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FlexPlan

FlexPlan.jl

An open-source Julia tool for holistic transmission and distribution **grid planning**

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Summary

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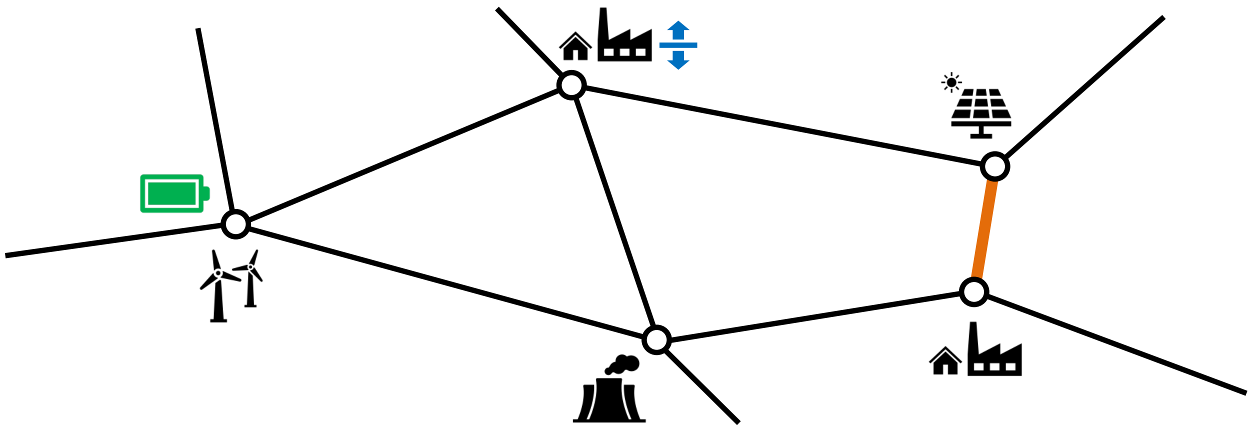
1. The FlexPlan project
2. Planning model overview
3. Implementation highlights
4. Transmission and distribution decoupling heuristic

The FlexPlan project

October 2019 – March 2023

*...aims at establishing a new **power grid planning methodology***
considering the opportunity to introduce
*new storage and flexibility resources in **T&D grids***
as an alternative to conventional network expansion.



Network planning model outline

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Input data

T&D **grid data** (AC and DC topology, electrical parameters, bounds…)

Hourly renewable generation and demand **time series** for multiple **scenarios** and planning years; scenario probabilities

Candidate investments for: storage, flexibilization of existing loads, lines and cables, transformers, AC/DC converters

Planning tool

Objective

Minimize total system costs (CAPEX + OPEX)

Variables

- investment decisions
- scenario-dependent operation set-points for dispatchable resources

Constraints

- T&D power flow equations
- storage power and energy constraints
- flexibility characteristics

Output

Optimal planning

- optimal investment decisions for candidates
- detail of system costs
- expected scenario-dependent operation setpoints for dispatchable resources

Objective function

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planning periods (years)
where investment decisions
have constant values

scenarios
representing different
stochastic realizations of
RES production and demand

operation periods (hours)
where continuous variables (power, voltage, …)
have constant values

$$\text{minimize} \quad \sum_{y \in Y} \left([\text{CAPEX}]_y + \sum_{s \in S} \pi_s \sum_{t \in T} [\text{OPEX}]_{t,s,y} \right)$$

new **storage** devices
flexibilization of **demand**
new **lines**, **transformers**, **converters**

scenario
probability

generation: cost, curtailment
demand: shifting, reduction, curtailment

Storage model

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$$E_{b,t,s,y} = (1-\lambda_b)^{\Delta t} E_{b,t-1,s,y} + \Delta t \left(\eta_b^{abs} P_{b,t,s,y}^{abs} - \frac{P_{b,t,s,y}^{inj}}{\eta_b^{inj}} + \xi_{b,t,s,y} \right)$$

- $E_{b,t,s,y}$: energy stored at time t
- $(1-\lambda_b)^{\Delta t}$: self-discharge
- $E_{b,t-1,s,y}$: energy stored at time $t-1$
- $P_{b,t,s,y}^{abs}$: power absorbed from network
- $P_{b,t,s,y}^{inj}$: power injected into network
- $\xi_{b,t,s,y}$: power of external process

Constraints

- bounds on stored energy and absorbed/injected power
- fixed energy at beginning of planning horizon
- lower bound for energy at end of planning horizon

⚠ No charge/discharge exclusivity constraint

Flexible load model

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absorbed power | reference power | upward and downward demand shifts | voluntary reduction | involuntary curtailment

$$P^{d}_{u,t,s,y} = P^{ref}_{u,t,s,y} + P^{sh,up}_{u,t,s,y} - P^{sh,dn}_{u,t,s,y} - P^{red}_{u,t,s,y} - P^{curt}_{u,t,s,y}$$

$P^{d}_{u,t,s,y}$: ≥ 0

$P^{sh,up}_{u,t,s,y}$, $P^{sh,dn}_{u,t,s,y}$: periodically rebalanced

$P^{sh,up}_{u,t,s,y}$, $P^{sh,dn}_{u,t,s,y}$, $P^{red}_{u,t,s,y}$: bounded to fraction of reference power

Open-source software stack

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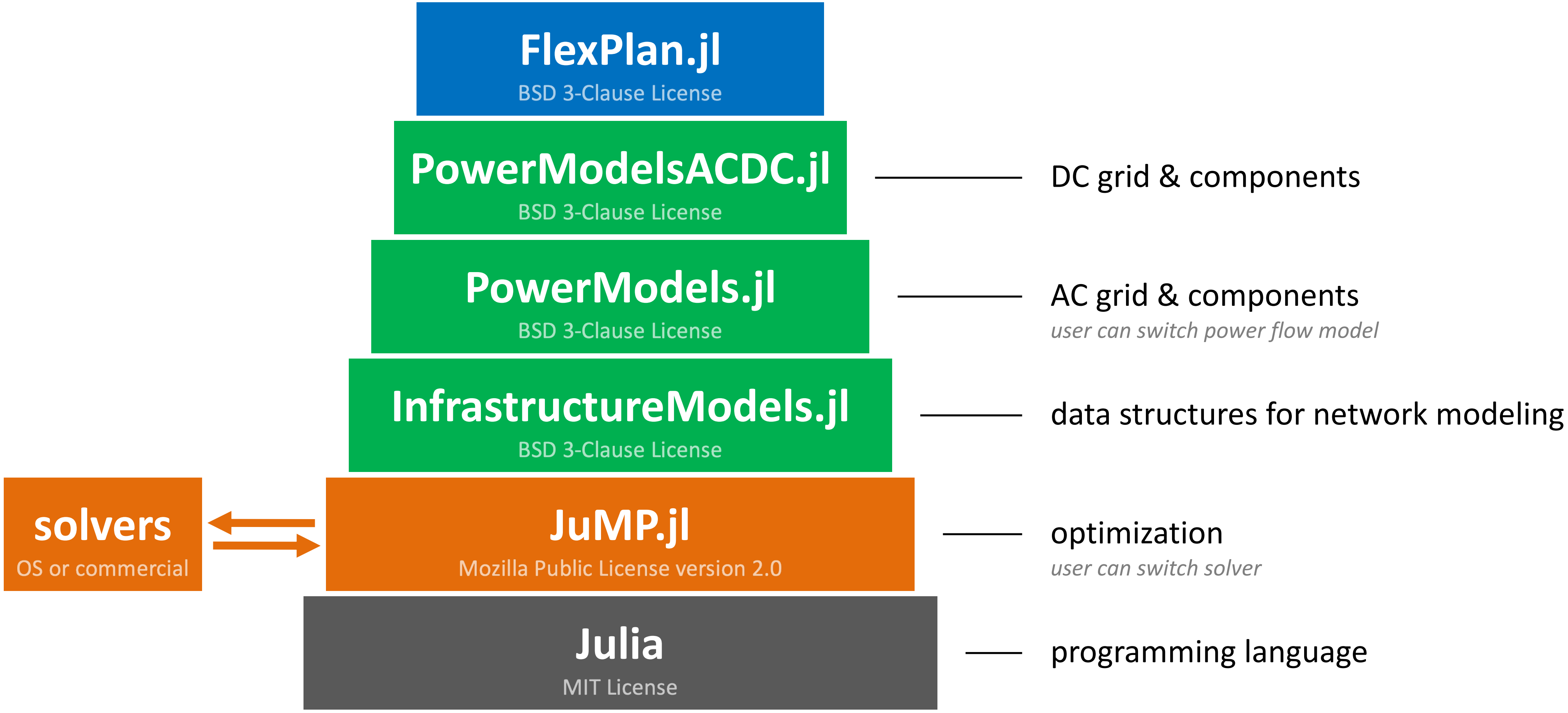

Result visualizations

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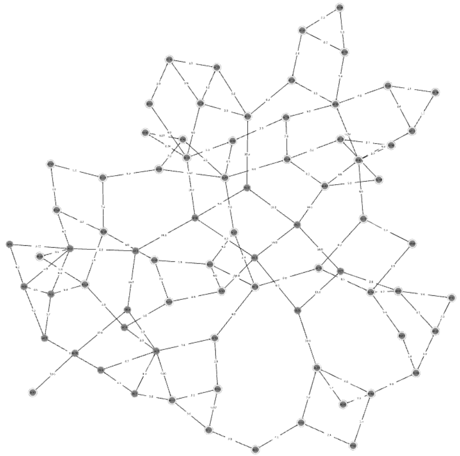

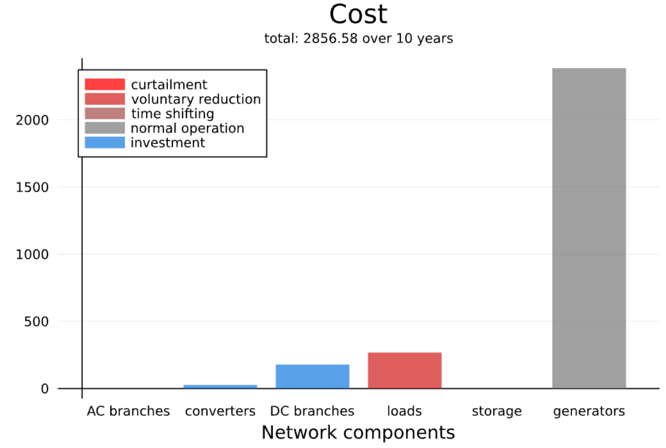

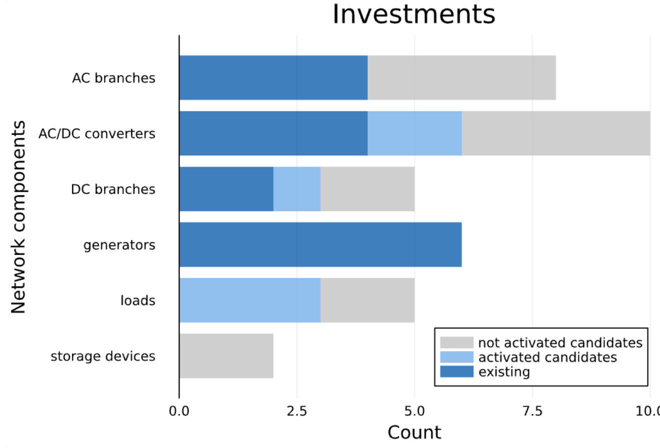

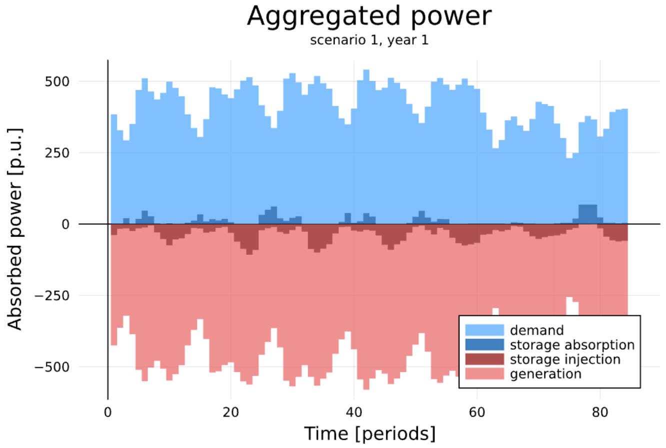

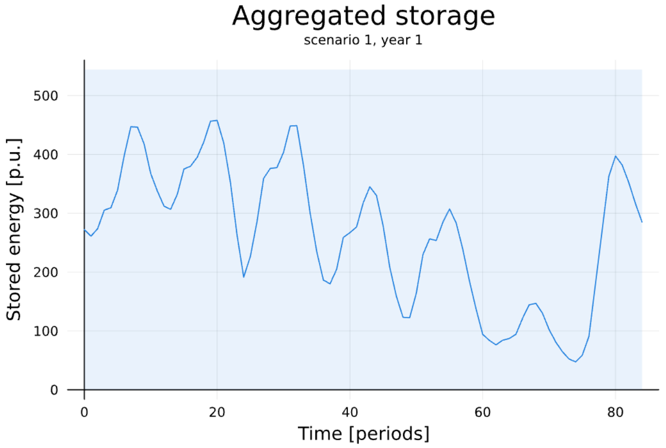

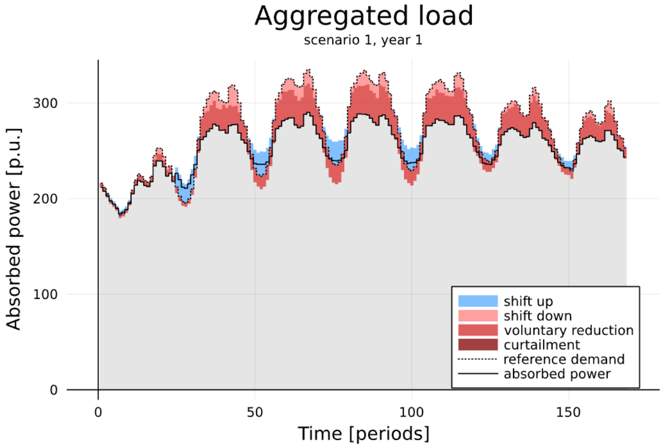

Combined T&D model

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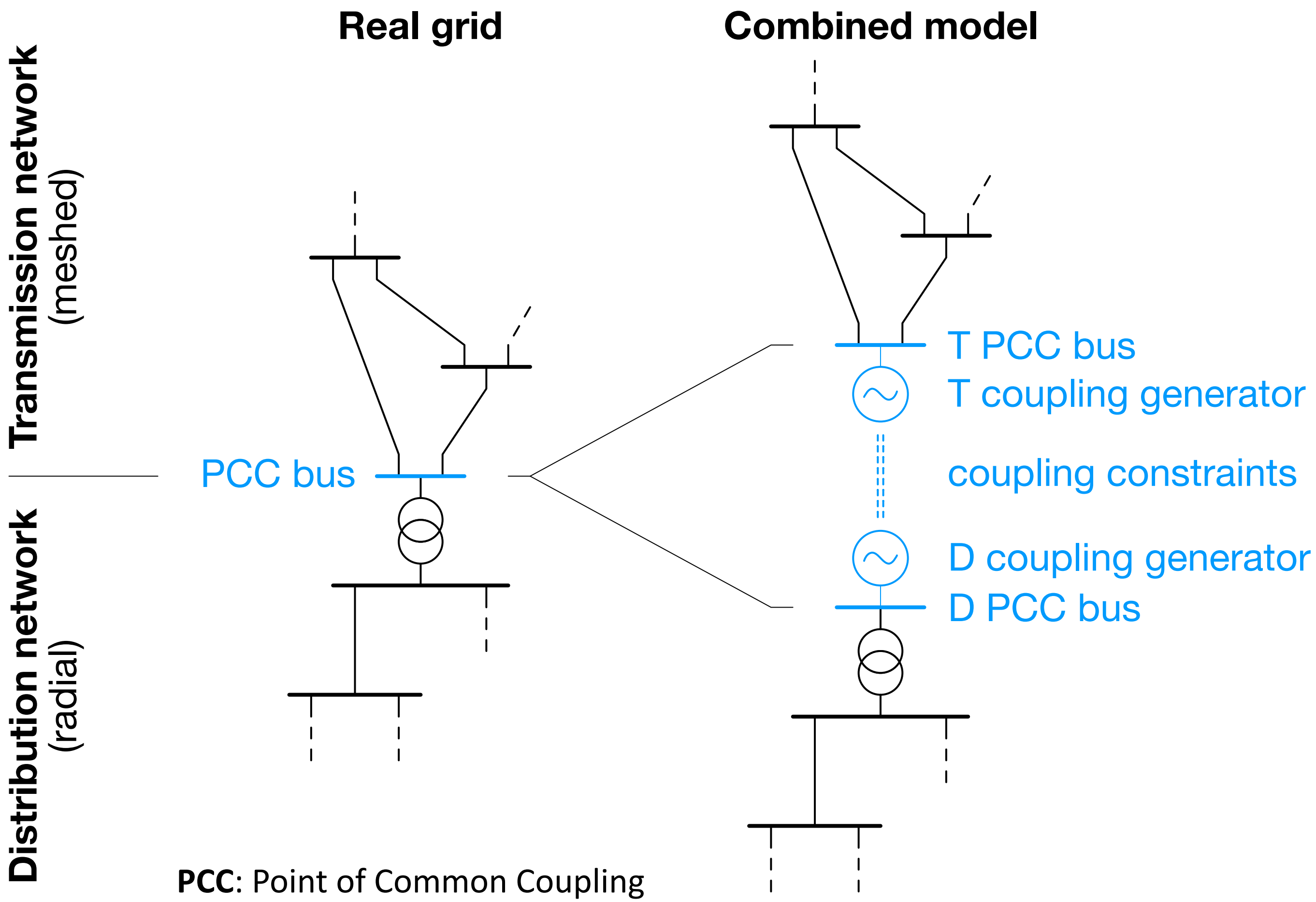

PCC: Point of Common Coupling

- ✓ Uses only standard network components
- ✓ Different power flow models for T&D
- ✓ Coupling constraints do not depend on the power flow model
- ✗ Voltage variables are not coupled

Suitable for planning, not for operation

T&D decoupling heuristic

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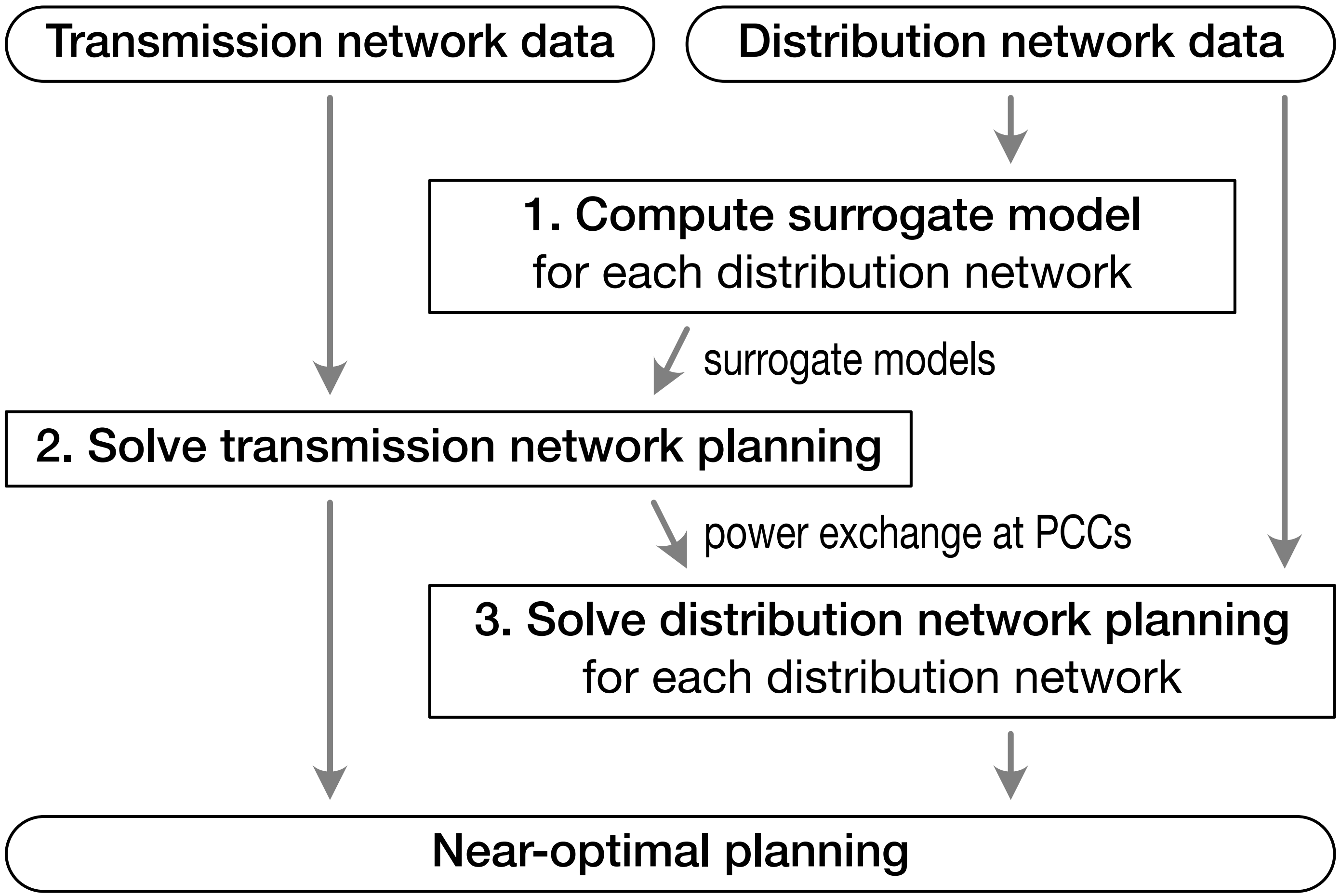


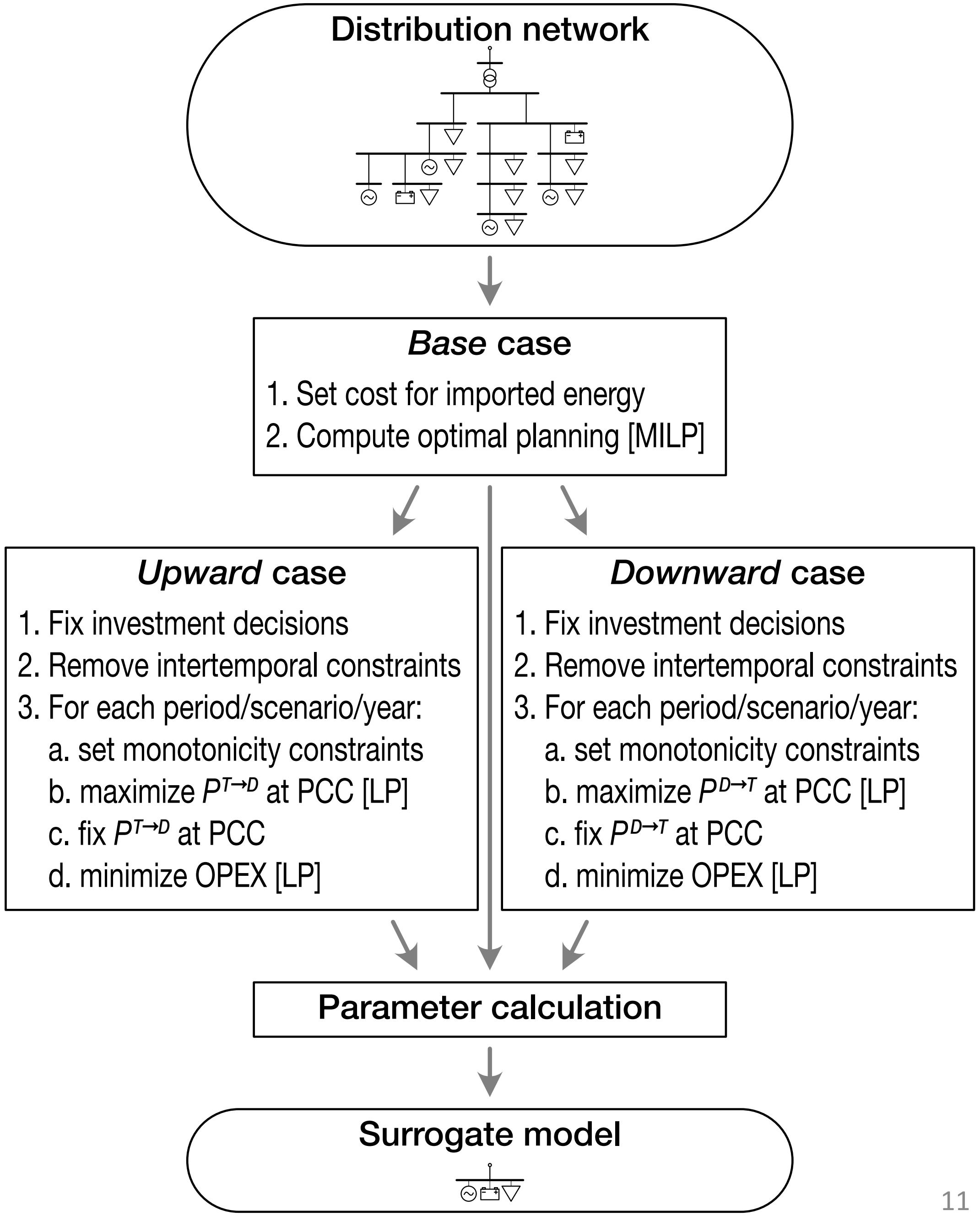
T&D decoupling heuristic

Surrogate model components:

- one generator
- one storage device
- one flexible load

with parameters such that:

- cost *approximates* cost in original model
- feasibility *implies* feasibility in original model



T&D decoupling heuristic

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Surrogate model assumptions ⟹ Effects on feasible power exchange at PCC

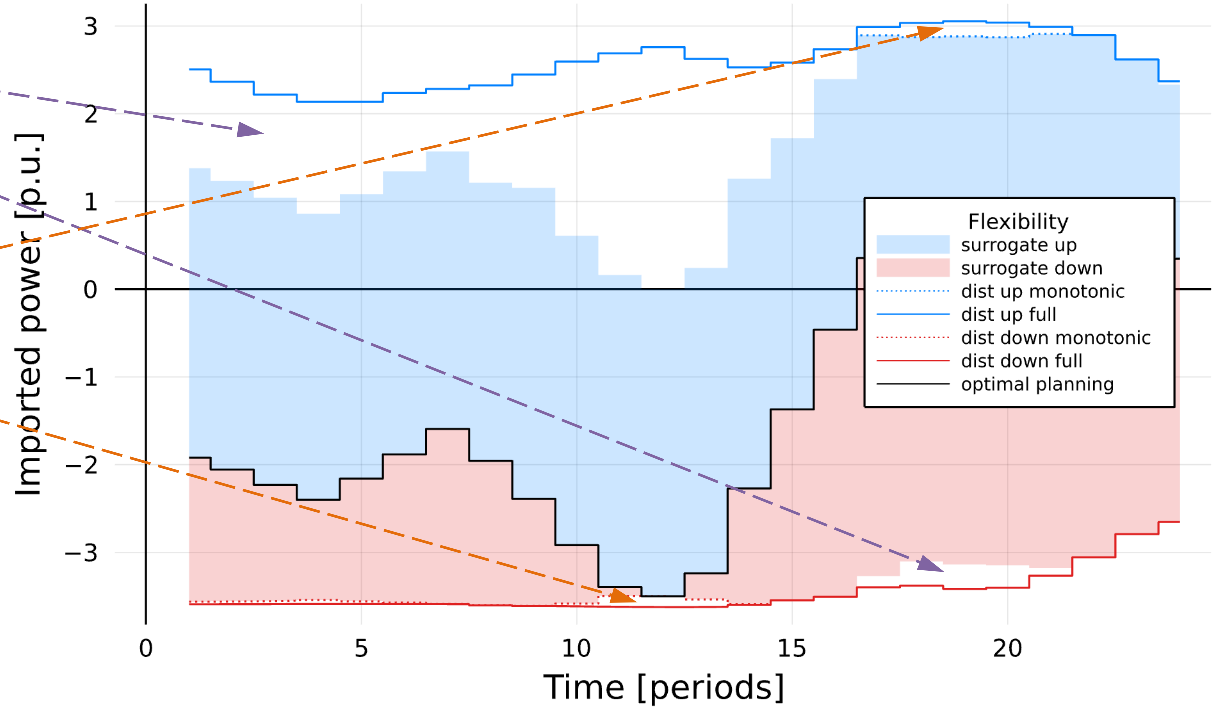
Independence of components

Generator, storage device and load can be used independently by transmission.

Monotonicity of power variations

A variation in power exchanged with transmission produces a variation of the same sign in devices connected to distribution.

Example: if imported power increases, then the loads cannot absorb less.



T&D decoupling heuristic

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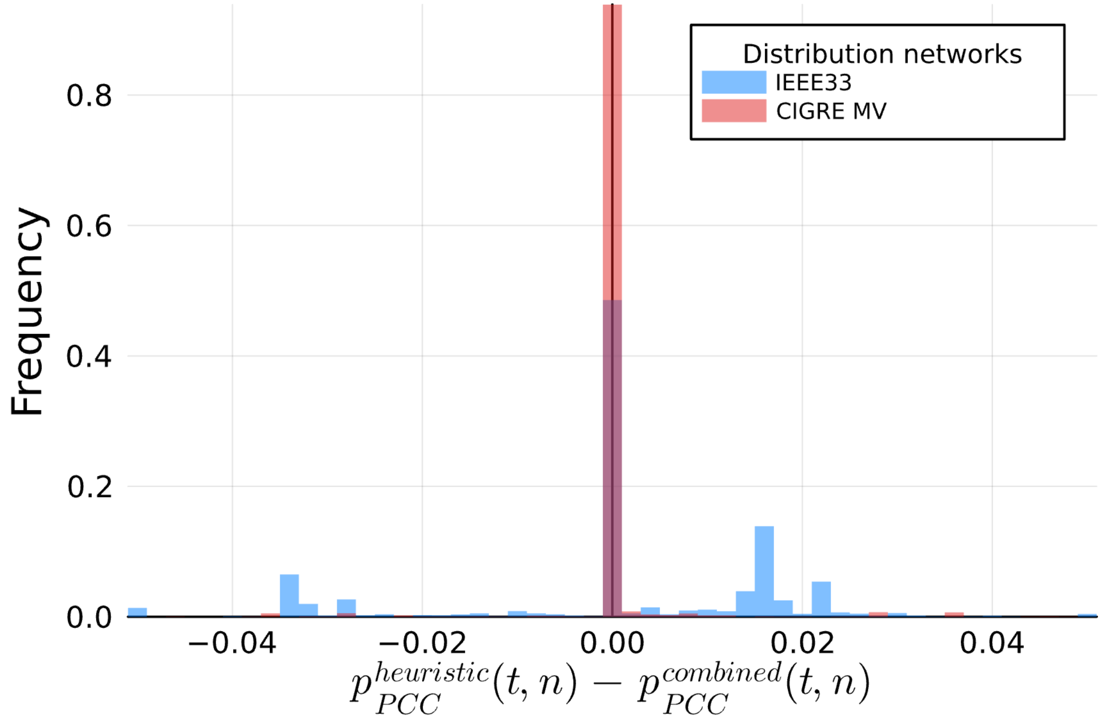
Test: attach to a transmission network (case67) a variable amount N_d of distribution networks (either IEEE33 or CIGRE MV)

N_d	binary variables	CPU time: combined model [s]	CPU time: decoupling heuristic [s]	CPU time: ratio	relative cost increase
case67 with N_d IEEE33 distribution networks					
1	83	38	21	**0.553**	$-1.1{\cdot}10^{-5}$
4	158	148	25	**0.169**	$6.0{\cdot}10^{-7}$
16	458	1139	41	**0.036**	$1.4{\cdot}10^{-6}$
64	1658	4228	87	**0.021**	$6.6{\cdot}10^{-5}$
case67 with N_d CIGRE MV distribution networks					
1	88	39	23	**0.590**	$-5.3{\cdot}10^{-15}$
4	178	79	20	**0.253**	$6.2{\cdot}10^{-5}$
16	538	210	30	**0.143**	$5.3{\cdot}10^{-15}$
64	1978	6479	59	**0.009**	$4.1{\cdot}10^{-4}$



T&D decoupling heuristic

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- ✓ Faster than combined model
  typical speedup: 10 ÷ 100 x
- ✓ Near-optimal result
  typical relative cost increase: < 10^{-4}
- ✓ Good solution quality
  typical power deviation at PCCs: < 1 %

- ✗ No voltage information shared between T&D
  as in combined T&D model

References

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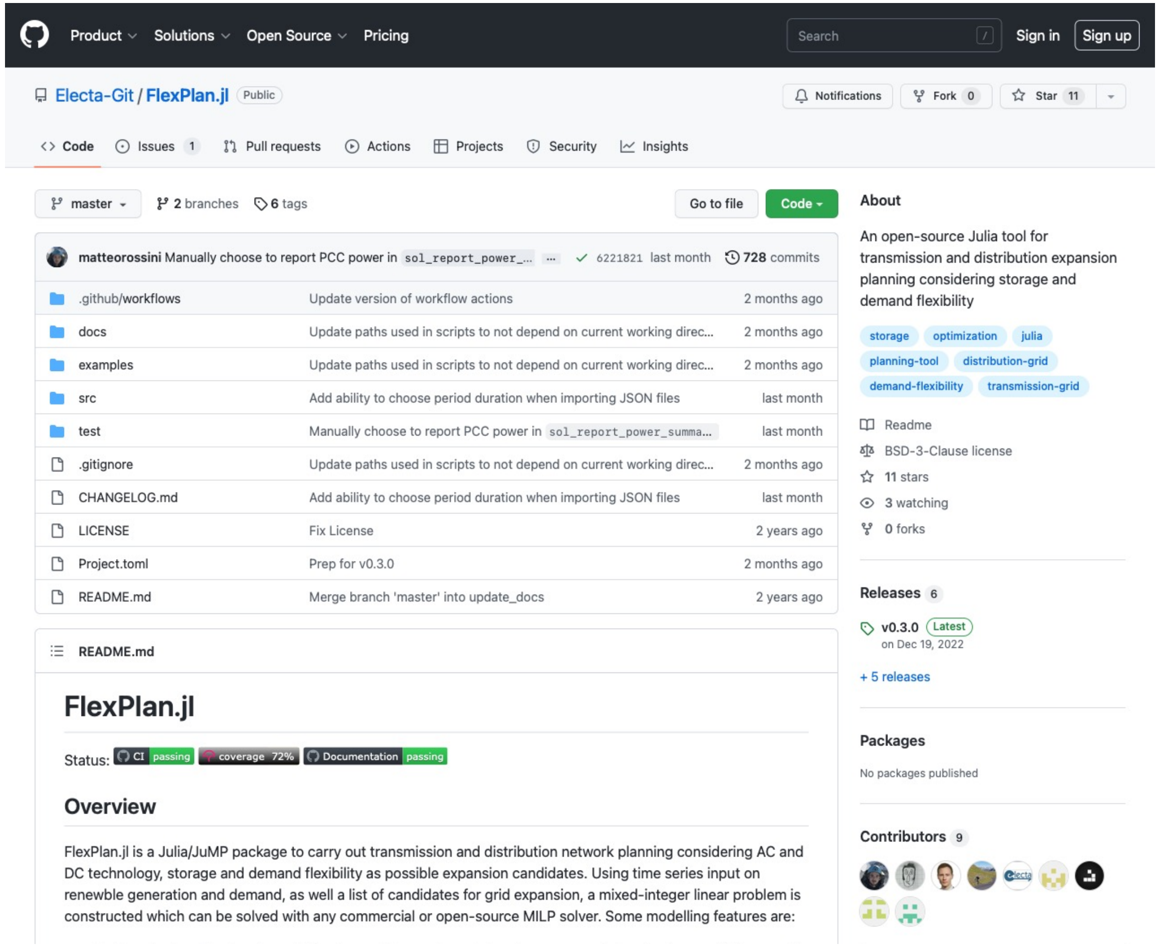

https://github.com/Electa-Git/FlexPlan.jl

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