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REEL Demo – Romande Energie ELectric network in local balance Demonstrator

Deliverable: 2b3 Successful deployment and impact measurement of COMMELEC-based control on MV

Demo site: Aigle

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1. Description of deliverable and goal

1.1. Executive summary

The goal of the activity is to develop a COMMELEC based framework for the real-time control of a 1.5 MW/2.5 MWh battery energy storage system (BESS) to follow a dispatch plan computed day ahead. COMMELEC is a framework proposed in the literature ([1], [2]) for the real-time control of power grids. It uses a hierarchy of agents to compute explicit active and reactive power setpoints for the resources connected to the grid. Each resource is equipped with a resource agent (RA) whose job is to translate the internal state of the resource into a device-independent format (advertisement). The advertisements are collected by the grid agent (GA), which computes the optimal power setpoints that optimize a global objective. The global objective is the weighted sum of various objectives, including tracking a predetermined dispatch plan at the slack bus, minimizing grid's nodal voltage deviations from the nominal value, limiting the line currents below the respective ampacities and achieving target internal states for the resources. Attention is paid to choosing the right weights of the individual objectives, to ensure the desired optimal behavior of the control. The activity involves the development of all the software agents needed to achieve the proper communication of the control framework with the BESS and the grid state estimator.

1.2. Research question

How can we control the power grid in real-time when we have limited information on the grid resources?

1.3. Novelty of the proposed solutions compared to the state-of-art

The main contribution of this work compared to past experimental validations of COMMELEC [3] is that a new method for the computation of the resources and grid objective weights is used. The goal of a typical grid objective is to achieve a target value for a given grid variable, such as the slack power or a nodal voltage. This method employs theoretical computations of upper bounds for the deviation of a certain grid variable from its target value as a function of the weight of the respective grid objective. Therefore, a desired maximum deviation from the target value can be chosen instead of the weight. Unlike the weights, these quantities can intuitively be chosen by the user, thus minimizing the time and effort needed to configure the parameters of the control algorithm and providing a priori a general idea of how the control will perform.

Although the setup used for the current experiments involves a single controllable resource (BESS), the proposed method also gives guidelines in designing appropriate cost functions for different types of resources, such that they are controlled in a fair manner. This will be crucial in potential future experiments, when a charging station for electric vehicles is deployed in the grid.

1.4. Description

Formulation of the COMMELEC framework

Figure 1 shows the decision process of the GA. At each COMMELEC cycle, the GA receives 1) the advertisements from all RAs, 2) an estimation of the state of the grid (nodal voltages and line currents) and optionally 3) a setpoint to be followed, that is advertised by and upper level GA. In our experiments, the upper setpoint is computed by the day-ahead dispatch plan. Then, the GA computes a set of active and reactive power setpoints for all resources that optimize a global objective. The duration of each cycle can be as small as 100ms, which is larger than the update frequency of the grid state estimation (typically 20ms). However, in our first experiments a 10s cycle was used, to ensure that the BESS can follow the changes in the setpoint requests.

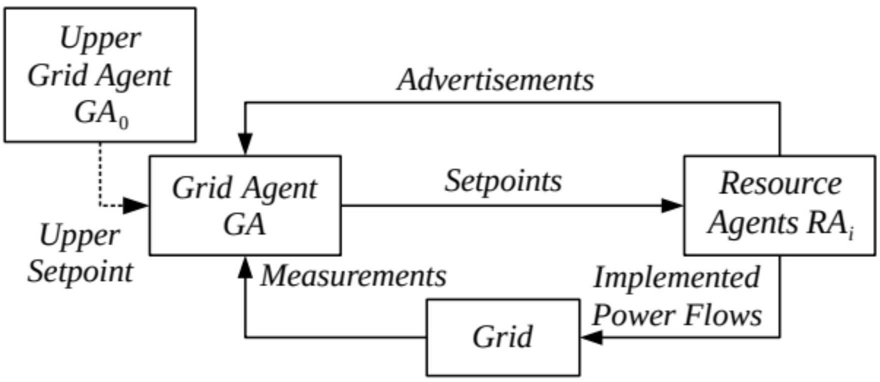

Figure 1. Decision cycle of the grid agent

Each advertisement message consists of three elements:

1. PQ profile: it is a set of all the (P, Q) points that can be implemented by the resource.
2. Cost function: the RA assigns a cost value to each point in its PQ profile, to denote the preference of the resource to implement a given point.

3. Belief function: it is a set-valued function that quantifies the uncertainty of the resource. For each point (P, Q) of the PQ profile, the RA advertises a set of all the points (P', Q') that might be implemented by the resource, if the point (P,Q) is requested by the GA.

In our experimental setup, there are two types of RAs, namely a battery agent (BA), which is used to control the BESS, and shadow agents (SA). The advertisement of the BA is computed as follows:

- The PQ profile reflects the capabilities of the BESS. It is computed using both measurements of the internal state of the battery, including SoC and DC voltage, and of the grid state, such as AC voltage and frequency. It is designed in such a way that the battery is restricted from charging when its SoC is greater than 90% and from discharging when its SoC is less than 10%.
- The cost function for the battery is chosen such that a target SoC is achieved in the long run:

$$C_b(P,Q) = |\Delta SoC|\frac{P^2}{4S} - \frac{\Delta SoC}{2}P + a_Q\frac{Q^2}{2S} \quad (1)$$

  where (P,Q) are the active and reactive power of the battery, S is its rated power and $|\Delta SOC|$ is the difference between its SoC and the target value (50% in our experiments). This function is designed in such a way that the charging of the battery is penalized if its SoC is above the target value, while the discharging is penalized otherwise. The purpose of third term of the objective, with a_Q a small positive constant, is to limit the internal losses of the power electronic converter that interfaces the battery with the grid.
- Since the battery is considered as a fully controllable resource, the belief function is a singleton, meaning that the battery can implement any point that is requested by the GA (within its capabilities) with no uncertainty.

A SA is placed on every node that cannot be controlled by the GA. This includes all nodes with loads and PVs. Since the SA is considered an uncontrollable resource, its PQ profile is a single point, equal to the estimated power injection of the respective node, while its cost function is 0. The purpose of the SAs is to forecast short-term bounds of the power prosumption of their respective node, which are expressed in the means of a belief function. To do this, the SAs employ both real-time state estimation and historical measurements. The purpose of this forecast is to ensure that the power setpoints computed by the GA in a given cycle will not steer the grid in an infeasible state until the next computation cycle.

In addition to the battery cost function, the optimization performed in the GA takes into account the following grid objectives:

1. Track the day-ahead dispatch plan

$$J_{P_s}(\boldsymbol{x}) = \frac{(P_s(\boldsymbol{x}) - P_t)^2}{2|P_s - P_t|_{\max}} \tag{2}$$

where $\boldsymbol{x}$ is the set of nodal power injections, P_s is the active power at the slack bus, P_t is the tracking value and $|P_s - P_t|_{max}$ is a user defined value, that defines the maximum desired deviation from the dispatch plan.

2. Minimize the voltage deviations from the nominal value

$$J_{V_k}(\boldsymbol{x}) = \frac{(V_k(\boldsymbol{x}) - V_{nom})^2}{\beta^2 - (V_k(\boldsymbol{x}) - V_{nom})^2} \tag{3}$$

where V_k is the voltage at node k, V_{nom} is the nominal voltage and β is a hard voltage constraint which is 5% of the nominal value. This cost function tends to infinity as voltage V_k tends to the value $V_{nom} \pm \beta$.

3. Keep the line currents below the respective ampacities

$$J_{I_l}(\boldsymbol{x}) = \frac{I_l^2(\boldsymbol{x})}{\left(I_l^{\max}\right)^2 - I_l^2(\boldsymbol{x})} \tag{4}$$

where I_l is the current and I_l^{max} is the ampacity of line l respectively. Similarly to the voltage cost function, this cost tends to infinity as I_l approaches I_l^{max}.

It should be noted that, unlike constraints β and I_l^{max}, which should be satisfied unconditionally, the constraint $|P_s - P_t|_{max}$ is a soft one, meaning that it will be satisfied provided that 1) the SoC of the battery is within its acceptable range (10-90%), 2) the grid's nodal voltages are close to the nominal value and 3) the line currents are far from the respective ampacities.

Finally, the global objective to be minimized by the GA is the following:

$$C_t(\boldsymbol{x}) = w_b C_b(P, Q) + w_{P_s} J_{P_s}(\boldsymbol{x}) + w_{Q_s} J_{Q_s}(\boldsymbol{x}) + \frac{1}{K}\sum_{k=1}^{K} w_{V_k} J_{V_k}(\boldsymbol{x}) + \frac{1}{L}\sum_{l=1}^{L} w_{I_l} J_{I_l}(\boldsymbol{x}) \tag{5}$$

where K is the number of buses, L is the number of lines and the weights $w_b, w_{P_s}, w_{Q_s}, w_{V_k}, w_{I_l}$ are computed according to our new method.

To optimize these objectives, the GA uses a gradient descent based algorithm. At each computation cycle it receives 1) an advertisement of the internal state of the battery by the BA, 2) short-term power forecasts by the SAs and 3) real-time estimation of the grid state. Then, it performs one step of gradient descent using a linearization of the power flow equations around the current state to estimate the gradient of the objectives. Since the battery is the only controllable resource of the system, we only need to compute the new power setpoint $\widehat{\boldsymbol{x}_b} = (\hat{P}, \hat{Q})$ for it:

$$\widehat{\boldsymbol{x}_b} = \underset{A}{\mathrm{Pr}}\left\{\boldsymbol{x}_{0,b} - s\nabla_{\boldsymbol{x}} C_t(\boldsymbol{x})|_{\boldsymbol{x}=\boldsymbol{x}_0}\right\} \tag{7}$$

where $\boldsymbol{x}_0$ is the current set of setpoints, s is the gradient descent step size and $\underset{A}{\mathrm{Pr}}\{\}$ is the Euclidean projection to the PQ profile A of the battery.

An iterative algorithm is also used to compute the gradient descent step s that yields the minimum total cost within the battery capabilities in a given cycle, in order to improve the performance of the real-time optimization. As a final step of the algorithm, the belief functions of the SAs are also employed, to ensure that the step size chosen will not steer the grid to an infeasible state until the next computation cycle.

It should be noted that this optimization algorithm is not guaranteed to result in the global optimum of the objective function (5) in one cycle. Rather, it is a fast algorithm that is able to provide approximate solutions to the problem in a few ms, thus being suitable for the real-time control COMMELEC is intended for.

Performance evaluation

To evaluate the performance of COMMELEC, experiments were run on a 12kV/20MVA MV distribution network in Aigle, Switzerland using a 1.5 MW/2.5 MWh BESS. The results, which are analyzed in deliverable D1.2.3b, verify the choice of the tracking cost function (3), as COMMELEC was able to achieve tracking of the dispatch plan within the desired tolerance, as long as the battery SoC remained within the appropriate bounds.

1.5. Regulatory and legal barriers for implementation

The revised electricity supply act provides the framework for the deployment of self-consumption communities in Switzerland. This will enable the utilization of the proposed solution in such cases. However, this does not include the energy communities without proximity among the members as a requirement. Such energy communities are not recognized yet, setting a barrier for the implementation of our proposed solution for the control of such distributed resources.

2. Achievement of deliverable:

2.1. Date

March 2021

2.2. Demonstration of the deliverable

The deliverable was achieved through the successful deployment of the software agents of the COMMELEC framework and their communication with the BESS and the grid state estimator.

3. Impact

Those results enabled us to strengthen our collaboration with Romande Energie. Indeed, a follow-up projects was defined and financed by SFOE in the frame of the European program, ERA-NET.

4. Scientific publications

[1] A. Bernstein, L. Reyes-Chamorro, J. Le Boudec, M. Paolone, “A composable method for real-time control of active distribution networks with explicit power setpoints. Part I: Framework”, Electric Power Systems Research, vol. 125, 2015, pp 254-264, ISSN 0378-7796, doi: 10.1016/j.epsr.2015.03.023.

[2] L. Reyes-Chamorro, A. Bernstein, J. Le Boudec, M. Paolone, “A composable method for real-time control of active distribution networks with explicit power setpoints. Part II: Implementation and validation”, Electric Power Systems Research, vol. 125, 2015, pp 265-280, ISSN 0378-7796, doi: 10.1016/j.epsr.2015.03.022.

[2] L. Reyes-Chamorro, A. Bernstein, N. Bouman, E. Scolari, A. Kettner, B. Cathiard, J. Le Boudec, M. Paolone, "Experimental Validation of an Explicit Power-Flow Primary Control in Microgrids," in *IEEE Transactions on Industrial Informatics*, vol. 14, no. 11, pp. 4779-4791, Nov. 2018, doi: 10.1109/TII.2018.2802907.