Quins són els principals reptes de la xarxa elèctrica? Quines són les possibles solucions?

Xarxes elèctriques. Situació i possibles solucions

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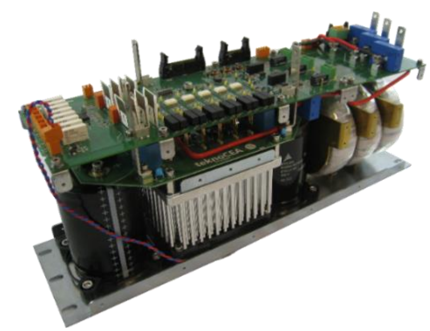
with support from Edu Prieto, Marc Cheah, Jie Song, Carlos Collados, and all colleagues from the AC/DC grids group in CITCEA-UPC

CITCEA-UPC

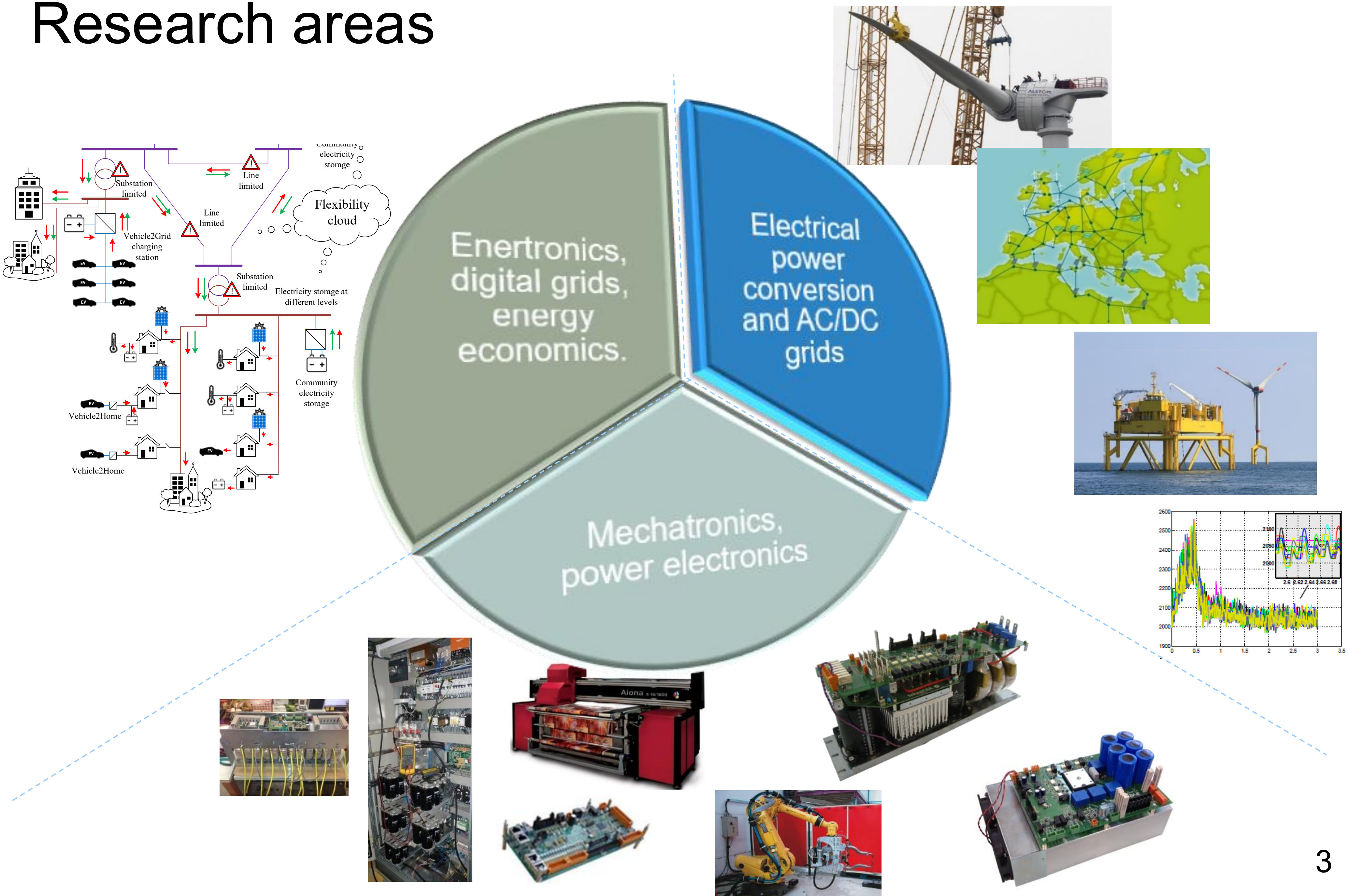
- Founded in 2001
- Part of the TECNIO network
- >80 members: 12 academics,
  >25 research engineers
  >30 doctoral students
  >20 Master and Bachelor students
  3 administrative staff.
- >100 customers
- >300 projects
- >10 patents
- >500 conference papers
- >300 journal papers
- **2 spin-off** companies (TeknoCEA,eRoots)



teknoCEA
Custom power electronics

eRoots

Research areas



Agenda

- Introduction
- Step 1: Cost of renewable energy
- Step 2: Variability of resource and system balancing
- Step 3: Electrical grid constraints
- Step 4: Stability and protection issues
- Conclusions

Introduction

Step 1: Cost of renewable energy

Step 2: Variability of resource and system balancing

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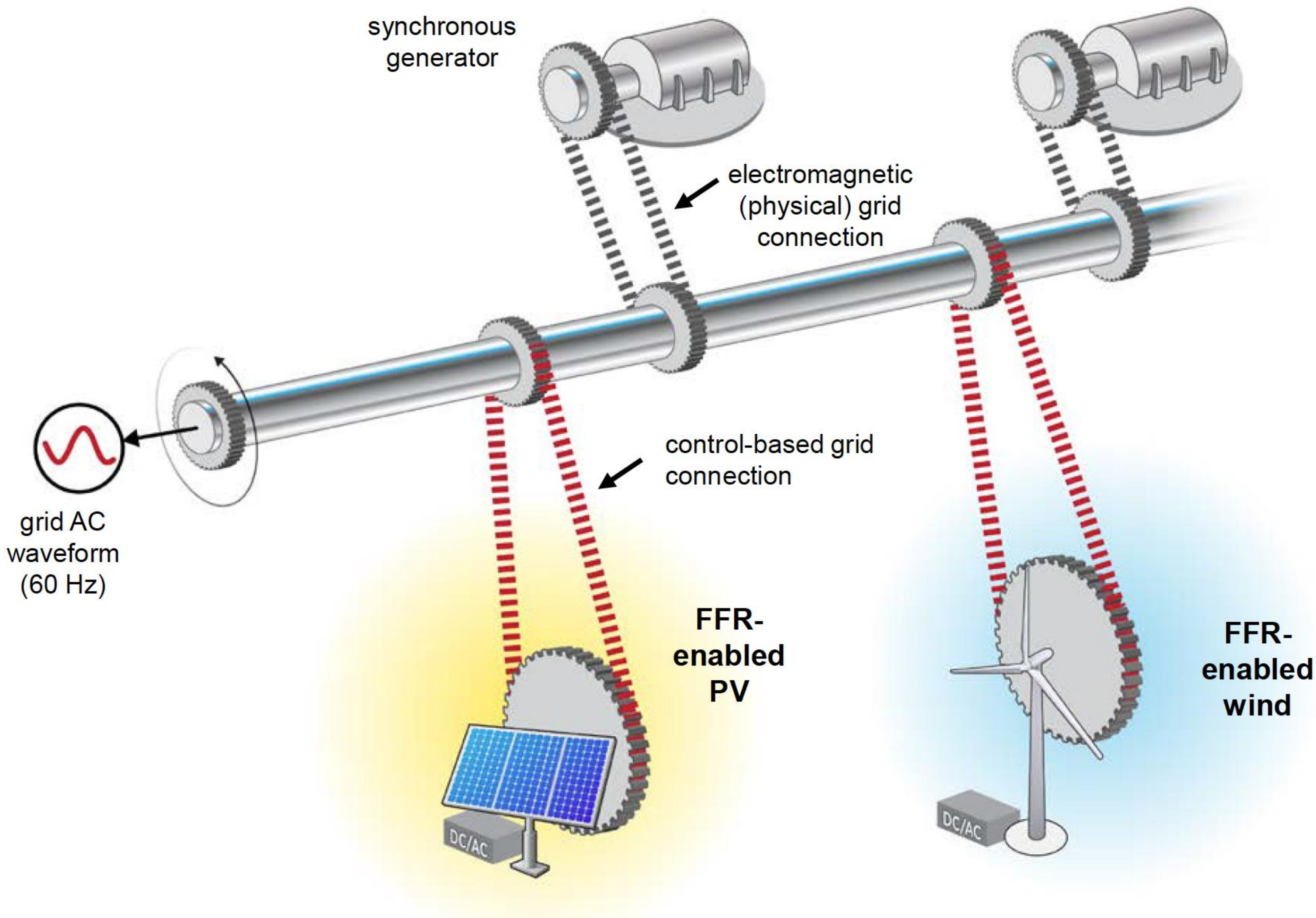
Conclusions

- The power grid is the framework for the production, transport and utilization of electrical energy.

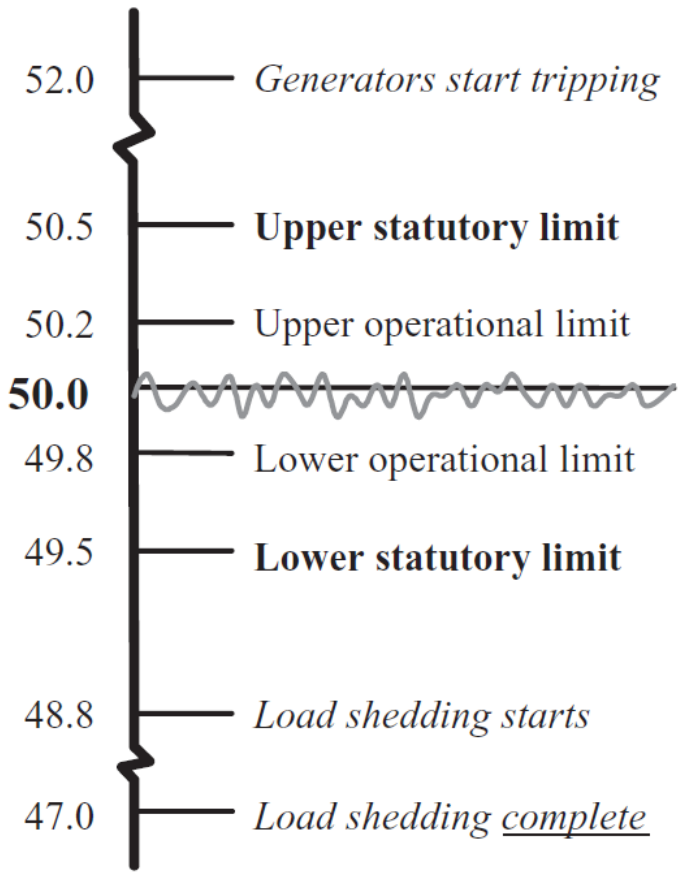


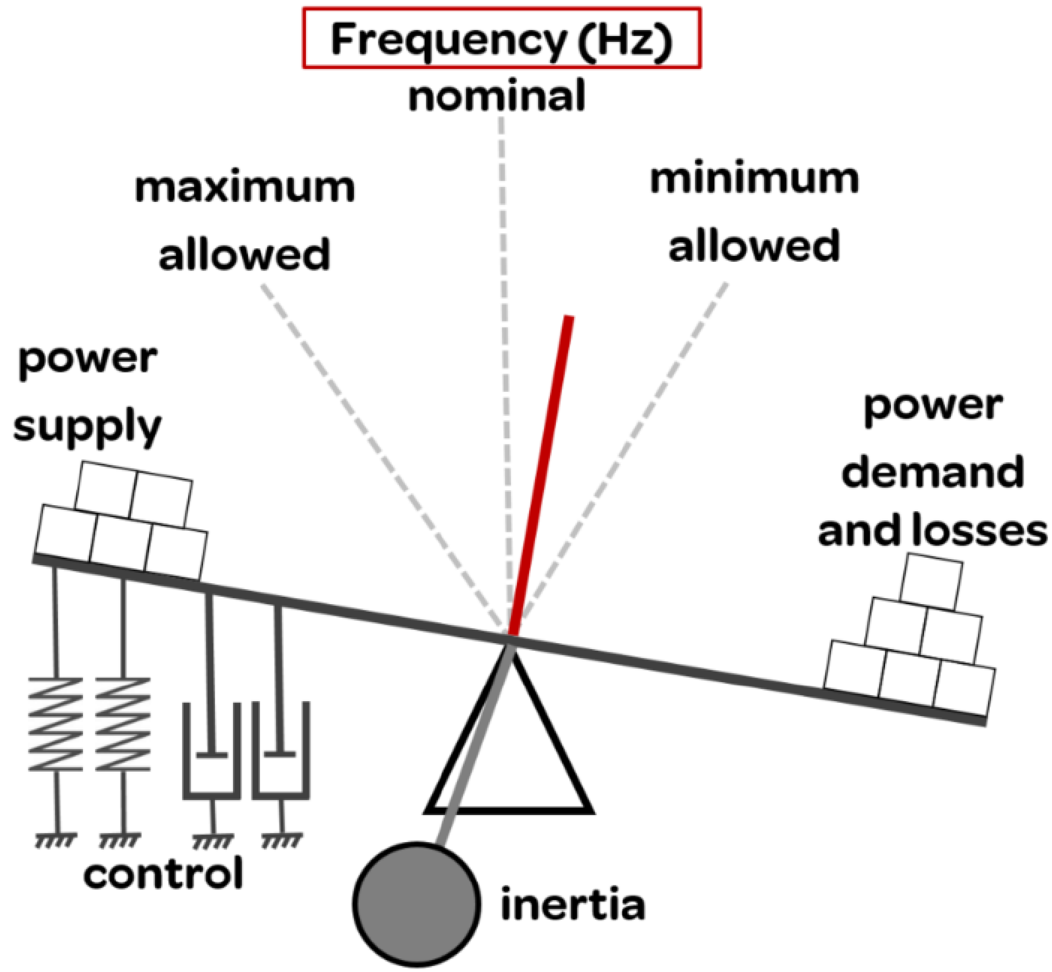
Source: National Renewable Energy Laboratory (NREL): Inertia and the Power Grid: A Guide Without the Spin Technical Report NREL/TP-6A20-73856, 2020.

- Frequency and voltage must be kept between an operational range for correct operation

$$P_m - P_e = M \frac{d\omega_m}{dt}$$

Frequency





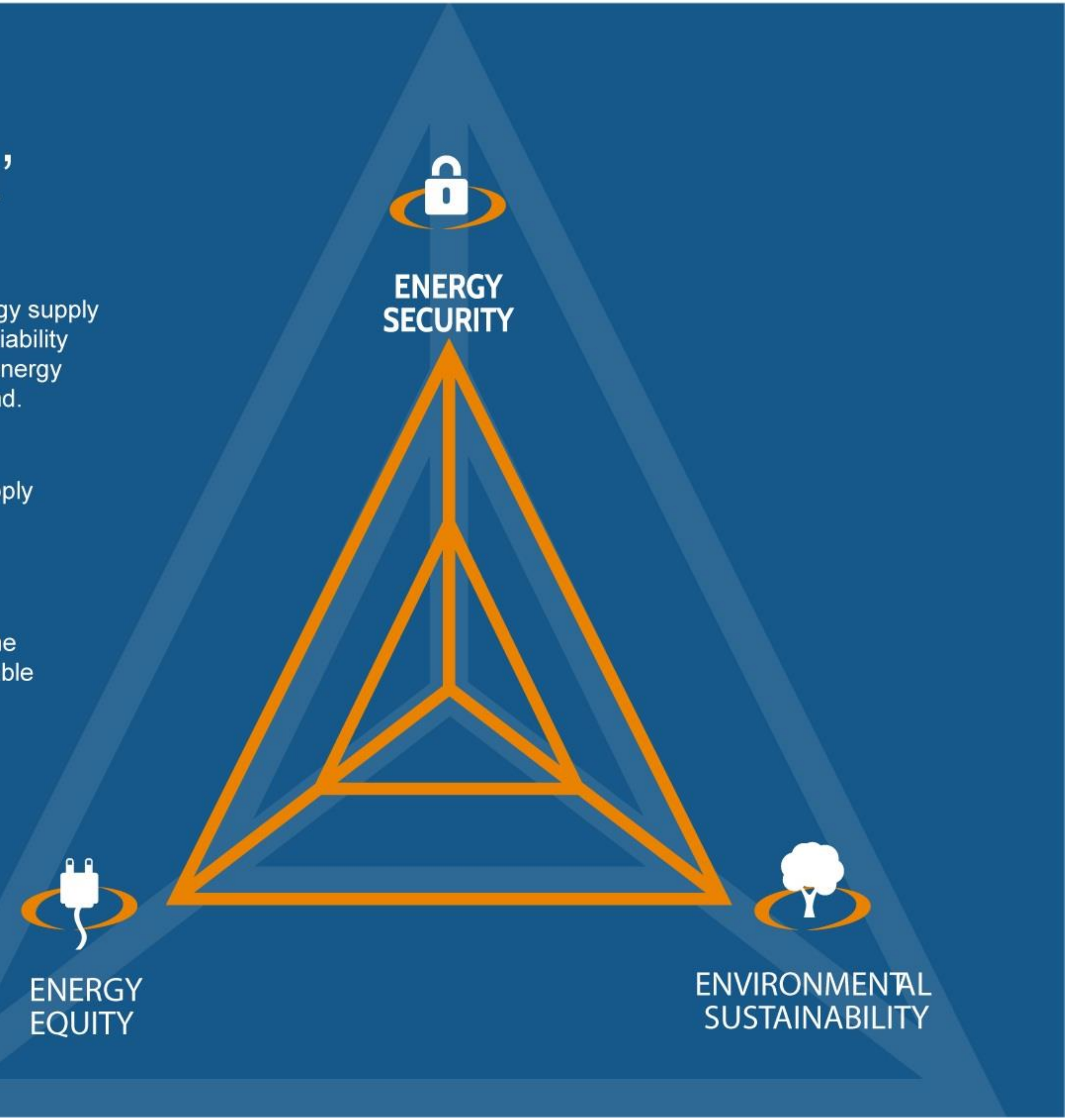
Source: Infield, D., & Freris, L. (2020). Renewable energy in power systems. John Wiley & Sons.

Balancing the 'Energy Trilemma'

Energy Security
The effective management of primary energy supply from domestic and external sources, the reliability of energy infrastructure, and the ability of energy providers to meet current and future demand.

Energy Equity
Accessibility and affordability of energy supply across the population.

Environmental Sustainability
Encompasses the achievement of supply and demand side energy efficiencies and the development of energy supply from renewable and other low-carbon sources.



Source: https://www.worldenergy.org/news-views/entry/energy-security-key-according-to-2015-world-energy-council-energy-trilemma-index

Introduction

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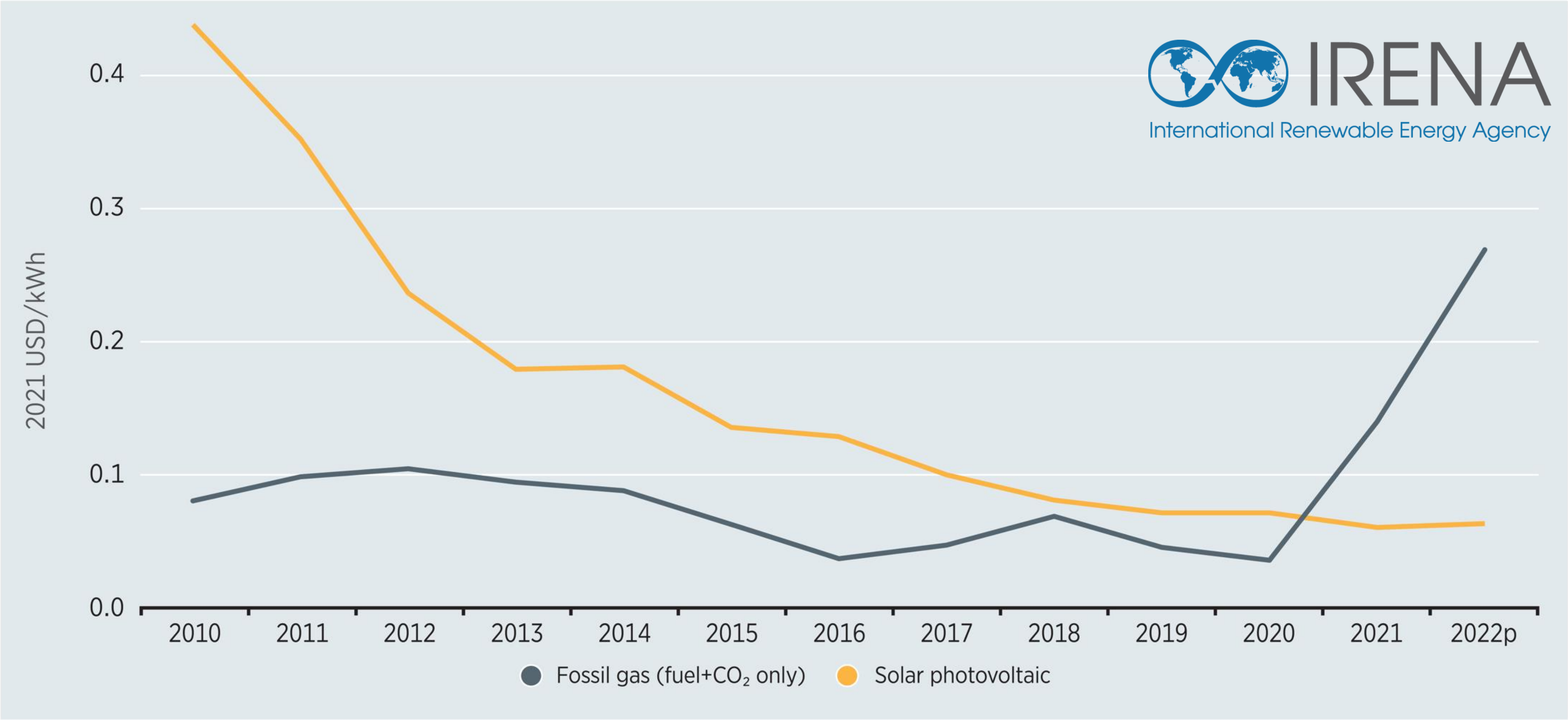
Renewables - Affordable?

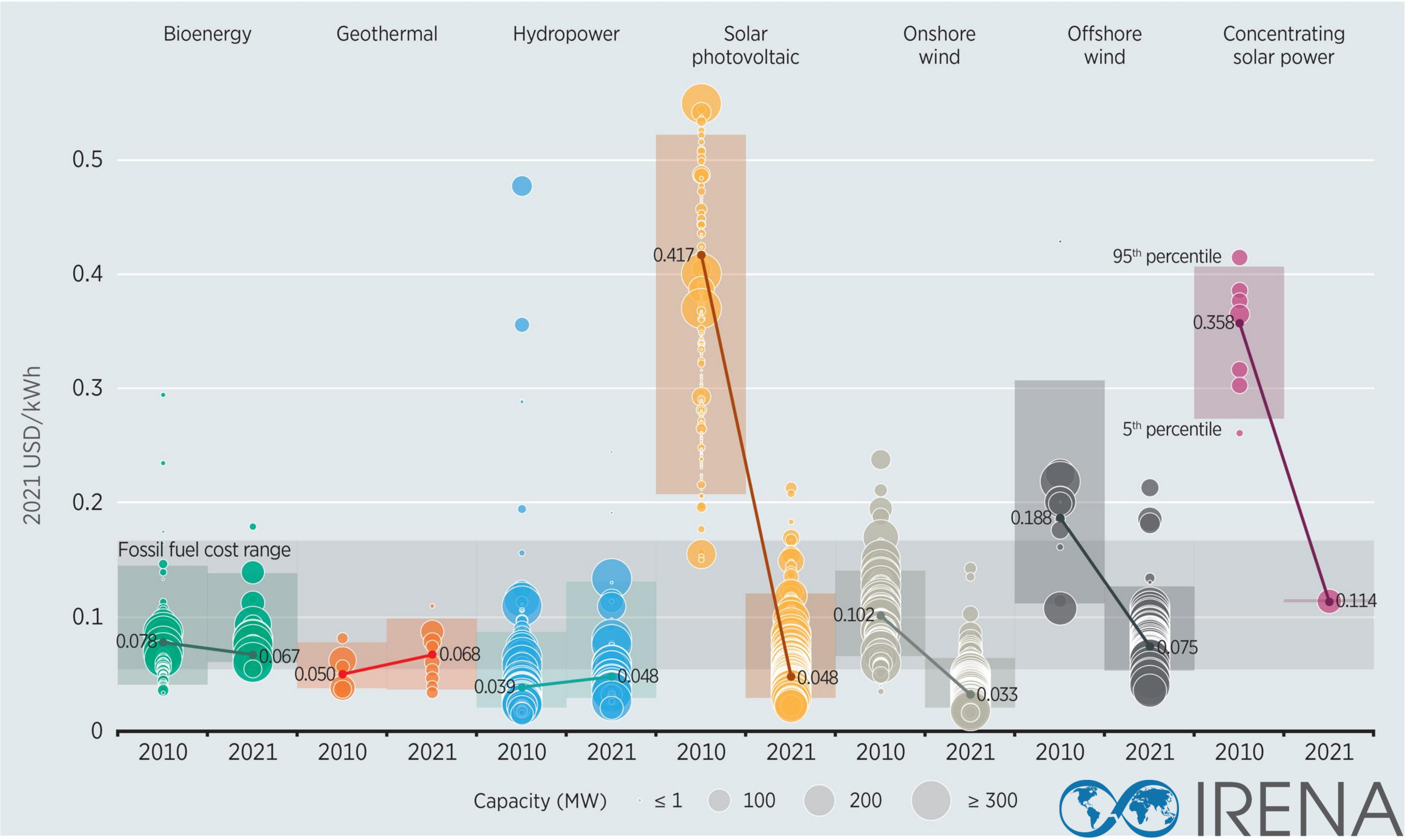
Figure S.3 The weighted average LCOE of utility scale solar PV compared to fuel and CO_2 cost only for fossil gas in Europe, 2010-2022



Note: 2022 values are possible outcomes for 2022 and not a forecast.

IRENA: Renewable Power Generation Costs in 2021

Figure 1.2 Global weighted average LCOEs from newly commissioned, utility-scale renewable power generation technologies, 2010-2021



IRENA: Renewable Power Generation Costs in 2021

Key conclusions of Step 1

- Renewables are competitive in cost (still considering the limited capacity factor)
- Generation and demand need to match at all times.
- Wind and solar PV are variable (non dispatchable). They can be predicted but they are not flexible
- Solar thermal, hydro, biomass, … are flexible
- In Step 2 we concentrate on flexibility and system balancing

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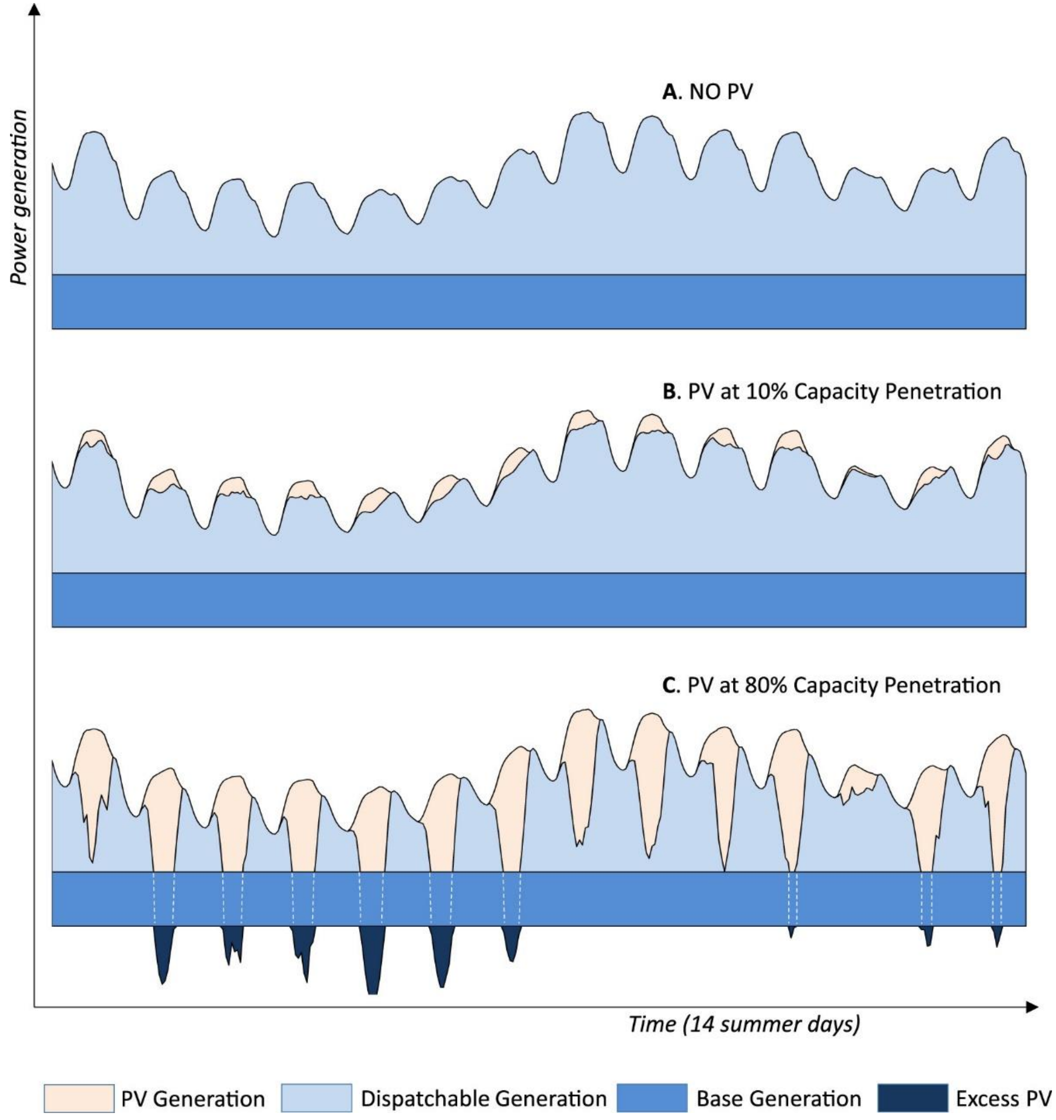
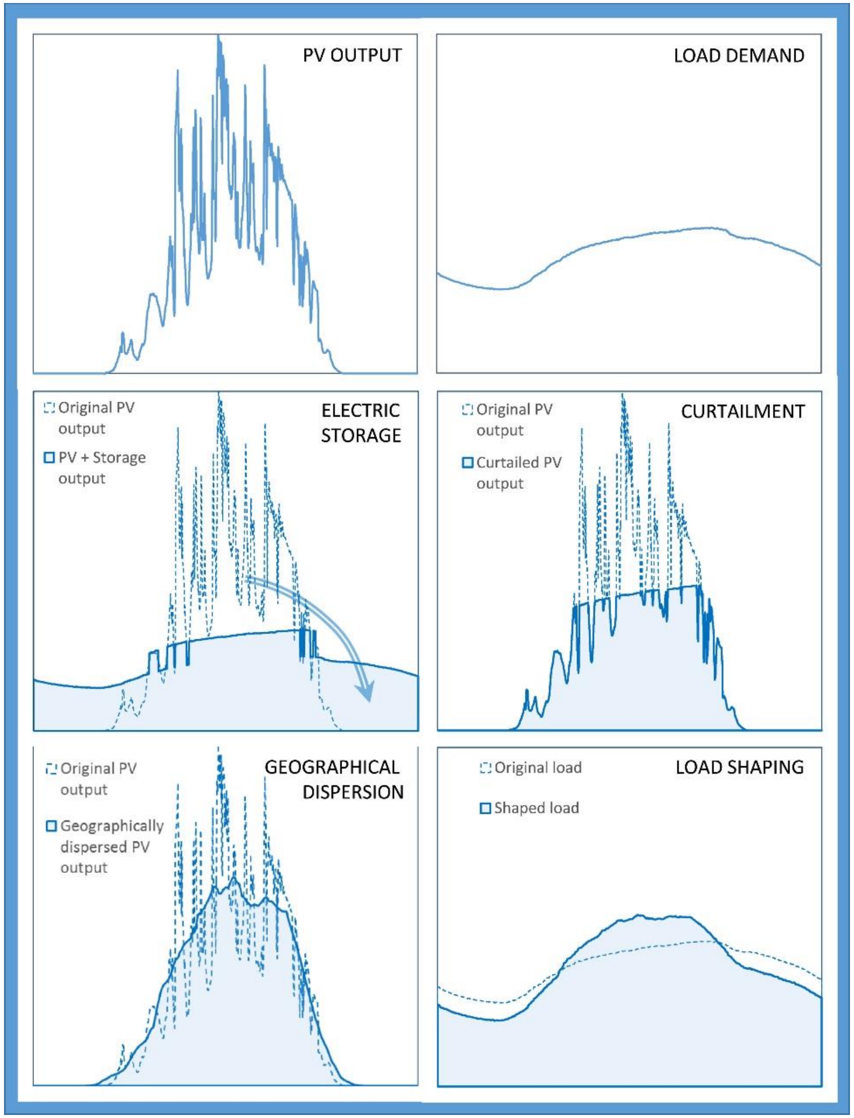
Challenging the power system

- Renewable (solar and wind) generation has strong variability and limited predictability. This is an important difference with conventional thermal and hydro power generation with controllable output.
- Renewable (solar and wind) power plant output varies periodically in different time scales (years, seasons, days)
- High penetration of renewable generation is a challenge for the transmission system:
  - Demand-generation balancing (Step 2)
  - Frequency fluctuations (Step 2-3)
  - Voltage and power flow issues (Step 3)

Renewable variability and conceptual solutions



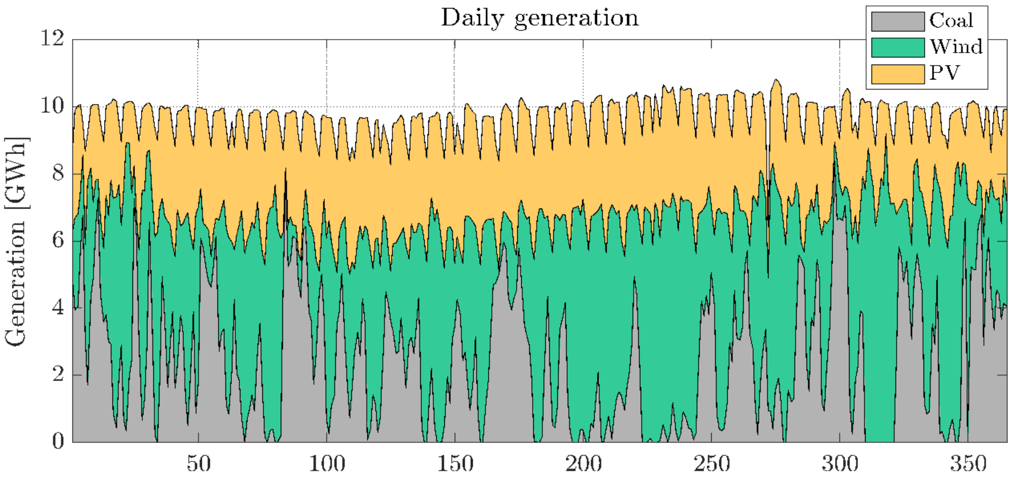


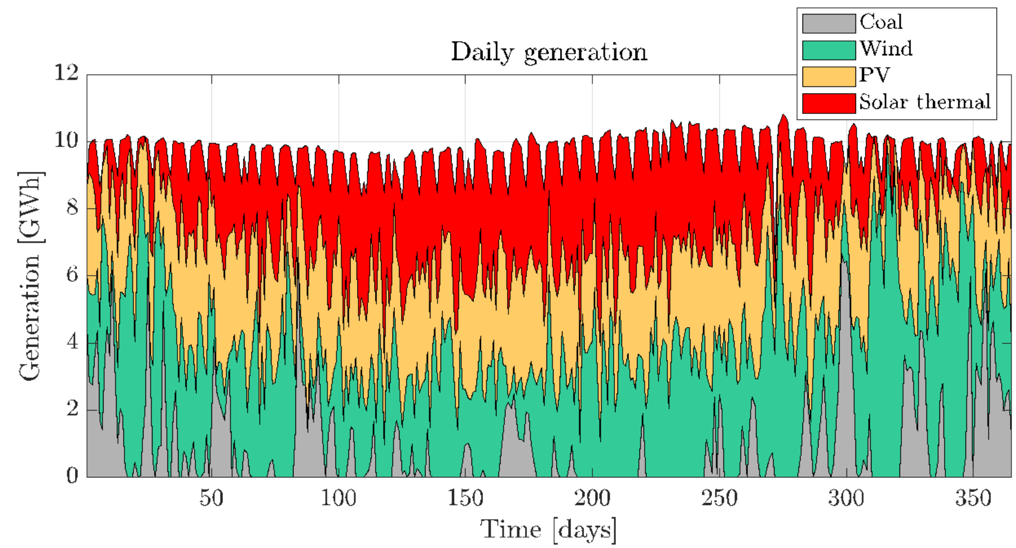
Perez et al "Achieving very high PV penetration – The need for an effective electricity remuneration framework and a central role for grid operators" Energy Policy 2016

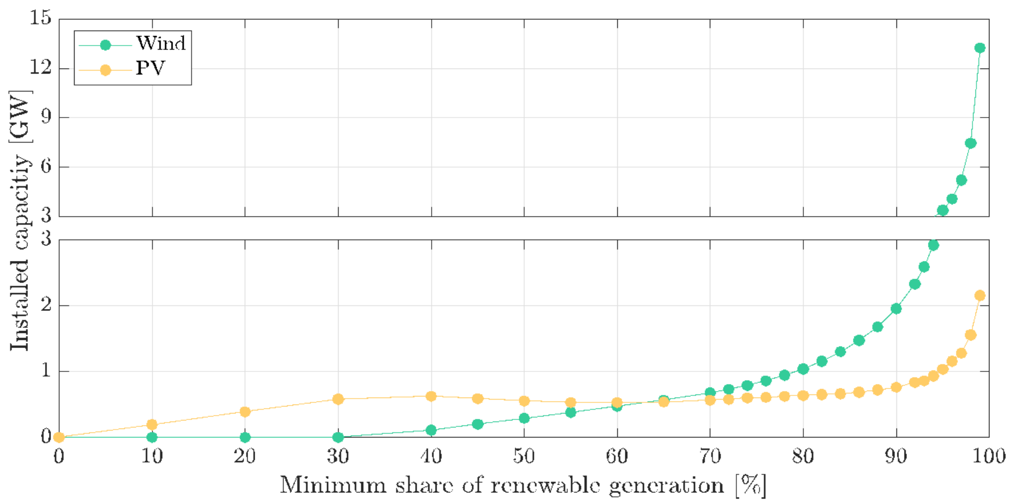
Achieving high penetration of renewables – towards 100 %

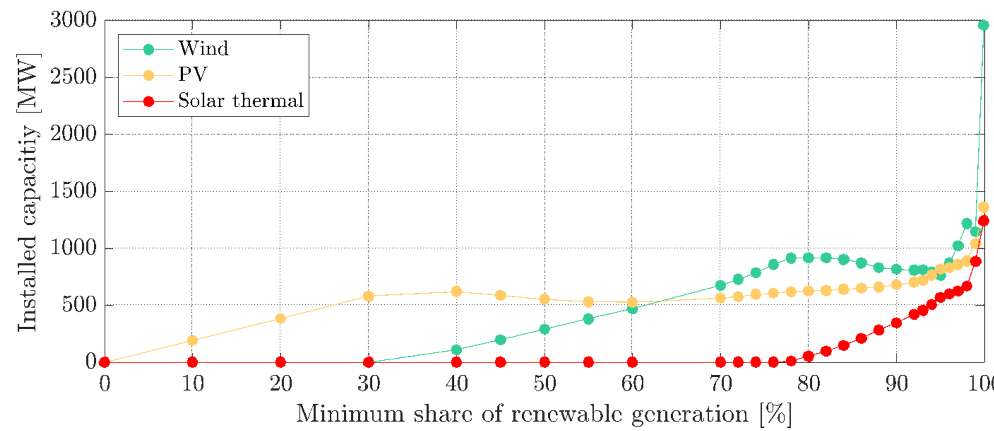
- **Variability in both demand and variable generation!**
- **How to address it?**
- If we use only variable renewables → huge curtailments and overcapacity installed.
- Some curtailment in solar PV and wind is necessary during some hours, to optimize system cost.
- The solution is to combine variable (low cost, solar PV and wind) renewables with
  - Renewables with more flexibility (hydro, solar thermal, biomass)
  - Energy storage
  - Demand management
  - Conventional generation (if not 100 % penetration), 99 % is different from 100 %!

Achieving high penetration of renewables – towards 100 %









Introduction to modern power systems

Where are we in renewable power systems?

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Conclusions

Key aspects

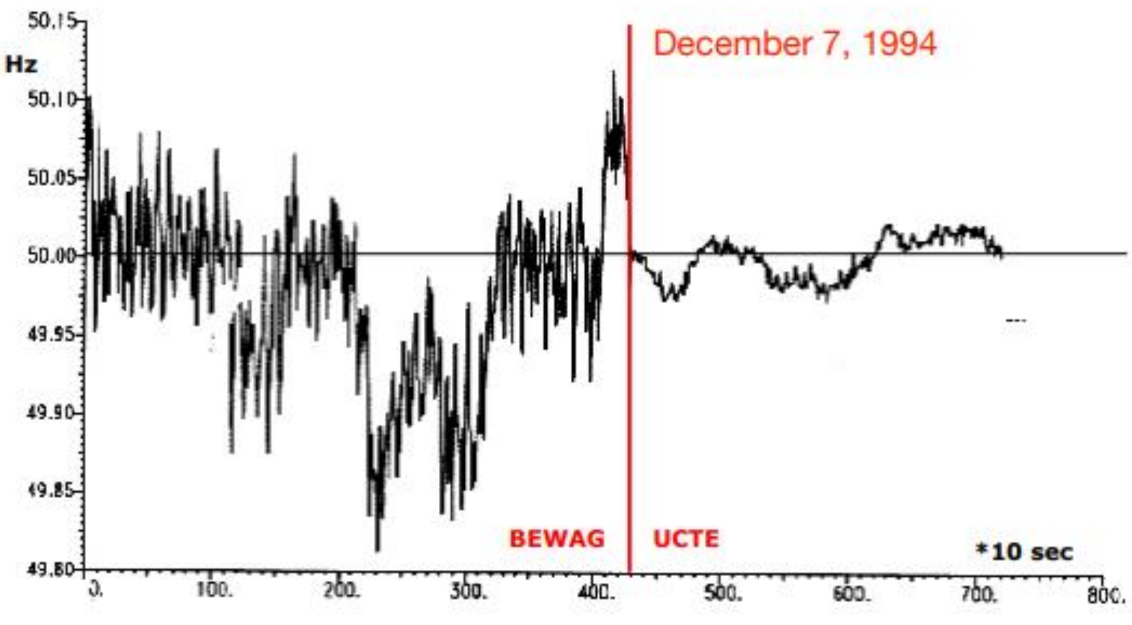
- The existing power system was not planned for the actual scenario!
- Potential problems related to:
  - Non existing power system in some locations.
  - Insufficient capacity to absorb the renewable generation.
  - Steady-state problems: line overloads, voltage variations
  - Dynamic problems (Step 4): stability, protections, transients.
- Solutions?
  - **Grid reinforcement**:
    - New overhead lines (OHL) or cables or repowering existing ones.
    - In some cases mandatory, for example to connect new offshore wind power plants or remote power plants
    - HVDC technology can be a good solution for long OHL or cables.
  - **Optimize existing infrastructure with**
    - Flexible AC Transmission Systems (FACTS)
    - Energy storage (peak shaving applications)

Key aspects

- What do we see here?

Examples - Berlin

Source: *Energie-Museum Berlin*



before re-connection: islanded operation based on batteries & single boiler

afterwards connected to European grid based on synchronous generation

Source: Prof. Florian Dörfler (ETH)

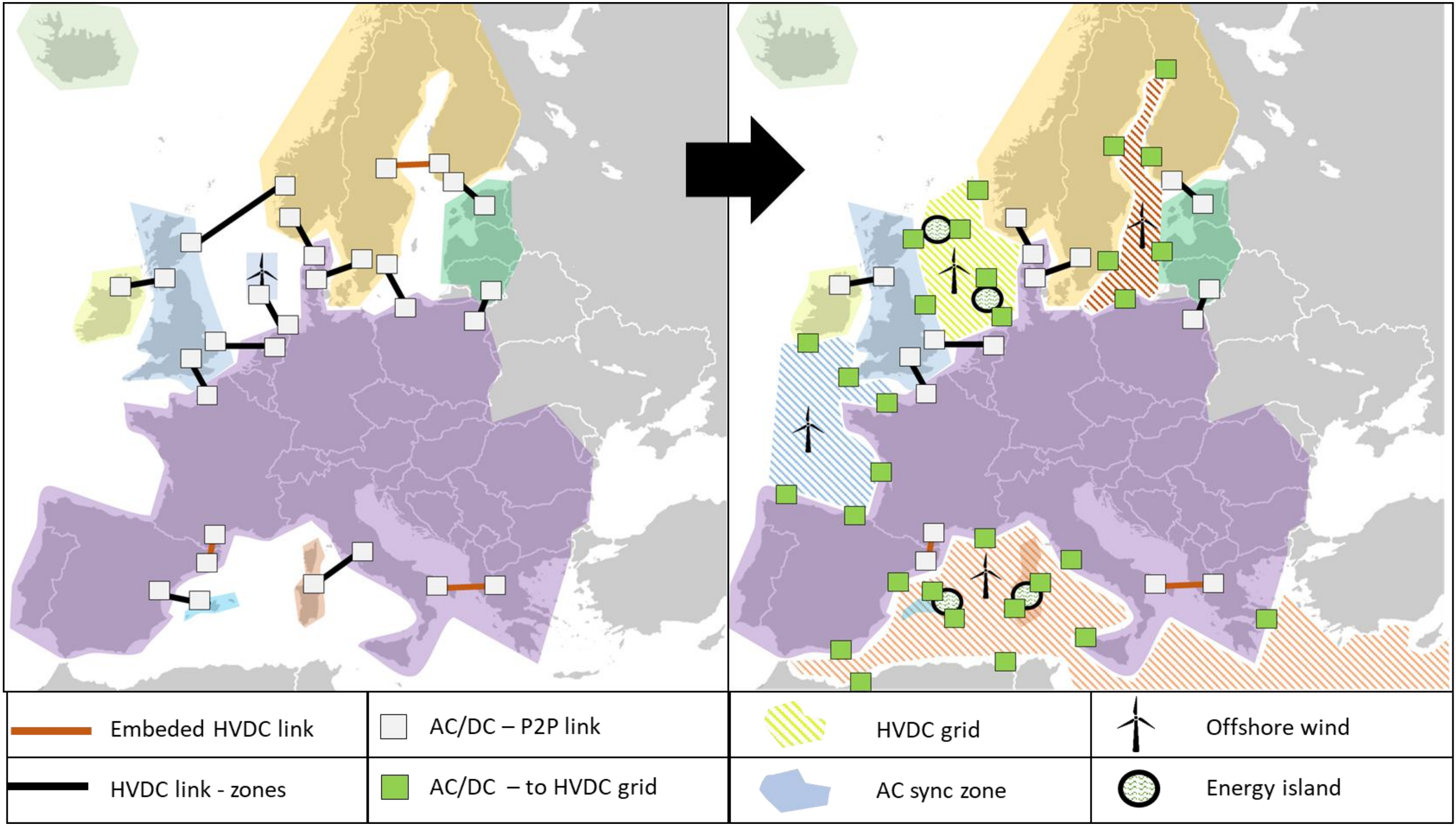
German example

- Energy transition
- Huge offshore and onshore wind deployment in the North
- Load centers in the South
- HVDC corridors interconnecting north to south while strengthening the overall network
- Fours different TSO involved: TenneT, 50Hertz, Amprion, Transnet BW.

Planned high voltage direct current power lines in Germany

https://www.cleanenergywire.org/factsheets/set-and-challenges-germanys-power-grid

From links to grids → A grid of grids



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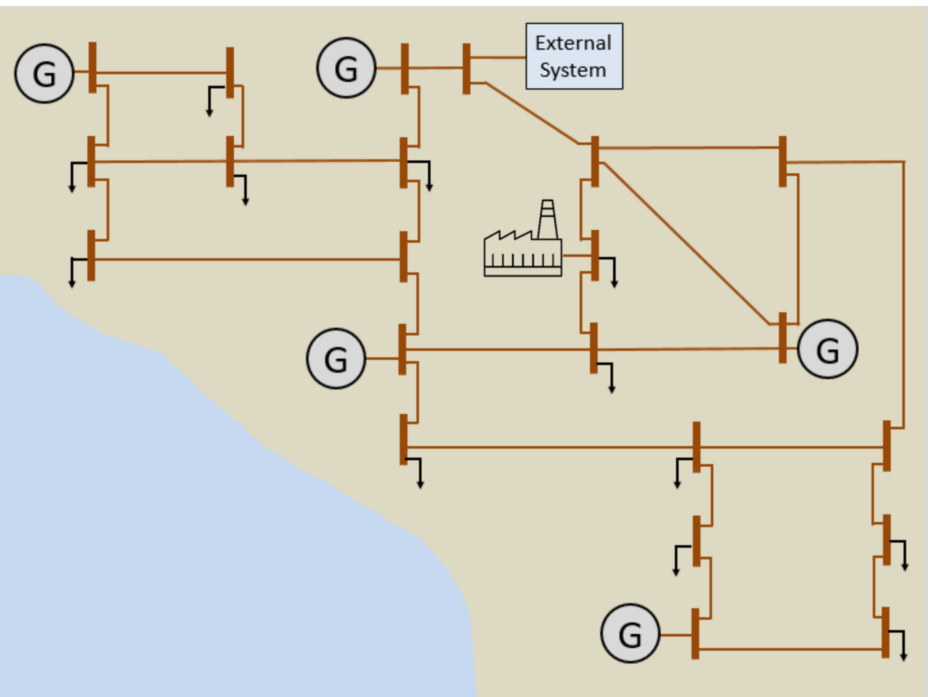
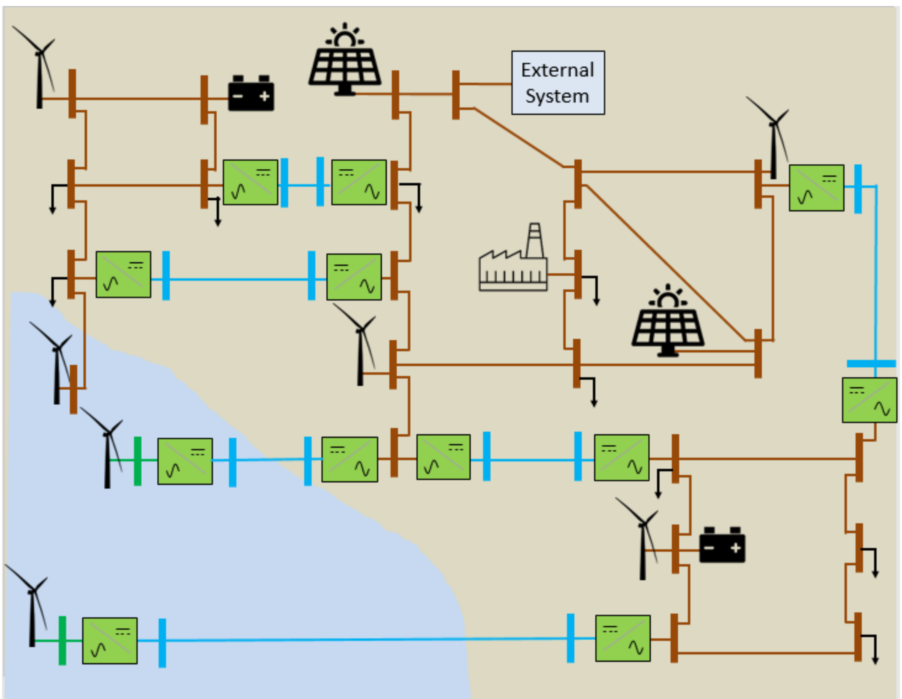
The network transition – a more technical view

Conventional network



Modern network



AC network | Classic generation | System loads

AC network | PV generation | Wind generation

DC network | Energy storage | Power electronics

Power electronics vs Synchronous generators

PEs are importantly **different from SGs**

Multi-stage steam turbine + generator

500 MW turbine

≠

Modular Multilevel HVDC converter

1000 MW converter

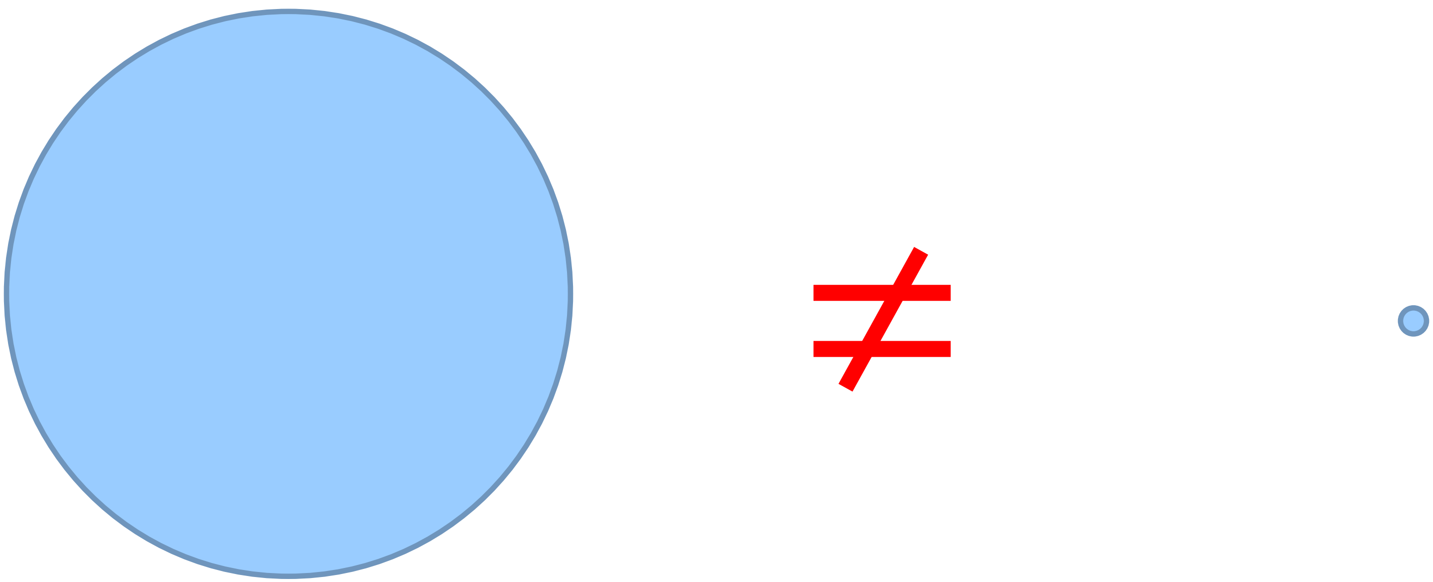
Source: Siemens

Power electronics vs Synchronous generators

PEs are importantly **different from SGs**

Multi-stage steam turbine + generator inertia

Converter inertia (example)



2+ seconds

30-60 ms

Research challenges

Specific converter characteristics:

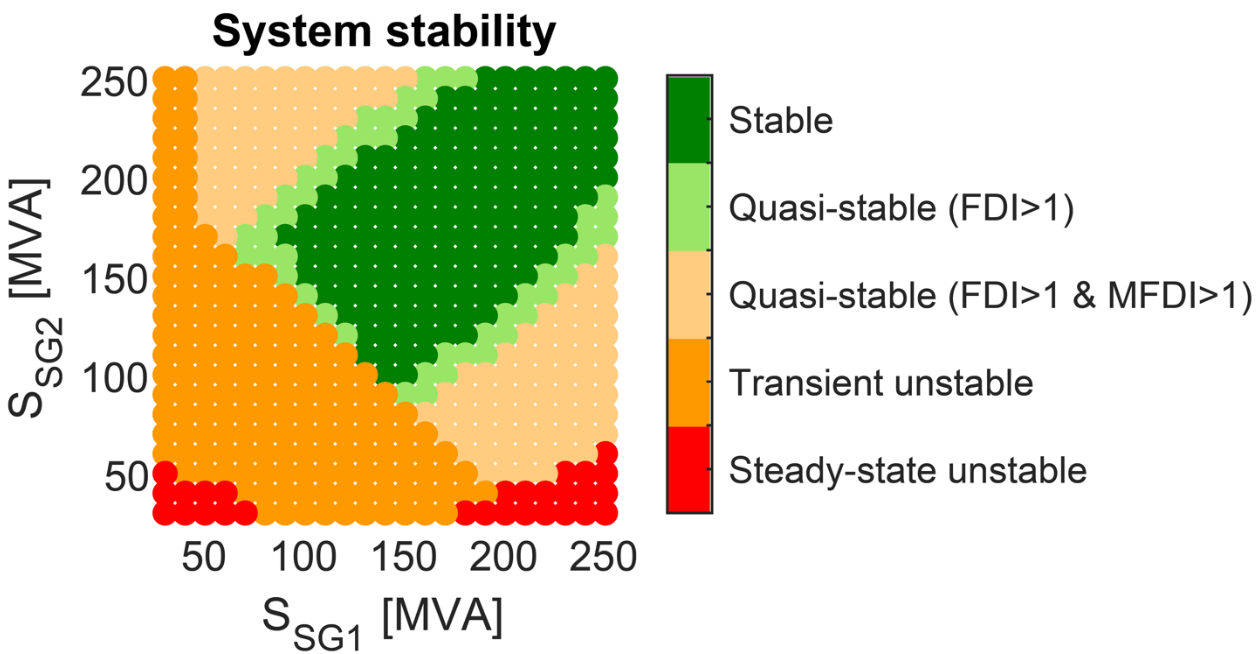
- Limited inertia
- Overload limitation (Current saturation, voltage → current source behavior)
- High controllability (Great adaptability, but potential interactions)

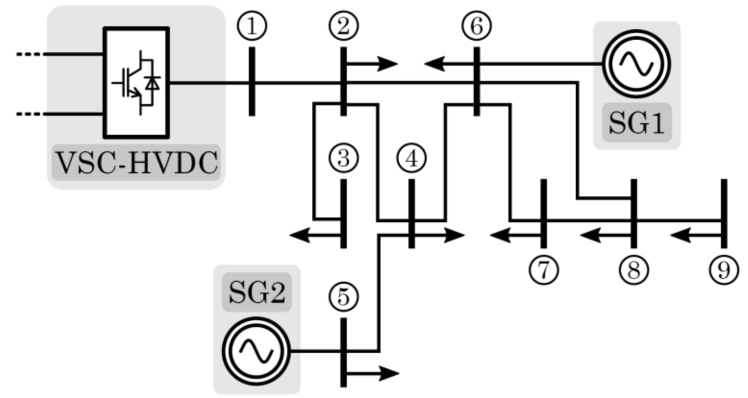
New concepts for grid synchronization and understanding of system stability and the role of frequency.

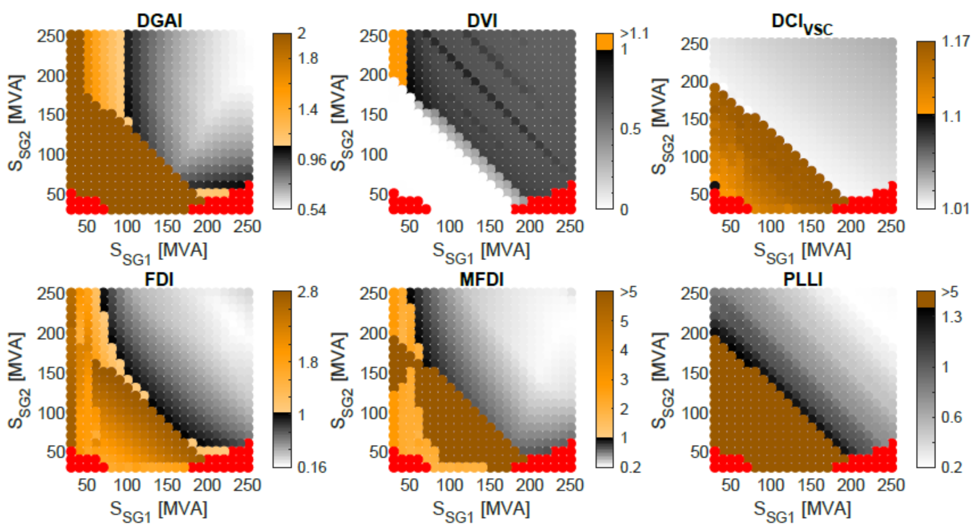
Understanding short-circuits (complex with interacting converter controllers during the fault). New methods required combining:

- Converter saturations / current source behavior
- Grid support schemes in the converters + Fault ride-through (Grid following / grid forming)
- Balanced / unbalanced faults

Role of modular multilevel converters (MMC)

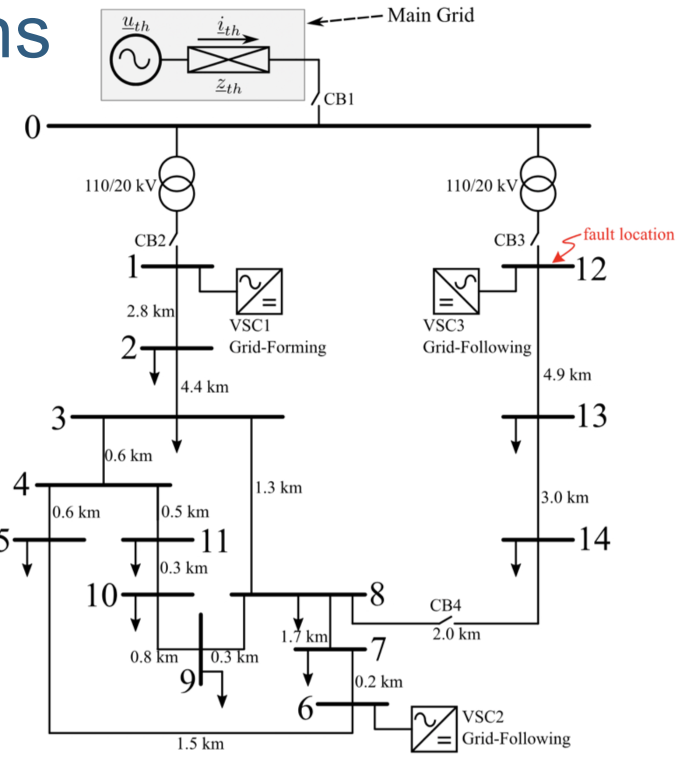


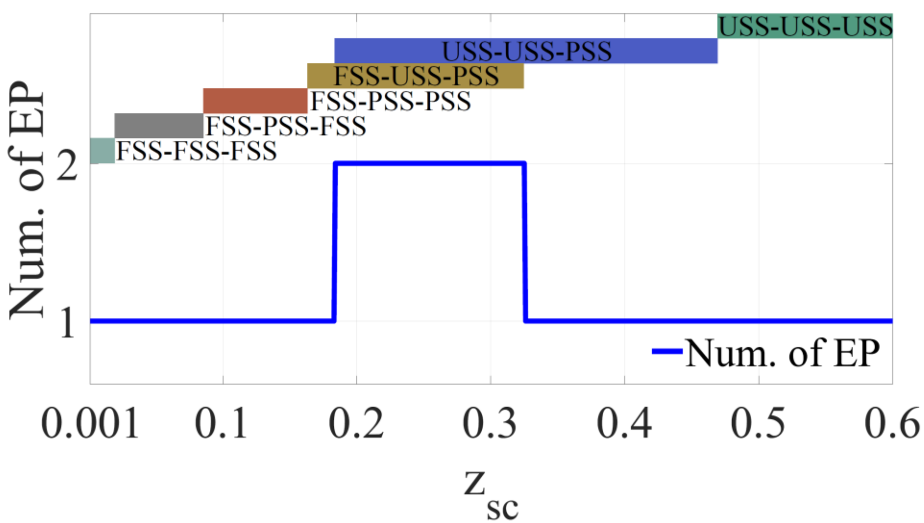


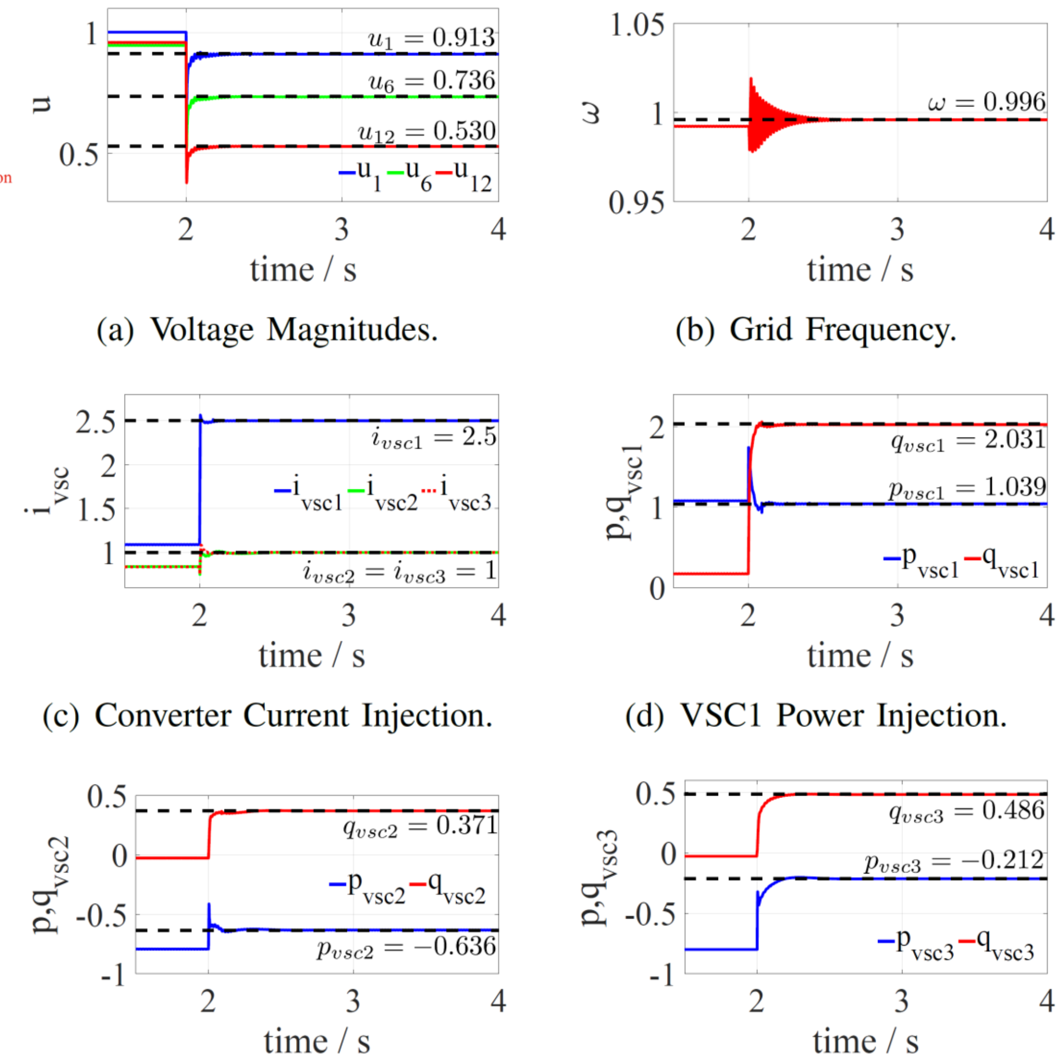


Dynamic Generator Angle Index (DGAI)
Dynamic Voltage Index (DVI)
Dynamic Current Index (DCI)
Frequency Derivative Index (FDI)
Maximum Frequency Deviation Index (MFDI)
PLL Index (PLLI)

Protections







(a) Voltage Magnitudes.

(b) Grid Frequency.

(c) Converter Current Injection.

(d) VSC1 Power Injection.

(e) VSC2 Power Injection.

(f) VSC3 Power Injection.

Short-Circuit Analysis of AC Distribution Systems Dominated by Voltage Source Converters Considering Converter Limitations IEEE Trans Smart Grid 2021

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- 100 % renewable power systems are possible, but there are many challenges. We divide the challenge in four steps:
- **Step 1 Cost of renewable energy**: Renewables were competitive before the energy crisis and they are progressing even more every year.
- **Step 2 Variability of resource and system balancing**: The variability of renewables needs to be addressed with a good generation mix and flexibility from storage and demand.
- **Step 3 Electrical grid constraints**: The system was not designed for this, upgrades are needed. The role of HVDC can be important.
- **Step 4 Stability and protection issues**: The modern system has a decreasing inertia, this is a challenge and an opportunity. The system can work but important changes are needed in system design, protection, operation and control.
- Summary: The energy transition offers great challenges and opportunities for engineers! Let’s do it!

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