Technische Universität Berlin

Chair of
Sustainable Electric Networks
and Sources of Energy

SENSE

Object-oriented Modeling for Planning and Control of Multi-Energy Systems: Framework and Application to Berlin-Adlershof

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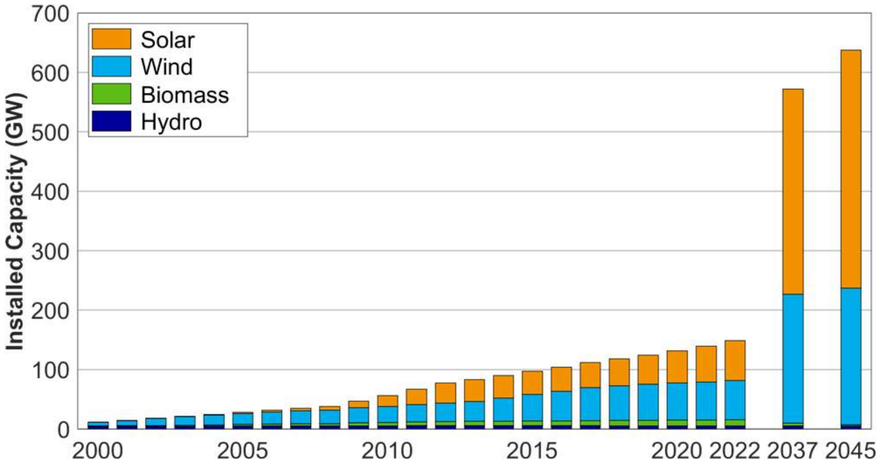
Agenda

1. Motivation
2. Object-oriented Modeling Framework
3. Modeling of Selected Resources
4. Validation in the Laboratory
5. Integration into Optimization Framework
6. Reducing Primary Energy Consumption in Multi-Energy System (MES)
7. Conclusions

1. Motivation

Increasing Installed Capacity of Renewables in Germany

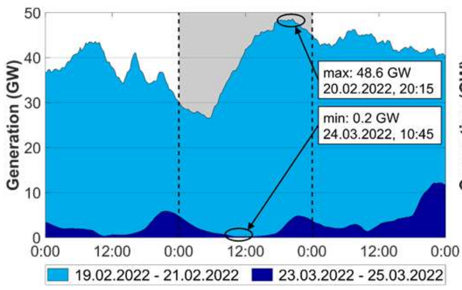


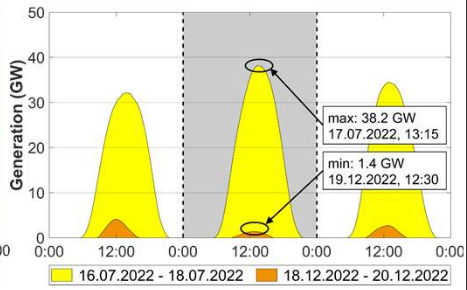
Data sources:
Years 2000 – 2022: Umweltbundesamt (UBA), Zeitreihen zur Entwicklung der erneuerbaren Energien in Deutschland
Years 2037/2045: Bundesnetzagentur (BNetzA), Szenariorahmen zum NEP 2037/2045

1. Motivation

Challenges

- Renewable power generation from wind turbines and photovoltaics is volatile



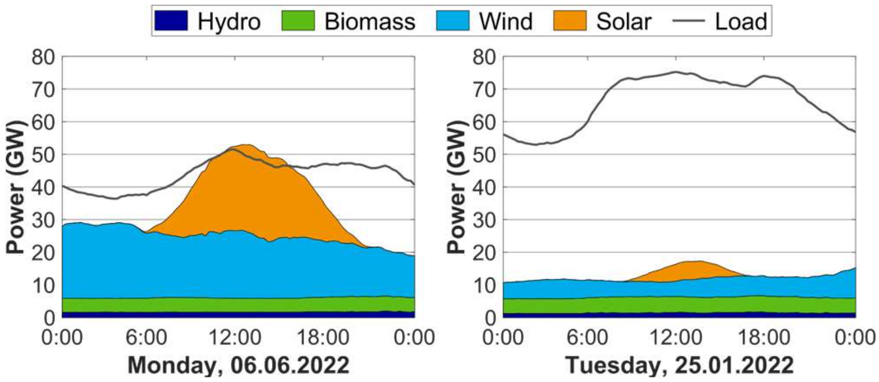


Data source: ENTSO-E Transparency Platform

1. Motivation

Challenges

- Electrical consumption and renewable power generation do not coincide in time

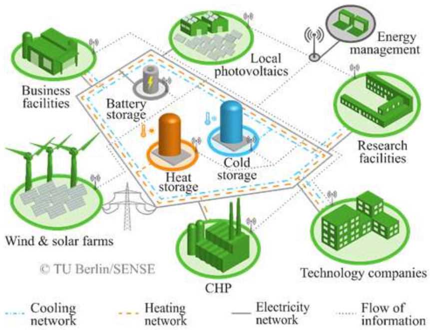


Data source: ENTSO-E Transparency Platform

1. Motivation

Multi-Energy Systems

- Multi-energy systems (MES) can provide increased flexibility for integration of volatile renewable power
- Electric part of power system benefits from available flexibility in networks of other energy carriers



- Those networks are connected to the electric power system by power conversion units
- These units can be controlled, making use of available flexible demand and storage capacity in the networks of other energy carriers

1. Motivation
Modeling of MES

- Multi-energy systems are to be well-integrated systems
- This integration should be reflected in the modeling
- This issue is addressed by the proposed object-oriented modeling
- The presented object-oriented structure defines base classes representing an MES to provide abstraction for such integration

1. Motivation
Features of Object-oriented Modeling Framework

- Abstraction is useful here, because many resources share the same type of operations even for different energy carriers
- For example, there are different storage types with common functions:

	Chemical energy storage (Battery)	Thermal energy storage
Energy carrier for charging, discharging	Electric energy	Thermal energy
Operations	Energy storing Charging Discharging	Energy storing Charging Discharging
Limits	Storage capacity Maximum dis-/charging power	Storage capacity Maximum dis-/charging power
Bounds	Initial and final energy level	Initial and final energy level
Efficiencies	$\eta_{\mathrm{cha}}, \eta_{\mathrm{dis}}, \eta_{\mathrm{sd}}$	$\eta_{\mathrm{cha}}, \eta_{\mathrm{dis}}, \eta_{\mathrm{sd}}$

2. Object-oriented Modeling Framework [1]

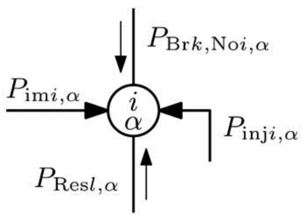
Overview

- In accordance with object-oriented programming, categories of network elements are formed
- The categories constitute the classes with regard to common attributes and functions
- Representing an MES, the three classes "Node", "Branch", and "Resource" are defined:
  - **"Node":** Ensures power balance, in analogy to Kirchhoff's current law
  - **"Branch":** Power transfer and intra-carrier power conversion
  - **"Resource":** Inter-carrier power conversion units, energy storage units, and prosumers

[1] S. Bschorer, M. Kuschke, and K. Strunz, "Object-oriented modeling for planning and control of multi-energy systems," *CSEE Journal of Power and Energy Systems*, vol. 5, no. 3, pp. 355–364, Sep. 2019

2. Object-oriented Modeling Framework

Specification of Class "Node"



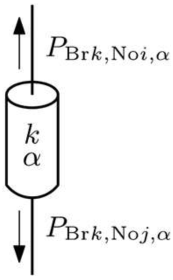
- Class "Node" represents network nodes, such as buses, junctions, and manifolds
- Nodes serve as coupling elements
- Nodal power injection $P_{\mathrm{inj}i,\alpha}$ represents uncontrollable demand and generation, such as lighting of household load or renewable power
- Power exchange with external networks is represented by the optimization variable for power import $P_{\mathrm{im}i,\alpha}$
- The net sum of power flows at each node object must equal zero:

$$P_{\mathrm{im}i,\alpha}(t_n) + P_{\mathrm{inj}i,\alpha}(t_n) + \sum_{k\in\mathcal{K}_i} P_{\mathrm{Br}k,\mathrm{No}i,\alpha}(t_n) + \sum_{l\in\mathcal{L}_i} P_{\mathrm{Res}l}(t_n) = 0$$

2. Object-oriented Modeling Framework

Specification of Class “Branch”

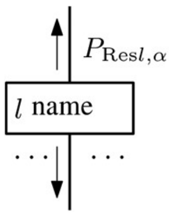
- Class “Branch” represents lines and pipes as well as intra-carrier conversion units like transformers
- A branch object is allocated to exactly two node objects of the same energy carrier



2. Object-oriented Modeling Framework

Specification of Class “Resource”

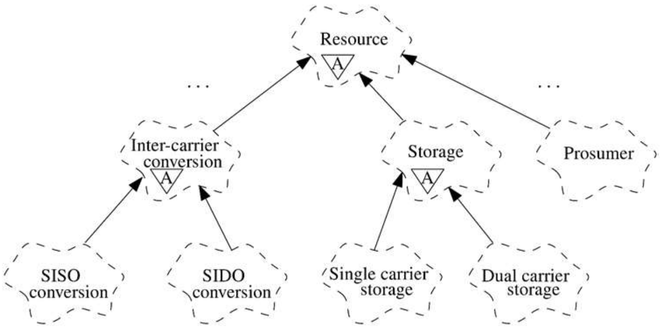
- Class “Resource” represents power conversion units, energy storage units, and prosumers
- Dependent on the type, resource objects are allocated to one or more node objects of different energy carriers



2. Object-oriented Modeling Framework

Specification of Class “Resource”

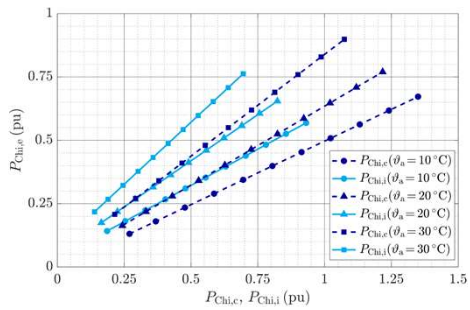
- As opposed to classes “Node” and “Branch”, the class “Resource” is an abstract class that has no instances
- Operation parameters, optimization variables, and operations are defined in subclasses



3. Modeling of Selected Resources

Compression Chiller

- A compression chiller converts electric power to cooling power operating on a vapor-compression cycle
- Electric power consumption depends on cooling demand, ambient temperature, and flow temperature

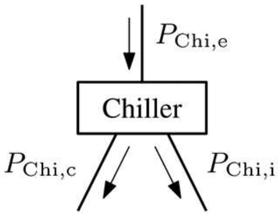


- Considered chiller can switch between two operating modes:
  - Mode “cooling”: flow temperature of refrigerant is +4 °C
  - Mode “ice”: flow temperature of refrigerant is -5 °C

3. Modeling of Selected Resources

Compression Chiller

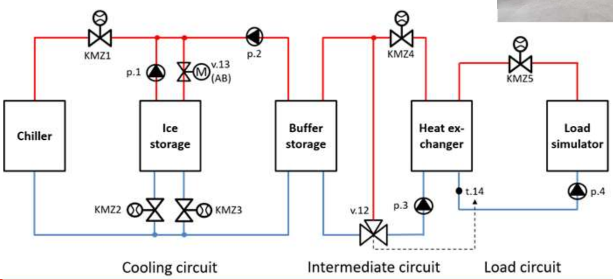
- To account for the operating modes, the chiller is allocated to an electricity node $\mathrm{No}_{i,\mathrm{e}}$, a cooling node $\mathrm{No}_{i,\mathrm{c}}$, and an ice node $\mathrm{No}_{i,\mathrm{i}}$
- As there are one input and two output nodes, the presented chiller is of class "SIDO conversion"



4. Validation in the Laboratory

SENSE Smart Grid Lab at TU Berlin

- Cooling network including chiller and ice storage unit is integrated into the SENSE Smart Grid Lab
- Facilitates tests in MES combining electricity and cooling networks
- Storage and chiller models are validated



5. Integration into Optimization Framework

- Developed modeling methodology can be integrated into an optimization framework for determining the optimal operation of the resources
- As a trade-off between computing time and modeling accuracy, nonlinear performance curves are linearized
- Solving the optimization problem, mixed integer linear programming (MILP) is applied
- Optimization problem is formulated in linear programming (LP) format, fitting the requirements of the most common MILP based solvers

6. Reducing Primary Energy Consumption in MES

Research Project “Energy Network Berlin-Adlershof”

Science Park “Berlin Adlershof”

- Most important science, business, and media site in Berlin
- Numerous non-university and university research institutes
- More than 1 000 companies
- Overall objective: Reduction of primary energy consumption

Project Motivation

- 10 % of the electricity consumption in Adlershof goes on cooling supply
- High potential for saving primary energy is assumed

Project Goals

- Implementation of a prototype district cooling solution
- Development of an energy management system

6. Reducing Primary Energy Consumption in MES

Research Project Test Site

- Technology and start-up center consisting of 8 buildings with offices, laboratories, and factory halls
- Existing cooling facilities with a total cooling capacity of 5 MW
- Ice storage unit with 5 MWh
- Electricity consumption: 5 000 MWh/a
- Cooling energy consumption: 1 000 – 2 000 MWh/a

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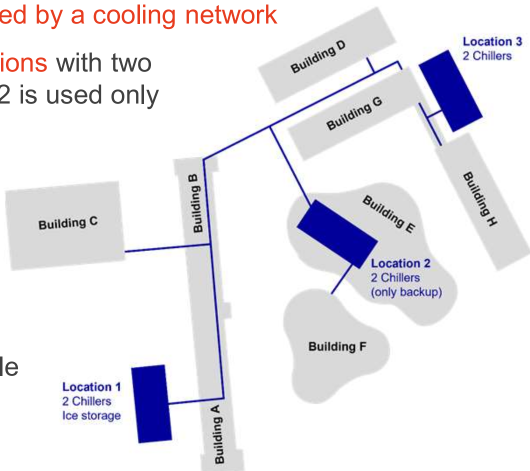
6. Reducing Primary Energy Consumption in MES

Research Project Test Site

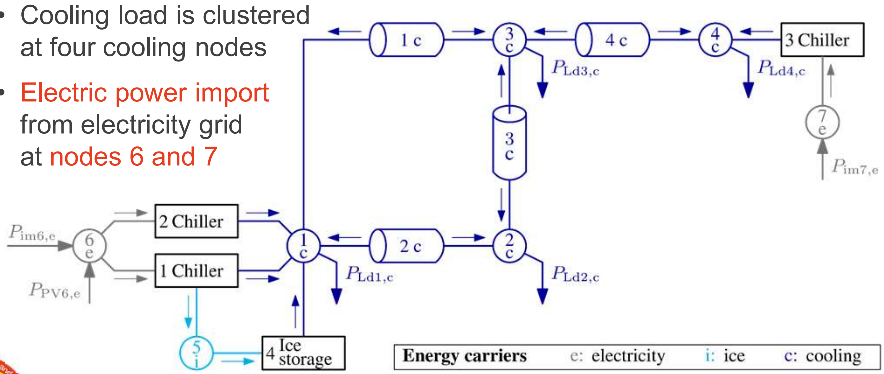
- Buildings A-H are connected by a cooling network
- Three cooling supply locations with two chillers each, but location 2 is used only for backup purposes
- Ice storage at location 1
- Cooling demand caused by process cooling and air conditioning
- Consistent measurements of cooling demand available for the year 2020



6. Reducing Primary Energy Consumption in MES

Application of Object-oriented Modeling Framework

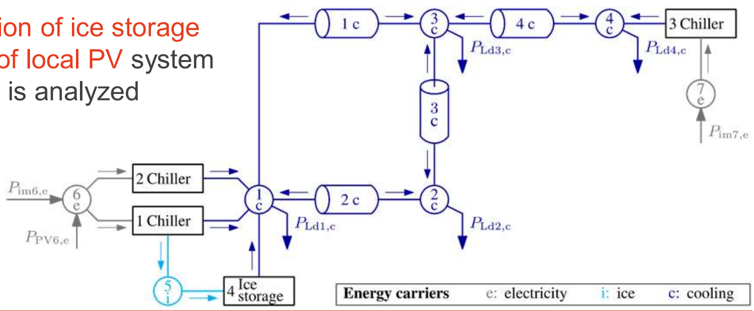
- Chiller 1 is object of class “SIDO conversion” and therefore able to both produce cooling power and to charge the ice storage unit
- Chillers 2 and 3 solely produce cooling power
- Cooling load is clustered at four cooling nodes
- Electric power import from electricity grid at nodes 6 and 7



6. Reducing Primary Energy Consumption in MES

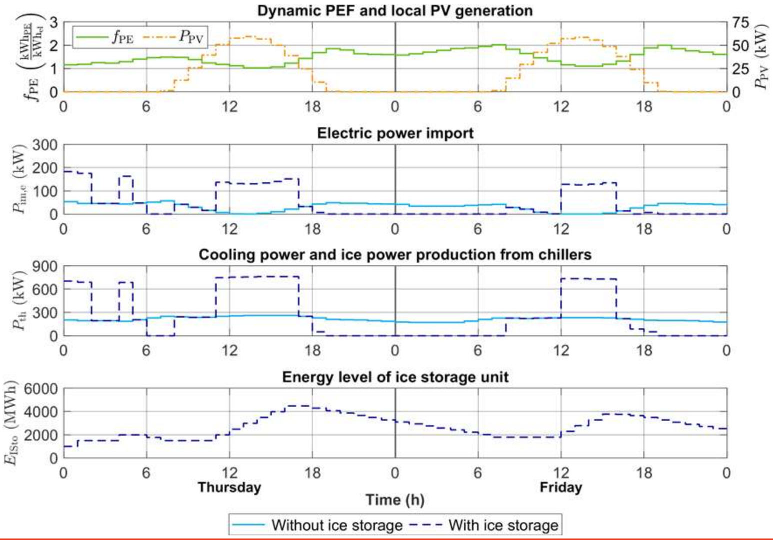
Application of Object-oriented Modeling Framework

- Objective is to minimize primary energy demand for cooling supply
- Primary energy demand is determined by electric power import and dynamic primary energy factor (PEF)
- PEF describes the ratio between consumption of electric energy and primary energy consumption
- Contribution of ice storage and size of local PV system at node 6 is analyzed



6. Reducing Primary Energy Consumption in MES

Results



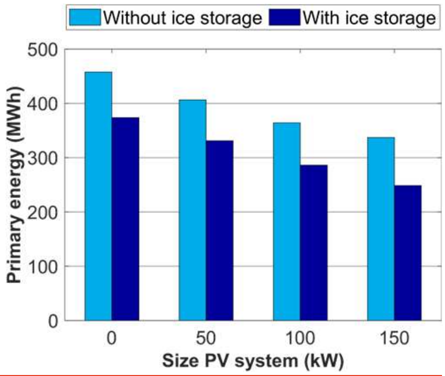
6. Reducing Primary Energy Consumption in MES

Results

- Without ice storage, cooling demand has to be met immediately by cooling production from chillers
- In this case, the MES cannot react to local PV production and dynamic PEF
- The utilization of an ice storage allows for decoupling of cooling demand from cooling production
- The ice storage is charged in times of low dynamic PEF and in times of local PV production
- In times of high dynamic PEF, the ice storage is discharged

6. Reducing Primary Energy Consumption in MES
Results

- The analysis of a whole year shows that the utilization of an ice storage can decrease the primary energy demand by 18 % to 25 %, depending on the size of the PV system
- Compared to the situation with no ice storage and no local PV system, an MES with ice storage and a local PV system of 100 kW results in a primary energy reduction of more than 35 %



7. Conclusions

- Proposed object-oriented modeling framework offers consistent integrated view of multi-energy systems
- Thanks to applied abstraction, classes are formulated by generalized functions independent of specific energy carriers
- Modeling can be validated in the SENSE Smart Grid Lab
- Modeling framework is applied in research project "Energy Network Berlin Adlershof" with a real cooling network including ice storage units

A comprehensive discussion of the topic is given in (open access):

S. Bschorer, M. Kuschke, and K. Strunz, "Object-oriented modeling for planning and control of multi-energy systems," *CSEE Journal of Power and Energy Systems*, vol. 5, no. 3, pp. 355–364, Sep. 2019