6 DynPOWER 2022

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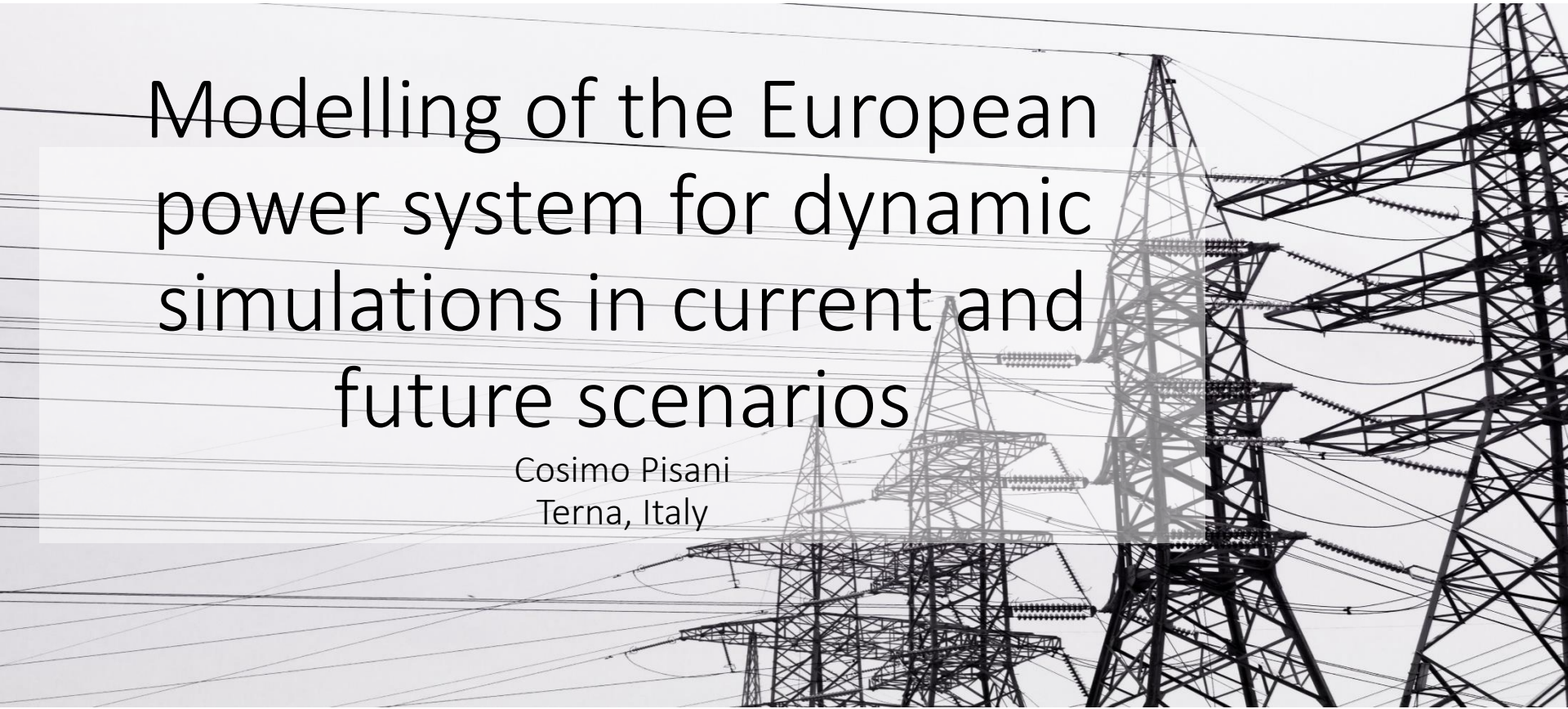
Zürcher Hochschule für Angewandte Wissenschaften

zh aw School of Engineering

IEFE Institut für Energiesysteme und Fluid-Engineering

Modelling of the European power system for dynamic simulations in current and future scenarios

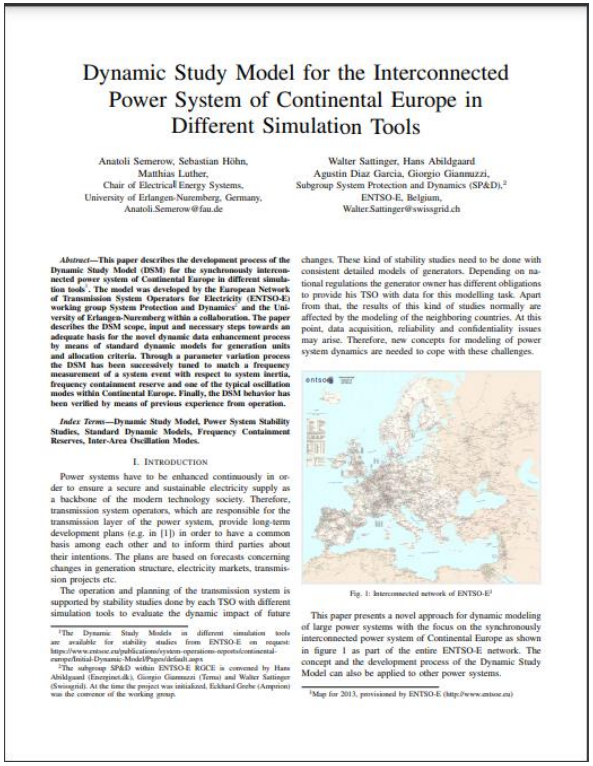
Cosimo Pisani
Terna, Italy



ISC - Uso INTERNO / INTERNAL Use

ENTSOe Dynamic Model “in numbers”

First version (2022 scenario)



Dynamic Study Model for the Interconnected Power System of Continental Europe in Different Simulation Tools

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***Abstract*—This paper describes the development process of the Dynamic Study Model (DSM) for the synchronously interconnected power system of Continental Europe in different simulation tools. The model was developed by the European Network of Transmission System Operators for Electricity (ENTSO-E) working group System Protection and Dynamics and the University of Erlangen-Nuremberg within a collaboration. The paper describes the DSM scope, input and necessary steps towards an adequate basis for the novel dynamic data enhancement process by means of standard dynamic models for generation units and allocation criteria. Through a parameter variation process the DSM has been successively tuned to match a frequency measurement of a system event with respect to system inertia, frequency containment reserve and one of the typical oscillation modes within Continental Europe. Finally, the DSM behavior has been verified by means of previous experience from operation.**

***Index Terms*—Dynamic Study Model, Power System Stability Studies, Standard Dynamic Models, Frequency Containment Reserves, Inter-Area Oscillation Modes.**

I. Introduction

Power systems have to be enhanced continuously in order to ensure a secure and sustainable electricity supply as a backbone of the modern technology society. Therefore, transmission system operators, which are responsible for the transmission layer of the power system, provide long-term development plans (e.g. in [1]) in order to have a common basis among each other and to inform third parties about their intentions. The plans are based on forecasts concerning changes in generation structure, electricity markets, transmission projects etc.

The operation and planning of the transmission system is supported by stability studies done by each TSO with different simulation tools to evaluate the dynamic impact of future changes. These kind of stability studies need to be done with consistent detailed models of generators. Depending on national regulations the generator owner has different obligations to provide his TSO with data for this modelling task. Apart from that, the results of this kind of studies normally are affected by the modeling of the neighboring countries. At this point, data acquisition, reliability and confidentiality issues may arise. Therefore, new concepts for modeling of power system dynamics are needed to cope with these challenges.

Fig. 1: Interconnected network of ENTSO-E[3]

This paper presents a novel approach for dynamic modeling of large power systems with the focus on the synchronously interconnected power system of Continental Europe as shown in figure 1 as part of the entire ENTSO-E network. The concept and the development process of the Dynamic Study Model can also be applied to other power systems.

[1]The Dynamic Study Models in different simulation tools are available for stability studies from ENTSO-E on request: https://www.entsoe.eu/publications/system-operations-reports/continental-europe/Initial-Dynamic-Model/Pages/default.aspx

[2]The subgroup SP&D within ENTSO-E RGCE is convened by Hans Abildgaard (Energinet.dk), Giorgio Giannuzzi (Terna) and Walter Sattinger (Swissgrid). At the time the project was initialized, Eckhard Grebe (Amprion) was the convener of the working group.

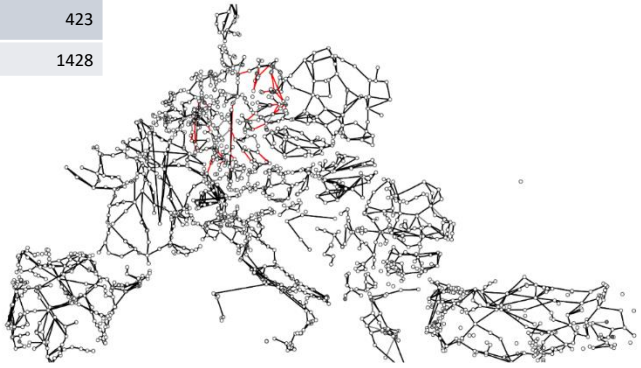
[3]Map for 2013, provisioned by ENTSO-E (http://www.entsoe.eu)

Second version (2025 scenario)

- ✓ Tailored on the main ENTSOE needs and **available standard tools** of the CE TSOs.
- ✓ Representing **future scenario** built upon a TYNDP load flow simulation
- ✓ Evolution for addressing frequency **stability** and **interarea oscillation** phenomena, by modeling explicitly the behavior of the synchronous generators and of the loads (any other local phenomenon is excluded)

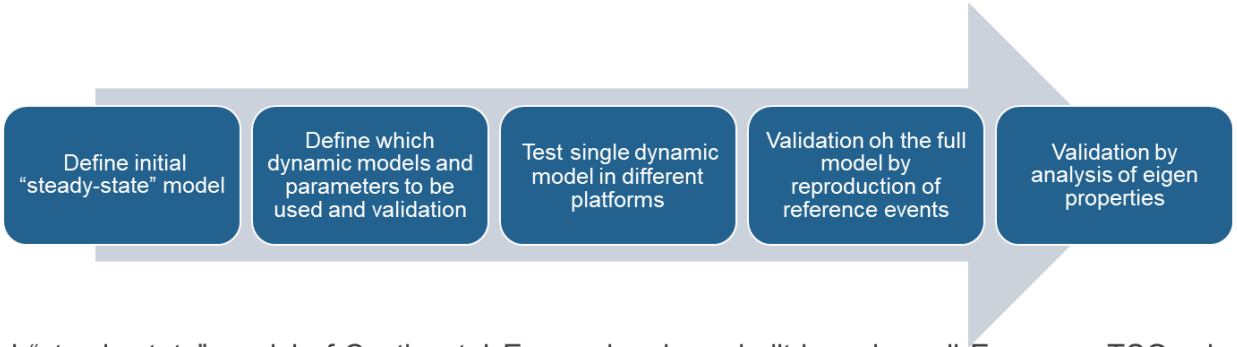
	Number of machines active	Inertia [GWs]
Hydro	22	27
Thermal	98	200
Steam	169	425
Nuclear	84	353
Other/Without Governor	1060	423
Total	**1433**	1428

Element	Number/Count
Substations	20 526
Bus Bars	25 996
Terminals	26 029
Locations/Sites	8 958
Branch Elements (total)	**34 612**



https://www.entsoe.eu/publications/system-operations-reports/#entso-e-initial-dynamic-model-of-continental-europe

Methodology for the development of the model



1. The initial "steady-state" model of Continental Europe has been built based on all European TSOs planning grid models provided in the CGMES format (i.e. 26 managed networks)

2. For the "Dynamic model 2027" the synchronous Generation is divided in **four categories**, each represented by a **general purpose model**.

4. It has been agreed to **validate** the **model** with respect to **three past incidents**. More specifically the model is tuned w.r.t. one of the three incidents and then the behaviour is tested for theagainst the other two incidents.

5. The **distance between** the **simulated** and **measured** results provides an indication of whether the modelling and data analysis techniques are aligned each other w.r.t. the inherent power system dynamic.

ENTSOe Dynamic model

The initial “steady-state” model of Continental Europe has been built based on all European TSOs planning grid models provided in the CGMES format. Based on a first **PowerFactory** model an additional **PSS®E version** has been developed.
To adopt this model for time domain simulations, several adjustments have been done on the original merged version.

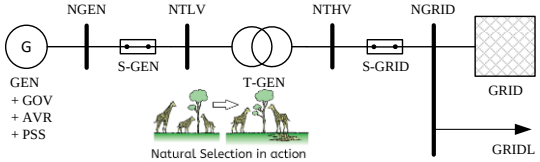
Dynamic model

For the “Dynamic model 2027” the **synchronous generation** is divided in **four** categories, each represented by a generic model. The choice of these 4 models was made based on the availability of these models in the various simulation tools used by European TSOs.

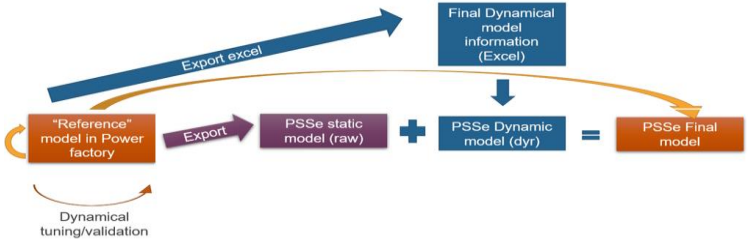
Thermal Classic	Classical thermal power plant with steam turbine	GovSteam1
Thermal Gas	Gas turbine model for both open and combined cycle	GovCT2
Nuclear	Nuclear power plant	GovSteamEU
Hydro	Hydro power plant (Francis, Pelton, Kaplan)	GovHydro4

Comparison of single model behaviour in different platforms

In a common dynamic model provided in different platforms it’s necessary to ensure the same results across the simulation tools in the intended time domain. On that account **step response tests** for generation and load models have been carried out and a comparison of results has been done.



Comparison of full model behaviour in different platforms



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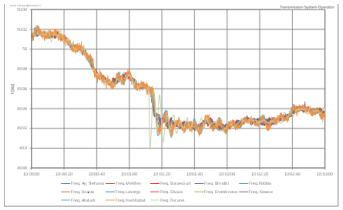
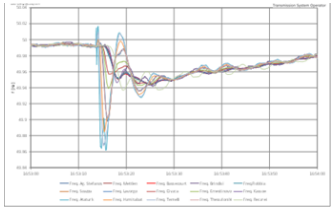
Time domain simulation validation

The incidents chosen for model validation:

1) Almaraz / ES: 10.4.2017 (NPP in Spain ~1GW)
2) C(Z)etes / TR: 04.11.2017 (~1800MW CC)
3) Karakaya / TR: 01.01.2019 (2x~500MW two Hydro units).



frequencies of Almaraz incident

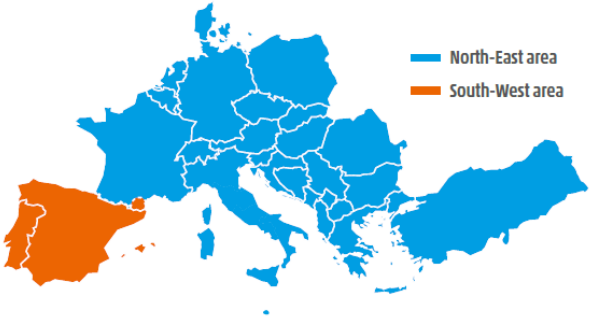


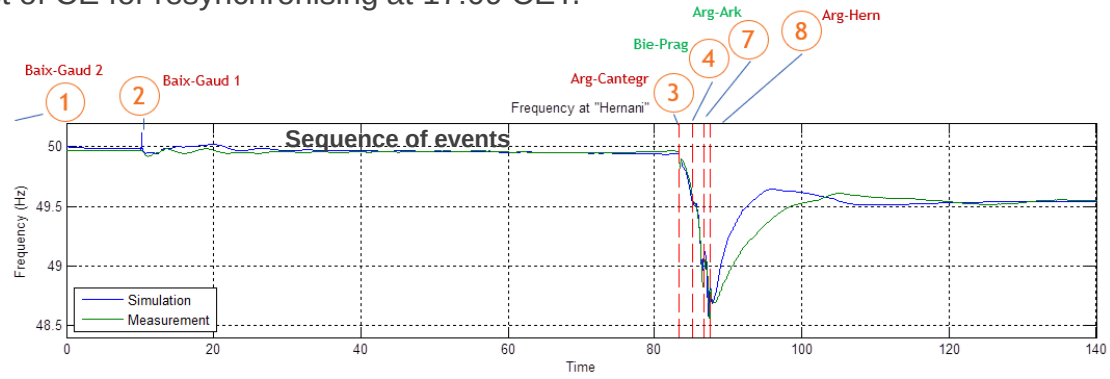
frequencies from Zetes incident

frequencies from Karakaya incident

Recent use for reconstruction of System split event in ENTSOE on 24th July 2021

On 24th July 2021 at 16:36 CET, the Continental Europe Synchronous Area was separated into two areas due to cascaded trips of several transmission network elements starting at the opening of a double circuit in France. The Iberian Peninsula (Spain and Portugal), was separated from the rest of CE for resynchronising at 17:09 CET.





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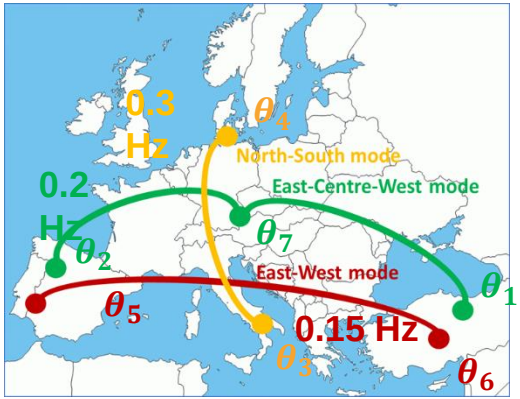
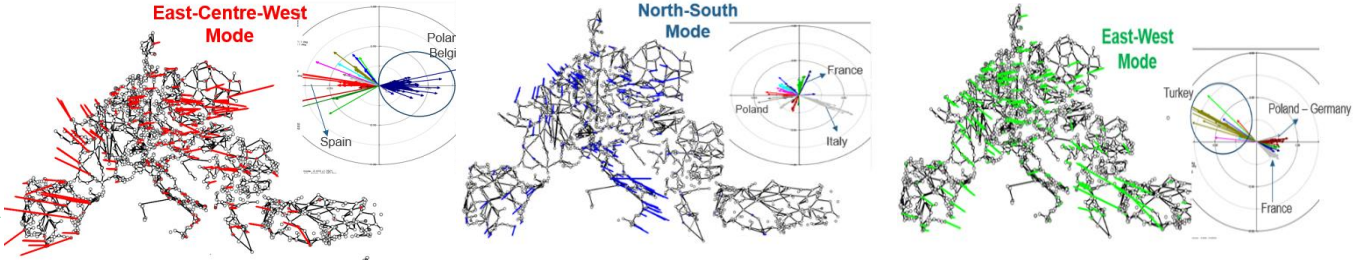
Modal analysis validation

Modal properties of Continental European power system are continously monitored by dynamic stability specialists and WAMS experts.



Three main inter-area oscillation modes, identified by the simulation



The **Modal Analysis** provides the eigenvalues and eigenvectors of a dynamic multi-machine system including all controllers and power plant models. Modes identification has been carried, in PowerFactory, by chasing the typical mode frequencies, deepening participation factors and identification of groups of synchronous machines oscillating in phase.

The three main inter-area oscillation modes derived from measurement are confirmed by simulation. There is just a slight shift in the frequencies of the oscillation modes compared to the real modes.

Conclusion and next steps

- The model developed represents a future operational scenario and was developed with a focus on **frequency stability** and **small signal stability**, explicitly modeling the behavior of synchronous generators and loads.

- The validation of the model was carried out by comparing the measurements of real events with the outcome of the simulation in some popular tools.

- A proper tuning of the inertia values was carried out to reduce the difference of the main frequency stability KPIs.

- Three main inter-area modes derived from measurements and practice are confirmed by simulations, the developed model is sufficiently accurate and in line with the aim of the small signal stabilities studies.

- Ongoing alignment beetwen PSS/e and Powerfactory for future publication of the dynamic model version 2;

- Activate the works for version 3 developments (2030 scenario) .

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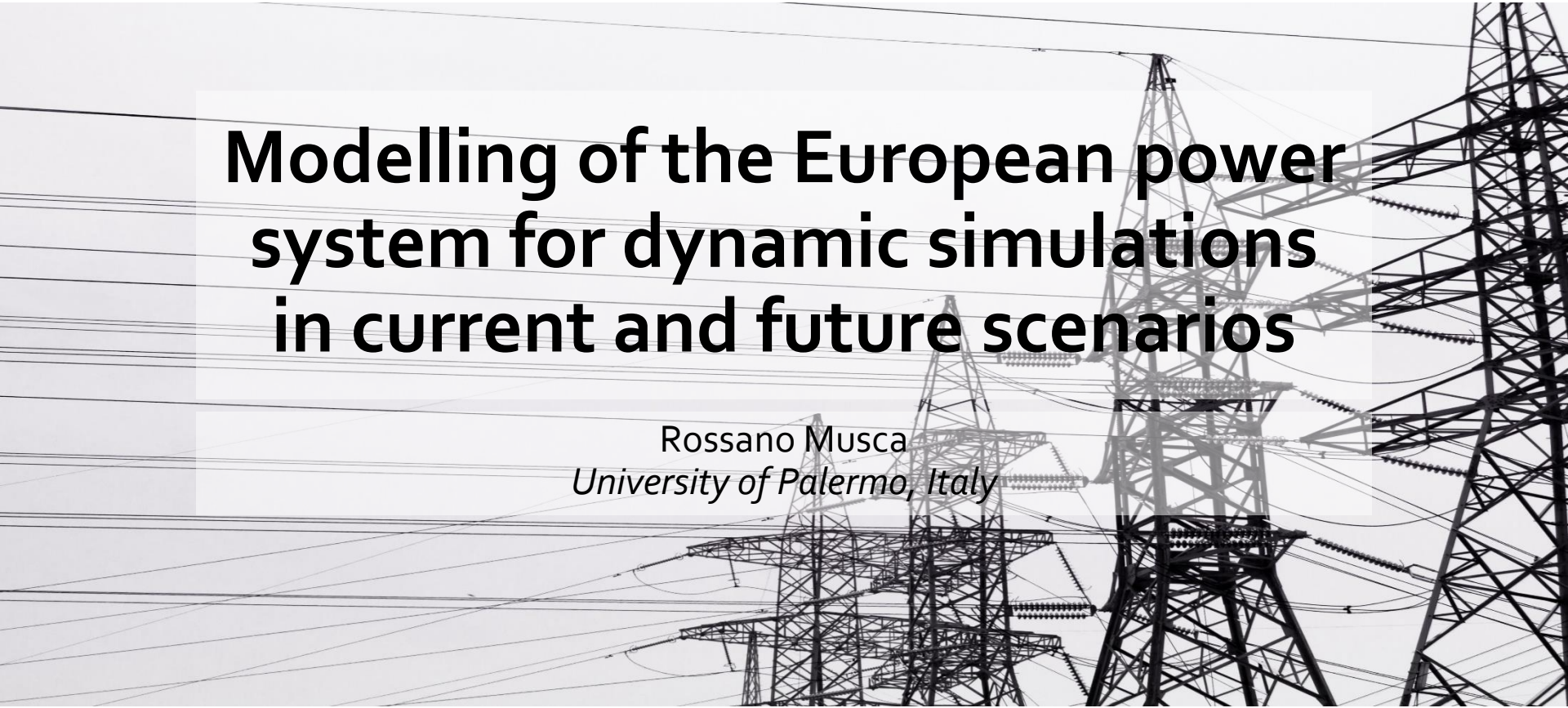


Modelling of the European power system for dynamic simulations in current and future scenarios

Rossano Musca

University of Palermo, Italy

Large-scale model of the European system

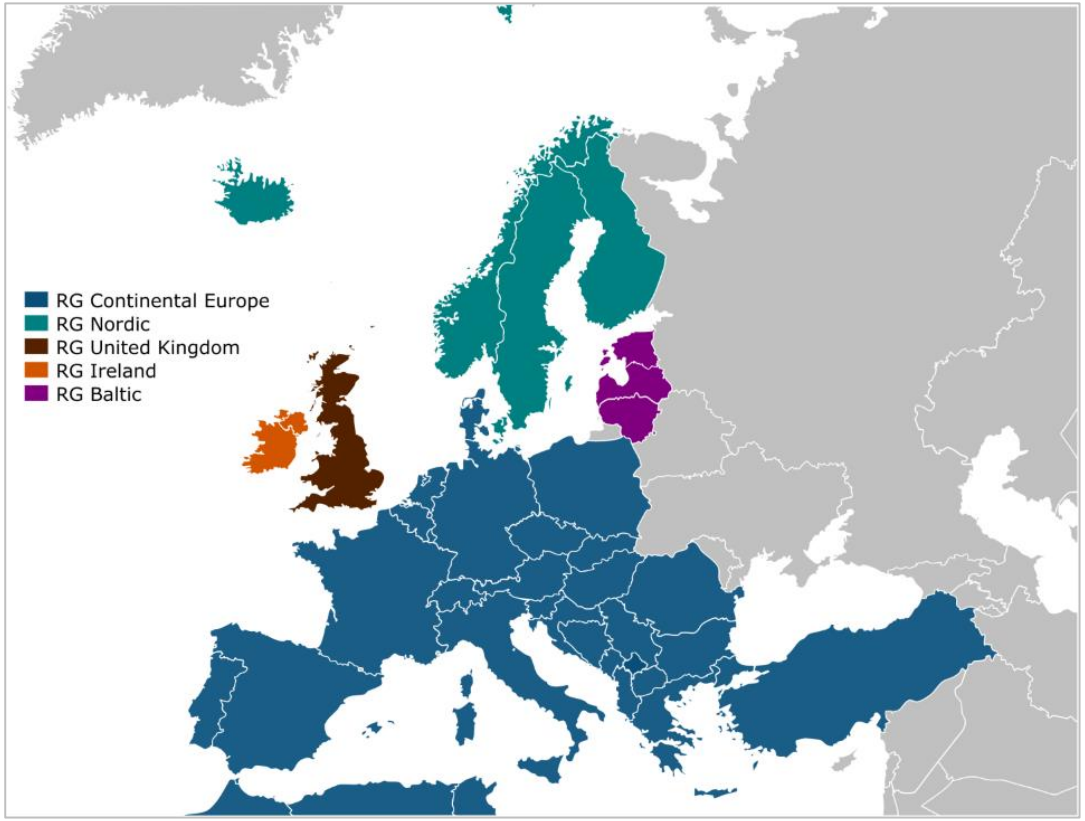
Model prepared and provided by the ENTSO-E System Protection and Dynamics (SP&D) group

Known as "Initial Dynamic Model"

Representation of the main frequency dynamics and inter-area oscillations phenomena

Available on request, after acceptance of the ENTSO-E

Large-scale model of the European system



Largest interconnected system in the world

26 countries, power peak 600 GW

Large-scale dynamic model
20 000+ nodes
7 000+ loads
1 000+ generators, **3 000+** controllers

Validated with WAMS frequency recordings by the ENTSO-E

Large-scale model of the European system

Research activities based on the ENTSO-E model

University of Erlangen, Nuremberg, Germany
Zurich University of Applied Science ZHAW, Winterthur, Switzerland
University of Palermo, Palermo, Italy
Ecole Centrale Nantes-LS2N-CNRS, Nantes, France
University of Ljubljana, Ljubljana, Slovenia
Friedrich-Alexander-University Erlangen-Nuremberg FAU, Erlangen, Germany
Brandenburgische Technische Universität Cottbus-Senftenberg, Cottbus, Germany
University of Leeds, Leeds, UK
University of Liege, Liege, Belgium
Research Center for Energy Networks, FEN ETH, Zurich, Switzerland
…

NOT EXHAUSTIVE

Large-scale model of the European system

Model applications and further modelling developments

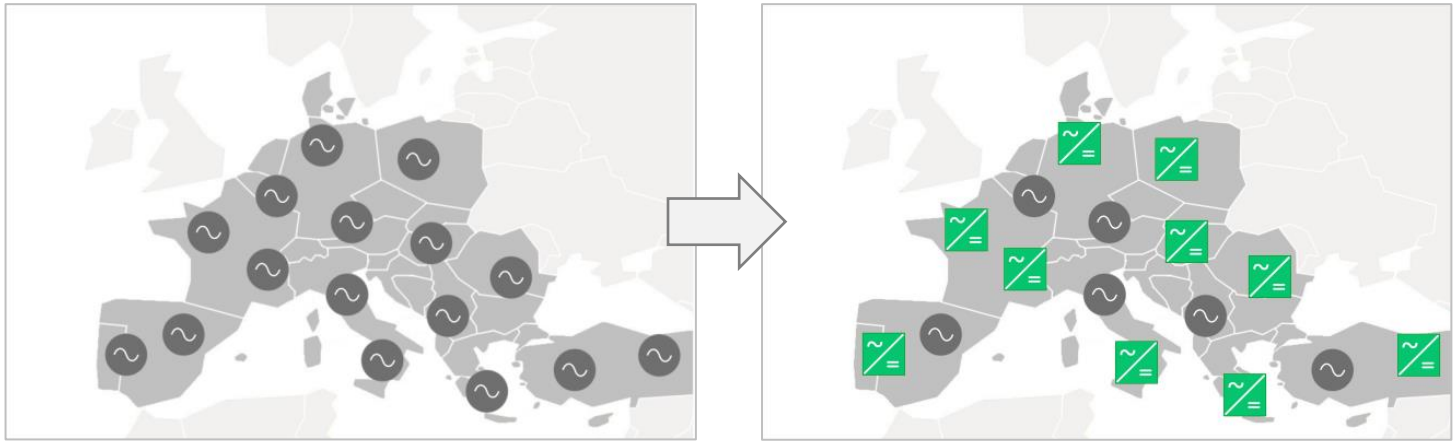
Model implemented and validated in NEPLAN

Main purposes/uses:

- Analysis of different conditions and scenarios
- Study of inertia distribution
- Study of integration of non-synchronous generation

Large-scale model of the European system

Integration of non-synchronous generation



Extension of the ENTSO-E model: integration of controlled sources (grid-following)

User-written models

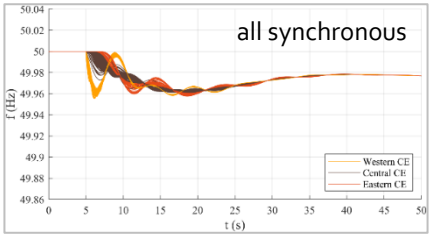
Ad hoc initialization procedure

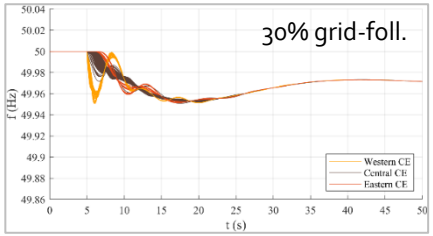
Different scenarios: **even** and **uneven distribution** of non-synchronous generation

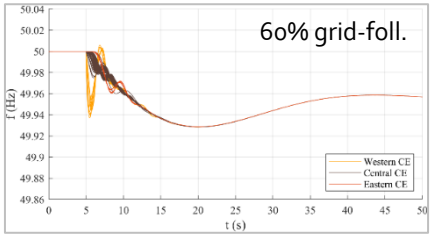
Large-scale model of the European system

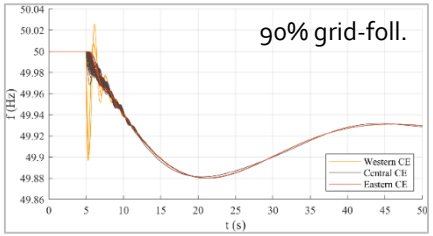
Integration of non-synchronous generation

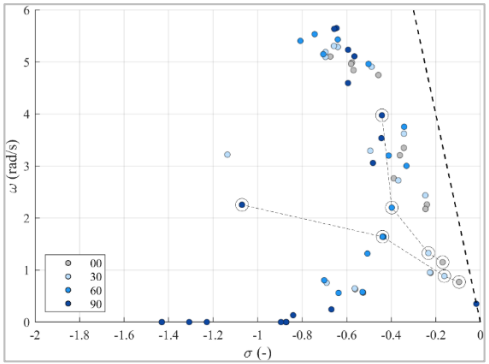
Even distribution of non-synchronous generation



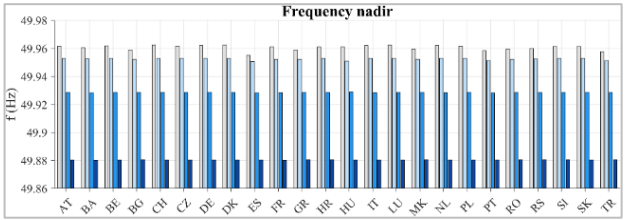


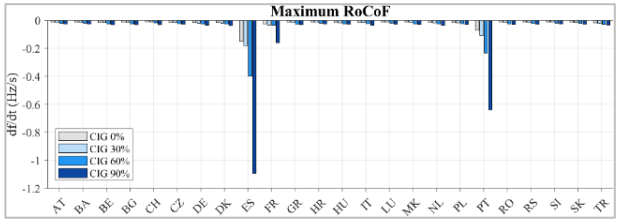






Oscillation modes in selected σ-ω region



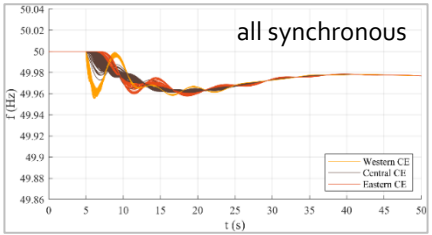


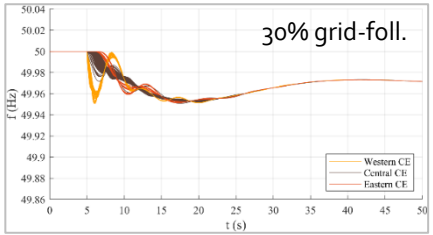
Frequency metrics per European country

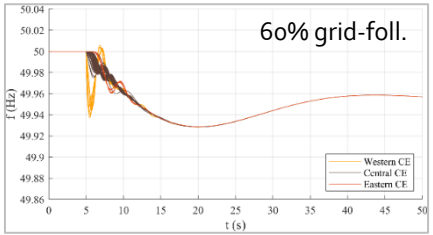
Large-scale model of the European system

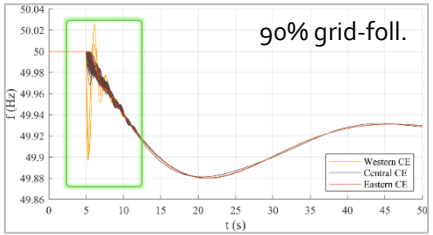
Integration of non-synchronous generation

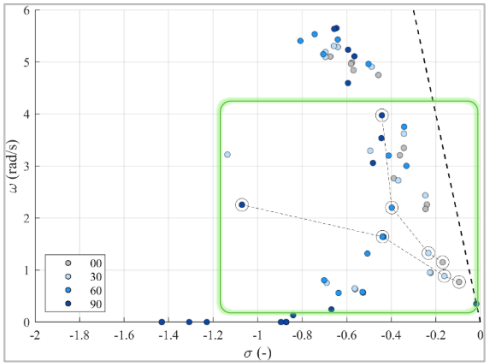
Even distribution of non-synchronous generation







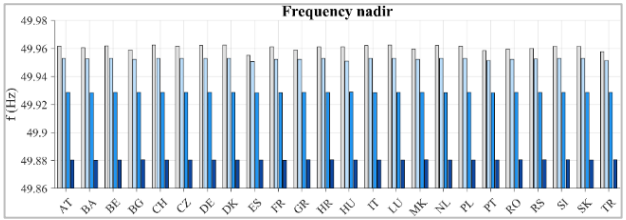


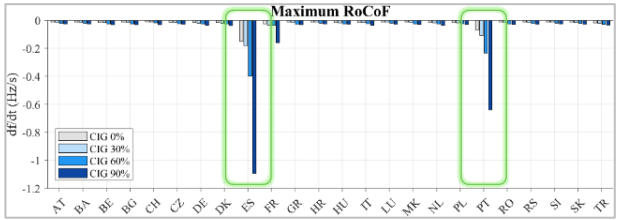


Oscillation modes in selected σ-ω region

Contraction of inter-area oscillations

Regional impact of RoCoF



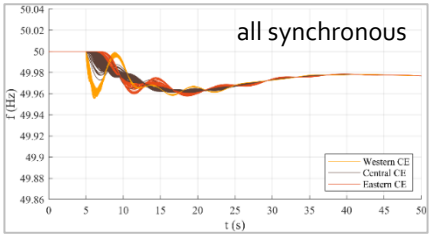


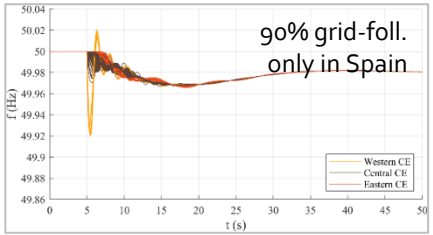
Frequency metrics per European country

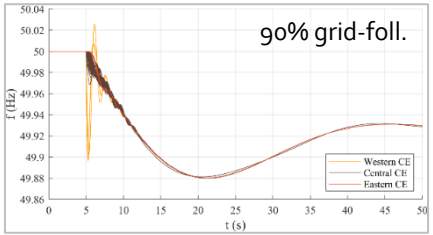
Large-scale model of the European system

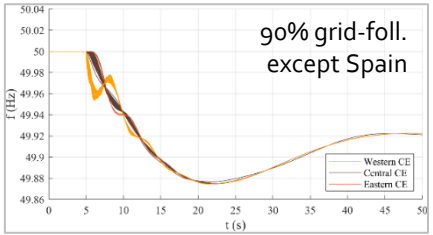
Integration of non-synchronous generation

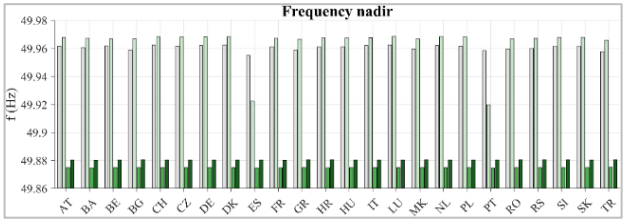
Uneven distribution of non-synchronous generation

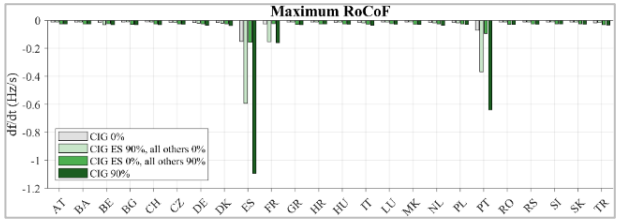










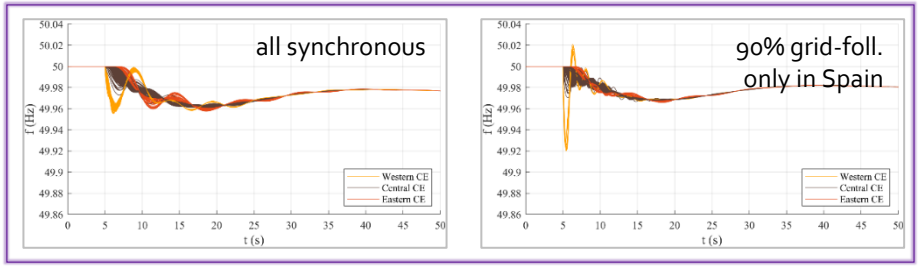


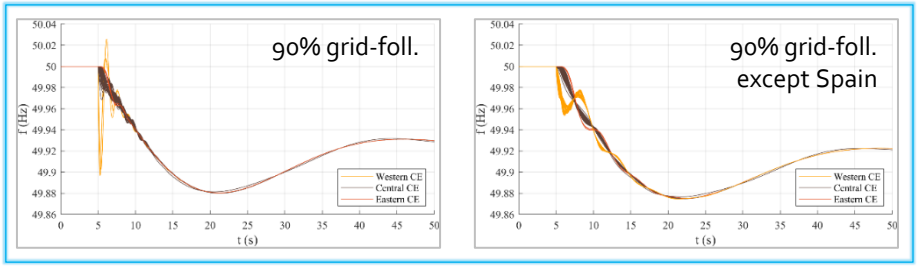
Frequency metrics per European country

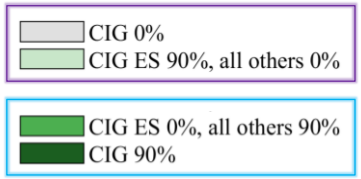
Large-scale model of the European system

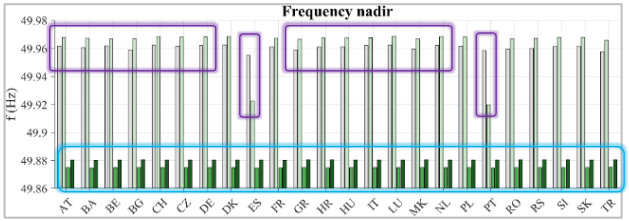
Integration of non-synchronous generation

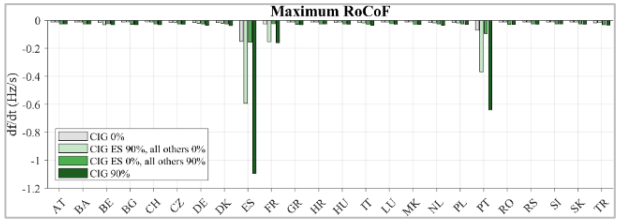
Uneven distribution of non-synchronous generation











Frequency metrics per European country

Overall better response, even with less synchronous generation

Spatial distribution of coupled oscillators

⇨ Change (weaking/strengthening) of the couplings between oscillators

Large-scale model of the European system

Integration of non-synchronous generation

Main observations:

- Different regional impact of frequency nadir and RoCoF
- Integration of grid-following NSG: increase of the frequencies of inter-area oscillations
- Possible better response with non-homogeneous distribution of NSG

Future studies/works:

- Study of different NSG integrations across the European countries
- Study of different control strategies (grid-forming)

Equivalent model of the European system

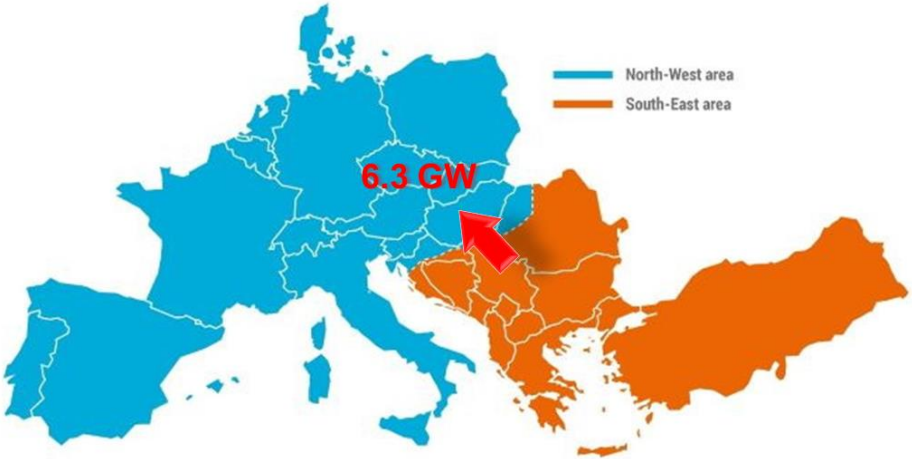
Derivation of an equivalent model

Validation with the large-scale ENTSO-E dynamic model

Main purposes/uses:
- Equivalent for the detailed model of the Sicilian power system
- Simplified modelling for the replication of actual events

Equivalent model of the European system

Split event (January 2021)



Tripping of a 400 kV busbar coupler

Split in two areas: North-West and South-East

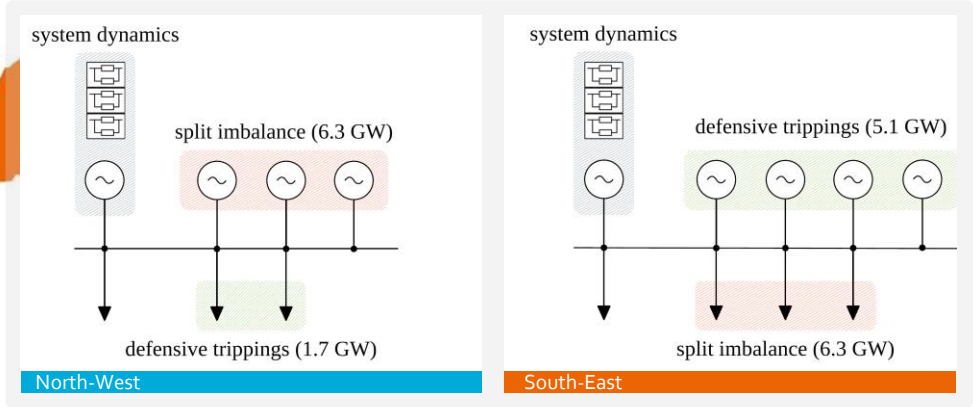
Initial power imbalance: 6.3 GW

Quick countermeasures (f.i. 1.7 GW of contracted interruptible services by RTE and Terna)

Equivalent model of the European system

Split event (January 2021)

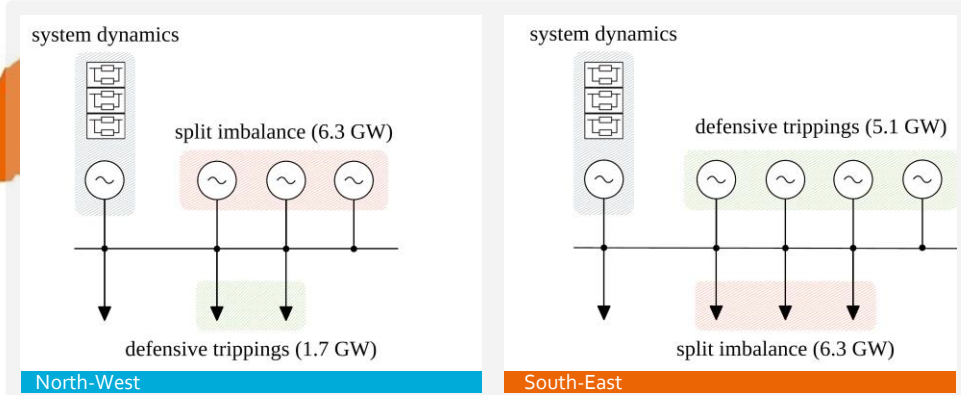
Two single-frequency bus (SFB) equivalent models



Equivalent model of the European system

Split event (January 2021)

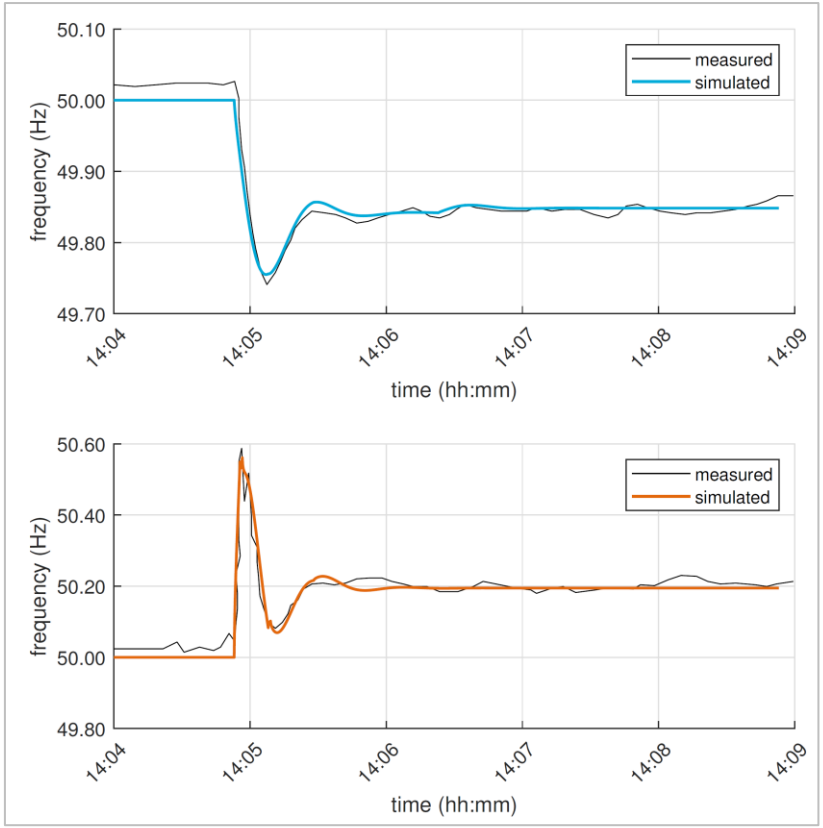
Two single-frequency bus (SFB) equivalent models



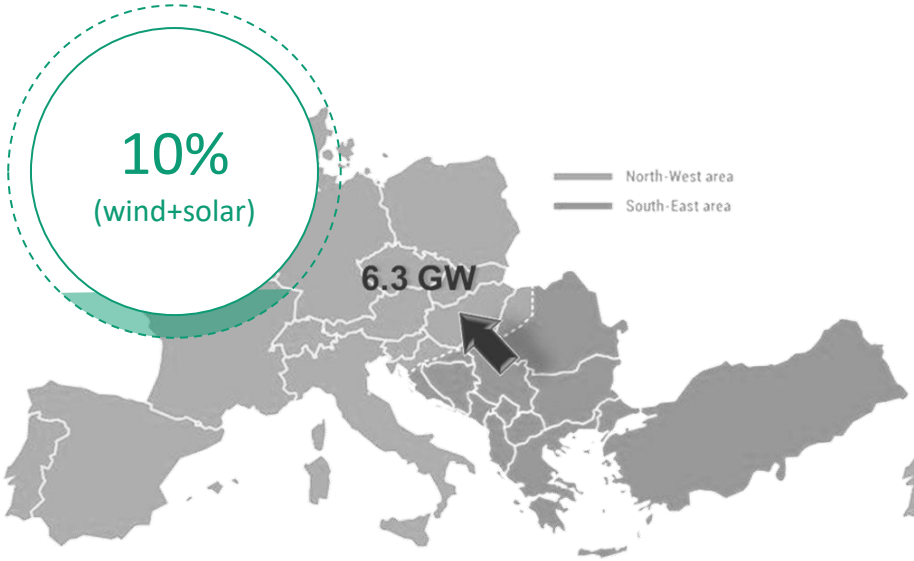
- Equivalent system dynamics
- Partition of the total power imbalance
- Temporal occurrence of ΔP

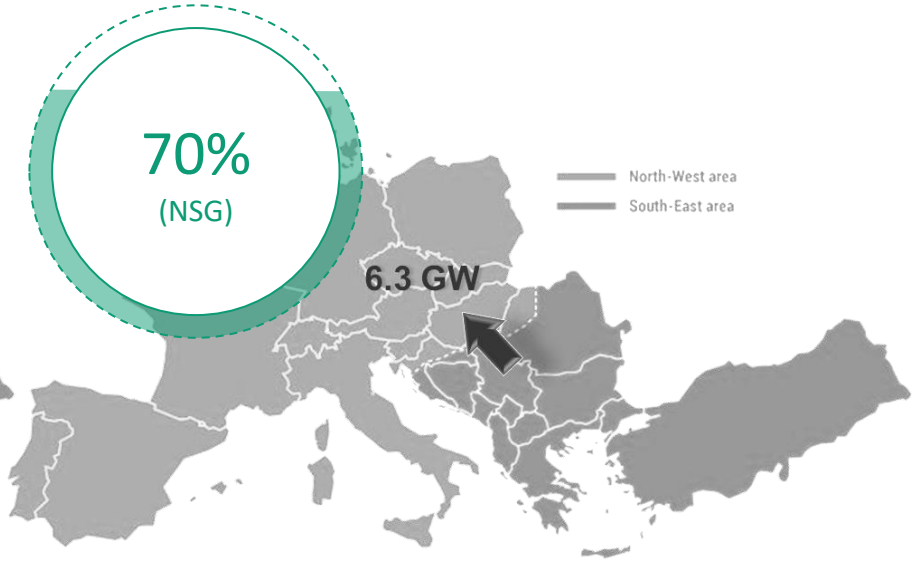
Equivalent model of the European system

Split event (January 2021)



Equivalent model of the European system

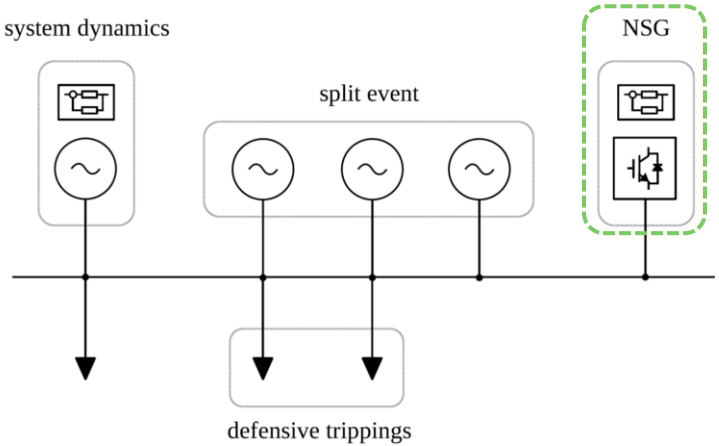




What if high share of renewable energy sources?

Equivalent model of the European system

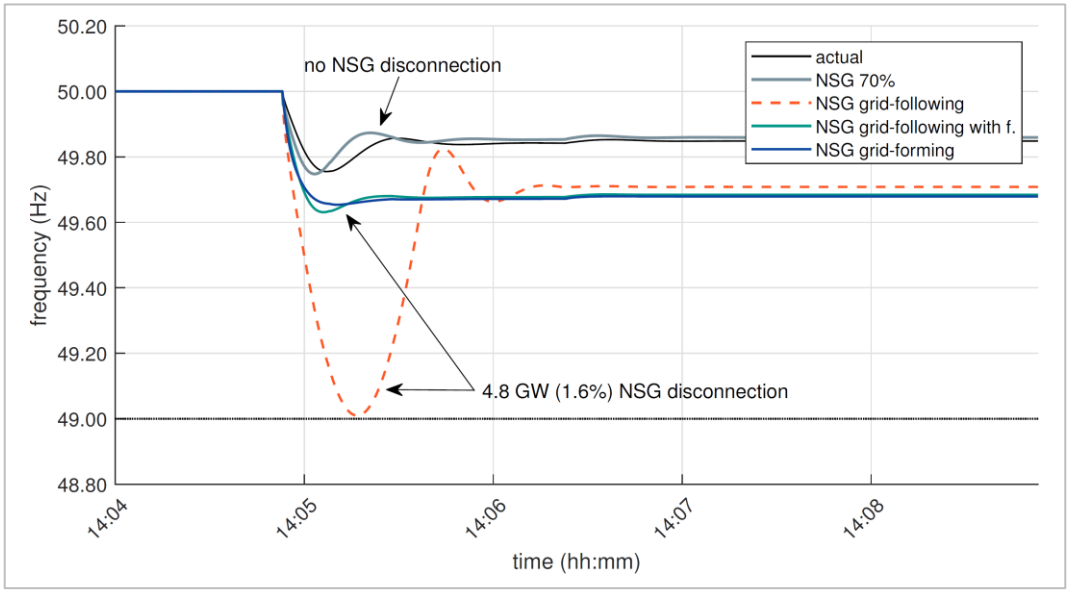
Non-synchronous generation: aggregated controlled current/voltage source



Either grid-following or grid-forming

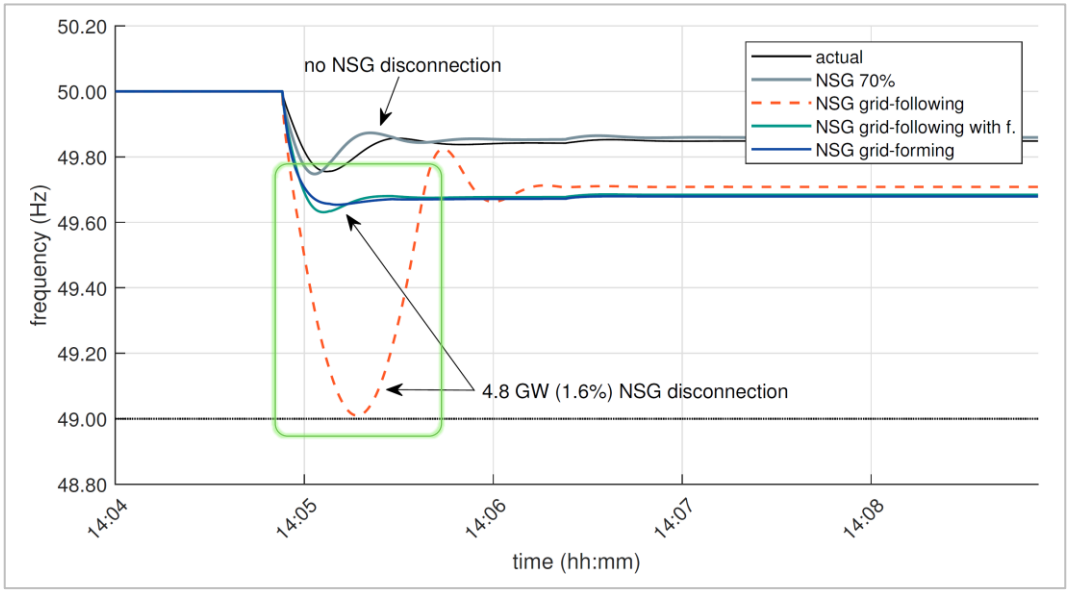
Equivalent model of the European system

Scenarios for disconnection of non-synchronous generation sources



Equivalent model of the European system

Scenarios for disconnection of non-synchronous generation sources



Effective transient support of non-synchronous generation sources
⇨ Second order dynamics VS higher order (synchronous machines)

Key-points

ENTSO-E dynamic model as most valuable tool

Analysis of the European system in current and future scenarios

Particularly useful also for research activities

Positive sequence RMS modelling: is still good enough?

Questions & Discussion

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