ELECTRICITY SECURITY: METHODS AND MODELS FOR SUPPORTING THE POLICY DECISION MAKING IN THE EU

Doctoral Thesis Defence

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Thesis structure

1. EU ENERGY SCENARIOS
   3. ENERGY AND ELECTRICITY SECURITY ATTRIBUTES

2. EU ENERGY POLICIES
   4. ELECTRICITY SECURITY MODELS AND APPROACHES

5. DECISION-ANALYTIC FRAMEWORK
   - NATIONAL CASE
   - REGIONAL CASE
   - EU PROOF-OF-CONCEPT

6. APPLICATIONS

7. CONCLUSIONS
Gross inland consumption: EU 4th largest in the world

Energy import dependency: EU 1st among world economies
Electricity plays an increasing role

Share of electricity in current trend and decarbonisation scenarios (in % of final energy demand)

Decentralised and centralised systems increasingly interact

Share of decentralised electricity in power generation (in %)

Source: European Commission 2050 Energy Roadmap
EU’s energy policies and targets

2020
- 20% greenhouse gas reduction
- 20% renewable energy
- 20% energy savings

2030
- ≥27% renewable energy
- 40% greenhouse gas reduction
- Energy efficiency: review in 2014

Competitiveness
- Market liberalisation
- Wholesale with/vs. retail market redesign
- Capacity mechanisms
- Research and innovation

Security of supply
- Energy resource structure
- Super grid with/vs. smart grid development
- Network infrastructure expansion
- Backup capacity management

Sustainability
- Energy efficiency improvement
- Renewable energy increase
- Emission reduction
- Socio-environmental impact
HOW SHALL ELECTRICITY SECURITY MODELLING AND ASSESSMENT METHODOLOGIES EVOLVE TO ADEQUATELY SUPPORT THE POLICY DECISION MAKING?

1. How to define electricity security?

2. What models and methodologies are available?

3. What works and what doesn’t in the current approaches?

4. How to improve electricity security policy decision making?
1. EU ENERGY SCENARIOS

3. ENERGY AND ELECTRICITY SECURITY ATTRIBUTES

5. DECISION-ANALYTIC FRAMEWORK

2. EU ENERGY POLICIES

4. ELECTRICITY SECURITY MODELS AND APPROACHES

NATIONAL CASE

REGIONAL CASE

EU PROOF-OF-CONCEPT

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Electricity security mind map

THREATS
- Natural
- Malicious
- Systemic
- Adverse events
- Time scale
- Spatial scale
- Dimensions
- Reliability
- Absence of vulnerability
- Observability
- Disciplines
- EU institutions
- National governments
- Regulators
- Grid operators (TSOs, DSOs)
- Market operators
- Manufacturers
- Producers
- Consumers
- Aggregators
- Researchers and analysts
- Asset owners
- Operational security assessment
- Flexibility assessment
- Adequacy assessment
- Resilience assessment
- Robustness assessment
- Integrated assessment
- Dynamic power system/grid
- Static power system/grid
- Power market/system
- Energy system/market
- Combined

MODELS & APPROACHES
- Operational
- Operational planning and scheduling
- System planning
- Strategic energy planning
- Engineering design

ACTIONS

PROBLEM FEATURES
- Complex
- Complicated

STAKEHOLDERS & DISCIPLINES
- Stakeholders

PROPERTIES
- Absence of vulnerability
- Robustness
- Hidden
- Politics
- Strategic
- Economic
- Regulatory
- Scientific
- Technical

SCALES & DIMENSIONS
- National
- Regional
- EU
- ...
Electricity security: threats and dimensions

Market and regulation dimension

Source dimension

Infrastructure dimension

Geopolitical dimension

VERY LONG-TERM (up to decades)

LONG-TERM (up to years)

MID-TERM (up to days/weeks)

SHORT-TERM (up to seconds/mins)

Threats: natural, accidental, malicious, system

Short circuits, unplanned outages...

Scarcity of back-up capacity, ...

Cyber attack to control centre, ...

Unplanned reverse power flows, ...

Nuclear energy phase-out, ...

Electricity security: threats and dimensions

9
**Operational security**: ability of the power system to maintain or to regain an acceptable state of operational condition after disturbances.

**Electricity security**: properties

- **Robustness**: long-term capability of the power system to cope with constraints/stresses originating outside the infrastructure dimension.
- **Adequacy**: the ability of the power system to supply the aggregate electrical demand at all times under normal operating conditions.
- **Resilience**: mid-term capability of the power system to absorb the effects of a disruption and recover a certain performance level.
- **Flexibility**: capability of the power system to cope with the short/mid-term variability of generation (like renewable energy) and demand so that the system is kept in balance.

**Geopolitical dimension**

- **Source dimension**
- **Infrastructure dimension**
How to classify electricity security models?

Four electricity model clusters:

- **Dynamic** power system/grid models: detailed short-term description of the power system, grid and protection components

- **Static** power system/grid models. They offer detailed representations of the power grid (component by component)

- **Power market/system models**: demand-supply equilibrium representation, and simplified grid representations

- **Energy system/power market models**: whole energy system representation, and selected portions of the power system-market

<table>
<thead>
<tr>
<th>MODEL CLUSTER</th>
<th>FEATURES</th>
<th>TIME HORIZON</th>
<th>SYSTEM REPRESENTATION DETAIL</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>SHORT TERM</td>
<td>MID TERM</td>
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<tr>
<td>DYNAMIC POWER SYSTEM / GRID MODELS</td>
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<td>STATIC POWER SYSTEM / GRID MODELS</td>
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<tr>
<td>POWER MARKET / SYSTEM MODELS</td>
<td>X</td>
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<td>X</td>
</tr>
<tr>
<td>ENERGY SYSTEM / POWER MARKET MODELS</td>
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</tbody>
</table>
Which approaches assessing which electricity security properties?

- **RELIABILITY** (op. security, flexibility & adequacy): ability of the system to perform its intended function \( \rightarrow \) ENGINEERING
  
  “how things should work”: higher probability-lower impact

- **VULNERABILITY** (lack of resilience & robustness): inability of the system to withstand strains and failures \( \rightarrow \) COMPLEX SCIENCE
  
  “how things might fail”: lower probability-higher impact

- **INTEGRATED**: cost-benefit analyses, multi-criteria analyses and indicators
5. DECISION-ANALYTIC FRAMEWORK

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NATIONAL CASE

REGIONAL CASE

EU PROOF-OF-CONCEPT
Framework applications

- **NATIONAL CASE:** ITALY
- **INFRASTRUCTURE**
- **OPERATIONAL SECURITY, ROBUSTNESS**
- **STATIC POWER SYSTEM/GRID MODELS**

**ELECTRICITY SECURITY DIMENSIONS**

**ELECTRICITY SECURITY PROPERTIES**

**ELECTRICITY SECURITY MODELS**
Georeferenced model for the Italian 380-220 kV transmission grid

220-380 kV IT grid

1200 buses, 240 generators
1400 lines, 200 transformers
Contingency analysis example: extreme weather scenario design

- Extremely cold days of winter in the Alps, and the temperature reaches -45 °C (record lowest temperature in the Alps)
- The highest recorded snowfall on the Alps 11.5 m assumed
- 220 kV interconnection lines between Switzerland and Italy disrupted by snow/ice (3500m average altitude)
Tripping of 380 kV line in Central Italy: line flows violation

normal state

After tripping
This test case showed how the decision makers (the system operator in particular), via Geographic Information System and model-based visual analytics:

- could gain quicker awareness of potentially critical system conditions
- and this would more speedily allow them to react
The Baltic case – models and scenarios

**Detailed steady-state models** of the electricity infrastructure are built to perform security and preliminary (market) adequacy analyses in the Baltic and adjoining regions in a set of anticipated **scenarios**.
The objective of the optimal power flow is to minimise generation cost considering grid constraints.

Locational marginal costs are provided for each Baltic power system (so that market zonal splitting due to congestion can be identified).
Contingency analysis performed on four scenarios to check the **operational security** of the systems, and the adequacy of resources available to the TSO to handle such contingencies.

Results useful to identify the criticalities of the system under different generation and load conditions.
The Baltic regional case

This test case showed how

- **coordinated regional security analyses** can be conducted across Member States, targeting multiple security properties and
- electricity security models can be used to support decisions beyond the techno-economic aspects and including the geopolitics.
ELECTRICITY SECURITY DIMENSIONS

NATIONAL CASE: ITALY
REGIONAL CASE: BALTICS
EU-WIDE CASE: ERIC NETWORK

ELECTRICITY SECURITY PROPERTIES

INFRASTRUCTURE
GEOPOLITICAL, SOURCE, INFRASTRUCTURE
GEOPOLITICAL, SOURCE, MARKET AND REGULATION, INFRASTRUCTURE

ELECTRICITY SECURITY MODELS

OPERATIONAL SECURITY, ROBUSTNESS
OPERATIONAL SECURITY, ADEQUACY
STATIC POWER SYSTEM/GRID MODELS
POWER MARKET/SYSTEM MODELS
PROOF OF CONCEPT FOR CROSS-CUTTING, INTEGRATED ELECTRICITY SECURITY ASSESSMENT

STATIC POWER SYSTEM/GRID MODELS
Real time co-simulation platform proof of concept

- **Real-time co-simulation** of a transmission-distribution system between 4 laboratories in Europe
- **Real-time remote access** to high-performance computing, data and infrastructure
- **Perspective integrated analyses** of different domains/systems: market, generation, transmission, distribution, consumers,...

http://www.eric-lab.eu/
This proof of concept showed how a real-time simulation platform can **overcome**

- **computational** power constraints
- **data confidentiality** constraints

towards accurate cross-national security analyses
7. CONCLUSIONS
1. How to define electricity security?

**Taxonomy at the cross-roads of science and policy for electricity security properties**

2. What models and methodologies are available?

**Classification, clustering and mapping of electricity security models and assessment methodologies**
3. What works and what doesn’t in the current approaches?

Critical review of electricity security models, procedures and actors in the framework of the EU energy transition

4. How to improve electricity security policy decision making?

Novel decision-analytic framework for electricity security and applications at national, regional and EU-wide scale
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Co-authorship of 12 ISI-listed journal papers, 2 magazine papers, 5 conference papers, 5 book chapters and 4 EC-JRC Reports

6 ISI-listed papers more directly linked to this PhD research


4. Bompard, E.; Fulli, G; Ardelean, M.; Masera, M.; It's a bird, it's a plane, it's a ... Supergrid, 2014, IEEE Power and Energy Magazine


Electricity security analyses - improvement areas

National scale:
- model **interlinking** across domains/systems: the electricity distribution & transmission, gas, heat,...
- incorporate **probabilistic/complex system** approaches in decision making process

Regional scale:
- better defining **roles** and **responsibilities** of the actors
- expanding security analyses in the **vulnerability** area and in modelling the **interfaces** with other energy systems

EU-wide scale:
- transmission-distribution **interfacing** issues
- streamlining **EU-wide & regional** modelling/analyses
- **dynamic** system representation (real-time simulation)
Current power system security and planning decision making
Framework contextualization in the planning process