Architecting Future Grid

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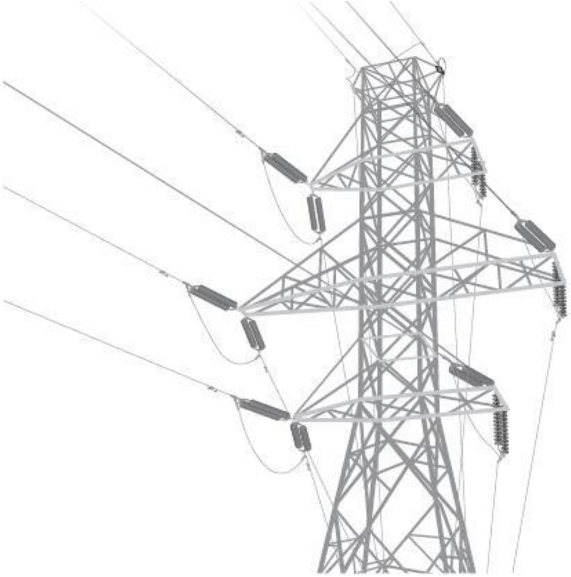
Power System: A Traditional View



Bulk Power System

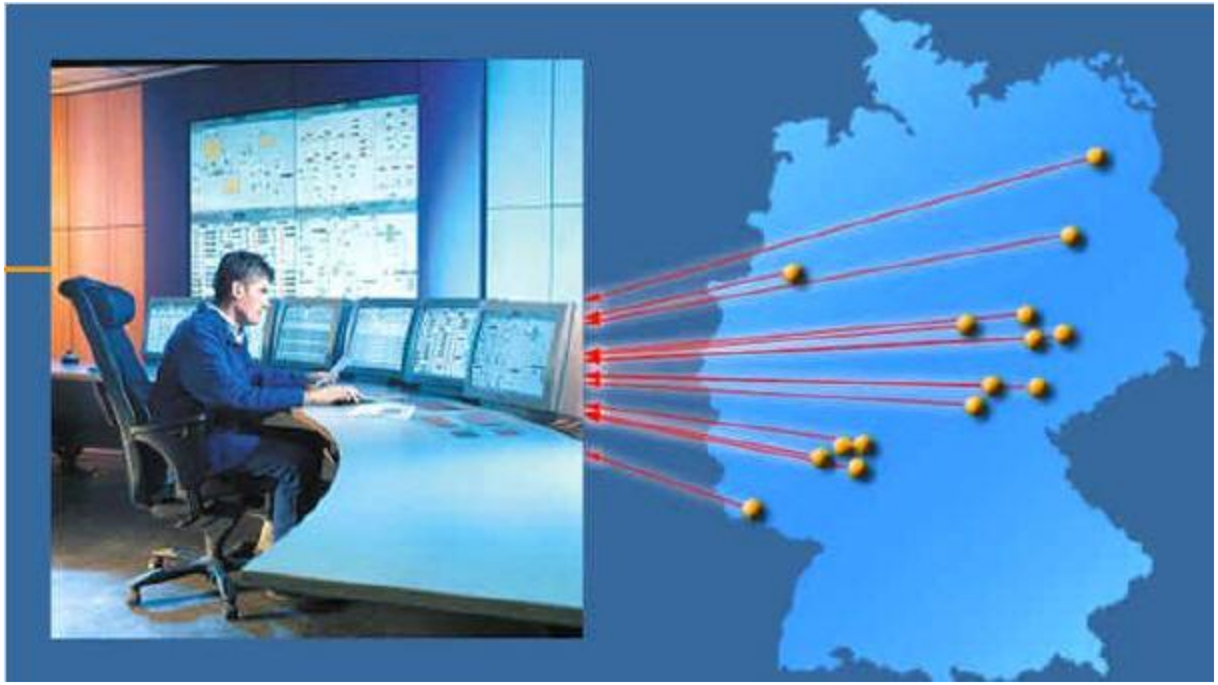
Distribution

Two separate systems

The lines between Transmission and Distribution are blurring

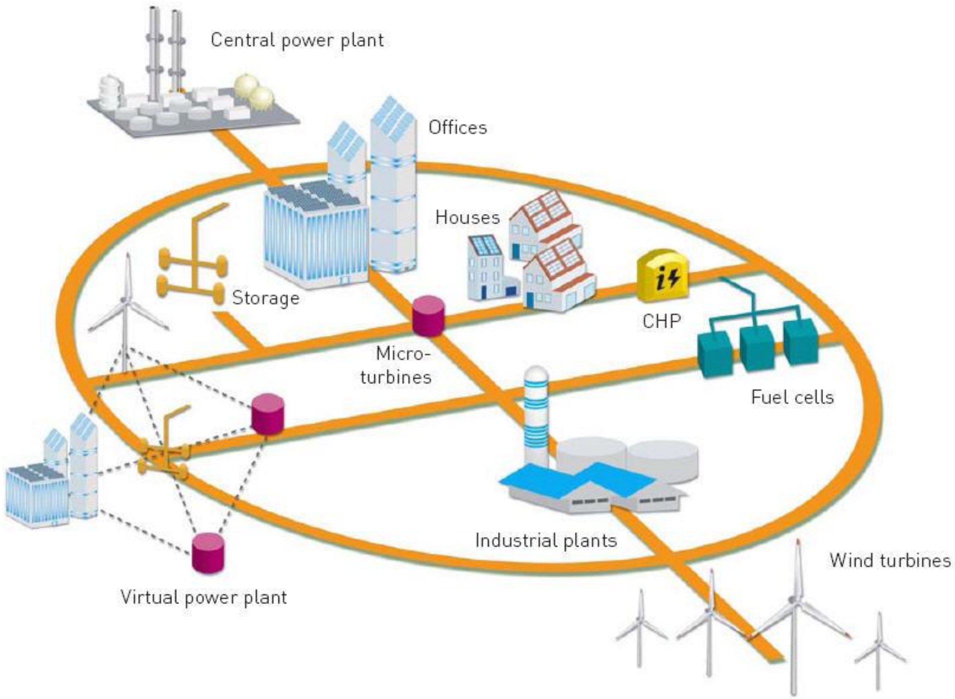
- Increasing number of generating resources located on the distribution network (e.g. wind turbines, solar arrays, microgrids, CHP)
- Demand resources playing a larger role in traditional “transmission level functions” (e.g. energy, reserves and emergency response)
- Virtual Power Plants (VPP)
- Regional Power System Control entities need more granular locational and capacity information for both demand and supply resources located on the distribution network

Distributed Resources



- Distributed energy resources are aggregated to participate in the bulk power system operation and wholesale markets

Microgrids



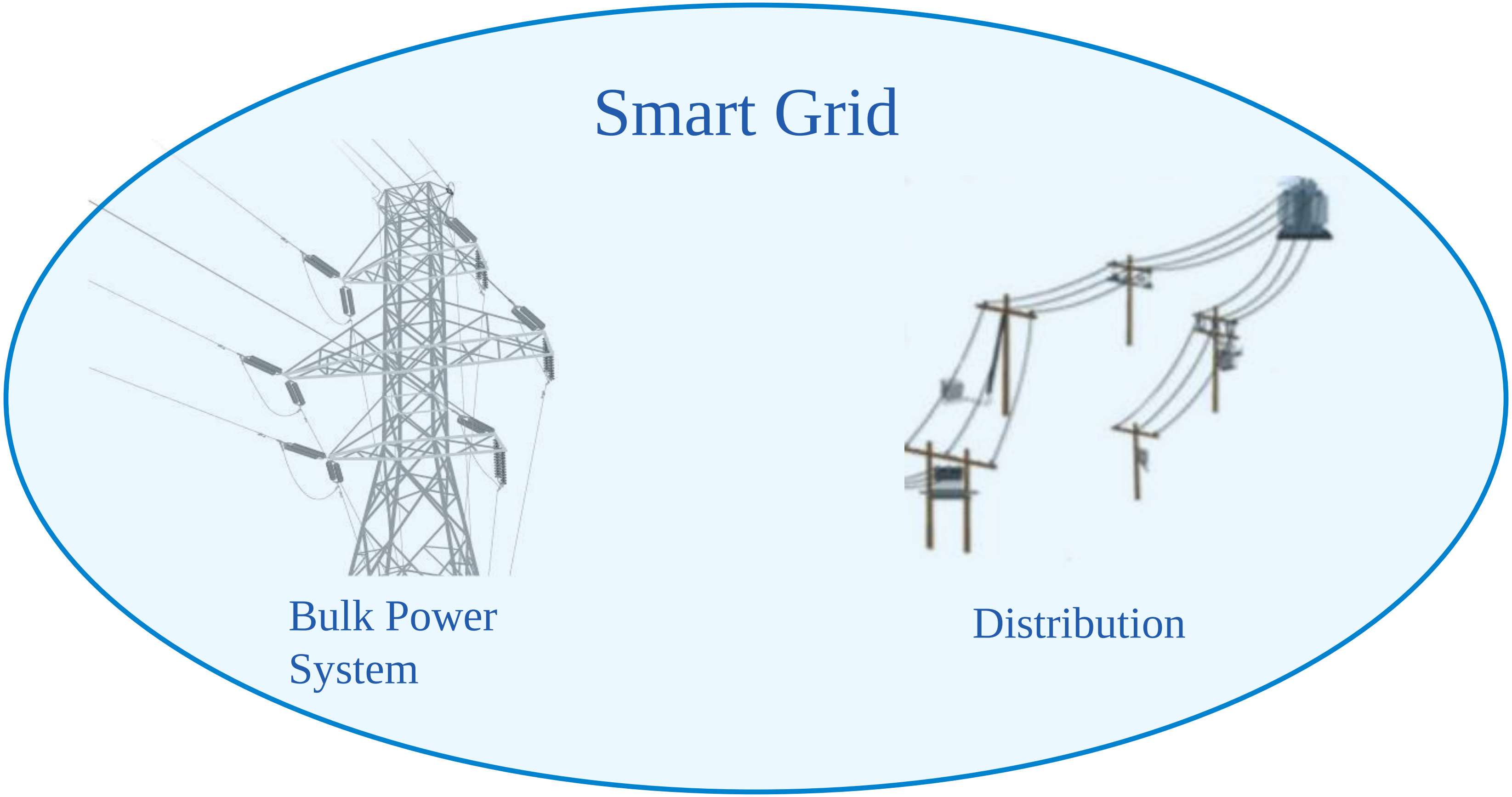
Source: EUROPEAN TECHNOLOGY PLATFORM SMARTGRIDS

- Microgrids
  - Microgrid is a comparatively small network with distributed generation and storage capable of both supplying its own loads and buying electricity from the grid
  - It is an alternative to transmission and requires new approaches in control and market integration

Electric Energy Storage

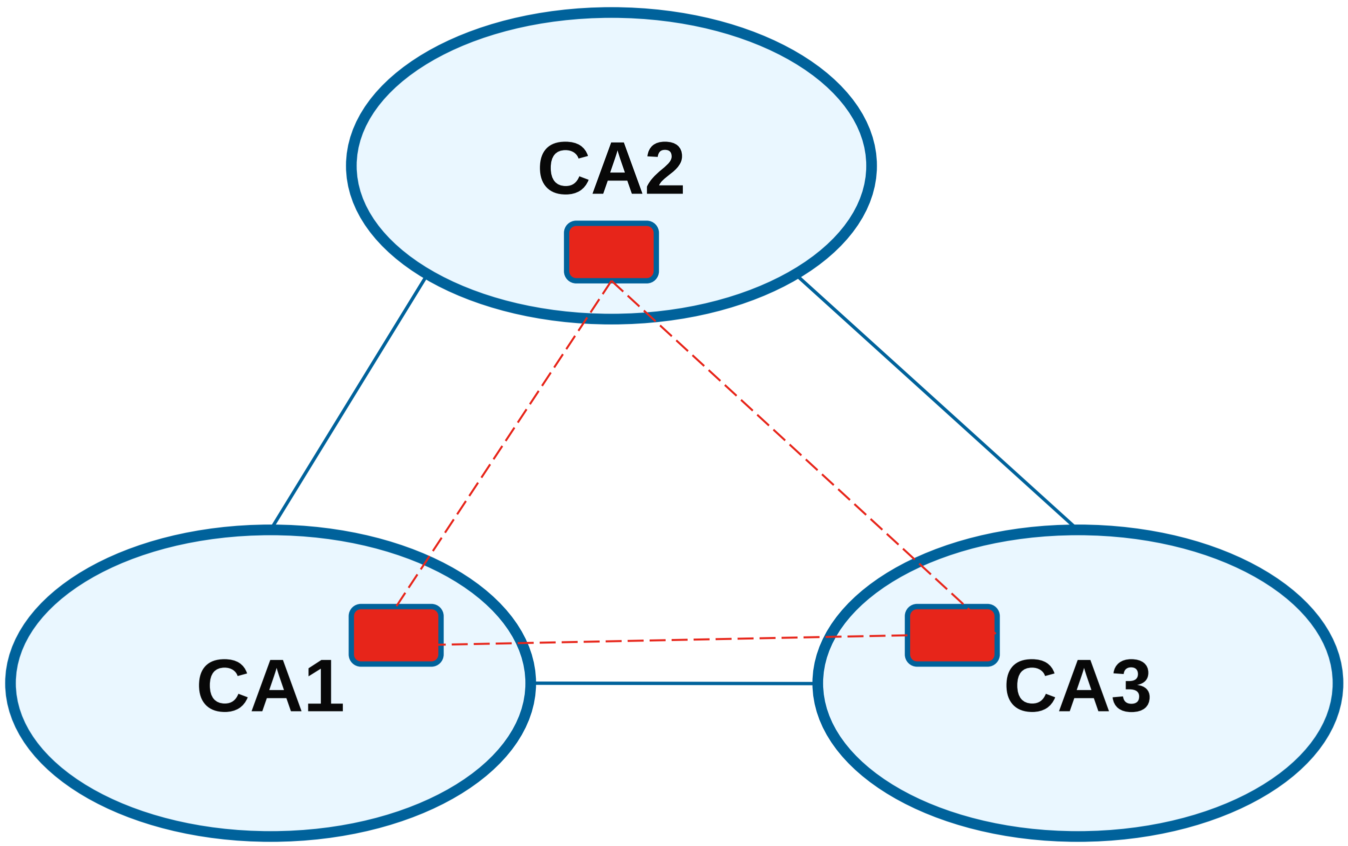
- Can be used to shave load peaks and in emergency conditions
- Reduce the variability of renewable resources
- Can be attached to the grid or be a part of virtual power plants, microgrids, wind farms, DR or PHEV aggregators, etc.
- Many different types: pump storage, electric batteries, compressed air, ice, flywheels, etc.

Power System: The Smart Grid

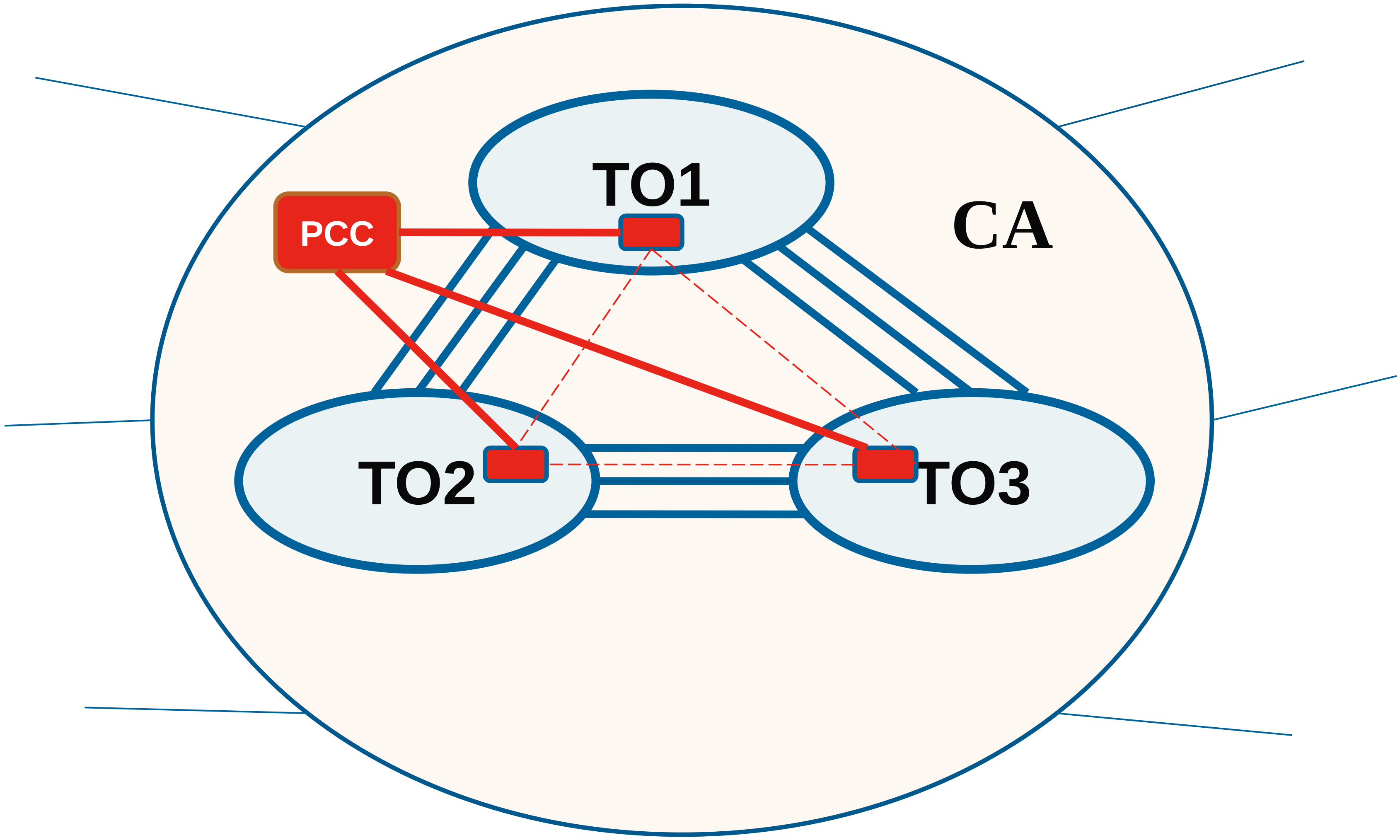


Common policies, reliability and control standards

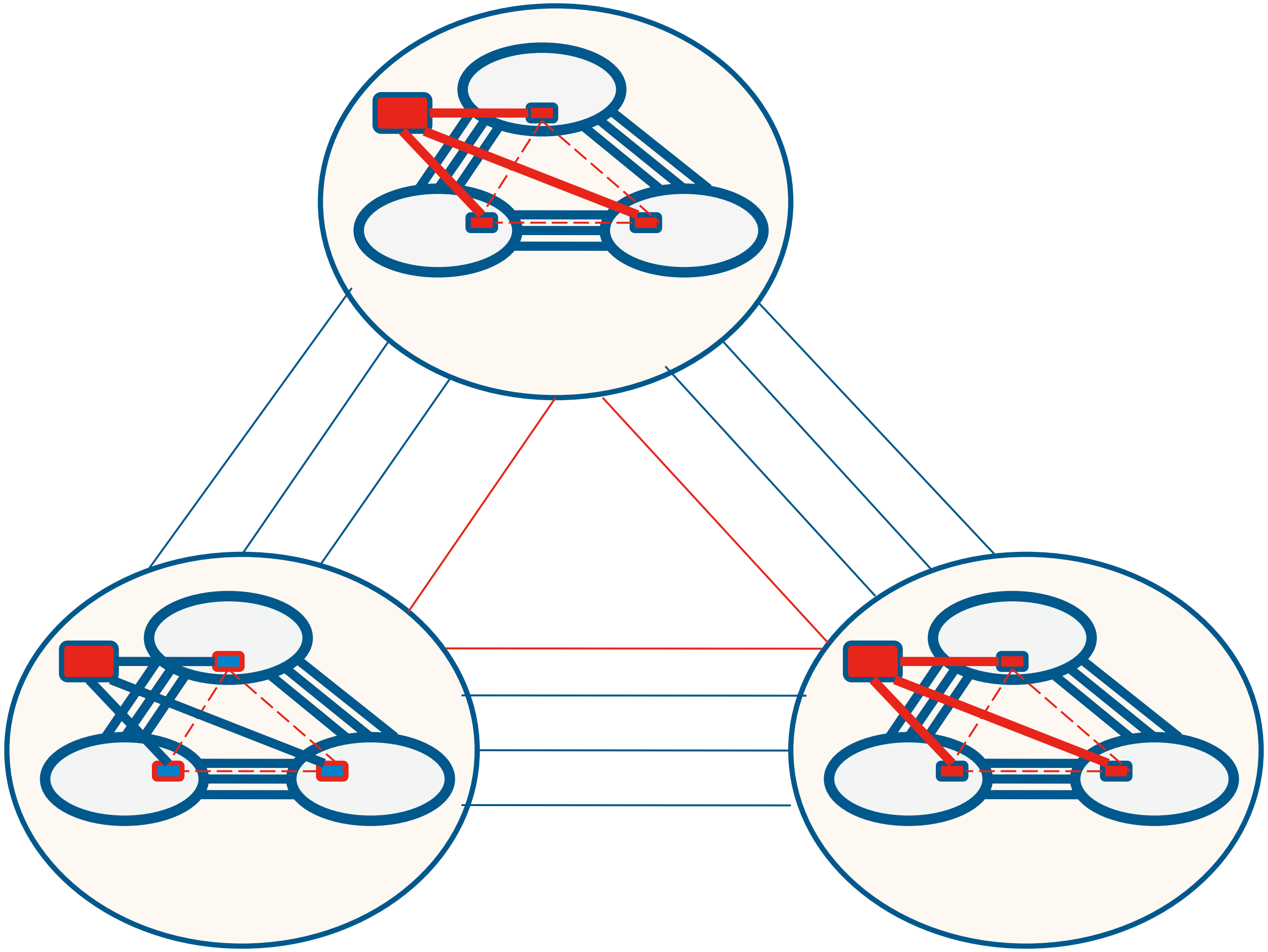
Power System Control Evolution (before 1969)



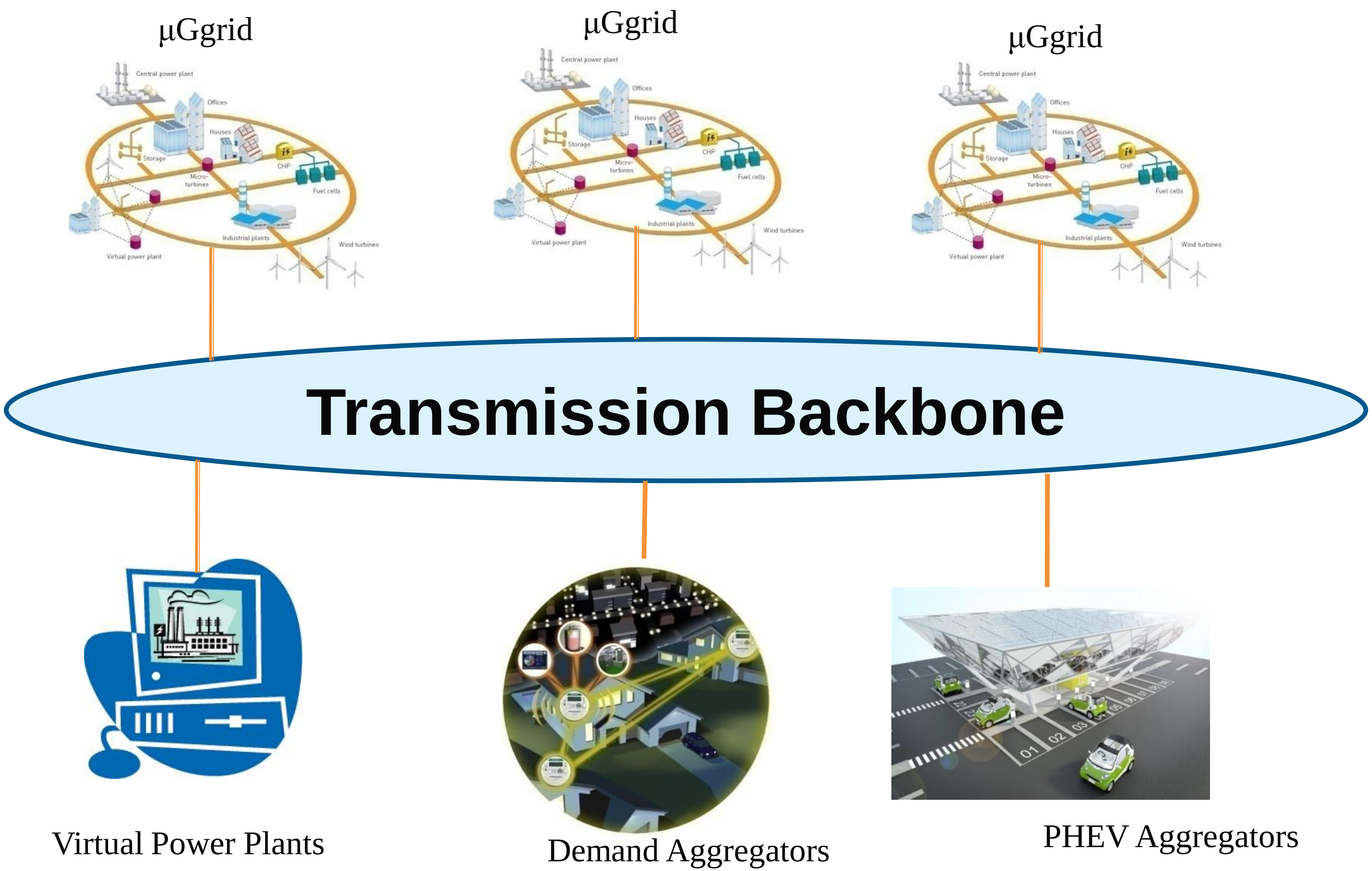
Power System Control Evolution (creation of pools)



Power System Control Evolution (markets)



Power System Control Evolution (what's next?)



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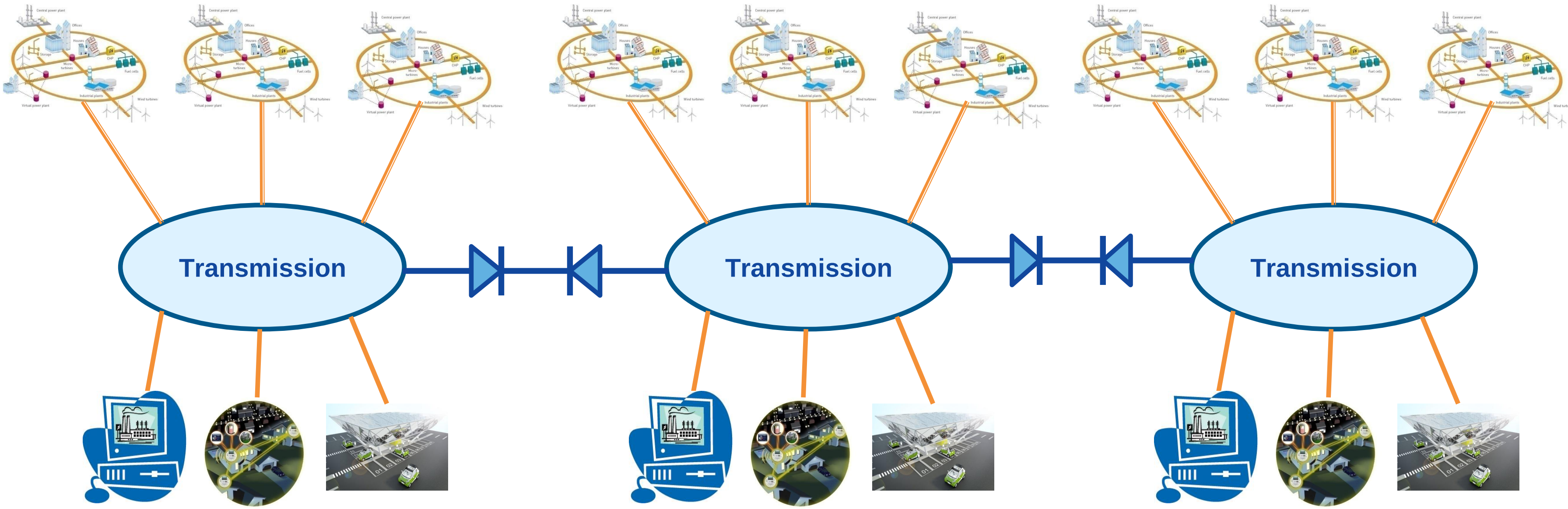

May be this?

Is Fully Decentralized Control Possible?

- Parallel flows
- Inability to store electricity in commercial quantities
- Sectionalized structure?
- Does wide area control require the model of the whole system?
- Is there a limit to the size of the market and system due to sub-optimality of the solutions for very large systems
- Can complexity be measured and controlled?

Much Higher Level of Uncertainty

- Region wide System Operations and Planning become much more complicated under the Smart Grid
  - Renewable and distributed resources offset the load
  - Much more challenging long term and short term load forecasting
  - Number, size and location of independently managed Microgrids
  - Demand response and price sensitive demand
  - PHEV
- Requires more frequent interaction among system control entities and new optimization approaches
- Requires new tools for both operations and planning
- Requires new tools and algorithms for the load forecasting

The Need for more Flexibility

- Ability to faster react on different disturbances
- More reliance on corrective actions
- Wide area monitoring
- System integrity protection – survivability vs. reliability
- Risk-based operation
- Online constraints calculation
- Adaptive and distributed control
- Mew optimization algorithms: robust and stochastic optimization, MIP

The Need for more Flexibility (cont.)

- New transmission technologies:
  - Power electronics
  - Superconductors
  - HVDC and HVDC-lite
  - Nanotechnologies
- Intelligent Electronic Devices – distributed intelligence
- Storage
- Dynamic and adaptive line ratings
- Power quality standards

Reliability

- Future grid poses great challenges to the conventional reliability concept:
  – the contingency definition, being binary on/off, is changing to include probability distributions
  – Computer and communication system contingencies will have an effect similar to traditional transmission or generation contingencies
  – defining contingencies for distributed resources or micro grid with multiple, sometimes geographically distributed connection points, would be non-trivial
  – with the responsive loads, the definition of a loss of load event would be ambiguous
  – Quality of service and spatially different reliability needs

Survivability

- New technologies will lead to emergent behavior – not necessarily positive
- Self-Organized Criticality - blackout cannot be avoided by tightening the current reliability criteria
- Concepts of survivability and robustness
- The realization of a survivable system will rely on advanced detection, control and coordination techniques
- Survivability is an *emergent property* of a system – desired system-wide properties “emerge” from local actions and distributed cooperation
- How do you effectively model, simulate, and visualize survivability?

Survivability

- The ability of the system to continuously provide energy to the customers in the presence of a failure or attack on the system
- Four properties of survivability:
  - Resistance to attack – system design, short term planning
  - Recognition of intrusion –local and wide-area monitoring
  - Recovery of essential or full service after attack – protection, emergency control, SPS/RAS, WASIP, reconfiguration
  - Adaptation/evolution to reduce effect of future attacks – cognitive systems
- Why is it so difficult to define the metrics for survivability? Rare but high impact events!

High Performance Computing

- Needed for much faster and adaptive system reaction to events
- On-line stability analysis
- Handling multiple scenarios
- PMU processing
- Agent-based simulation
- Cloud computing
- GPU-based computations