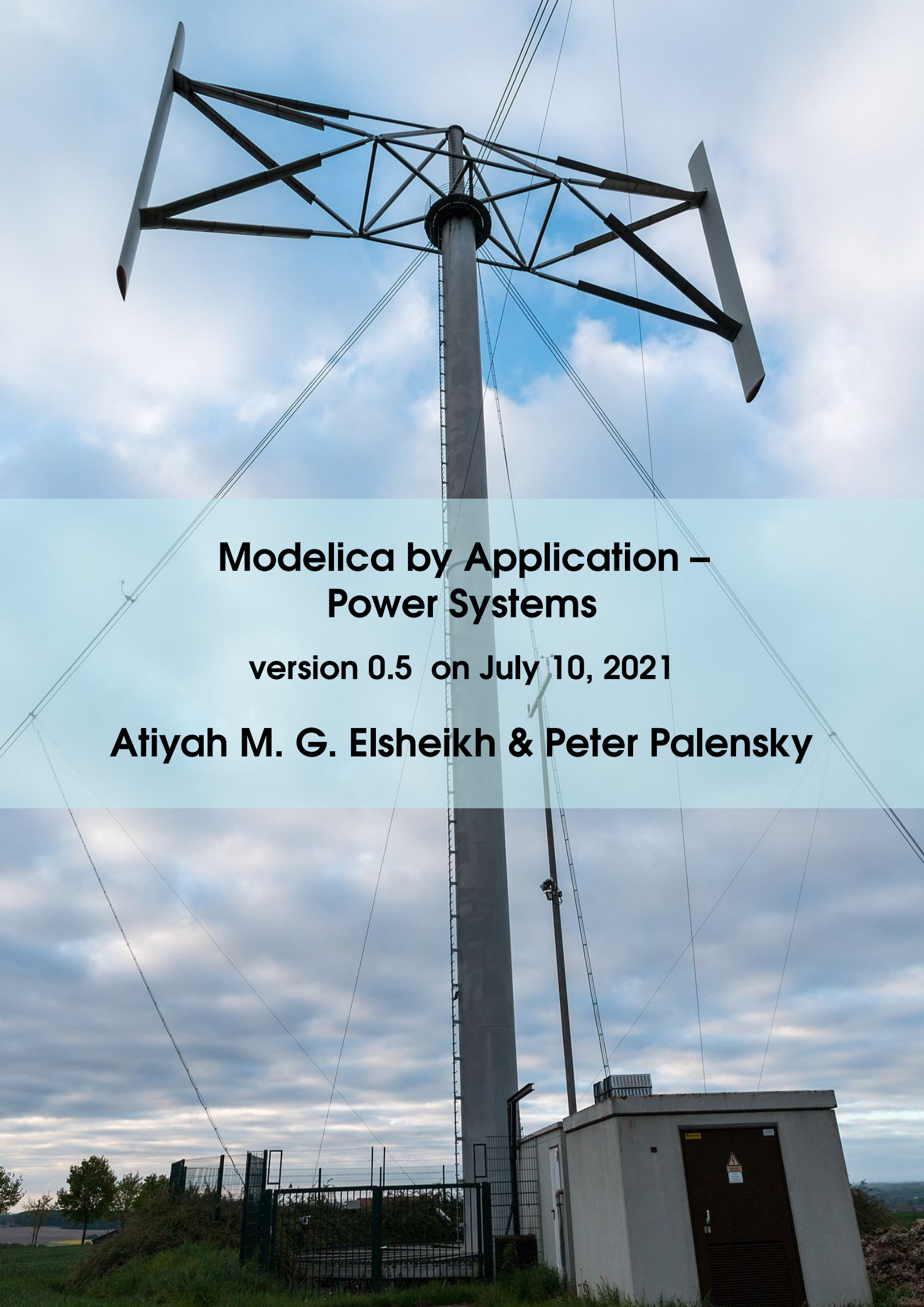

Modelica by Application – Power Systems

version 0.5 on July 10, 2021

Atiyah M. G. Elsheikh & Peter Palensky

Book Website:

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

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

Subscripe to newsletters and posts from
Mathemodica.com @
https://gumroad.com/mathemodica

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

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.

Overleaf.com

In case you don't have an account on overleaf.com, to this book benefit's consider creating an account using the following referral link:

https://www.overleaf.com?r=e7d83309&rm=d&rs=b

Contact

Consider contacting atiyah.elsheikh -at- 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.

About Mathemodica.com

By the time of relasing version 0.5 of the book (July 2021), Mathemodica.com is currently a virtual organization. It currently reflects the main hobby-based (but occoasionally professional) activites of the first author ususally on his free-time.

One of the idea behind Mathemodica.com, which is still evolving and subject to continuous improvement, is to provide a transparent, collaborative and independent platform for those who would like to sponsor their own ideas and works concerning Modelica-like technologies (libraries, tools, educational e-books, tutorials, etc.).

It is hoped that the resulting products to be open-source and free. If you'd like to become a part of this and contribute to the evolve of Mathemodica.com consider viewing:

http://mathemodica.com/modelicans/

Any questions or suggestions are welcomed.

Sponsorship

Sponsorship (cf. to the quick urls given at the begining of the book) is appreciated as an aid and accelerator for

- financing the continuation of maintaining, actualizing and progressing this book
- executing similar initiatives for establishing educational contents (tutorials, books and libraries)
- among other similar activities by members of Mathemodica.com, cf.
  http://mathemodica.com/projects

These activities are in conformance with the spirit of open science initiative.

Probably sponsorship would be best suited from organizations, both from academy and industry, benefiting from having such works being disclosed, published and spread. Another possible alternative, usually specific amount of money in some organizations, departments, institutes etc. should be spend before the end of the year. If there is a confusion how to spend available money, I would appreciate a sponsorship in form of donation that would allow to accelerate the progress of this book.

If you are a representative of an organization which would like to sponsor such works, please let us know what would you like to see in order to sponsor this work.

Acknowledgment

We are acknowledging our former employer, Austrian Institute of Technology GmbH. This book has started initially as a technical report during our roles there. The early version was still in a primitive state until it was recently decided to re-write it as 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, We'd like to thank (in alphabetical order of family names):

- Prof. Andrea Benigni, RWTH Aachen and Research Center Jülich, with his great help, this book was further tuned for Electrical Engineers. Particularly, major parts of Chapter 2 and Section 10.1 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.

We 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 us (despite apparently being a very busy person with his own duties)

We 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[1]

We also would like to thank

- Dr. Mathias Legrand for allowing to employ this wonderful latex template accessible

[1] By the release version 0.4, I still did not invest enough time in this issue. If anyone with proper technical knowledge would like to get engaged he/she is thankfully encouraged to contact us

under
https://www.latextemplates.com/template/the-legrand-orange-book

The pictures in this book come from:

- Dietmar Rabich / Wikimedia Commons / “Dülmen, Rorup, Windenergieanlage – 2015 – 5972” / CC BY-SA 4.0
- Dietmar Rabich / Wikimedia Commons / “Schöppingen, Schöppinger Berg – 2015 – 8513” / CC BY-SA 4.0
- Peter Haas / Wikimedia Commons / Windpark Höflein, Niederösterreich / CC BY-SA 3.0
- J. E. Wolters / Wikimedia Commons / Wasserkraftwerk an der Isar bei Niederaichbach / CC BY-SA 4.0
- Kreuzschnabel / Wikimedia Commons / Das Kraftwerk Heilbronn / CC BY-SA 3.0
- Dmitry Makeev / Wikimedia Commons / Stung Hav Coal Power Plant / CC BY-SA 4.0

Anyone who made his own nice pictures and would like to share it here is encouraged to contact us.

Contents

I Introduction

1 Motivation and Outline 15

2 Modeling Challenges 19

2.1 Terminologies of power systems 19

2.2 Traditional power system simulation studies 20

2.2.1 Load-flow studies 20

2.2.2 Transient stability simulation 21

2.2.3 Electromagnetic / Electromechanical transient stability simulation 21

2.3 Modern aspects in power system modeling applications 22

2.3.1 Monitoring and control 22

2.3.2 Complexity 22

2.3.3 Variety of time scales 22

2.3.4 Stochastic effects 23

2.3.5 Communication aspects 23

2.3.6 Design process 23

3 The Rise of Modelica 25

3.1 Pre-era Modelica 25

3.1.1 Block diagrams 25

3.1.2 Bond graphs 26

3.2 The evolve of the Modelica language 27
3.2.1 In the beginning it was Dymola . . . 27
3.2.2 Hardware technologies . . . 28
3.2.3 Compiler methods . . . 28
3.2.4 The differential index problem . . . 28
3.2.5 And then Modelica came . . . 29
3.3 Advantages of the Modelica language 29

II Designing a Modelica library

4 Basic concepts . . . 33
4.1 Equation identifiers 33
4.2 Physical units 34
4.3 Packages 35
4.4 Organization of packages and subpackages 37
4.5 Connections 38
4.6 Model components 40
4.7 A simple electrical network 42

5 Object-Oriented features . . . 45
5.1 Abstract models and inheritance 45
5.2 Arbitrary phase systems by an abstract packages 46
5.3 Function interfaces 47
5.4 Implementation of function interfaces 49
5.5 Generic connectors 51
5.6 Generic components 52

6 Examples . . . 55
6.1 A power flow study 55
6.2 Power generation and consumption 58

III Actual Aspects

7 Current state of Modelica . . . 63
7.1 Language specification 63
7.2 The Modelica Standard Library 64
7.3 The functional mockup interface 66
7.4 Projects 68
7.5 Modelica simulation environments 69

7.6 Conferences and user groups 70
7.7 Modelica Association Membership 70
7.8 Modelica Newsletters 71
7.9 Educational materials 71

8 Relevant Modelica Libraries ... 73
8.1 Open-source Power systems libraries 73
8.2 Energy in buildings and/or districts open-source libraries 77
8.3 Useful open-source libraries 79
8.4 Commercial libraries 83

IV Advanced Aspects

9 Scalability and runtime performance ... 87
9.1 Limitations 87
9.1.1 Translation to one single big block of equations ... 88
9.1.2 Single-rate numerical integration ... 88
9.1.3 No exploitation of sparsity patterns ... 89
9.1.4 Insignificant local events cause tremendous computation ... 89
9.2 Active research agenda for improving runtime performance 90
9.2.1 Exploiting sparsity patterns and sparse solvers ... 90
9.2.2 Multi-rate numerical solvers ... 91
9.2.3 Solvers for massive number of state-events ... 91

10 Summary and Outlook ... 93
10.1 Advantages of the Modelica language 93
10.1.1 Object-oriented paradigm ... 93
10.1.2 Domain-independent multi-physical modeling concepts ... 94
10.1.3 Advanced methods for efficient runtime simulation ... 94
10.1.4 Standardized (co-)simulation interfaces ... 94
10.1.5 Code generation capabilities ... 95
10.1.6 Various open-source and commercial libraries in power-system (related-) domain(s) ... 95
10.1.7 Further useful libraries ... 95
10.1.8 Modelica for power system modeling applications ... 96
10.2 Challenges and Future directions 96

A Bibliography ... 99

Bibliography ... 99

I Introduction

1 **Motivation and Outline** 15

2 **Modeling Challenges** 19

2.1 Terminologies of power systems

2.2 Traditional power system simulation studies

2.3 Modern aspects in power system modeling applications

3 **The Rise of Modelica** 25

3.1 Pre-era Modelica

3.2 The evolve of the Modelica language

3.3 Advantages of the Modelica language