Anselm Erdmann, Anna Marcellan, Dominik Hering, Michael Suriyah, Carolin Ulbrich, Martin Henke, André Xhonneux, Dirk Müller, Rutger Schlatmann, Veit Hagenmeyer, On Verification of Designed Energy Systems Using Distributed Co-Simulations, 24th International Symposium on Distributed Simulation and Real Time Applications (IEEE/ACM DS-RT 2020), 14.-16.09.2020, Prague, Czech Republic
doi 10.1109/DS-RT50469.2020.9213689

On Verification of Designed Energy Systems Using Distributed Co-Simulations

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Abstract

An essential part of the energy systems design procedure is simulation, since it serves as a tool for verification of the respective design. It serves the verifying of a stable operation of developed energy systems infrastructure, before it comes to the realization. As energy systems integration becomes an important part in a low carbon energy scenario in the future, the cooperation of experts specialized in various domains crucial to single aspects of the energy system is indispensable. Co-simulation, yet, enables the modelling in the familiar environment of the experts, but requires a detailed coordination of the simulation interfaces between the specific expert models. Hence, standardized interfaces are crucial to the efficient use of expert knowledge in distributed co-simulations. Therefore, in the presented paper a workflow for the co-simulation development of energy systems simulations, which simplifies the coordination procedure significantly by standardizing the interfaces between the models and their simulations, is introduced. The approach is exemplarily applied to the energy system design of a district comprising electricity and heat in order to show its successful performance.

1 Introduction

As the international focus on reducing the number of available fossil power plants intensifies [1–4], cheap and strongly fluctuating generation from renewable energies is growing. The challenging transition of the current energy system into a sustainable multimodal energy system needs new operating strategies [5].
Common approaches and surveys about the future design of the energy system are dealing with a top-level approach from a national or international perspective (e.g. [6–9]). Yet, operating issues and local needs have to be considered in further steps. In lower level simulations the operability of the designed energy system can be verified. The modelling of energy systems comprising many different technologies [10–12] requires a high effort to consider all system attributes in the same simulation development environment and therefore requires specific expertise.
In this context, distributing simulations into co-simulations [13–15] enables the collaboration of specialists from the various areas of expertise. By doing so, the existing simulations including the latest research and insights by specialized experts can be fully integrated into the co-simulation. Nevertheless, this approach requires a high coordination effort between the cooperation partners. Reducing this effort by defining a unique interface between the simulation parts at the beginning simplifies the collaboration fundamentally. Therefore, introducing a new approach for obtaining an interface definition is the main purpose of the present paper.
The remainder of this paper is organized as follows: Section 2 discusses related work in this area of interest. Section 3 and Section 4 introduce a coordinating approach to the distribution procedure of simulations by defining the interfaces between the simulations on multiple layers. This approach is exemplarily applied to the energy system design of a district in Section 5. Finally, Section 6 concludes with a discussion and outlook.

2 Related Work

Distributed co-simulations for multimodal energy systems are rare in the literature. Partly, this rarity is probably due to the lack of expert knowledge across all the respective fields. In this context, an approach that takes into account the whole hierarchy between the European transmission grid and local prosumers is contained in the Energy System Development Plan (ESDP) [16]. This approach builds local energy cells with assumptions for distribution grids. These energy cells are interconnected via the real European transmission grid [16]. Thereby, the gap between locally available flexibility and transregional flexibility demand is bridged by simulating a market-driven mode of operation. In these cells, the flexibility is available for the entire network. Heat is considered in the form of demands and heat-supplying energy conversion units. The simulation consists of different steps, in which a market simulation determines the schedule and the transmission grid behaviour is simulated in a steady state power flow simulation [16]. Since the simulation is split into a sequentially executable toolchain, the data exchange between the simulations is straightforward.
Another approach with focus on various heating systems is MESCOS [17], which also includes an electrical grid simulation. In [17], models are developed in a couple of modelling tools and co-simulated via network communication. Thereby, the interfaces between the different simulators are defined in a scenario description file.
Furthermore, in [18] a gas and a heat grid simulation is integrated into the OpSim platform [19] by linking already existing simulation tools for the respective domains. The simulation tools used are adapted to the OpSim message bus according to the OpSim Proxy/Client concept [18].
Moreover, a simulation framework for multi-carrier energy systems is presented in [20]. It is designed for the cooperation between experts of various domains in particular. The central orchestration of the co-simulation is performed in MATLAB®. The interface design between the different simulations is recognized as a central challenge. However, a high number of different simulation tools is seen as an obstacle [20].
In [21], requirements for coupling of simulators are identified.
Besides the special application field of multimodal energy system simulations, there are more general ambitions for coupling physical simulations. Initial efforts to standardize physical simulation interfaces on the technical level are already in use with the Functional Mockup Interface (FMI) definitions [22, 23]. In the future, the new standard for network co-simulation DCP [24] could also play an important role.
In this context, to the best of our knowledge, there is no holistic procedure for defining interfaces for the distributed simulation of energy systems. Hence, it is an open scientific problem to define these interfaces for enabling a frictionless model development by the individual domain experts. Therefore, the present paper introduces a clear interface definition for energy systems simulations in order to avoid time-consuming adaptions of the simulation models and incompatibilities that may occur in the end.

3 Interfacing Simulations

The interfacing has to be carried out in several layers, of which the procedure is presented in Section 4. In the present section, the stack of simulation interfaces for distributed simulations is introduced. For this, a single simulation that is a part of the distributed simulation is called a *simulation module*. Table 1 gives an overview of the layers.

3.1 Semantic layer

The semantic layer considers the energy system, which is intended to be modelled. It further defines the respective scenario(s), for which this modelling is undertaken. It consists of energy grids and connected devices. In this perspective, the energy flow through the system is considered. All scientific investigations of the energy system design are dealt with this layer. Furthermore, the initial splitting of the logical simulation parts is performed.

Table 1: Interface layers for energy system co-simulations

Layer	Name	Description
3	semantic	scenario(s), infrastructure, energy flow
2	information flow	variables, information direction
1	simulators interaction	simulation control and communication
0	simulation technology	(simulator dependent)

3.2 Information flow layer

Information exchange is an essential part of distributed simulations. The simulation modules are considered as black boxes with interfaces for data exchange with other simulation modules. The calculation of the current state in the black box can require input data delivered from external simulation modules.
In the information flow layer the interfaces of the simulation modules and their dependencies are specified. Each interface contains the value of a floating point variable, which represents a physical quantity with one unit. Formally, an interface consists of a quadruple {identifier, type, value, unit}, where the identifier is a unique name, the type is either input or output, the value is a floating point number, and the unit is a SI-unit. An input interface is defined for each variable that a simulation module requires from another simulation module. Similarly, an output interface is defined for each state variable that a simulation module provides for transmission to other simulation modules. To ensure the operability of the simulations, every input interface needs to be connected with an output interface of a fitting quantity.
The assignment of the output interfaces to corresponding input interface is performed according to the scenario defined in the semantic layer. The information flow is always directed from an output interface to an input interface. Bidirectional connections can be represented by two opposite directed connections.
A complete definition of this layer contains a list of all interfaces of all simulation modules, and additionally, the corresponding output interface for each input interface.

3.3 Simulators interaction layer

The simulators interaction layer provides the information exchange between the simulation modules according to the connections determined in the information flow layer. The communication between the simulation modules has to be clearly specified and implemented by each associated simulation module. Alternatively, simulation tools can be adapted to the specified communication format with an interconnected module. Most of the co-simulation standards are using this concept, like the FMI standard [23] for local co-simulation or DCP [24] for distributed co-simulation as well as the co-simulation frameworks [17, 19, 25].
During the simulation run, the values of the single variables are transmitted from the output interfaces to the input interfaces according to the specification in the information flow layer.

3.4 Simulation technology layer

On the bottom layer, each simulation tool has its own simulation technology. To provide the required interface for the simulation interaction layer, an intuitive solution is the implementation of individual adaptions for existing simulation tools by using their program code APIs in the simulation tools (like applied in [17, 18]) or adapting them otherwise. In [20], a Python wrapper is implemented to adapt commercial simulation tools to their co-simulation framework.
Simulation tools that already provide the widespread FMI standard can be easily integrated by creating an adaptation for the FMI standard once as applied in [25] or for a smart grid simulation framework in [26].

4 Distributing a Simulation

Verification by simulation is an important part in designing energy systems. For this verification, detailed simulation modules of different domains are needed. For an efficient modelling of multimodal energy systems by experts of the respective domains in parallel, a coordination procedure is required. In the present section, the procedure of distributing the simulation is introduced. The splitting begins after an appropriate simulation scenario is determined. Finally the independently developed simulation models are united in a common co-simulation without any adaption effort.

4.1 Finding an appropriate level of detail

Energy systems can have very different dynamic behaviours. While dynamic investigations of electricity grids consider time periods of subseconds, the dynamic behaviour of gas and heat grids is much slower. From a technical point of view, it is possible to create a co-simulation respecting all these issues. However, the execution of this type of co-simulation requires an enormous amount of computing power. But if effects occurring in one subsystem have a negligible influence on other subsystems, these effects can be excluded from the co-simulation and investigated in an independent additional simulation. For this reason, the level of detail is determined by the issues to be investigated.
Seasonal behaviour is an important factor in energy systems integration. Investigations usually consider periods

of one year or even more (e.g. [6, 12]). The computational executability within an acceptable execution time has to be taken into account by every simulation module (see also subsection 4.3). A typical example for the adjustment of the level of detail in the simulations is given in this case for the modelling of the power grid. To consider large time scales, the electricity grid is simulated in a steady state power flow simulation. This simulation is repeated periodically in a period of typically 15 minutes to one hour.

4.2 Splitting the simulation

To achieve a frictionless fitting of the distributed simulation parts, all interfaces are defined before the individual models are created.

After the scenario is clarified, the interface definition can be performed according to the interface layer stack introduced in Section 3. On the semantic layer, the energy system is sketched in the shape of grids and connected components like consumers or generators. Energy and material like fuel is exchanged between the connected components across the grid. From this sketch, the competence responsibilities for components and grids are segregated between the participating experts. The subsequent independent modelling of these components in separate simulation modules is the responsibility of the experts.

In the next step, the correspondingly assigned experts identify the required information transfer on the information flow layer for each energy or material flow. To do this, they draw up a list of individual interfaces, each consists of a variable with the corresponding unit. For physical simulations, the variables depend on a real-world system. Modelled representations of these systems have a high similarity. Thus, for the time-step based simulation of physical systems, a generalization of the interfaces is possible due to the low level modelling of a real system. A reusable definition of interfaces on this layer for electricity and heat grids is shown in Section 5. In simulations considering communication behaviour or other kinds of event-based simulation, reusable definitions of interfaces are not feasible in general.

A common used co-simulation platform has to provide the connections between the simulation modules according to the elaborated list of interfaces. The co-simulation platform will conduct the composed distributed simulation in the end. An important question regarding the choice of the platform is whether the simulation should be performed locally on one machine or distributed on several machines. Furthermore, confidentially obligations can necessitate the execution of some simulation models in a geographically restricted area, which needs a platform supporting co-simulations over large distances.

The development and simulation tool for each simulation module is individually chosen by each expert, but the compatibility between the co-simulation platform and the chosen simulation tool is mandatory. It is meaningful to take this already into account while choosing the co-simulation platform to avoid costly simulation tool adaptations. In [20], the selection of an appropriate simulation environment is actually recommended as first step.

The whole procedure for a district combined heat and power simulation case is exemplarily applied in Section 5.

4.3 Independent model development

The great advantage of distributing simulations is the separation of the simulation models. Different research groups can develop and implement simulation models that represent different systems. The individual models are developed independently of each other and differ both in their representation and in their runtime environment. They can be represented as differential equation systems, discrete automata, etc. The only restriction is the supply of interfaces according to the specified interface list in the information flow layer. Thus, the modelling is done on the level of subsystems without having the coupled problem in mind. Ideally, these models have been created by experts in their respective field and are properly validated and thus recognized. Since the subdomains involved already use numerous established technologies and simulation tools, distributed simulation enables the easy reuse of these simulation models. On the other side, these existing models do not need to be adapted to the respective simulator architecture or even reformulated. Each model is developed on its own platform and in such a way that the later unified distributed simulation is carried out by black box operation of the subsystems with minimal computational effort. The simulation modules are calculating their delivered output variables in dependence of the incoming input variables and the simulation time. In some cases precalculations during the model development can reduce the calculation effort during the simulation run significantly.

4.4 Unifying the distributed simulation

After the independent modelling is completed, all simulations are linked together. If the interface specifications are met, no further configuration in the simulation modules is required. The mapping of the simulation output and interfaces according to the specification on the information flow layer as well as further global settings is executed by the co-simulation framework. When a simulation is started, the different simulation modules are

exchanging information via the specified interfaces. At the semantic level, the operation of the energy system is simulated in order to achieve the specific goals initially set (e.g. low emissions, low costs).
The physical simulation represents a continuous process, which is usually simulated in time steps. Control can also be integrated time-step-based via specified interfaces. Alternatively, a direct event-based addressing of the controlled units can be independently implemented beyond the physical simulation. The co-simulation platform has to ensure a deadlock-free execution sequence of the simultaneously running simulations.

4.5 Effects on distributing a simulation

Distributing a simulation is accompanied by accuracy issues. An issue concerns the splitting of the systems behaviour describing equations. Representing the whole considered system in a closed system of equations is unpractical due to the huge computation effort solving this system. This can be overcome by splitting the simulated system into weakly coupled subsystems as described in [27] and accepting the accompanying inaccuracies. For this reason a skilled selection of the subsystem borders is beneficial. If there are unavoidable delays in the simulation, it is possible to capitalize them as described in [28]. In energy systems this could become interesting when control systems are considered and the time step size is appropriately small.
Increasing the accuracy by reducing the time step size is possible. However, this is accompanied by a higher computational time demand. Hence, the optimal compromise between the required accuracy and computation time has to be determined for every application case. The usage of various time step sizes is discussed in [20].

5 Exemplary Application

The approach described in the previous sections is demonstrated in the following using the example of a district simulation with a photovoltaic system, heat storage, electricity storage and mini-CHP (Combined Heat and Power unit). This test case has been selected as a useful addition in the context of large transmission grid simulations, which are usually limited to optimization strategies at a higher dispatch level with long-term optimization. It is assimilable to the energy cell simulations of the ESDP [16]. This example can be used to consider effects on the shorter time scale, such as fluctuations in energy demand and availability, energy costs, maintenance planning, or storage capacity. Different operating strategies can be tested as well as the effects of fluctuations in weather conditions. Furthermore, universal interface definitions on the interface flow layer for power grids and for heat grids are provided.

5.1 Application case

A demonstration district with exemplary consumption data is simulated with individual system models representing state-of-the-art technologies. A power grid model based on real-world data is integrated with a generic heat grid model. A photovoltaic installation, a heat storage, an electricity storage and a mini-CHP are connected to each other and to the power and heat grid. In this test case the mini-CHP and the power storage are operated in order to use a high share of the generated electrical energy and photovoltaic feed-in while simultaneously ensuring the thermal supply.

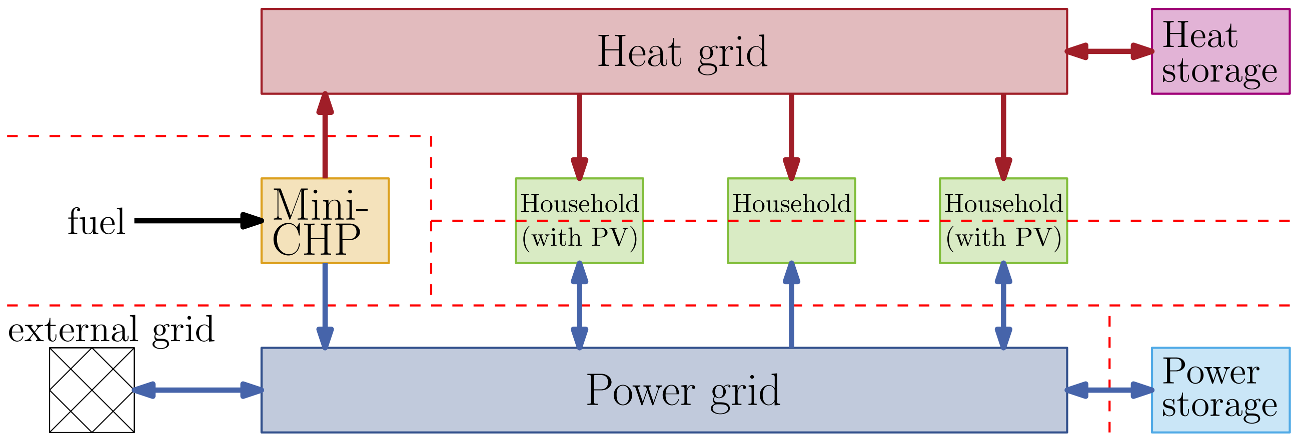

Figure 1: Distributed simulation case on the semantic layer

Table 2: Interfaces for the fluid water heat grid and connectors

Pos.	Interface	Unit	Note
(1)	District heating grid		
(1.1)	ambient air temperature	K	
(2)	District heating grid		per connector
(2.1)	water temp. in grid direction[1]	K	
(2.2)	mass flow rate[2]	kg/s	
(3)	Connector heat source		
(3.1)	return temperature	K	
(3.2)	mass flow rate[3]	kg/s	
(3.3)	*setpoint(s)*	(data)	
(4)	Connector heat sink		
(4.1)	flow temperature	K	
(4.2)	*setpoint return temperature*	(data)	
(5)	Gas turbine, like (3), additionally		
(5.1)	ambient air temperature	K	
(6)	Heat storage, like (3) + (4)[4], additionally		
(6.1)	ambient air temperature	K	

5.2 Applying the interface determination procedure

The interface determination procedure, introduced in Section 4 is applied to the presented simulation case. First the simulation scenario is split into the responsibilities of the experts. Figure 1 shows the distribution for the introduced application case. The individual simulation modules are a heat grid simulation including a storage and the heat consumers, a mini-CHP simulation, photovoltaics and electricity consumer simulation, electricity storage simulation, and power grid simulation. Additionally there is a (not depicted) weather simulation, which provides ambient air temperature and radiation data for the other simulation modules.

Subsequently, the interfaces on the information flow layer are determined. The district heating grid connects a heat supply to multiple consumers with pipes. For the majority of existing district heating, consumers use heat exchangers or direct connections to the grid. The power transport in a heat exchanger is mainly driven by the fluid temperatures and the fluid mass flow rates at primary and secondary side. For the representation of connections, generalized connector input interfaces for the heat grid are shown in Table 2. The interfaces on the information flow layer regarding the heat grid and its connectors can be deduced from Table 2. The grid itself needs the ambient air temperature (1.1) as an input. This information is processed internally in the heating curve. The heating curve determines the setpoint for the flow temperature in the heat grid. Furthermore, for every connector of the district heating, an input interface describing the mass flow entering the heat grid (2.2) and an input interface containing the corresponding temperature of the incoming fluid (2.1) is defined. Heat source connectors (3) need the return temperature (3.1) from the grid and heat sink connectors (4) the flow temperature (4.1). For heat sources, the mass flow rate (2.2) can alternatively be shifted to the source side (3.2), if the water pump is part of the grid model.

Since the interface definition is orientated on the input interfaces, the output of the heat grid is listed as the input interfaces of the connectors (3) and (4). (5) and (6) are special instances of (3) and (4). Every heat grid model requires the ambient air temperature (1.1) once and the input interfaces (2) once for each linked connector. Thereby, the design decision is made, that the heat grid model requires an input interface (2.2) containing mass flow rate information for each connector. This decision represents a typical operation of a district heating grid. Usually, the grid does not have information about the demand at each consumer. Instead, each consumer increases or decreases the mass flow rate individually. Hence, the demand sets the mass flow rate (2.2). The total mass flow rate of the grid is the sum of all demands and needs to be supplied by the heat grid model.

Setpoints (printed in italic) are actually not really physical quantities, since they represent only transmitted information. This information consists of simple data without any physical quantity. Otherwise, they can be treated as the physical quantity this information is associated with, or they can be excluded and treated event-based beyond the physical simulation.

[1] return temperature for heat sinks, flow temperature for heat sources
[2] for sources (2.2) is only used if the pump is placed on the source side
[3] (3.2) is only used if the pump is placed on the grid side
[4] without setpoints in passive operation mode

Table 3: Input interface list for a generic CHP

Interface name	Pos.	Type	Unit	Connected to simulator
T_ret	(3.1)	input	K	heat grid
m_flow	(3.2)	input	kg/s	heat grid
P_th_set	(3.3)	input	(kW)	controller
T_amb	(5.1)	input	K	weather

The exemplarily deduced input interface list for a generic CHP is shown in Table 3. Next to the interfaces, the connection to the associated simulator is noted in the last column. The associated simulators have to provide an appropriate output interface. The list of utilized output interfaces is determined from the connection information of the overall input interfaces of all simulators.
In the presented simulation case, the water pump is shifted from the heat grid simulation module to the mini-CHP simulation module. Following the mass flow input interface has to be moved from the mini-CHP module to the heat grid module. In return the mini-CHP module receives an additional setpoint for the flow temperature.
The generalized interface specification for steady state electricity grid simulations with slack bus is shown in Table 4.
The electricity grid receives the active and the reactive power for every connected load (1) or generator (2). The only difference between the input interfaces is the sign of the value of the active power. While the active power of a load (1.2) is represented by a positive value, the active power of generators (2.1) is negative. (3), (4), (5) are generators, (6) is an instance of a generator as well as of a load.
For connecting the specified interfaces on the simulators interaction level, the co-simulation platform presented in [25] is utilized.

5.3 Simulation Development

All simulation modules are developed independently from each other. The co-simulation platform supports all required simulation tools.
The district heating grid is an idealized grid modelled in Modelica®. For the model generation, components of the AixLib library [29] are used. The pipe model was developed in [30] and is able to simulate thermal losses, pressure losses and temperature wave propagation. For the demonstration of co-simulation, a simple model is used. The grid supplies three buildings, with a combined peak heat demand of 176 kW. Furthermore, a thermal energy storage is added. The embedding into the co-simulation framework is performed by FMI export. The combined heat and power unit (CHP) integrated in the co-simulation is a microturbine based CHP with an AE-T100/Dürr CPS. With an electrical output of 100 kW and a thermal output of about 180 kW the CHP is integrated with a flexible burner, so that the machine can be operated with various fuels such as natural gas, biogas and synthesis gas with a calorific value of 7 to 49 MJ/kg. The cogeneration unit is modelled in a stationary 0-D simulation tool that is suitable for fast and robust analysis of complex cycles [31]. The model is implemented in MATLAB®/SIMULINK® and allows the modelling of various CHP subcomponents such as turbomachinery, burner, recuperator, heat exchanger, electric generator and intermediate circuit. For the modelling of the components, all gas flows are assumed to be ideal gas mixtures. Temperature dependent polynomials are used to calculate the heat capacity, viscosity and thermal conductivity of pure substances. The behaviour of turbomachinery is calculated based on the pressure ratio and the isentropic efficiency, which are interpolated from uploaded maps according to the operating point. Heat and pressure losses are taken into account and the model is validated with experimental data. The model output is delivered as a 5D look-up table, in which the performance of the CHP in terms of fuel consumption and emissions is available for different electrical/thermal setpoints, different conditions of the district heating grid and ambient temperature. The integration of the 5D look-up table is performed by a Java implementation using an Octave engine for Java.
The simulation module simulating the electricity storage is directly implemented in Java. The characteristics of the associated power electronic of the inverter is integrated in an exchangeable file.
For the calculation of the power flow in the electricity grid, the MATPOWER library [32] is used in an Octave implementation for the co-simulation framework. The photovoltaics injection depends on the weather (radiation and temperature) and the time, from which the solar altitude can be derived for a specified location. To avoid computational effort, the solar injection is precalculated and replayed during the simulation run. This is possible because the values of all input interface dependencies can already be determined before the simulation run. The resulting time series is injected in the co-simulation framework as well as time series for the temperature and the loads in the CSV format.

[5] reactive power supply in dependence to the current active power
[6] removed, if the time at simulation start is known

Table 4: Interfaces for the AC power grid and connected devices

Pos.	Interface	Unit	Note
(1)	Electricity grid		per load
(1.2)	active power	W	≥ 0
(1.3)	reactive power	VA	
(2)	Electricity grid		per generator
(2.1)	active power	W	≤ 0
(2.2)	reactive power	VA	
(3)	Photovoltaic system (incl. inverter[5])		
(3.1)	direct radiation	W/m^2	
(3.2)	diffuse radiation	W/m^2	
(3.3)	ambient temperature	K	
(3.4)	(date and time[6])	(UTC)	
(4)	Wind power plant		
(4.1)	wind speed	m/s	
(4.2)	wind direction	rad	
(4.3)	*phase angle setpoint*	(data)	
(5)	AC-generator (synchronous)		
(5.1)	torque	Nm	
(5.2)	*phase angle setpoint*	(data)	
(6)	Storage		
(6.1)	*power setpoint*	(data)	$\gtrless 0$

5.4 Simulation Execution

The simulation run is demonstrated according to the simulation scenario depicted in Figure 1. The mini-CHP contains the micro gas turbine and the water pump. The water flow rate is calculated as a function of the thermal power setpoint and the flow temperatures determined by the heat grid simulation module. The available interfaces on the information flow layer for the mini-CHP simulation module are shown in Table 5.
The loads of the households are synthetically created in dependence to weather data supplied by [33] using the tools [34, 35]. Figures 2 to 5 are showing the district energy systems behaviour during three exemplary days. The heat profiles and the charge state of the heat storage are shown in Figure 2. The operation of gas turbine based mini-CHP has a threshold of 60 kW (thermal). During noon, the mini-CHP is stopped due to cheap available electrical power from photovoltaics. In the mean time the heating is supplied by the passive heat storage. Figure 3 shows the consumed and injected power, whereby the injected power is negative according to Table 4. Figure 4 shows the temperature behaviour at the connection points of the gas turbine as well as the ambient air temperature [33]. When the mini-CHP is not operating, the water mass flow stops. Thus, water in the pipes cools down and cold water enters the mini-CHP after a restart. Figure 5 shows the water mass flow trough the mini-CHP and the accompanying natural gas fuel consumption and carbon emissions.

Table 5: Interface list for the simulation module containing the mini-CHP and the water pump

Identifier	Description	Type	Unit
`T_amb`	ambient air temperature	input	K
`T_ret`	return temperature	input	K
`P_th_set`	thermal power setpoint	input	(kW)
`T_flow_set`	flow temperature setpoint	input	(K)
`T_flow_real`	real flow temperature	output	K
`m_flow`	water mass flow	output	kg/s
`P_th_real`	real thermal power	output	kW
`P_el`	electrical power (active)	output	kW
`Q_el`	electrical power (reactive)	output	kVA
`m_fuel`	fuel consumption	output	kg/s
`CO2`	carbon dioxide emissions	output	kg/s
`CO`	carbon monoxide emissions	output	kg/s

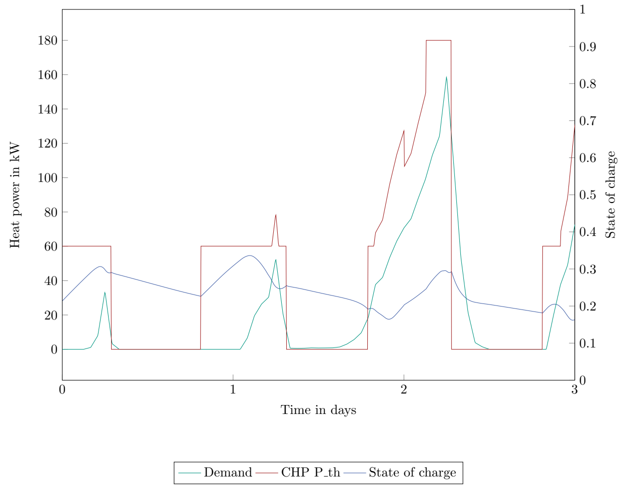

Figure 2: Heat power profiles

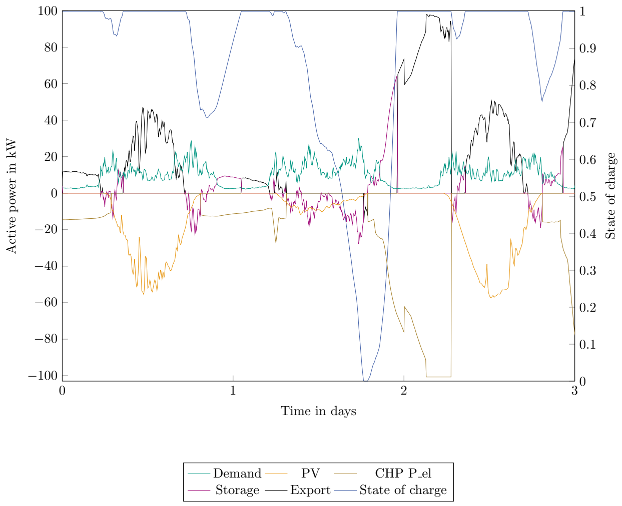

Figure 3: Electrical power profiles

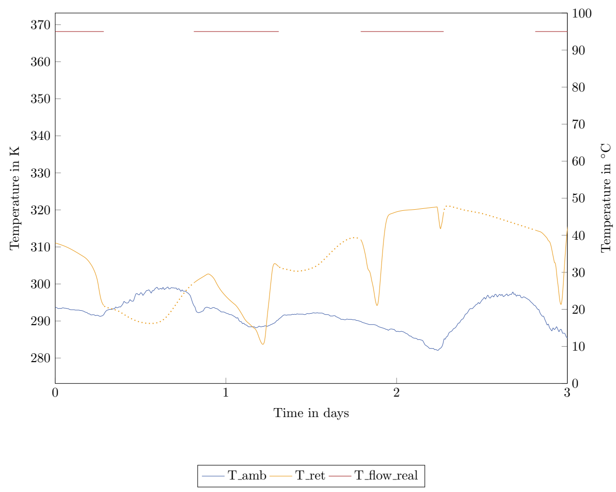

Figure 4: Mini-CHP temperature profiles

6 Conclusions

The verification of multimodal energy system design is particularly qualified for distributed simulation. Successful cooperation between experts from different research areas requires systematic coordination. The present contribution enables the reduction of the coordination effort by defining a clear approach. It comprises the holistic definition of the interfaces between the simulation parts from the semantic view of the investigated

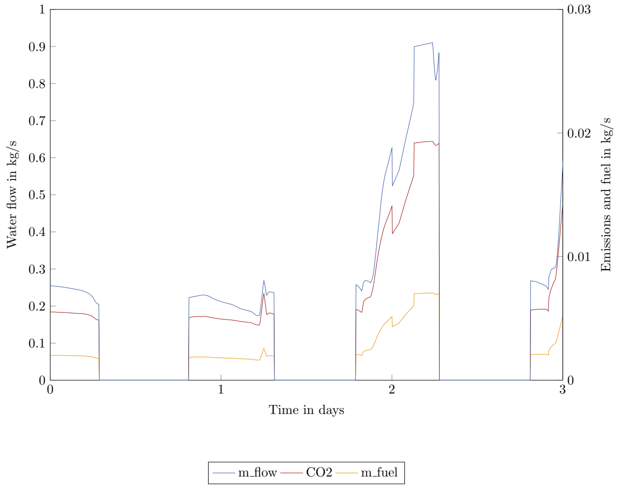

Figure 5: Mini-CHP water flow and emission profiles

energy system up to the technical view. An unambiguous specification of the interfaces between the simulation parts enables independent modelling by the specialists and subsequently a frictionless fitting of the distributed developed simulation models. A generic interface definition is prepared for the simulation of energy systems with district heating and power grids. The application is exemplarily demonstrated for a district simulation with a photovoltaic system, heat storage, electricity storage and mini-CHP.
This procedure enables a smooth model development by the individual domain experts, the source code—if confidential—does not need to be disclosed, while time-consuming adjustments of the simulation models and possible incompatibilities at the end are avoided.
For the design of energy systems, the verification of developed concepts by simulation is an established approach. The carrying out of the associated investigations including design and operational optimization in interdisciplinary research cooperations is a future goal.

Acknowledgement

This work was funded by the Initiative and Networking Fund of the Helmholtz Association in the future topic "Energy Systems Integration" under grant number ZT-0002.

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