Real-Time Control of Electrical Distribution Grids with Explicit Power Setpoints

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September 19, 2016

NetCPS 2016, TU München

Credits

Joint work with
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Supported by

Energy Turnaround
National Research Programme NRP 70

SCCER – FURIES
Shaping the FUtuRe SwIss Electrical InfraStructure

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Abstract

What would happen today if we would instantly add a very large amount of renewables to the electricity mix? First, many distribution grids would face power quality problems such as over- and under-voltages and excessive line-currents. Second, the existing reserve mechanisms that are required to maintain power balance at all times would not be able to cope with the high variability and uncertainty of renewables. These problems can be solved if we are able to control the huge number of electrical resources that are located in distribution grids, which poses a number of new challenges in terms of scalability and reliability. In this talk we discuss these challenges and how they can be addressed by innovative information technology solutions, which involve in particular a scalable and composable framework (Commelec) for the development of real-time control agents .
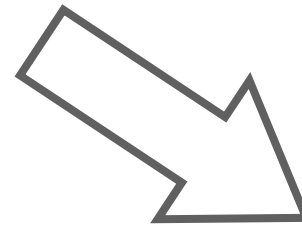
Variability and uncertainty of renewables
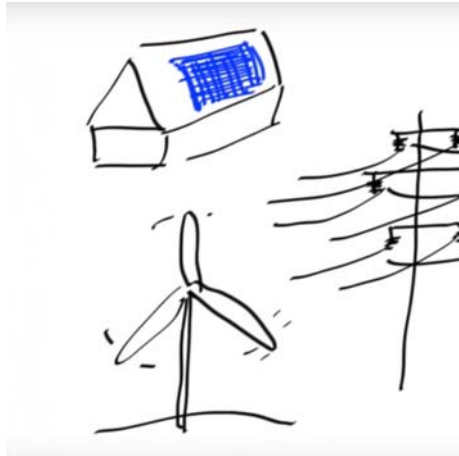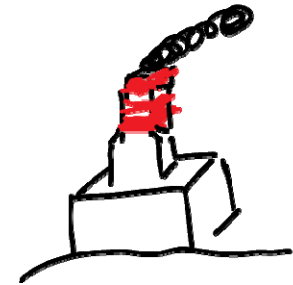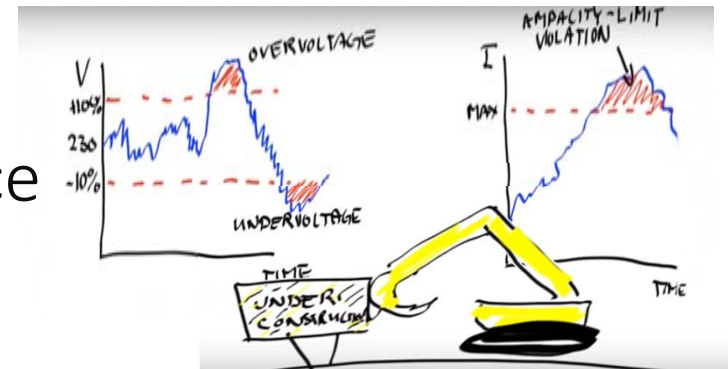
Large, stochastic loads

More reserves

More fuel based generators for regulation
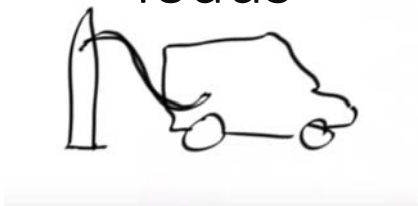
fast ramping gas power plant

Quality of service in distribution grids

Grid reinforcement

We can solve do better with real-time control of electrical distribution grids with storage and demand-response


Goals of control:

- Optimal use of local resources

- Distribution grid supports main grid

- Local solution of quality of service issues

- Islanded operation on demand

Explicit control of power flows
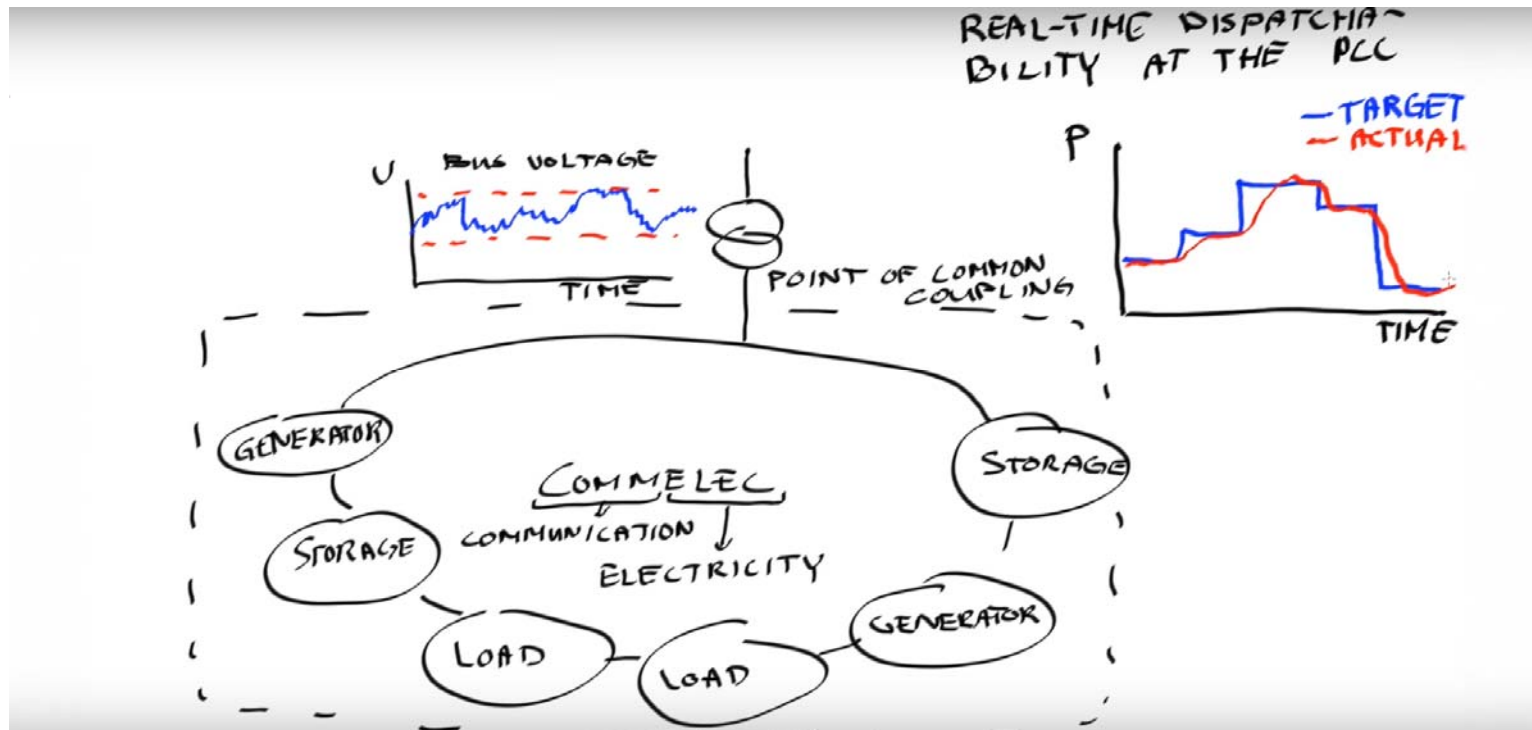
- alternative to droop control

- instruct battery, heat pump, EV charging...

- manages quality of service in grid

- respond to main grid's signals

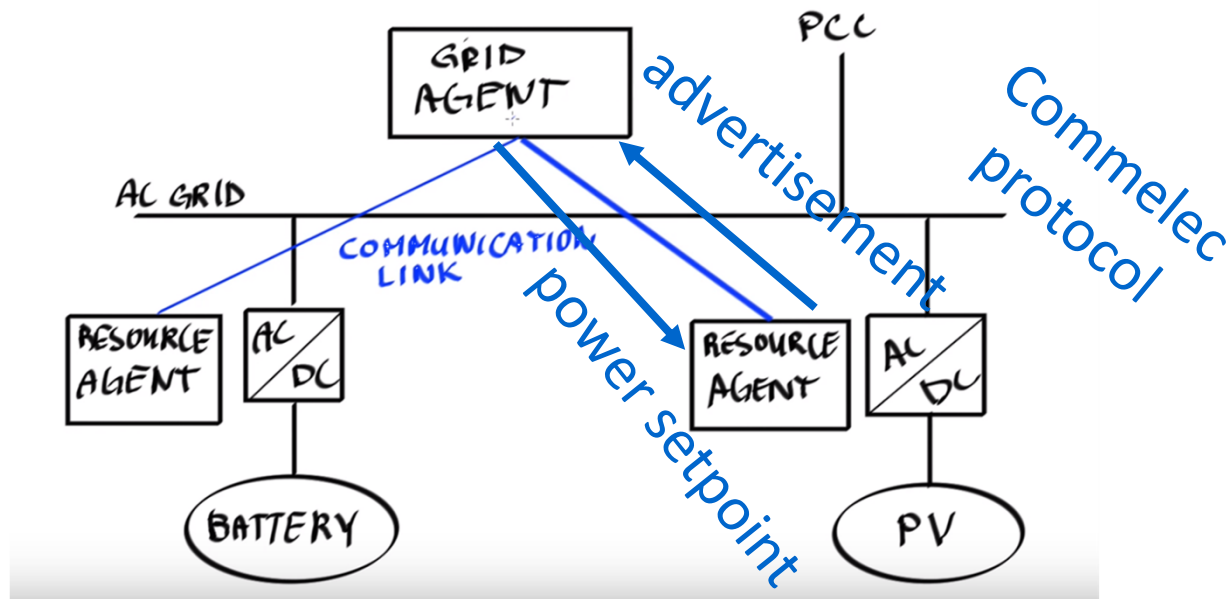# Challenges for explicit control of power flows
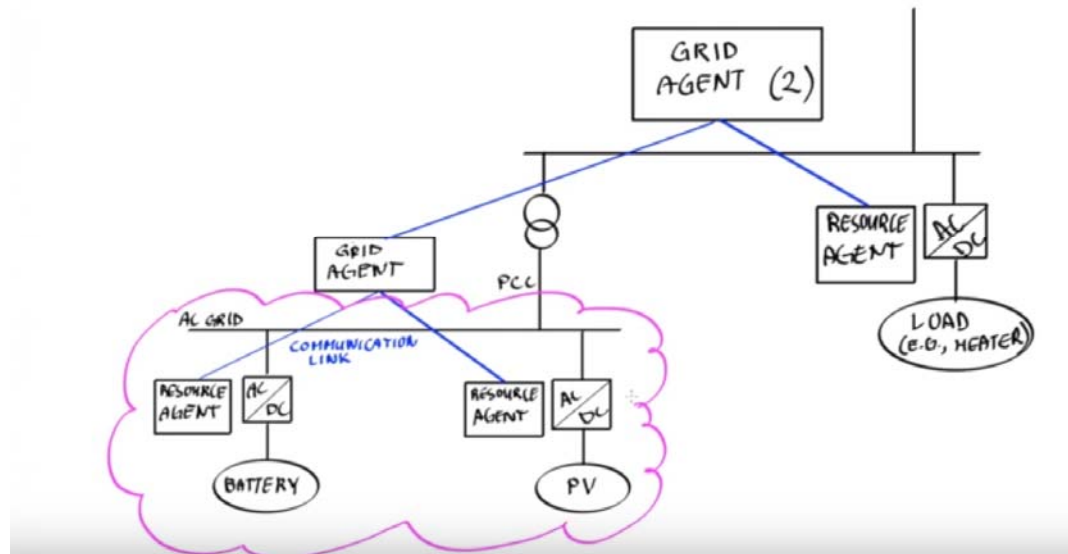
- Off-the-shelf commodity hardware

- Reliability, Quality of code

Addressed by the Commelec framework for real-time control of electrical grids
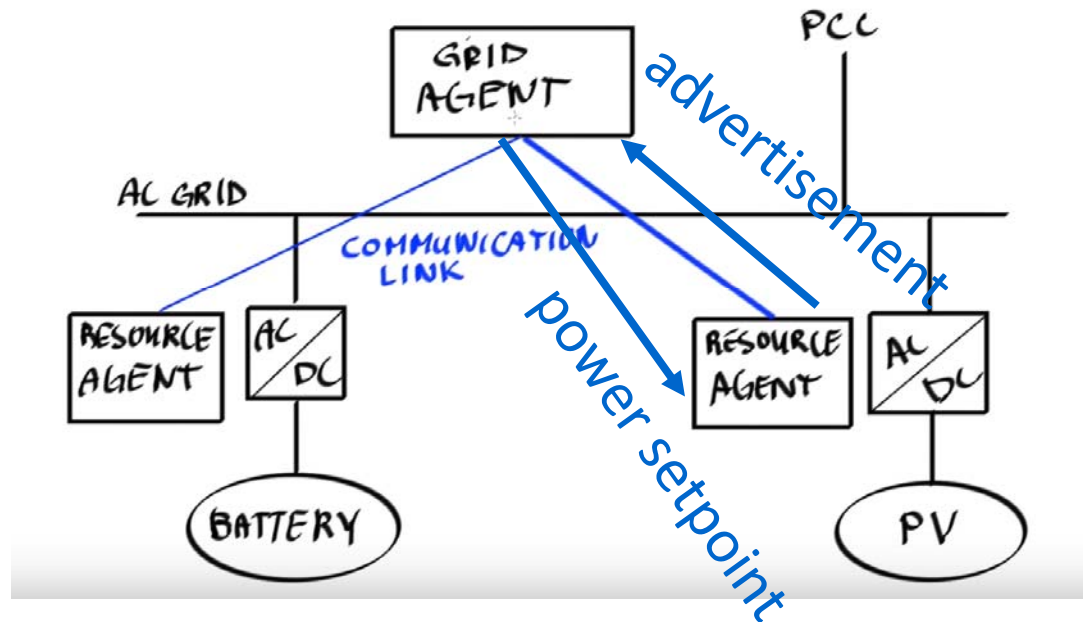[Bernstein et al 2015, Reyes et al 2015]

Commelec design principle #1: distribution of control by simple advertisement/setpoint protocol

Every 100 msec

- Central controller (Grid Agent) issues power setpoints
- Local controllers (Resource Agents) advertise state and constraints

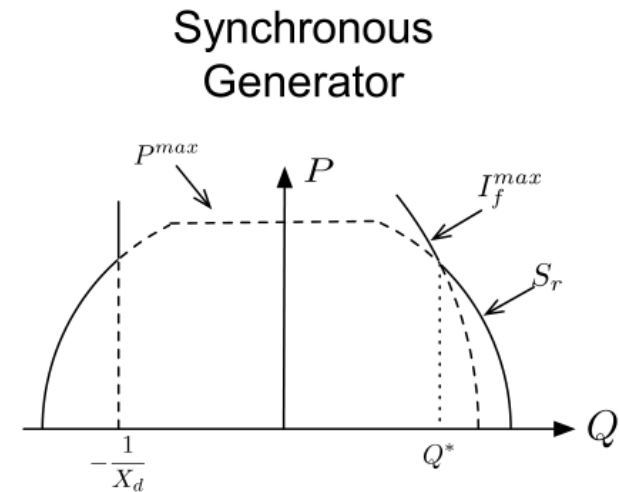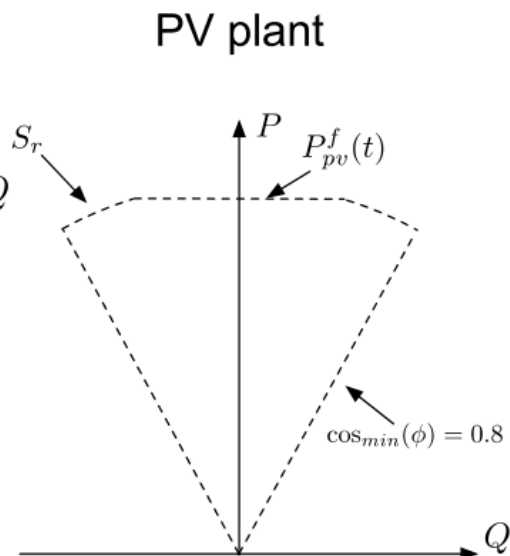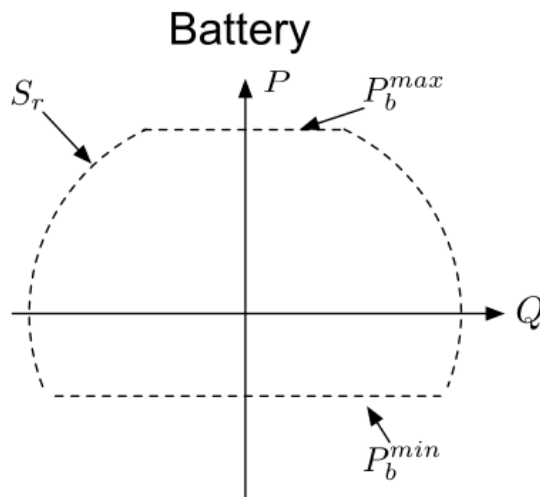# Commelec design principle #2: resource independence

Advertisements contain only the following abstract, universal objects:

- PQ profile, Virtual Cost and Belief Function

PQ profile = capability set in (P, Q) plane

Examples of PQ profiles

Virtual cost act as proxy for resource state
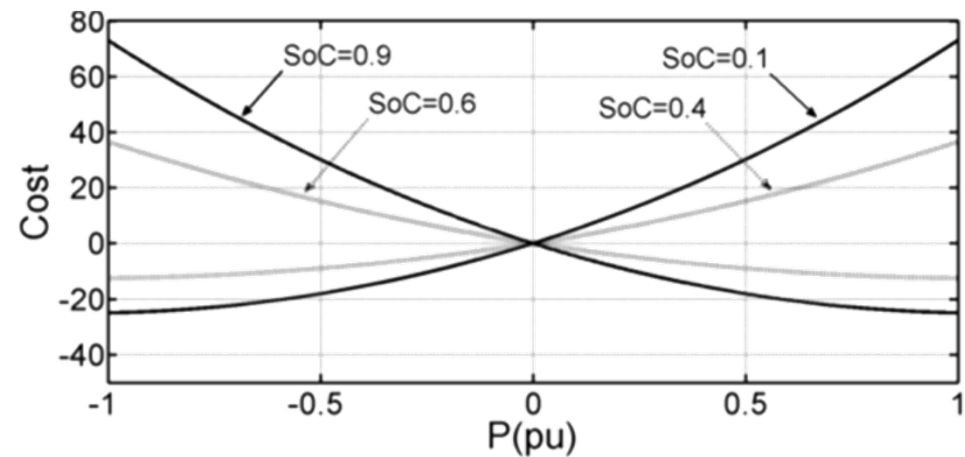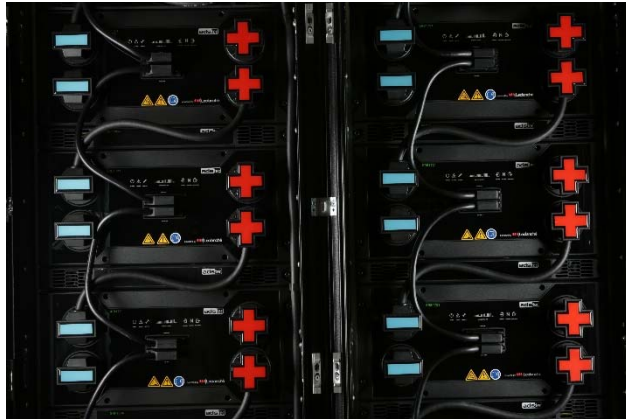

BA

I can do P, Q
It costs you (virtually) $C(P, Q)$

GA

Battery used for regulation:

If state of charge is 0.7,
I am willing to inject power

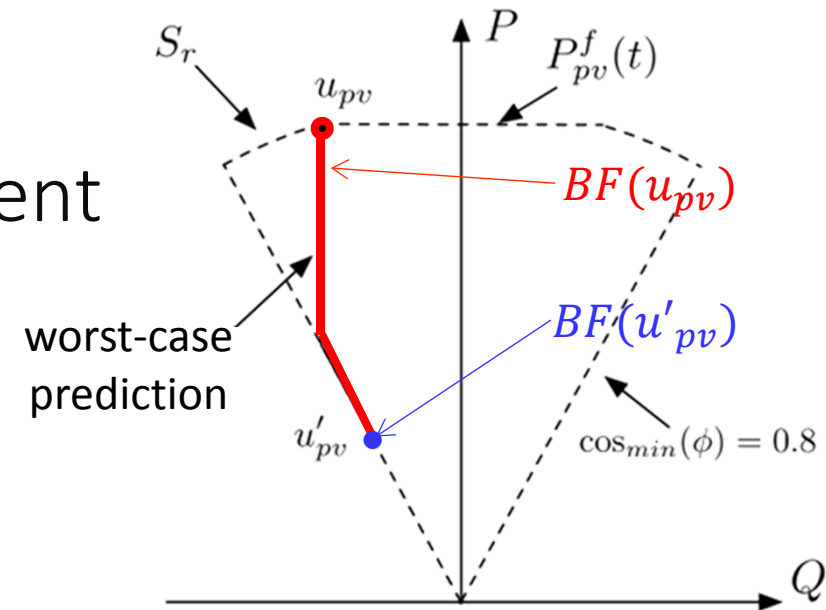If state of charge is 0.3,
I am interested in consuming power

$$C_b(Q) = 0$$

Belief function captures uncertainty set

Say grid agent requests setpoint (P_{set}, Q_{set}) from a resource; actual setpoint (P, Q) will, in general, differ.

Belief function $BF(.,.)$ exported by resource agent guarantees that

$$(P, Q) \in BF(P_{set}, Q_{set})$$

worst-case prediction

S_r

P

$P^f_{pv}(t)$

u_{pv}

$BF(u_{pv})$

$BF(u'_{pv})$

u'_{pv}

$\cos_{min}(\phi) = 0.8$

Q

Belief Function for a PV resource

Essential for safe operation

Grid Agent computes setpoints
for resource agents based on

- Electrical state estimation
- Advertisements received
- Request from main grid

Grid Agent minimizes

Cost of power flow at point
of common connection

$$J(x) = \sum_i w_i C_i(x_i) + W(z) + J_0(x_0)$$

Virtual cost of the
resources

Penalty function of grid electrical state z
(e.g., voltages close to 1 p.u.,
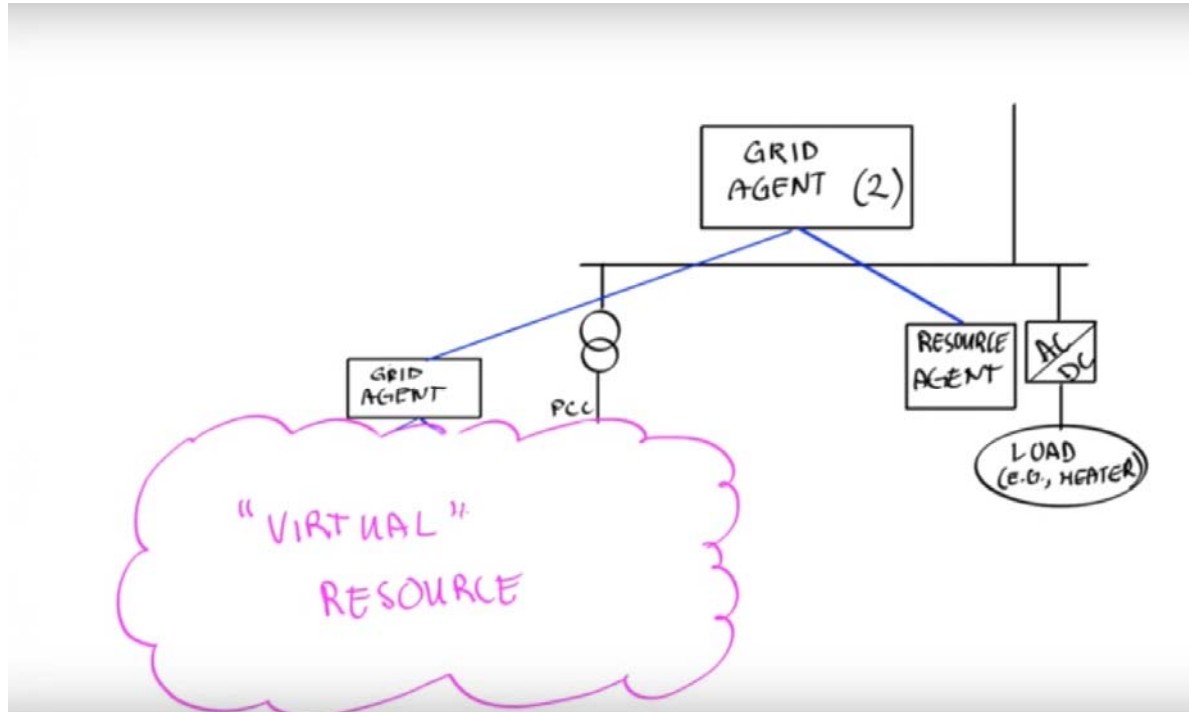line currents below the ampacity)
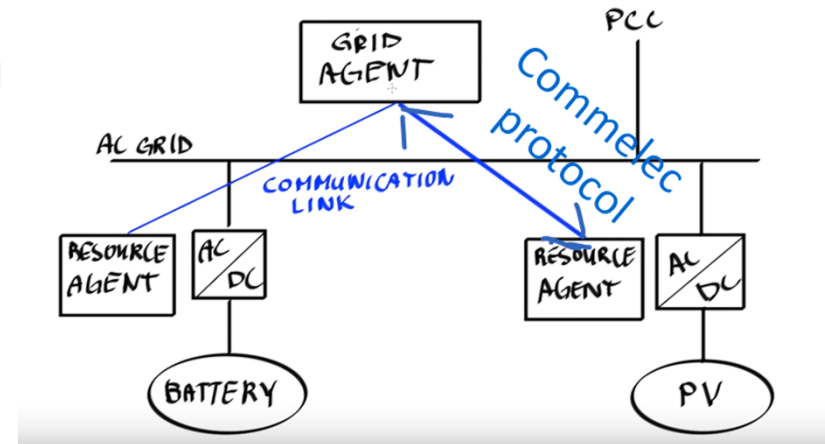
Grid Agent does not see the details of resources;
Problem solved by grid agent is always the same

Grid agent's main job involves

- Testing whether a given collection of power setpoints is feasible, given uncertainties of belief functions and given the characteristics of the grid
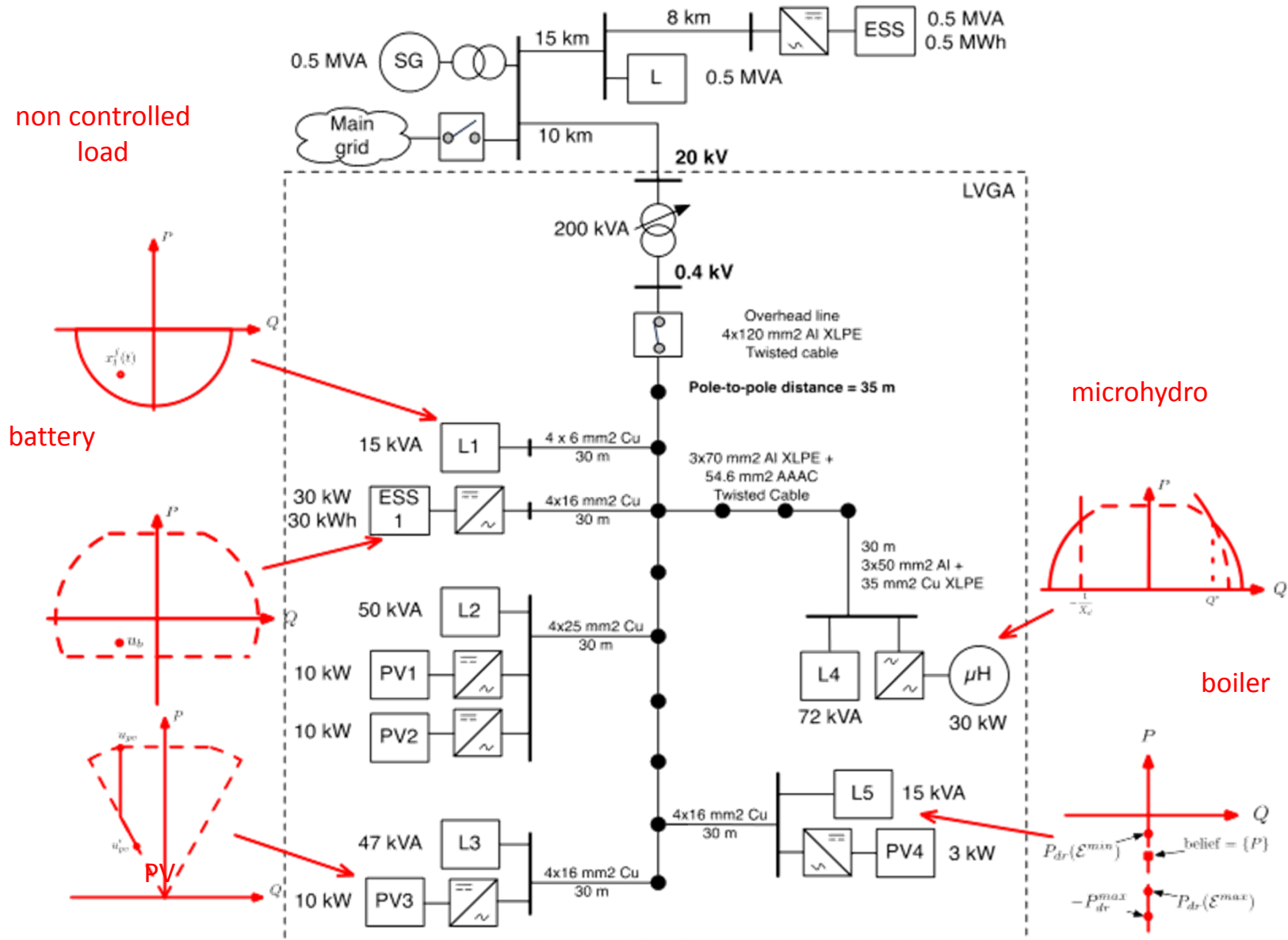
- This is known as a robust load flow

We have developed a very fast innovative method adapted to distribution networks (linear complexity, sub ms run time) [Wang et al. 2016]

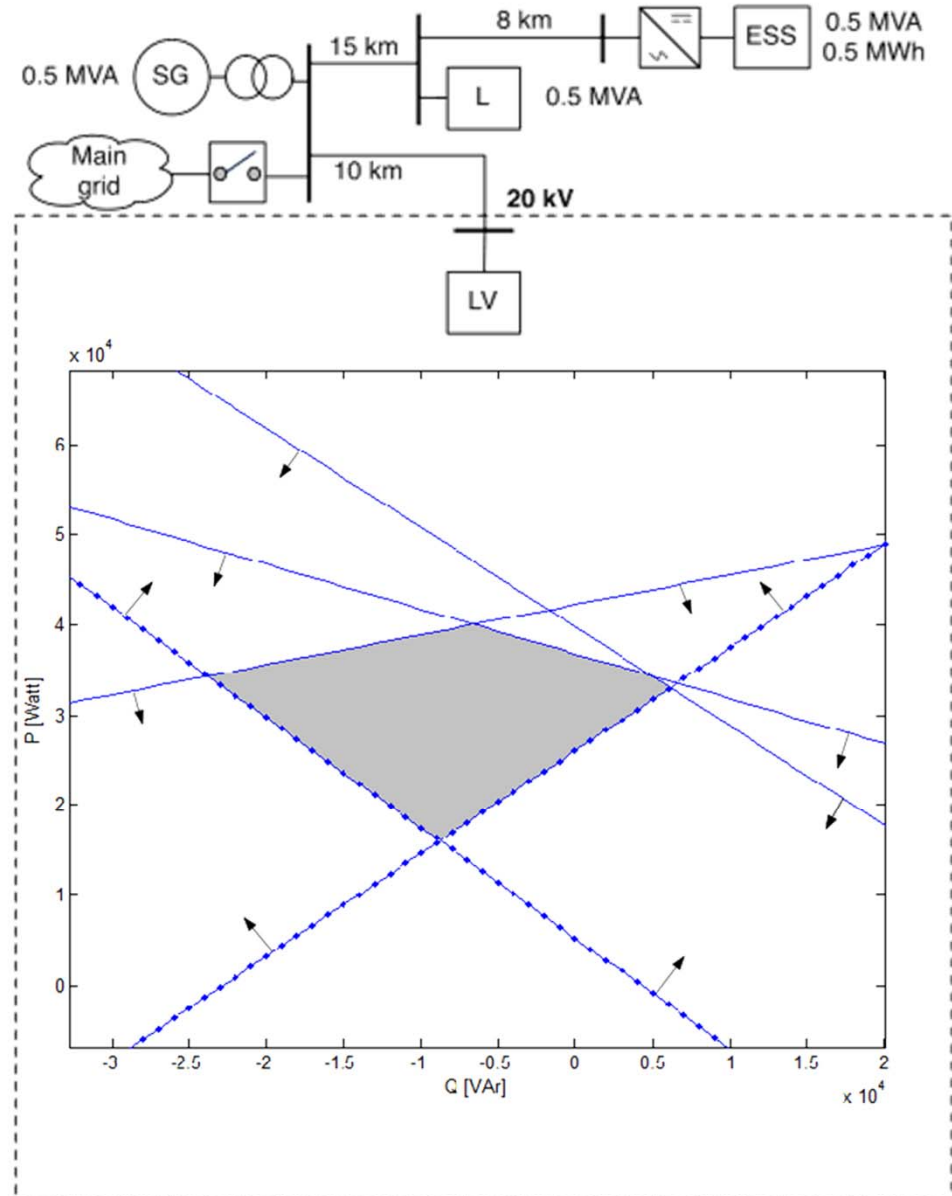# Commelec design principle #3: composability

- an entire sub-grid can be abstracted as a single resource

Aggregation example

non controlled load

battery
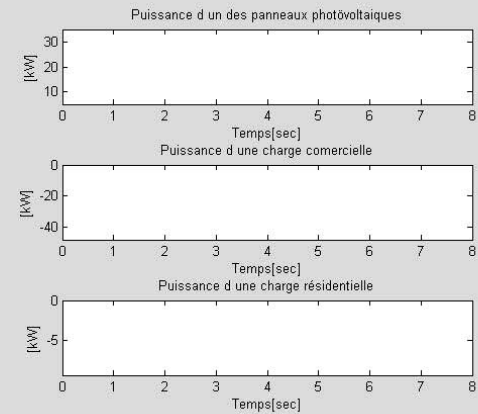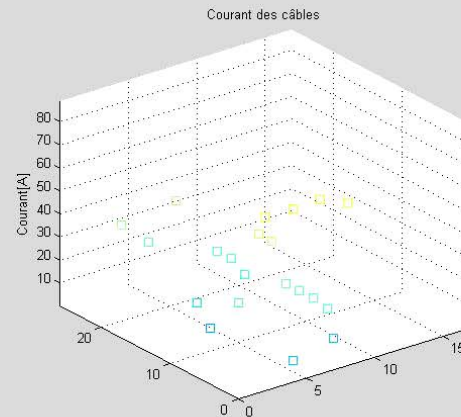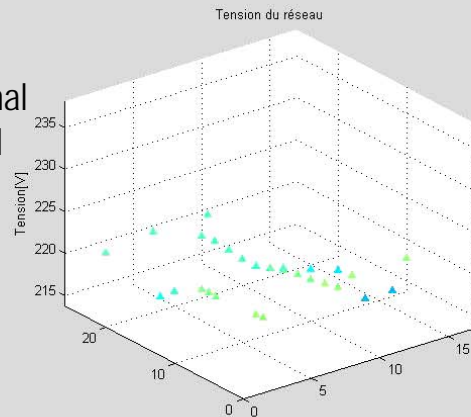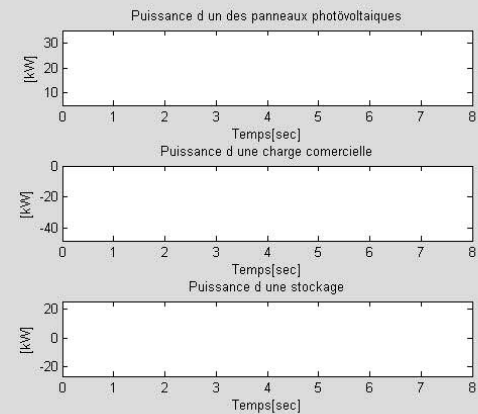
PV

microhydro

boiler

Aggregated PQt profile

17

Aggregated
Belief Function

18

Commelec grid integrates all resources to keep microgrid safe
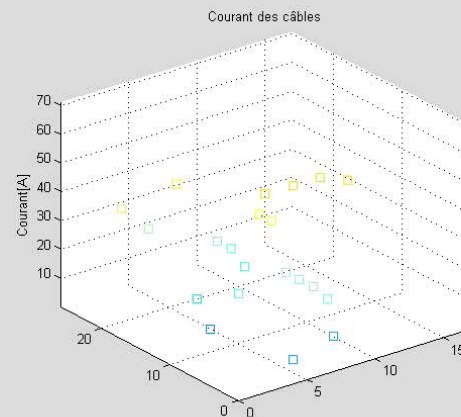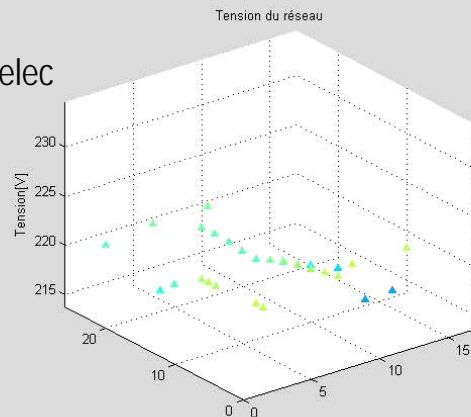
Commelec grid provides frequency support to main grid
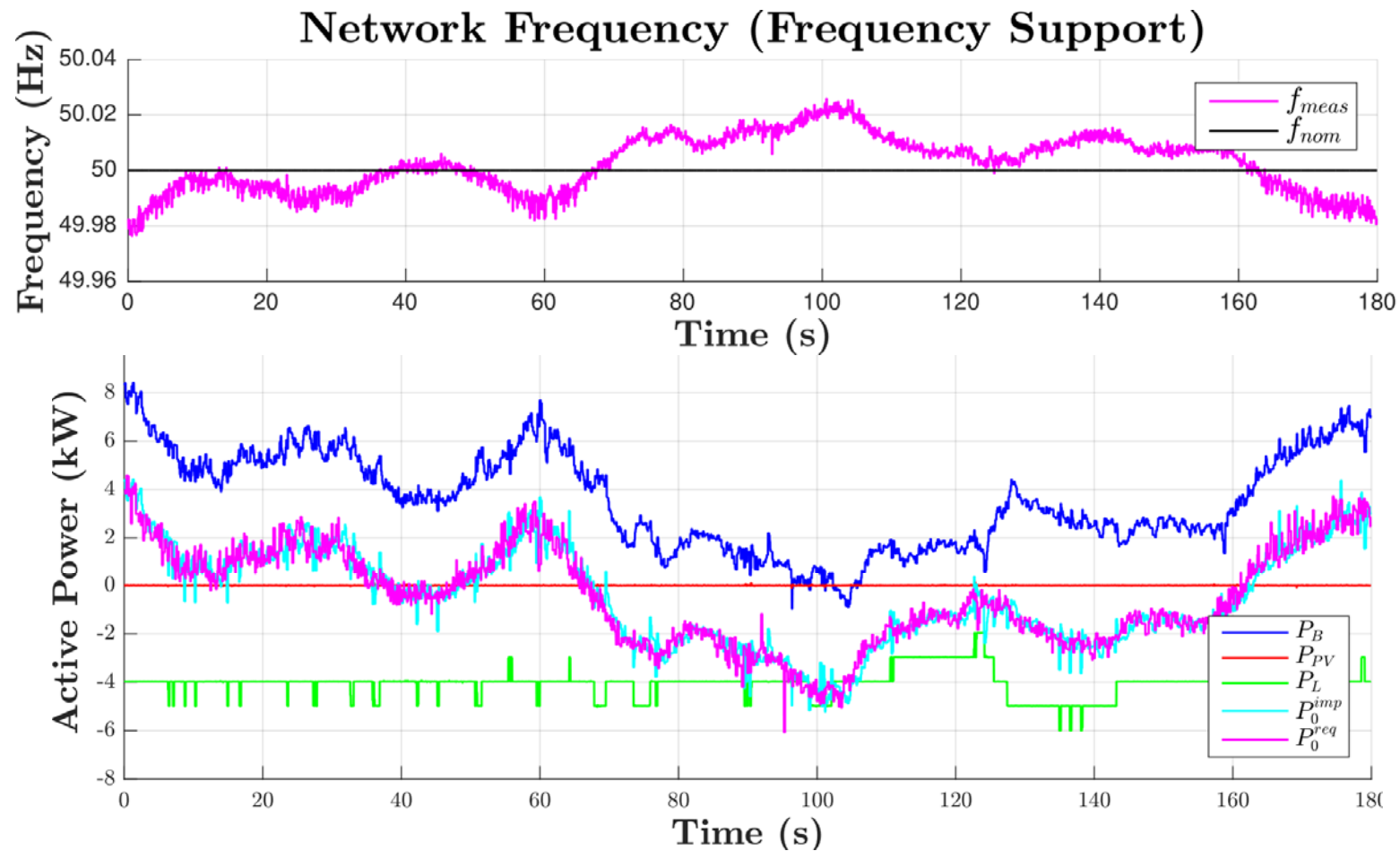
Commelec microgrid is dispatchable
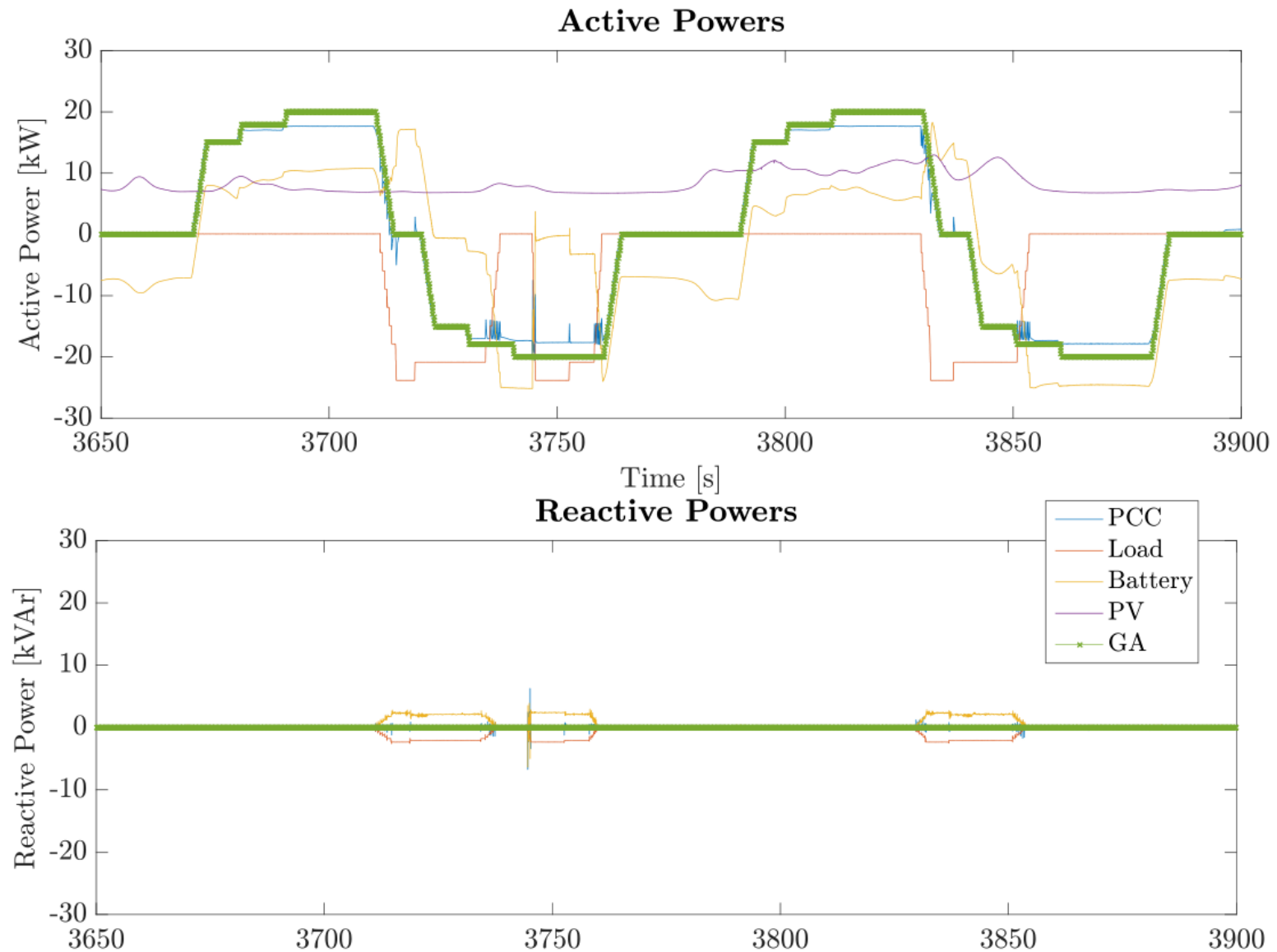
EPFL Microgrid running Commelec

CABLES

3 x 6 mm2 3G 1 mm2	SC2, SC6
3 x 16 mm2 3G 2.5 mm2	FD4, FD5, FD6, SC1, SC3
3 x 25 mm2 3G 4 mm2	SC5
3 x 35 mm2 3G 6 mm2	FD3
3 x 70 mm2 3G 10 mm2	FD1, FD2, SC4

EPFL's 20kV grid

20 kV

630kVA   630 kVA

0.4 kV

CONNECTION POINT

4I   4V

4I   4I

FD1 70m

15 kVA   UL1   SC6 30m

FD2 35m

25 kW 25 kWh   B   SC5 30m   FD6 105m

SC1 30m

FD3 70m

23 kVA   UL2   SC4 30m

30 kWp   Roof PV2

CL

75 kW 2 kWh   SC

27 kVA   D   12.5 kVA

FD4 105m

HP   10 kW

25 kVA   UL3   SC2 30m

FD5 35m

Faç. PV1   10 kWp

15 kW   FC   SC3 30m   FD5 35m

6 kW   EL

☐ PMU locations
☐ LC locations
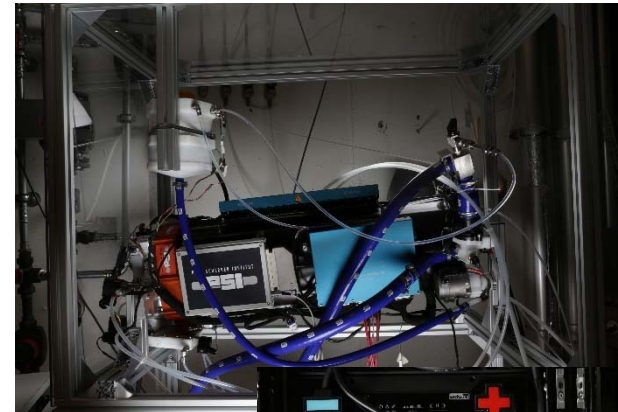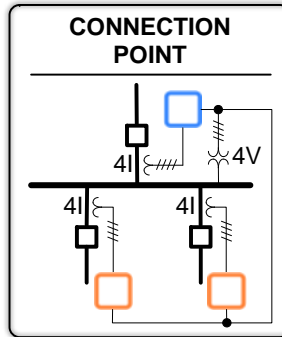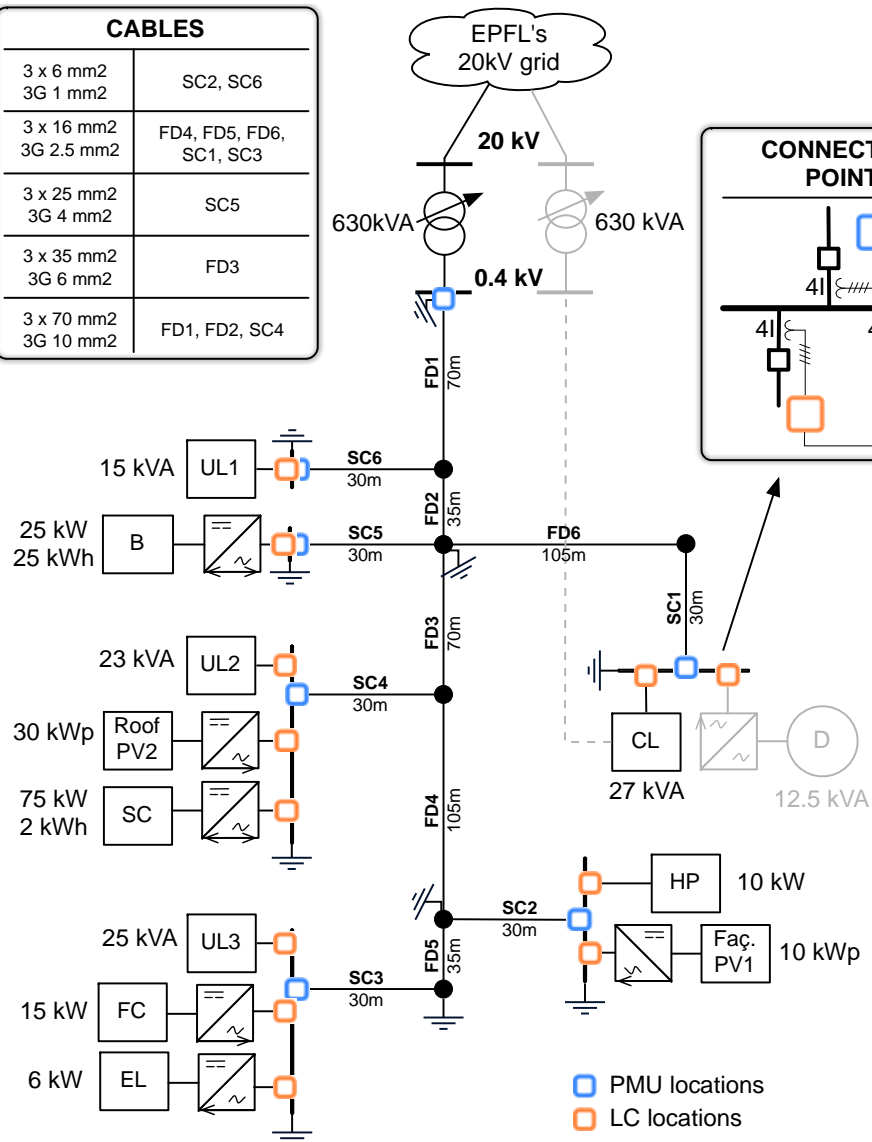
Reliability

- Use the BIP framework

- A single code for all grids

- Network Reliability by iPRP

- Tolerance to delay faults by Axo

Cyber-Security

- Control and sensing messages are authenticated with D-TLS and ECDSA for multicast
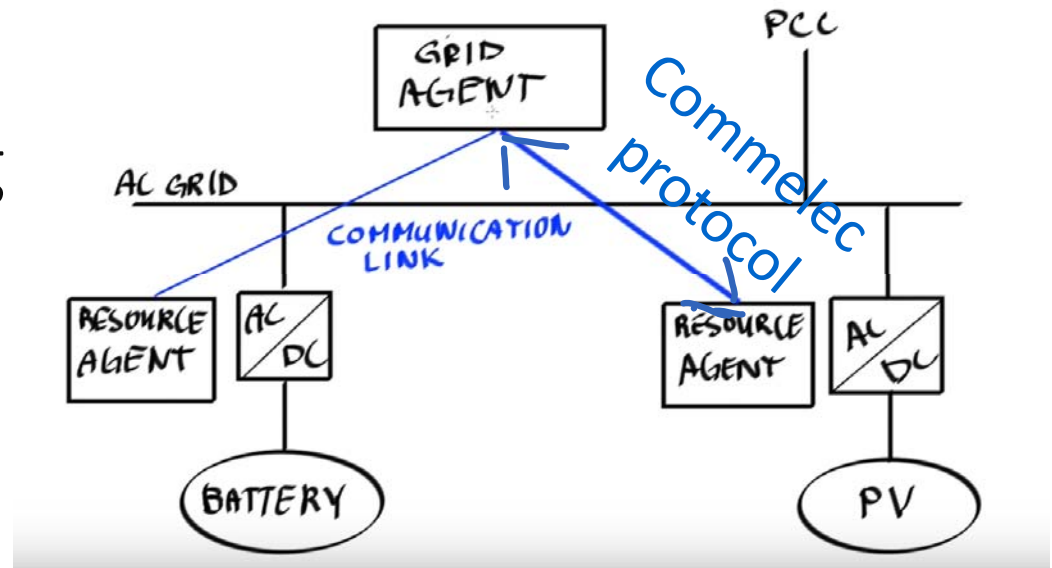
- Timing Attacks:
  Time Sync is used everywhere in smartgrid
  Phasor Measurement Units: require $\leq \mu$sec (GPS- PTP)
  Other sensors / actuators require ≈ 1 msec (NTP- PTP)

Conclusion

- Real time control of power flows will enable integration of large amounts of renewables

- IT Challenges are similar to those of autonomous vehicles

References

- http://smartgrid.epfl.ch

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