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Federal Department of the Environment, Transport, Energy and Communications DETEC

Swiss Federal Office of Energy SFOE
Energy Research and Cleantech Division

REEL Demo – Romande Energie ELectric network in local balance Demonstrator

Deliverable: 4a2 Sizing and siting of a utility scale distributed battery energy storage system

Demo site: Aigle

Developed by
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1. Description of deliverable and goal

1.1. Executive summary

The report focuses on the development of a practical and scalable methodology for the planning and operation of Active Distribution Networks (ADNs) with particular reference to the integration of Energy Storage Systems (ESSs) owned, and directly controlled, by the Distribution Network Operators (DNOs).

In this respect, an exact convex formulation of the Optimal Power Flow (OPF) problem, called Augmented Relaxed OPF (AR-OPF), is first proposed for the case of radial power networks [1]-[3]. The proposed formulation takes into account the correct model of the lines (i.e., the non-approximated two-port Π model) and, therefore, the full AC load flow equalities. Moreover, the security constraints related to the nodal voltage magnitudes, as well as the lines ampacity limits, are suitably incorporated into the AR-OPF using a set of more conservative constraints. Therefore, the AR-OPF is characterized by a slightly reduced space of feasible solutions where the removed space is in correspondence of the ones close to the technical limits of the grid. Sufficient conditions have been identified to guarantee that the solution of the AR-OPF formulation is feasible and optimal, i.e., the relaxation used in the formulation is exact [1]. Moreover, by analyzing the exactness conditions, it is revealed that they are mild and hold for real distribution networks operating in feasible region.

Then, by making use of the AR-OPF method, we formulate a specific optimization problem associated to the optimal resource planning and operation in ADNs with particular reference to the case of Battery Energy Storage Systems (BESSs). In this respect, it is assumed that the ESSs are owned, and directly controlled, by the DNOs. The objective function is augmented aiming at finding the optimal trade-off between technical and economic goals. In particular, the proposed procedures accounts for (i) network voltage deviations, (ii) feeders/lines congestions, (iii) network losses, (iv) cost of supplying loads (from external grid or local producers) together with the cost of ESS investment/maintenance, (v) load curtailment and (vi) stochasticity of loads and renewables production. The use of decomposition methods for solving the targeted optimization problems with discrete variables and probable large size is also investigated (see [3] for further details). More specifically, Benders decomposition and Alternative Direction Method of Multipliers (ADMM) techniques are successfully

applied to the solution of the targeted problems.
The developed technique is the applied to the siting and sizing problem of the BESS in the electrical distribution feeder of Onnens (medium voltage) that was initially expected to be used as demonstration site.

1.2. Description

As show in the deliverable 1.4.4.a, the Onnens feeder is expected to face over-voltages and lines' congestion when the 8.5 MW PV plant is fully operational. Therefore, we would like to quantify the size (power and energy) as well as the location of a BESS capable to steer the grid within the safe operation limits for both node voltages and line currents.
The BESS is expected to provide both active and reactive powers on all the four quadrants of the PQ-plane with the constraint of the apparent power of its power electronic interface.
An overview of the services that should be provided by the BESS is given here below.

1) Voltage control: the BESS should be able to keep the nodal voltage magnitudes in the acceptable region (-4% , +2%) by controlling its nodal injections of both active and reactive powers.
2) Lines congestion management: as for the case of the voltage control, the BESS should be able to keep the line current magnitudes below the respective ampacity limits by controlling its nodal injections of both active and reactive powers.
3) Enable the dispatchability of the targeted feeder: the BESS should be able to dispatch the operation of the distribution feeder hosting heterogeneous prosumers according to a trajectory with 5 min resolution, called dispatch plan, established the day before the operation. This goal may be accomplished using the procedure illustrated in [4].

In order to quantify the size and allocation of the BESS, we used the process illustrated in [2]. The objective function includes minimization of (1) nodal voltage-magnitude deviation (2) lines' congestions, and (3) nodal voltage fast fluctuations[1].

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[1] For further details regarding the AR-OPF and detailed optimization models, please make reference to [1]-[3].

The BESS sizing and siting has been performed with the following criteria:

- lines rating: <90% of the nominal ampacities;
- node voltages: within -4% and +2% of rated values;

The topology of the Onnens medium voltage feeder (20 kV) is shown in Figure 1. The obtained optimal location of the BESS is in correspondence of the node where the PV plant in installed. The size of the BESS is shown in Table 1.

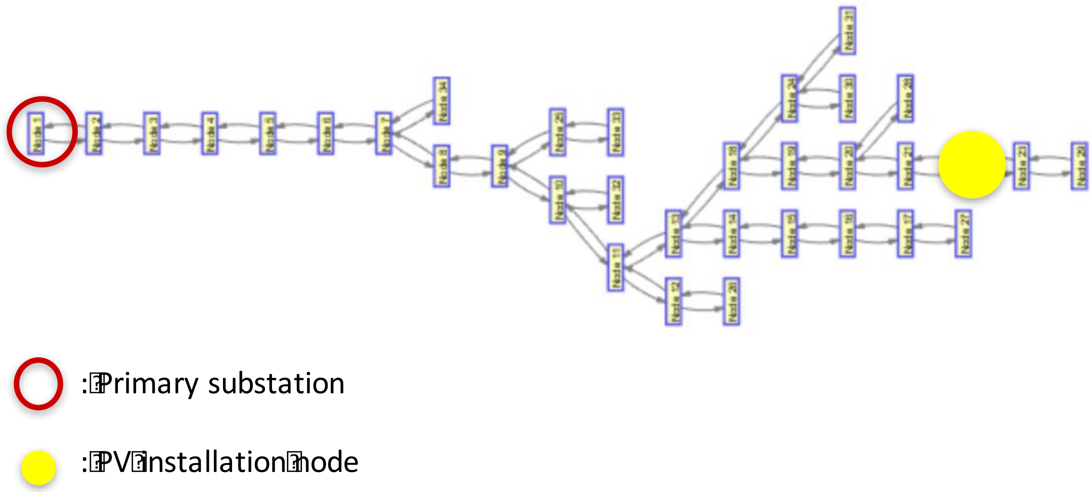


Figure 1: Topology of the Onnens 20kV feeder.

Table 1: Identified optimal size of the BESS

Energy reservoir (MWh)	3 (for the local grid control) + 1.8 (for achieving the dispatchability of the feeder)
Power rating (MVA)	3

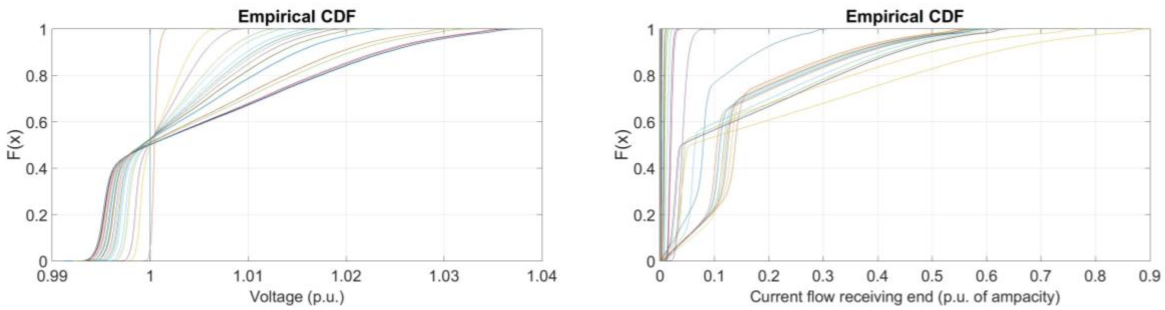
2. Achievement of deliverable:

2.1. Date

This deliverable has been achieved on December 2017.

2.2. Demonstration of the deliverable

In the deliverable D1.4.4a we have quantified the probability of the Onnens medium voltage feeder, selected to host the Romande Energie demonstrator, to exceed node voltages and line currents security constraints. Since these violations are driven by the presence of a single large PV plant located almost at the end of the feeder (see Figure 1), we considered the worst scenario of D1.4.4a that corresponds to the summer period. Figures 2.a and 2.b recall the obtained Cumulative Distribution Functions (CDFs) for the Onnens feeder nodal voltages and line currents for the summer period. Since for Swiss medium voltage power grids, the maximum allowed voltage is of 2% above the rated value, Figure 2.a shows that this limit is violated by at least 4 nodes with a probability of about 10%. Additionally, Figure 2.b shows that there is at least one line that suffers a congestion problem since its maximum current may exceed 90% of its ampacity.



a. CDF of nodal voltage magnitudes b. CDF of the lines' current

Figure 2: CDF of the nodal voltages and lines' current of the Onnens medium feeder in the summer period without the presence of the BESS: a) CDF of nodal voltage magnitude in p.u. b) CDF of lines' current in per unit of their corresponding ampacity limit.

In order to show the effects of the BESS on the Onnens feeder voltages and line currents, we here study the feeder behavior assuming the highest possible PV injection in summer (see Figure 3) with the lowest expected loads. In agreement with the results illustrated in the deliverable 1.4.4a, this assessment is performed with a simulation time step of 15 minutes.

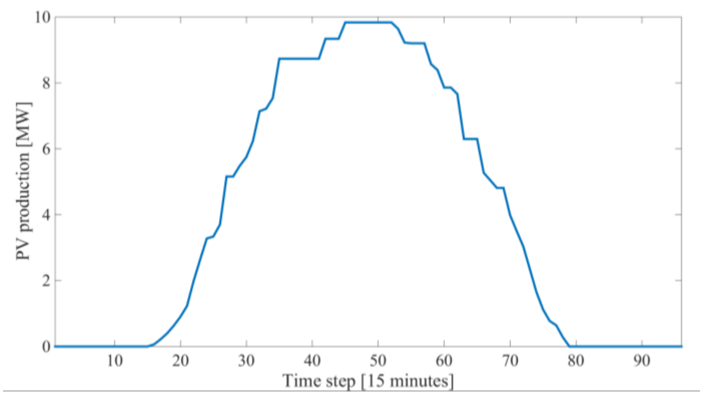


Figure 3: Highest expected PV injection in summer for the Onnens feeder.

By controlling the BESS using the process illustrated in [1], we obtain the profiles of the node voltage-magnitudes shown in Figure 4 and lines' current flow (in per unit of their respective ampacity limit) shown in Figure 5.
We can observe that the nodal voltage-magnitudes are all kept below 1.02 p.u. and that all the lines' current are kept below 90% of their respective ampacity limit.

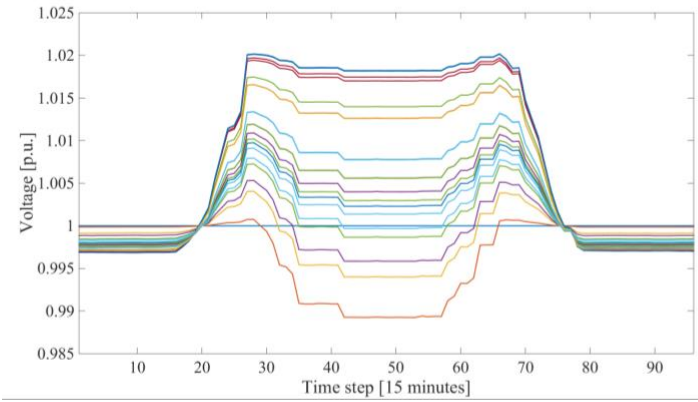


Figure 4: Profiles of the node voltage magnitudes of the Onnens feeder for the PV injection shown in Figure 3.

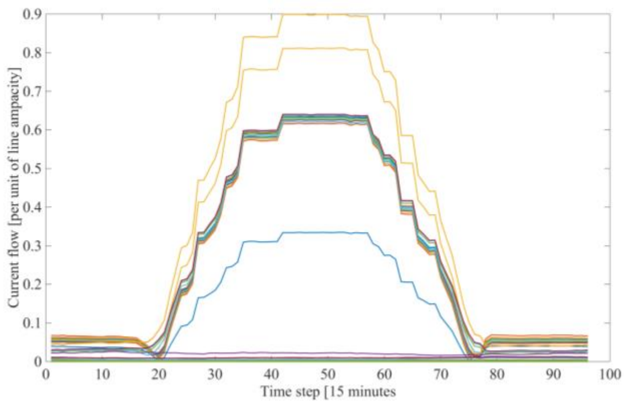


Figure 5: Profiles of the lines' current flow (in per unit of their respective ampacity) of the Onnens feeder for the PV injection shown in Figure 3.

In order to show the effects of the BESS on the fast voltage fluctuations originated by the rapid changes of the PV output, we have used a high-resolution (1 second) irradiance time series measured at the EPFL-DESL during a partial cloudy day and transformed in the power injection of the PV plant connected to the Onnens feeder (the load conditions are the same used to obtain the results of Figures 4 and 5). Figure 6 shows the profile of the fluctuating PV injection that might take place in the Onnens feeder due to such condition. The Onnens node voltage profiles without the action of the BESS are shown in Figure 7.a, whilst the ones with the optimal control of the BESS are shown in Figure 7.b. Also for this last simulation, the BESS is controlled with the AR-OPF method illustrated in [1].

The results of Figure 7 show the benefits of the BESS, suitably controlled by the AR-OPF, to smooth the voltage fluctuations on top of respecting the grid operational constraints.

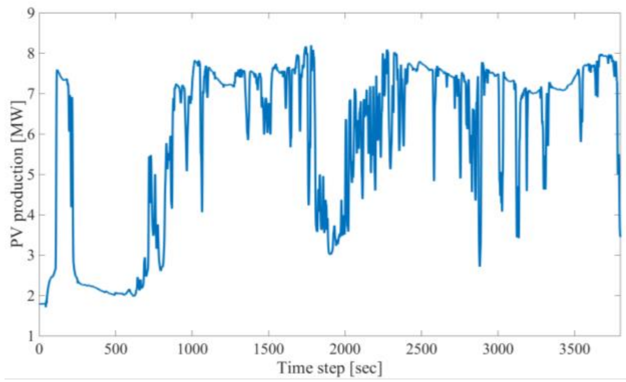
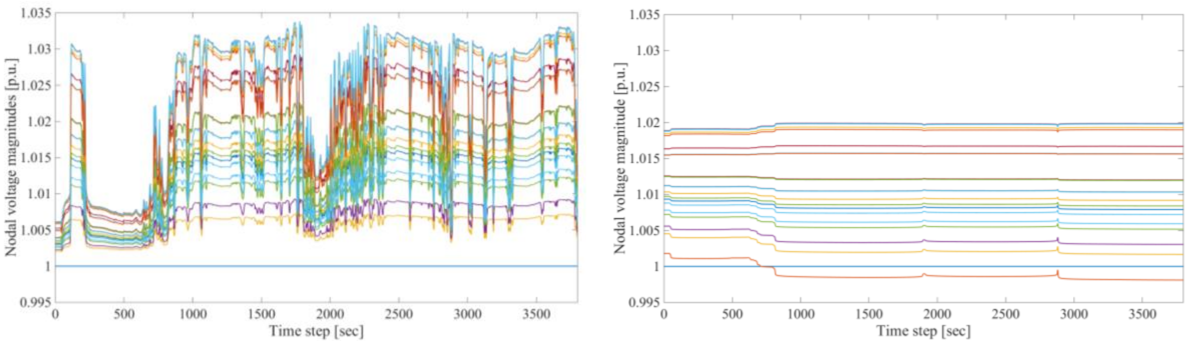


Figure 6: Profile of the fluctuating PV injections that might take place in the Onnens feeder inferred using high-resolution irradiance profiles measured at the EPFL-DESL.



a. Without BESS

b. With BESS

Figure 7: Onnens node voltages obtained with the PV profile high intermittent PV output (each plot shows the profile for one node)

3. Impact

The AR-OPF has been the first exact convex OPF formulation capable to consider the full AC equalities of the load flow problem with no approximations.

We do think that its flexibility, suitably exploited by distribution grids planning and control problems, is the most important result from the fundamental research perspective. Then, by leveraging on this model and with particular reference to the case of the Onnens feeder expected to host the Romande Energie demonstrator, we quantified the benefits related to the optimal placement and control of a BESS in distribution networks hosting massive amount of stochastic renewable generation.

References

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