



Modelica by Application – Power Systems

version 0.3.1 on April 23, 2021

Atiyah M. G. Elsheikh & Peter Palensky

Book Website:

[https://github.com/Mathemodica/
ModelicaPowerSystemBook](https://github.com/Mathemodica/ModelicaPowerSystemBook)

Copyright © 2021 Atiyah Elsheikh (Mathemodica.com)

This book is provided under the terms of CC BY-NC-SA 4.0 license, cf.

<https://creativecommons.org/licenses/by-nc-sa/4.0/>

Basically, you are free to:

1. **Share**, copy and redistribute the material in any medium or format
2. **Adapt**, remix, transform, and build upon the material

under the terms:

1. **Attribution**: You must give appropriate credit, provide a link to the license, and indicate if changes were made. You may do so in any reasonable manner, but not in any way that suggests the licensor endorses you or your use.
2. **NonCommercial**: You may not use the material for commercial purposes.
3. **ShareAlike**: If you remix, transform, or build upon the material, you must distribute your contributions under the same license as the original.

Dedication from the first author to

Meram

میرام

میرام

About

This is a comprehensive but a concise and educational (e-)book aiming at advertising Modelica-based technologies particularly useful for power system modeling applications. Whatever aspect that could be useful has been included, to the best of author's knowledge. We hope that this book is useful not only for power system modelers desiring to get a quick idea about the benefits of employing Modelica but also for those Modelica modelers desiring a starting guide into the world of Power System.

Involvement & Conditions

If you are clearly involved in power-system related activities using the Modelica language, you are highly encouraged to actively improve the state of this book whenever and/or wherever possible. For this reason, this book is available on the platform Overleaf which allows collaborative writing.

However, it is important to note that, any suggested enhancement should be valuable, concise, accurate and elegant. The authors have the right to reject or to ask for specific corrections or improvements to any suggested enhancement.

Contact

Consider contacting atiyah.elsheikh@mathemodica.com if you would like to:

- contribute to the text: Consider providing a brief summary in advance of the purpose of your desired involvement
- provide suggestions or pdf-annotated review, suggested corrections, suggested text, etc.
- provide a general feedback
- provide suggested topics or materials that this book should cover
- have access to the latex sources for whatever purpose you need, e.g. project proposals, user guides, etc.

Recognition

Your useful scientific involvement, in whichever form, shall be acknowledged, unless explicitly communicated that this is not desired.

First Edition (V1.0) to appear 1st of Sep. 2021

Pre-order a free (electronic) edition 1.0 @

<https://gum.co/mathemodica-powsys-free>

Sponsor the maintenance and progress
by the first author through

I. Pre-ordering the book for
as-much-as-you-think-this-book-deserves

<https://gum.co/mathemodica-powsys>

II. Get a continuous access to the actual version:
through sponsorship

A. Single-time sponsorship @

<https://www.paypal.com/paypalme/mathemodica>

B. Periodic sponsorship @

<https://gum.co/mathemodica-powsys-sponsorship>

<https://github.com/sponsors/AtiyahElsheikh>

Subscribe to newsletters and posts from
Mathemodica.com @

<https://gumroad.com/mathemodica>

Acknowledgment

Atiyah Elsheikh is acknowledging his former employer, Austrian Institute of Technology. This book, initially as a technical report, has been started during his role there. The early version was still in a primitive state until he recently decided to write a comprehensive book.

Moreover, couple of capitals of this book has been written by others. Without their contribution, the book would be definitely less valuable. Thus, I'd like to thank (in alphabetical order of family names):

- Prof. Andrea Benigni, RWTH Aachen and Research Center Jülich, with his great help, this report is suitable for Electrical Engineers. Particularly, major parts of Chapter 2 and Section ?? were originally written by him.
- Assoc. Prof. Omar Faruque, Florida State University, for presenting this initiative at a PES general meeting
- Prof. Antonello Monti, RWTH Aachen, being the initiator of the idea of having a comprehensive report that gathers all useful aspects Modelica can provide for power system modeling applications. The first chapter was originally written by him.

I also would like to thank

- Dr. Mathias Legrand for allowing to employ this wonderful latex template accessible under
<https://www.latextemplates.com/template/the-legrand-orange-book>

I believe that online Modelica educational materials need to be gathered together and since the idea of having a freely accessible book that is meanwhile sponsored (or to be sponsored) by any one on the basis of pay-as-much-as-you-think-this-book-deserve is inspired by the author of the book "Modelica by Examples", thus, my special appreciation goes to Dr. Michael Tiller, for:

- his initial agreement in hosting or linking a future html-version of this book to the platform
<https://modelica.university>
- his technical tips, recommendations and his willing to help me (despite apparently being a very busy person with his own duties)

I hope to have enough energy in near future to learn the technology needed to bring this book to the platform modelica.university and to establish url-links to adequate materials in his book whenever more in-depth clarification of Modelica syntax is needed. In that way, the focus of this book can remain on the applications side of power systems rather than attempting to illustrate the tiniest details of the Modelica language.



Contents

I	Motivation	
1	Motivation and Outline	13
2	Modeling Challenges	17
2.1	Traditional power system simulation studies	17
2.2	Modern aspects in power system modeling applications	19
2.3	Mutli-physical phenomena in power systems (TO Complete)	20
3	The Rise of Modelica	21
3.1	Pre-era Modelica	21
3.2	The evolve of the Modelica language	22
3.3	Predecessors of Modelica (To complete)	24
3.4	Benefits of the Modelica language	24
II	Designing a Modelica library	
4	Basic concepts	29
4.1	Variables, parameters and constants	29
4.2	Physical units	30

4.3	Packages	31
4.4	Organization of packages	32
4.5	Connections	32
4.6	Components	33
5	Object-Oriented features	37
5.1	Abstract Models and Inheritance	37
5.2	Arbitrary phase systems by an abstract package	38
5.3	Interfaces	39
5.4	Implementation of Functions	40
5.5	Generic connectors	41
5.6	Generic components	42
6	Examples	45
6.1	A power flow study	45
6.2	Power generation and consumption	47

III

Actual Aspects

7	Current state of Modelica	53
7.1	Language specification	53
7.2	The Modelica Standard Library	54
7.3	The functional mockup interface	56
7.4	Projects	57
7.5	Modelica simulation environments	59
7.6	Conferences and user groups	59
7.7	Modelica Association Membership	59
7.8	Modelica Newsletters	60
7.9	Educational materials	60
8	Open-source Modelica Libraries	61
8.1	Power systems libraries	61
8.2	Energy in buildings and/or districts	65
8.3	Useful libraries	66

IV

Advanced Aspects

9	Scalability and runtime performance	73
9.1	Limitations	73
9.1.1	Translation to one single big block of equations	74
9.1.2	Single-rate numerical integration	74
9.1.3	No exploitation of sparsity patterns	74
9.1.4	Insignificant local events cause tremendous computation	75
9.2	Active research agenda for improving runtime performance	75
9.2.1	Exploiting sparsity patterns and sparse solvers	75
9.2.2	Multi-rate numerical solvers	75
9.2.3	Solvers for massive number of state-events	76
9.2.4	Hybrid modeling paradigms (TO COMPLETE)	77
9.2.5	Agent-based modeling paradigms (TO COMPLETE)	77
9.2.6	Parallelization (TO COMPLETE)	77
10	Applications of Sensitivity Analysis (To Write)	79
11	Summary and Outlook	81
11.1	Advantages of the Modelica language	81
11.1.1	Object-oriented paradigm	81
11.1.2	Domain-independent multi-physical modeling concepts	81
11.1.3	Advanced methods for efficient runtime simulation	82
11.1.4	Standardized (co-)simulation interfaces	82
11.1.5	Code generation capabilities	82
11.1.6	Considerable amount of open-source libraries in power-system (related-) domain(s)	82
11.1.7	Further useful open-source libraries	83
11.1.8	Modelica for power system modeling applications	83
11.2	Challenges and Future directions	83
A	Bibliography	87
	Bibliography	87



Motivation

1	Motivation and Outline	13
2	Modeling Challenges	17
2.1	Traditional power system simulation studies	
2.2	Modern aspects in power system modeling applications	
2.3	Mutli-physical phenomena in power systems (TO Complete)	
3	The Rise of Modelica	21
3.1	Pre-era Modelica	
3.2	The evolve of the Modelica language	
3.3	Predecessors of Modelica (To complete)	
3.4	Benefits of the Modelica language	



1. Motivation and Outline

Original text by

Prof. Antonello Monti (Enhanced by AE)

Traditionally modeling and simulation has been conducted within a single physical domain type. Electrical engineers used to develop electrical systems primarily focusing on grid modeling and mostly neglecting other interacting domains. One of the significant exception to this rule has been a simplified representation of the rotating mass for stability analysis [139, 222].

In the last decade though, we have experienced a growing interest towards multi-physics design in many different areas of applications. Two concrete examples of this type are the avionics industry and ship industry in relation to programs such as More Electric Aircraft [108, 192] and All Electric Ship [216, 219]. The development of such projects has shown the limitation of the single-domain approach and has paved the way to comprehensive approaches for multi-physical modeling and simulation.

One response to the problem has been the development of co-simulation interfaces and standards [28, 103, 166]. Co-simulation offers the user the possibility to operate in a domain-specific environment and to relegate the integration of other simulation platforms to be mostly a software challenge.

While this approach has some clear advantages from user perspective, first of all the possibility to continue operating with the same tools also in the new operating conditions, co-simulation tends to have a significant computation and implementation overhead given

by the co-presence of more than one simulation platform. Nevertheless, many tools exist simplifying the co-simulation implementation overhead, e.g. [169, 234].

Furthermore, it is quite easy to face versioning issue created by the fact that the project as a whole is stored in multiple files. There are also so many technical issues that goes beyond this text.

Proposition 1.1 In summary, one day co-simulation will be most effective if it converges to the state that a modeler is neither aware nor technically caring that his descriptive models are executed via co-simulation.

Consequently there is a growing interest towards multi-physical modeling languages. Multi-domain languages provide an interesting solution, majorly because they are languages and not simulation platforms.

This means that the modeling effort and the solution effort are clearly separated. This separation brings an incredible benefit from the user point of view that is able to migrate from one simulation tool to another without repeating the modeling effort.

Proposition 1.2 Converting from a tool user to a model designer via a well-designed modeling language extends the horizon of realizable applications to an extent that is beyond imagination.

There are many simulation languages of this type available s.a. VHDL-AMS[12], gPROMS [106] and Modelica [72]. The last language has been developed as an initiation for a standard modeling language used by a large modeling community in many modeling domains. This has resulted in an open-source non-property specification language continuously maintained, supported and progressed both from academia and industry.

Outline of this book

The outline of the book is structured as follows. In Part I we first review the major challenges in power system modeling and simulation. These demonstrates new requirements for modeling and simulation tools for modern power system modeling applications. In order to appreciate the evolution process of such modern modeling languages, we reveal how the accumulation of progressive milestones along many decades led to the concepts on which current state of the art of modeling language are based on.

In Part III, we dive into the Modelica language, giving a non-familiar reader though rather a compact overview of the language but hopefully generous enough to recognize its potentials in the scope of power system modeling applications. This demonstration is based on one of the existing and elegant open-source libraries. This particular library provides the opportunity to demonstrate many syntactical and significant features of the Modelica

language.

In Part III we overview current state of the Modelica language. Particularly, we summarize

- language specification, the underlying process of its development through the Modelica association
- the Modelica Standard Library and some of its major components significant for power system modeling,
- the functional mockup interface including related projects
- as well as other significant related topics that may matter the reader

Furthermore, reflecting our humble struggle to eliminate the thirst of a knowledge seeker, we provide a comprehensive list of open-source Modelica libraries in the field of (and in many areas related to) power systems. The list includes libraries in the field of energy in buildings and cities as well as other fundamental methodological libraries, e.g. for generating statistical distributions or for imitating a hybrid paradigm.

Finally, since power systems models are naturally large-scale, in Part IV we demonstrate current challenges facing the Modelica language addressed together with recently and actually conducted research efforts for overcoming these challenges. We summarize with a list of benefits the Modelica language can offer in the context of modern power system modeling applications. We overview a list of potential extensions to the Modelica language in order to enable further capabilities, e.g. partial differential equations or prototyping of simulation-optimization problems.