8. Relevant Modelica Libraries

A large ever-growing set of third-party open-source libraries exist and they get monitored whenever an update takes place (Tiller and Winkler 2014), cf.

www.modelica.org/libraries

or

https://github.com/modelica-3rdparty

Most of these libraries are distributed under **Modelica BSD-like licenses**, cf.

https://www.modelica.org/licenses

for more details. To the best of our knowledge, we provide a list of existing open-source libraries that are or can be useful for power system modeling applications. In this section, a quick overview of existing open-source libraries are summarized.

R Consider reporting us a library that you think it should be listed here

8.1 Open-source Power systems libraries

Power system modeling is an active application area within the Modelica community since an early stage of the Modelica language (Bachmann and Wiesmann 2000). The MSL provides some basic capabilities based on first-principle models (e.g. resistors, capacitors, inductors, etc.) for constructing of power system networks, cf. Table 7.1.

Table 8.1 provides an overview of existing open-source Modelica libraries for various power system modeling applications including classical power network modeling.

Table 8.1: Open-source Modelica libraries in power system modeling applications

`Clara` (Brunnemann et al. 2012; Gottelt, Hoppe, and Nielsen 2017) www.claralib.com/	**Thermo-hydraulic behavior of stream power plants** with **coal dust firing** with focus on technologies for **carbon capture and its storage**. Processes governing fuel handling, cooling of combustion chamber and electrification of the stream in turbo generators among others are treated. Components include heat exchangers, pumps, valves, reservoirs, turbines, compressors, absorbers, steam accumulator (Richter, Oeljeklaus, and Görner 2019), gases and solvents. Transient analysis of power outputs can be performed. Capabilities for controller testings and investigation of start-up and shut-down processes are provided (Marx-Schubach and Schmitz 2019).
`ComplexLib` (Enge et al. 2006)	**Steady-state analysis of electro-mechanical drives** with electrical AC subsystems employing the phasor method
`ModPowerSystems` (Minz, Netze, and Monti 2016)	A modeling framework facilitating the increasing employment of **power electronics** in power systems. Capabilities for static and dynamic phasors simulation as well as **electromagnetic transient** are present.
`ObjectStab` (Larsson 2000)	Focus is devoted for modeling **transient and voltage stability analysis**. Components include generators as slack or PV nodes, 3rd or 6th order dq-models of excitation and governor control systems, transmission lines, reactive power compensation devices; shunt reactors, shunt capacitance and series capacitance, transformers, static and dynamic loads, buses and faulted lines among others. Although maintenance and progress is inactive, the library is suitable for educational purposes as it does not exploit later established advanced language features.

`OpenIPSL` (Baudette et al. 2018; Vanfretti et al. 2016a)	Validated set of power system components based on **phasor-time approach** validated against reference models from common power system tools. Power system models, including common known bus-systems models, **electro-mechanical transients** comprising power generation, transmission and consumption together with equipment components for control and stabilization can be constructed. Initial guesses corresponding to power-flow simulations are provided through other simulation tools. The library is not only suited for realistic applications but also for educational purposes (Murad et al. 2017).
`PhotoVoltaics` (Brkic et al. 2019)	**Photovoltaic components** including cells, modules and plants, enhanced with **power converters based on MSL** components among other features. Validation was conducted using selected industrial module data sheets. (Brkic et al. 2019) includes a good summary on the features of other PV libraries and their limitations.
`PowerGrids` (Bartolini, Casella, and Guironnet 2019)	Modeling of **electro-mechanical phenomena** in power systems including power generation and transmission targeting **European transmission system and distribution system operators**. Power flow analysis is expressed as initial equations which solution is the initial values of the power system network. By providing a good-initial guess, transient stability analysis can be conducted. The library was used for feasibility studies of realistic large-scale networks with thousands of nodes, generators and lines represented by over half-million equations (Casella, Leva, and Bartolini 2017).
`PowerSystems` (Franke and Wiesmann 2014)	**Arbitrary phase systems** in one single framework covering a large set of components for DC and three-phase AC. Steady-state, transient and asymmetric analysis can be conducted. An extensive overview is presented in Chapters 4, 5 and 6.

`SPOT`	One of the earliest libraries for power systems with extensive set of model components suited for detailed modeling of **transient effects** (Bachmann and Wiesmann 2000). Its implementation has influenced many subsequent libraries including the `PowerSystems` library. SPOT provided **a uniform treatment of natural (abc) and modal (dq0) coordinates** in one framework. Per-unit system for parameterization is supported (Franke and Wiesmann 2014). Although current development is inactive, its contents is of educational value as it is using less advanced language features that did not exist in earlier versions of the Modelica language. Actually, before implementing a new library, it is encouraged to explore and learn from the implementation of SPOT.
`SolarTherm` (Calle et al. 2018)	Typical components, with varying degree of complexity, for building a **solar thermal power plant**. Components include receivers, plates, pumps, heat-transfer, fluids, energy storage, power generation, whether data, control. The library is associated with a range of Python-based tools and scripts that automate the process of testing, simulating, optimizing and visualizing the results.
`ThermoPower` (Casella and Leva 2006; Schiavo and Casella 2007)	Dynamic modelling of **thermal power plants** with components for water and gas properties. Heat exchangers and electric generators are included. The library has been particularly useful for the study of control systems in traditional and innovative power plants and energy conversion systems including **steam generators, coal-fired power plants, combined-cycle power plants, nuclear power plants, solar plants, organic Rankine cycle plants, and cryogenic circuits for nuclear fusion applications**.
`TransiEnt` (Andresen et al. 2015; Andresen et al. 2019; Heckel and Becker 2019)	Coupled energy supply grids: **electricity, district heating and gas grids** (Andresen, Bode, and Schmitz 2018) with attention in **energy storage** in the presence of **fluctuating renewable energies** (Bode and Schmitz 2018; Dubucq and Ackermann 2017). Components include conventional and renewable power plants, electrical and thermal loads, buildings, districts, cities, electric- heat- and gas distribution elements and storage. **Conversion technologies s.a. power-to-gas (involving electrolyzer (Webster and Bode 2019)), power-to-heat, gas-to-heat and gas-to-power** are tools for enabling the transition to renewable energy source powered society (Bode and Schmitz 2018).

WindPowerPlant (Eberhart et al. 2015)	Simulation of **wind power plants** with components for wind turbines, generators and control

The underlying assumptions would usually presume that (Casella, Leva, and Bartolini 2017):

1. three-phase voltages and currents are always balanced, and can thus be described through the phasor approach (Araujo and Tonidandel 2013; Steinmetz 1893)
2. network frequency remains within an acceptable range around its reference value and thus a constant impedance is considered
3. a fixed network topology is assumed throughout network simulation

Many of these libraries commonly realize most of the following aspects:

- capabilities of browsing, reusing, modifying or extending existing model components
- flexible way of modeling, e.g. acausal modeling principles make networks construction very cumbersome, by simply connecting loads, busses, generators and lines together rather than relying on traditional admittance matrix methods
- uniform framework gathering detailed mechanical power generation (e.g. wind turbines), thermal aspects (e.g. PVs and thermal flow), weather forecast data, classical grid components, control components and strategies, faults, switches and events all together
- flexible mixing of different components from different libraries

Special attention has been neutrally devoted to the `PowerSystem` library. This library realizes the following advantages:

- can provide several analysis aspects only in one package including detailed dynamic transient analysis, quasi-steady state and steady state (i.e. transient and voltage stability) analysis and power flow calculations.‘
- Uniform treatment of phase-systems (DC, AC one-phase, AC three phases). Modelers will be able to easily switch between different phase systems.
- Uniform treatment of different coordinate representation (e.g. natural abc representation, model dq- and dq0 representations). In other words, modelers will be able to easily simulate the same models with different representation of phase systems.

More detailed comparisons among some of the listed Modelica libraries can be found in (Winkler 2017).

8.2 Energy in buildings and/or districts open-source libraries

Modern energy systems modeling applications may view buildings as a part of the electrical grid. They are not only energy consumers, but can be also energy producers within the electrical grid. While building modeling applications are usually focused on the internal thermal behavior, still small-order building models can be employed in the context of large-scale energy simulation at district-level (Frayssinet et al. 2017) including communication and transportation (Bollinger et al. 2018; Lu et al. 2019).

The interactions between thermal, gas and electrical networks and the opportunity of storing excess of electrical power in the form of thermal energy and/or hydrogen among other possibilities make libraries from the buildings modeling community of a vital interest for modern power systems modeling applications.

Table 8.2 provides an overview of existing open-source libraries in the buildings/districts domain.

Table 8.2: Open-source Modelica libraries in (thermal-)energy modeling of buildings and districts

`AixLib` (Müller et al. 2016)	**High and reduced order building models** with focus on **HVAC systems**. It has been employed in the field of district heating and cooling networks (Mans et al. 2019) as well as in hardware-in-the-loop (Schneider et al. 2015) among others.
`Buildings` (Wetter et al. 2014) simulationresearch.lbl.gov	A comprehensive library with extensive set of components for modeling aspects of **thermal energy behavior** in buildings including HVAC, multizone heat transfer and airflow among others. The library is enhanced with a package **interfacing and interacting with the electrical grid** in two directions (Bonvini, Wetter, and Nouidui 2014). Package includes weather modeling for renewable production, PVs, wind turbines among others.
`BuildingSystems` (Nytsch-Geusen and al. 2016)	Main focus on **thermal energy** (heating and cooling) in buildings and districts. Building models range from **simplified 0-dimensional low-order model to 3-dimensional multi-zones models**. Components for HVAC, solar thermal systems and photovoltaic systems are provided.
`DisHeatLib` (Basciotti and Pol 2011)	Modeling **thermal energy** aspects (Heating, cooling, pipes, storage, control, etc.) in **districts** with optional interfaces to the electrical power grid (Leitner et al. 2019).

DCOL (del Hoyo Arce et al. 2018) https://zenodo.org/record/818289	**District heating and cooling systems**, including distribution networks and thermal energy storage. The library was used in establishing a virtual test-bed of a district cooling production plant with compressor and absorption chillers (Zabala et al. 2020). Components include water storage, pipes, multi-zone air-flow, actuators, dampers, valves, radiators, heat pumps, etc.
FastBuildings (Baetens et al. 2015)	**Low-order building models** employing common components of electrical circuits ideal for smart grid modeling applications
GreenHouse (Altes-Buch, Quoilin, and Lemort 2019)	Modeling **greenhouse climate** including indoor climate, ventilation, climate control, generation and storage units (Combined Heat and Power (Altes-Buch, Quoilin, and Lemort 2018) and heat pumps), thermal energy storage and corp yield.
IDEAS (Jorissen et al. 2018a; Jorissen et al. 2018b)	Main focus is on **district thermal energy simulations** with interfaces to electrical systems, for instance the impact of PV and heat pumps on low-voltage electrical grids can be investigated (Protopapadaki and Saelens 2017; Protopapadaki and Saelens 2019).
modelica-ibpsa (Wetter and al. 2015)	**Basic interfaces and components common for modeling applications of energy of buildings**. It provides guidelines and **standardization** for advanced Modelica libraries in the Energy in Buildings domain. By relying on this standard, it easier to exchange components among various Modelica libraries targeting different scope of applications. There are many libraries listed in this Table that are based on modelica-ibpsa.

8.3 Useful open-source libraries

Table 8.3 provides a list of some 3rd-parties open-source Modelica libraries providing fundamental methodologies and/or tools for useful purposes. These libraries are not directly related to modeling of power systems but still they can be useful in some aspects. Many of these libraries are actively maintained, and some of them are discontinued. Thus, for those who are involved in similar activities, they can

- build on these efforts rather than starting from scratch
- directly contribute to these libraries and/or make these efforts active again

Table 8.3: Open-source Modelica libraries potentially useful for some Power Systems Modeling applications

`ABMLib` (Sanz, Bergero, and Urquia 2018)	**Agent-based modeling framework**. Source can be obtained under `www.euclides.dia.uned.es`.
`ADMSL` (Elsheikh 2014)	A demonstrative example for computing **dynamic parameter sensitivities** of Modelica models using **equation-based algorithmic differentiation techniques** (Elsheikh 2015)
`AdvancedNoise` (Klöckner, Knoblach, and Heckmann 2017)	Additional features to the existing Noise library within MSL incorporating more **stochastic distributions** and tools
`AlgebraTestSuite` (Sielemann, Casella, and Otter 2013)	Models for **testing initialization problems** of typical large-scale differential algebraic equations using a proposed initialization heuristic (Sielemann and Schmitz 2011; Sielemann 2012)
`CellularAutomataLib` (Sanz, Urquia, and Leva 2014; Sanz, Urquia, and Leva 2016)	**Describing dynamic phenomena dependent on spatial coordinates**. One- or two-dimensional cellular automates are present.
`DESLIB` (Sanz et al. 2012) `www.euclides.dia.uned.es`	Simulation of **discrete-event systems** following DEVS formalism. This has been used to reproduce some parts of the SIMAN language (Sanz et al. 2013). A library corresponding to the arena simulation language (Prat, Urquia, and Dormido 2006) suited for industrial dynamics (Forrester 1961), e.g. describing processes of factory automation, is included.
`ExternalMedia` (Casella and Richter 2008)	Enabling inclusion of **external fluid property code** in Modelica compatible to interfaces provided by MSL. Focus is devoted on **two-phase single-substance fluids**.

FailureMode (Pop et al. 2012)	A collection of failure modes assisting modelers to systematically recognize the **root-cause of common runtime** errors through useful debugging information by a Modelica simulation tool. Typical errors include incorrect parameterization, invalid initialization, boundaries violation among others. This is particularly useful in the development stage.
FaultTriggering (Linden 2014)	**Proposed standardization for triggering common faults during simulation runtime**. This is realized by fault-output blocks attached to model components to trigger user-chosen faults.
FMITest	**Testing connections of FMUs** particularly during initialization and iteration.
LinearMPC (Hölemann and Abel 2009)	**Model-based predictive control** for linear processes
Modelica_DeviceDriver (Bellmann 2009; Thiele et al. 2017)	Allows **access to hardware devices** such as input devices (keyboard, 3D-connecion, SpaceMouse, etc.) within Modelica models. This is particularly useful for interactive simulations with animations, Human-in-the-Loop and/or Hardware-in-the-Loop simulators as well as control applications. Part of the library is included in MSL 4.0.0.
Modelica_LinearSystems2 (Baur, Otter, and Thiele 2009; Otter 2006)	Data structures for **linear time-invariant differential and difference equation systems** as well as polynomial-based operations on complex numbers. Typical operations on these structures are provided enabling description of transfer functions for common linear control analysis.
Modelica_Requirements (Otter and al. 2015)	Formal modeling of **requirements and their verification** during simulation
Optimisers	**Specification of dynamical optimization** using Modelica components. The optimization problem is solved using external solvers.

ModelicaDEVS (Beltrame and Cellier 2006)	A realization of **discrete event system simulation formalism** (Ziegler 1976) in Modelica, cf. Subsection 9.2.3
ScalableTestSuite Casella 2015b & ScalableTestGrids	A collection of parameterizable large-scale Modelica models appropriate for **benchmarking**. The later library is recently developed and is more focused on power system models. The library is to be reported in the Modelica conference 2021 in Linköping.
SystemDynamics (Cellier 2008)	Modeling various dynamical phenomena in many areas including economics, industry, environments, according to **the principles of system dynamics** of J. Forrester (Forrester 1969; Forrester 1971a; Forrester 1971b)
ThermalSeparation (Joos, Dietl, and Schmitz 2009)	Gas-separation, absorption, adsorption and rectification processes including heat and mass transfer within mixed-phases mediums (Marx-Schubach and Schmitz 2019).
XogenyTest	**Unit testing** of Modelica models and libraries using Modelica components

8.4 Commercial libraries

R To the owners of relevant commercial Modelica libraries, your library can be reported here. The table is ordered in alphabetical order. As the case with Open source Modelica libraries, the description of any library shall not exceed 100 words. However, as many academic references as possible can be reported. A URL to a comprehensive and actual description of the library can be also provided, where then an interested reader can explore more details.

Table 8.4 provides an incomplete list of commercial Modelica libraries that are directly or indirectly useful for power system modeling applications.

Table 8.4: Open-source Modelica libraries potentially useful for some Power Systems Modeling applications

`ElectricPower-` `-System` (EPSL) Dassault Systèmes (CAUJOLLE et al. 2019)	EPSL enables **phasor based modeling of AC and DC, as well as combined AC/DC (hybrid) networks**. Key components are provided at different levels of detail. The so-called architectural level uses "standard" phasor theory resulting in a quasi-static description of the system. The functional level uses dynamic phasors (Yang, Bozhko, and Asher 2014) to cover dynamic effects in the models. Additionally the EPSL enables the description of harmonics of the one or multiple independent fundamental AC frequencies, which can be either constant or variable. Currently, AC components are either single or three-phased.