Le réseau
de transport
d'électricité

(R)Evolution of the electrical system and its challenges

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Lucas Saludjian – R&D program director

Outline

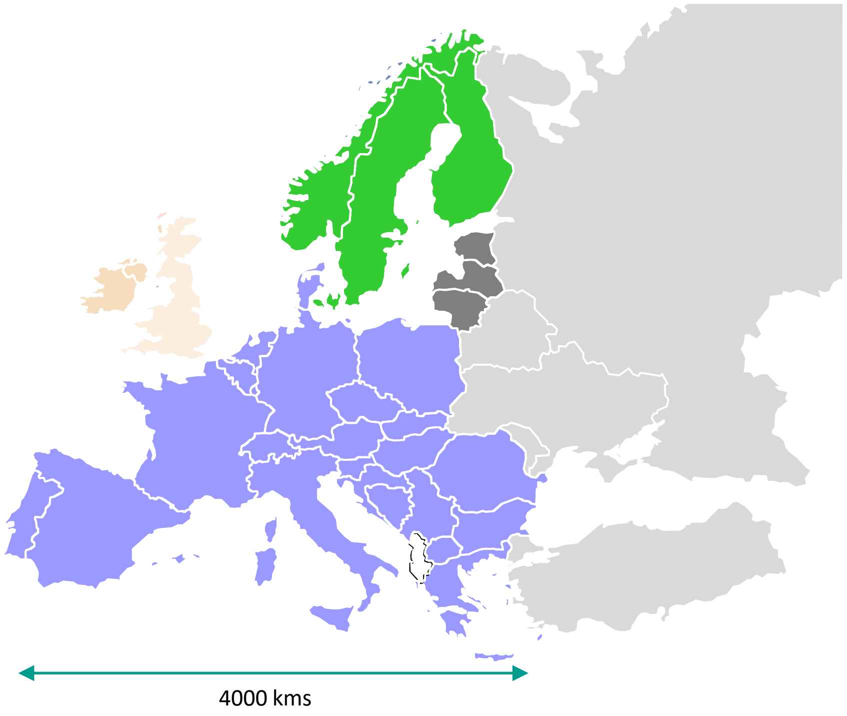
1. European Electrical System & RTE
2. (R)evolution of power systems
3. Stability issues
4. New control architecture
5. Towards 2050

European electricity today

36 interconnected countries (43 TSOs)
- Security of the power system in real time
- Economic optimization
- Security of supply

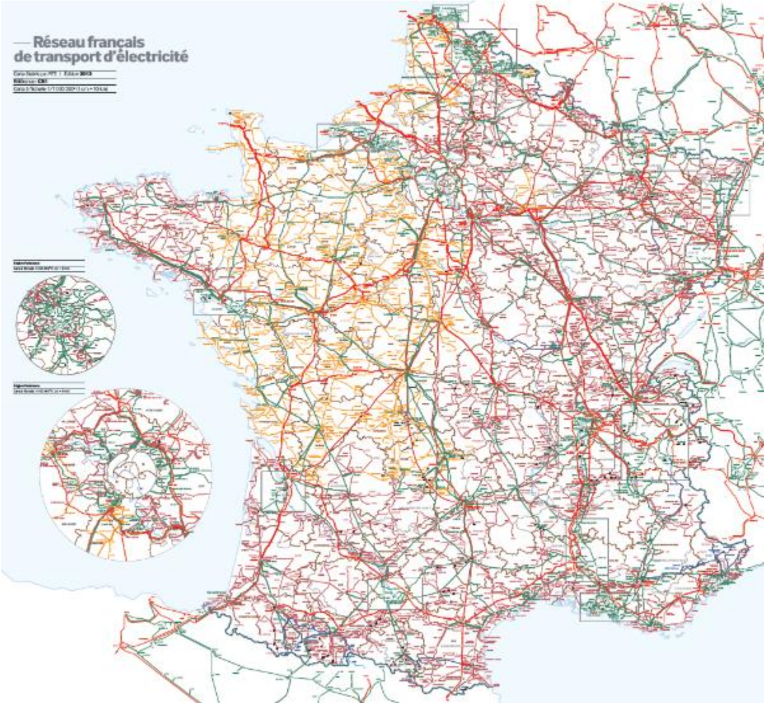
5 synchronous zones
- Scandinavia
- United Kingdom
- Ireland
- Continental Europe
- Baltic countries

Installed capacity : ~**1140 GW**
Consumption : ~**3,600 TWh/year**
Peak Load : ~**500 GW**
Physical exchanges : ~**425 TWh/year**
Population : **500 Million +**



RTE Overview

RTE: French Transmission System Operator
SO & TO: system operation, grid maintenance, grid access, grid development



1

RTE operates and maintains the power transmissi system, which is constantly being upgraded

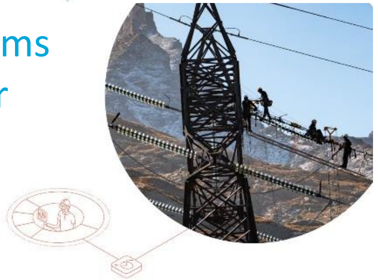
- 105 000 km transmission line (63 kV to 400 kV)
- 2800 Substations
- 22000 km optical fibers
- 48 interconnectors

2

RTE maintains a constant balance between power supply and demand in real time, maintains security of supply and upholds electrical solidarity across the regions in France and in Europe.

3

RTE designs and implements market mechanisms on electricity markets in order to obtain power from the most financially competitive sources across the whole of Europe.



RTE Key Figures

Exports : 72 TWh
Imports: 33 TWh

€ 4,5 billion **Turn Over**
€ 1,5 billion
Investments

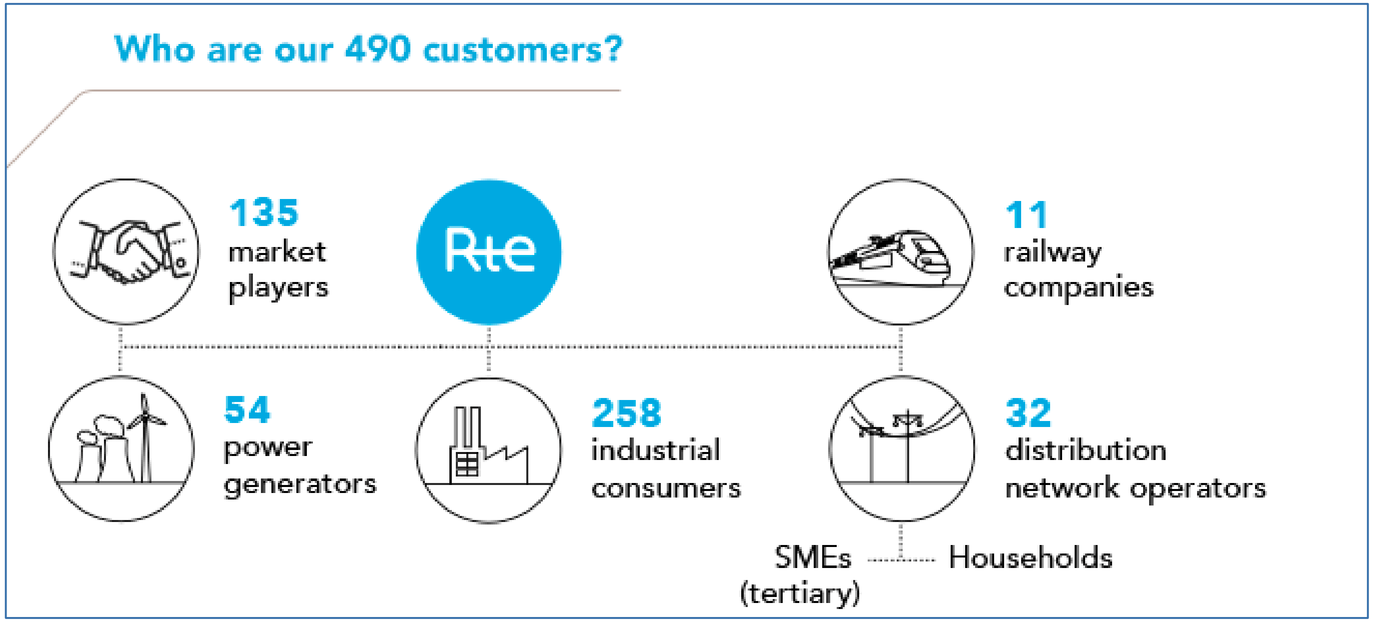
8 500
Employees

477 TWh:
Total energy injected in the French grid

100 GW **Peak Load**

R&D

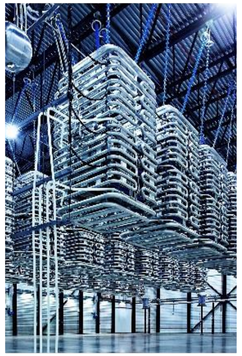
€ 35 million/year **- 120 full time people**



(R)Evolution of power systems

A huge increase of the system complexity !

Renewable energies with characteristics such as almost no marginal costs with power electronics interfaces, **more intermittent generation**, **dispersed in distribution grids**, which are out of phase with the dominant sources of electricity today. RES are **less predictable & less observable**



Decrease of inertia in the system involves **faster dynamics** but **emerging solutions** on **storage.**

Need to coordinate a large population of devices/agents with partial autonomy

Future impacts of **electric mobility** ?

New societal exceptions and **low public acceptance of new infrastructures**

An **increasing number of stakeholders** – economic & technical – x 1000 – **prosumers** promoting autarchy ! NIMBY & BANANA effects

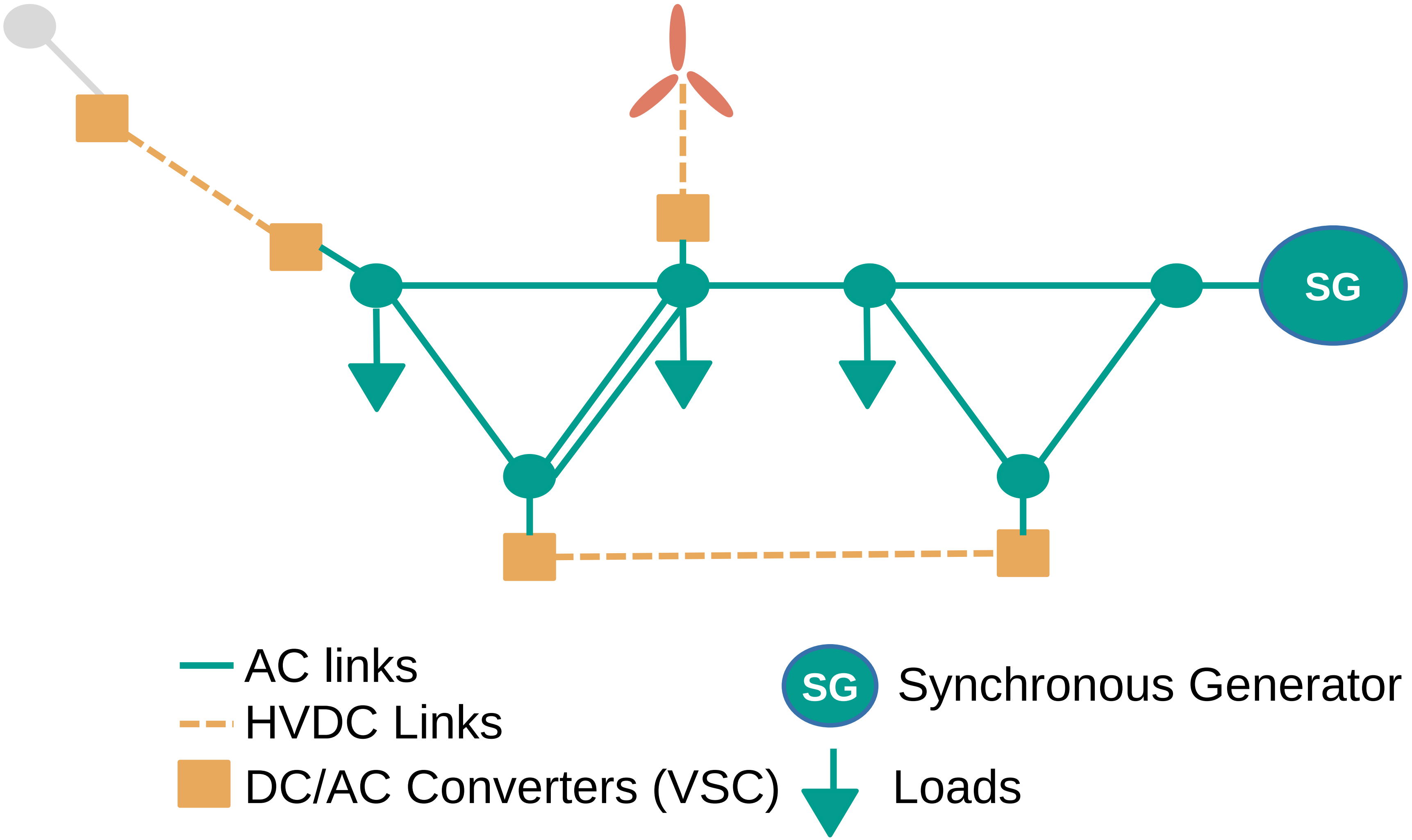
There is a urgent need to rethink both <u>**economics and dynamics of power systems**</u>. Patches to adapt marginally the historical design are perhaps not a good approach even if the migration path is a critical issue.

Stability issues

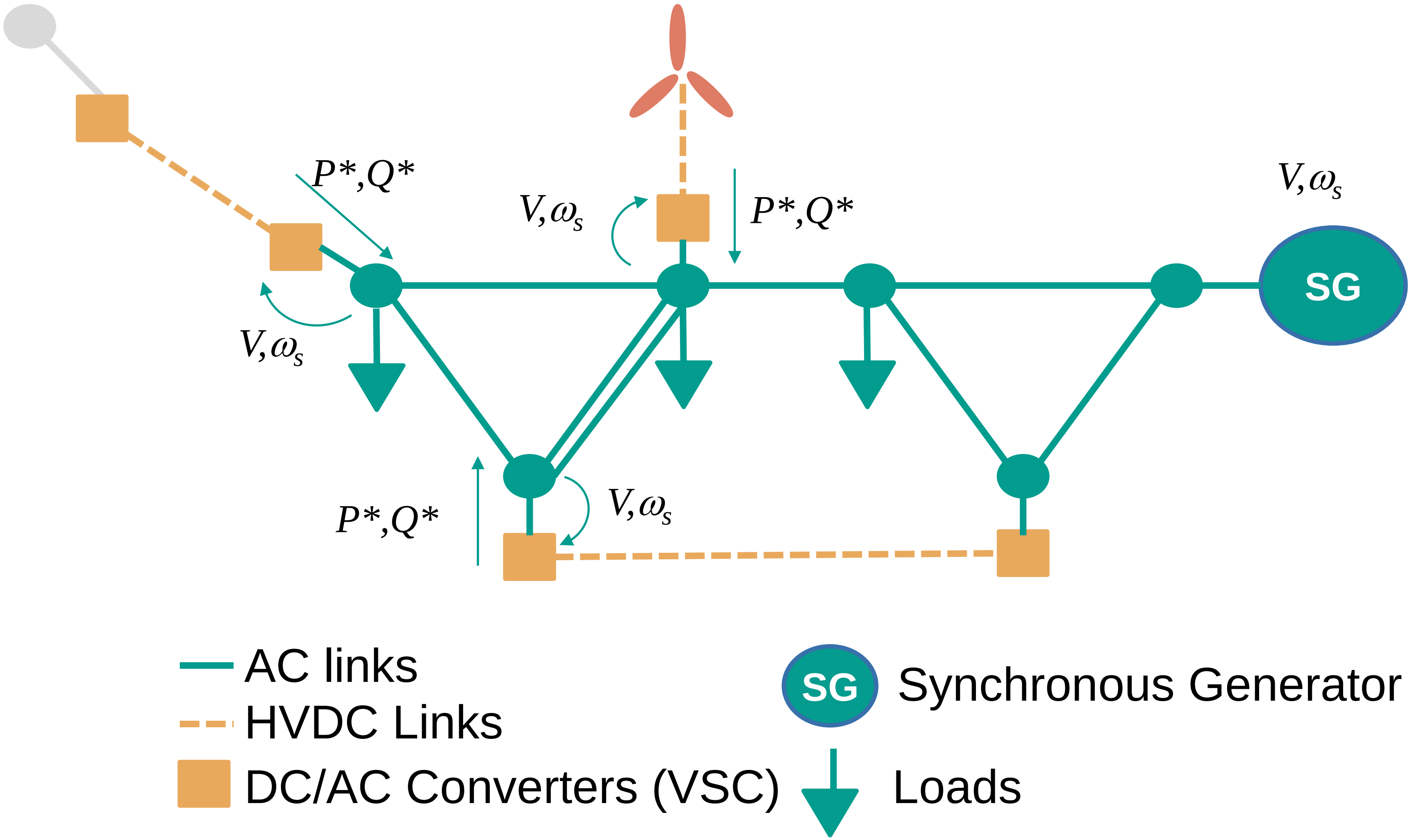
Stability issues

Power system stability is the ability of an electric power system to regain state of operating equilibrium after being subjected to a physical disturbance so that practically the entire system remains intact.

An example …


SG
AC links
HVDC Links
DC/AC Converters (VSC)
SG
Synchronous Generator
Loads

An example ...



P*,Q*
V,ω_s
V,ω_s
P*,Q*
V,ω_s
SG
P*,Q*
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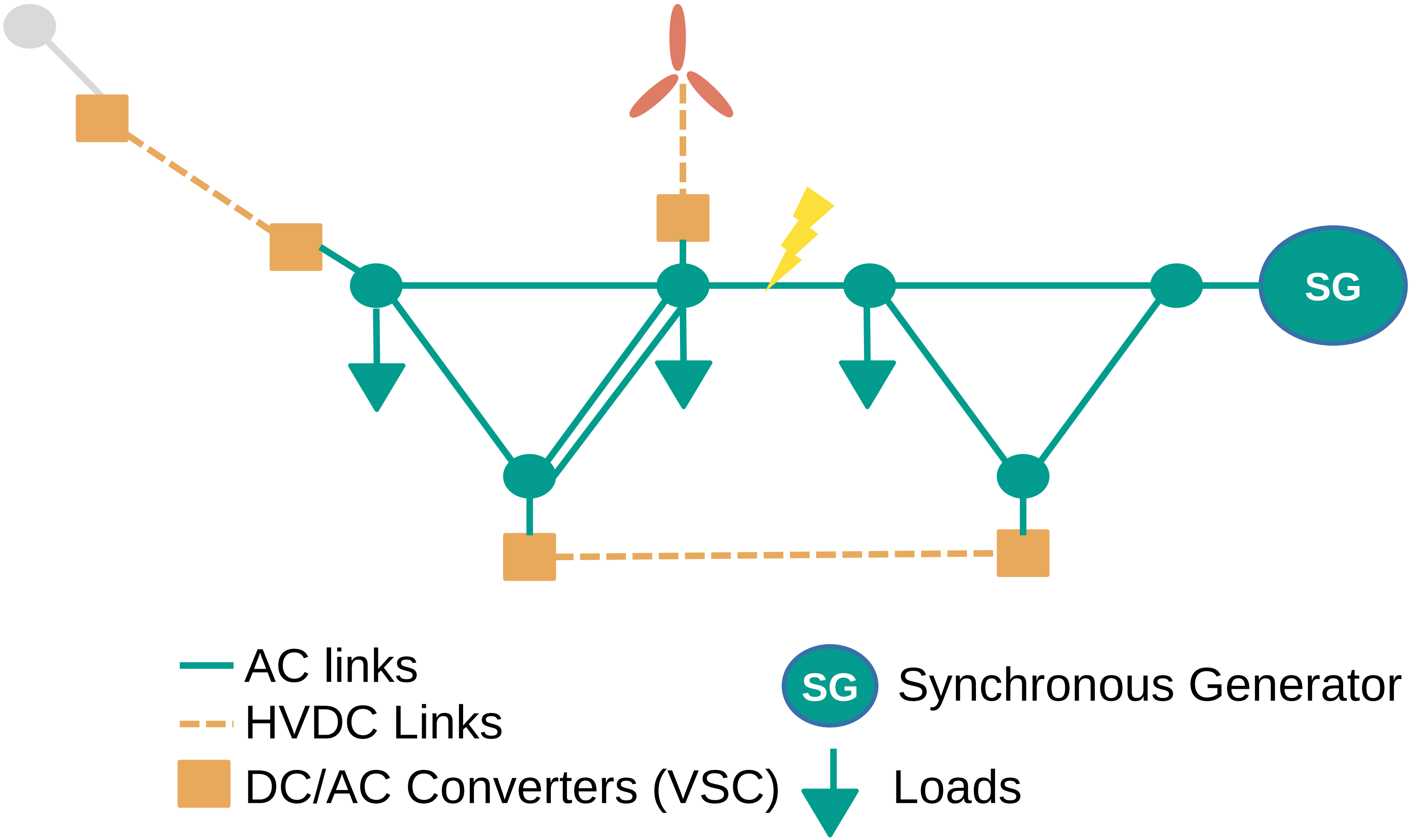
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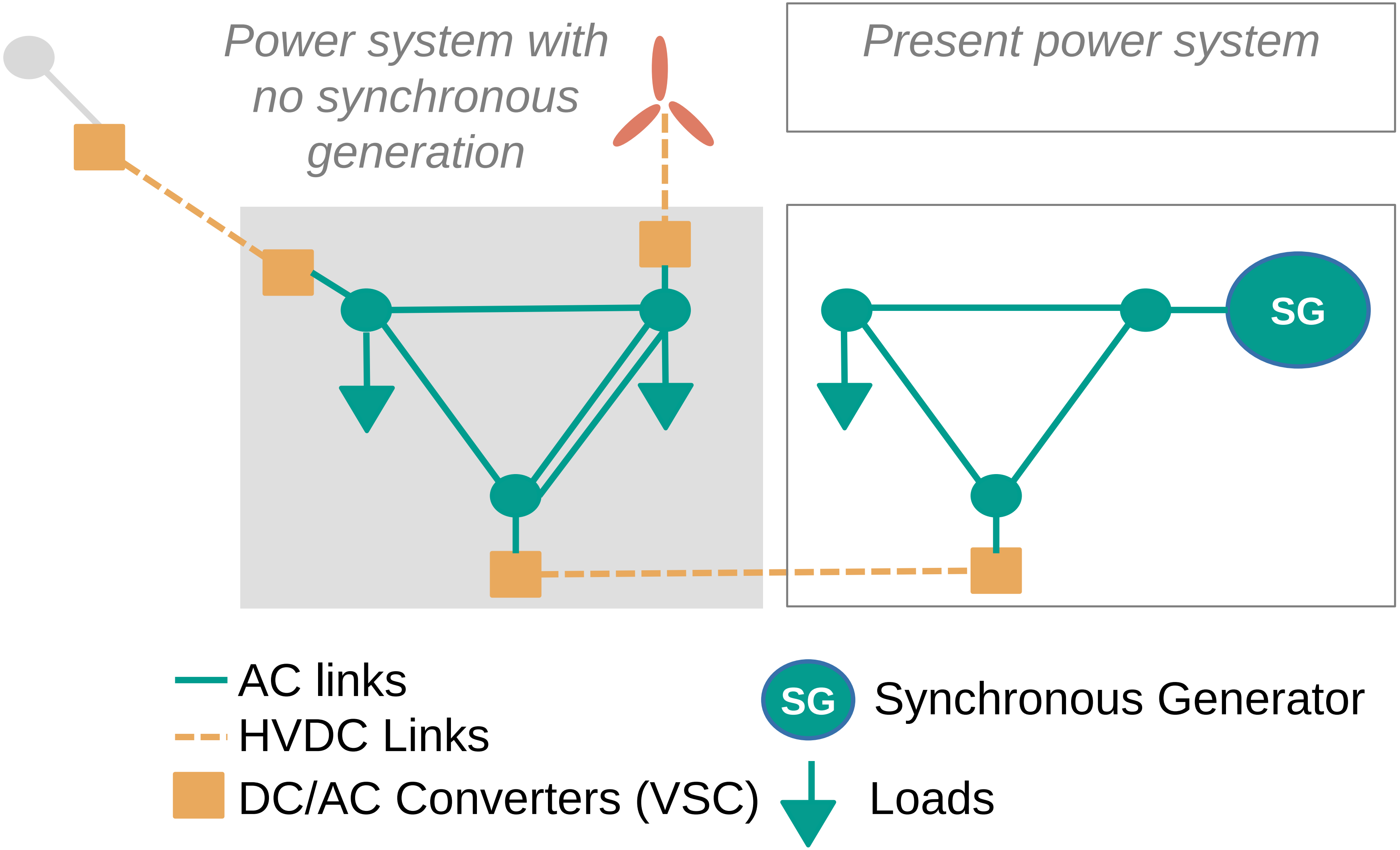
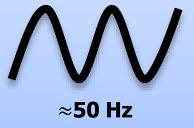


Power system with no synchronous generation
Present power system
SG
AC links
HVDC Links
DC/AC Converters (VSC)
SG
Synchronous Generator
Loads

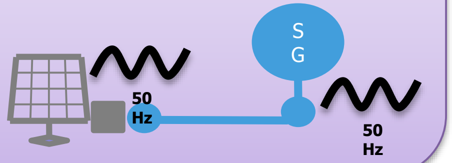
Grid Forming & Synchronization

- What if, there is no signal to lock on

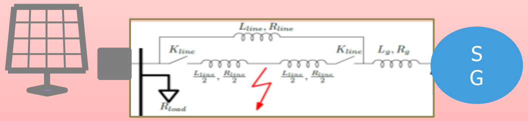
Stiff voltage source behavior



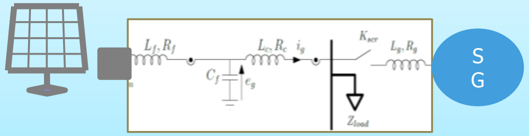
Synchronizes with other sources (REN, SG, GF)



Current-limiting strategy



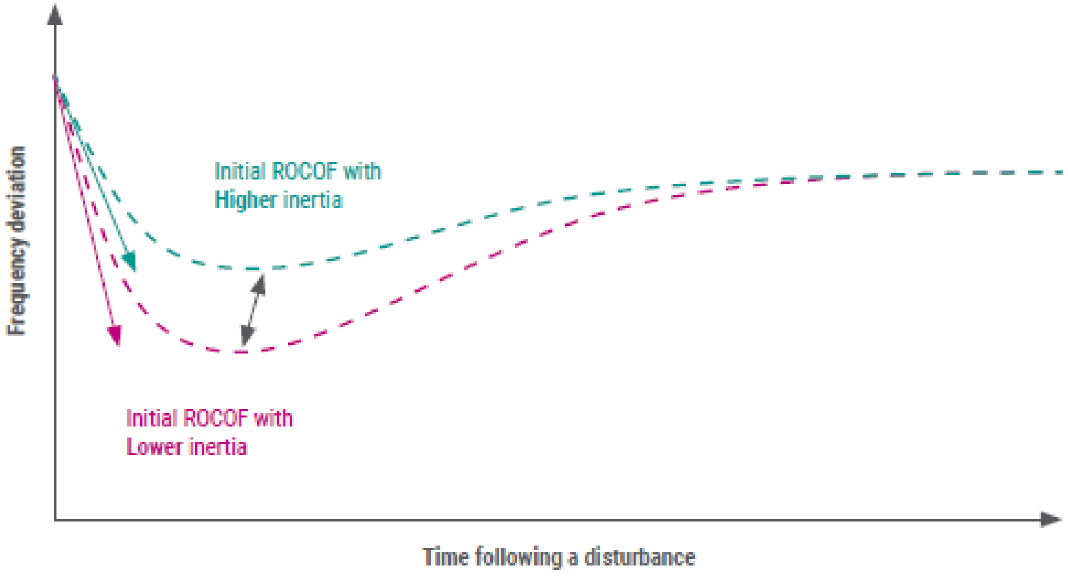
Islanding



Grid Forming !

Inertia

Power electronics leads to a decrease the inertia on a conventional system



Initial ROCOF depends on **inertia** and **generation demand imbalance**

- Theoretical mitigation measures include acting on available inertia or limiting the potential initial imbalances

Subsequent frequency recovery will depend on the size and full activation time of **Frequency Containment Reserves**

- Theoretical mitigation measures include acting on the speed and quantity of available active power control

Dynamics of frequency variations more important for the same disturbance on the network.

New Grid Forming controls to counterbalance the decrease of inertia

Sensitive loads !

Historical loads were sensitive to both frequency and voltage.

This has been used to design many control loops and defense plans !

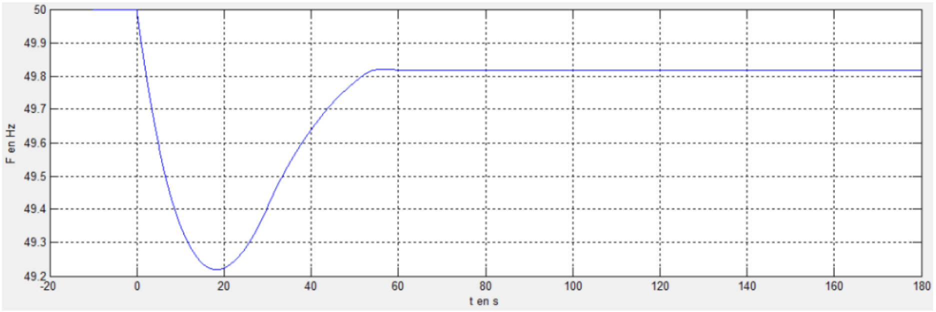


Figure 4: Comportement de la fréquence lors de l'incident de référence (perte de 3 GW de production)

Today, loads – EV, Heating, Motors, Domestic appliances (Washing machine, TV, Computers) …Electrolyzers …

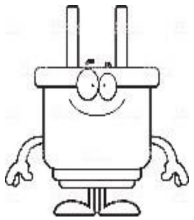
… are controled with PE for consumer oriented objectives.

Decision making problems

Making a « Good » Decision ➔ « Optimization »

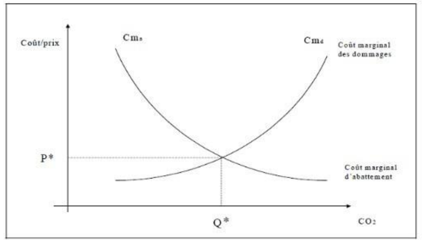
➔Developing, Maintaining, Operating the Power grid requires making many complex decisions at different time scales:

- Build new assets,
- Maintain existing assets or renew them
- Operate the existing system to best satisfy the grid users

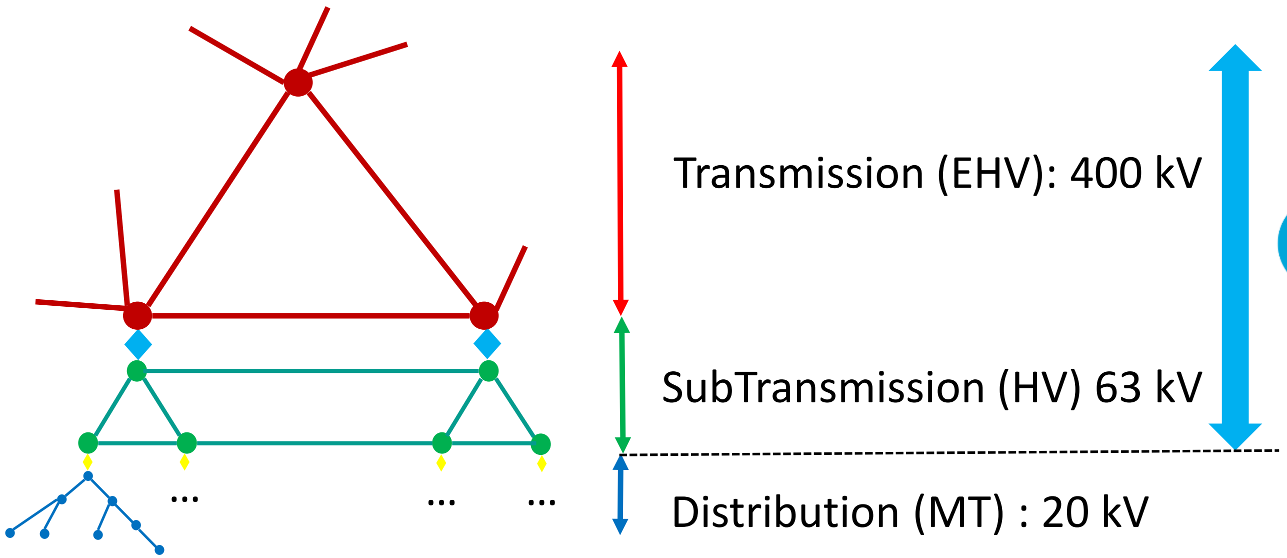


➔ Making a "good" decision requires balancing benefits and costs

- respecting physical and/or regulatory constraints
- taking into account uncertainties
- but also decisions that will still be possible in the future.



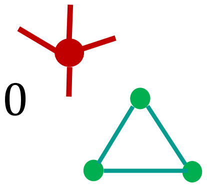
A power grid: structure and modeling (simplified)



➔ Hierarchical graph meshed for Transmission et SubTransmission (Quasi Chordal Δ : N-1 criteria)

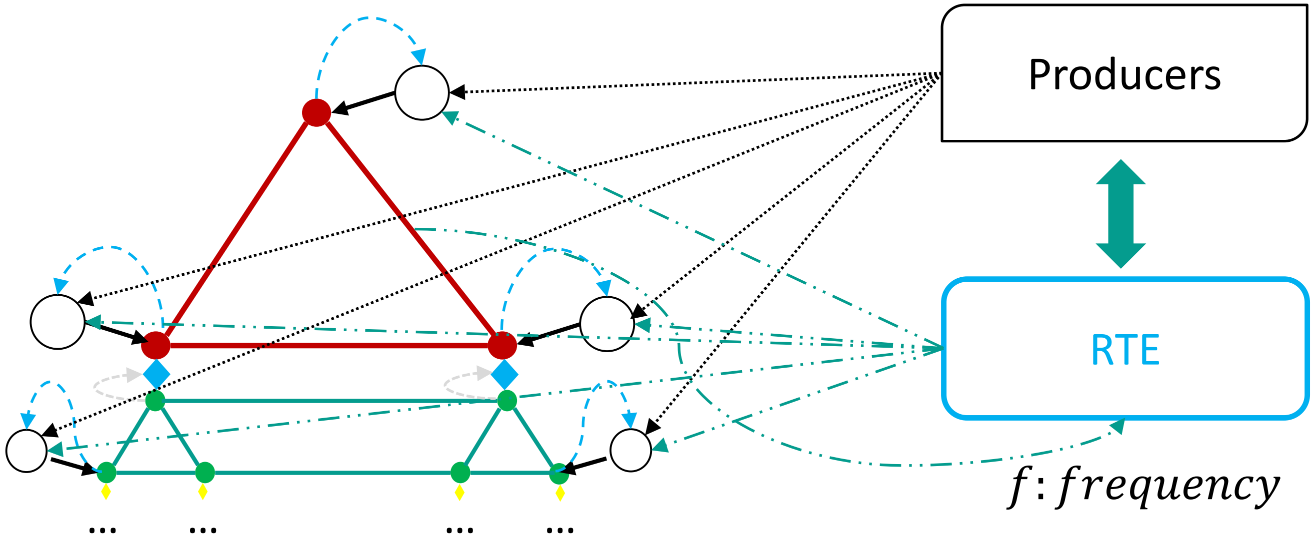
➔ Two key variables: Current (I) et Voltage (V) : «Phasors» $v_t = \boldsymbol{Re}\{V_t e^{j\varphi(t)}\}$. frequency $f_t = \frac{d\varphi(t)}{dt}$

- Kirchhoff' law:
  - $Current: \sum_{b \in \{branche(node)\}} I_b = 0$
  - $Voltage: \sum_{n \in clique(node)\}} (V_n - V_{n+1}) = 0$



- Ohm's law: link between V and I on branches

Current control architecture



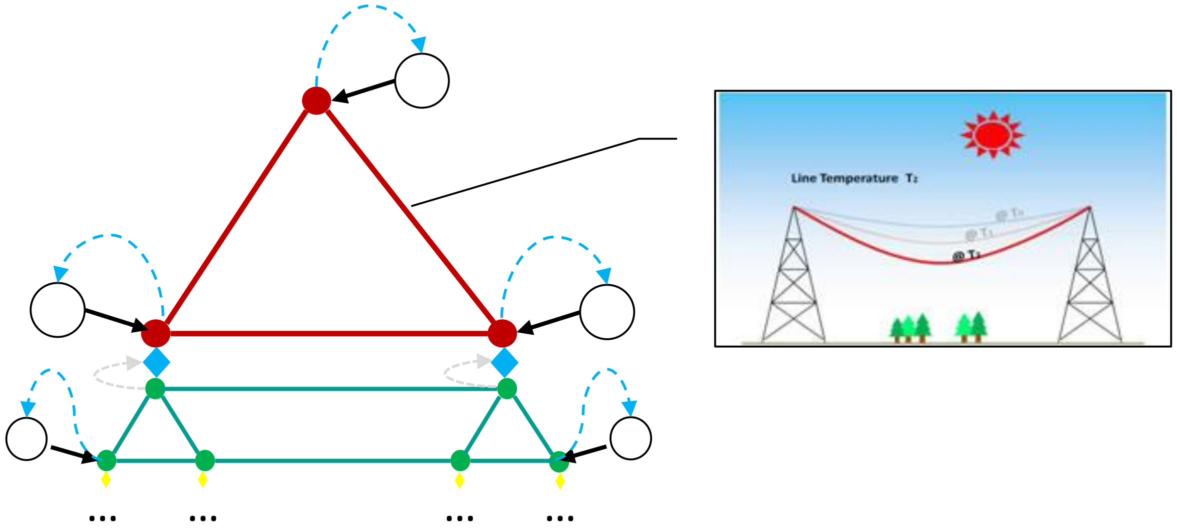
Local Controls:

- Generator: Frequency and Voltage magnitude
- Transformer with tap changer : Voltage magnitude

Centralized controls:

- Generation schedules : «Producers», time step 30 min, window 24 h, “ ~ open loop”, updated each 3 hours
- Load Frequency Control (AGC) : «RTE», Integral control 10s. $f \rightarrow f_n = 50\ Hz$. System balance P = C

New needs for the energy transition : a better management of grid congestions



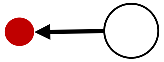
- ➔ More closed controls are required: Intermittency of wind/solar power creates volatile power flows in the grid.
  - Taking advantage of dynamic ratings (DLR) depending on local weather conditions
  - Using new actuators:
    - ➔ Reconfiguration of substation, Electrical Batteries, « Smartwires », Phase-Shifting transformer,
    - ➔ Curtailment of wind/solar power

Available actuators

- On «Branches»

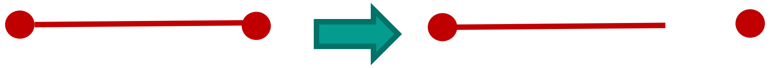
  - Transformers with tap changer , Phase-Shifting Transformers, … near substation.

- At «Buses» : injected/consumed power

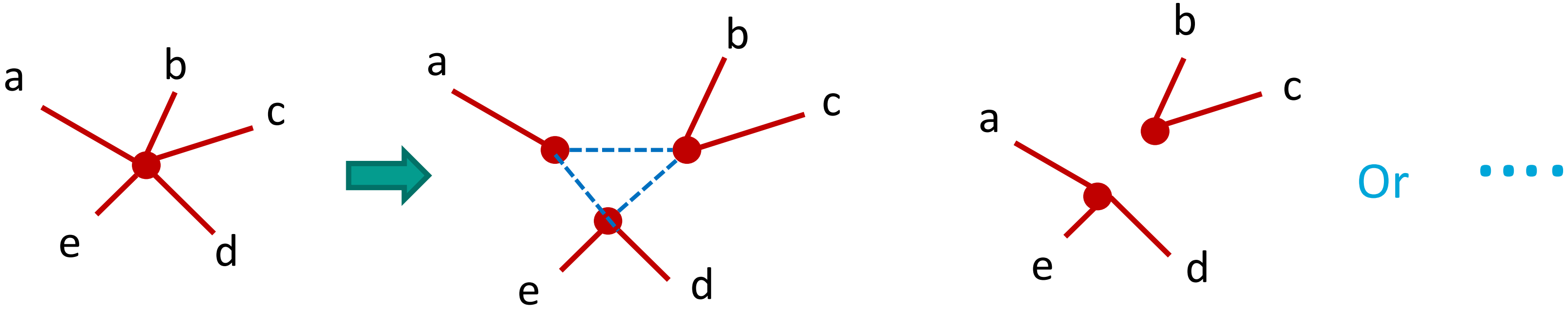


  - Power adjustments of generating units, Reduction of large loads (factory, …), Power adjustments of converters on HVDC links, …

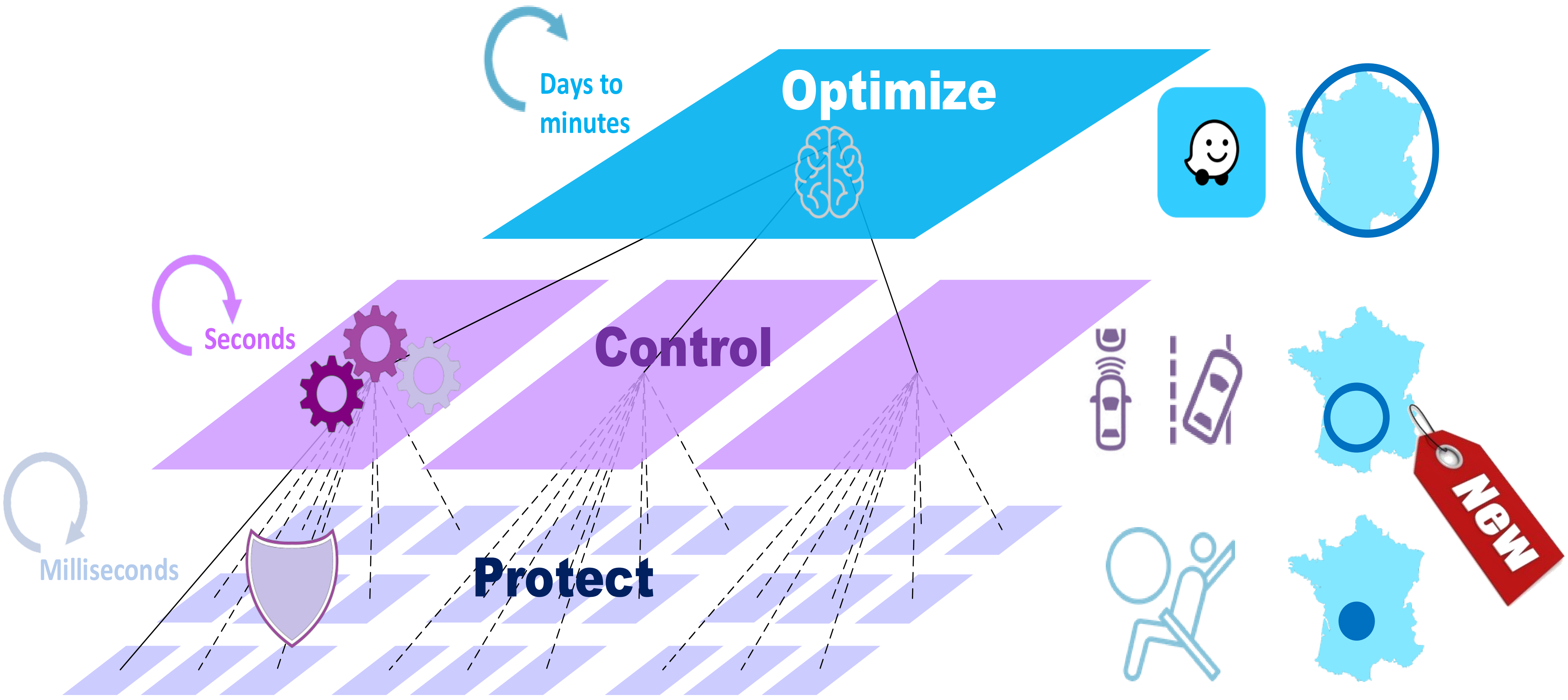
- Topological actions :
  - Open/Close Power Line :



  - Substation reconfiguration



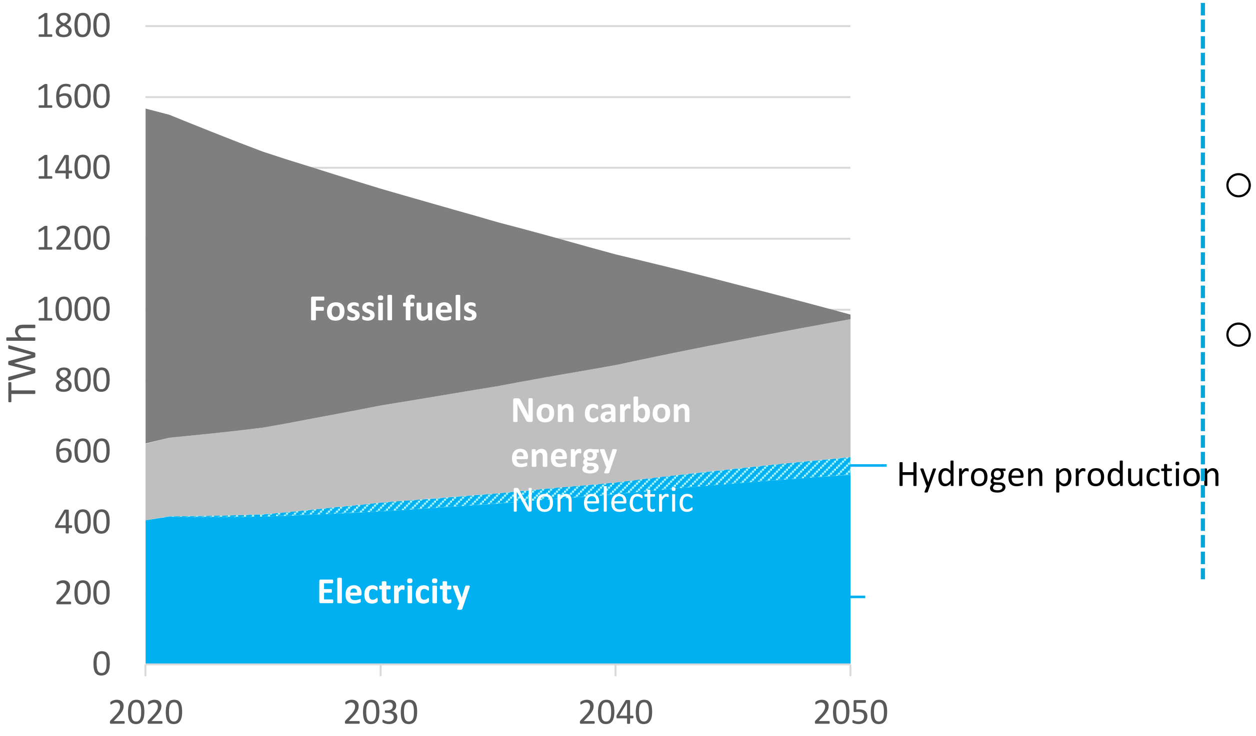
A new control Architecture – CyberPhysical System of Systems



Towards 2050

Evolution of Energy Consumption in France and share of electricity

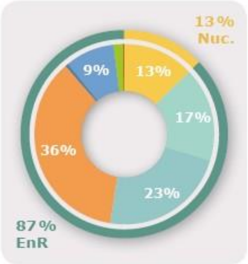
French National Low Carbon Strategy

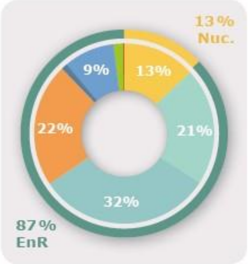


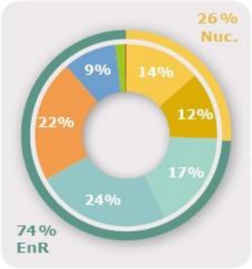
- **-40% in Energy final consumption**
- **+ 35% for Electricity**

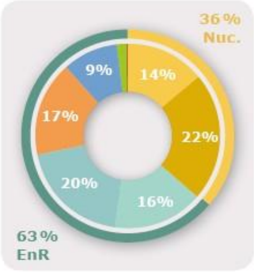
Potential new mixes

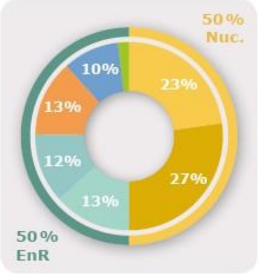
M0 100% REN In 2050	M1 100% REN distributed	M23 100% REN Large parks	N1 REN+ new nucl	N2 REN+ new nucl	N3 REN+ new nucl







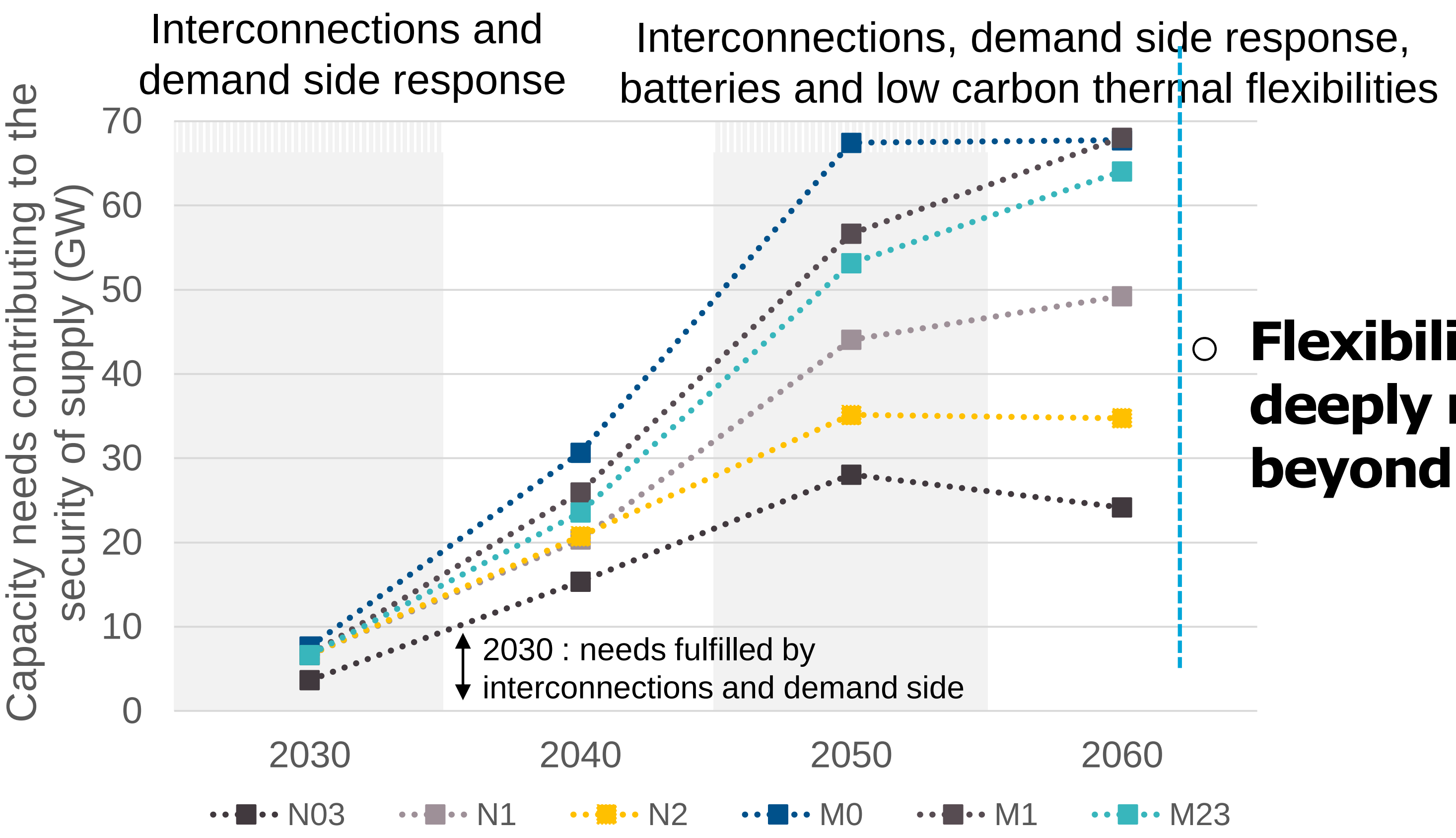




M0	M1	M23	N1	N2	N3
PV : (x22)	PV : (x21)	PV : (x13)	PV : (x12)	PV : (x8)	PV : (x7)
On WF: (x4)	On WF: (x3,5)	On WF: (x4)	On WF: (x3,3)	On WF: (x2,7)	On WF: (x2,3)

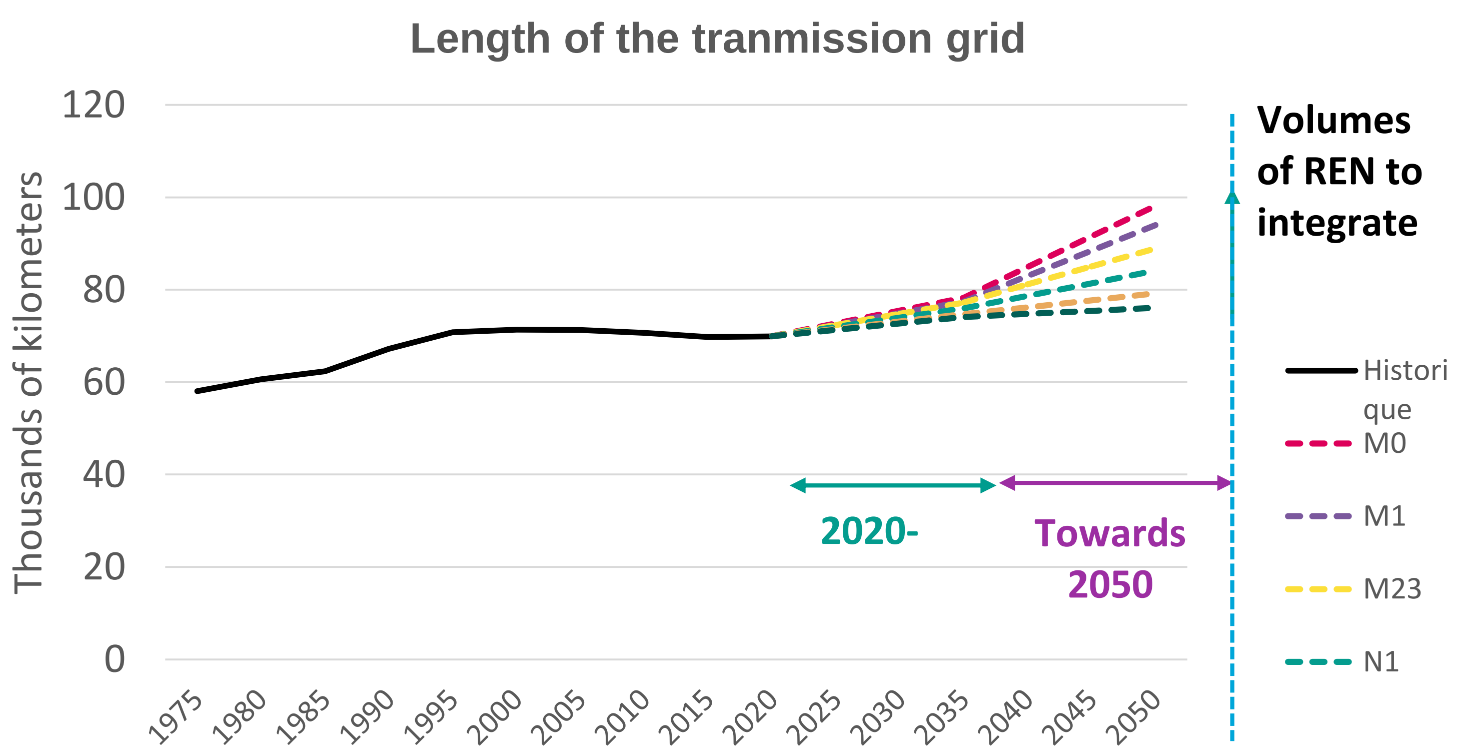
- **REN is a top priority whatever the scenario**

Needs for flexibilities



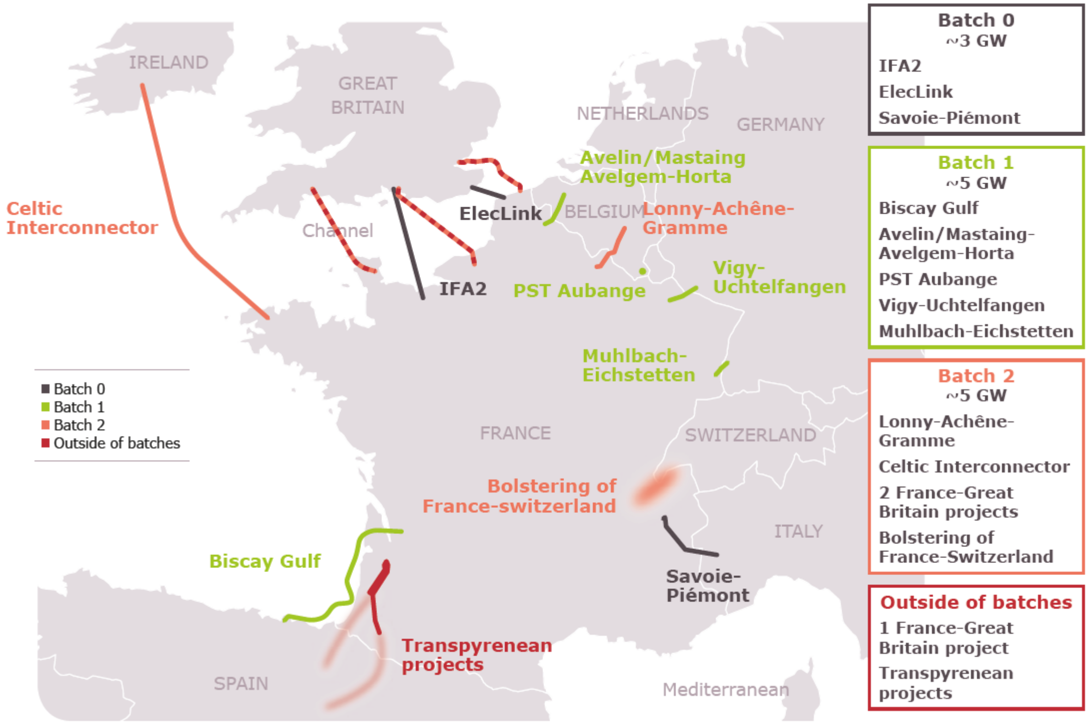
- **Flexibilities are deeply needed beyond 2035**

Needs for transmission grid



- Grid development is a challenge

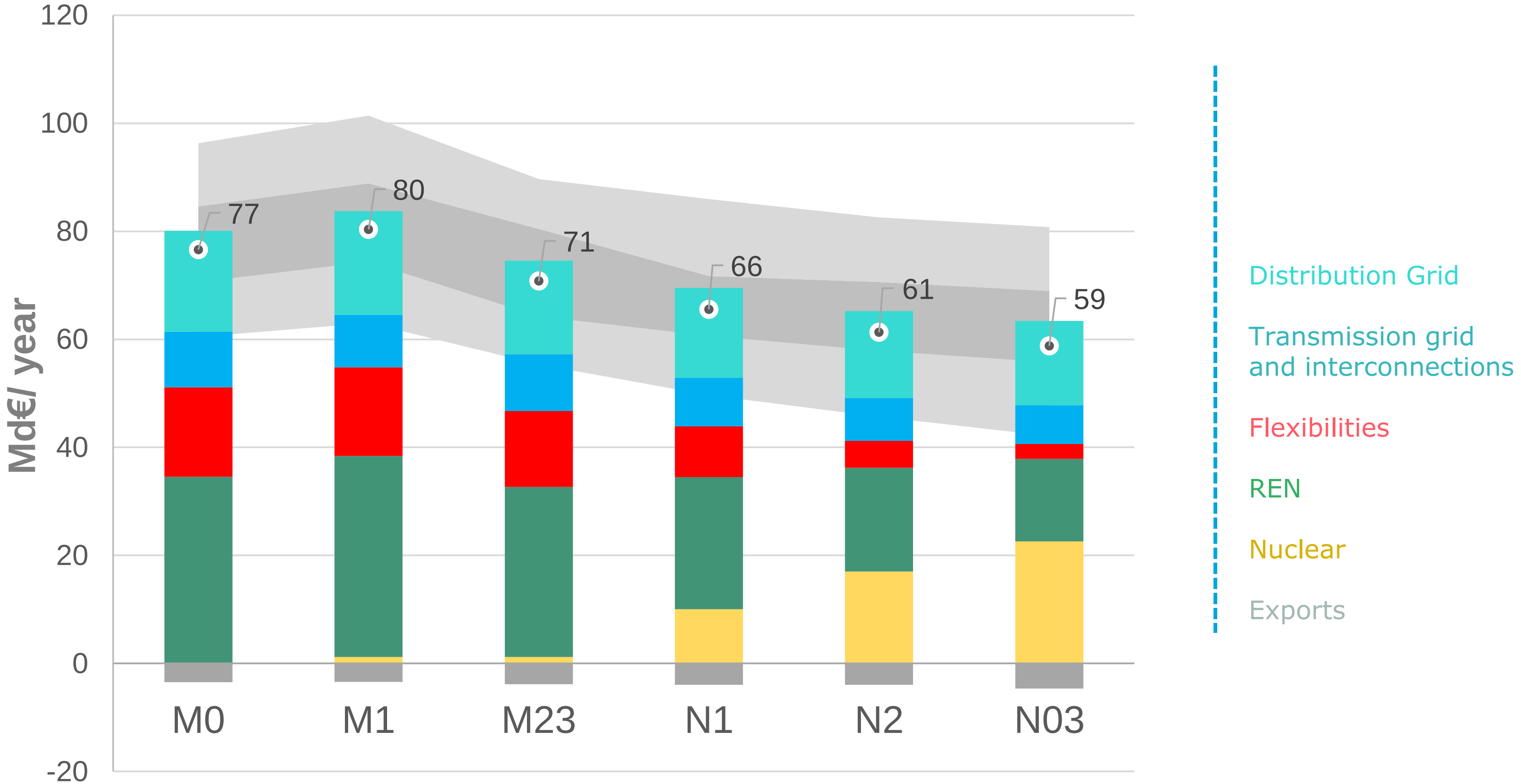
Reinforcing the European Grid



French Transmission Ten Year network development plan - 2019 edition

- Power Exchange Capacities **doubled by 2035**
- 39 GW of Capacities by **2050**

Needs for investments in electricity power system in France



- **Financing the transition is challenging**

Merci !