Increasing the integration of EU electricity system from the network operation and market perspective
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Research context and motivation

- Europe's power sector is facing new issues and evolving scenarios towards enghanicng energy security, sustainability, and indepenceny. To achieve these energy targets, currently there are some challenges:
  i. Integration of part of EU to non-EU power systems (Baltic-Russia)-energy security issue;
  ii. Higher electricity market integration while allowing for higher renewable penetration;
  iii. Strengthening the cooperation among Eurppean TSOs for network management;
- My research aims at addressing these challenges through modelling a European market clearing and network management tool, which can provide precise insight into the impact of different EU energy policies on market performance and energy security within Europe and support policy makers to achieve their energy targets in a cost-efficient manner.

Addressed research questions/problems

> *Baltic power systems' desynchronization from IPS/UPS and re-synchronization to Europe*

I analyzed and compared the prospective Baltic de-synchronization schemes from market performance, congestion management, and system security perspectives and found the optimum option.
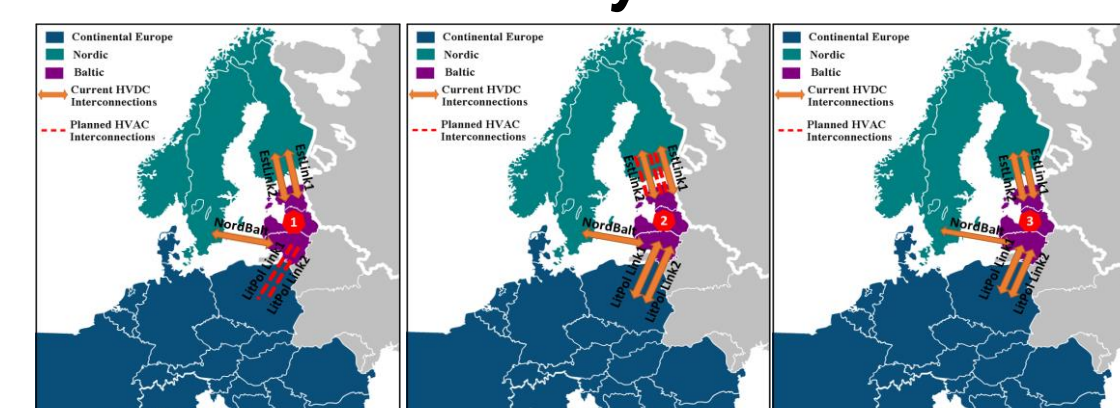

Fig.1. Baltic-EU interconnections under different desynchronization schemes

> *Integration of the European day-ahead and intraday electricity markets under high share of renewables*

I developed a network-constrained Europe-wide integrated day-ahead and intraday market modelling tool, including 34 countries, with stochastic modelling of wind/solar and demand.
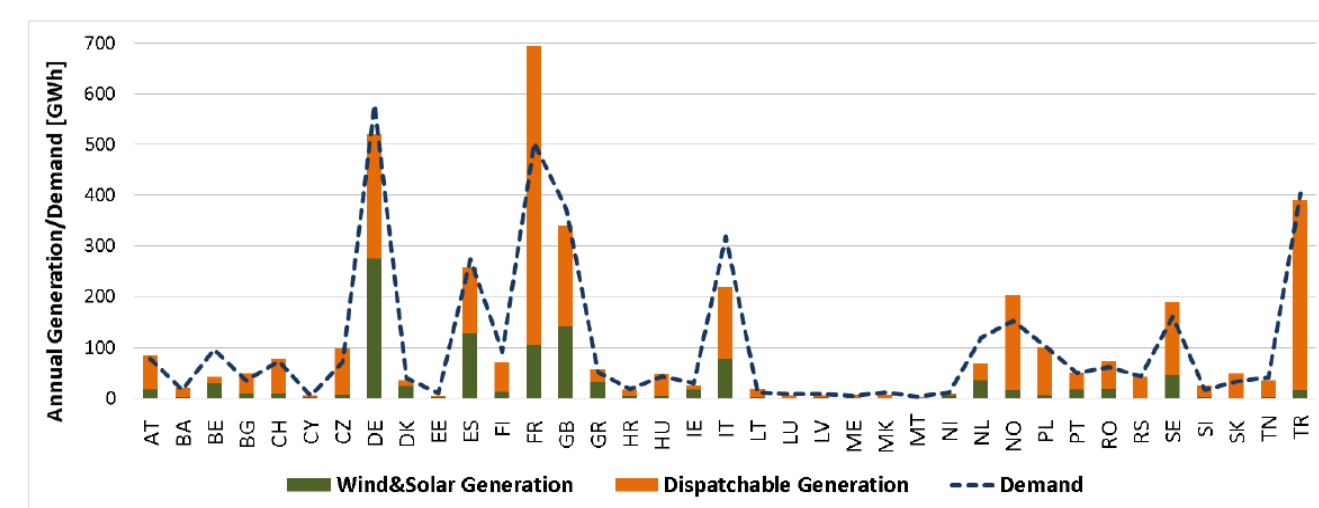
The model can be used to analyze the impact of different market-related decision-making problems in Europe, e.g. network enhancement plans, impact of different penetration level of renewables, and the role of storage technologies on EU market performance.

Fig. 2. Annual generation/demand within each country by 2030

> *A multi-area assisted rotational load shedding approach for mutual support of interconnected power systems under abnormal situation*

I developed a decision making algorithm for regional crisis management in interconnected power systems to utilize the available supply and demand side resources more efficiently. The decision making problem prioritizes the supply of different load categories based on their sensitivity to supply protected loads and to ensure availability of operating reserves within the region.
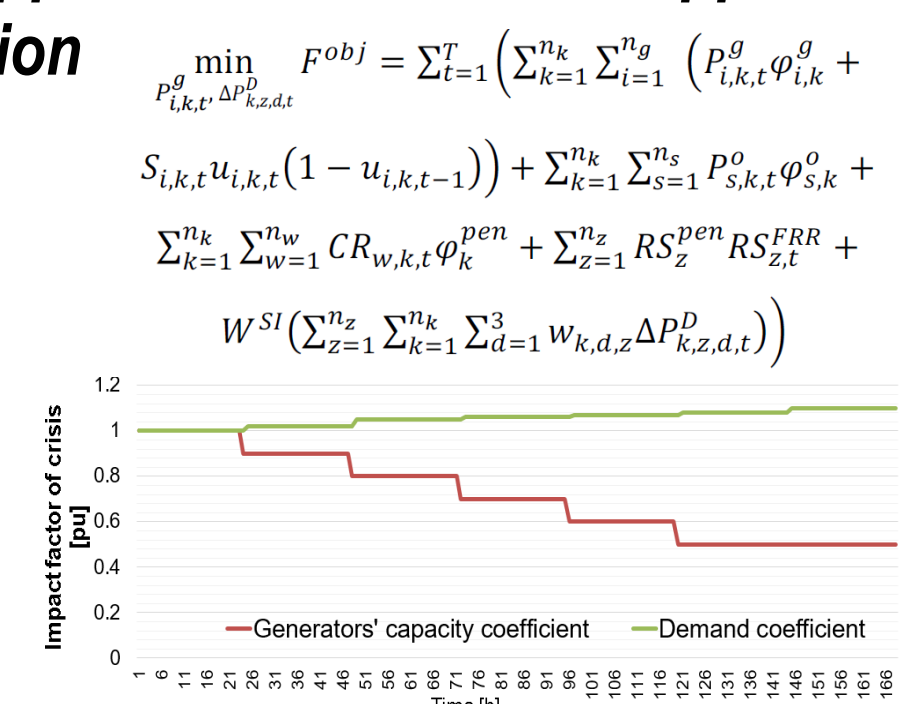
$$\min_{P_{i,k,t}^g, \Delta P_{k,d,z}^D} F^{obj} = \sum_{t=1}^{T} \left(\sum_{k=1}^{n_k} \sum_{i=1}^{n_g} \left(P_{i,k,t}^g \varphi_{i,k}^g + S_{i,k,t} u_{i,k,t} (1 - u_{i,k,t-1}) \right) + \sum_{k=1}^{n_k} \sum_{s=1}^{n_s} P_{s,k,t}^o \varphi_{s,k}^o + \sum_{k=1}^{n_k} \sum_{w=1}^{n_w} CR_{w,k,t} \varphi_k^{pen} + \sum_{z=1}^{n_s} RS_{z,t}^{pen} RS_{z,t}^{FRR} + W^{SI} \left(\sum_{z=1}^{n_s} \sum_{k=1}^{n_k} \sum_{d=1}^{3} w_{k,d,z} \Delta P_{k,d,z,t}^D \right) \right)$$

Fig. 3. Gradual impact of crisis (dry season) on generation capacity and demand

> *An incentive payment mechanism for enhancing active participation of flexible demands in electricity markets to manage renewables' uncertainty*

The profitability of flexible demands by providing load shifting into the market with high renewable penetration is analyzed and an incentive payment mechanism is proposed to provide additional revenue for DR providers and guarantee their profitability.
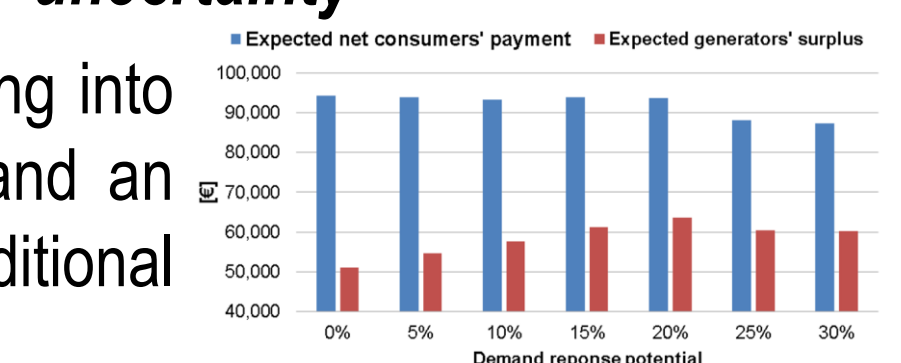

Fig. 4. Impact of DR on generators' surplus and cost to load

Submitted and published works

- Zalzar, S. , Purvins, A., Bompard, E., and Masera, M., "The Impacts of an Integrated European Adjustment Market for Electricity under High Share of Renewables", Energy Policy Journal (minor revision).
- Purvins, A. , Huang, T., Zalzar, S., Pi, R., Flego, G., Masera, M., Fulli, G., Bompard, E., L'abbato, A., "Integration of the Baltic States into the EU electricity system: A technical and economic analysis", Monograph, EU Publications, ISBN: 978-92-79-68379-4, 2017
- Bompard, E. , Zalzar, S., Huang, T., Purvins, A., and Masera, M., "Baltic Power Systems Integration into the EU Market Coupling under Different Desynchronization Schemes: A Comparative Market Analysis", Energies, 11, 1945 , 2018
- Zalzar, S. , Bompard, E., "A Day-Ahead Joint Energy and Uncertainty Reserve Market Clearing Model to Manage VRE Uncertainty", IEEE 18th International Conference on Environment and Electrical Engineering and 2nd Industrial and Commercial Power Systems Europe, Palermo, 2018.
- Zalzar, S. , Bompard, E. , "The Impacts of an Integrated European Dayahead and Intraday Electricity Market on Market Performance: The Iberian Region Case", PowerTech 2019, Italy, Milan, 23-27 June, 2019.
- Zalzar, S. , Bompard, E. , Chicco, G. , Huang, T. , Blanco, M. , Zani, A. , Fulli, A. , "A Multi-area Assisted Rotational Load Shedding Plan for Mutual Support of Power Systems Under Abnormal Situations", IEEE PES Innovative Smart Grid Technologies Europe (ISGT-Europe), Bucharest, Romania Sep 28- Oct 2, 2019.
- Zalzar, S. , Bompard, E. , "An incentive-based settlement mechanism for participation of flexible demands in day-ahead markets", 2nd International Conference on Smart Energy Systems and Technologies, Porto, Portugal, 9-11 Sep, 2019.
- Zalzar, S. , Bompard, E. , "Assessing the impacts of demand-side flexibility on the performance of the Europe-wide integrated day-ahead electricity market", 2nd International Conference on Smart Energy Systems and Technologies, Porto, Portugal, 9-11 Sep, 2019.
- Mazza, A. , Rogin, A. , Zalzar, S., Estebsari, A. , Bompard, E. , "Creation of a computational framework for the European transmission grid with Power-to-Gas", 54th International Universities Power Engineering Conference (UPEC 2019), Bucharest, Romania, 3-6 Sep. 2019.

Novel contributions

- A comprehensive study on the full integration of Baltic countries into the European power systems, from market operation and security perspective.
- Providing a detailed Europe-wide day-ahead and intraday market modelling tool with implicit allocation of cross-border transmission capacities, incorporating the national and regional FCR and FRR reserve requirements.
- Assessing the operational and economic impact of intraday market coupling under high renewable penetration, in terms of expected generation cost, average prices, generators' surpluses, and cost to loads, through a stochastic optimization approach.
- Addressing the potential impacts of flexibility provided by active participation of hydro pumped-storage generators and DR programs in European integrated day-ahead and intraday markets by 2030.
- Proposing a rotational load shedding approach through multi-area coordination among TSOs to manage abnormal situations within interconnected power systems
- Assessing the economic impact of demand-side flexibility from customers' perspective and proposing an incentive-based settlement mechanism to ensure DR profitability.

Adopted methodologies

> *Europe-wide integrated market modelling*
- Zonal pricing approach
- Modelling day-ahead (DA) and intraday (ID) markets
- Inter-zonal and intra-zonal congestion management
- Modelling uncertainty of wind/solar generation and load
- Modelling frequency control reserve constraints within market zones according to the current system operation rules
- Modelling demand-response programs in DA & ID markets
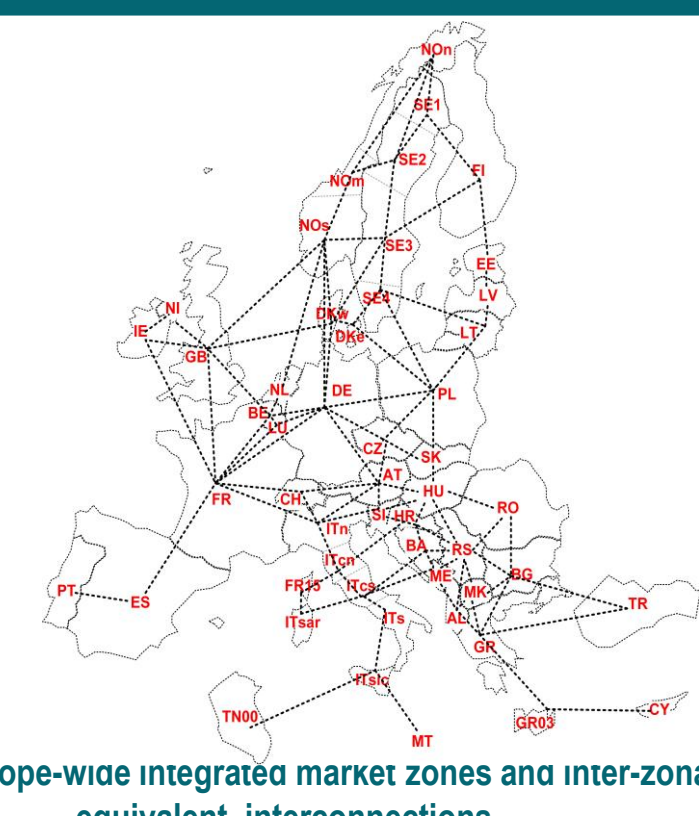- Scheduling of hydro pump-storage generators in market

Fig. 5. Europe-wide integrated market zones and inter-zonal equivalent interconnections

> *Decision-making algorithm for multi-area assisted load-shedding*
- Optimization problem formulated as Mixed integer linear programming (MILP)
- Simultaneous optimization of energy and reserves
- Security constrained unit commitment algorithm under N-1 security criterion
- Optimum scheduling of storage technologies to provide energy and reserves

> *Stochastic market clearing approach*
- Scenario-based approaches for modelling uncertainty
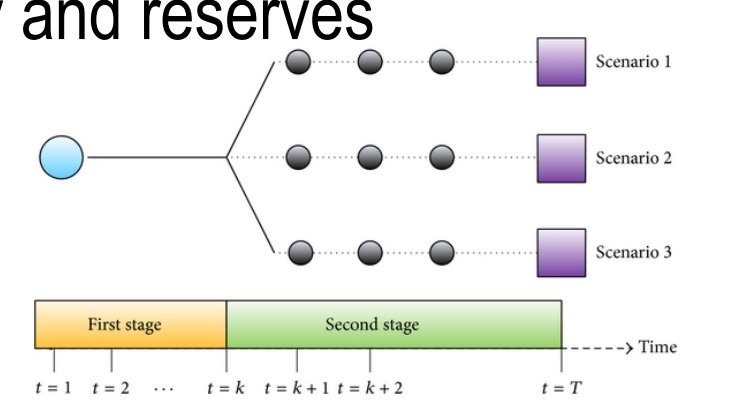- Monte-Carlo simulation
- 2-stage stochastic programming

Fig. 6. Illustration of scenario-tree in 2-stage stochastic

Projects

- Performance-based regulation for enhancing the resilience of distribution system (Cooperation I-RETI – PoliTO)
- Regional smart load shedding strategies (Cooperation Joint Research Centre – PoliTO)
- Integration of the Baltic States into the EU electricity system: A cost-benefit and geo-political energy security analysis (Cooperation Joint Research Centre – PoliTO)

Future work

- Proposing a new electricity pricing mechanism in markets with high penetration of renewables with close to zero marginal cost.
- Re-designing market zones in EU electricity markets according to the increasing penetration of renewables.

List of attended classes

- 01RZOIU – Bilevel programming and its applications to Logistics and Energy Management (26/7/2017,16.67)
- 01SWJRV – Control and optimization in Smart Grids (1/6/2018,26.67)
- 01LYXRV – Electrical load management, forecasting and control (21/9/2018,41.67)
- 01LCPIU – Experimental modeling: costruzione di modelli da dati sperimentali (16/4/2018,44.00)
- 02ITTRV – Generatori e impianti fotovoltaici (30/3/2018,41.67)
- 02PKLRQ – Ottimizzazione in condizioni di incertezza: modellazione e metodi di soluzione (12/7/2017,40.00)
- 01RQXRV – Pattern recognition and neural networks (5/5/2017,66.67)
- 01LEVRV – Power system economics (2/10/2017,25.00)
- 01NDLRV – Lingua italiana I livello (3/7/2018)
- 02LWHRV – Communication (16/2/2017,6.67)
- 01RRPRV – Lean startup e lean business for l'innovation management (19/7/2017,33.33)
- 08IXTRV – Project management (19/9/2017,6.67)
- 01RISRV – Public speaking (16/2/2017,6.67)
- 02RHORV –The new Internet Society: entering the black-box of digital innovations (19/9/2017,8.00)