Milan - June 6th, 2018

Trends and Challenges in Power Systems

UnCoVerCPS Workshop

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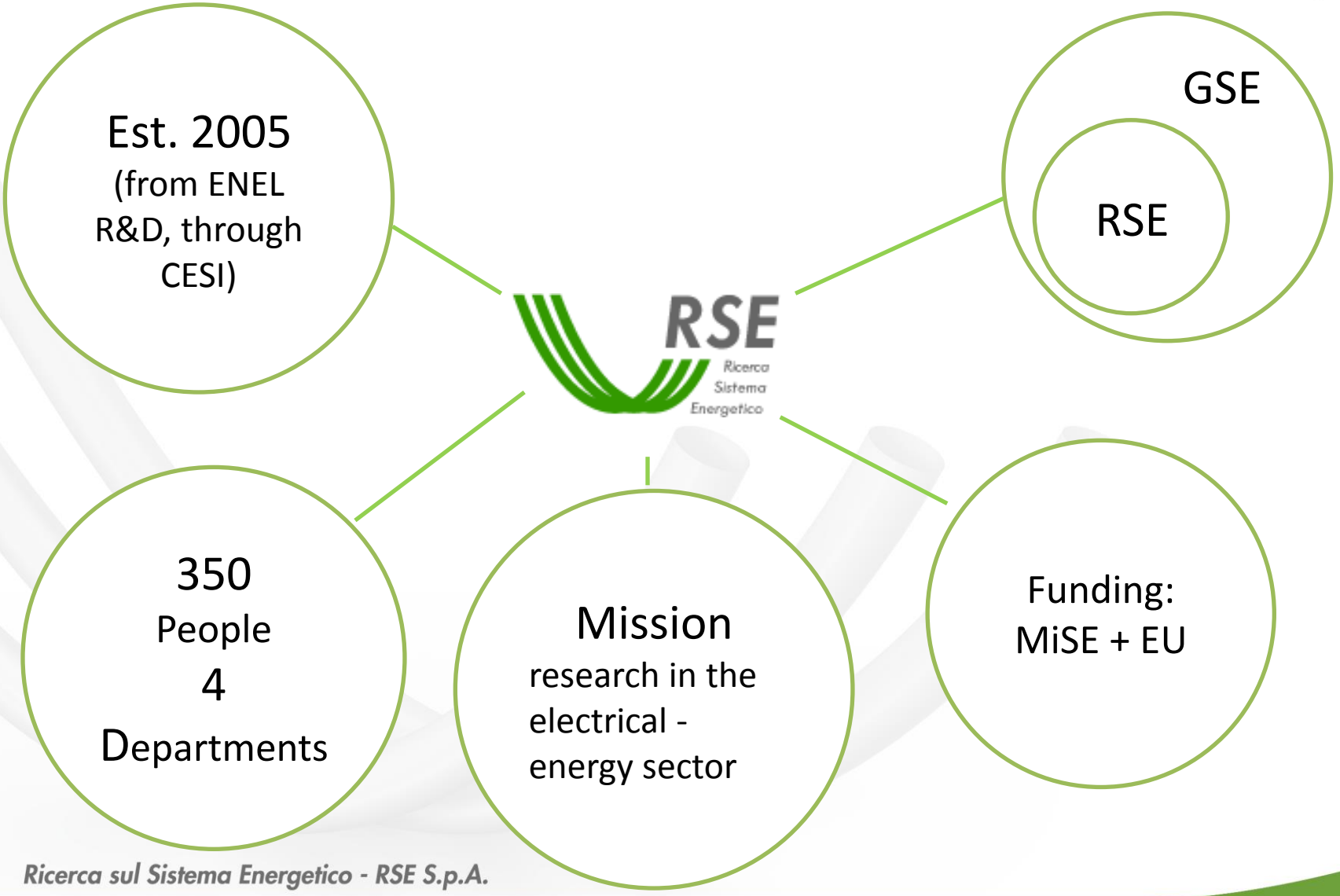
Ricerca sul Sistema Energetico – RSE SpA



Trends in Power System evolution

Past

- Strict distinction between generation, transmission and distribution
- Centralized generation
- Very low uncertainty
- Monodirectional energy flows
- Big synchronous generators provide mechanical inertia
- High carbon emissions

Future

- Generation also in distribution network
- High uncertainty due to renewables
- Bidirectional energy flows
- Mechanical inertia decreases due to power converters
- Introduction of Energy Storage Systems
- Lower carbon emissions

Trends in Consumers evolution

Past

- Passive: buy energy from the main grid
- Stiff energy prices
- Simple business models

Future

- Active: can buy and sell energy
- Elastic energy prices, due to more flexible demand
- Availability to provide flexibility services
- Advanced business models, involving multiple actors

Trends in Consumers evolution

Past

- Passive: buy energy from the main grid
- Stiff energy
- Simple busi models

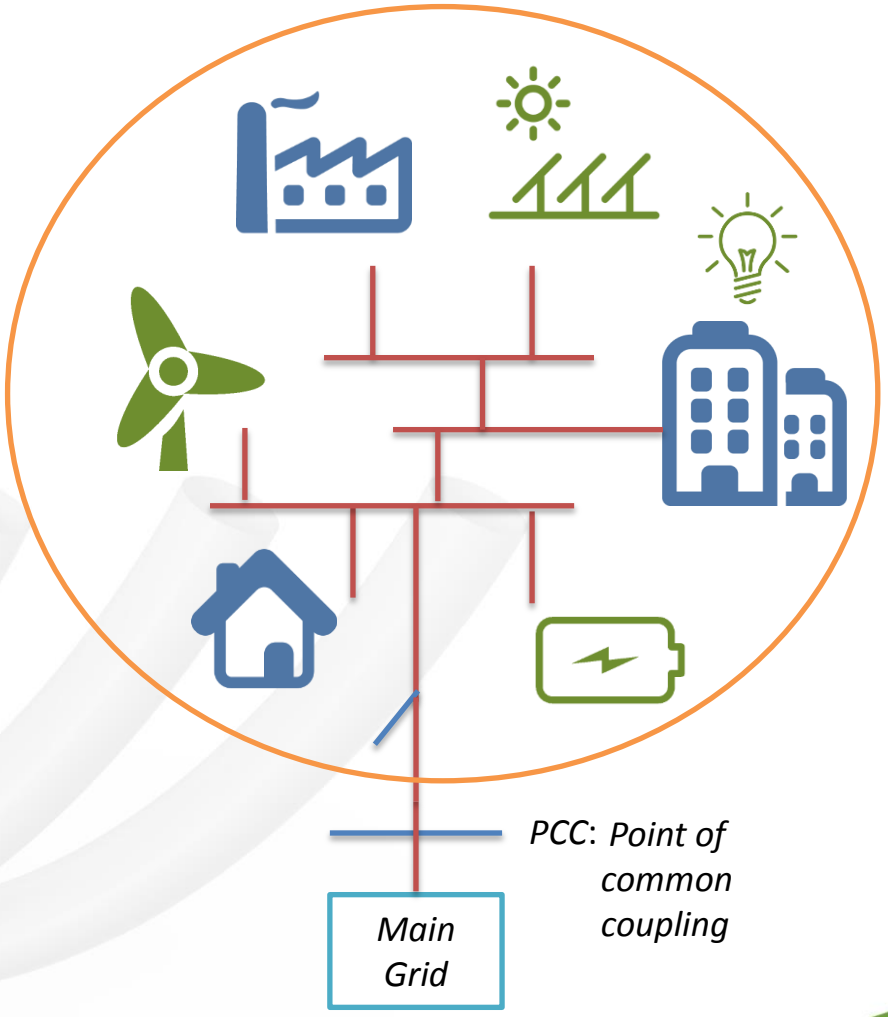
All these new features give rise to the concept of **Microgrids**

Future

- Active: can buy and sell energy
  - energy prices,
  - more flexible
  - nd
  - bility to provide ility services
  - ced business models, involving multiple actors

Microgrid: features

- Group of distributed energy resources: both generators and load
- Electrically interconnected
- Well defined electrical boundaries
- Can act as a single controllable unit, with respect to the main grid
- Can disconnected and reconnect to the main grid, operating both in connected and islanded modes



Traditional control levels in power systems

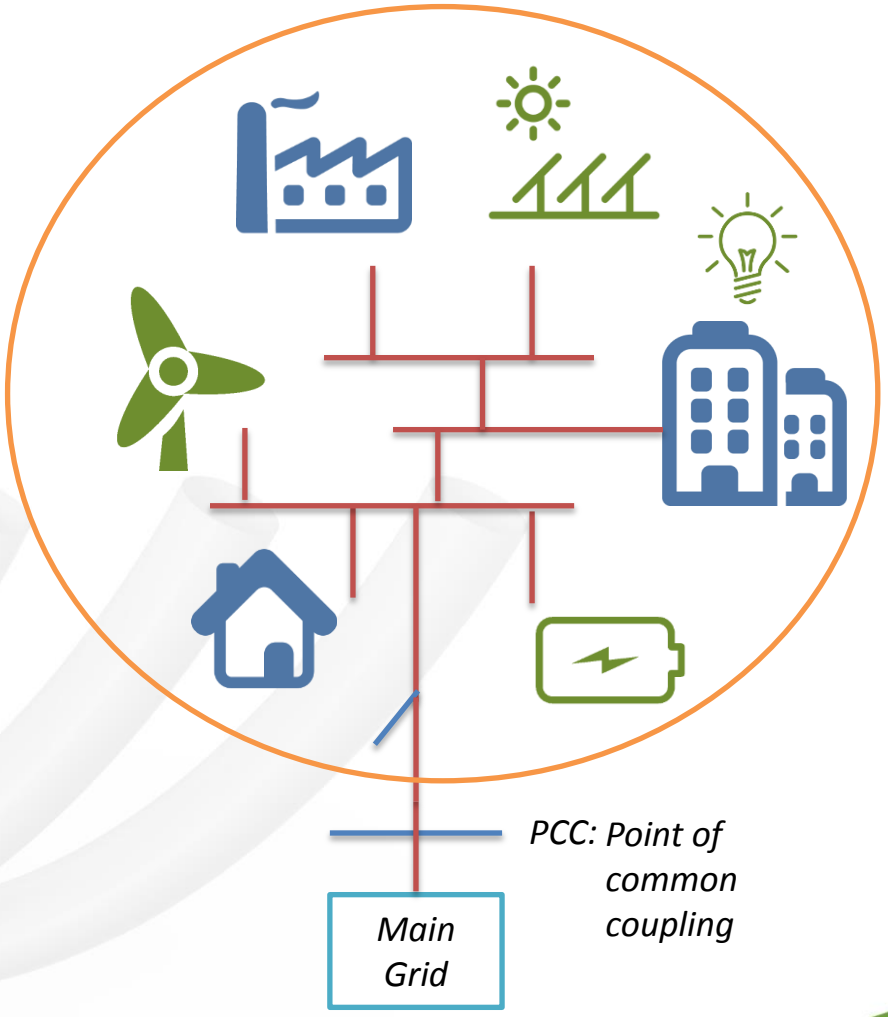
Primary control	Secondary control	Tertiary control
• Local controllers • No communication • Fast reaction	• Coordinated device management • Communications needed	• Optimization • Interactions with outside world

Work well in traditional contexts

Need to be revised to tackle the new challenges

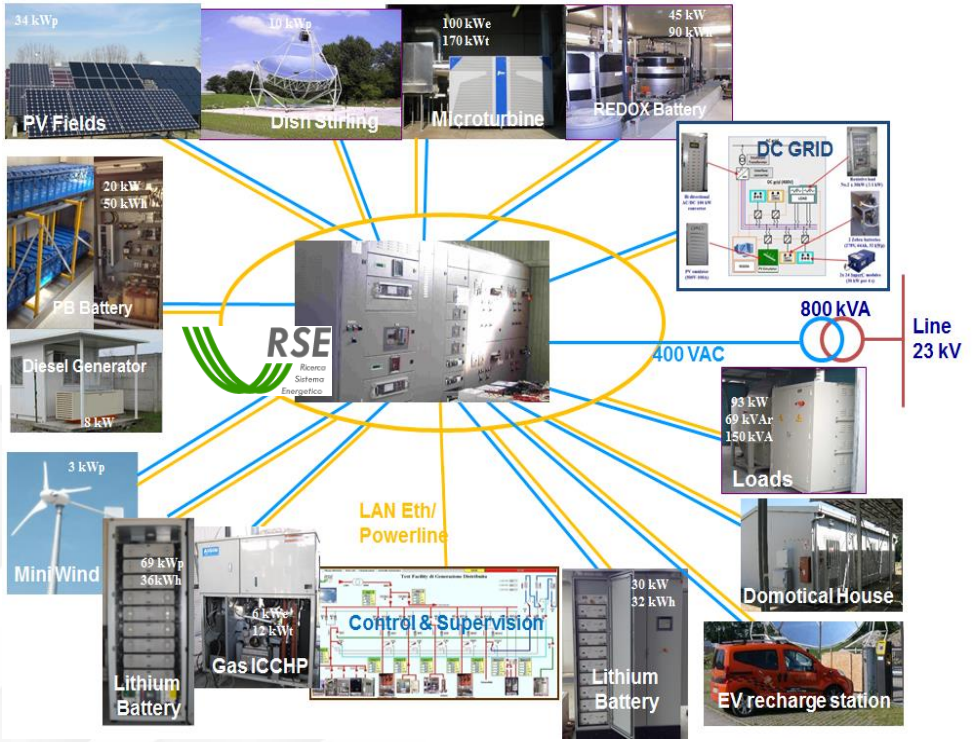
Microgrid: new challenges

- In islanded mode stability is not guaranteed (low or no inertia)
- Optimal management of energy resources is needed to minimize costs
- Control algorithm should be robust against uncertainty (PV, wind…)
- Connection and disconnection with the main grid has to be smooth
- Coupling between multiple energy domains (mainly thermal and electrical)
- Deal with coupled AC/DC networks

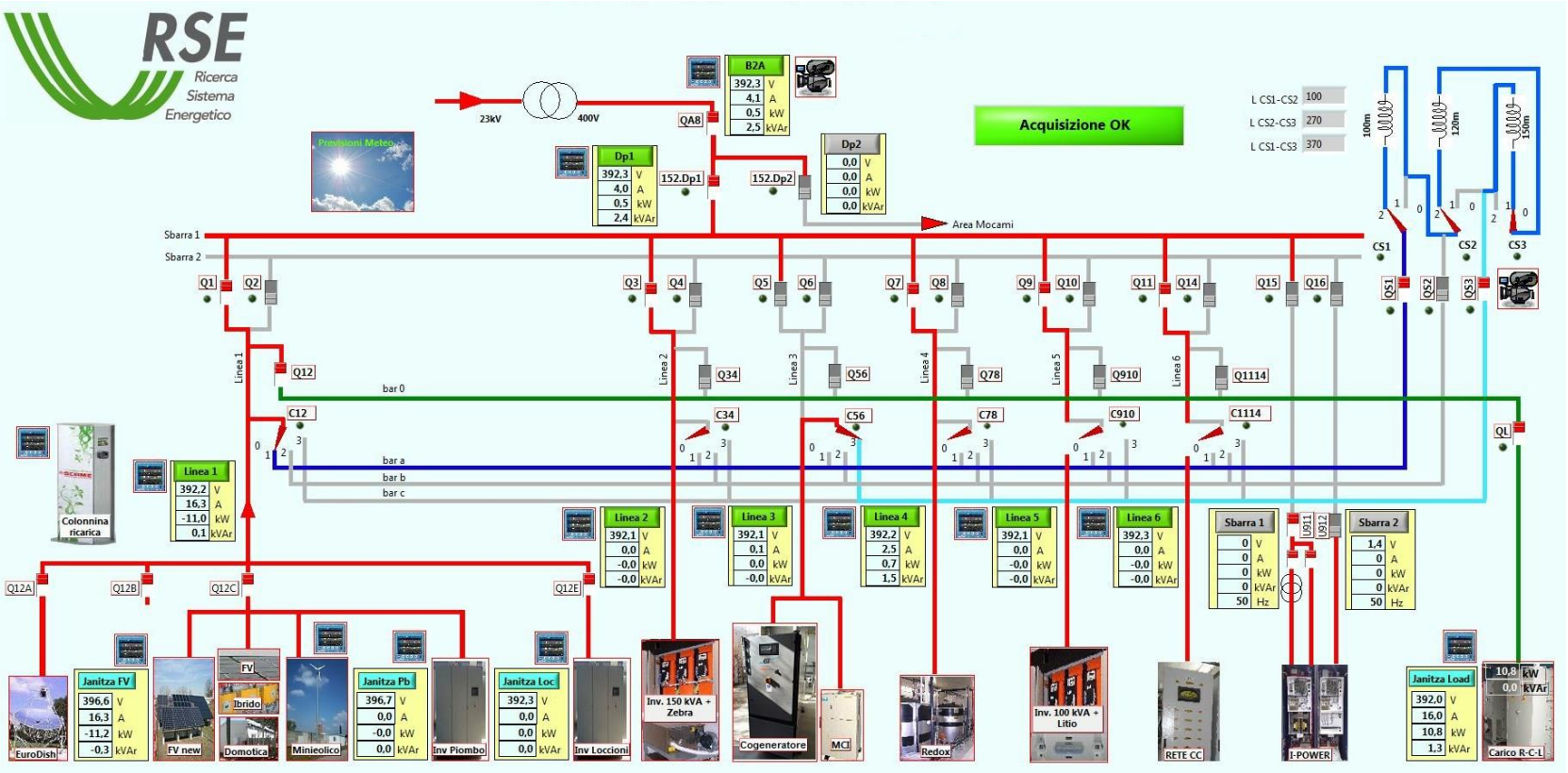


An example of microgrid: RSE Test Facility

- Low Voltage Microgrid
- Medium Voltage direct connection
- Power: 350 kWe / 250 kVAr
- Configurable grid topology: Radial and Meshed
- Resources:
  - Generation (45 kW renewable, 70kW gas fired)
  - Storage (180 kW, 235 kWh)
  - Loads (100 kW)
  - DC Grid mesh
- Area: 20.000 m2
- Max feeder length: 1 km



Test Facility SCADA



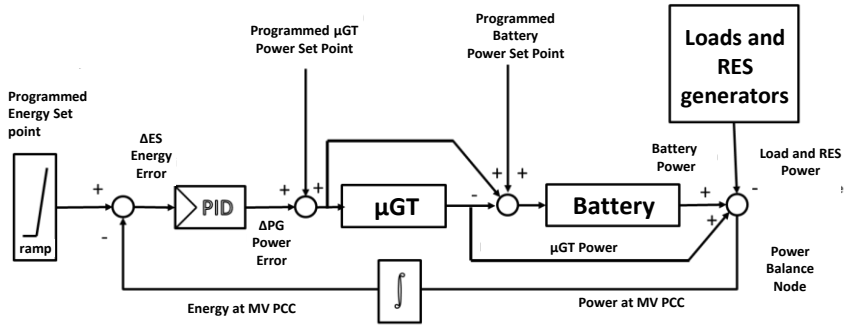
- Interfaced with LabVIEW
- Allows remote monitor and control of the entire Test Facility (power flows, voltages, breakers, etc…)

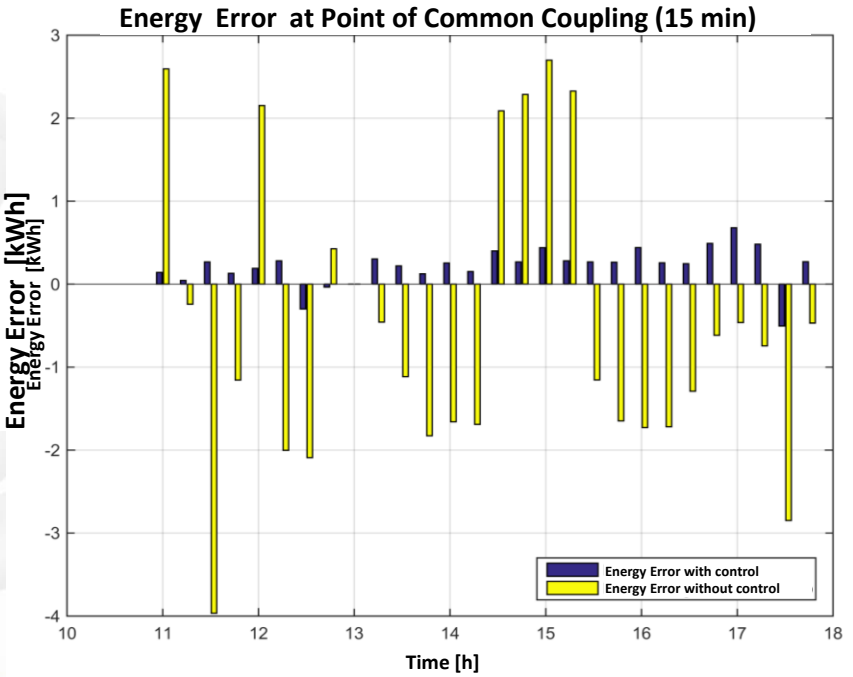
RSE experimental activities on the Test Facility

- **System Testing** with Holistic System Validation approach (ERIGrid project)
- **Resources management**: economical optimization functions and balancing functions at PCC
- **Renewable resources balancing** and control functions by means of storage and weather forecast integration
- **Remote control functions** from DSO Primary Substation (aggregated control, protection logic selectivity)
- Microgrid **islanding management** (droop control) and grid reconnection control functions
- **DC Microgrid** management and control

An experimental activity: Energy Tracking

- **Prosumer benefits:** unbalancing penalties avoided or reduced
- **Grid benefits:** reduction of uncertainties due to stochastic power generation/demand
- Closed loop control to minimize energy unbalance at coupling point
  - Multiple algorithms:
    Daisy-chaining PID (merit order)
    Hybrid Model Predictive Control





Ongoing research activity: advanced secondary control

Now

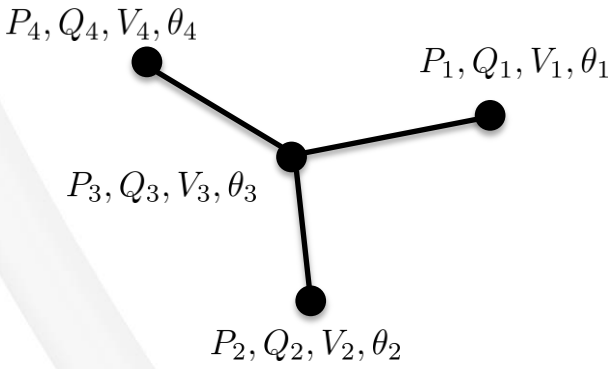
1. Restores reference frequency and voltages in the microgrid
2. Implemented via classical control techniques (usually PI)
3. Easy to implement
4. Sub optimal performances

Future upgrade

1. Restores reference frequency and voltages in the microgrid. Can deal with more complex tasks, like managing state of charge of batteries
2. Implemented via optimal control techniques (e.g. Model Predictive Control)
3. More complex to implement, requires knowledge of the model. Possible scalability issues
4. Optimal performances
5. **Flexibility: by modifying the cost function, the user can choose a desired functionality. Also takes into account primary control**

New feature!

1. Obtaining the model of the power network



- Write «power flow» equations

True for all nodes.
Algebraic Equations

$$P_k = V_k \sum_{j=1}^{N} V_j (G_{kj} cos(\theta_k - \theta_j) + B_{kj} sin(\theta_k - \theta_j))$$

$$Q_k = V_k \sum_{j=1}^{N} V_j (G_{kj} sin(\theta_k - \theta_j) - B_{kj} cos(\theta_k - \theta_j))$$

- Add the model for nodes of interest (e.g. droop control, link to battery…)

$$P_k = P_{ref,\ k} - D\dot{\theta}_k$$

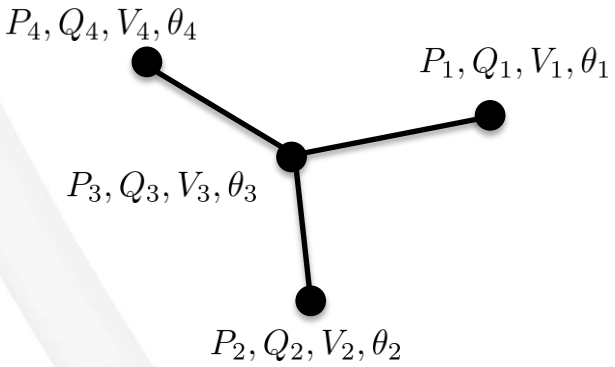
Primary droop control:
feedback on frequency.
Differential Equation!

- Group all equations

$$\dot{x} = f(x, y)$$
$$g(x, y) = 0$$

DAE System!

2. Obtaining a control law: MPC approach



- Linearize dynamics and constraints
- Unroll dynamics and constraints on a fixed horizon
- Optimize the sequence of inputs
- Apply first control action.
- Repeat

Challenges and current research direction

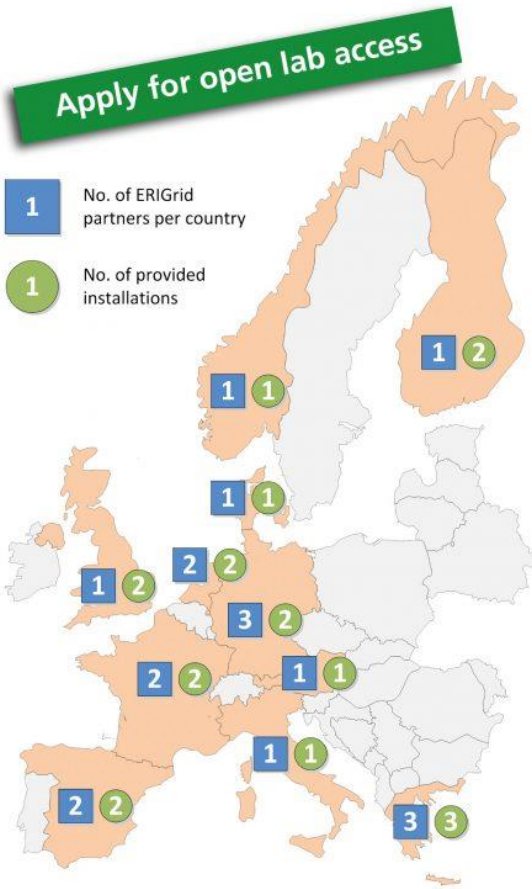
- Stability guarantees?
- Verification of closed loop system properties?
- Robustness against disturbances or model modifications over time?
- Scalability?
- Exploiting low coupling between different subsystems?
- …

EU H2020 Programme GA No. 654113

- European Research Infrastructure supporting Smart Grid Systems Technology Development, Validation and Roll Out

- Users from research, academia and industry are invited to apply for **free access** to top European smart grids research laboratories of ERIGrid partners.

- Apply at: https://erigrid.eu/transnational-access/



Model Predictive Control of Large Wind Parks for Improving Stability of Power Grids

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