Assessment of allocation of the impact of RES penetration on Power System Security

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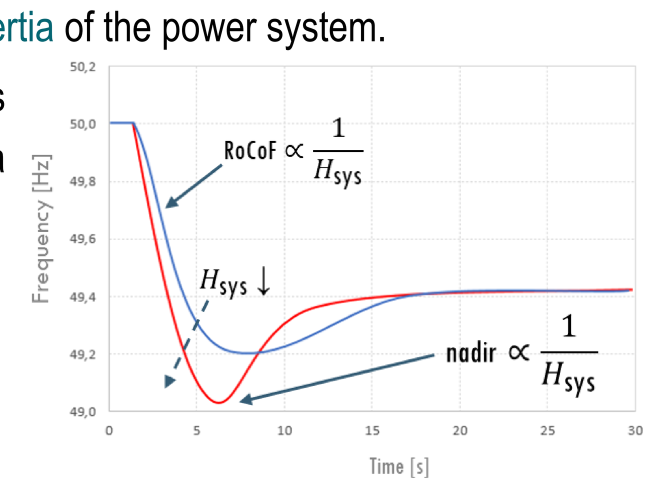
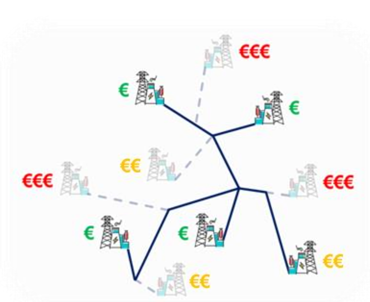
Research context and motivation

- In 2020, more than two-thirds of the total energy supply of the EU was still coming from fossil fuels, including coal, oil, petroleum, and natural gas.
- Due to the lack of local fossil resources, almost 60% of the EU's energy needs were met by net imports.
- To decrease the energy dependency of EU countries, an electricity-centered energy transition balancing the energy trilemma *(security, sustainability, affordability)* is necessary and not deferrable.
- The increasing amount of penetration of Renewable Energy Sources is leading to new challenges in managing and operating electricity transmission systems, particularly in the area of system stability. Specifically, IBPS *(Inverter Based Power Sources)*, including solar and wind, have an impact on the inertia of the power system.
- Inertia is a key property in the evolution of frequency transients, as it affects both the rapidity and the amplitude of oscillations, since when inertia decreases:
  I. RoCoF (Rate of Change of Frequency) increases
  II. The nadir of the frequency transient becomes deeper





- Inertia, in an electrical system with a strong amount of IBPS, is considerably variable even in short-term period, due to market mechanism: only dispatched inertia is available, that is the sum of the inertial contributions of the generators operating in the network.

Addressed research problems

- My research, in collaboration with RSE S.p.A. *(Ricerca sul Sistema Energetico)*, aims to investigate the distribution of inertia in large power grids, with specific regard to the Italian one.

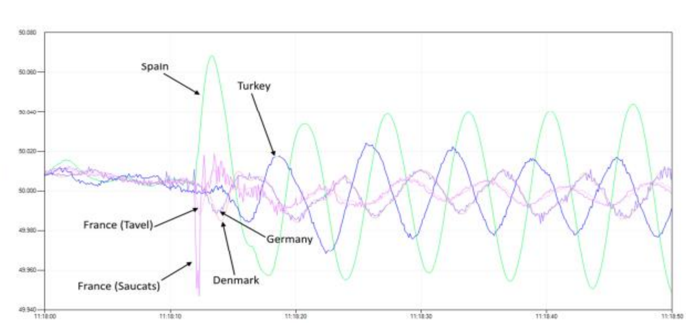
  In particular, the three main pillars are:

  1. Understanding the inertia distribution and how it could affect the stability
  2. Develop a public dynamic model of the Italian transmission power grid
  3. Implementing tools for an optimal location of new resources in the grid, such as synchronous compensators or virtual inertia

- Traditionally, frequency is considered to be a global property, as its oscillations propagate very rapidly to the whole synchronous zone; for this reason, studies concerning inertia have so far been based on single-bus equivalents, in which the power grid was not modeled.

  For large systems, such as Continental Europe, the way in which inertia is distributed can have an impact on the dynamic response of the electrical system, being able to lead to interarea oscillations.

  These analyses must be performed in a new kind of model that takes into account topology of the network and parameters of the lines.

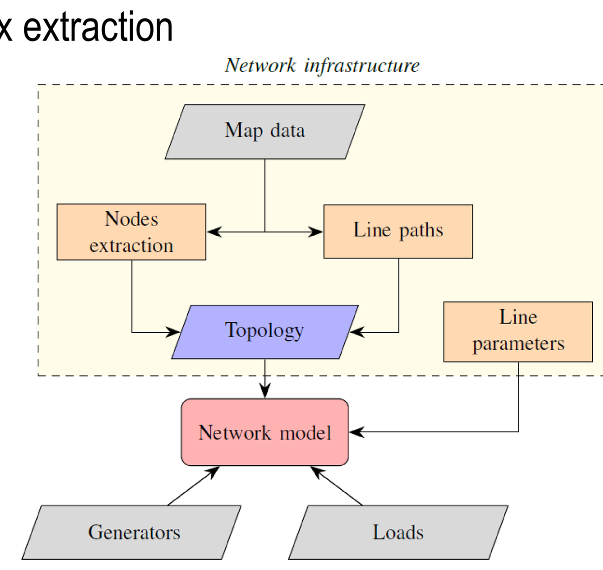


Novel contributions

- One source of publicly accessible georeferenced data can be collaborative map services.

Pros:	Cons:
⊕ Open license	⊖ Usually only geographical information is available (no topology, no parameters)
⊕ In areas with many active users, high level of detail	⊖ No official validation
⊕ More updated respect to official reports	⊖ More complex extraction
⊕ Unique data format	

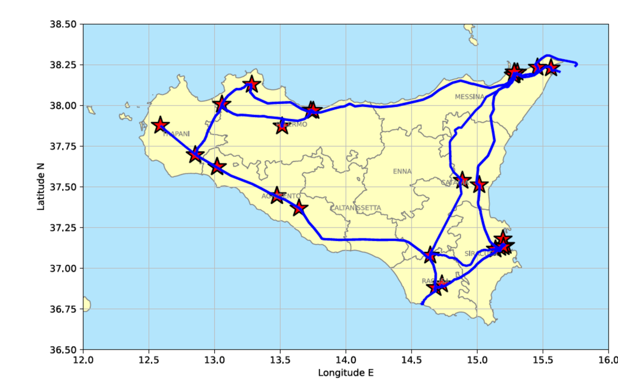
- Publicly available large-scale electricity grid models are one-bus models or zonal models, but to investigate the propagation of dynamic transients they are oversimplified. One of the goals of my research is to define methods for implementing synthetic nodal models of transmission networks.
- Advantages of nodal models:
  - ⊕ Better spatial granularity
  - ⊕ Identifying critical nodes and assessing their impact on grid resilience
  - ⊕ Finer control of generation and load resources



- Many HVDC lines are already operational around the world, especially in China, Northern Europe and North America, but they are all point-to-point or three-terminals connections (the first of this type in the world was SACOI in 1987), sometimes in back-to-back configuration. The only existing "grid" is 4-terminal, single-mesh Zhangbei HDCV, active from 2021. The proposed configuration for the European hybrid HVDC/HVAC transmission network, on the other hand, is completely meshed.

Adopted methodologies

- Development of a procedure to automatically extract grid information from OpenStreetMap using *Overpass API* and reconstruct the topology, based on Python scripts:
  I. Convert area name or zonal codes into OSM identifier
  II. Query nodes *(power substations)* information
  III. *Query* lines sections information of selected voltage levels
  IV. Reconstruct power lines
     a. *Isolate elements from the same line*
     b. *Look for and exclude parallel sections*
     c. *Arrange and compose line sections*
     d. *Remove terminal forks*
  V. Connect topology
  VI. Compute length and estimate parameters



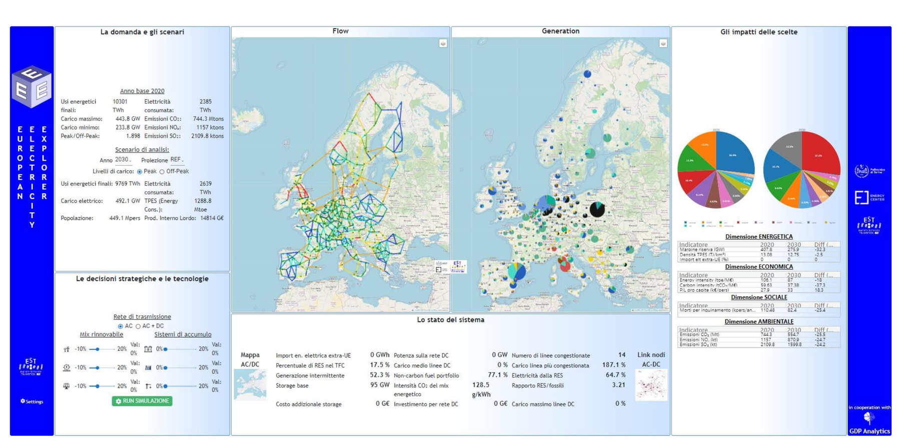
Tested on Sicilian grid (compared to *"Elenco impianti RTN"*):
- 6 of 6 380 kV stations found
- 13 of 13 220 kV stations found
- 1 new 380 kV station identified (Villafranca 2)
- All 220 kV and 380 kV lines mapped (length error < 1%)

- A georeferenced Italian dynamic model of the power transmission grid has been constructed, starting from a static and non-georeferenced European public model from *ENTSO-E TYNDP 2018*, in DIgSILENT PowerFactory format, to run dynamic simulations with various contingencies (e.g. fault on a line, loss of a relevant power plant).

  1. Separation of the Italian grid from the European one, replacing cross-border connections with equivalent generators set to preserve power flows.
  2. Identification of network nodes and georeferentiation.
  3. Dynamic generator models, following a procedure based on categorization in power classes and type of generator (primary source, type of cycle). For each of these categories a different dynamic model and an associated set of parameters have been defined.

Static and dynamic models of the Italian power grid is composed by:
- 575 sites
- 1940 substations
- 990 lines
- 3069 synchronous generators
- 1105 transformers

- Contribution in developing a platform to integrate an HVDC grid in the existing HVAC European infrastructure, creating an hybrid infrastructure to allow a larger penetration of RES, w.r.t. European Commission scenarios.
  - RESs and electricity demands are not evenly distributed geographically in Europe
  - Peak and off-peak demands in 2022: 590 GW and 264 GW (France, Germany, UK, Italy and Spain accounted for 57% of the total among 35 ENTSO-E countries)
  - Power transfer corridors, already had several bottlenecks in integrating RESs, incurring high congestion costs
  - RES curtailment in 2040 due to congestion is estimated to be 81 TWh



Future work

- The dynamic equivalent of foreign countries is still under study, with a focus on a structure of equivalent layers of nodes interconnected to each other and to the Italian border nodes, in order to reproduce the dynamic behavior of the European grid at the border of the Italian one.
- The usage of multi-metric clustering methods to the dynamic responses of the various network nodes as the reference perturbation changes is under investigation, to highlight groups of nodes with similar behavior.

Publications

Published works: 2 journals, 1 conferences

- Wu Haoke, Lorenzo Solida, Tao Huang and Ettore Bompard. "Allowing Large Penetration of Concentrated RES in Europe and North Africa via a Hybrid HVAC-HVDC Grid" Energies 16, no. 7 (March 30, 2023): 3138. https://doi.org/10.3390/en16073138
- Lorenzo Solida, Gianfranco Chicco, Ettore Bompard, Tao Huang, Andrea Mazza, and Marco Raffaele Rapizza. "Topological Aspects of Building Synthetic Models for Power Transmission Networks from Public Data" In 2022 57th International Universities Power Engineering Conference (UPEC), 1–6. Istanbul, Turkey: IEEE, 2022. https://doi.org/10.1109/UPEC55022.2022.9917609