Laboratory for Computer Communications and Applications 2
Distributed Electrical Systems Laboratory

LCA2/DESL - EPFL

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REAL-TIME CONTROL OF ACTIVE DISTRIBUTION NETWORKS BY USING EXPLICIT POWER SETPOINTS (COMMELEC)

The COMMELEC control framework

Communication and computation resources are now inexpensive and easy to use -- **explicit control by computers is now possible.**

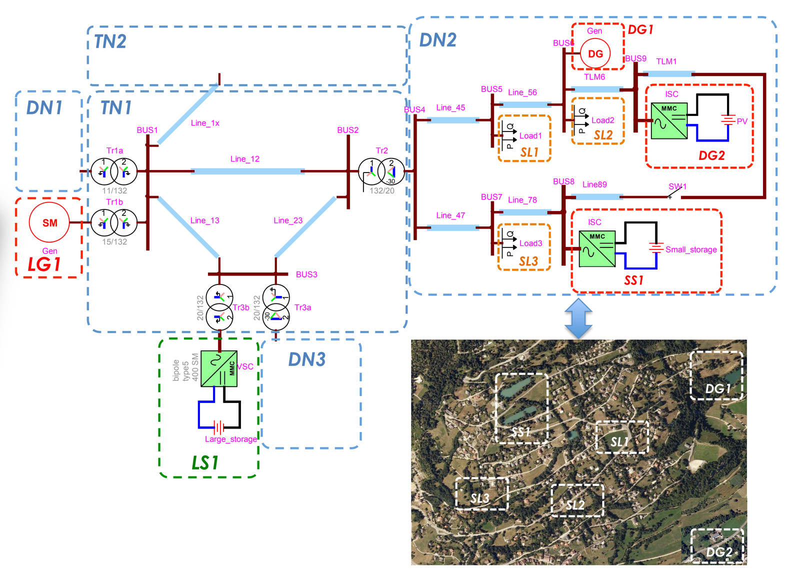
Multiple benefits:
- avoid deep infrastructure changes required by renewables
- seamless degradation instead of blackout
- support automatic islanding

Main features

- **Abstract Framework**
  It applies to all electrical subsystems and specifies a simplified view of their internal state.
- **Composition of Subsystems**
  It is possible to aggregate a set of interconnected elements into a single entity.
- **Separation of Concerns**
  Grid agents manipulate only data expressed by means of the abstract framework and do not need to know the specific nature of the resources in their grid.

Architecture

- **Software agents** associated with:
  - Resources: load, generators, storage
  - Entire subsystems, including grids
- **Real-time** control using **explicit power setpoints**

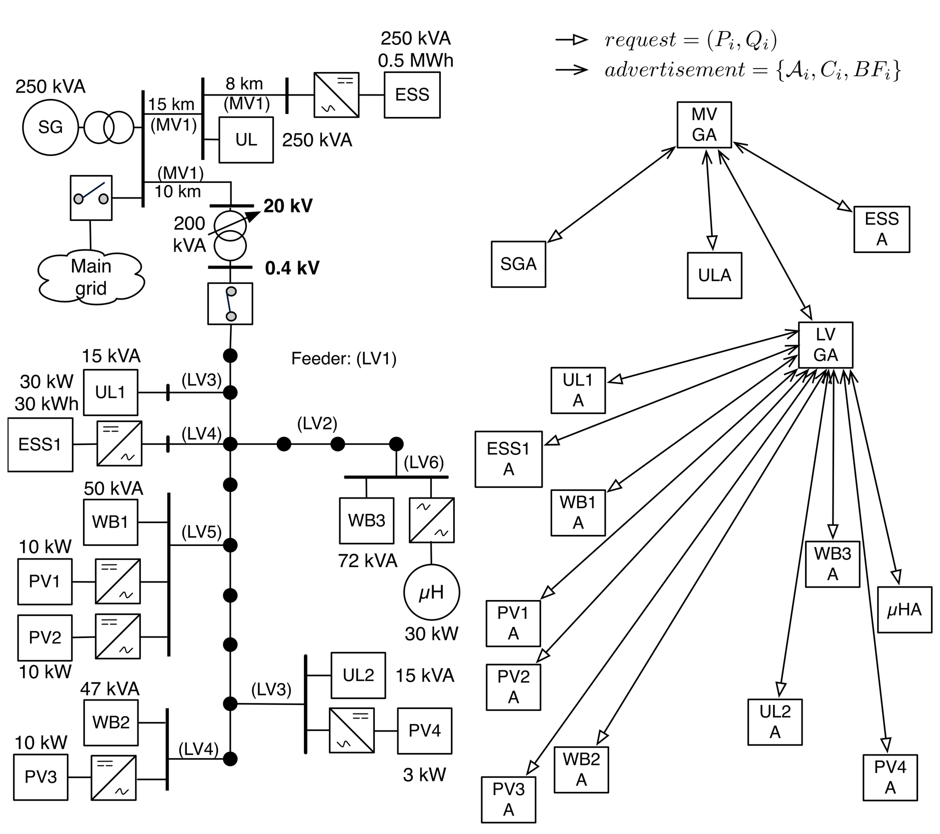


Interaction between Agents

1. Follower agents advertise periodically **a simplified representation** of their state.
2. Leader agents send **explicit power setpoints** to their followers.
3. Followers **set, if possible, their operation** according to the requested setpoint.

Case Study

- **Resources**
  - Controllable: synchronous generators (SG, uH, batteries)
  - Partially controllable: PVs, boilers
  - Uncontrollable: loads
- **Each resource is assigned to a resource agent**
- **Each grid is assigned to a grid agent (MV grid agent, LV grid agent)**
- **Leaders and followers:**
  - Resource agents are followers of their grid agent
  - LV grid agent is a follower of MV grid agent



Advertisement Messages

Followers periodically advertise to the leader…

PQt Profile: *Flexibility*

- Region of feasible (P, Q) setpoints that this follower is willing to accept.

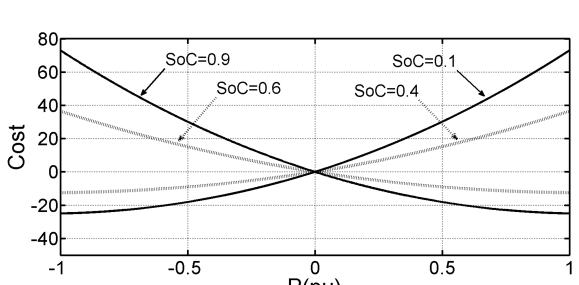
Virtual Cost: *Preference*

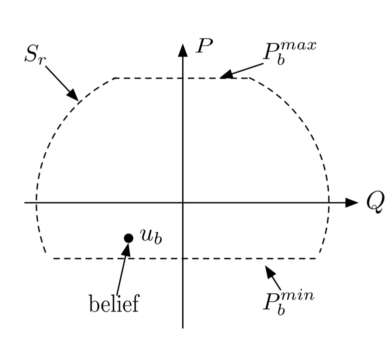
- Can represent how close the subsystem is to its operational constraints or operation preference

Belief function: *Uncertainty*

- Given a setpoint (P_{set}, Q_{set}), the belief $BF(P_{set}, Q_{set})$ is a region in (P, Q) plane (set-valued function).
- This region represents all the possible values of (P,Q) that the system may implement when it receives (P_{set}, Q_{set}).
- Takes into account the uncertainties in the resources (larger for partial and non-controllable ones).

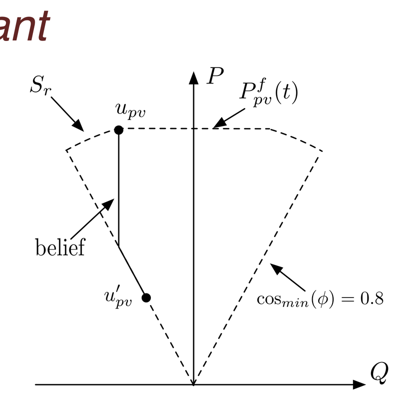
Battery



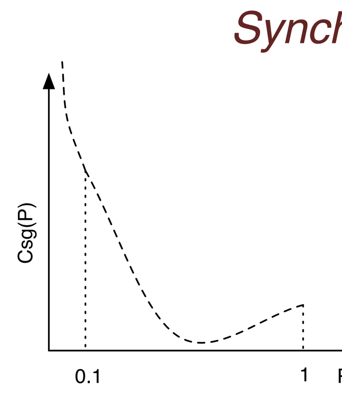


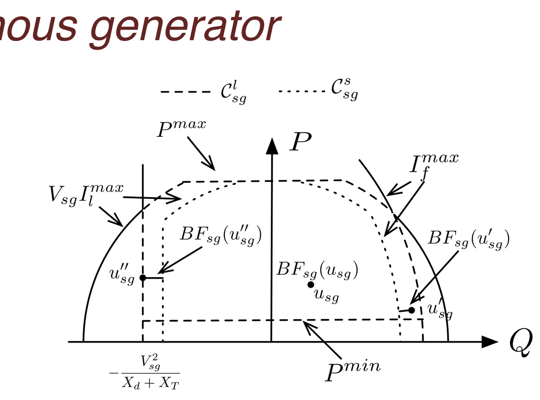
PV Plant

$$C_{pv}(P,Q) = -P + Q^2$$

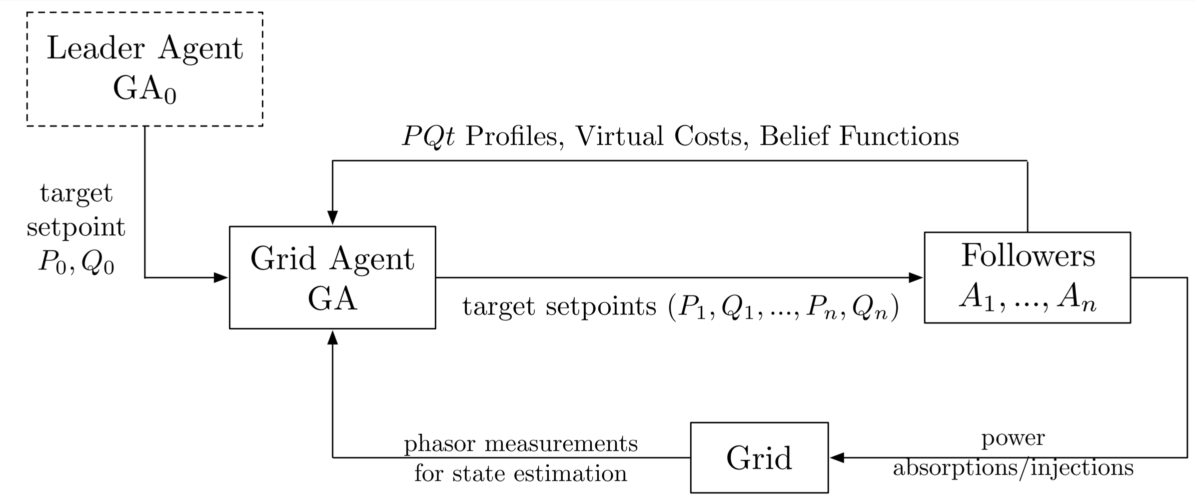


Synchronous generator





Grid Agent's decision process



- Leaders (LV grid agent, MV grid agent): compute and send **explicit power setpoints** $x = (P_i, Q_i)$ to their followers based on
  - Estimated state of their grid,
  - The advertisements from their followers and
  - The requested power from the leader (as in case of LV grid agent in our case study).
- The computed setpoints **steer the electrical state** of the grid to:
  - Minimize the **cost of the followers**
  - Satisfy the **leader's request** as much as possible
  - Maintain the grid in a **safe state of operation**

$$C(u) + J_0(P_0, Q_0; P_0(u), Qo(u)) + J(u)$$

- The cost of followers is considered as **a weighted combination** of the specific cost functions.

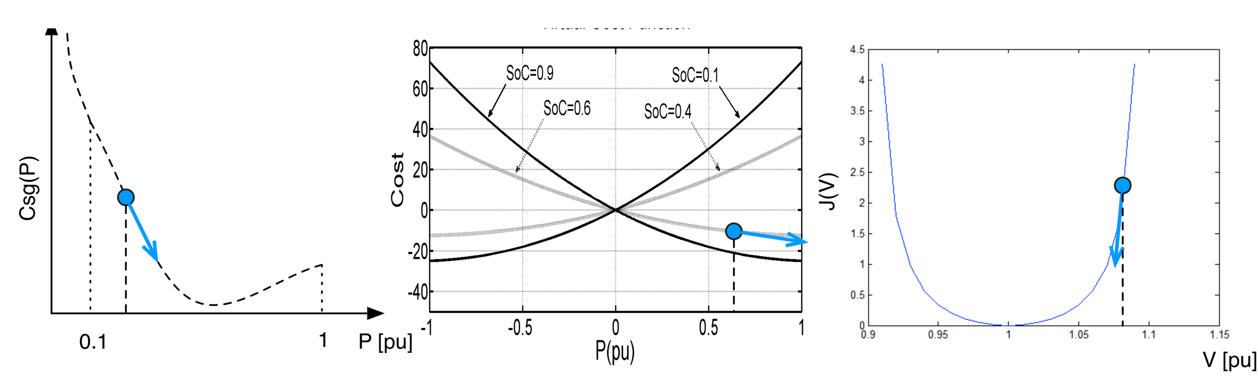
$$C(u) \triangleq \sum_{i=1}^{n} \omega_i C_i(P_i, Q_i)$$

- The belief functions are essential for the leader to compute **safe setpoints**: for each $(P,Q) \in BF(P_{set}, Q_{set})$, the QoS of the grid is acceptable (in terms of voltage magnitudes and congestions). Example of grid safe state in static conditions:

$$J(u) \triangleq \sum_k \frac{(V_k(u) - V_k^{nom})^2}{\beta_k^2 - (V_k(u) - V_k^{nom})^2} + \sum_l \frac{I_\ell(u)^2}{(I_\ell^{max})^2 - I_\ell(u)^2}$$

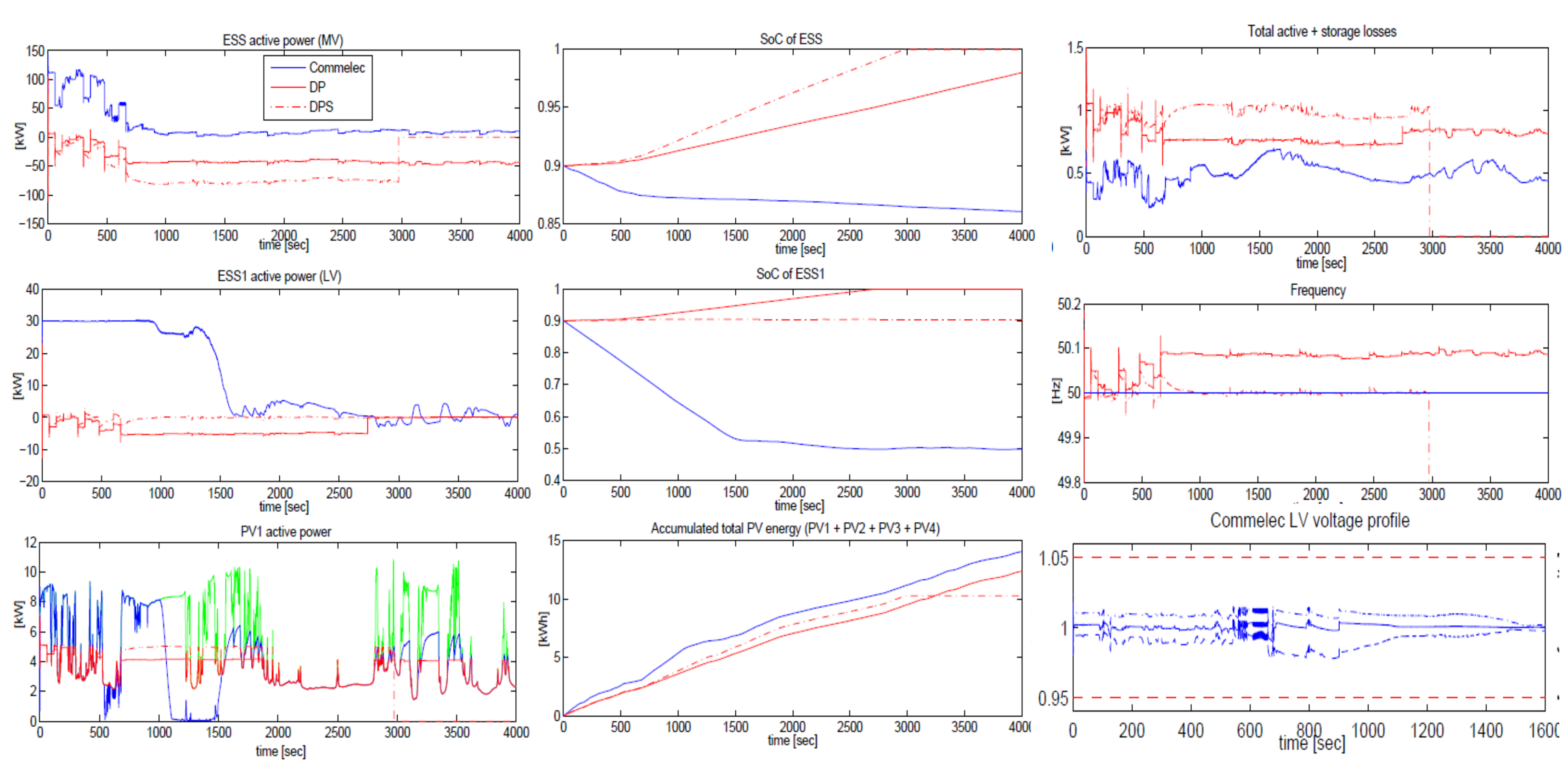
- Gradient-based approach: given the current (measured/estimated) setpoint $x = (P_i, Q_i)$, the computed next setpoint is given by $u = \mathcal{P}(\hat{x} + \Delta u)$
  - Δu is a vector in the direction **opposed to the direction of the gradient** of the overall objective function
  - $\mathcal{P}\{\}$ is the **projection to safe setpoint**

Synchronous Generator | Battery | Voltage deviation penalty



Simulations and Conclusions

- Comparison between Commelec vs standard droop control
- **Scenario:** overall **overproduction** in the grid **from renewables** (PV) with **minimum load consumption**
- Adopted to challenge both control methods to deal with a system characterized by a **low margin of controllability.**



Main conclusions

- **Controls the reserve of the storage systems, thus maximizing the autonomy of the islanding operation**
- **Reduces the curtailment of renewables**
- **Identifies local power compensations**
- **Keeps the system in safe operation conditions preventing the collapse.**
- **All this is obtained in real-time with a simple and generic protocol**
- **It does not require the exchange of resources specific states**