DESSLib – Benchmark Instances for Optimization of Decentralized Energy Supply Systems

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Abstract. DESSLib provides benchmark instances obtained by real world data for synthesis problems of decentralized energy supply systems (DESS). In this paper, the considered optimization problem is described in detail.

Decentralized Energy Supply Systems

An energy system consists of a subsystem of energy consumers and a subsystem of energy suppliers. In this case the different forms of final energy consumed, are satisfied by different supplier technologies. Since the supplier subsystem is represented by multiple decentralized, on-site components, we speak of a *decentralized energy supply system* (DESS). The application of DESS encompasses, e.g., chemical parks, urban districts, hospitals or research complexes. Besides climatic goals, energy costs usually match the companies' profits in magnitude and energy efficient DESS can reduce energy cost significantly [2]. Thus, optimally designed decentralized energy supply systems can lead to a considerable increase of profits. DESS can consist of several energy conversion components (e.g., boilers and chillers) providing different utilities (e.g., heating, cooling, electricity, steam). DESS are highly integrated and complex systems due to the integration between different energy forms and connection to the gas and electricity market as well as the energy consumers. An example for a DESS is shown in Figure 1.

The target of optimal synthesis of DESS is the identification of an (economically) optimal structure and optimal component dimensions, while simultaneously considering the optimal operation of the selected components [4]:

1. Structure: Which energy conversion components and how many of each type?
2. Dimension: How big should these components be?
3. Operation: Which components are operated at which level at what time?

These three decision-levels could be considered sequentially. However, the levels influence each other, thus only a simultaneous optimization will find a global optimal solution. For some literature about synthesis of DESS see [6], [7], [5].

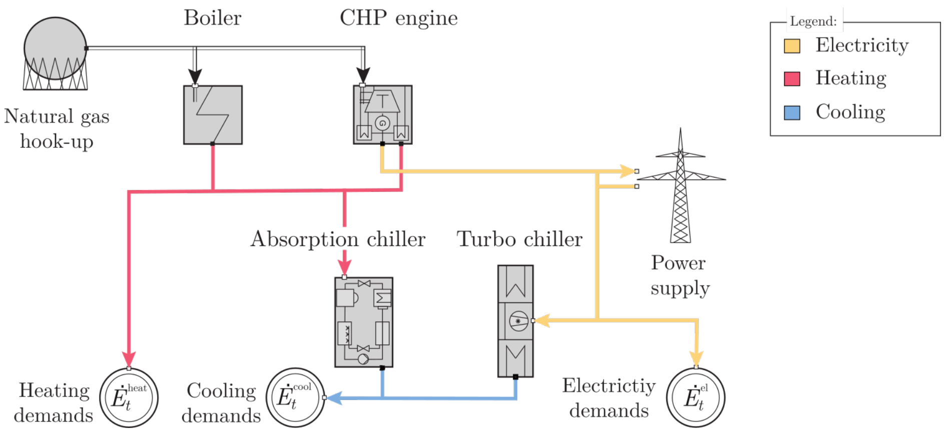

Fig. 1. Example of a decentralized energy supply system.

Problem Description: Optimal Synthesis of DESS

We consider four different energy conversion technologies in the supplier subsystem: (i) boilers and (ii) combined heat and power engines (CHP) burn gas to produce thermal energy in the form of heat. In addition, CHP engines generate electrical energy via power-heat coupling. (iii) Absorption chillers and (iv) turbo chillers produce cold. Former use heat as an input power, latter electrical energy. The input energy forms, gas and electricity, can be bought from the energy market, whereas surplus electrical energy can be sold on the electricity market. For the model, quasi-stationary system behaviour is assumed. Output energy is immediately available, components have no start-up time. Energy storage is not possible.

We consider a *superstructure-based* approach to model the synthesis of a DESS. The optimization of the energy system is based on a given site structure, i.e. superstructure, hence the maximum number of components of each type is fixed before the optimization takes place. The set of energy conversion components, which can be set up to meet the demands is denoted by superstructure

$$S = B \,\dot{\cup}\, C \,\dot{\cup}\, T \,\dot{\cup}\, A$$

and encompasses a set of boilers B, a set of combined heat and power engines C, a set of turbo-driven compressor chillers T and a set of absorption chillers A.Apart from their component type, all components $s \in S$in the superstructure are not further specified at this point. Note that an optimal DESS is likely to contain multiple components of one type which is in strong contrast to classical process synthesis problems [3].

The set of load cases considered for the operation of the DESS is denoted by L. The length of load case $\ell \in L$ is denoted by $\Delta_\ell \geq 0$. Furthermore,

$$\dot{E}_\ell^{\text{heat}} \geq 0,\ \dot{E}_\ell^{\text{cool}} \geq 0 \text{ and } \dot{E}_\ell^{\text{el}} \geq 0$$

are the demands of heating, cooling and electricity, which has to be satisfied with equality in the DESS in every load case $\ell \in L$. Energy demands have to be satisfied with equality, an emission of surplus energy to the environment is not allowed.

For each set up component $s \in S$, its continuous size

$$\dot{V}_s^{\mathrm{N}} \geq 0$$

has to be determined. It specifies the maximum (nominal) output energy and has to be between a given minimum size $\dot{V}_s^{\mathrm{N,min}}$ and a given maximum size $\dot{V}_s^{\mathrm{N,max}}$. For combined heat and power engines the output is not unique (heat and electricity), in this case the size refers to the maximum heat output. The investment costs of component $s \in S$ depend on its size $\dot{V}_s^{\mathrm{N}}$ and is given by the nonlinear function $I_s(\dot{V}_s^{\mathrm{N}})$. Further, maintenance costs are considered as given constant factors $m_s \geq 0$ in terms of investment costs.

The output power of component $s \in S$ at load case $\ell \in L$ has to be determined and is denoted by

$$\dot{V}_{s\ell} \geq 0.$$

Again, for CHP the output power refers to the heat output. The nonlinear function $\dot{V}_{s\ell}^{\mathrm{el}}(\dot{V}_{s\ell}, \dot{V}_s^{\mathrm{N}})$ describes the electricity output of a CHP $s \in C \subseteq S$. For each component $s \in S$ operated in load case $\ell \in L$, a minimum part-load operation is required, thus the condition $\alpha_s^{\mathrm{min}} \dot{V}_s^{\mathrm{N}} \leq \dot{V}_{s\ell} \leq \dot{V}_s^{\mathrm{N}}$ with given minimum part-load factor $0 \leq \alpha_s^{\mathrm{min}} \leq 1$ has to be hold. If $s \in S$ is not operated in load case $\ell \in L$, we set $\dot{V}_{s\ell} = 0$. The input, which is needed to generate the output $\dot{V}_{s\ell}$, is described by the nonlinear part-load performance function $\dot{U}_s(\dot{V}_{s\ell}, \dot{V}_s^{\mathrm{N}})$.

Parameters $p^{\mathrm{gas,buy}}$, $p^{\mathrm{el,buy}}$, and $p^{\mathrm{el,sell}}$ denote the purchase price of gas and electricity and the selling price of electricity from and to the grid. In the objective of the optimization problem the net present value $\mathrm{APVF}(i, \gamma^{\mathrm{CF}}) \cdot R_{\mathrm{CF}} - I$ is maximized. The parameter

$$\mathrm{APVF}(i, \gamma^{\mathrm{CF}}) := \frac{(i+1)^{\gamma^{\mathrm{CF}}} - 1}{i \cdot (i+1)^{\gamma^{\mathrm{CF}}}}$$

denotes the present value factor and depends on given discount rate i and given cash flow time γ^{CF}. I denotes the total investments and R_{CF} denotes the net cash flow, which are the annual revenues from sold electricity $\dot{V}_\ell^{\mathrm{el,sell}}$ minus the cost for electricity $\dot{U}_\ell^{\mathrm{el,buy}}$ bought from the grid and secondary energy $\dot{U}_s(\dot{V}_{s\ell}, \dot{V}_s^{\mathrm{N}})$ consumed by the boilers and CHP engines as well as maintenance costs $m_s \cdot I_s(\dot{V}_s^{\mathrm{N}})$ for all set up components $s \in S$.

For a description of the functions and parameters used to describe the system and components, see the documentation *DESSLib - Parameters, component models and performance instance generation* [1] found on DESSLib website:

http://www.math2.rwth-aachen.de/DESSLib

References

1. Bahl, B., Goderbauer, S., Arnold, F., Voll, P., Bardow, A., Koster, A., Lübbecke, M.: DESSLib - Benchmark Instance Structure, Component Models and Parameters (2016), http://www.math2.rwth-aachen.de/DESSLib
2. Drumm, C., Busch, J., Dietrich, W., Eickmans, J., Jupke, A.: STRUCTese - Energy efficiency management for the process industry. Chem. Eng. Process: Process Intensification 67(0), 99–110 (2013), http://www.sciencedirect.com/science/article/pii/S0255270112001845
3. Farkas, T., Rev, E., Lelkes, Z.: Process flowsheet superstructures: Structural multiplicity and redundancy. Computers & Chemical Engineering 29(10), 2198–2214 (sep 2005), http://dx.doi.org/10.1016/j.compchemeng.2005.07.008
4. Frangopoulos, C.A., Spakovsky, M.R.v., Sciubba, E.: A brief review of methods for the design and synthesis optimization of energy systems. International Journal of Applied Thermodynamics 5(4), 151–160 (December 2002)
5. Goderbauer, S., Bahl, B., Voll, P., Lübbecke, M.E., Bardow, A., Koster, A.M.: An adaptive discretization algorithm for optimization of decentralized energy suppy systems (in prep)
6. Voll, P., Klaffke, C., Hennen, M., Bardow, A.: Automated superstructure-based synthesis and optimization of distributed energy supply systems. Energy 50, 374–388 (2013)
7. Voll, P.: Automated Optimization-Based Synthesis of Distributed Energy Supply Systems. Ph.D. thesis, RWTH Aachen University (2013)