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14. Symposium Energieinnovation,
„ENERGIE FÜR UNSER EUROPA“

Simulation Framework for Analysis of the European Transmission System under a Wide Range of Operating Conditions

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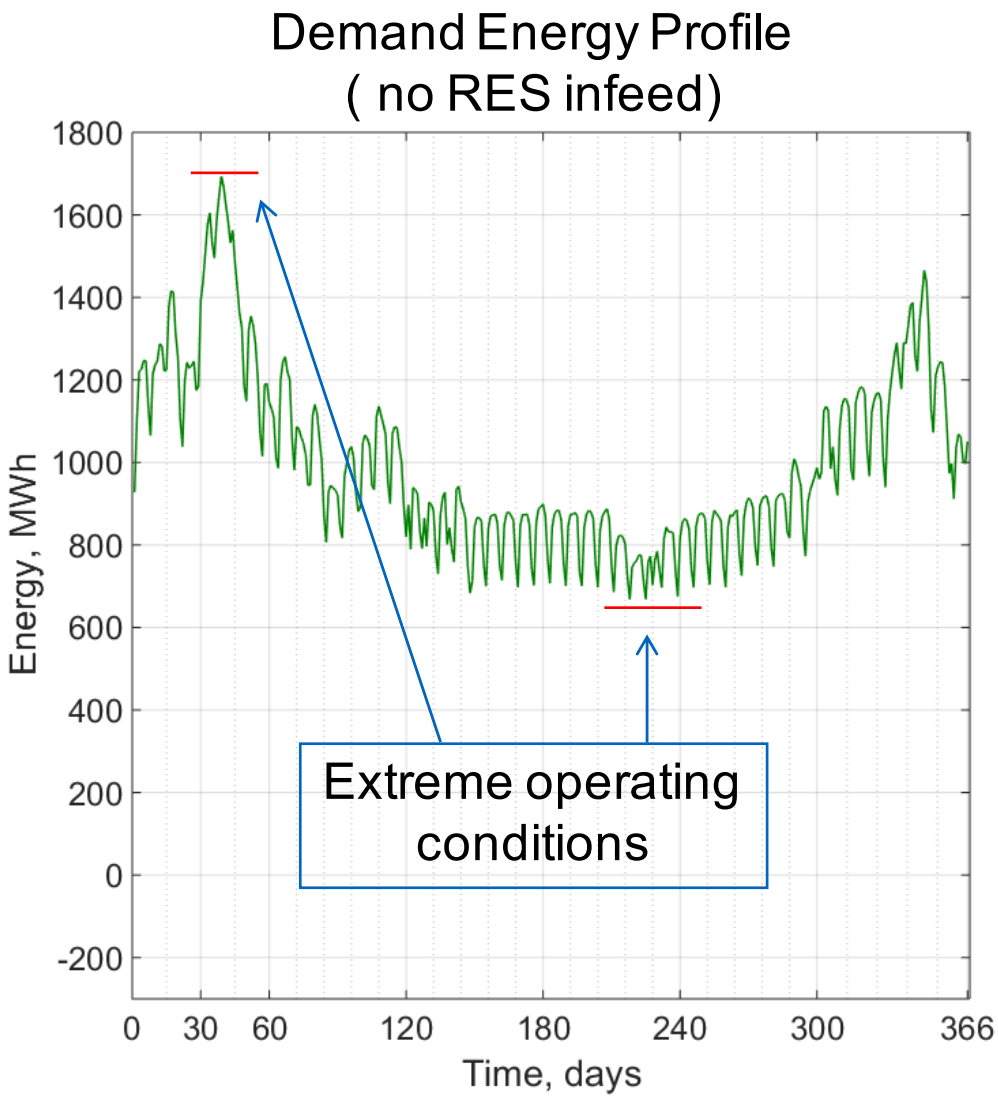
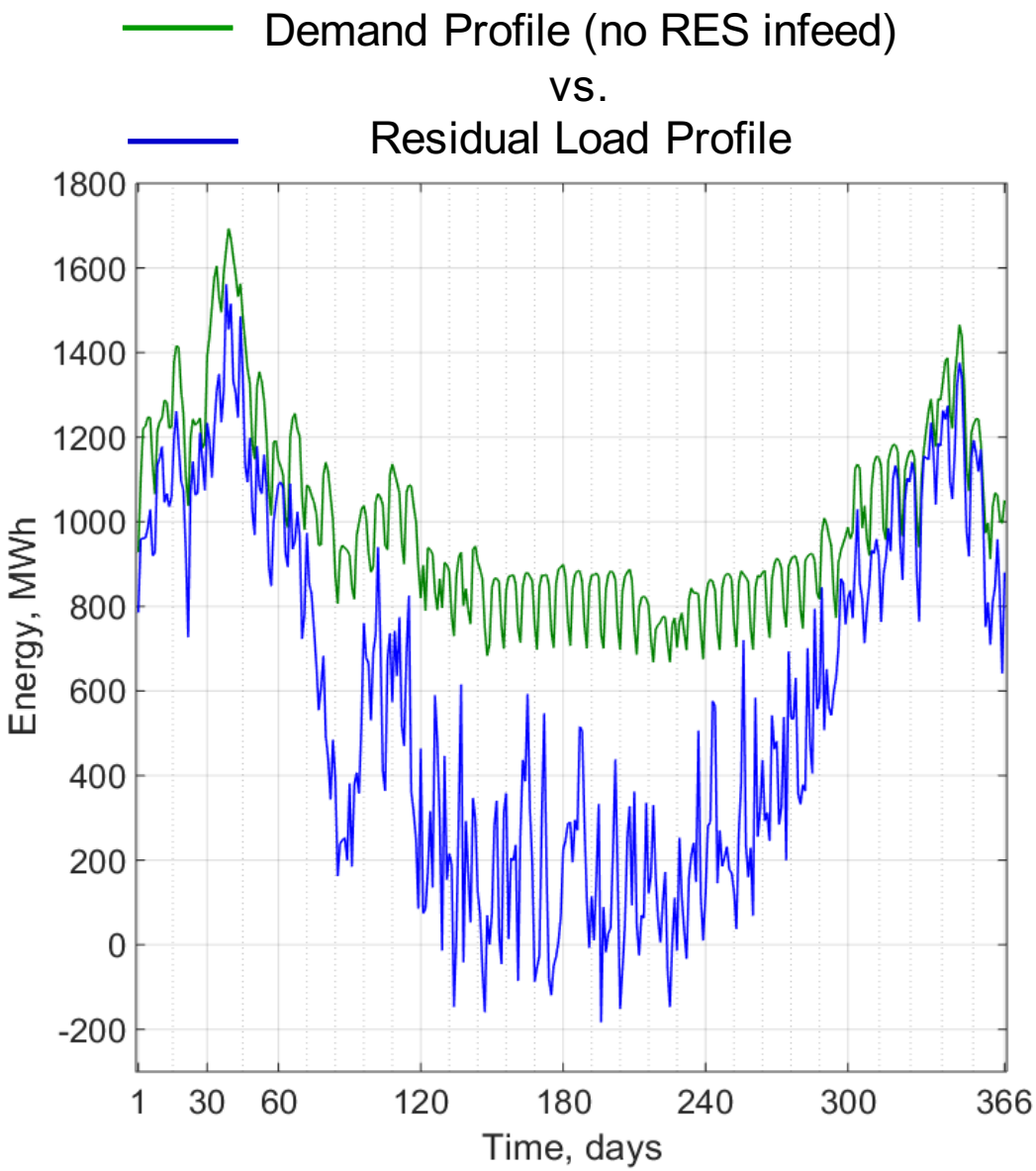
Problem Statement

- Past
  - Low complexity of the network
  - Dispatchable generation
  - Repeated load pattern
  - “Independence” of network levels
  - Extreme conditions in the system ~ extreme loading



Problem Statement

- Present – Future
  - High complexity of the network
  - Renewables infeed:
    - Dispatch schedule difficult to predict
    - Reversed power flow
    - Frequent shortage of rotating inertia
    - Increased ramping requirements
  - Demand-side management programs
  - “Worst Cases” do not necessarily correlate with extreme loading



Problem Statement

- Present – Future

- "Worst Cases" do not necessarily correlate with extreme loading

- Influencing factors:

  - ✓ Weather
  - ✓ Economic situation
  - ✓ Demand management strategy

→ ***Multiple time instances/simulations must be considered***

Problem Statement: Existing models of the European Transmission System (public domain)

Detailed/Geographically mapped

- Benchmark system of J. Bialek (DC LF) [1]

Problem:
- Results are partly realistic

Advantages:
- Res[illegible] No Model published!
- Sui[illegible]e of topology/ parameters

DC LF/ Market Model

AC LF/ Dynamic Model

- DC model of Energynautics

Problems:
- Results are partly realistic
- Model modification problem

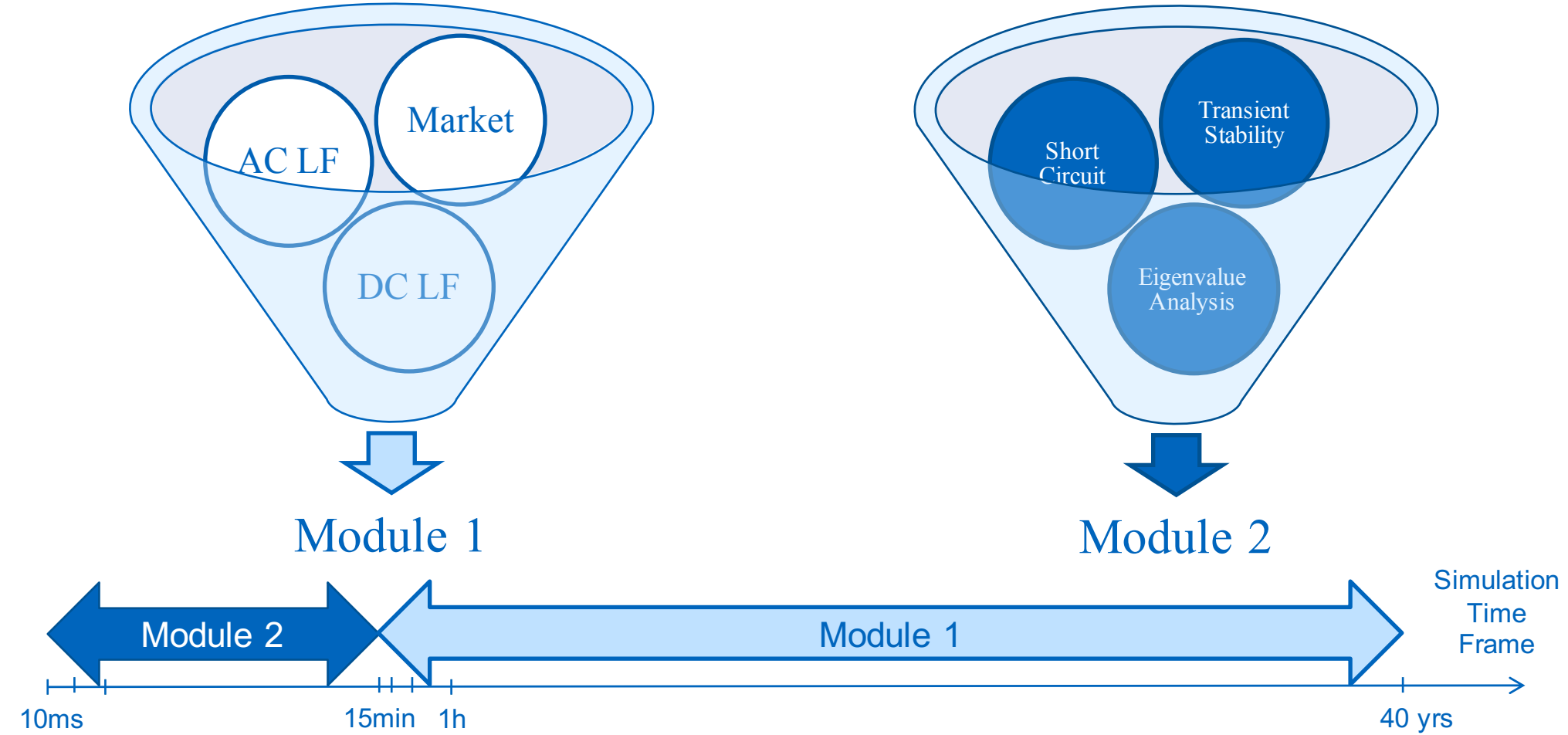
- Transmission system model of Energynautics (AC LF) [3]
- ENTSO-E Initial Dynamic EU Model [7]

Problem:
- Model modification problem

Approximated/Encoded

Framework Structure

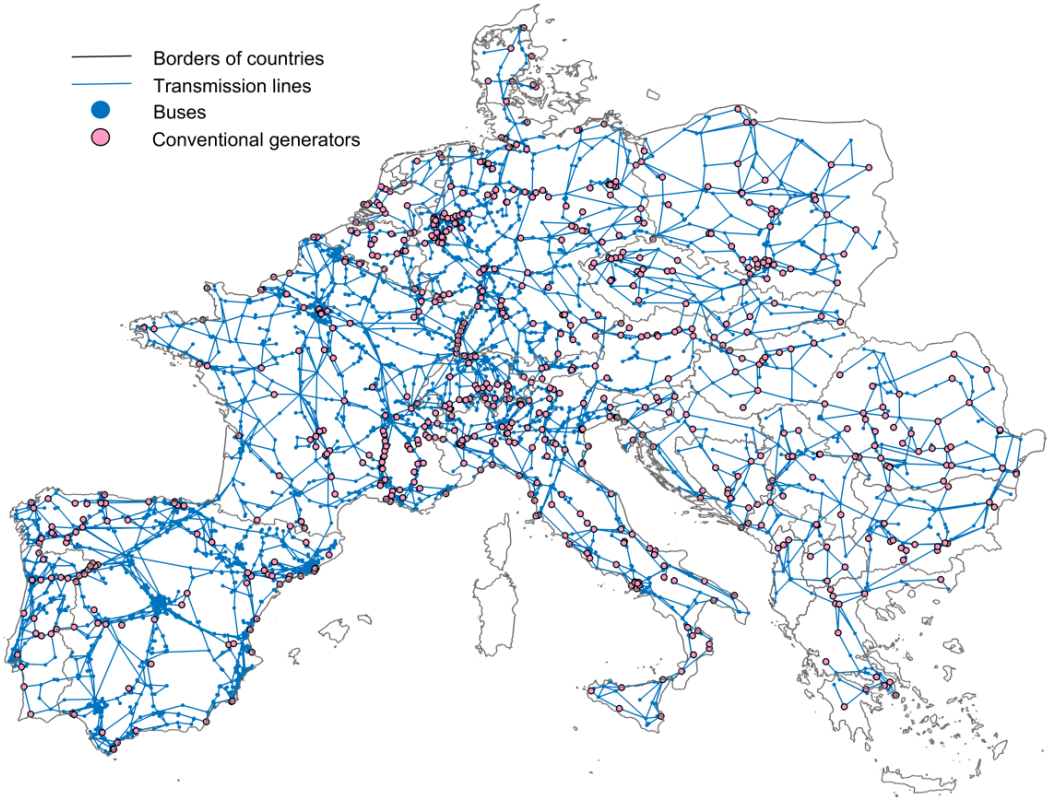
System under steady-state conditions	System under dynamic conditions



Project Definitions

Scenario

- Topology
- Peak load for every country
- Installed capacities of PV & Wind
- Power plant fleet



Scenario 2012

6000 buses (including almost 900 conventional generators), over 7000 lines and about 1700 transformers

Project Definitions

Profile Case

- Yearly profiles of power demand/generation
- For active power and reactive power
- Historical (realistic) and Synthetic (projected or statistically generated)

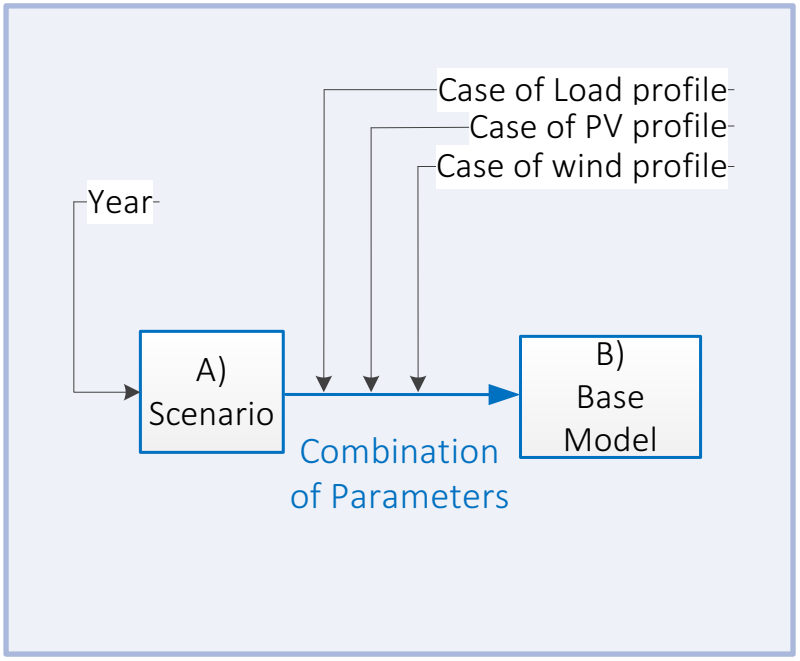
Profile Cases

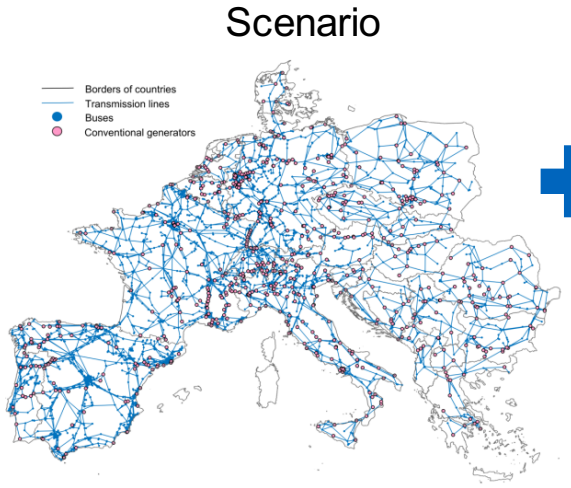
Load Profile | PV Profile | Wind Profile

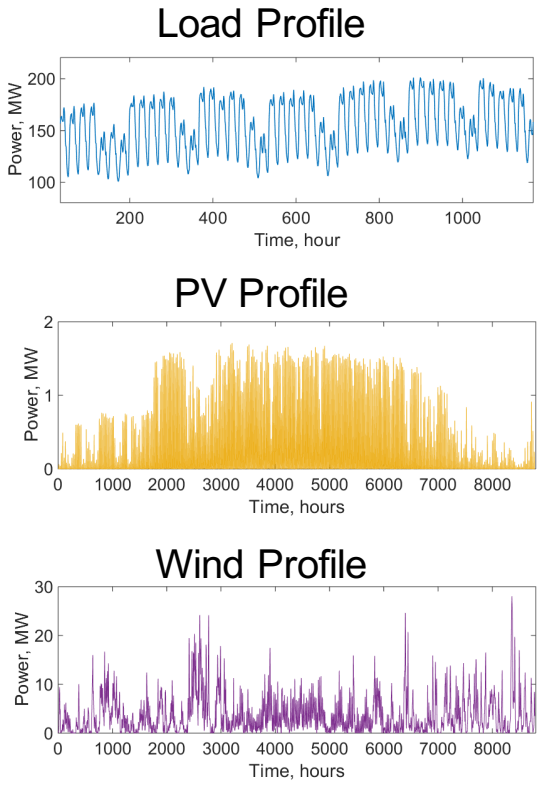
Historical	Synthetic
• **2012** • …. • **2015** • ….	Examples: • 2030 • 2050 • Sunny Winter • 50% wind in Summer ….

Module 1: Quasi-Stationary Models and Time-Series Simulations

- Stepwise transition DC → AC LF







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- Stepwise transition DC → AC LF

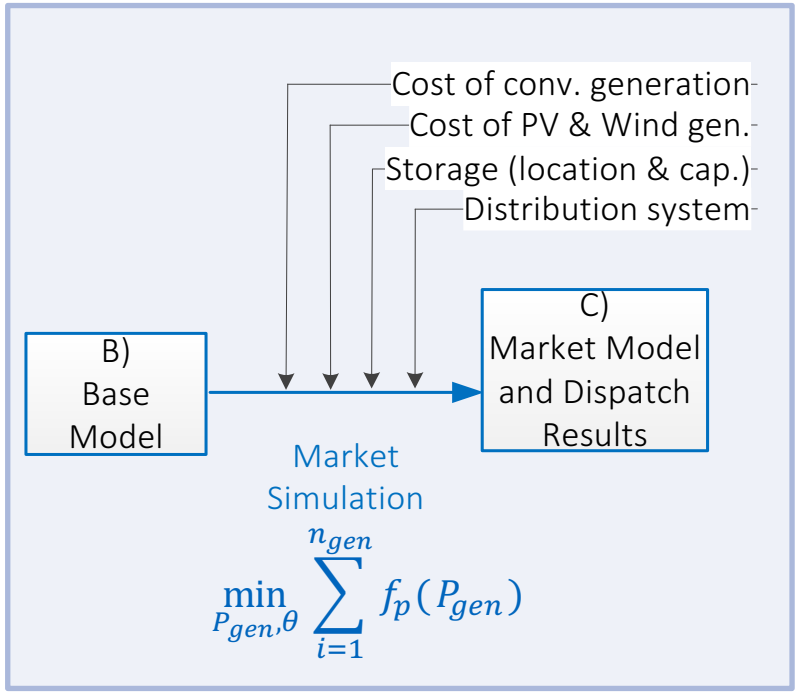


Fig: Cost Functions $f(P_{gen})$

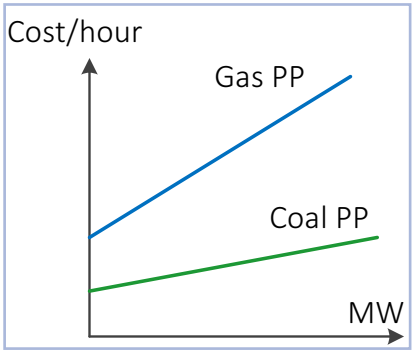
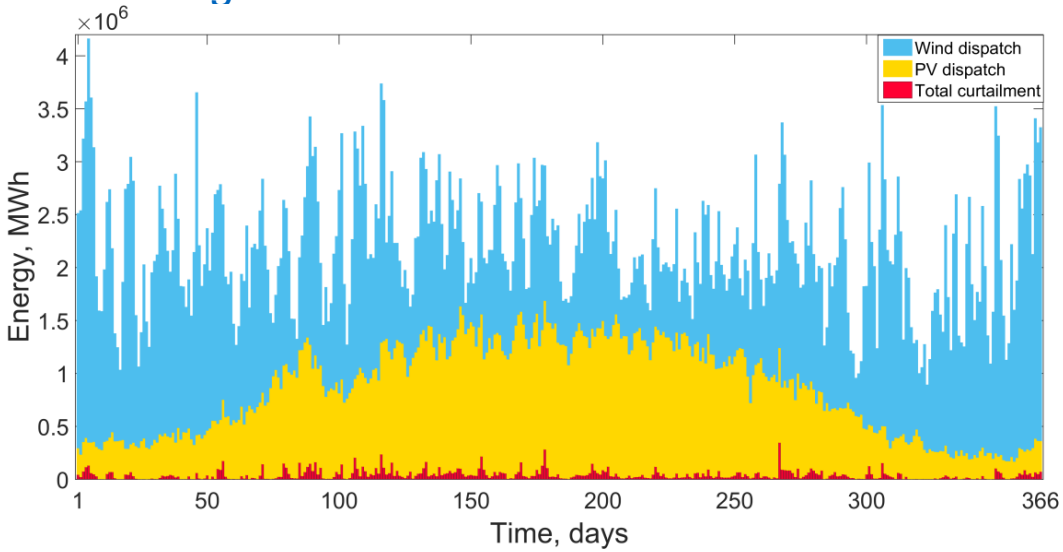


Fig: Daily dispatch and curtailment of PV and Wind generation



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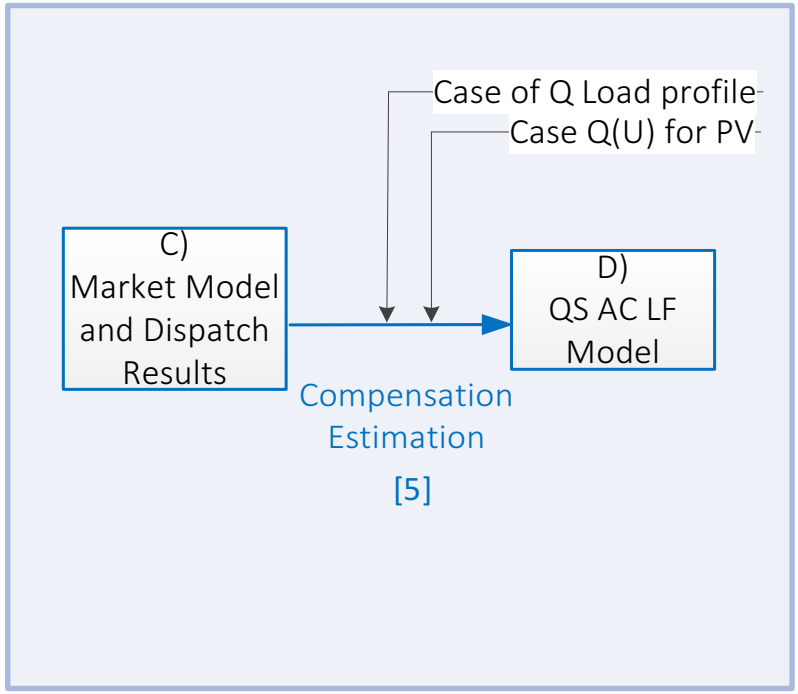

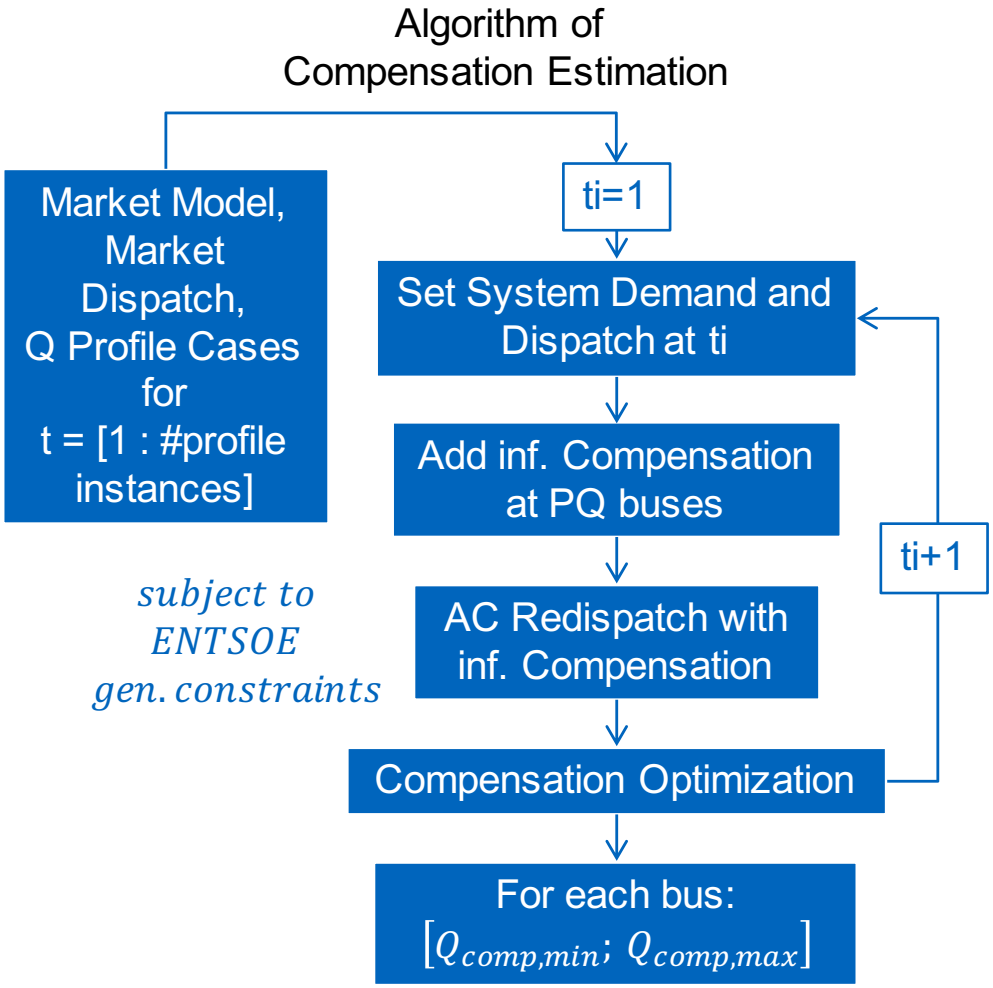

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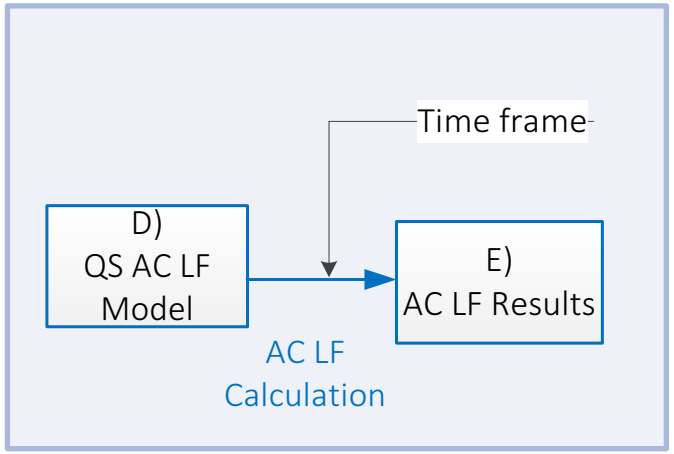


Fig:
Voltage profile
(23 March, 8:00)

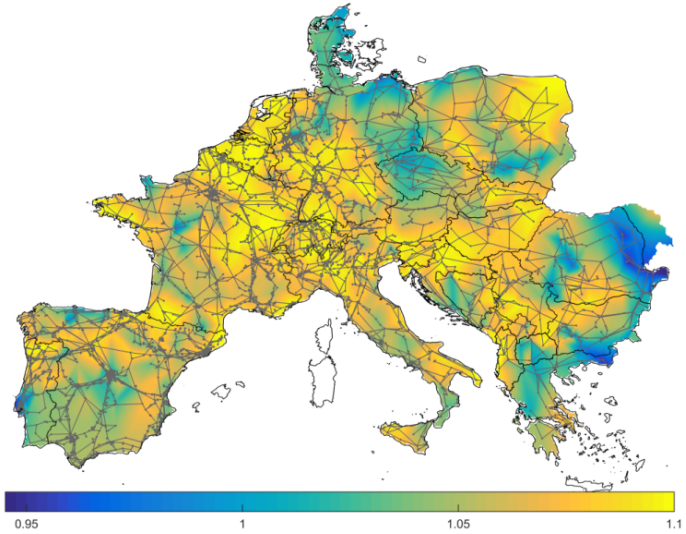
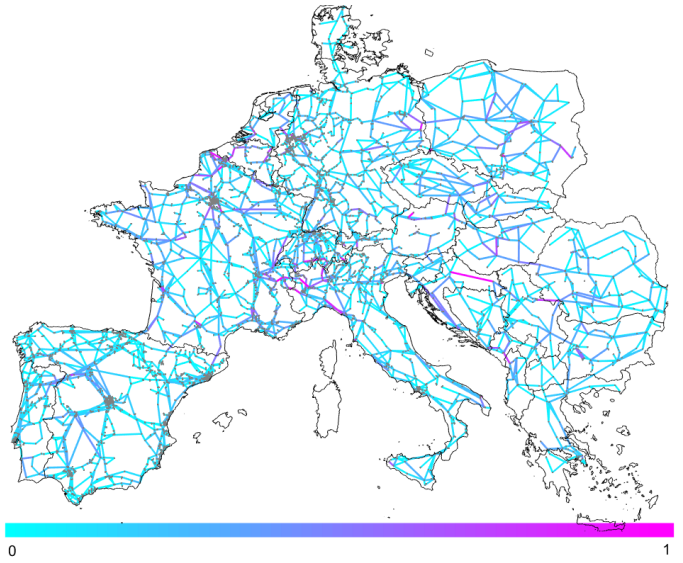
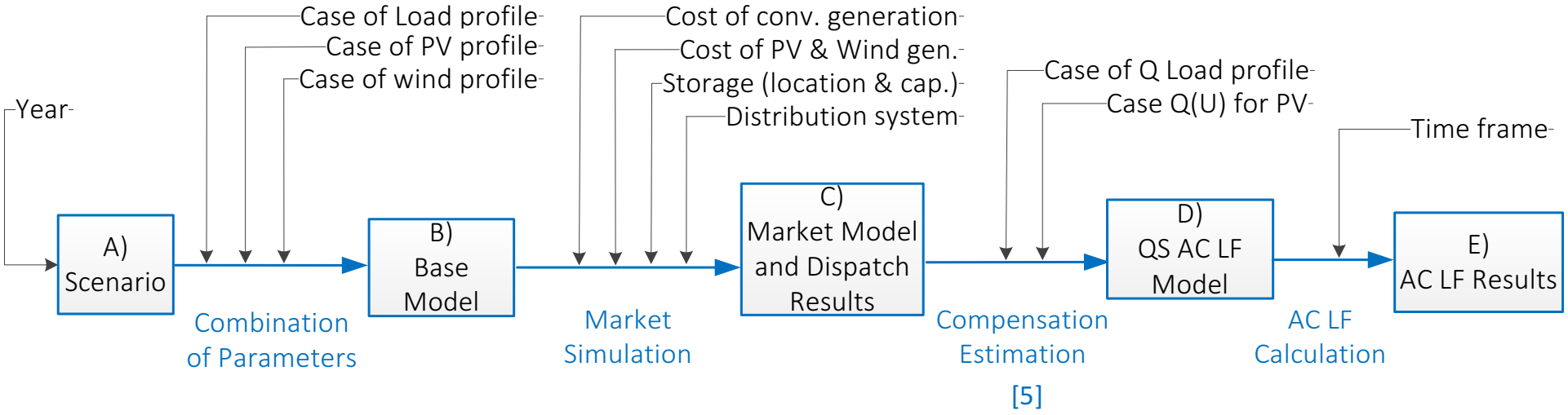


Fig:
Line Loading
(23 March, 8:00)



Module 1: Quasi-Stationary Models and Time-Series Simulations

- Stepwise transition DC → AC LF



Module 2: RMS Dynamic Simulations

- Transition AC LF → Dynamic

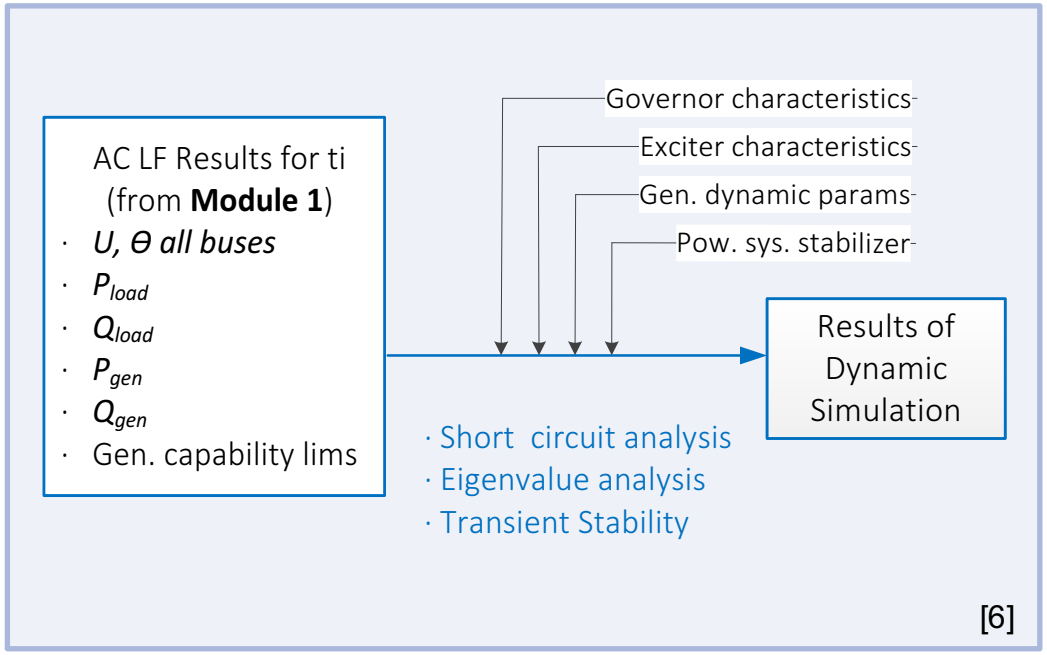


Fig: Voltage Profile after 3-ph short circuit

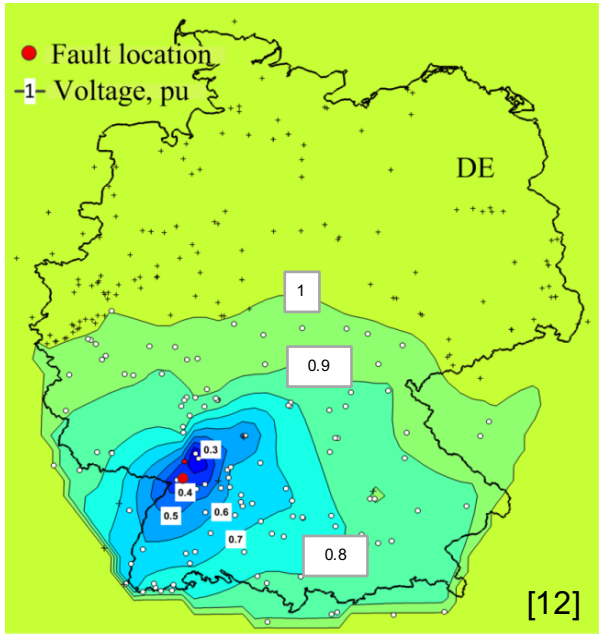
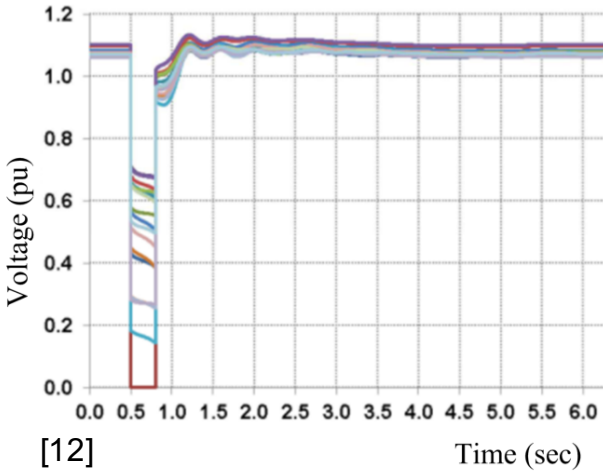
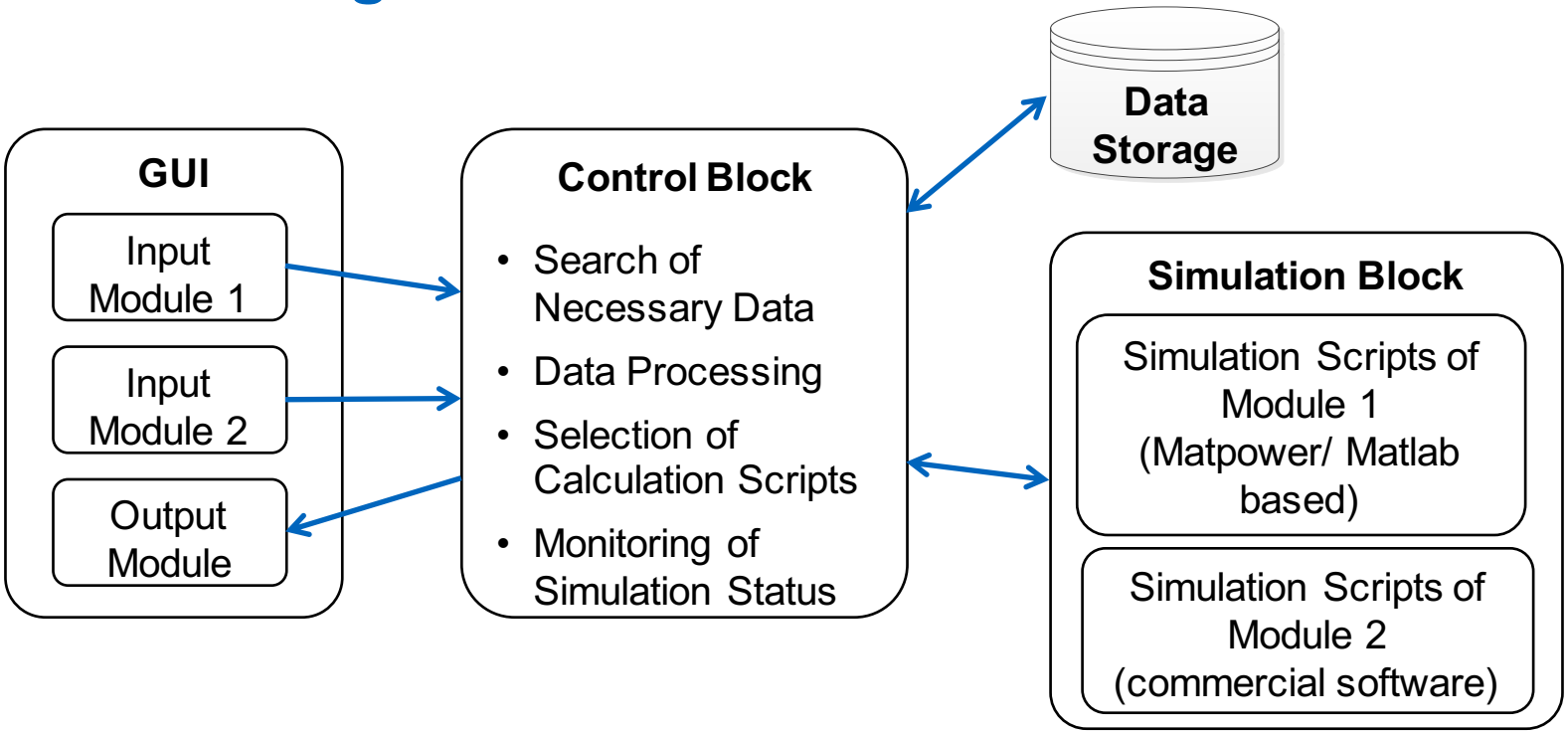


Fig: Voltage transient at nodes near SC



Framework Organisation



Prototype:

- Matlab/ Matpower/ PSS®Netomac based
- Data storage in a table form (.csv files)

Conclusions

Framework allows:

- Obtaining DC, market, AC LF and dynamic representations of the ETS
- Considering various weather, economic, demand situations
- Conducting studies of the ETS independent from availability of TSO‘ data

Potential Framework Applications:

- Market and AC LF simulations
  - Cascading Failures Analysis
- Dynamic simulations
  - Virtual inertia

Thank you for the attention!

Reference

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Back Up Slides

Existing models of the European Transmission System:

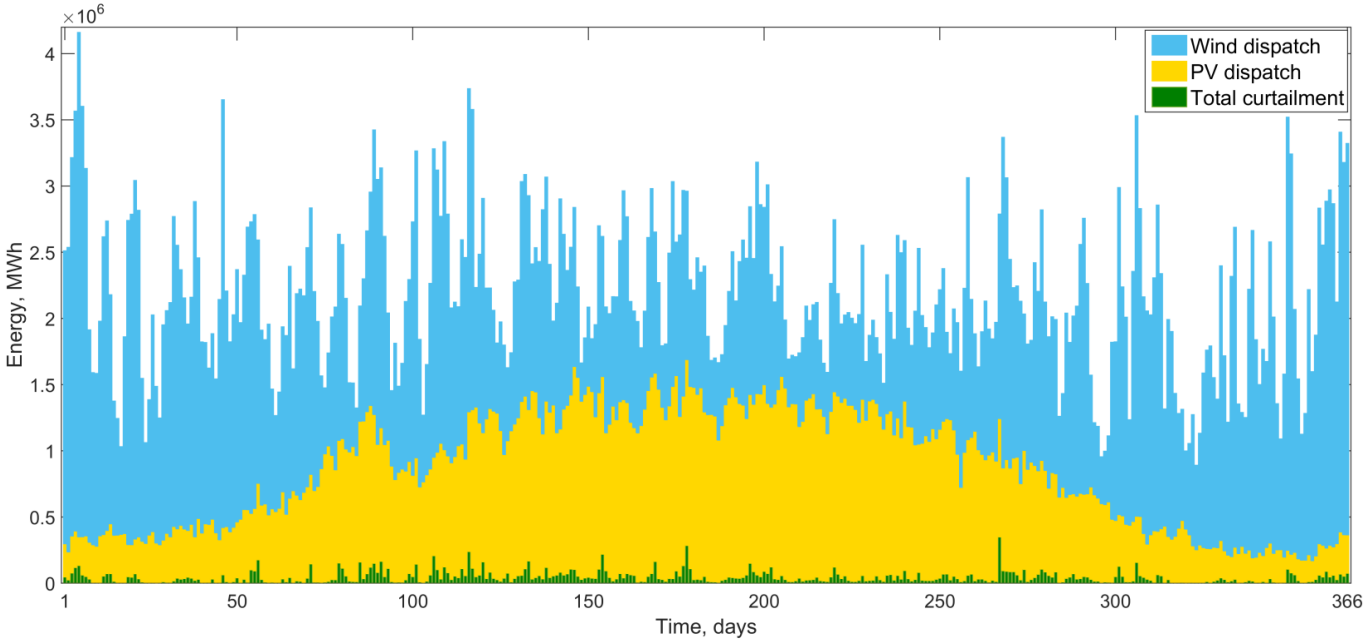
Model	Characteristics		
	Year of creation	Dedication	Dimensions
1. Benchmark system of J. Bialek [1]	2005	DC load flow calculations for cross-border trades analysis	1st synchronous UCTE region (18 countries); 1254 nodes, 378 generators (no RES included); 220 – 750 kV
2. ELMOD market model of TU Dresden [2]	2006	Market simulations (DC model)	16 western European countries; 2120 nodes, generators >100 MW 110, 220, 380 kV
3. Model of DIW Berlin [4]	2013	Market simulations (DC model)	3216 nodes, 4724 power plants; generator capacities >10 MW; HVDC lines included 220 – 380 kV
4. Transmission system model of Energynautics [3]	2011	DC and AC load flow and optimal load flow calculations for analysis of scenarios of the future network development	200 nodes represent the aggregation of generation,consumption and main transmission corridors; HVDC lines included; 220 – 380 kV
5. ENTSO-E Model [7]	2015	Dynamic (transient) analysis for 2020 peak load case	26 synchronous countries of continental European; 21382 nodes, 10829 generators with dynamic characteristics;

Results of the Core Simulations: Market Simulation

Scenario 2030

- Total PV+Wind capacity: 385,9 GW (prospective 2030)
- 40% PV, 60% Wind of total installed for each country
- Historical Demand and Weather Profile Cases 2012
- Upgraded Line Flow Limits (prospective 2023)

Fig: Daily dispatch and curtailment of PV and Wind generation

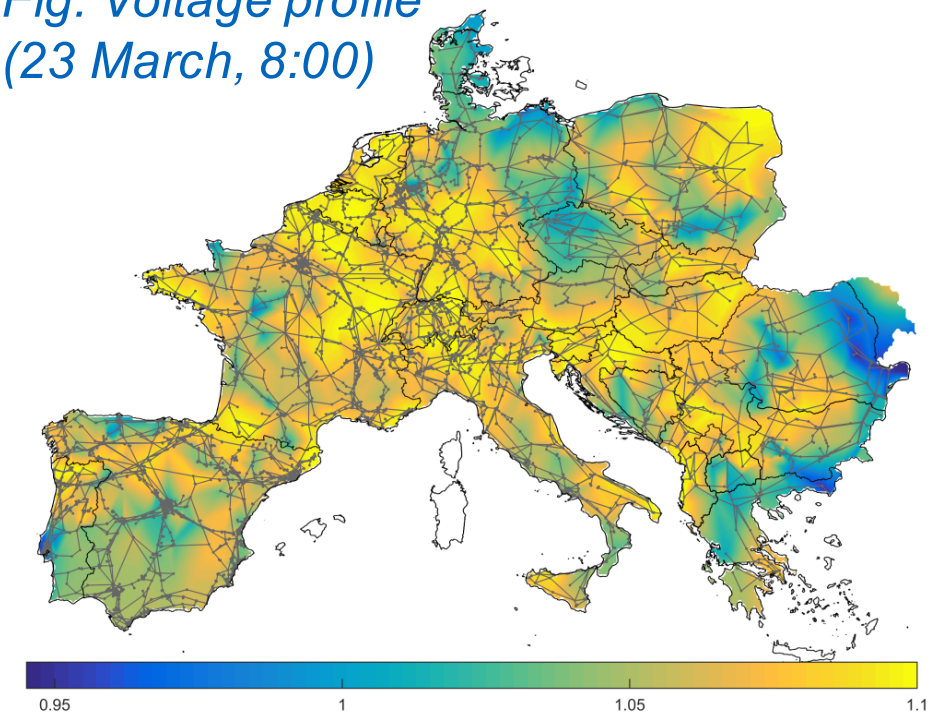


Results of the Core Simulations: AC LF Simulation

Scenario 2012

- Historical Demand and Weather Data 2012 (ENTSO-E)
- No RES feed-in

Fig: Voltage profile (23 March, 8:00)



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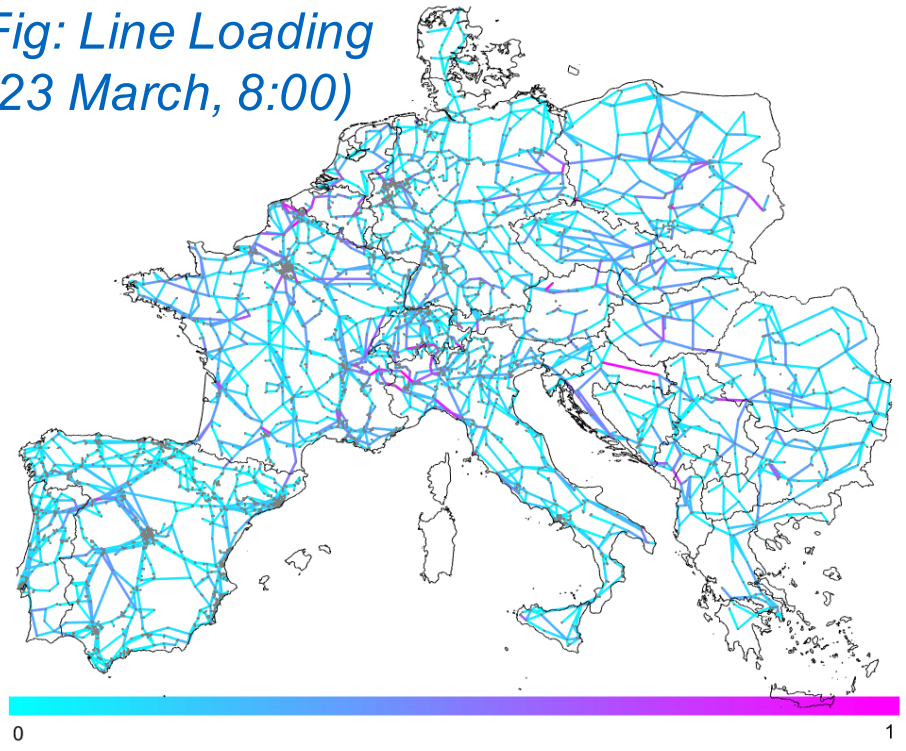
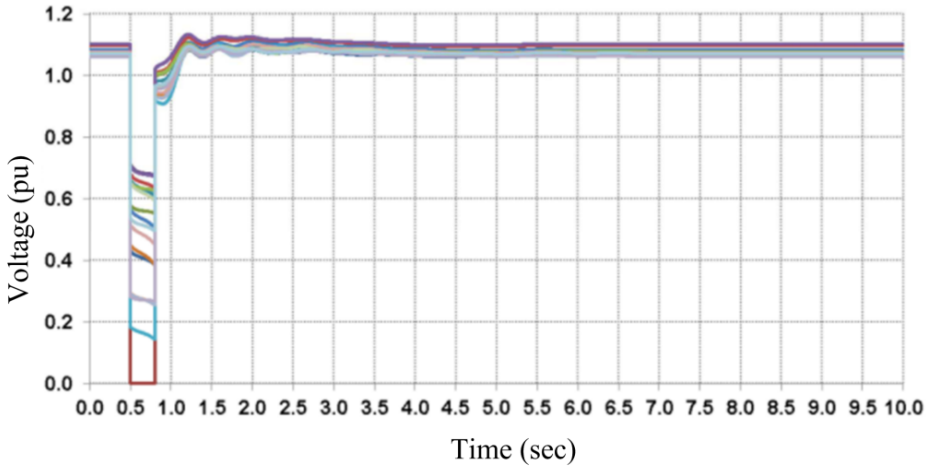


Results of the Core Simulations: Short Circuit [12]

- **Scenario 2012**
- 300 ms 3-phase short-circuit, sbst. Pulverdingen, Germany

Fig: Voltage transient at nodes near SC



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