Optimization of multi-carrier energy systems using an FMI-based co-simulation approach

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Traditional simulation tools and models are typically focusing on only one respective energy domain. They are thus not capable of properly describing multi-carrier energy systems in detail (including their controls), which is an important prerequisite for a suitable design process and optimized operation. Tool coupling approaches (co-simulation) provide a promising alternative, facilitating the detailed assessment and optimization of the interactions between the various domains. A prototype implementation of a modular and flexible framework is presented, which uses a co-simulation approach to enable a detailed analysis and optimization process. It relies on established methods and tools where available and extends the state-of-the-art where necessary. Furthermore, the applicability of the Functional Mock-up Interface (FMI) specification within this context is demonstrated, which facilitates modularity and flexibility with regard to the utilized models and tools.

1. THE FUNCTIONAL MOCK-UP INTERFACE (FMI)

- The Functional Mock-up Interface (FMI) [1] defines a generic but powerful API and model description scheme to encapsulate and link models and simulation tools
- FMI is a non-proprietary, industrial-strength specification, developed by both academia and industry

- FMI-compliant simulation components are called Functional Mock-up Units (FMUs)
- FMI for Model Exchange:
  - standardized access to model equations
  - models described by differential, algebraic, and discrete equations
  - solved with integrators provided by embedding environment
- FMI for Co-Simulation:
  - stand-alone black-box simulation components
  - data exchange restricted to discrete communication points
  - system model is solved by internal solver

2. CO-SIMULATION OF MULTI-DOMAIN ENERGY SYSTEMS

The FUMOLA co-simulation environment has been used:
- developed on top of the Ptolemy II [2] simulation environment
- specifically designed to support the features offered by the FMI specification
- utilizing the FMI++ Library for handling FMI-based co-simulation components

3. OPTIMIZATION OF CO-SIMULATION MODELS

Application of co-simulation in the context of design optimization is challenging:
- no closed (semi-)analytical representation of the overall system is available
- therefore no closed (semi-)analytical representation of objective functions or its derivatives
- prevents the straightforward deployment of many optimization algorithms
- use instead metaheuristics that rely solely on the evaluation of the objective function, which can be easily achieved using co-simulation

4. THE DIFFERENTIAL EVOLUTION METHOD

- a metaheuristics that treats optimization problems as black boxes without the need of computing derivatives [3]
- optimizes a problem by maintaining a population of candidate solutions
- creates new candidate solutions by combining existing ones according to a simple procedure
- at each iteration, the candidate solution associated to the smallest value for the objective function is kept
- implementation used here is an object-oriented adaptation of openly available MATLAB code, containing the algorithm in its full functionality

5. EXAMPLE APPLICATION: HYBRID THERMAL-ELECTRICAL NETWORK

System layout:
- either a boiler or a heat pump (HP) feeds into a thermal buffer, which is connected to the thermal loads
- main source of electricity is the external grid, but there is also a PV system and a battery available

The boiler, the battery, and the HP are operated with the help of an energy management system (EMS):
- goal: use local electricity generation from renewable energy sources to operate the HP and reduce the utilization of the boiler
- in case of PV overproduction or when the battery is sufficiently charged, the EMS prioritizes the HP over the boiler
- charge the battery in case of PV overproduction but no need to operate the HP or enough PV overproduction to have a surplus even if the HP is running

The EMS and the physical system have been modeled independently, then exported as FMUs and coupled in a co-simulation model according to Figure 2.

6. EXAMPLE APPLICATION: OPTIMIZATION RESULTS

- degrees of freedom for optimization procedure:
  - heat pump power $P_{HP}$
  - battery power $P_{bat}$ electrical power consumption when turned on
  - battery size $E_{bat}$
  - optimization function:
    $$ E_{tot} = E_{bat} + P_{HP} \times t_{bat} $$
    with $E_{bat}$ the total thermal energy produced by the boiler, and $t_{bat}$ a measure for the battery’s utilization

REFERENCES