elena international

Hybrid microgrid planning using selected Open-Source frameworks

Dr. Sabine Auer, Jan Liße, Supriya Mandha & Christina Horn

4th International Hybrid Power Systems Workshop 2019, Crete

funded by Leibniz Competition

PIK

eit Climate-KIC

HUMBOLDT INNOVATION
RESEARCH CREATING REALITY

Gefördert durch:
Bundesministerium für Wirtschaft und Energie
aufgrund eines Beschlusses des Deutschen Bundestages

ESF Europäischer Sozialfonds für Deutschland

EUROPÄISCHE UNION

eXIST Existenzgründungen aus der Wissenschaft

elena – electricity network analysis

elena international

Our Vision: Enabling Renewable Power Grids

with grid planning based on Open-Source Software

Dr. Sabine Auer
Founding partner

Christina Horn
Founding Partner

Jan Liße
Chief Software Architect

Supriya R. Mandha
Chief Project Manager

eit Climate-KIC

funded by Leibniz Competition

eXIST Existenzgründungen aus der Wissenschaft

Winners of Leibniz Gründerpreis

Company Profile

elena international

Our Services:

- assembly of weather and load data to understand your power system better
- simulation models of your power grid to improve your grid planning
- optimal sizing of storage, generation and transmission capacities
- cost-effective operational strategies with unit-commitment modeling
- control solutions for a stable and reliable RES integration
- transient frequency and voltage stability analysis

Outline

1. Motivation for Hybrid Microgrids
2. Why Open-Source?
3. Hybrid Microgrids Design & Stakeholder Requirements
4. Selection of Open-Source Power System Planning Tools
5. Evaluation & Take-home message

1. Why Hybrid Microgrids?

elena international

- to decrease electricity prices, gain independence from diesel price fluctuations & transportation
- a cost-efficient energy transformation
- to reach high shares of renewables
- maintain grid stability and increase infrastructure lifetime

Central Question

elena international

What are adequate Open-Source frameworks for hybrid microgrid planning?

2. Why Open-Source?

elena international

- Harmonization (across software tools)
- Flexibility (modifiable & extendable)
- Transparency (no black-box modeling)
- Data security
- Cutting-edge (R&D, maintenance from Open-Source community)
- No licensing costs

Outline

1. Motivation for Hybrid Microgrids
2. Why Open-Source?
3. **Hybrid Microgrids Design & Stakeholder Requirements**
4. Selection of Open-Source Power System Planning Tools
5. Evaluation & Take-home message

3. Design & Stakeholder Requirements

elena international

- Load and renewable time series data

Step 1: System sizing

- Generation, storage & transmission capacities

Step 2: Identification of optimal operational strategies

- Generation & storage profiles/ time series

Step 3: Grid analysis

- Grid stability functions (e.g. spinning reserve requirements)

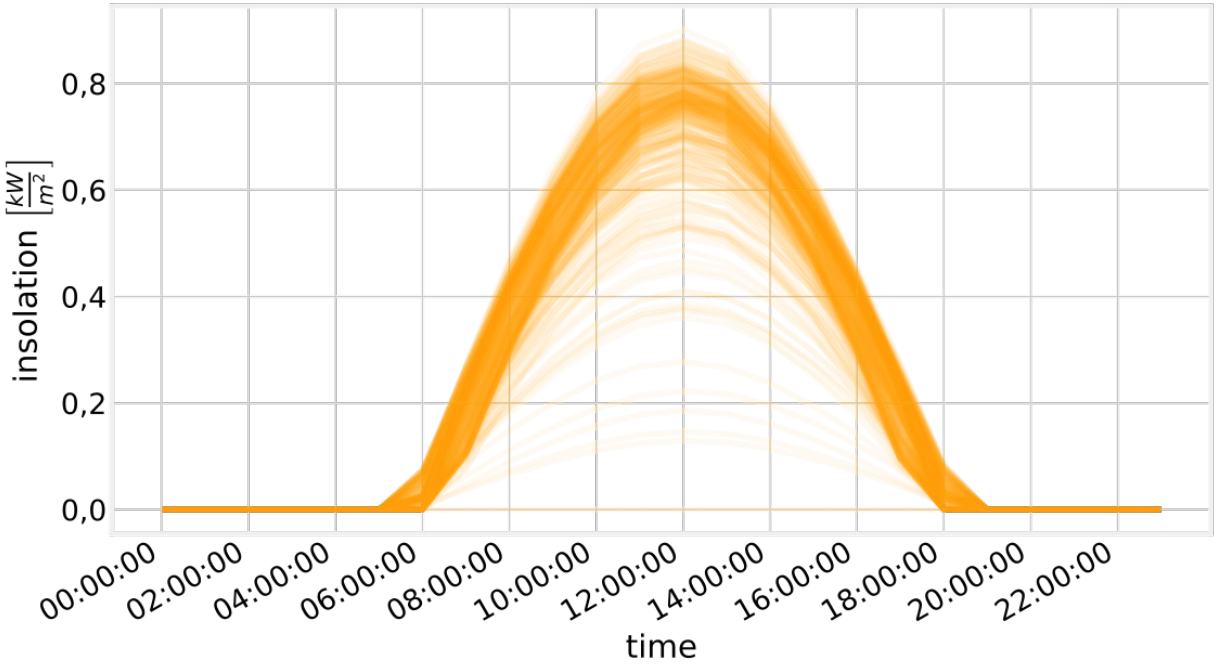
S. Berendes et. al. HPW (2018)

Input Data for Step 1 - System Sizing

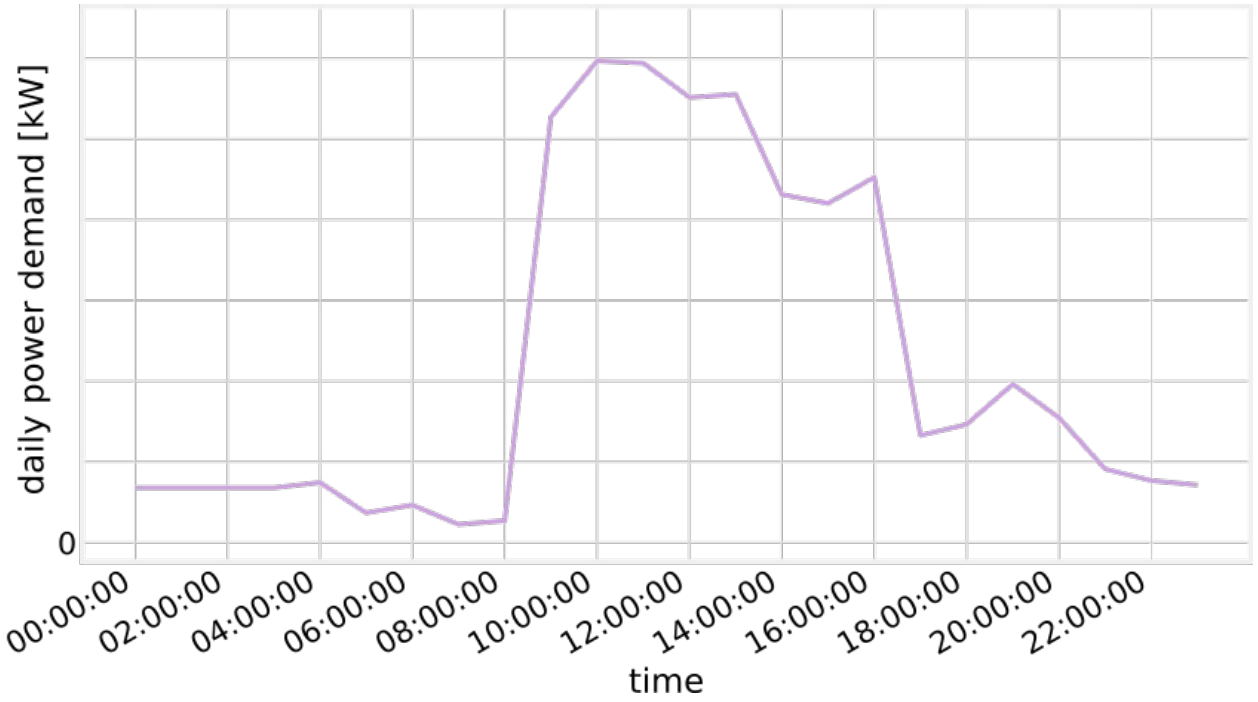
elena international

secondary functionality (couple with resource data and load profiles, update uncertain parameters over the course of optimization horizon).

Solar irradiance



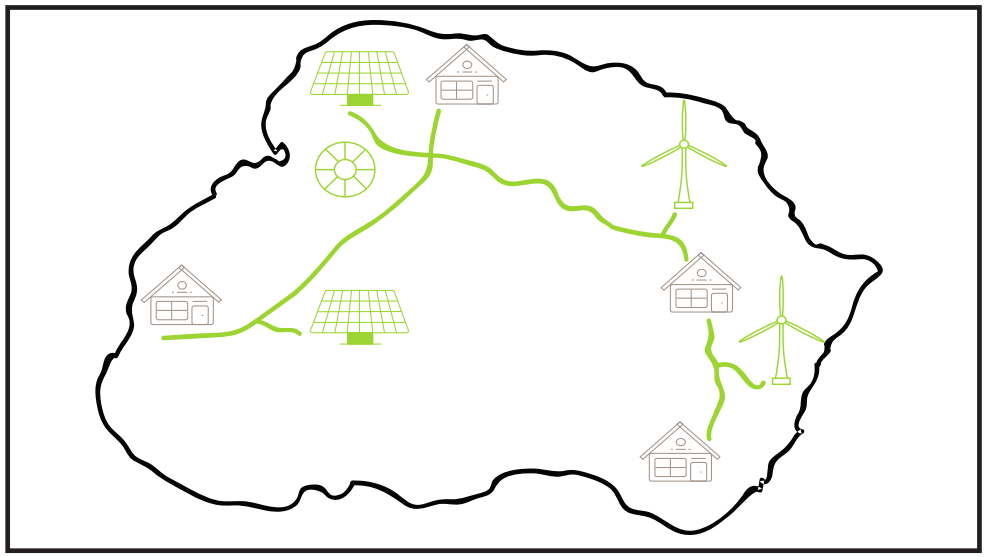
Demand data



Step 1: System Sizing

What microgrid components should a model contain?

- high: PV, battery storage (lead acid, Li-ion), multiple diesel generators, controller strategies, inverters, AC- and DC coupling
- medium: wind, biomass, hydro-turbines, thermal storage, fuel cell, grid
- low: geothermal components, tidal sources, high-temp. battery storage



Step 1: System Sizing

elena international

"Copper plate"

- Optimization
- no power flow
- Simple power balance

Linear Optimal Power Flow

- Linear cost function
- linearized power flow as constraint

Optimal Power Flow

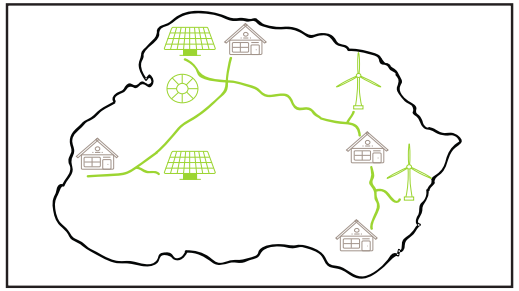
- Nonlinear cost function
- Nonlinear power flow as constraint

Increasing complexity/ nonlinearity

- to include storage in this optimization it is necessary to model a multi-period optimization

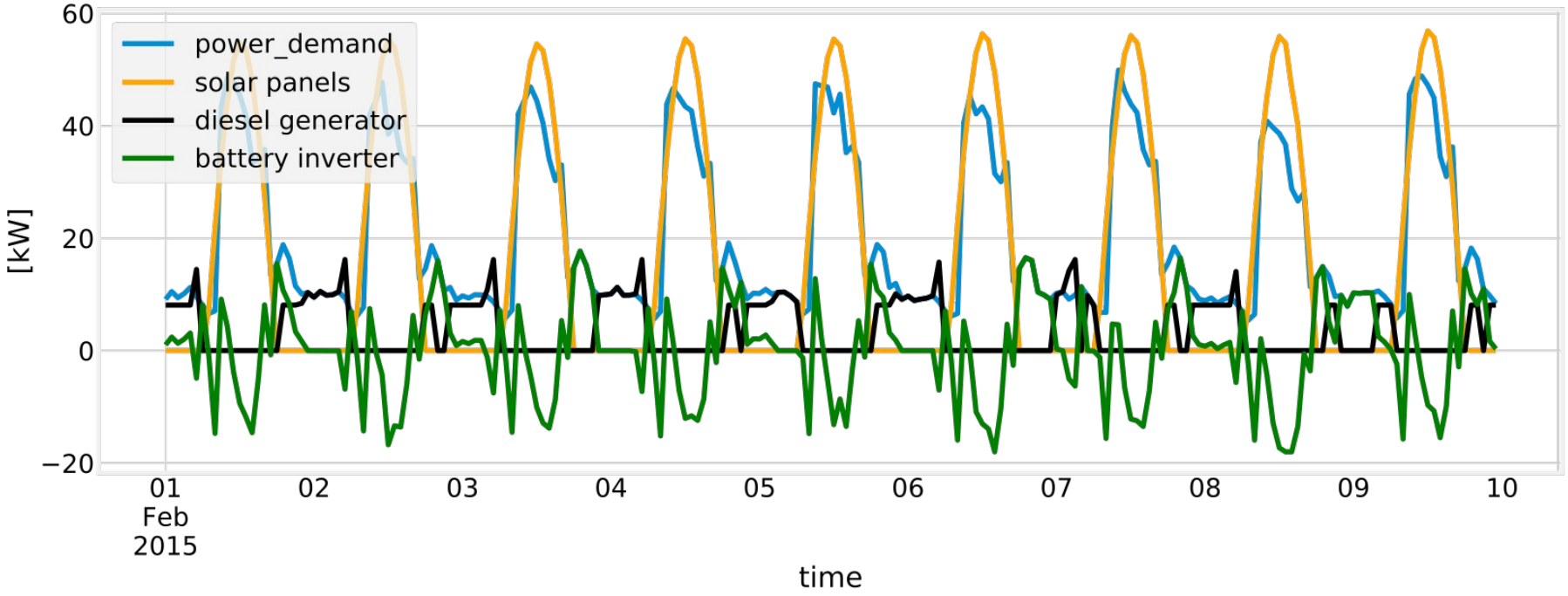
Step 2: Unit-Commitment Modeling

elena international



Generation, storage & transmission capacities fixed

→ how to dispatch generators? What are operational strategies?

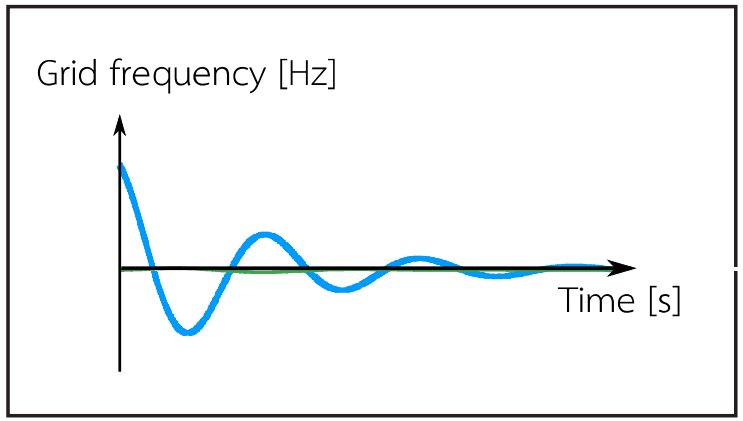


Step 3: Grid Analyses

Choose snapshots from these Generation & storage profiles/ time series

For Grid Analyses

- DC Power Flow
- AC Power Flow
- Short-circuit analysis
- Harmonic analysis
- Transient frequency and voltage stability analysis



Outline

elena international

1. Motivation for Hybrid Microgrids
2. Why Open-Source?
3. Hybrid Microgrids Design & Stakeholder Requirements
4. **Selection of Open-Source Power System Planning Tools**
5. Evaluation & Take-home message

4. Selection of Open-Source Tools

elena international

...for planning Hybrid Power Systems/ Microgrids

- Open-Source frameworks that take grid constraints into account
- tools available in Python or Julia
- no ready-for-use tools but demand a certain level of programming expertise

General Information	Open-Source Frameworks						
	PyPSA	PowerSimulations.jl	PowerModels.jl	Joulia	OEMOF	GridCal	pandapower
license	GPLv3	BSD	BSD	MIT	GPLv3	GPLv3	BSD
programming language	Python	Julia	Julia	Julia	Python	Python	Python
first published	01/2016	upcoming	08/2017	03/2019	11/2015	03/2016	01/2017
last commit	04/2019	04/2019	04/2019	03/2019	02/2019	03/2019	04/2019
contributors	12	8	14	1	24	4	31

Comparison Criteria	Open-Source Frameworks						
	PyPSA	PowerSimulations.jl	PowerModels.jl	Joulia	oemof	GridCal	pandapower
multi-objective optimization	yes and manual	no?	manual	no	yes?	no	no
system sizing	yes	planned	manual	no	yes	no	manual
operational strategies/ UC	yes	yes	manual	yes	yes	no	no
Sector coupling	yes	yes	manual	yes	yes	no	yes
Time resolution	flexible	flexible	flexible	hourly	flexible	flexible	flexible
Optimization Constraints:							
Power Balance	yes	yes	yes	yes	yes	no	yes
Linear Optimal Power Flow	yes	yes	yes	yes	no	no	yes
Nonlinear Optimal Power Flow	no (planned)	yes	yes	no	no	no	yes
Multi-period Optimization	yes	yes	yes	yes	yes	no	yes
Bus components:							
Variable Renewable Energy Sources	yes	yes	manual	yes	yes	yes	yes
Inverters	yes	yes	manual	no	yes	yes	yes
Battery Storage	yes	yes	manual	yes	yes	yes	yes
Diesel generators	yes	yes	manual	yes	yes	yes	yes
Biomass	yes	no?	manual	yes	yes	no	no
Hydro turbines	yes	yes	manual	yes	yes	no	no
Thermal storage	yes	yes	manual	yes	yes	no	no
Fuel cell	yes	no	manual	no	manual?	no	no
Renewable feed-in data	partially	no	no	no	yes	no	no
Grid Analysis:							
DC power flow	yes	yes	yes	yes	yes	yes	yes
AC power flow	yes	no	yes	no	no	yes	yes
Short-circuit analysis	no (planned)	no	no	no	no	yes	yes
Transient Stability	no	no	no	no	no	no	no
Harmonic Analysis	no	no	no	no	no	no	no

PyPSA* / EnergyModels.jl

elena international

"**Py**thon for **P**ower **S**ystem **A**nalysis", by the Karlsruhe Institute of Technology (EnergyModels.jl - Julia correspondent, WIP)

Strengths:

- Preimplemented features for system sizing and unit commitment modeling with LOPF
- Sector coupling possible
- DC & AC Power Flow Analysis
- components like solar, diesel & storage implemented

Weaknesses:

- No nonlinear optimal powerflow (WIP)
- No short-circuit, harmonic or transient stability analysis

*github.com/PyPSA/PyPSA

Oemof*/ micrOgridS

elena international

.. is an"**O**pen **E**nergy System **Mo**delling **F**ramework" in Python by the Reiner Lemoine Institut and the Center for Sustainable Energy Systems. micrOgridS was developed by applying the Open Energy Modelling Framework.

Strengths:

- System sizing and unit commitment modeling
- Sector coupling
- Input data can be generated with demandlib (load profiles for electricity and heat) and the feedinlib (PV and wind feed-in data)

Weaknesses:

- no integration of grid constraints
  - no DC or AC power flow
  - no optimal power flow
  - no short circuit analysis etc.

*github.com/oemof

pandapower*

elena international

.. combines data analysis library pandas and the power flow solver PYPOWER to analyze and optimize power systems, developed by the University of Kassel and the Fraunhofer IEE,

Strengths:

- Predefined objectives like maximization of generation or loss minimization.
- DC & AC Power Flow as well as Linear & Nonlinear Optimal Power Flow with different solvers
- Short-circuit analysis

Weaknesses:

- No preimplemented features for unit commitment and system sizing
- no harmonic or transient stability analysis

*github.com/e2nIEE/pandapower

5. Take-home message(s)

elena international

- Open-Source frameworks can cover planning process (from system sizing to unit commitment modeling and power flow analyses)
- depending on the focus of microgrid planning we choose and combine different frameworks
- frameworks are under strong & continuous development → further improvement
- In this review tools for transient stability excluded, here we choose PowerDynamics.jl (co-developed and maintained by elena)