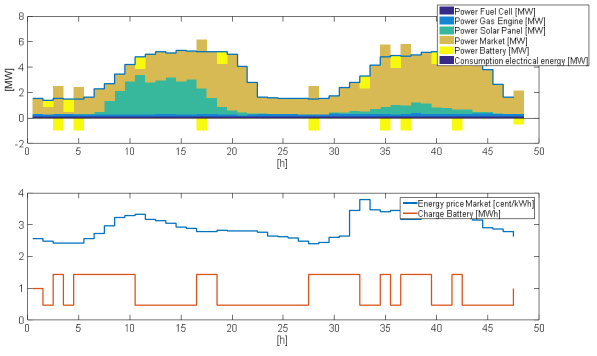

Figure 3. Optimization of supply cost of electric energy on 18.-19.7.2017.

On the second row there are power level distributions of gas engines and solar PV generation and buy/sell electricity from the grid. It can be seen from the histograms that e.g. solar PV generation is very modest. From 4 MW installed capacity during app. 5800 hours from annual 8760 hours, the generated power has been between 0-100 kW. However, this is not a typical situation because summer 2017 was exceptionally rainy and cloudy. However, this kind of situations should also to be taken into account, when planning weather dependent generation systems.

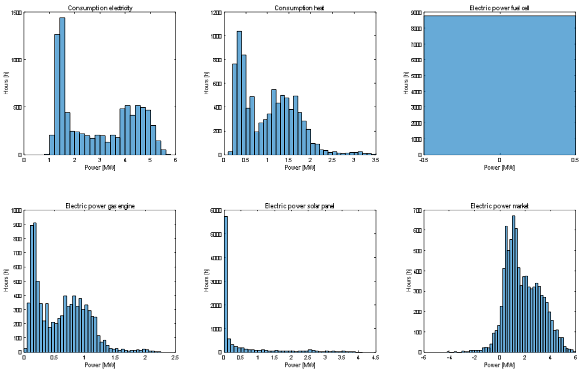

Figure 4. Histograms of hourly power levels of consumptions and production capacities.

The third histogram on row two shows that most of the time the microgrid is buying electricity from the grid.

Duration curves presented in Figure 5 show the same information as histograms in figure 4.

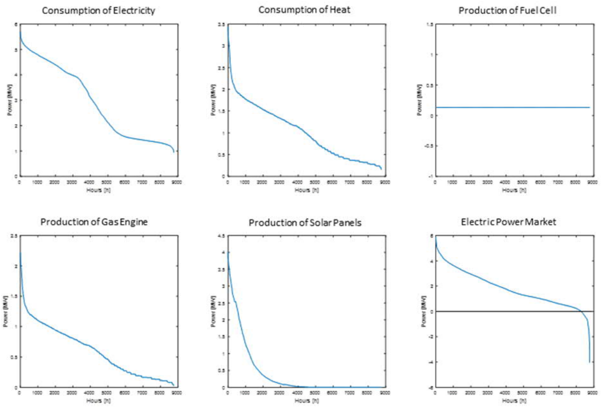

Figure 5. Annual duration curves for loads and production resources.

The two first curves on the first row show durations of electricity and heat loads. The third curve is the constant 65 kW generation from fuel cells. On the second row the two first curves show the duration levels of gas engine electric power and solar PV generation. The third curve shows that most of the time the microgrid is buying electricity from the grid.

Conclusions and Next Steps

Marjamäki microgid offers a remarkably versatile environment for microgrid related research activities in general, such as:

- MW-level large-scale solar power system and several smaller PV units located in the buildings
- Management and automation solutions of the microgrid system operating in parallel with the supplying network of the local DSO or as a separated island
- Utilizing the microgrid and its various resources as a flexible resource for frequency controlled reserve markets in the national power system
- Using microgrids to improve security of supply of the DSO as an alternative to other options (e.g., cabling in rural areas)
- optimization of various energy resources in resource efficient energy management
- regulation, roles and business of different actors in the microgrid framework

The next steps in the development of Marjamäki area are adding the generation and flexibility resources of the energy community and minimizing of the total costs. An important goal is the development of an internal cost-sharing mechanism so that the cost of the community is minimized when the cost of the members is minimized. This will lead to the process aiming at the optimal development of the whole area instead of short time benefits of individual players.