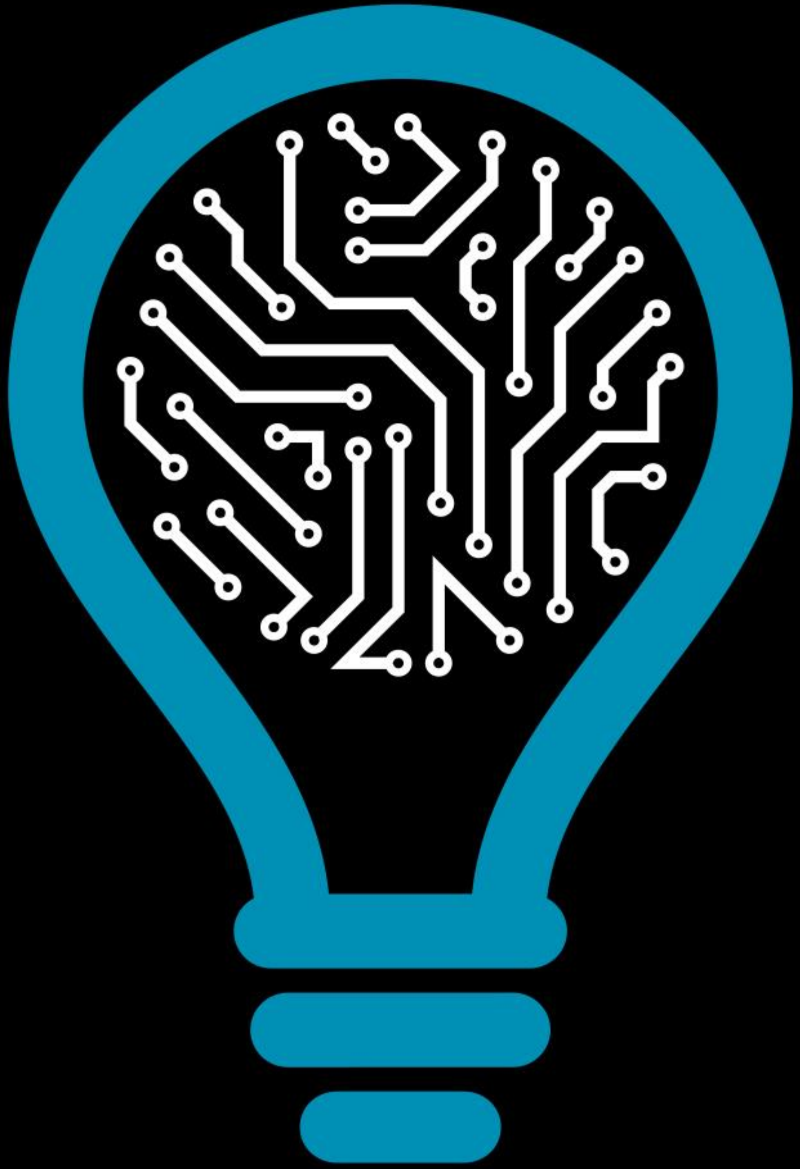
Global Energy Interconnections



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INESC TEC

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INSTITUTE FOR SYSTEMS
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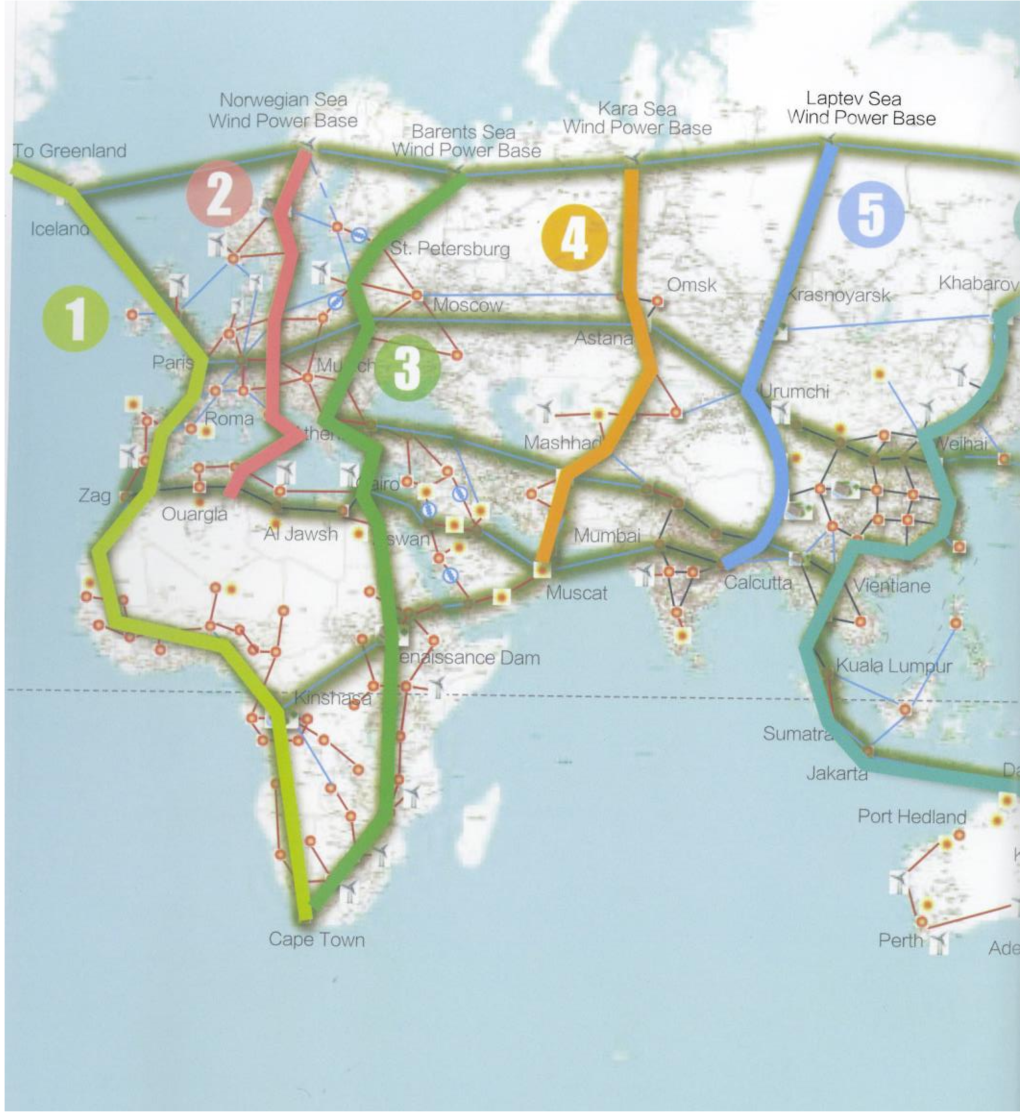
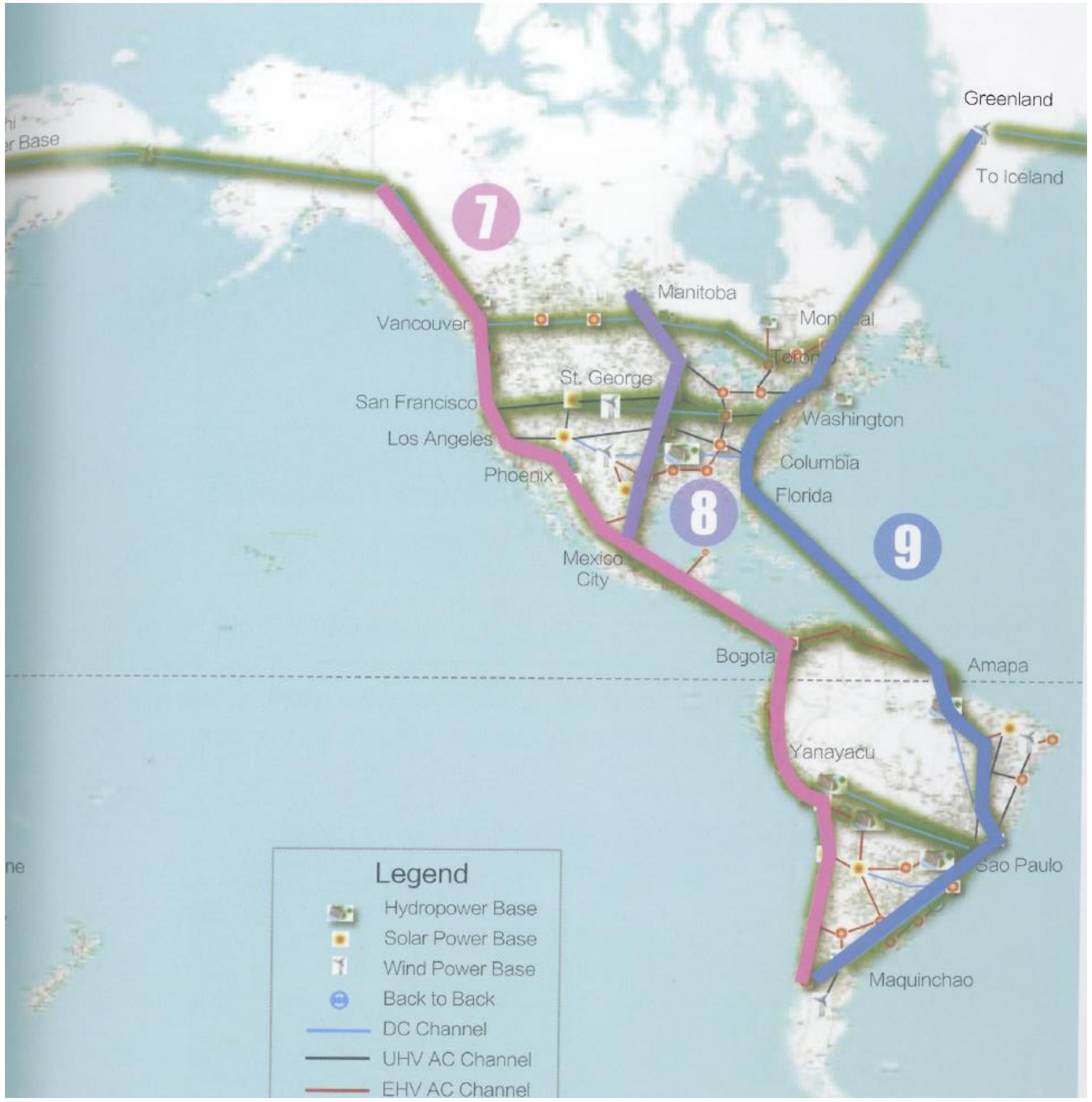
TECHNOLOGY AND SCIENCE

Global Electricity Interconnections





Global Energy Interconnections - GEI

- GEI are an essential platform for large scale deployment of clean energy in a world wide range;

- GEI are a fundamental solution to accelerate transition of energy and realize low-carbon, safe, eficiente and sustainable development of global energy;

- Smart Grids + EHV / UHV (DC) + Clean and renewable primary energy sources

- Scientific approach

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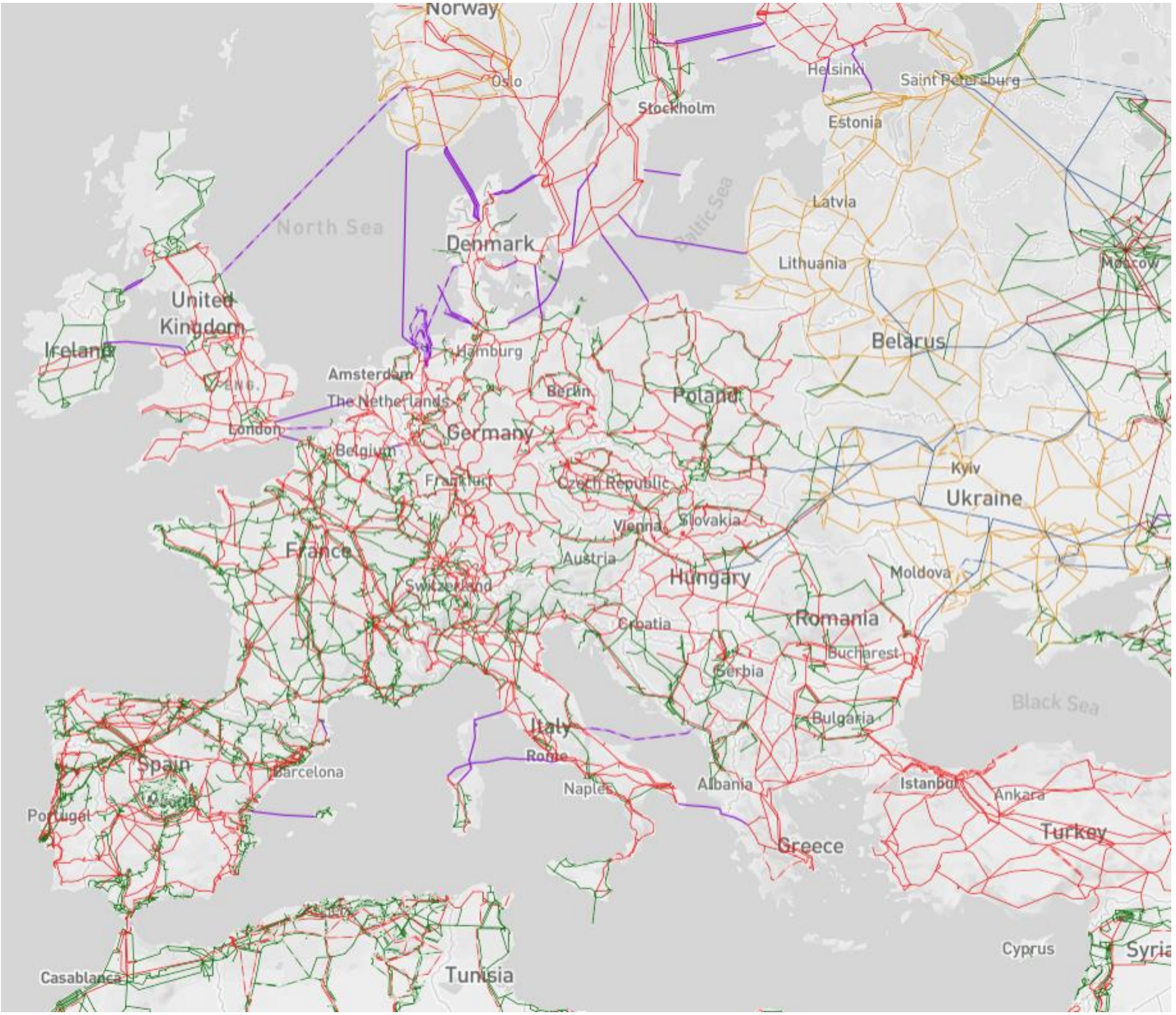
An overview of the European Transmission Grids:



Source: https://www.entsoe.eu

Since the 1950s the European countries have developed interconnections and strong coordinating actions with neighbors for increased system security.

Making the maximum transmission capacities available for trade while at the same time maintaining Europe’s very high system security standard is a fundamental objective for ENTSO-E and TSOs.

Trans-European Networks for Energy

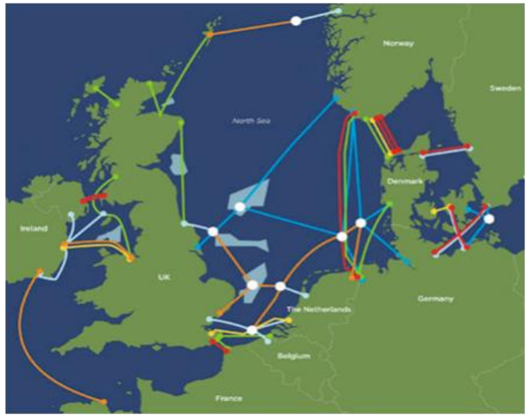
The Trans-European Networks for Energy (TEN-E) strategy is focused on linking the energy infrastructure of EU countries by identifying priority corridors that require urgent infrastructure development in electricity, gas or oil.

These networks are indented to strength existing cross-border interconnections, thus contributing for the creation of an integrated market, as well as to support the integration of more renewables (provision of advanced services for the security of the electricity grid).

Example: the INELFE cable linking French and Spanish systems (HVDC, 2000 MW), expanding the interconnection capacity from 1.4 GW to 2.8 GW.

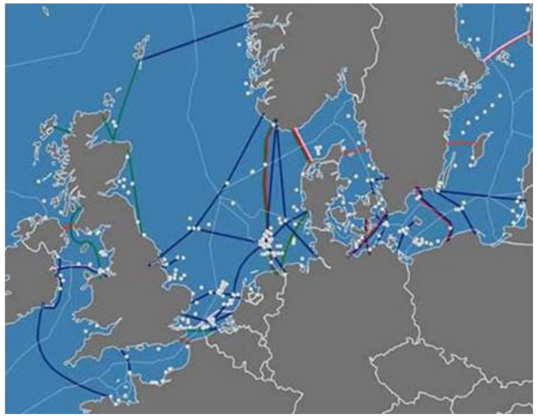
Iberian and French TSO have advanced in the assessment of relevant projects in order to raise the capacity of electricity exchanges between Spain and France to 8 GW

EWEA



Friends of the SuperGrid

European Commission

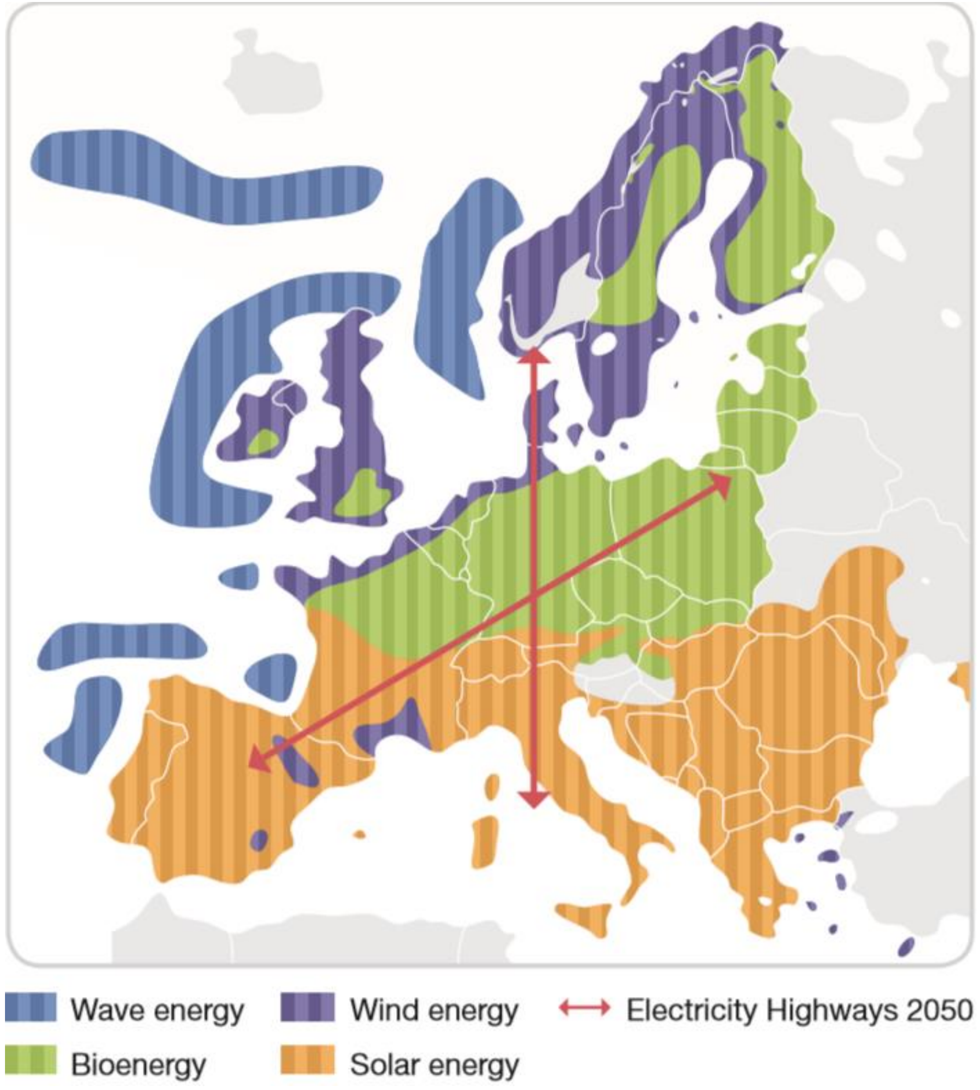


Trans-European Networks for Energy

A Trans-European electricity grid is also required in order to facilitate the future transport of wind energy from the North Sea and solar power from north Africa or biomass electricity from Russia, for example, to consumption centers via electricity highways.

HVDC is the enabling technology:

- Power flow in a DC transmission line can be precisely controlled
- It can contribute to stabilize the backbone of the system, thus improving grid resilience
- DC is the only option for the underground and underwater transmission of power over distances of more than about 50 kilometers



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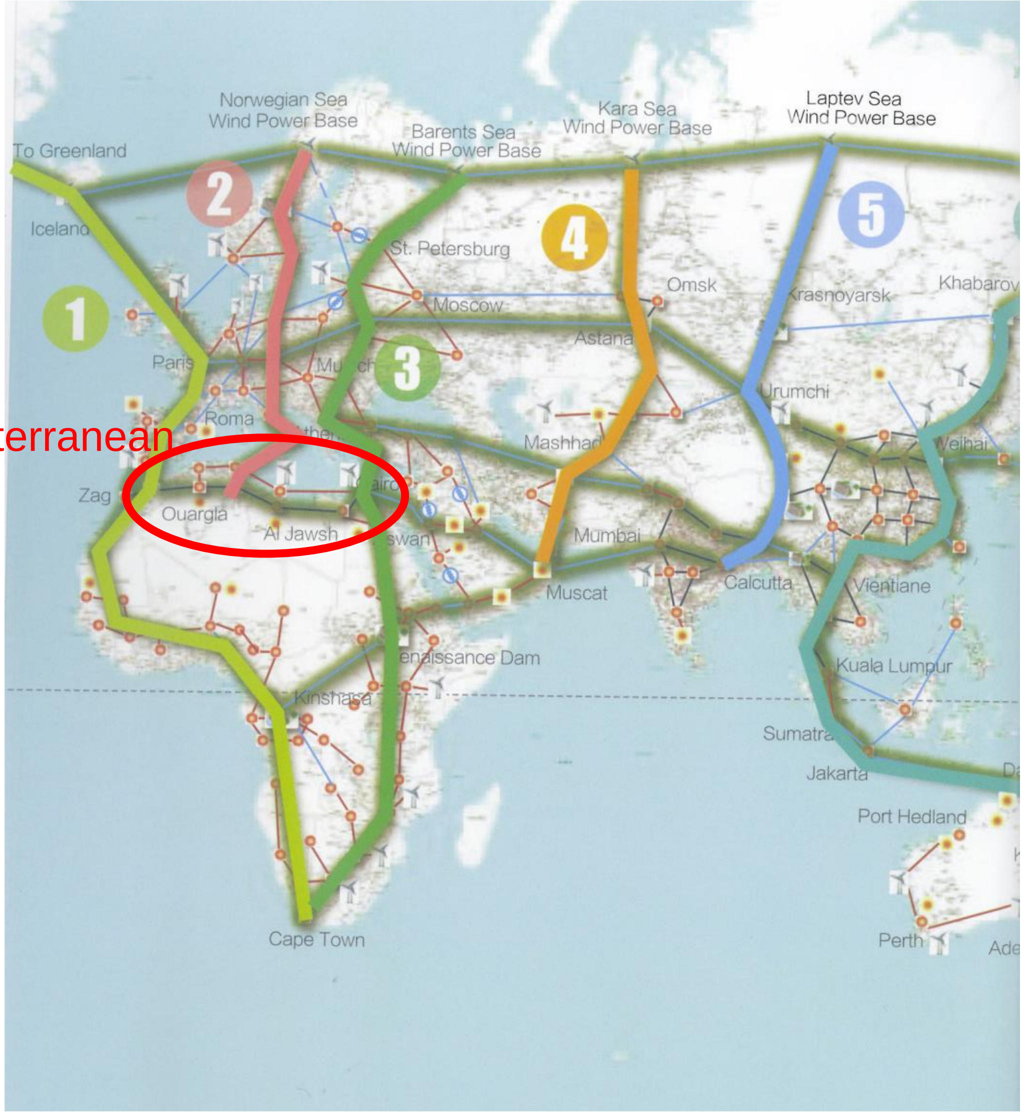
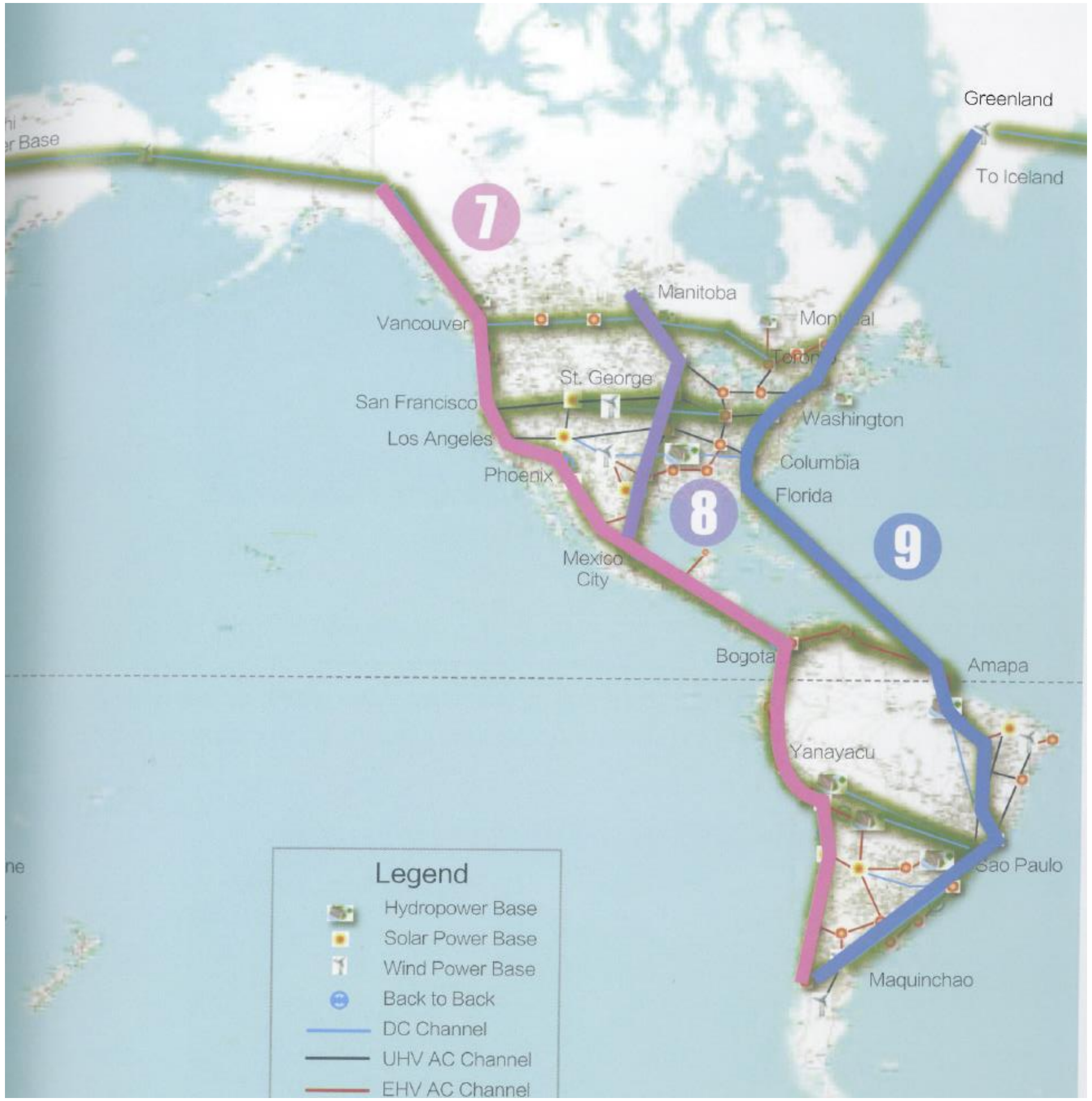
Global Electricity Interconnections

Mediterranean Area





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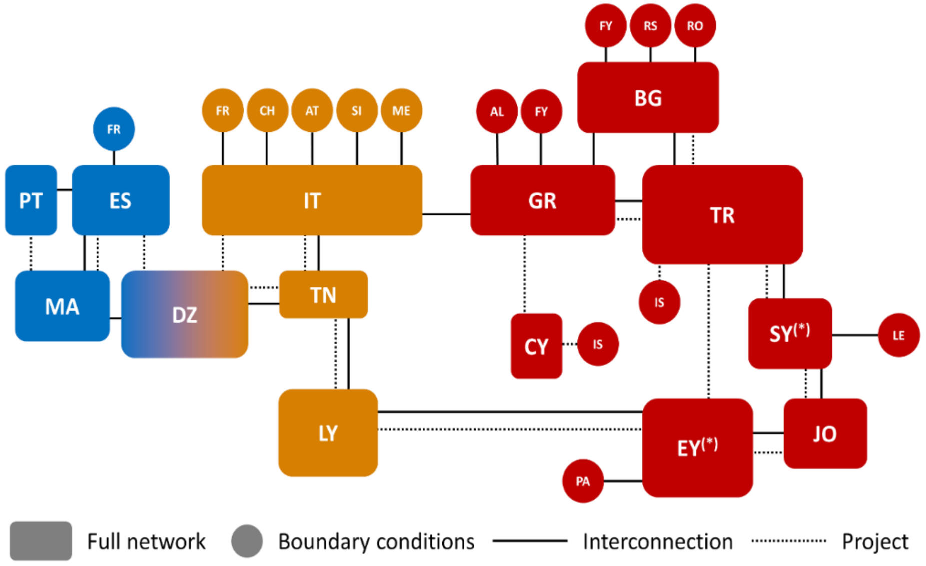
OVERVIEW

- Collaborative project with IIT COMILLAS to identify the network reinforcements required to integrate 14 new projects of electrical interconnections (HVAC and HVDC) between countries of Southern Europe and North Africa



MAPT Project

- The work consisted on:
  - ✓ Elaboration of operation scenarios based on market studies and the operating rules of each country
  - ✓ Merging the operation scenarios of each country to create a joint network model
  - ✓ Contingency analysis N-x for the joint network model
  - ✓ Identification of internal network reinforcements and respective technical validation
  - ✓ Estimation of investment cost for the new interconnection projects and the network reinforcements as well as other economic indicators such as annual losses

PROJECTS STUDIED

- **PINT method (Put IN one at the Time)**
  - Considers each new grid element one-by-one and evaluates the network flows with and without the network reinforcement
    - Different from TOOT method (Take Out One at the Time)

- **Western Corridor**
  - Morocco – Portugal: MAPT → 1000 MW (**HVDC**)
  - Morocco – Spain: MAES → 1000 MW (HVAC)
  - Algeria – Spain: DZES → 1000 MW (**HVDC**)

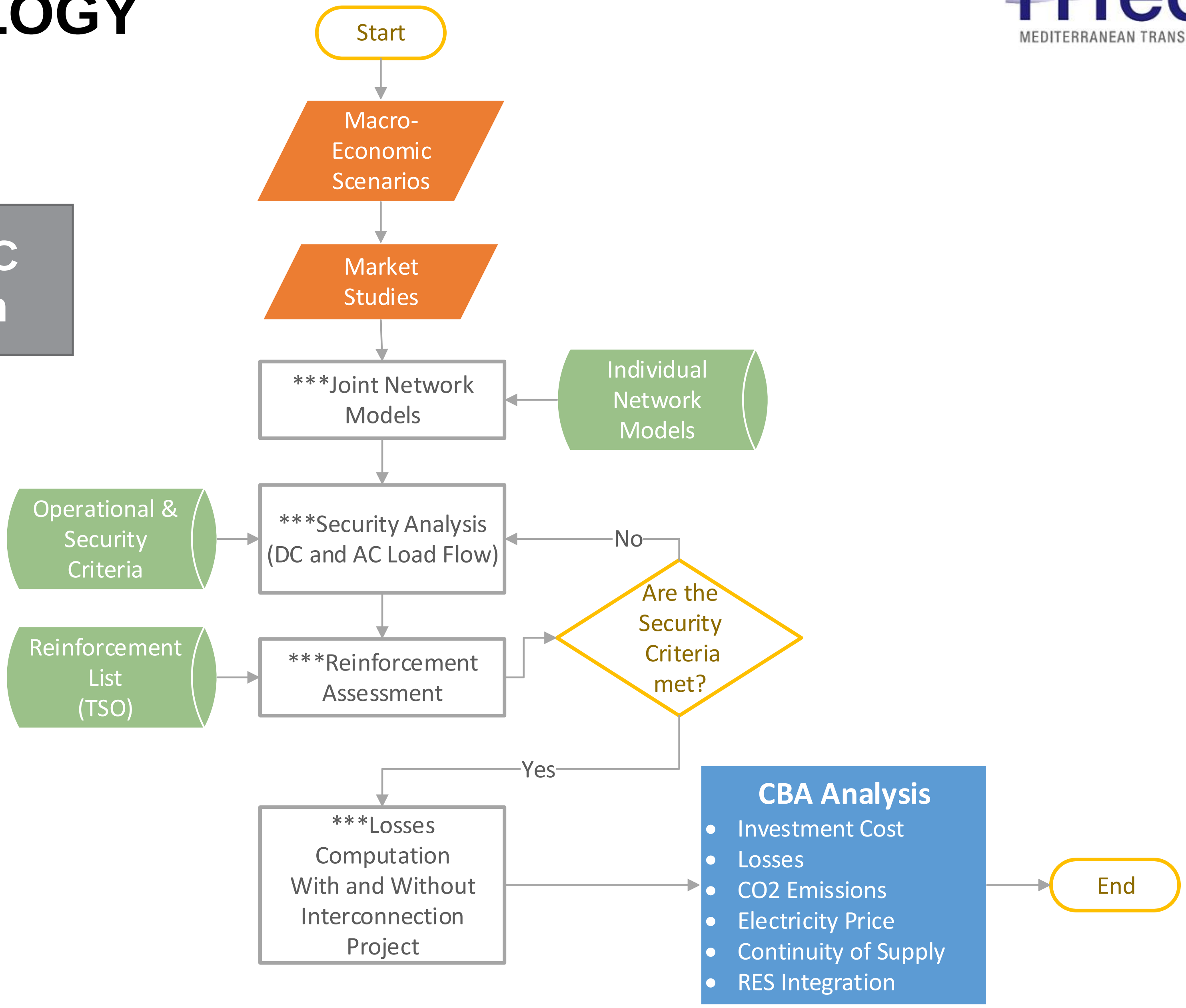
PROJECTS STUDIED

- **Central Corridor**
  - Algeria – Italy: DZIT → 1000 MW (**HVDC**)
  - Tunisia – Italy: TNIT → 600 MW (**HVDC**)
  - Tunisia – Italy: TNIT2 → 2x600 MW (**HVDC**)
  - Algeria – Tunisia: DZTN → 700 MW (HVAC)
  - Tunisia – Libya – Egypt: TNLYEY → 1000 MW (HVAC)

- **Eastern Corridor**
  - Turkey – Egypt: TREY → 2000 MW (**HVDC**)
  - Turkey – Israel: TRIS → 3000 MW (**HVDC**)
  - Jordan – Egypt: EYJO → 550 MW (HVAC)
  - Jordan – Syria – Turkey: JOSYTR → 800 + 600 MW (HVAC)
  - Greece – Turkey – Bulgaria: GRBGTR → 1000 MW (HVAC)
  - Greece – Cyprus – Israel: GRBGTR → 2000 MW (**HVDC**)

METHODOLOGY

*****INESC TEC Contribution**

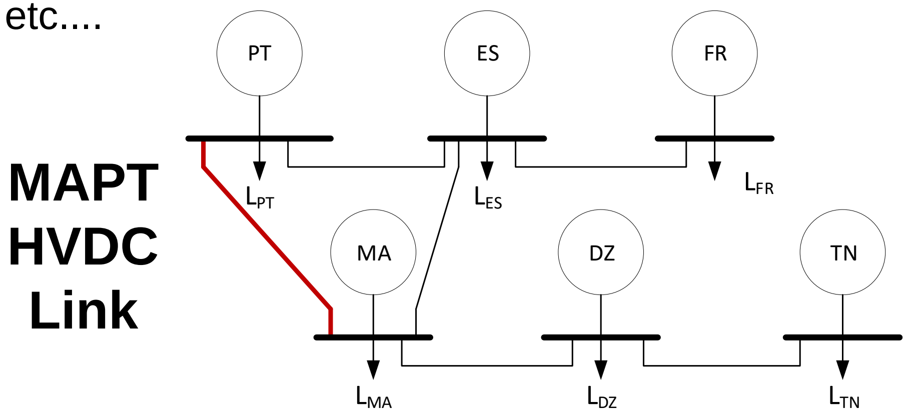


NETWORK OPERATION SCENARIOS

- Market studies were carried out for 4 macroeconomic scenarios to determine hourly operation points for all interconnected systems
  - Countries modeled without transmission systems
  - Exchanges in the interconnections limited by the Net Transmission Capacity
  - Minimization of production costs, maximization of RES, etc....

- Total production by technology
  - Solar, wind, hydro, nuclear, oil, gas, coal, others..

- Tool
  - Grid Reliability and Adequacy Risk Evaluator (GRARE)



POINT-IN-TIME SELECTION

- Extreme operation scenarios for given points-in-time (PiTs) were selected by the TSOs to create network models
  - High loading in the interconnections (on both directions)
  - Extreme (high/low) load in the countries involved
  - Extreme (high/low) RES production of different categories

- Extreme operation scenarios must be allocated to generators and loads
  - Merit order and/or must-run units (information supplied by the TSOs)
  - Distributed RES not directly connected to the transmission network was subtracted from the bus load
  - Different network configurations for winter/summer (e.g. summer rates are traditionally lower than winter)

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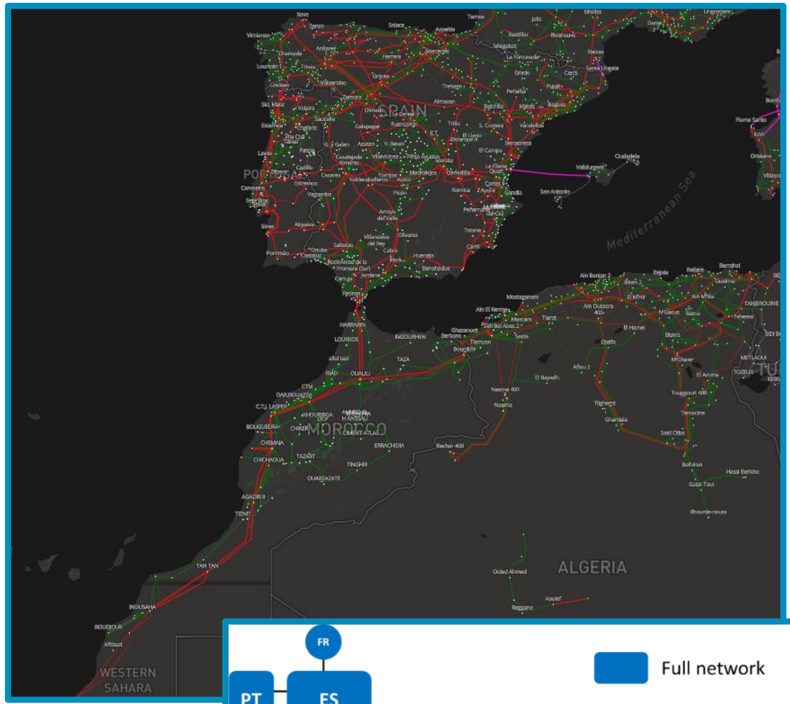
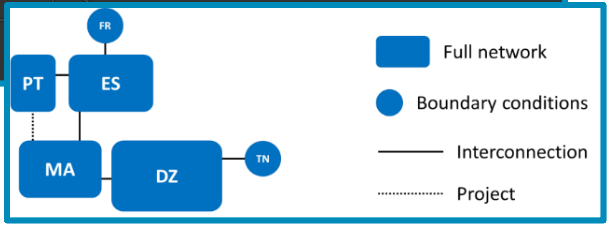
JOINT NETWORK MODEL

- Process for creating the joint network model
  a) Allocate generation, load and the dummy generation/load in X-nodes according to the operational rules of each country
  b) Run DC load flow per country to check active power flows
  c) Run AC load flow per country to check reactive power flows/voltages and compute losses
  d) Decrease the load to guarantee programmed exchanges
  e) Renumber buses to create a coherent joint network model
  f) Remove the dummy generators/loads in X-nodes and merge individual network models
  g) Run DC and AC load flows (preferably FDLF) to check convergence
  h) Run AC OPF to optimize reactive power/voltages, recheck interconnection flows and if necessary adjust loads

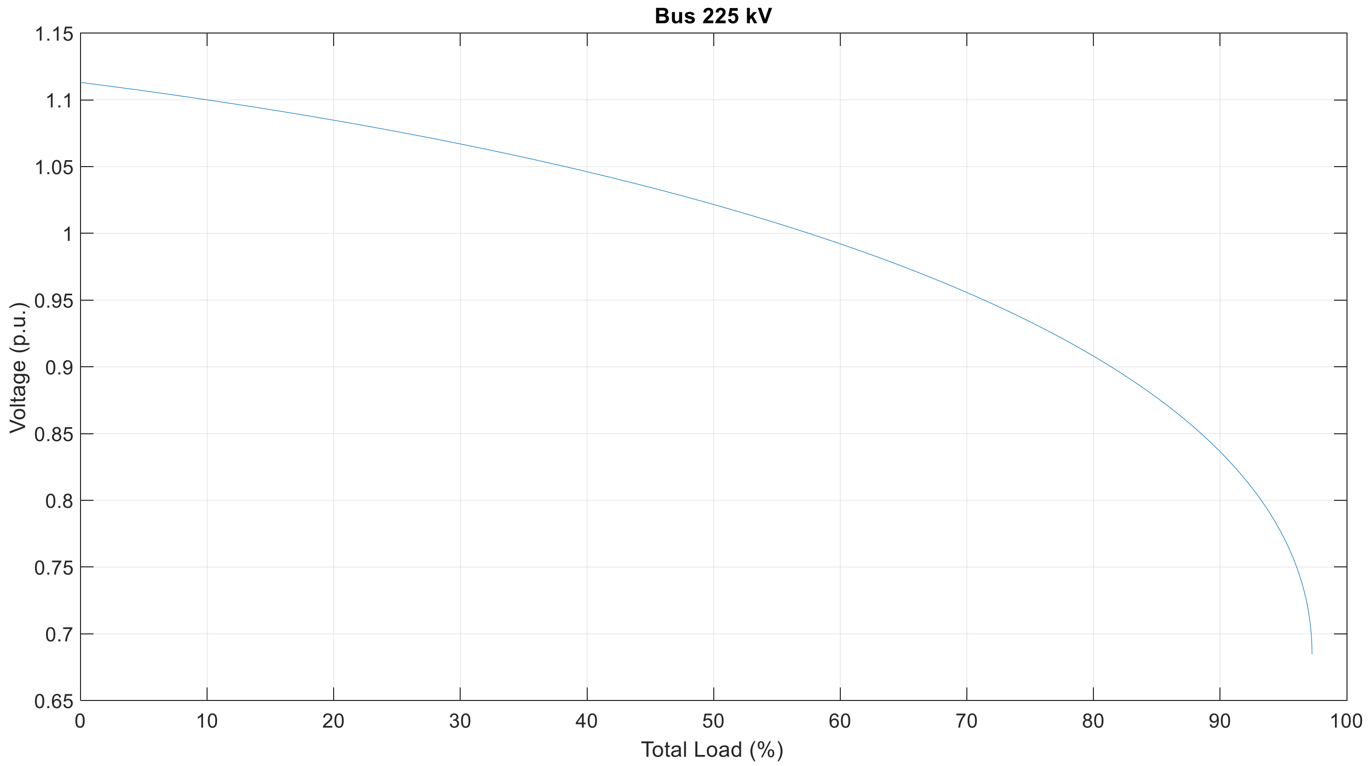
MAPT Project Joint Network Model (~3300 buses & ~4000 generators)





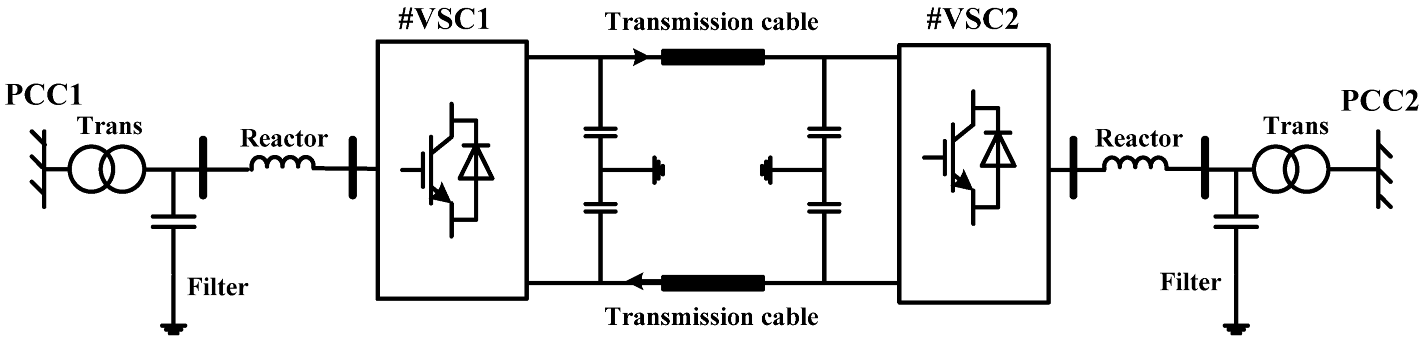
JOINT NETWORK MODEL

- The merging process is not easy and voltage collapse can occur due to insufficient transmission capacity (detected with Continuation Power Flow)



JOINT NETWORK MODEL

- HVDC-VSC link model
  - In AC one of the side controls the DC voltage while the other side controls the DC current
    - It is also possible to control the AC voltage or power factor at the PCC



  - In DC both terminals were modeled as PV buses

SECURITY ANALYSIS

- Consists on running load flows corresponding to N-x contingencies of equipment including the new interconnections
  - Redispatch criteria for loss of generation and/or interconnection
  - Role of secondary/tertiary reserve need also to be taken into account in some cases (e.g. share of reserves in case of loss of interconnection)
- 98 network models were created in the Med-TSO project
- Simulation engines
  - DC and/or AC load flow (AC load flow can lead to non-convergence situations)
- Security criteria in N and N-x
  - Maximum overload, maximum/minimum voltage levels

REINFORCEMENT ASSESSMENT

- Market studies were conducted for 4 visions from which PiTs were selected
  - S1 – Business as usual and security of supply improvement
  - S2 – Green future based on gas and on local integration of renewable energies
  - S3 – High economic growth which supports high interconnection development
  - S4 – Green future and market integration at an international level

- Planning directive: **ROBUSTNESS!!!**
  - The reinforcements must guarantee secure operation for the PiTs selected, which means that the probability of scenarios has not been taken into account

- Iterative process is used to select best reinforcements → **Intensive Computations**
  - Viable option since grids are well developed, which means that there are not many corridors available for building new lines/substations

LOSSES COMPUTATION

- Representative operation scenarios were created to simulated average operation conditions with and without the new interconnection projects
  - Exports/imports normally lead to increased losses

- Computation of losses for HVAC or HVDC interconnections

$$p_{CABLE} \approx \sum_{h=1}^{8760} r_l d \left(\frac{P(h)}{V}\right)^2$$

$$p_{CONVERTER\ STATIONS} = \sum_{h=1}^{8760} A \frac{P(h)}{V} + B$$

CONCLUSIONS

- The methodology leads to one robust investment plan with several attributes
  - Active power losses
  - Investment costs for lines, transformers, substations, bays, etc
  - RES integration
  - CO_2 emissions
  - Continuity of supply
  - Electricity cost

- However, a risk analysis can be a more adequate approach...
  - Plans can be tailor-made for each macro scenario or set of scenarios and then tested on the network models built for the other macro scenario to determine the plan exposure to adverse scenarios
  - VaR & CVaR metrics