(R)evolution of Power Systems : a cyber-physical system of systems perspective

Energy meets 5G Mobile Networks
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Outline

- ✓ (R)evolution of power systems
- ✓ Dynamics of power systems
- ✓ One use case: minimal curtailment of wind power
- ✓ Cyber-physical systems of systems

(R)evolution of power systems

- The massive integration of generating units based on renewable energy sources (RES) with nearly **zero marginal costs** and mostly connected through **power electronics** to the grid imposes us to rethink how to protect, control and optimize power systems.

- The low controllability of RES generating power pushes to envision solutions based on **storage devices** and **demand responses** in order to balance the system. These evolutions are disruptive, historical design assumptions are becoming obsolete: No electrical storage, inflexible demand.

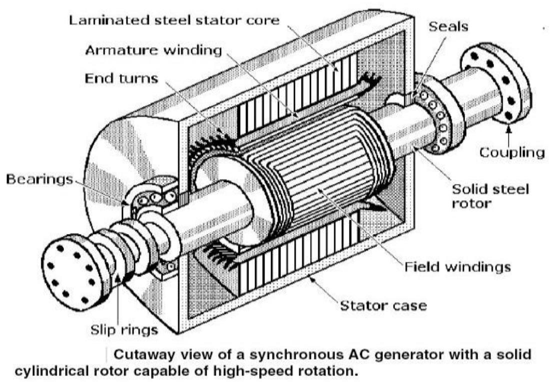
- There is a urgent need to rethink both **economics and dynamics of power systems**. Patches to adapt marginally the historical design are perhaps not a good approach even if the migration path is a critical issue.

- Let's focus of some issues on **power system dynamics**.

Energy Transition: new type of generating units

✓ Integration of more and more wind, solar power generating units in electrical grids

► Smaller units interfaced through power electronics to electrical grids: Central Europe Synchronous Grid



Thousands of large synchronous generators > 500 MW

Millions of power electronics interfaced generators < 100 MW

System dynamics imposed by

Physical laws and hardware ➔ Controllers and software

From Inertia to Synchrony

- ✓ Actual system "Inertia" is not a requirement
- ➔ Consequence of the existence of large synchronous generators

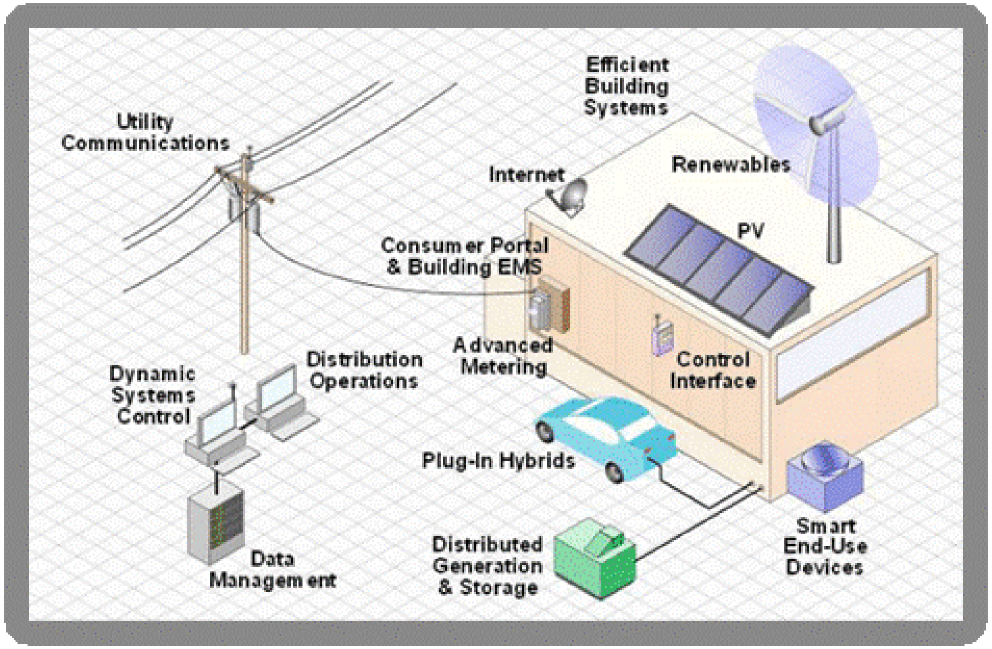
- ✓ But we need "synchronization" and frequency control
- ➔ Actual Inverters follow the grid frequency. With more electronics power connected generators, some inverters should create the frequency (**grid-forming**).

- ✓ Voltage sources required but maximum currents of inverters are very close to their nominal currents …

- ➔ EU Project MIGRATE: **M**assive **I**nte**GRAT**ion of power **E**lectronic devices, (01/2016 – 10/2019), www.h2020-migrate.eu

Energy Transition: Distribution grids become active

✓ Yesterday: random passive behaviors helping the system: no synchronization and instantaneous impedances!



Tomorrow:

►A lot of possible controls!

►Which objective?

➔Too local objectives could jeopardized the system reliability

Active Distribution Networks (ADN)

- ▶ Smart ≠ Synchronous and fast behaviors

- Synchronization of prosumers' behaviors

With demand response based on market prices and GPS-synchronized (< 1s.)

✓ Smart buildings could start simultaneously to consume more or less

➔ big and fast variations of power injections in the system

- Fast voltage controls in distribution grids

"Contribution of distribution network control to voltage stability: A case study" P. Aristidou, G.Valverde, Member, T. Van Cutsem

"This fast load power restoration may precipitate system collapse, making the situation more severe than with classical LTC control."

- ▶ Objectives of local controls in ADN must take into account their impacts of the overall system dynamics

One use case:
minimal curtailment of wind power

Réseau de transport d'électricité

Minimal curtailment of wind power in a 90 kV pocket of the French Grid

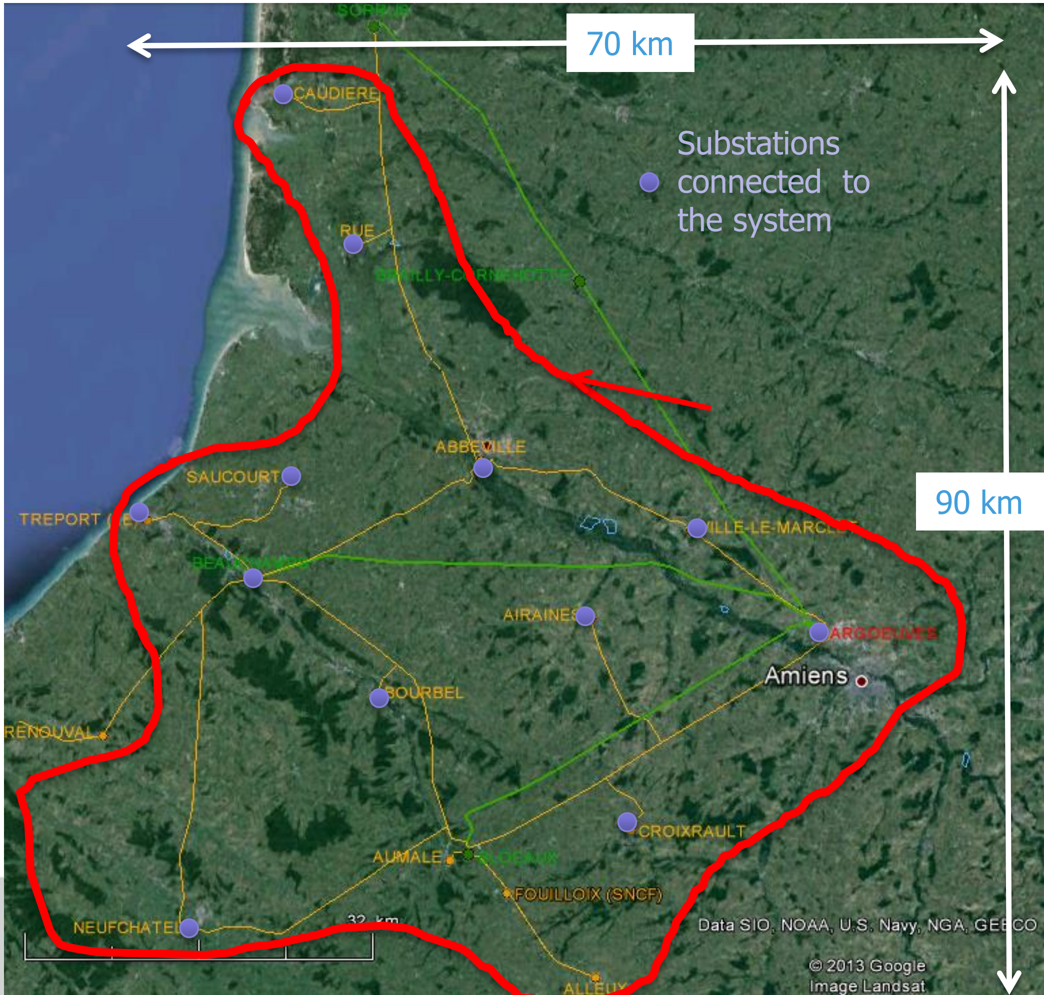
Automatic control of an area from a Master Substation

<u>Objective:</u>

Integration of more wind power without grid expansion

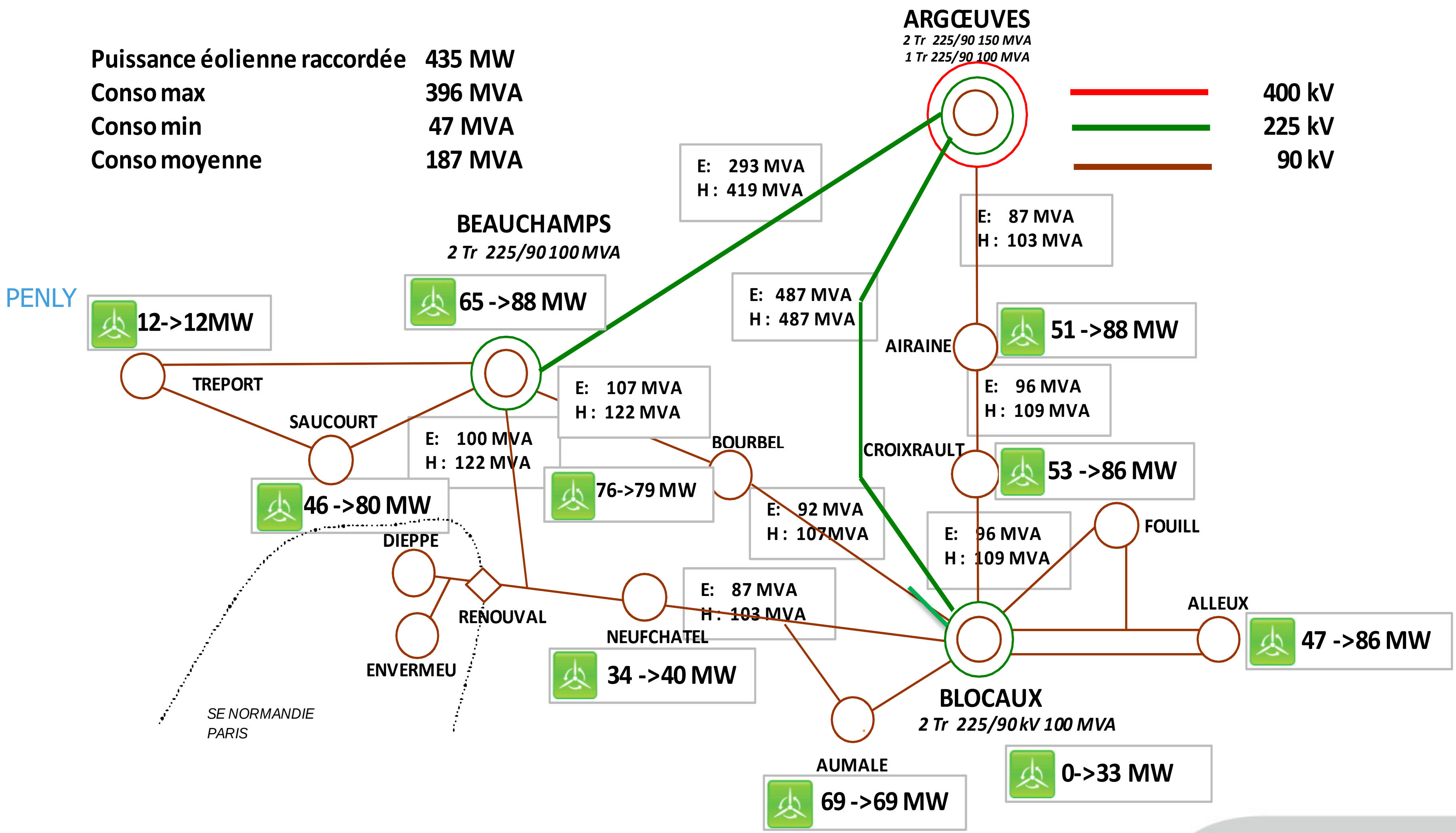
► Keeping a meshed operation of the grid to ensure a good quality of supply: N-1, voltage

► 12 substations involved (pocket 90 kV around Blocaux),



Description of 90 kV pocket: new wind farm projects

Puissance éolienne raccordée	435 MW
Conso max	396 MVA
Conso min	47 MVA
Conso moyenne	187 MVA



Dynamic rating of power lines, topological actions then wind power curtailment

DLR Weather based

- Modeling of the thermal behaviour of conductors based on dedicated weather sensors in specific substations at the boundaries of the area (flat land without obstacles), Possible anticipation (30 min. to 3 hours)
- 16 power lines = 380 km, minimun expected extra capacity : 18%, maximun extra capacity > 100%

State estimation for the area (DC approx)

Minimal curtailement of wind power (DC approx.) taking into account

- Dynamic rating of power lines
- Switching of breakers (bus merging/bus splitting)

➔ First implementation: myopic conservative control

➔ Target: forecast and Model Predictive Control

Hierarchical controls in large power systems

- What to decide locally?
- Interactions between the different levels of controls?
- Flexible local control policies decided by the upper level?
  - ➔ Contextual,
  - ➔ Not only set points or parameters but new controls (pieces of codes), modern IT solutions

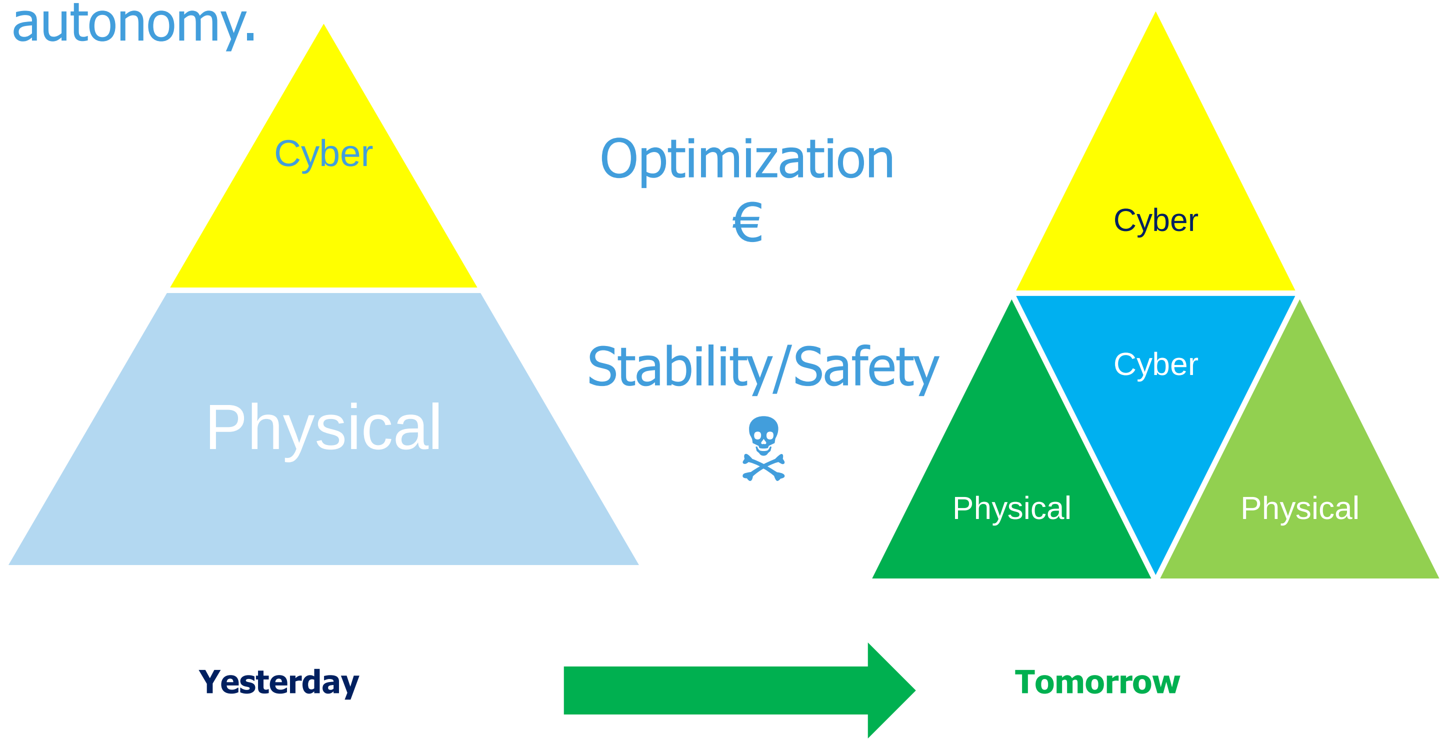
    "RIAPS (NODES) DOE ARPA-E project"

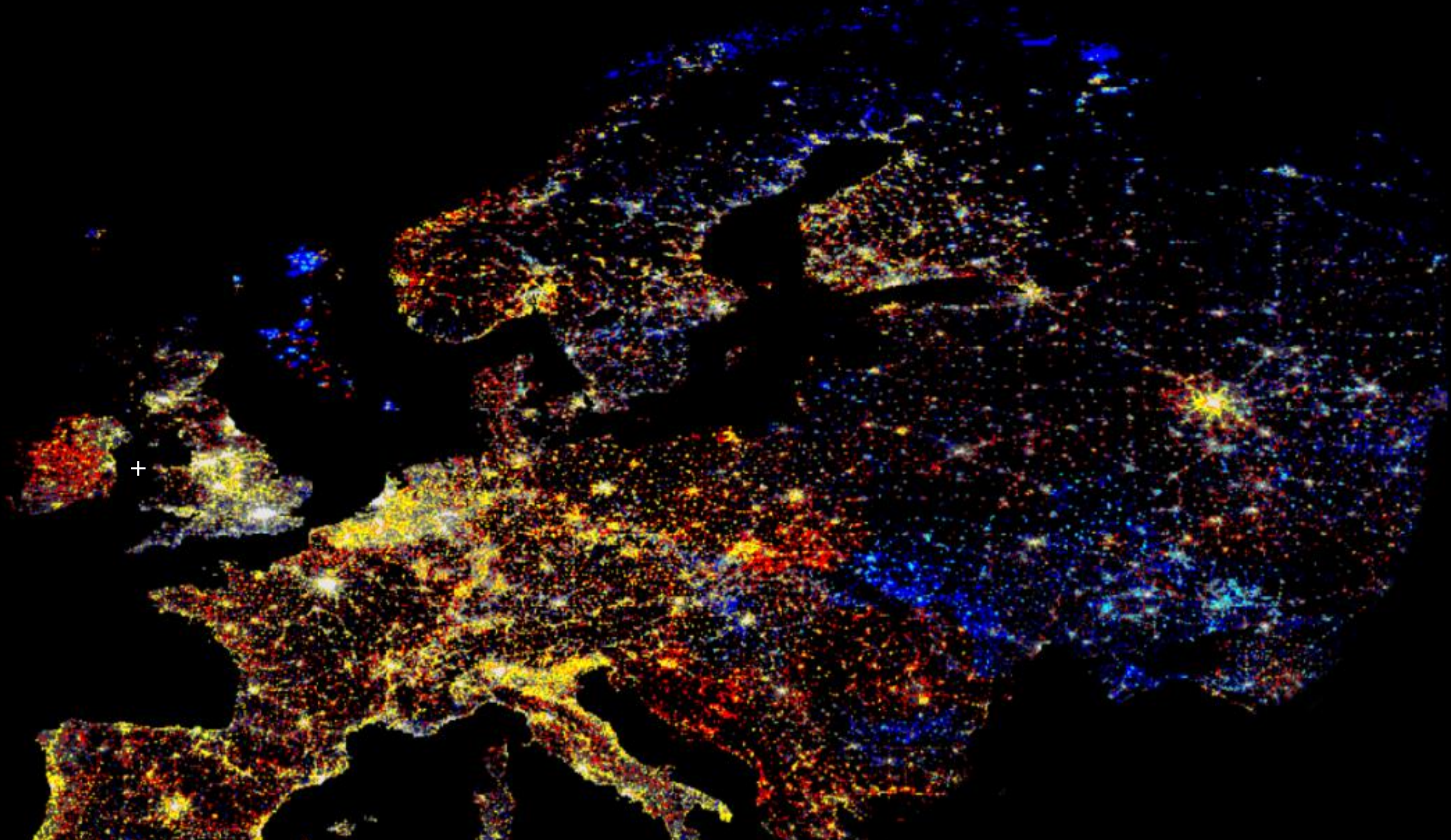
Complexity: Security assessment performed at the upper level must be aware of the existing advanced controls embedded in the lower levels!

Cyber-physical systems of systems: ICT more and more at the core of power system….

✓ Energy Transition pushes towards more dispersed generation and distributed controls

To ensure a secure and efficient operation of large power systems ➔ observability / controllability of large population of devices/agents with partial autonomy.





THANK YOU FOR YOUR ATTENTION

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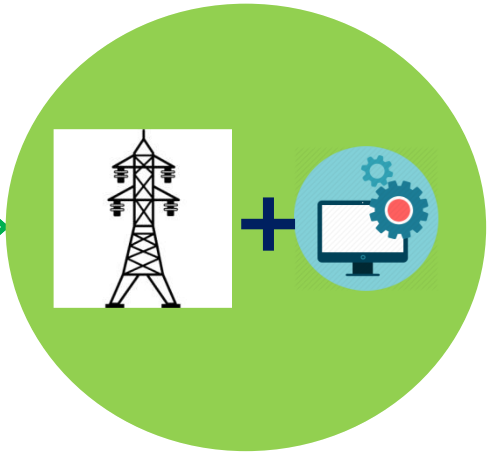
Cyber-Physical Systems of Systems

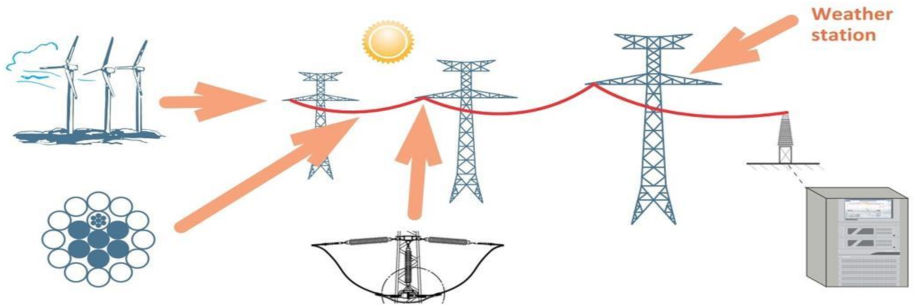
✓«Cyber» dimension in all the decision making processes from system design to system operation

- Yesterday:  then 

➔ Co-design of «hardware/software»



e.g.: «Dynamic Line Rating»



✓ advanced ICT for complex, critical infrastructures