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Practical aggregation of small energy resources for frequency control

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Practical aggregation of small energy resources for frequency control

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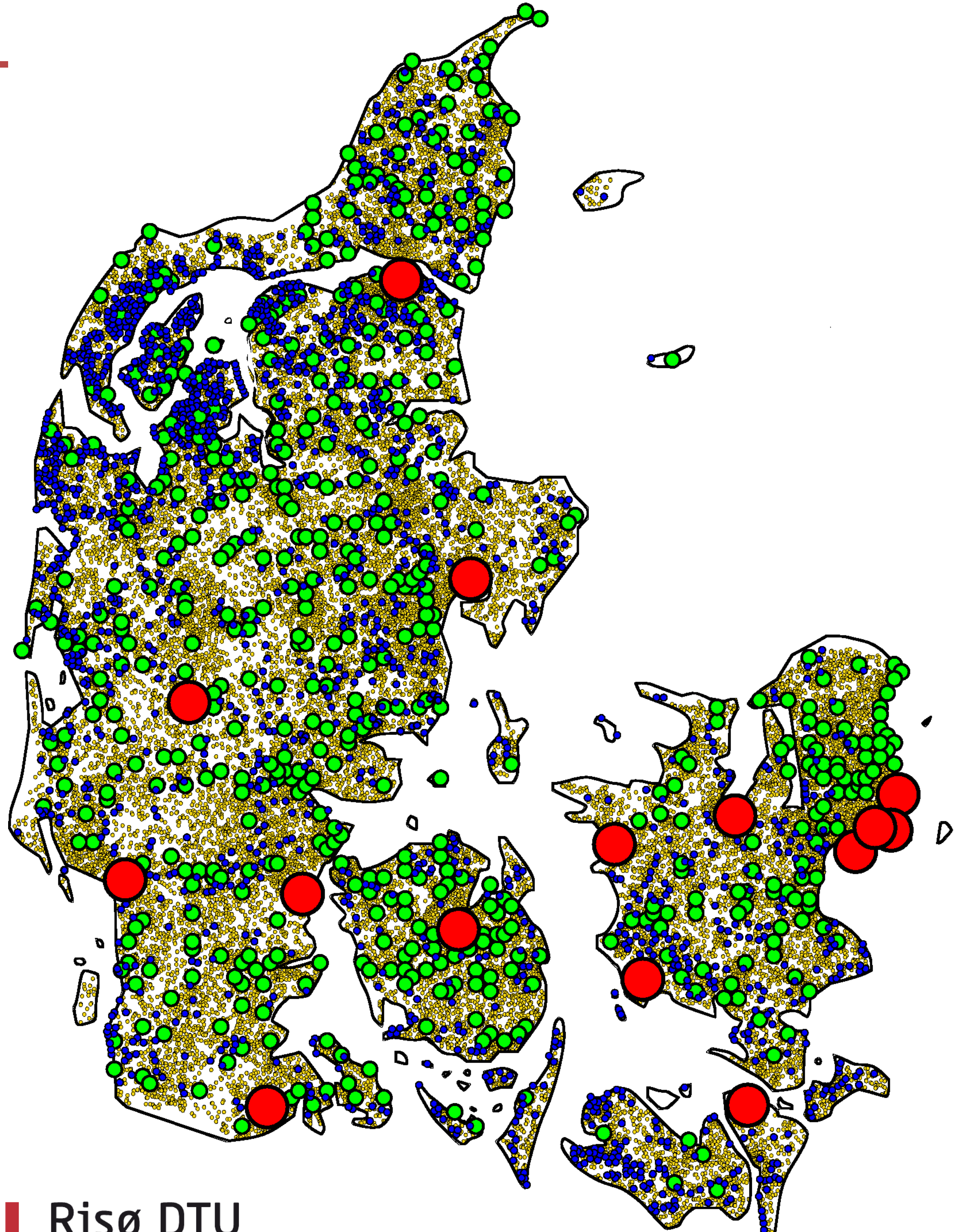
Motivation



Year 2025:

- 15 central power plants
- 500 local CHP plants
- 6.000 wind turbines
  (50% of energy)
- 1.000.000 small energy resources (households, vehicles, industrial consumers)

Small energy resources need to participate in the provision of ancillary services.

Types of SER interaction

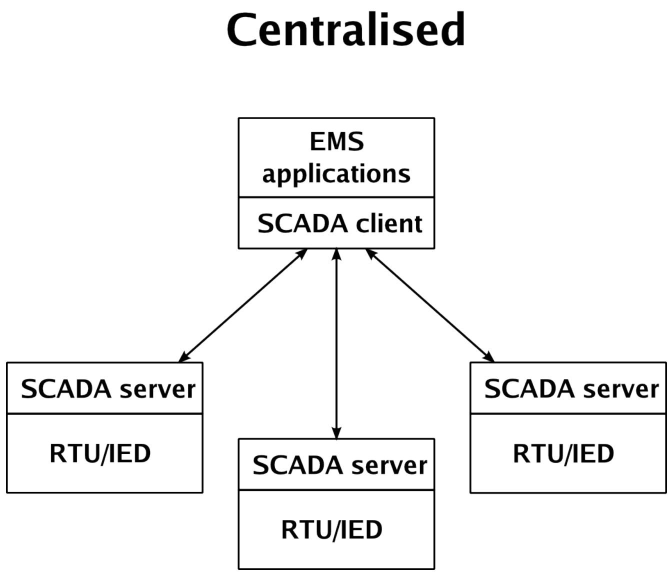
Interaction between small energy resources and "the grid":

- Data acquisition (WAMS) (real-time, one-way)

- Provision of ancillary services (real-time, two-way)
  - Frequency control
  - Voltage control
  - Capacity optimisation

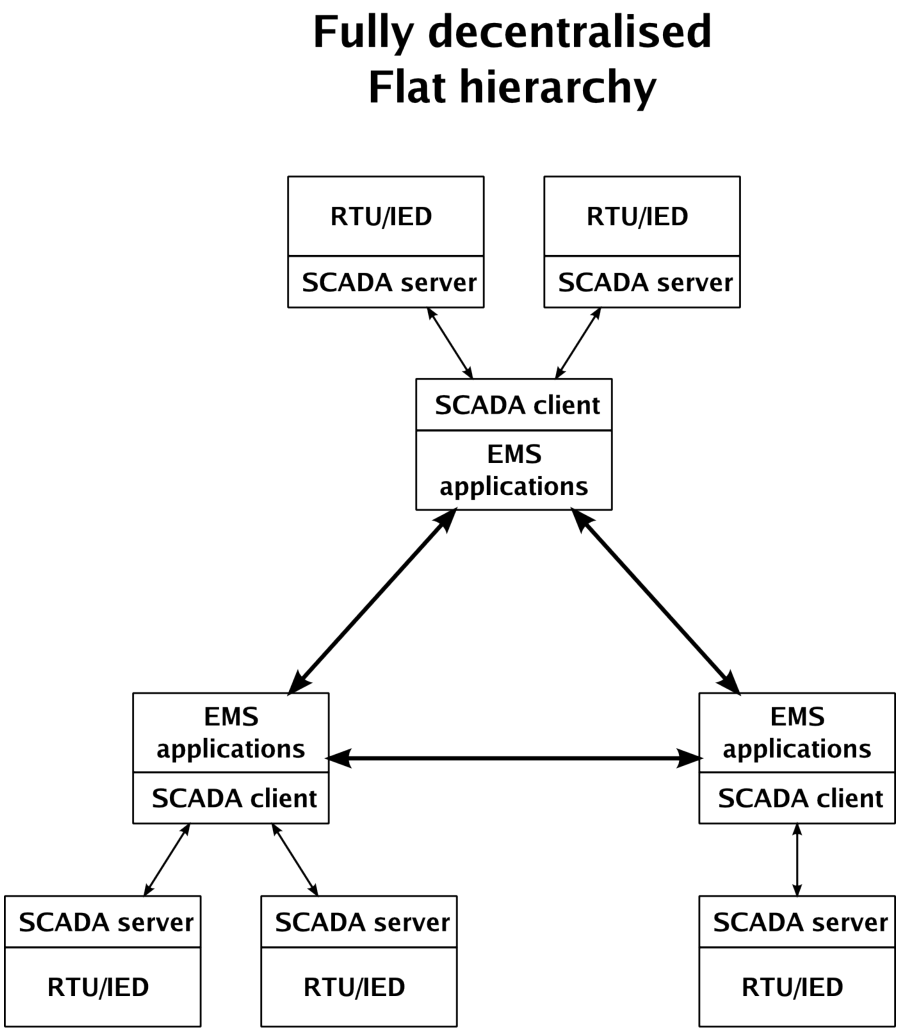
- Business operations (asynchronous, two-way)
  - Metering
  - Bidding

Control structures: Centralised



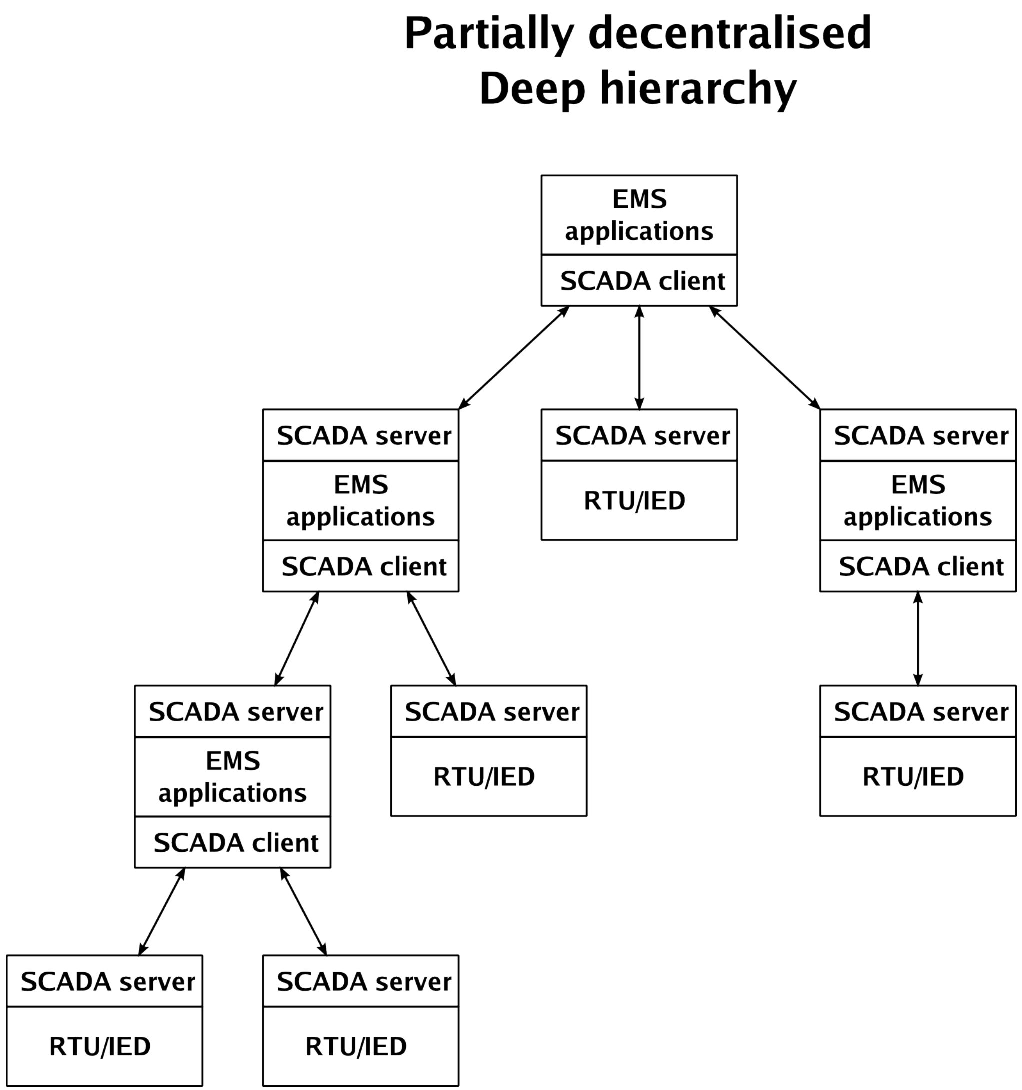
- Dominant structure in today's EMS/DMS/SCADA systems
- Difficult to scale to a very large number of energy resources due to inherent bottlenecks
- The central controller forms a single point of failure

Control structures: Fully decentralised



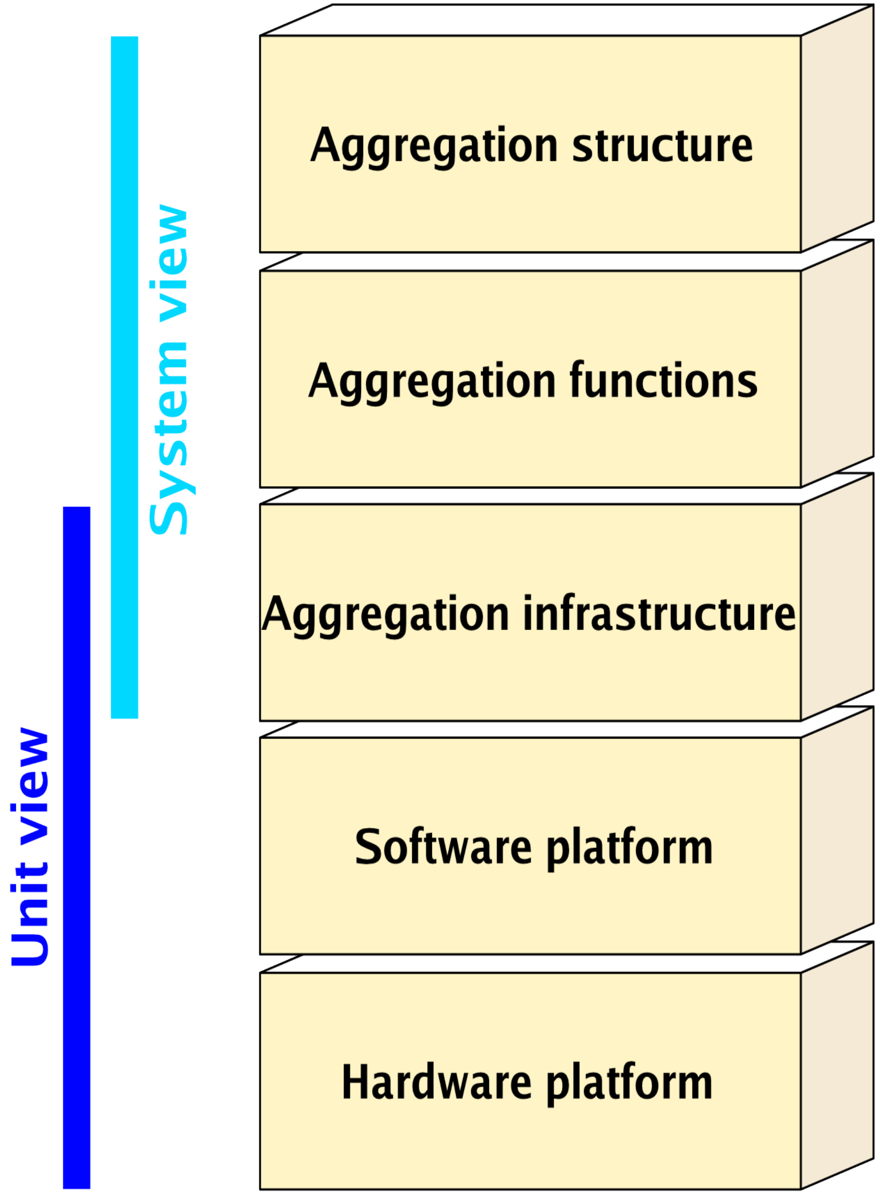
- Vision: "Electricity like the internet"
- Loose federation of communicating controllers
- Implemented where globally observable quantities exist (Primary frequency control)
- If a control task requires explicit global coordination, it becomes difficult to scale to a very large number of energy resources due to inefficient communication
- Decentralisation of isolated tasks may not improve anything without decentralising all dependencies

Control structures: Aggregation hierarchy



- Compromise: Hierarchy of aggregators
- Gain of scalability through divide-and-conquer.
- Aggregation: grouping or clustering of resources which all offer an identical or functionally equivalent service, into a larger entity.
- The resources in the aggregate are maintained by an aggregator in such a way that they appear as a single unit.
- In order to decouple the levels of the hierarchy, devices on each level must act as aggregators.

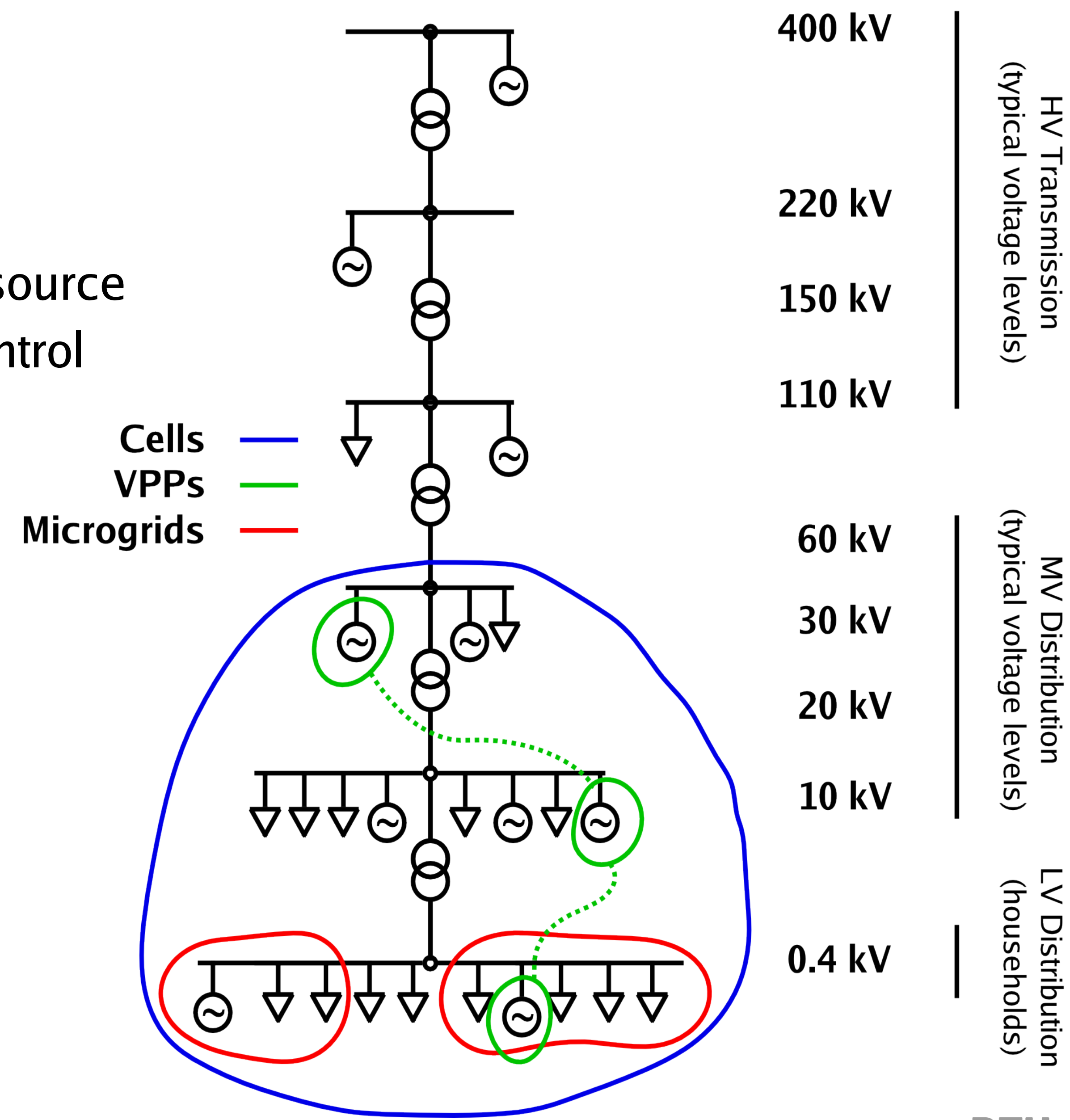
Building blocks for an aggregation hierarchy



- Aggregation structure defines **what** to aggregate
- Aggregation functions specify **how** to aggregate
- Aggregation infrastructure **implements** structure and functionality
- Hardware and software platform define capabilities and limitations of the entire system.

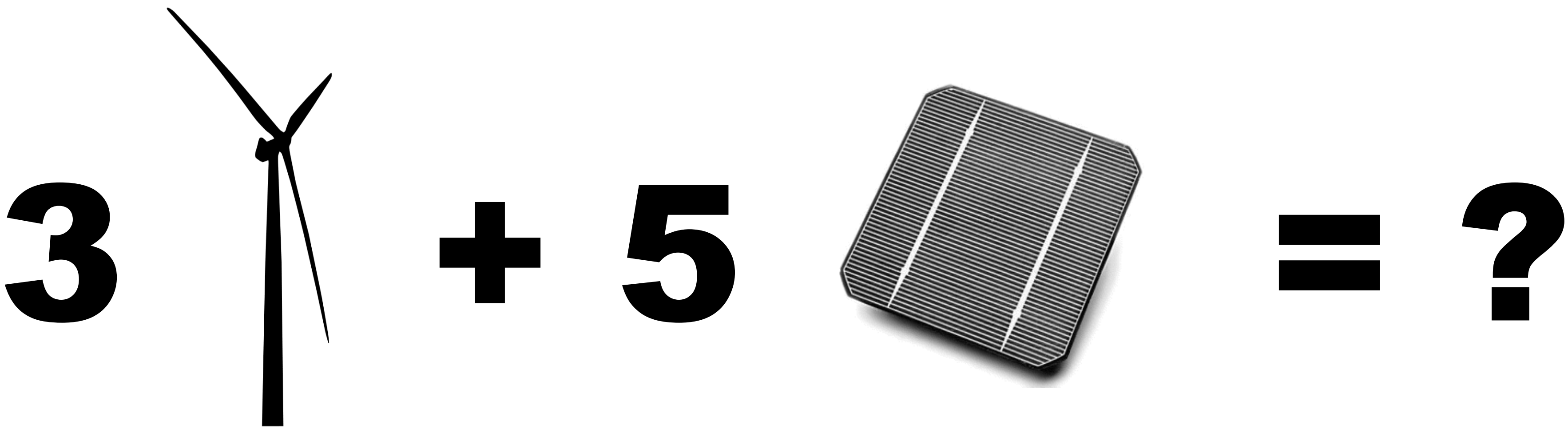
Existing aggregation concepts

- Several existing concepts for resource aggregation in power system control
- Microgrids
- Cells
- Virtual Power Plants



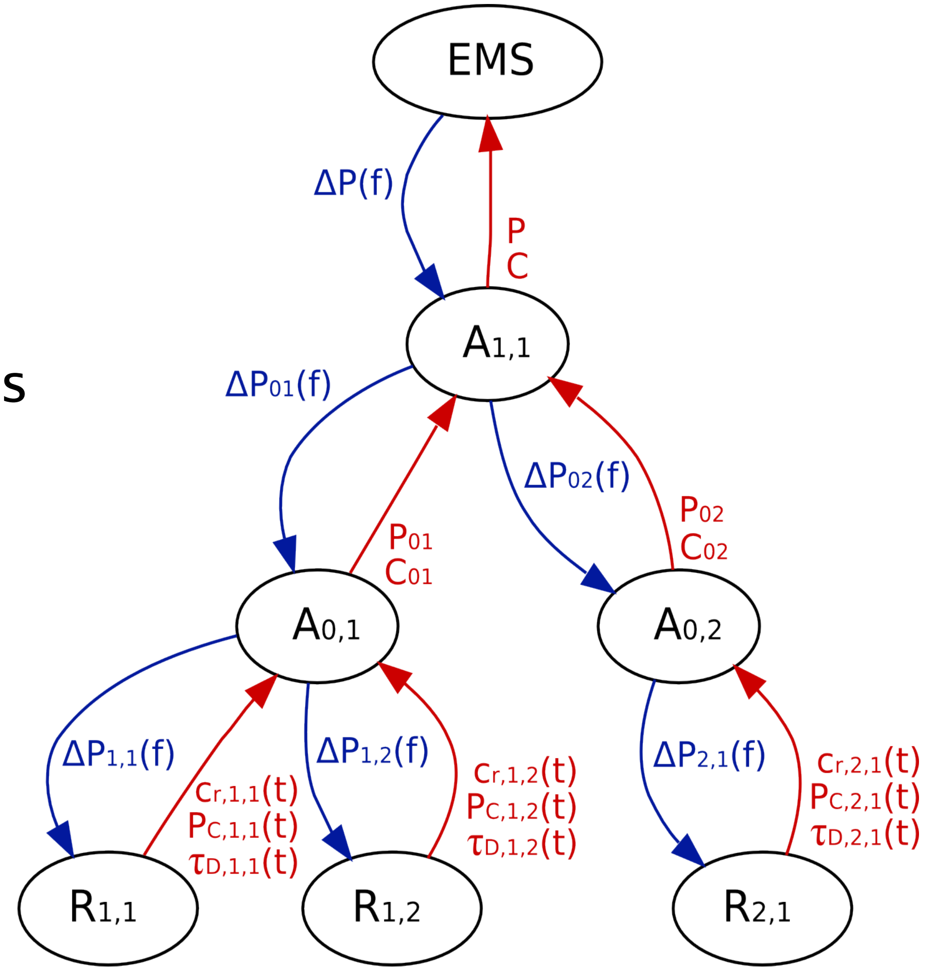
I. Aggregation needs similarity

- Aggregation of dissimilar entities ranges from awkward to impossible.
- Lack of similarity creates difficulty for discovery as well.
- Similarity is difficult to exploit in the present communication model, which emphasises structure, not function.



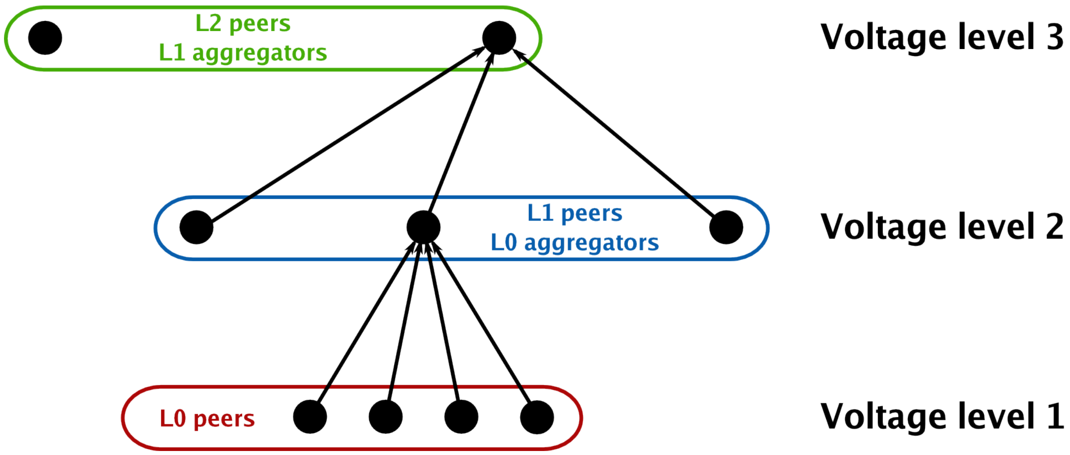
- Distributed resources should have the capability to advertise their function in immutable terms, in addition to identity and structure.

- Beyond simple data collection, control requires both aggregation (upstream) and deaggregation (downstream).
- In many applications, **aggregation** rules require only simple arithmetics (summation, averaging etc.), whereas **deaggregation** is more complex and involves fair and/or optimal dispatch or scheduling of resources.
- The different stages in an aggregation hierarchy must be decoupled to preserve scalability.



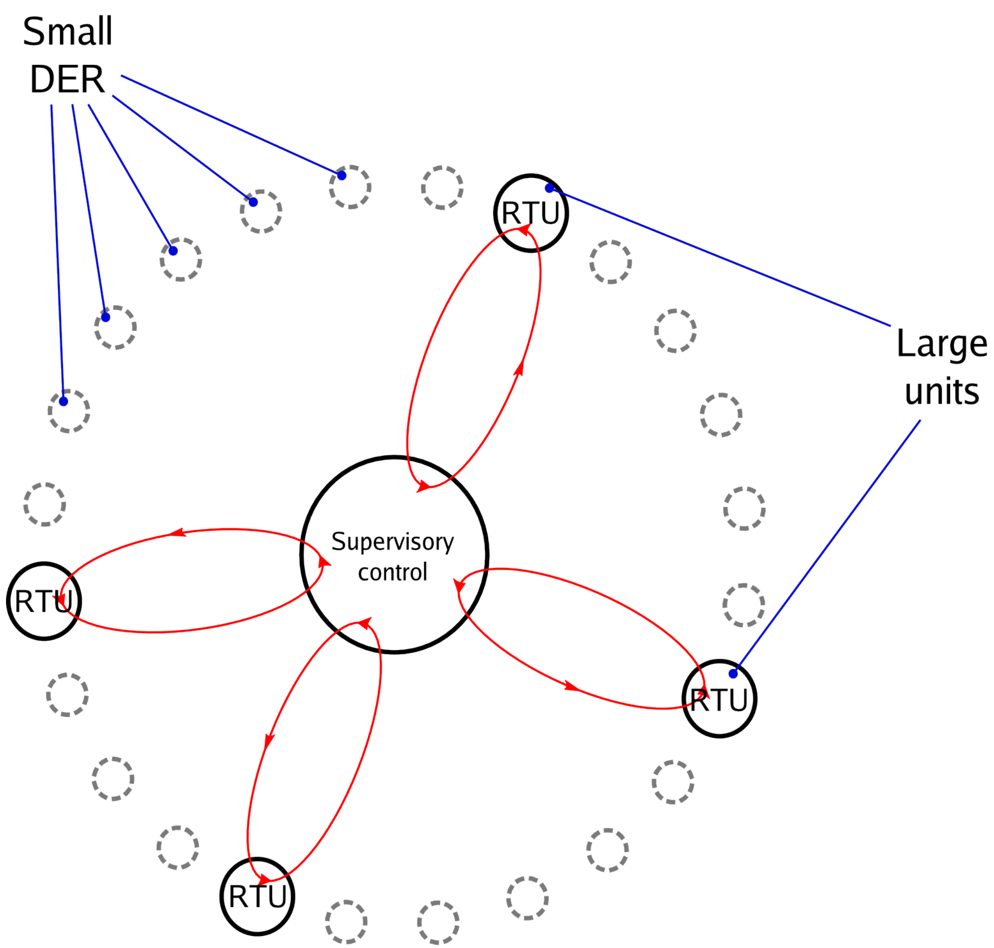
III. Keeping the aggregation structure up to date

- Unlike e.g. web services, communication path and service delivery path are not the same in power system control.
- The most useful aggregation structure would therefore be one that matches the physical topology of the grid.
- The aggregation hierarchy must track changes in grid topology, and adapt accordingly.
- The large number of peers requires an automatic system.



IV. Dealing with imperfect communication

- Current SCADA systems use synchronous communication. They assume reliable links, defined bandwidth and latency.
- Small energy resources require low-cost communication solutions which do not have these properties.
- Control strategies must be changed to allow asynchronous interaction of controller and energy resources.



V. Security issues

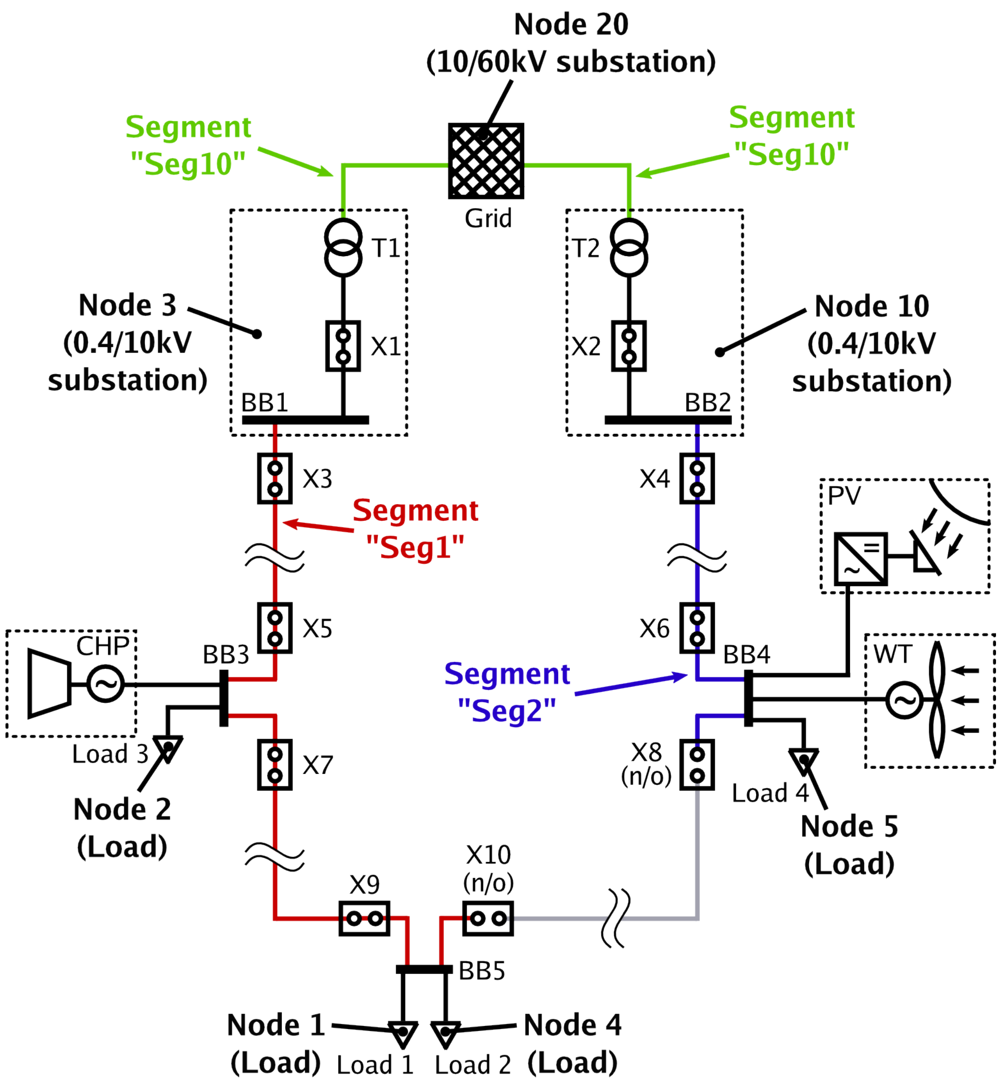
- Wherever programmable systems are deployed *en masse* within the physical reach of end customers, they will be hacked.
- Existing low-cost, mass-market systems (e.g. SIM-cards) provide some degree of secure authentication, but not enough.
- To contain a breach, authentication and verification must exist at all stages of an aggregation hierarchy.

Summary

- Present-day SCADA/EMS/DMS systems are not prepared for a large growth in the number of controllable energy resources.
- Aggregation hierarchies are a promising way of implementing scalable control systems in the power grid.
- Different aggregation-based control concepts have been proposed. Their implementation requires a common set of problems to be solved: The exposure of similarity between units, the adaptation of the aggregation hierarchy, the imperfections of low-cost communication, the development of suitable deaggregation algorithms and the security issues of a customer-accessible IT infrastructure.

Thank you

Self-organisation

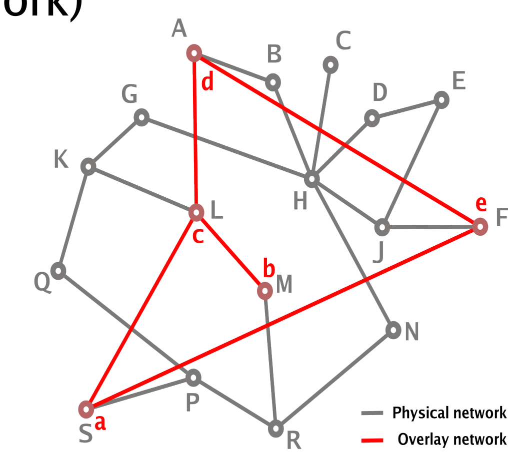


Case study: Automatic adaption of an aggregation hierarchy after the reconfiguration of a distribution feeder.

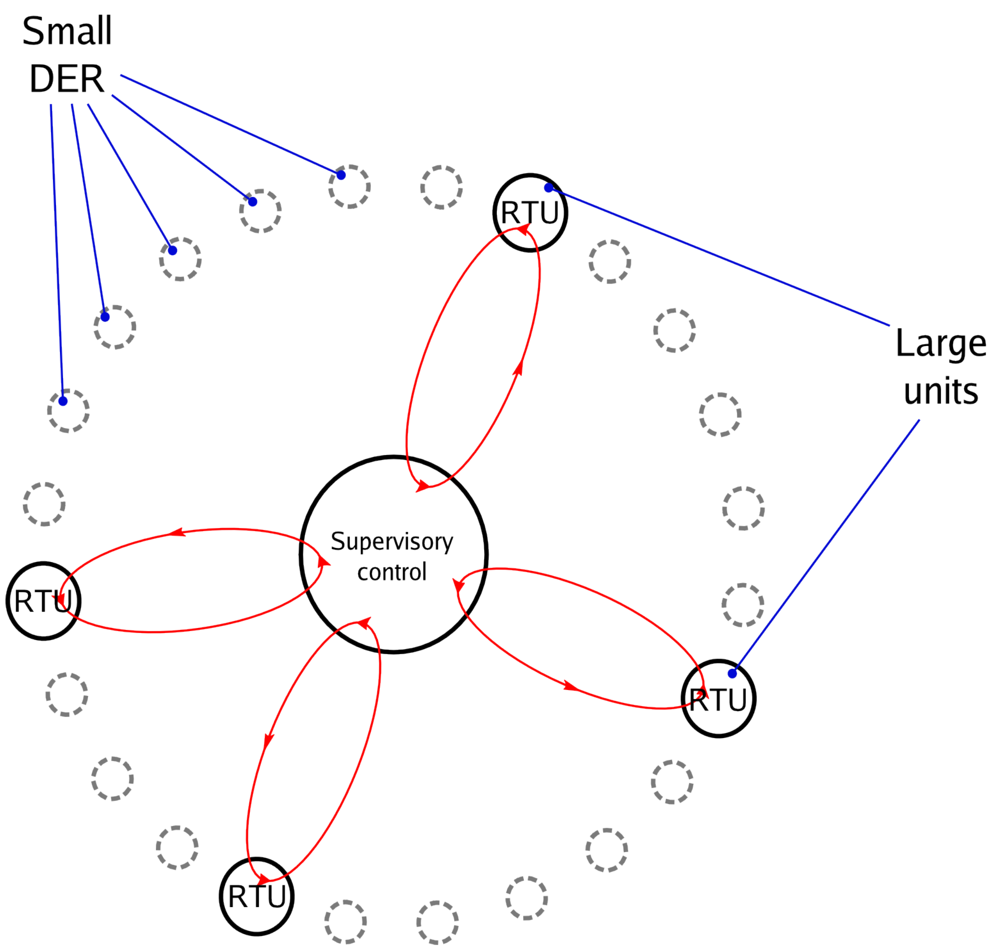
Definition of self-organisation: Adaptive change of structure without central control

Principle behind self-organisation: Mechanism and counter-mechanism

If the individual devices cannot move physically, a mechanism is required to represent logical movement (overlay network)



Asynchronous control using policies



Present-day supervisory control (SCADA/EMS) systems use tightly coupled, closed loop control.

This assumes reliable, low-latency, bidirectional communication between control center and RTU.

The present control paradigm is not well suited for small energy resources at the lowest voltage levels.

Development of a set of policies for autonomous action, in order to reduce the realtime requirements.

Development of a policy representation (spinoff PhD project)

How can a power system with a large number of distributed resources be maintained and controlled?

- "it will use agents which will find a solution among themselves."
- "it will self-organize. (...self-heal, self-configure, self-*)"

On which level should we look for self-organization?

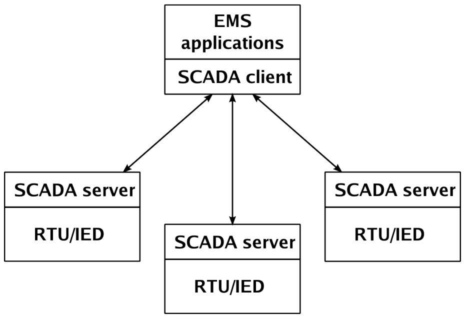
- Physical self-organization (like a sand dune, determined by physics)
- Self-organizing control (like an beehive, determined by behaviour)

How can self-organization be implemented?

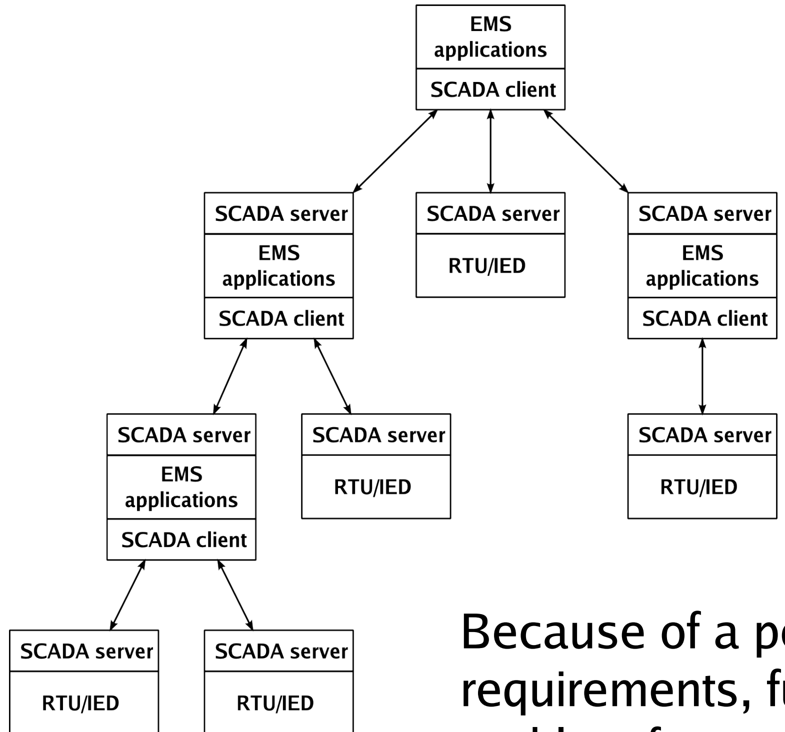
- What are the system requirements? What are the technological limits?
- Which of these requirements are not met by present EMS/SCADA systems, and which technologies could provide them?

Decentralised control and aggregation

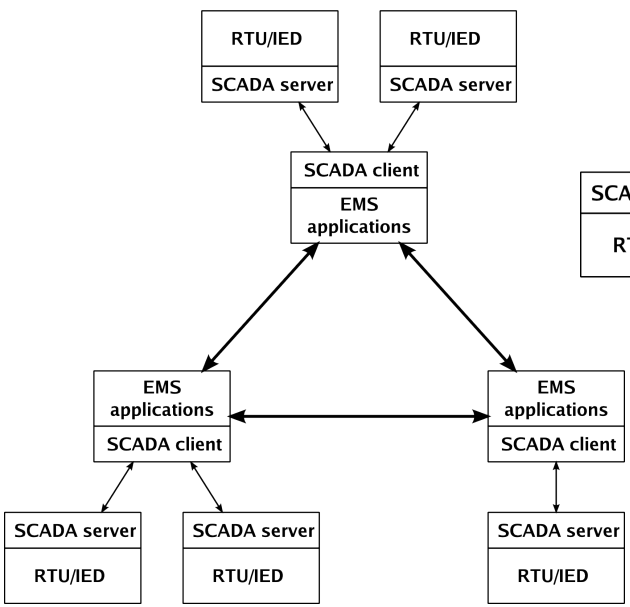
Centralised



Partially decentralised
Deep hierarchy



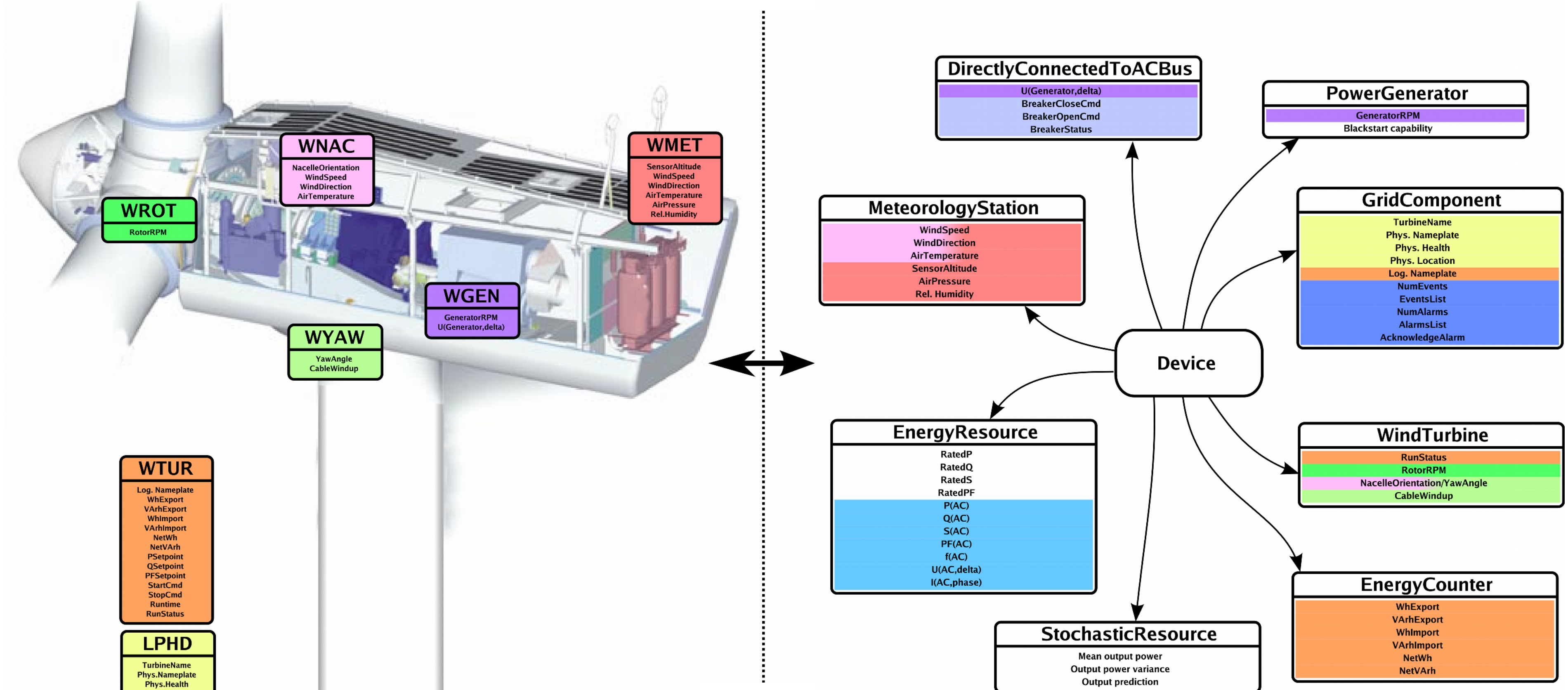
Fully decentralised
Flat hierarchy

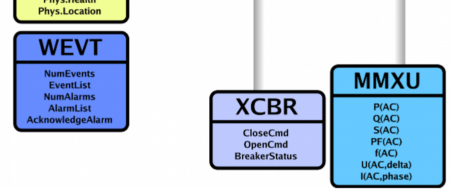


Because of a power system's realtime requirements, full decentralisation is a hard problem for most EMS functions requiring coordination.

Aggregation hierarchies can be a compromise, but they must be able to adapt to changing conditions (e.g. topology).

Functional communication model





In many cases, aggregation of dissimilar entities is next to impossible.

Similarity is difficult to exploit in the present communication model, which emphasises **structure, not function**.

Development of a parallel, functional system model and communication protocol