Designing and Validating the future, intelligent, electric power systems

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Web-of-Cells Concept and Control Scheme

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www.ElectraIRP.eu
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
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 !)

**Objective : System balance restoration**
Frequency is/was a convenient observable (but inertia is declining, DC, ....)
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
Voltages: obvious
System Balance: restore as aggregated effect of restoring local cell balances
   - Cell balance setpoint = (aggregated) cell tie-line powerflow schedule (cfr FCR)

- 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 \(\Rightarrow\) smaller cell
  - secure and efficient decision in computational tractable time
  - Mitigate communication and aggregation/disaggregation complexity, delays and risks
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).
• 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.

\[ V_{sb,\text{min limit}} - \Delta V < V < V_{sb,\text{max limit}} + \Delta V \]

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

\[ \text{MIN } P_L = \frac{1}{2} \sum_{i=1}^{N} \sum_{j=1, j \neq i}^{N} g_{ij} [V_i^2 + V_j^2 - 2V_i V_j \cos(\delta_i - \delta_j)] \]
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
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 (inverter 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)
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)
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)

![Diagram of Web-of-Cells Balance Control](image)
Web-of-Cells Control Scheme

Inertia
- Measure Inertia
- Set Inertia

Inertia Steering

System Frequency
- Limit deviation
- Δf activate

Frequency Containment

Σimbalance
- Adjust setpoint

Balance Steering
- Allowed deviation
- Imbalance signal
- Drive to Setpoint

Cell Balance

Intra- and inter-cell state

Balance Restoration

Control function

System variable associated with control objective
Web-of-Cells Control Scheme

- System Voltage
  - Limit deviation
- ΔU → Primary Voltage Control
  - Optimal setpoint
  - Post-primary voltage control
- Imbalance signal
- Balance control
  - Goto
• 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)
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