Session III: Novel planning methodologies at pan-European level

Optimization based approach to address methodology challenges in long-term grid planning studies

Patrick Panciatici, RTE – Work Package leader
Objective

► Definition of a new methodology and specification of new tools
≠ Not a grid planning study

• Scientific correctness and practical relevance

• Practical relevance checked using realistic data but not necessarily actual data

• Requirements of computational power (HPC)
Outline

- High-level problem statement
- State of the art and challenges
- Proposed methodology
- Test case results
- Conclusion & Discussion
High-level problem statement

► An optimal design of a very large grid including its modular development plan over a very long time horizon
  • Minimizing grid CAPEX and OPEX
  • Without control on generation planning (defined by scenarios)
Sequence of well-defined problems

- Assumptions: scenarios
- Computational engines
- Enhanced modular grid long term planning
Formulation of an “optimisation” problem

► The current practices for grid expansion planning are based on simulation tools and expert knowledge to find the “optimal” solution

► Generally for a single time horizon and a single scenario
  • The modular development plan over a very long time horizon with multiple future scenarios?

► Most of the time at the national/state level with boundary conditions

► The modelling of stochastic factors impacting the electrical system is generally very simple: selection of “typical” snapshots by the experts
  • Load: peak and off-peak but now with massive integration of wind and solar power?

→ Complexity is increasing, need for more advanced tools to help the planners
State of the art (academic)


- Title with “transmission planning”, “expansion planning” or “transmission expansion”
- 41 papers

- 100% deal with single-scenario methodologies
- 78% do not consider stochastic behaviour of system components
- 58% with single time-horizon methodologies

Paper closest to the proposed high level problem statement:
Challenges

- Spatial complexity: Europe to smart cities
- Temporal complexity: msec to decades
- Stochastic complexity: weather conditions and human behaviors
Overview of the proposed methodology

STEP 1 – ADEQUACY WITHOUT GRID

STEP 2 – DETECTION OF OVERLOAD PROBLEMS

STEP 3 – NETWORK REDUCTION ACCORDING TO CRITICAL BRANCHES (≈100 NODES)

STEP 4 – OPTIMAL GRID EXPANSION AT ZONAL LEVEL FROM TODAY TO 2050

STEP 5 – GRID EXPANSION AT NODAL LEVEL

STEP 6 – ROBUSTNESS OF THE PROPOSED GRID ARCHITECTURES

[Diagram showing the steps with time horizons and scenarios]
Adequacy without grid

- **STEP 1 – ADEQUACY WITHOUT GRID**
- **STEP 2 – DETECTION OF OVERLOAD PROBLEMS**
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Adequacy without grid

Objective: compute the hourly dispatch of controllable generation and consumption and calculate time series of power injection in each location of the system

- List of scenarios
  - Generation of correlated time series of stochastic inputs
    - Correlated time series of stochastic inputs
      - Power adequacy simulations without grid constraints
        - Time series of controllable generation and consumption for several Monte Carlo years
Adequacy without grid

► Maintenance scheduling of thermal units
► Time series generation of stochastic inputs (load, wind and solar generation, hydro inflows, outages of thermal units):
  • Seasonality, trend, stochastic properties
  • Spatial correlations
    o Sensitivity of the adequacy results (energy in excess, unsupplied energy...) to spatial correlations → reliability assessments
    o Inter-zonal exchanges are impacted → reinforcement needs

► Weekly decomposition of hydro resources
► Modelling of the flexibility of thermal units
  o Minimum up/down times, minimum stable power, start-up costs
► Modelling of Demand Response
Detection of overload problems and assessment of congestions’ severity

- **STEP 1 – ADEQUACY WITHOUT GRID**
- **STEP 2 – DETECTION OF OVERLOAD PROBLEMS**
- **STEP 3 – NETWORK REDUCTION ACCORDING TO CRITICAL BRANCHES (≈100 NODES)**
- **STEP 4 – OPTIMAL GRID EXPANSION AT ZONAL LEVEL FROM TODAY TO 2050**
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All time horizons and scenarios

First two time horizons
Detection of overload problems and assessment of congestions’ severity

Initial European grid (≈ 8000 nodes)

- Reduction of the initial network

  Simplified nodal grid (≈ 1000 nodes)

- Automatic mapping of generation and consumption on nodes

  Simplified nodal grid with generation and consumption

- Identification of overload problems

  List of critical branches

- Reduction of the nodal initial grid according to critical branches

  Simplified nodal initial grid (critical branches in red)

  Zonal initial grid

- Assessment of congestions’ severities and associated costs

  List of congestions: location, severity, costs
Detection of overload problems and assessment of congestions’ severity

- A innovative network reduction approach to define zones while minimizing the intra-zonal need for reinforcements
  - Congestion is a main driver of transmission expansion decisions
  - Detection of frequently congested lines over all scenarios, time horizons and Monte Carlo years: selection of critical branches
  - Network partition according to “most” critical branches
Detection of overload problems and assessment of congestions’ severity

► Calculation of equivalent physical capacities of corridors

- Lack of references, difficult problem
- Proposed method:
  - Maximum bilateral inter-zonal physical capacity using the nodal grid ~ Maximum power transferred while respecting thermal limits of tie lines composing the inter-zonal corridor
  - For each base case \( \rho \), calculate maximum inter-zonal flow \( F_{A \rightarrow B, \rho} \)
  - Maximum physical capacity \( C_{X \rightarrow Y} = \max_{\rho} (F_{X \rightarrow Y, \rho}) \)
Optimal grid expansion at zonal level

1. Adequacy without grid
2. Detection of overload problems
3. Network reduction according to critical branches (≈100 nodes)
4. Optimal grid expansion at zonal level from today to 2050
5. Grid expansion at nodal level
6. Robustness of the proposed grid architectures
Optimal grid expansion at zonal level

**Objective:** find a modular development plan minimizing CAPEX and OPEX

- **List of congestions:** location, severity, costs
- **Zonal initial grid**

**Optimal Grid Expansion at Zonal Level**

- **Elaboration of a list of possible new transmission capacities**
- **Selection of representative snapshots**

  - List of candidates for zonal expansion
  - List of snapshots for grid expansion

**Optimal Grid Expansion Diagram**

- Initial grid (current conditions)
- Grid for an intermediate time horizon common to all scenarios
- Grid for final time horizon and a given scenario

**Scenarios**

**Time Horizon**
Optimal grid expansion at zonal level

► Selection of representative snapshots over all the Monte Carlo years for a given scenario and a given time horizon
  • Preserving some key properties: nodal price differences, non controllable demand/generation
  • Tradeoff between computation time and accuracy

► Selection of candidates: 2 steps
  • Ex-ante estimation of the profitability
  • Selection among the first set based on a simple, fast optimization

► Transmission expansion planning optimization over all scenarios and time horizons
  • Common expansion plan for the two fist time horizons (10 years)
  • Maximum annual investment
  • Possible anticipation of investments
Grid expansion at nodal level

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Grid expansion at nodal level

Objective: define precise nodal grid expansions for 2025 and 2030 ensuring system reliability (N-1)
Grid expansion at nodal level

Same transmission expansion problem than for the zonal level, but optimization:

- On the nodal network (1000 nodes)
- Over the first 2 time horizons where there is a common development for all scenarios
- With additional constraints on inter-zonal capacities using the results from the zonal transmission expansion plan:
Robustness of the proposed grid architectures

STEP 1 – ADEQUACY WITHOUT GRID

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STEP 4 – OPTIMAL GRID EXPANSION AT ZONAL LEVEL FROM TODAY TO 2050

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STEP 6 – ROBUSTNESS OF THE PROPOSED GRID ARCHITECTURES
Robustness of the proposed grid architectures

Objective: check that proposed grid architectures could be operated without major voltage and stability issues

List of snapshots for grid expansion

- Selection of snapshots subject to possible voltage and stability problems
- Reduced list of snapshots for robustness analysis
- Development of realistic base cases and estimation of associated costs

Generic dynamic models for robustness assessment

- Dynamic models
- Assessment of possible problems for each phenomenon
- Acceptable grid architectures
Robustness of the proposed grid architectures

 ► Development of a procedure to build an AC load flow model from a DC one
   • Dispatch of voltage-reactive power control resources (shunt devices, transformer taps, generator setpoint voltages)
   • New algorithm to solve lack of convergence issues

 ► Investigation on the impact of models and controls of wind generators and HVDC links on transient stability
   • Control schemes should be chosen carefully: they can improve or deteriorate transient stability
   • System Stability should be assessed using realistic modelling of all the components: e.g. wind generators seem to improve transient stability while HVDC links deteriorate it
Test case results

► Test case description
  • Part of the European network (≈ 5,000 nodes)
  • 3 scenarios x 3 time horizons x 100 Monte-Carlo years for each scenario and time horizon: 900 years
  • Parallelization on 9 servers (16 cores/server): 100 years/server

► Complexity
  • 1,000 nodes to 100 zones
  • 7,884,000 to 45 snapshots
  • 9,900 to 56 candidates for zonal expansion
## Test case results

<table>
<thead>
<tr>
<th>Module</th>
<th>1 year</th>
<th>900 years</th>
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<tbody>
<tr>
<td><strong>STEP 1</strong> Time series generator</td>
<td>10min</td>
<td></td>
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<tr>
<td>Adequacy simulations (52 weekly MILP problems/year)</td>
<td>2h 40min</td>
<td>30h</td>
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<td><strong>STEP 2</strong> Nodal DCOPF (8736 hourly linear problems/year)</td>
<td>2h 10min</td>
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<td>Network reduction according to critical branches</td>
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<td>15min</td>
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<td><strong>STEP 3</strong> Zonal DCOPF (8736 hourly linear problems/year)</td>
<td>40min</td>
<td>4h</td>
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<tr>
<td>Snapshot selection (5 per scenario/horizon)</td>
<td>-</td>
<td>3h</td>
</tr>
<tr>
<td>Candidate selection</td>
<td>-</td>
<td>2h 30min</td>
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<tr>
<td>Zonal TEP</td>
<td>-</td>
<td>2h</td>
</tr>
<tr>
<td><strong>STEP 5</strong> Nodal expansion</td>
<td>-</td>
<td>~ 5h</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>~ 47h</td>
<td></td>
</tr>
</tbody>
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**Graph**:
- **Zonal TEP**: cumulative installed capacities
  - Investments (GW)
  - Scenarios: 2030, 2040, 2050
  - Labels: Scenarios 1, 2, 3

**Diagram**:
- Flowchart illustrating the process:
  - **STEP 1**: Adequacy without grid
  - **STEP 2**: Detection of overload problems
  - **STEP 3**: Network reduction according to critical branches (~100 nodes)
  - **STEP 4**: Optimal grid expansion at zonal level from today to 2050
  - **STEP 5**: Grid expansion at nodal level
  - **STEP 6**: Robustness of the proposed grid architectures
Conclusions

► Proof of concept, only prototypes
  • Formulation of the planning expansion problem as an optimization problem, while the state of the art is based on expert knowledge and simulation tools
    ○ Help the planner to make investment decisions

► Development of an industrial IT solution is required
  • Formal approximations and improvements on zonal TEP problem seem possible to solve this complex optimization problem using HPC: 1000 servers 16 cores during 24h
    ○ Estimated cost to rent this amount of computational power is around 20 k€

► Possible implementation of some methods in existing tools and planning studies
  • Spatial correlations for time series generation
  • Development of an AC load flow model from a DC one
Deliverables

- **D8.1** “High-level definition of a new methodology for long-term grid planning, analysis of the challenges, and necessary approximations”
- **D8.2** “Enhanced methodology for Demand/Generation scenarios and the associated prototype”
- **D8.3** “Enhanced methodology to define optimal grid architectures for 2050 and the associated prototype”
- **D8.4** “Enhanced methodology to define the optimal modular plan to reach 2050 grid architectures and the associated prototype”
- **D8.5** “Enhanced methodology to assess robustness of a grid architecture and the associated prototype”
- **D8.6** “Detailed enhanced methodology for long-term grid planning and specification of tools associated with the enhanced methodology”
- **D8.7** “Recommendations about critical aspects in long-term planning methodologies”
Thank you for your attention!

Contact: rte-e-highway2050@rte-france.com
Web: www.e-highway2050.eu
Follow us on Twitter: @e_Highway2050