electra
Turn on the Grid of the Future

Desiging and Validating the future, intelligent, electric power systems

Kassel, September 6th 2017

Web-of-Cells Concept and Control Scheme

Chris Caerts

vito
vision on technology

European Commission

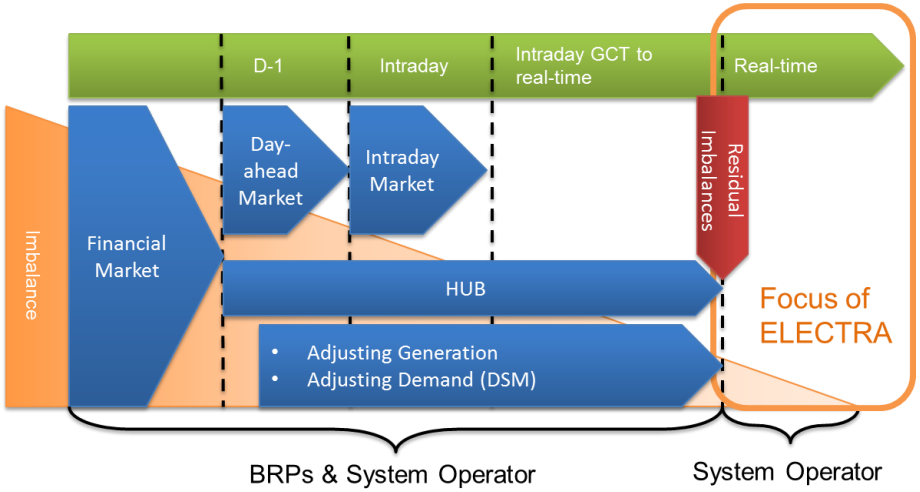
The research leading to these results has received funding from the European Union Seventh Framework Programme (*FP7/2007-2013*) under *grant agreement* n° 609687

EERA
European Energy Research Alliance
Smart Grids Joint Programme

www.ElectraIRP.eu

Web-of-Cells Concept

1. **Decentralized control scheme** for future reserves activations based on local observables : **solving local problems locally** and **separation of concerns / divide-and-conquer**



2. Load Frequency Control Areas ➔ smaller *cells* that are responsible both **detecting the need** for reserves activations as well as for the reserves **activation itself**

3. **Local collaboration** between cells based on **local observables** instead of global collaboration based on frequency as global observable

Trends and Challenges

- From: Transmission grid connected dispatchable synchronous generators with downstream power distribution

To: Large number of small intermittent generators that are located everywhere (all voltage levels)

- From: Generation follows Load

To: Load follows Generation

Trends and Challenges

- Active control of flexible loads and storage
- Increased amount of DRES (at medium/low voltage levels) grid
- Increased electrical loads (at medium/low voltage levels)
- Grids used closer to their limits

Reverse powerflows

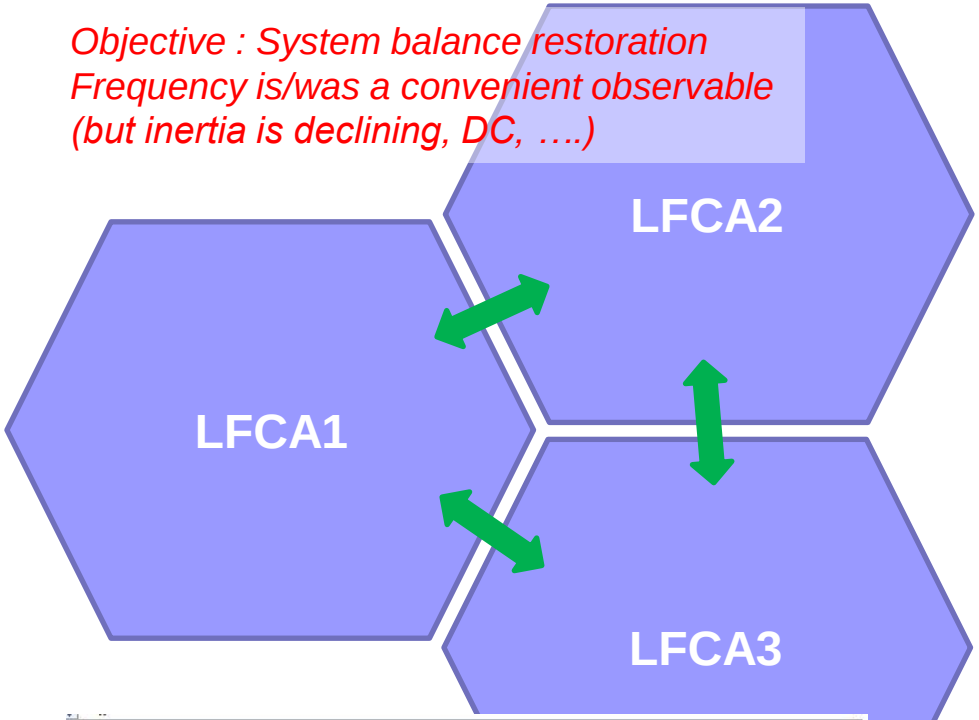
Congestions

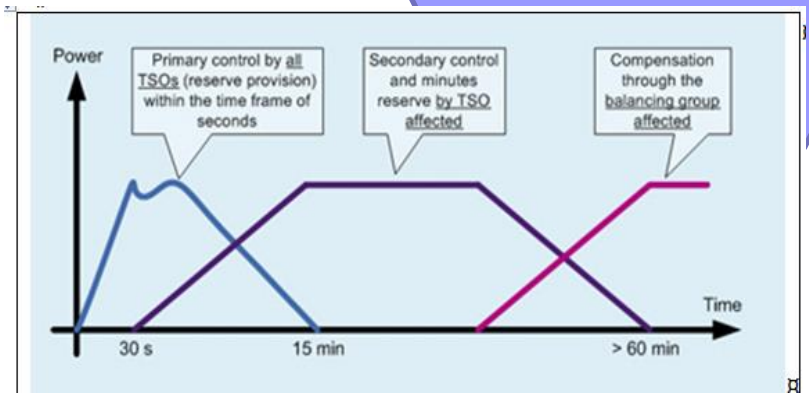
Voltage problems

Inefficiencies, losses

Current control scheme Balance/Frequency

Objective : System balance restoration
Frequency is/was a convenient observable
(but inertia is declining, DC, ….)





1. FCC : Frequency
   - **Contain** frequency deviation with slow (inertia bearing) generators
   - Collaborative and Global
2. FRC : Tie-line Powerflow and Frequency
   - **Restore** system balance and frequency
   - Local and Responsibilizing ('polluter pays')

- Small number of contributors connected to well-known transmission grid
- Activation without considering actual distribution grid status
- Trigger = **system imbalance** observed through frequency (aggregated deviations) ⇔ local issues (imbalance netting !)

Current control scheme Challenges

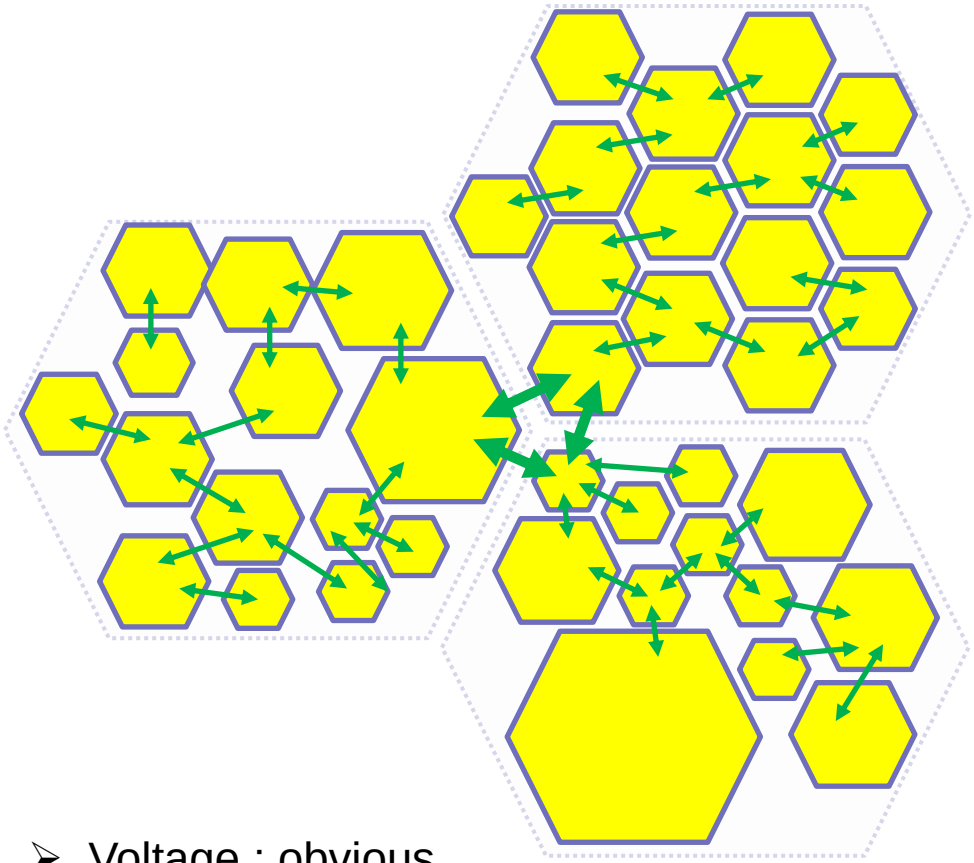
- Challenge 1 : Central **detection of the need** for reserves activations
  - **Local** voltage problems and congestions
  - Imbalance netting '**hides**' local deviations/problems (only considers the 'aggregated' deviation/problem)
- Challenge 2 : Secure and efficient **activations** of distribution grid connected reserves providing resources
  - What, and how much, can be activated where, so that no new local voltage or congestion problems are caused by these activations

⇒ Improve distribution grid observability/monitoring

⇒ Improve TSO/DSO coordination

Optimality, security, effectiveness ⇔ communication complexity, cost and latencies, and computational tractability, cost and latency

Web-of-Cells Concept



- **Detect and Solve local problems locally** based on local observables, and using local resources, acknowledging that:
  - causes are highly distributed and local *(the problem)*
  - reserves providing resources are (can be) local *(the solution)*
  - detailed local information is needed to activate securely and effectively
- Divide-and-conquer / **Separation of Concerns:** large LFCA ➔ smaller cell
  - secure and efficient decision in computational tractable time
  - Mitigate communication and aggregation/disaggregation complexity, delays and risks

- Voltage : obvious
- System Balance : restore as aggregated effect of restoring local cell balances
  - Cell balance setpoint = (aggregated) cell tie-line powerflow schedule (cfr FCR)

Cell Definition

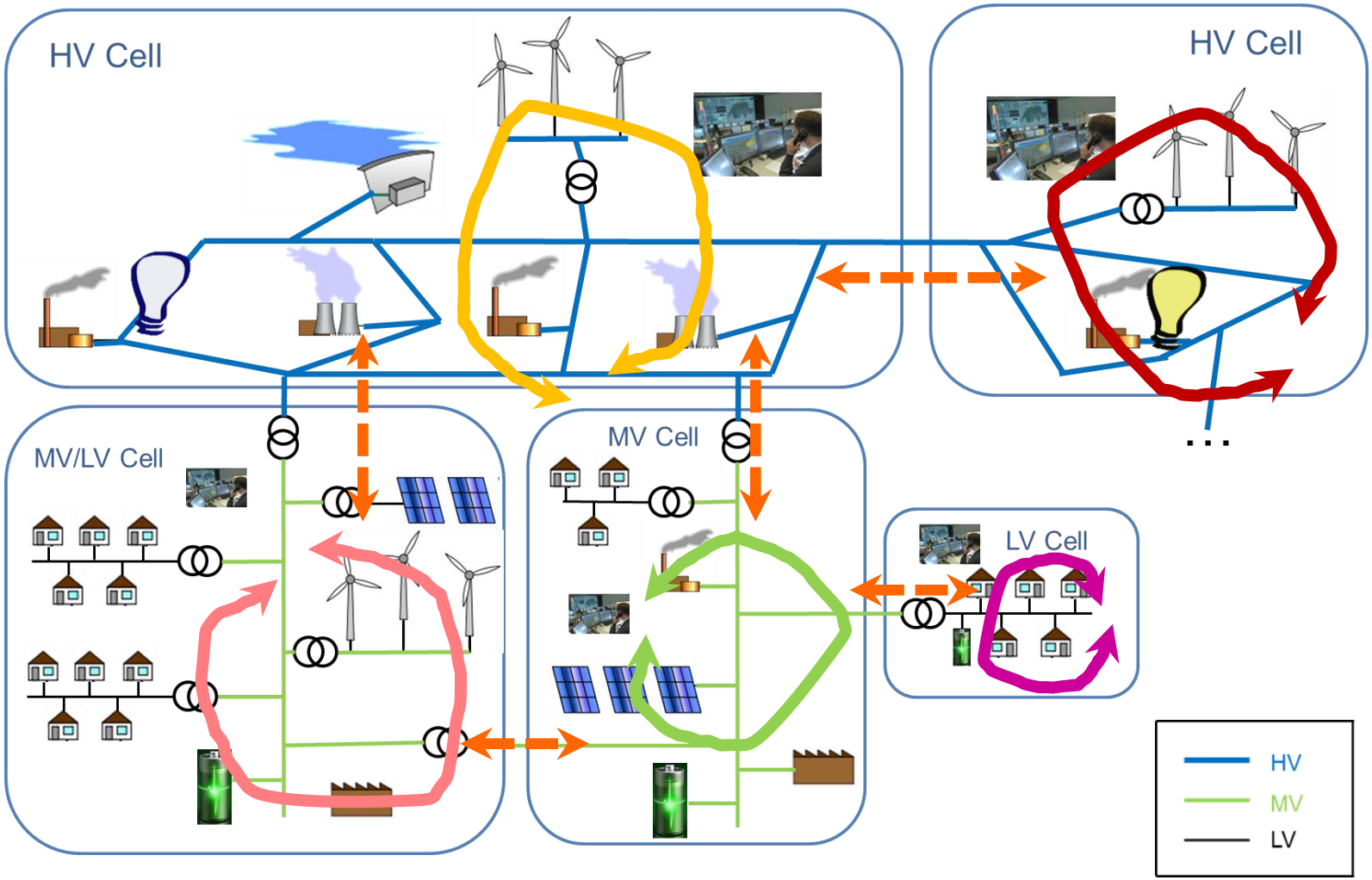
An ELECTRA Cell is a group of interconnected loads and distributed energy resources (DER), generation units (both central and distributed) and storage units within clearly defined electrical boundaries, that **autonomously but collaboratively** manages its aggregated consumption and generation profiles according to system-level defined **cell balance setpoints** in a local grid-secure manner.

ELECTRA Cells are connected to one or more neighbouring cells and can exchange power and data with them via one or more inter-cell physical tie-lines, and there is no restriction in how these inter-cell connections are organized: this can be radial/tree-like or a mesh.

Cells can span multiple voltage levels.

All cells are equal (no hierarchy).

Web-of-Cells Concept



Web-of-Cells Voltage Control

- In each cell: Periodic Proactive recalculation of voltage setpoints of AVR/PVC nodes, tap changing transformers, ….
  - To calculate voltage set-points that are within the safe band specified by the regulation considering a robustness tolerance, to avoid the recalculation of the set-points too often.

$$V_{sb,\min limit} - \Delta V < V < V_{sb,\max limit} + \Delta V$$

  - Calculate the set-points of the PPVC resources that **optimize the power flows** for getting minimum losses

$$MIN\ P_L = \frac{1}{2}\sum_{i=1}^{N}\sum_{\substack{j=1 \\ j\neq i}}^{N} g_{ij}\left[V_i^2 + V_j^2 - 2V_iV_j\cos(\delta_i - \delta_j)\right]$$

Web-of-Cells Voltage Control

- Leverage the WoC advantages …
  - Increased observability at all voltage levels
  - Increased number of (fast acting) controllable resources
  - Cellular architecture : manageable communication and calculation (OPF) complexity

- …to allow the **voltage control optimization** to be accomplished in a **single step … and periodically**

- Periodic Proactive: using updated forecasts and measurements
  - Safeband violations (measured at pilot nodes) will pre-empt a period and start a new optimal setpoint calculation

Web-of-Cells Balance Control

- Cell balance setpoint = (aggregated) cell tie-line powerflow schedule (cfr FCR)
- Determined by system level market : leverage availability of system-level cheap/sustainable energy
- Market Clearing/System Balance ➔ Cell Balance setpoints

- System Balance restoration: monitoring and correcting (aggregated) tie-line powerflow schedules
  - BRC concept ~FRC concept at smaller scale
  - **One-step Balance Restoration** leveraging high amounts of **fast acting resources** (invertor coupled) with high ramping rate
  - BRC and FCC running **at same time** (compared to FRC taking over from FCC)
  - FCC as an safety net to support BRC (esp. for large incidents)

Web-of-Cells Balance Control

- System Balance restoration = aggregated effect of (**bottom-up) Cell Balance restoration**
  - Based on local observables: responsibilisation
  - More activations (loosing imbalance netting advantage), but
    - using other (no fuel) resources
    - reducing losses (locality of correcting powerflows)
    - increased security and more effective use of resources (see challenges)

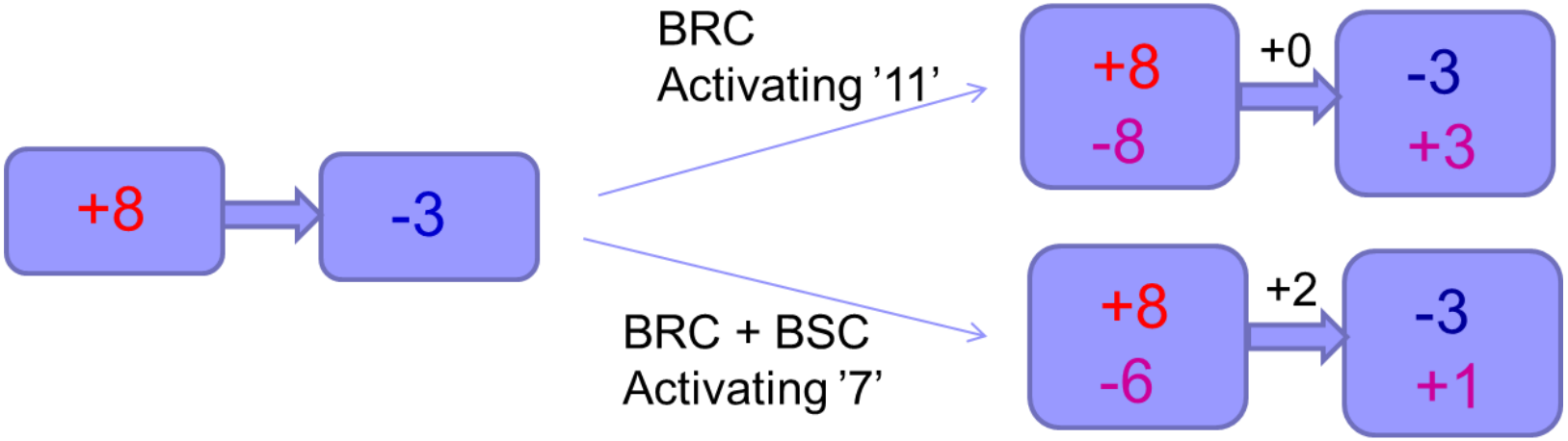
- Cell Imbalances are caused by:
  - Intra-cell forecast errors or incidents
  - Deviations in neighbouring cells (physical connections) ➔ local collaboration
  - Intra-cell reserves activations for voltage control (unavoidable) or frequency/balance control (try to avoid: **Adaptive FCC**)

Web-of-Cells Balance Control

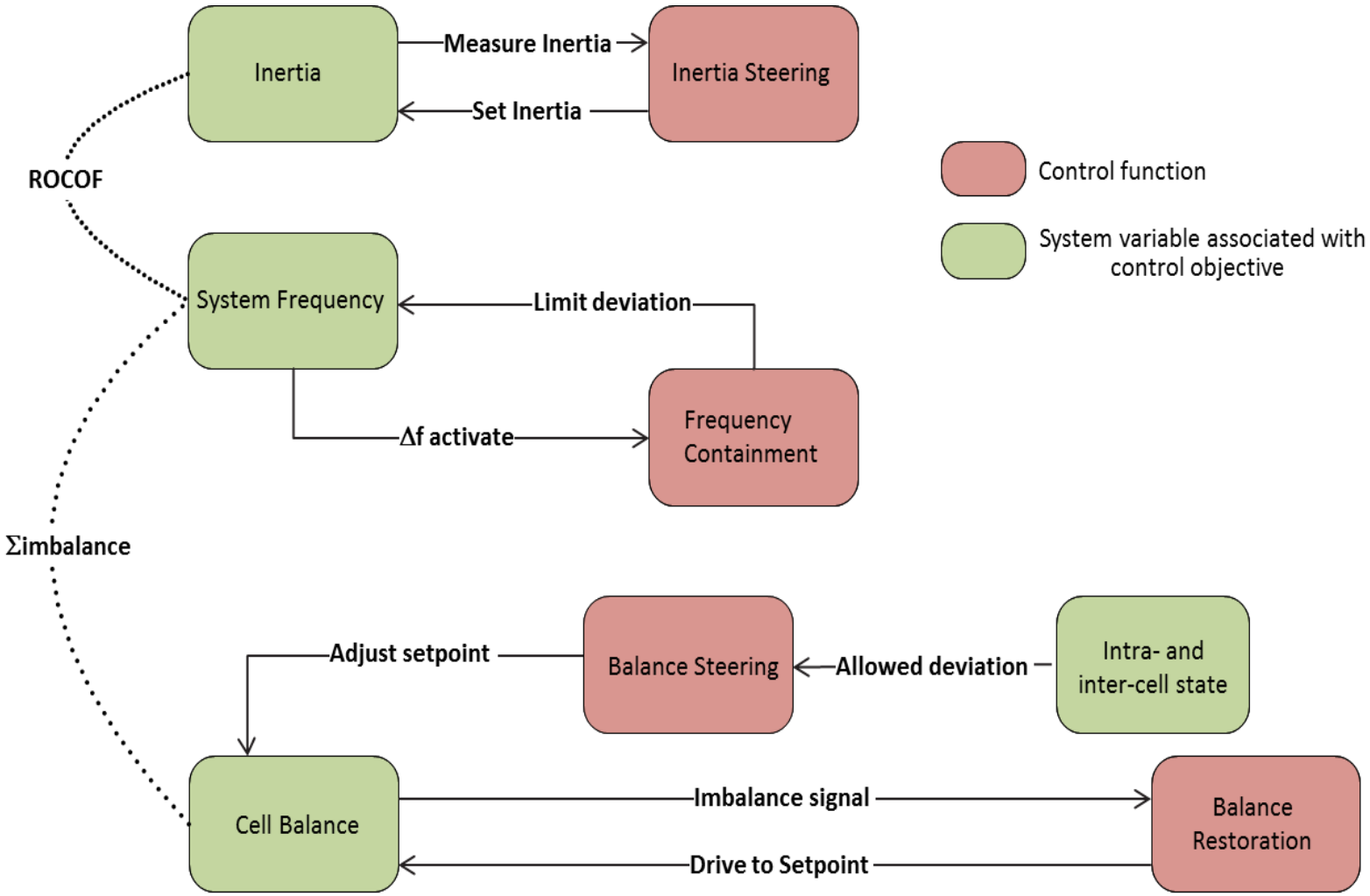
- **Adaptive FCC**
  - ‘solve local problems locally’: avoid frequency deviation triggered activations in
    - Cells that are ‘in balance’
    - Cells that are not causing the deviation : responsibilisation
  - focus FCC activations in cells that are causing the measured imbalance (0/1, fuzzy logic controller, …)
  - do not cause additional cell imbalances by acting on a remote cell imbalance
  - (Local) collaboration ⇔ full responsibilisation: the WoC concept features locality and proportionality when reacting to deviations

Web-of-Cells Balance Control

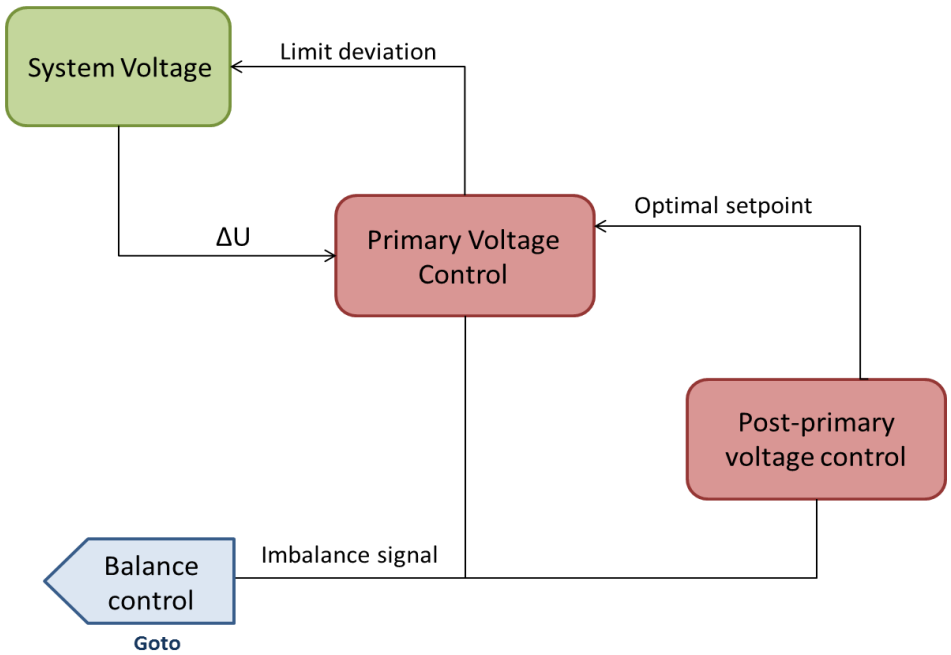
- **Balance Steering Control**
  - Local (peer-to-peer) coordination among cells
  - Cfr distributed peer-to-peer imbalance netting (change cell balance setpoints in a coordinated manner and within all grid constraints)



Web-of-Cells Control Scheme



Web-of-Cells Control Scheme



Summary WoC

- **Decentralized control scheme based on local observables using local resources**
- **Periodic Proactive voltage control**
- **Decentralized (bottom-up) system balance restoration as aggregated effect of cell balance restoration**
  - **Cell balance = adhering to system-level agreed/cleared power import/export schedule**
  - **~FRC, but smaller entities, using load/storage resources, concurrent with (iso taking over from) aFCC**
- **Local coordination/collaboration based on local observables (peer to peer imbalance netting)**

CONTACT

INFORMATION

Chris Caerts
chris.caerts@vito.be

ELECTRA IRP website link:
www.ElectraIRP.eu