DAY-AHEAD DISPATCH OF AN ACTIVE DISTRIBUTION NETWORK HOSTING STOCHASTIC DISTRIBUTED GENERATION VIA GRID-AWARE CONTROL OF A BESS

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## The control time scales for ADNs

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**Time scales:**
- hours
- minutes
- seconds
- mins-seconds
Objective

Experimental validation of day-ahead dispatchability of a distribution network hosting stochastic RES-based generation via grid-aware real-time control of a BESS

Control in two stages: a **day-ahead optimization** and a **real-time control**

Optimal profile of the feeder power for the **next day** and determination of BESS offset profile:
- data-driven forecasting
- scenario-based optimization

In **real-time**, the BESS is controlled to track the optimal profile:
- grid-aware OPF-based control
- battery equivalent circuit model
Overall framework

**Day-ahead computation**
- Optimal profile of the power feeder for the next day + offset BESS profile

**Real-time control**
- Real-time PMU measurements
- Real-time grid state estimation
- OPF solution for the calculation of BESS P,Q
- Real-time GHI measurements
- Selection of feasible set-point
- BESS

- Battery model parameters estimation
- Region of feasibility selection

Real-time BESS status

\[ (v^\text{DC}_t, \text{SOC}_t) \]
Dispatch plan definition

Day-ahead

Every 24 hours, we solve a robust optimization problem:

**find:**
• a dispatch plan for the next 24 hours using a scenario-based iterative AC OPF (**Codistflow**), which accounts for forecasts of RESs and load profiles with 95% confidence interval with 1h time resolution

**such that:**
• the **dispatch error** ($|\text{sum}(\text{dispatch plan} - \text{PCC power})|$) is **minimized** within 1h
• the BESS offset profile for **SoC compensation** is included and such that:
  • the BESS **energy limits** are respected
  • the BESS **power limits** are respected
  • the grid **ampacity and voltage constraints** are respected
  • **end-of-day SoC** is within 10% around initial SoC
RT OPF-based BESS control

Real-time control

For each 1 hour slot, we solve robust OPF problems every 1 min, that considers the dispatch plan and BESS offset profile:

\[
\text{while } i < i_{\text{max}} \text{ do:} \\
\bullet \text{solve } (i_{\text{max}} - i) \text{ OPF for each time step of the 1h interval in receding time horizon} \\
\text{such that:} \\
\bullet \text{the dispatch error } (\sum |\text{dispatch plan} - \text{PCC power}|) \text{ is minimized within 1h} \\
\bullet \text{the BESS offset profile for SoC compensation is included} \\
\bullet \text{the accumulated error during the previous } (i - 1) \text{ timesteps is considered and compensated} \\
\text{and such that:} \\
\bullet \text{the BESS energy limits are respected} \\
\bullet \text{the BESS power limits are respected} \\
\bullet \text{the grid ampacity and voltage constraints are respected} \\
\text{end}
Different OPF methods

Accuracy VS Computation Complexity

• **Linearized OPF** [1]
  - The system states are modeled by the sensitivity coefficients which can be uniquely determined as a function of grid states and topology, and are assumed to be constant within the control time interval.

• **Second-order cone ACOPF (SOC-ACOPF)** [2]
  - Relying on the branch flow formulation based on the transmission line Π-model.
  - The original AC-OPF is convexified by employing SOC programming relaxation on the ampacity constraint associated to power losses.
  - The loop constraint of V phase angle is derived so that the branch flow model is valid also for meshed power networks.
  - The feasible solution of the original AC-OPF can be recovered from the optimal solution of the SOC-ACOPF and the relaxation of the SOC-ACOPF model is tight under high power load conditions.

• **Augmented Relaxed OPF (AR-OPF)** [3]
  - Relying on the branch flow formulation based on the transmission line Π-model.
  - While employing the SOCP relaxation on the ampacity constr. associated to P losses, aux. variables related to the state variables (line P-flow, V and I) are introduced to build a set of augmented operating constraints to guarantee the exactness of the SOCP relaxation.
  - The exactness is valid under mild conditions which holds for realistic radial distribution networks.

Employed state estimation method

Zaphiro develops the **first grid automation system** based on high-speed & time-synchronized PMUs

17 Zaphiro’s PMU (Phasor Measurement Unit) devices:
- Time-synchronized
- High-speed measurements (50 meas/sec)

**Modular and scalable big-data processing software platform**

**Real-time monitoring**
- Estimation of entire grid state up to 50/60 times per second

**Outage management**
- Automated fault location to reduce the duration or even prevent blackouts

**Battery control**
- Control of a 1.5 MW battery to:
  - Maximize PV generation
  - Guarantee grid stability
  - Provide ancillary services

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1.5 MVA/2.5 MWh BESS

PQ capability curves as function of the real-time BESS status & grid status

\[ h(P_t^{AC}, Q_t^{AC}, v_t^{DC}, v_t^{AC}, SOC_t) \leq 0 \]
**BESS modelling**

Equivalent battery TTC model

\[ \begin{aligned}
C_1 \frac{dv_{C1}}{dt} + \frac{v_{C1}}{R_1} &= \frac{v_s}{R_s} \\
C_2 \frac{dv_{C2}}{dt} + \frac{v_{C2}}{R_2} &= \frac{v_s}{R_s} \\
C_3 \frac{dv_{C3}}{dt} + \frac{v_{C3}}{R_3} &= \frac{v_s}{R_s} \\
v_s + v_{C1} + v_{C2} + v_{C3} &= E - v_{DC}'
\end{aligned} \]

\[ E(SOC_t) = a + b \cdot SOC_t \]

Reference BESS scheme for the AC voltage prediction

- **Prediction of DC voltage** \( (v_{DC}', SOC_t) \)
- **Prediction of AC grid voltage** \( (v_{AC}', SOC_t) \)

\[ v_{AC}' = v_{AC,m}' + Z_{eq} \cdot jX_T \]

\[ h(P_{AC}', Q_{AC}', v_{DC}', v_{AC}', SOC_t) \leq 0 \]

Converter feasibility region

BESS
1.5 MVA/2.5MWh

Base voltage: 21 kV
Base 3-phase power: 6 MVA
Total PV gen. capacity: 3.2 MWp (1xMW-scale)
Total hydro gen. capacity: 3.4 MVA (1xMW-scale)
17 PMUs distributed along the network

\[
\begin{align*}
\sum_{i} P_{load_i} &; \sum_{i} Q_{load_i} \\
\sum_{j} P_{PV_j} &; \sum_{j} Q_{PV_j} \\
\sum_{k} P_{hydro_k} &; \sum_{k} Q_{hydro_k}
\end{align*}
\]
Prosumption data analysis and PV disaggregation
Day-ahead scenarios generation and Realization

27 October 2020
Where we are now

Original plan

BESS and PMUs installation

Set up and tuning of hardware and IT

Data collection for prediction models building

Time

Apr 2020  May 2020  …  Set 2020  Oct 2020

Actual plan due to pandemic

BESS and PMUs installation

Set up and tuning of hardware and IT

Time

Apr 2020  May 2020  …  Set 2020  Oct 2020
Conclusions

• We are deploying a framework for the day-ahead dispatchability of a distribution network hosting stochastic RES-based generation via grid-aware RT control of a BESS

• We have put in place a field experimental setup with advanced top-edge technology for the real-time monitoring and control of an ADN

• We have established field data collection and performed first analysis to assess the stochastic behavior of loads and distributed RESs after disaggregation

• We have performed BESS equivalent model identification tests for its optimal control

• An online disaggregation and forecasting tool for PV production and load consumption is operational.

• The RT dispatcher will be fully operational by mid-November
Thank you

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