Energy transition: *coordinating a large population of partially autonomous agents*

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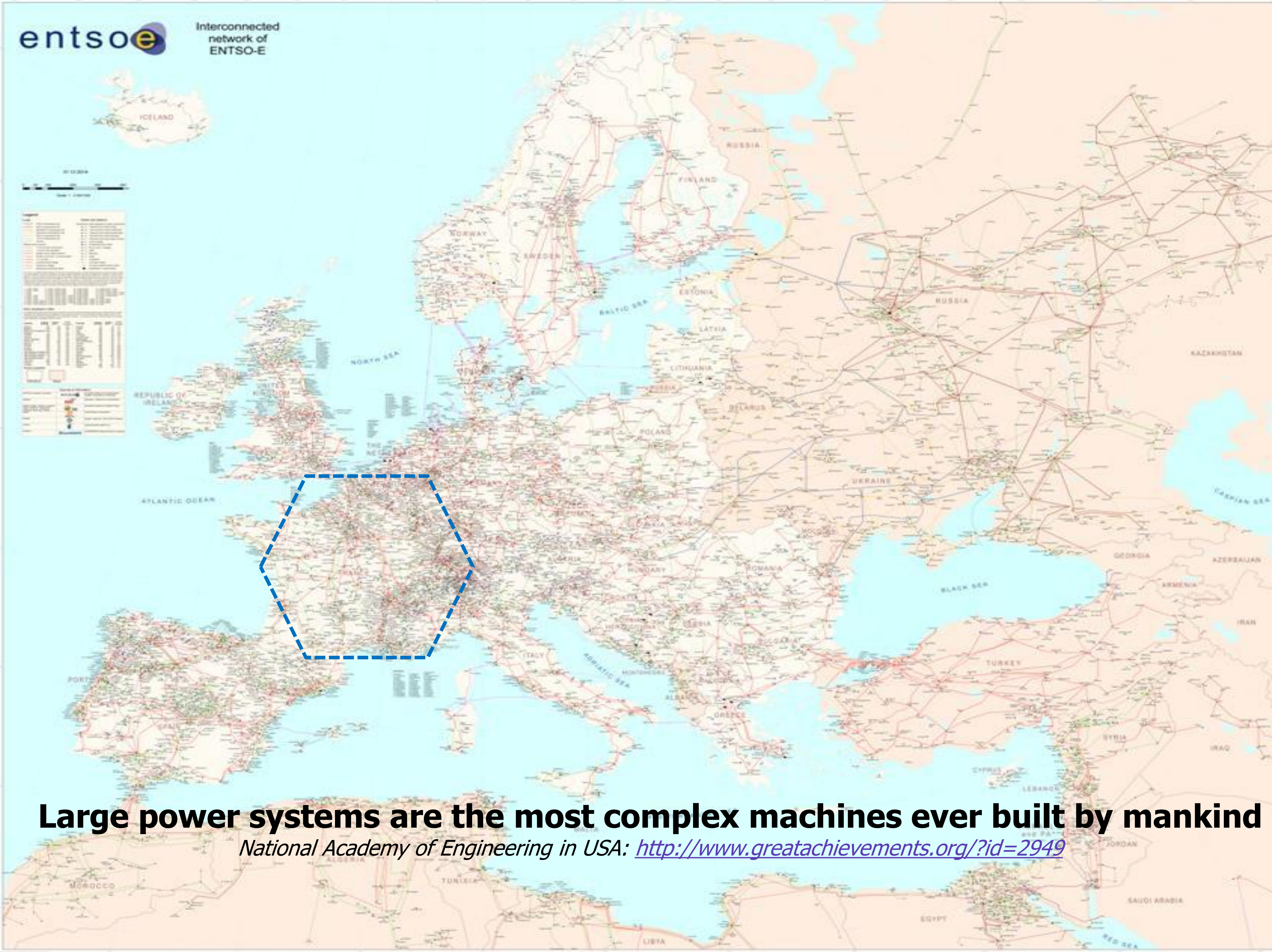
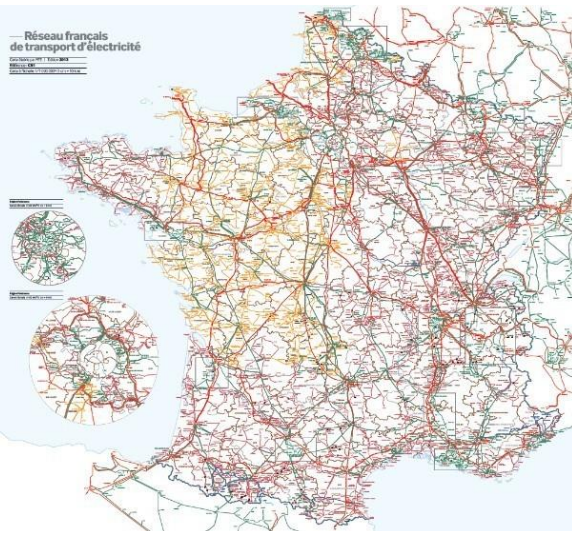


Large power systems are the most complex machines ever built by mankind

National Academy of Engineering in USA: http://www.greatachievements.org/?id=2949

RTE Overview

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



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

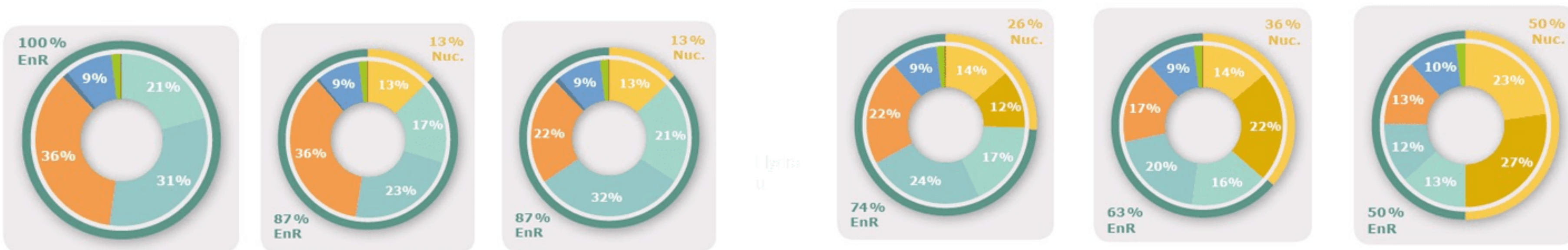
- 105 000 km transmission line (63 kV to 400 kV)
- 2800 Substations
- 22000 km optical fibers
- 48 interconnectors

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 helps to design and implements market mechanisms in order to obtain power from the most financially competitive sources across the whole of Europe.

France - Potential new mixes 2050

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

- ***In all scenario more dispersed generation (PV x7)***
- ***Main option for 2035 : too late to build new big power plants***

Coordination of large populations of agents /devices

- ✓ 1 Nuclear Generating unit : 1 GW ➔ Largest French wind park (around 200 MW * 30%) =60 MW

  Yesterday: 1 control signal ➔ Tomorrow : ~ 20 control signals

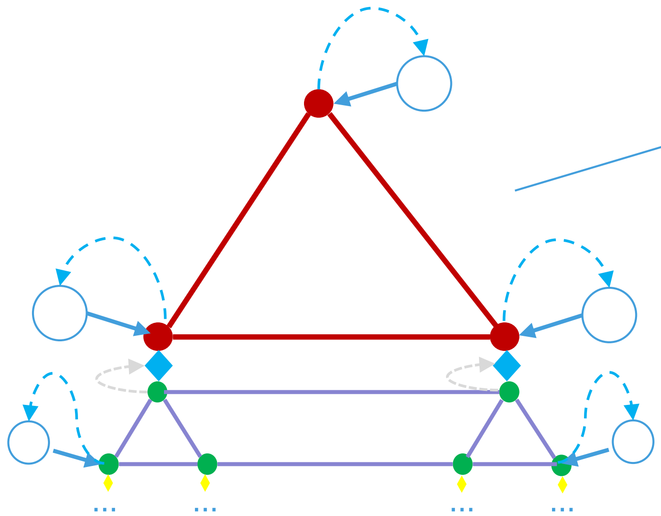
- ➔ PV generation : 2020 = 10.5 GW, only 650 MW connected to the transmission grid.

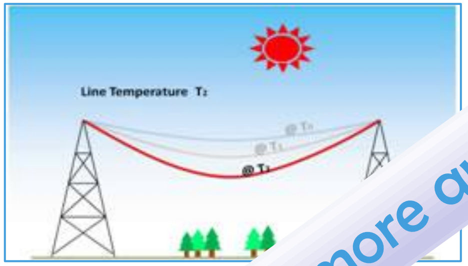
  Target +4 GW/year ➔ > 10^6 installations of rooftop PV panels!

- ➔ More dispersed generations and more active consumptions can create local congestion in the electrical grid but also offer new possible controls. **More local controls seem mandatory**.

- ➔ Grid expansion planning is based on 70% of the maximum RES capacity. During the few hours of the year when power exceeds this limit, **automatic controllers are required for curtailing the power of many small renewable generation units.**

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

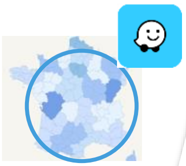




- More closed controls are required: … mittency of wind/solar power creates volatile power flows in the gri…
  - Taking advantage of d… ratings (DLR) depending on local weather conditions
  - Using all levers (… rs):
    - Recon… of substation, Electrical Batteries, « Smartwires », Phase-Shifting transformer,
    - … ent of wind/solar power

Nowadays, preventive open loop policy requires more and more margins

A new control Architecture – Cyber Physical System of Systems



Optimize

CENTRALISED CONTROLS – OPTIMIZATION
View : global & anticipative in control center room
Goals : anticipated set-points = coordination layer + preventive action and human in the loop!

Smart assistant

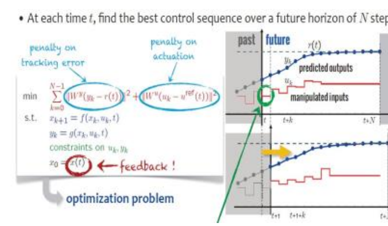
Control

Cyber Physical System

AREA CONTROLS

NEW

Autonomous Area : substations (~10)
Curative actions
Goals : closed loop control - using Model Predictive Control + applying actions while following set-points received from higher layer

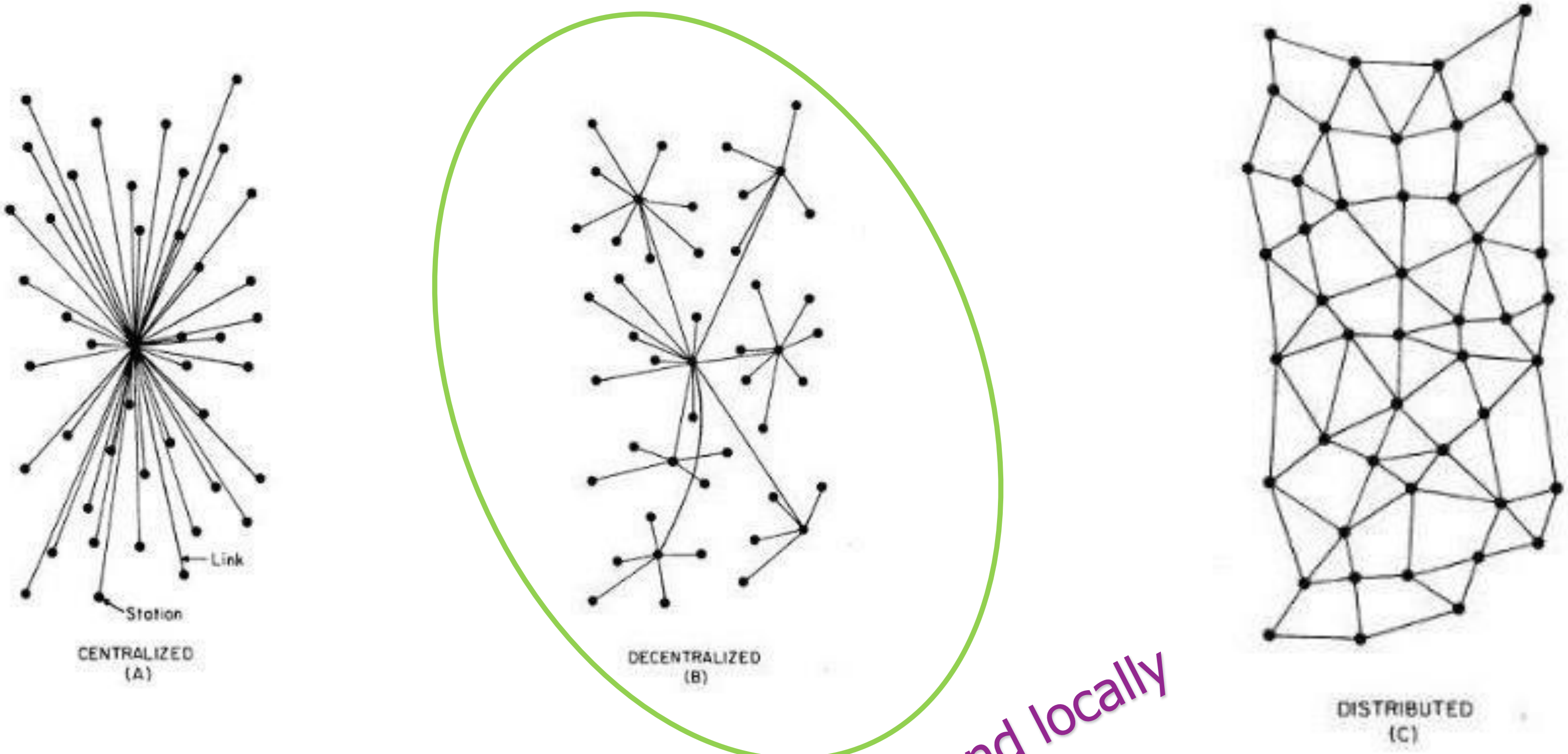


Automatic actions

Protect

SUBSTATION PROTECTIONS
In a substation
Goals : ensure last resort equipment and person protection
Simple & Reliable

“Edge computing” to manage complex system



Hierarchical and locally distributed

Challenges

→ **Design of new fully automatic control layers**

- Model predictive control seems a good framework, but with delays, uncertainties, non linear system, discrete decisions, partial observability..
- This is a critical system: validation and certification mandatory: formal verification including the ITC implementation
- Industrial generic solutions: several hundred instances in France in 2035, simple tuning methodology
- Coordination via the upper layer “optimal trajectory and setting”, setpoints (trajectory), subset of “secure” actions based on safety requirements and abstractions of the local controllers are needed!

Conclusions

- Advanced distributed controls and edge computing are vital in managing the interactions and dynamics of the evolving power system.

- The automatic control community should play an important role in helping us find solutions.

Some of our related works:

Online Feedback Optimization for Subtransmission Grid Control, L.Ortmann, J. Maeght, P. Panciatici, F. Dörfler, S. Bolognani https://arxiv.org/abs/2212.07795

Power grid segmentation for local topological controllers, N. Henka, Q. Francois, S. Tazi, M. Ruiz, P. Panciatici, https://doi.org/10.1016/j.epsr.2022.108302

Predictive control based on stochastic disturbance trajectories for congestion management in sub-transmission grids, N. Dkhili, S. Olaru, A. Iovine, M. Ruiz, J. Maeght, P. Panciatici, https://doi.org/10.1016/j.ifacol.2022.09.041.

THANK YOU FOR YOUR ATTENTION

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