Optimal Control Platform for Coupling Energy Vectors

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CSEM is working in a consortium of European partners to develop a smart energy management platform. This platform provides tools to use the flexibility of existing controllable equipment and conversion systems between energy vectors (electricity, gas, heat). District operators using it will be able to integrate large shares of renewable energy at optimal costs and comfort.

Since power generation from centralized plants (combustible fuels, nuclear) is expensive to modulate, balancing power production and consumption in real time has always been a challenge. This challenge is only getting bigger with increased variability and uncertainty of electricity consumption (e.g., electric vehicles) and distributed power generation (solar and wind) [1].

This issue can be addressed by increasing the flexibility of electric loads and storage equipment, or by using cross-vector conversion systems. However energy carriers (electricity, gas, heat) are usually considered separately in energy management solutions, resulting in an under-optimal use of the capabilities of energy systems. An optimal synergy between energy vectors would increase the flexibility at local level and contribute to grid stability and market operations.

The European project PENTAGON intends to provide such a solution by developing a smart energy management platform for eco-districts based on a model predictive control (MPC) approach. The control algorithm is executed every 15 minutes and consists of three main steps:

- Computing the 24-hour forecast of consumption and production profiles for loads and renewable generators respectively. This computation uses machine-learning algorithms and advanced physical models.
- Solving a mixed-integer linear program (MILP) where these profiles provide information on the future, operational limits of each equipment in the eco-district define the constraints, and the cost function considers discomfort of households, curtailment of renewable generators, and the cost of supplying a utility network. The results represent the optimal operation schedules over the next 24 hours.
- Dispatching the first time step of the optimization results through building management systems (BMS) to each device seen as a controlled actuator. Feedback from on-site smart meters help to improve the forecasting algorithms of step one.

A typical eco-district is depicted in Figure 1 with the aggregated consumption of households represented by a single dwelling. Controllable energy conversion systems allow the transformation of electricity to heat (heat pump) and gas to heat (gas boiler). External ties act as infinite sources of energy and determine the cost of supplying the eco-district by importing or exporting power.

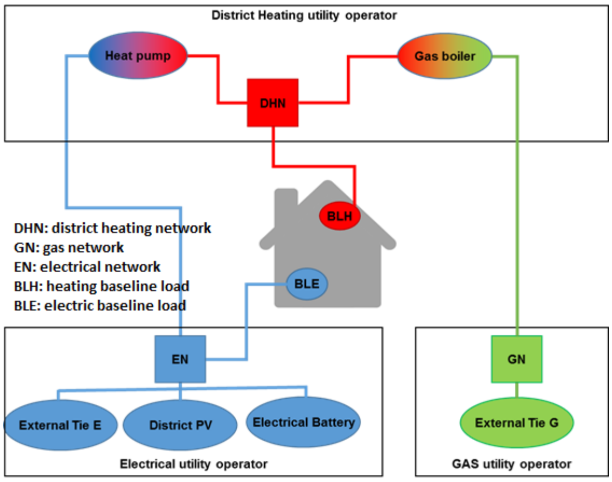

Figure 1: Component diagram of an eco-district with energy carriers interconnected through energy conversion systems (heat pump and gas boiler).

Prior to deployment on a demonstration site, we have validated the control platform by simulating its operations on the eco-district of Figure 1 over two weeks of forecast household consumption and solar production. The optimization problem was solved for every 15-minute time step. The resulting 24-hour profiles for each device are shown on Figure 2.

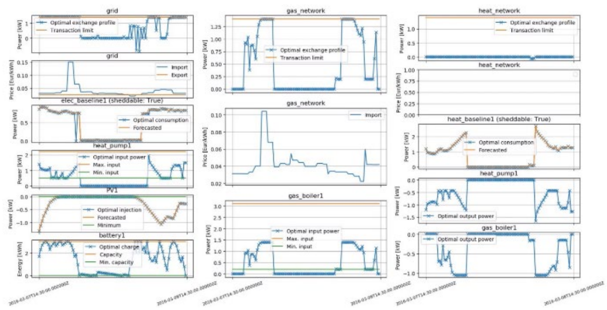

Figure 2: Optimized operation profiles each equipment of the eco-district (left: electrical devices; center: gas devices; right: heating devices).

The optimizer has efficiently managed to meet device constraints while minimizing the cost of supplying the three energy carriers. Curtailment of solar power was avoided and conversion systems were optimally operated with respect to power availability and cost.

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[1] R. A. Verzijlbergh, L. J. De Vries, G. P. J. Dijkema, P. M. Herder, "Institutional challenges caused by the integration of renewable energy sources in the European electricity sector", Renewable and Sustainable Energy Reviews, vol. 75, pp. 660–667, Aug. 2017.