COORDINATED CONTROL OF DISPERSED BATTERY ENERGY STORAGE SYSTEMS FOR SERVICES TO NETWORK OPERATORS

Guillaume FOGGIA, Alexandre NETO
Alstom Grid – France
guillaume.foggia@alstom.com

Andrea MICHIORRI, Alexis BOCQUET
Mines Paristech, PSL - Research University - France
andrea.michiorri@mines-paristech.fr

ABSTRACT

Distributed Battery Energy Storage Systems, controlled either per resource or in coordination, can provide many services to the network operators. The present study emphasizes the contributions of dedicated scheduling applications in order to enhance the reliability, performance and life expectation of the storage assets, based on the Nice Grid case, a Smart Grid pilot project.

NOMENCLATURE

BESS: Battery Energy Storage System
CL: Commercial Location
DERMS: Distributed Energy Resource Management System
LVGB: Low Voltage Grid Battery
MBMM: Master Battery Management Module
NBA: Network Battery Aggregator
NEM: Network Energy Manager
PCS: Power Converter System
PSB: Primary Substation Battery
SOC: State of Charge
SSB: Secondary Substation Battery

INTRODUCTION

The increasing impact of Renewable Energy sources, mostly random and intermittent, on the networks, motivates new interests for the use of Battery Energy Storage Systems (BESSs), a mature technology which is only emerging into the power systems. There is currently a worldwide exploratory assessment of the modalities of participation of distributed BESS installations in services for network operation or within market mechanisms. Through its storage capacity and the huge flexibility offered by smart power converter interfaces, medium-capacity BESS units (from 1 kW to several MW) connected on the Distribution Network could provide numerous services, like energy-shifting, active VAR/Power management, voltage control, power swing mitigation, frequency regulation, RE production smoothing and firming, peak load shaving, islanding/back-up power. The relevance of these services depends greatly on the location of the BESS unit on the network and on the role of its owner (GENCO, ISO, utility, other stakeholder). The scope is here restricted to services to the network.

BESS units shall consequently support different operating modes that can be categorized in two classes: local control from on-site measurements or centralized control, possibly in combination with other network devices (e.g. Volt-VAR Control). Another major differentiating characteristic is the time horizon for the control decisions, from long-term planning to instantaneous action. The present paper emphasizes the importance of planning for storage units: even during periods of local control, it is essential to ensure also a rationalization of the uses of the resource to avoid a premature ageing, due to sub-optimal and multiple charge/discharge cycles. These scheduling functionalities shall be taken in charge by a dedicated set of applications interfacing with the monitoring and supervision infrastructure.

NICE GRID PILOT PROJECT

From these considerations, the present paper intends to show the benefits of a management system for dispersed BESS units, ensuring a set of scheduling, dispatching and monitoring functionalities. The study case is an implementation for Nice Grid, a Smart Grid demonstration pilot, which is part of GRID4EU, a FP7 project [1]. Nice Grid aims at anticipating the challenges of the rapid increasing of intermittent DER penetration on the Distribution Network, with a special focus on the case of the small Photovoltaic installations, mostly residential, connected on the low voltage grid. The location of the demonstration is Carros, a city of the far South-East of France, with 10,000 inhabitants and with a total capacity of PV installations already reaching around 2 MW_p.

The main Nice Grid use cases are: a) winter power demand reduction, for TSO; b) summer mitigation of PV-induced overvoltage issues, for DSO; c) micro-grid islanding operation. These use cases address network congestion issues, either local or regional, by using the active power flexibility provided by controllable loads and storage units. The mobilization of these local distributed resources is meant to be an alternative to distribution network reinforcements, which can be seen as the reference scenario for any long-term performance assessment of the Nice Grid solutions. The distributed resources are not directly operated: their participation is ensured through new dedicated stakeholders, the *DER aggregators*, which submit flexibility offers on a common transaction place, so that these offers can be activated by the Network Operators in order to fulfil their needs.

The local transaction platform is one component of an instance of *Distributed Energy Resource Management System* (DERMS), that realizes the orchestration of the processes and the interconnection between all the potential providers of flexibility (e.g. aggregators) and the “final users” of flexibility (e.g. DSO / TSO). The

DERMS appellation within the project is “Network Energy Manager” (NEM). The NEM is hosted in DSO IS environment and is under DSO responsibility, as the performance of its applications requires an accurate knowledge of the actual topology and equipment constraints of the distribution network. A more detailed overview of the Nice Grid system is presented in [2].

NETWORK BATTERY AGGREGATION

As described, the main operational paradigm of the project is to make available, for ISOs, some levers of *preventive action*, i.e. scheduled operations on DERs, which are planned through a local transaction place. Community BESS units, directly interconnected on the Distribution Network, were installed at different locations of the distribution grid. These BESS assets, despite being in practice under the responsibility of the DSO, are assumed to be operated separately by one new, specific and independent stakeholder, the *Network Battery Aggregator* (NBA).

The local market product features are unified: “flexibility” is characterised as half-hourly active power time series (i.e. a scheduled negative / positive variation in the power consumption / injection at a coupling node) expressed at a unique transaction area level, also designated as “Commercial Location” (CL). This transaction level corresponds to a set of nodes on the distribution network, delimiting generally a perimeter with similar marginal influence on recurrent congestion issues. This zoning depends on the seasonal constraints and shall be adapted to the network topology.

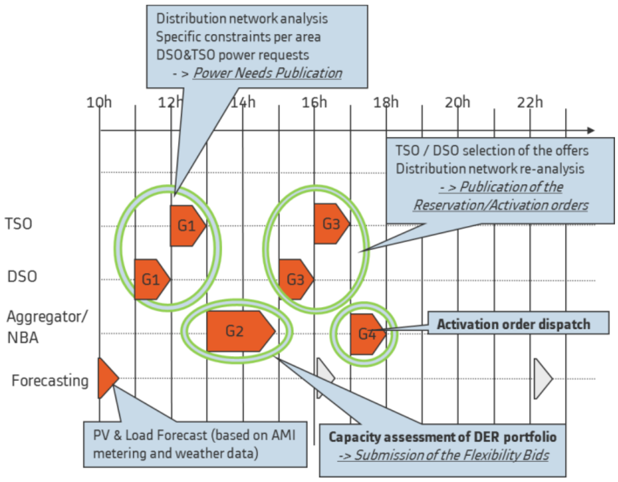

Figure 1: day-ahead process for DER flexibility scheduling

Transactions’ rules define the assumptions and conventions that are shared between all the participants in the local flexibility marketplace. Prices are included and attached to every flexibility offer. They shall reflect the total cost of the DER solicitation to fulfil the aggregated flexibility schedule. These prices are expressed under the form of half-hourly time series (in €/kW). On the local transaction place, flexibility provided by storage assets, is indistinguishable from the flexibility provided by the aggregated controllable loads. Therefore, it guarantees that the DERMS selection of the offers, during the clearing step, on behalf of DSO or TSO, is fair, not-discriminatory and based on the least-cost solution.

The NBA system shall be hence synchronized with the DERMS daily (or on a shorter time horizon, for Intraday process) workflow framed through pre-defined gates at the Transaction Place. This DERMS workflow is represented in the Figure 1 (in bold, the two main processes of the NBA Scheduling system). The NBA participation implies the use of specific methods for battery commitment and market bid construction as well. These business applications are the following:

1. The calculation of flexibility offers, from a portfolio of BESS units and from “Power Needs” expressed on transaction areas (CLs); the resulting output bids shall be submitted at the corresponding gate G2 during the day-ahead DERMS transaction process;
2. The schedule implementation of the selected bids, after reception of an activation order from the DERMS platform; the activation order shall be disaggregated, resource per resource, through a Dispatch on the portfolio of Electrical Storage units.

One feature of this portfolio in the project Nice Grid is the heterogeneity of the Li-ion storage resources, with a range of nominal power from 33kW to up to 1MW. Li-ion battery technology has been chosen in reason of the significant improvements of the lifetime and energy-density of the units. Three types of BESS can be defined, depending on the voltage level and on the connection node:

- Primary Substation Battery (PSB), connected on a dedicated MV Feeder, next to the HV/MV main distribution station;
- Secondary Substation Battery (SSB), connected on a dedicated LV Feeder, next to the MV/LV main distribution station;
- Low Voltage Grid Battery (LVGB).

Each type can address local and global issues as well. For instance, LVGB assets fit with an use during summer to mitigate overvoltage occurrences along a LV feeder, but these assets may also participate in a common realization on the whole area if needed, e.g. after a TSO request. Getting several BESS units on the same transaction zone allows the NBA to optimize the participation of its resources. The scheduling applications capture indeed the non-linearity of the energy models of the BESS, and so determine different dispatch results, depending on the total amount of power the NBA is willing to offer.

The aggregation functionality, i.e. the combination and aggregation of BESS assets into a same CL, while offering flexibility on the transaction place, is hence a major characteristic of the BESS scheduling applications. The applications shall support any zoning, as delimitation of the transaction zones (CL) may be frequently updated to fit with the evolution of the constraints on the distribution network. The reference [3] details the consequences of a non-exclusive zoning (defined by a topology matrix) on the algorithms of battery aggregation scheduling.

BESS SUPERVISION ARCHITECTURE

The issue of BESS scheduling is often investigated in the literature from a rather global perspective, by considering the utilization of BESS models in the power system operation planning for electricity markets or utilities, as referenced for instance in [4]. By contrast, the design choice for the project adopted an "upward" approach, from the local level to the global level (i.e. the final usages, possibly on a large area). NBA has the responsibility to manage at any time operation planning and control actions, ensuring firstly that the storage systems are maintained in a secure and non-destructive state at the resource level. From this fundamental requirement, the scheduling applications shall determine the available permissive capacity of each unit, before any aggregation and cost optimization.

Access to real-time monitoring data such as the variable parameters of the equipment shall enhance the performance and reliability of the solicitation of the flexibility provision from BESS (through the NBA). The BESS supervision and communication architecture is determinant, as it provides some of the I/O parameters that the scheduling applications shall deal with.

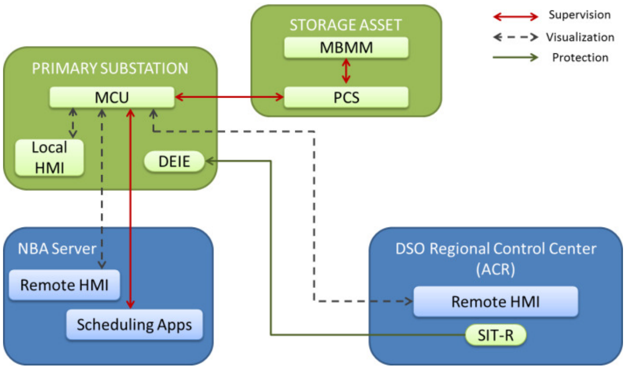

Figure 2: BESS Supervision architecture

As represented in the Figure 2, one characteristic of the architecture is the redundancy of the communication, control and protection levels. The context is the relative novelty of the BESS on the French public distribution network. The installation of the different types (PSB, SSB, LVGB) of storage assets for the project brings useful feedbacks to the DSO, regarding the necessary preparation for this kind of DER: site selection, administrative procedures, civil works, risk analysis, elaboration of safety measures, training of the control operators and technicians, adaptation of the operation processes and adaptation of the protection schemes. In this context, a particular attention was held to the remote control and monitoring for all the storage assets, independently of their type: for the sake of the demonstrations, even the smallest units (33 kW LVGB) are included. The DSO Regional Control Center (ACR) has the responsibility to manage and control 24/24 the MV distribution network. ACR operators have access through a remote HMI to the alarms, the monitoring and operational data; via the HMI it is also possible to change the BESS Operation Mode, to set manually a new schedule, or to shut off the PCS and the battery in case of emergency. For the PSB asset, an additional emergency device, DEIE, remotely controlled from the DSO's own SCADA (SIT-R), enables to open the main circuit breaker on the dedicated MV feeder.

The same HMI for BESS data is available from the NBA server, as the responsible person for the battery operation shall have the possibility to intervene at any time on the resource control. Therefore, for different objectives and missions, both NBA and DSO are able to by-pass the automatic normal Operation Mode, where the operation settings are determined by the NBA scheduling applications. These applications get data about the availability and the state of BESS units from the MCU that manages a small SCADA system, acting as data historian and protocol driver. The MCU interfaces with the PCS of all BESS resources connected downstream the primary substation, plus other types of equipment (meters, tap changer).

There are also supplementary control layers at the resource level, within the PCS and MBMM. The set of nominal battery operation parameters, used by the scheduling applications, do not capture the whole operating limits that are monitored by the Battery Management System controls, set by the manufacturer. In addition to the mandatory functionalities of cell balancing and protection, the MBMM prevents any deviation from the permissive range, in order to avoid a premature and irreversible deterioration of the asset. Active power, voltage, DC current, temperature, etc., are continuously checked relatively to the limits of these parameters. A deviation triggers corrective actions, alarms, and possibly an emergency shut-off [7].

As a consequence, the availability, the state and the operation mode at the resource level may evolve abruptly given the redundant control levers of the supervision architecture. It justifies a frequent update of the resource scheduling and of the NBA position, compared to the aggregated target, i.e. the activation schedule order on the CL area. The NBA system orchestration shall implement periodical re-optimizations of the portfolio dispatch.

BATTERY AGGREGATION SCHEDULING

As described in the previous sections, the objective of the NBA is to operate the portfolio of BESS to offer services to network operators in a local market framework. The scheduling is performed by two applications: Bidding and Dispatch.

Modelling

The NBA portfolio contains batteries of different types, sizes, number of cycles and locations on the network. This means that each resource can be subject to specific limitations, for instance due to network constraints during periods of the day or of the year. The parameters attached to the storage resource are the following: maximum charge and discharge power, minimum and maximum SOC, charging and discharging efficiency and a set of parameters necessary to calculate the cost associated to every plan.

Additional time series setting dynamical constraints, specified for each half-hour of the day, are also used: it specifies the value of charge or discharge constraints, operator imposed targets on the load profile or on the SOC and charge and discharge electricity prices.

Bidding

The Bidding calculation is triggered at the publication of the Power Needs by the DERMS platform. For each concerned CL, the NBA prepares flexibility offers taking into account the availability and the state of the connected batteries. Each offer is composed of the schedule for the next day, the corresponding reservation and activation prices and a minimum mobilization time. If the offer is selected, the activation order signal shall be sent early enough in order to respect this mobilization duration.

The challenges associated with the application are:

1) Developing optimal plans for multiple batteries under multiple constraints;
2) Taking into account the effect of these plans on the aging of the battery;
3) Taking into account constraints manually set by NBA or DSO operators;
4) Proposing reduced configurable number of alternative offers in partial or full response to the requested volume.

Dispatch

Once the action orders have been received, the NBA shall respect its commitments and dispatch the corresponding operation settings per BESS unit. In case of any unforeseen significant event a new Dispatch calculation is run, in order to determine a new set of schedules aiming at satisfying the activation commitments, by an optimal use of the remaining flexibilities of the available batteries in the same commercial location.

The optimisation problem solved by the NBA consists in minimizing a cost function taking into account the target for each commercial location and the characteristics and constraints of each storage unit. The objective of the algorithm is to minimise a cost function cost(P) for the whole portfolio.

This cost function, described in Equation 1, measures the distance between the requested flexibility at each commercial location target CL_i^T and the sum of the flexibilities offered by each battery of the commercial location. The term $e(P_{iB})$ in Equation 1 represents the effect of the efficiency *eff* of the charge-discharge process of the battery and is calculated as in Equation 2. The state of charge of each battery is then calculated as in Equation 3, where Cap is the capacity of the battery and dt is the time frame.

$$\mathrm{cost} = \sum_{iCL}\left(\mathrm{target}_{iCL} - \sum_{iB} P_{iB}\cdot e(P_{iB})\right) \qquad (1)$$

$$e = \begin{cases} 1/\sqrt{\mathrm{eff}} & \text{if } P_{iB} > 0 \\ \sqrt{\mathrm{eff}} & \text{if } P_{iB} < 0 \end{cases} \qquad (2)$$

$$\mathrm{SOC}(i) = \mathrm{SOC}_0 + \sum_{t=1}^{i} P_t \frac{dt}{\mathrm{Cap}} \qquad (3)$$

With this set of constraints and objective function it is possible to optimize the answer of the portfolio of batteries to the multiple requests in different CLs.

STUDY CASE

An illustrative example of the behaviour of the NBA is here described and illustrated in Figure 3. In this example two batteries (B1 and B2) are located in one CLs (CL1) where there is a target for injecting 100kW into the network between 10:00 and 11:00. An unexpected event modified the plan of the two batteries at midnight and the dispatch function is called to identify new suitable plans able to satisfy the target. The original target plan is represented in red and the plan re-calculated by the dispatch function is represented in blue. In Figure 3 it's possible to observe the trajectories of the SOC for the two batteries. Since the requested target is smaller than the combined capacity of the two batteries, there are infinite possible paths satisfying this request and the NBA selects two schedules which limits power oscillations and achieve the imposed final SOC.

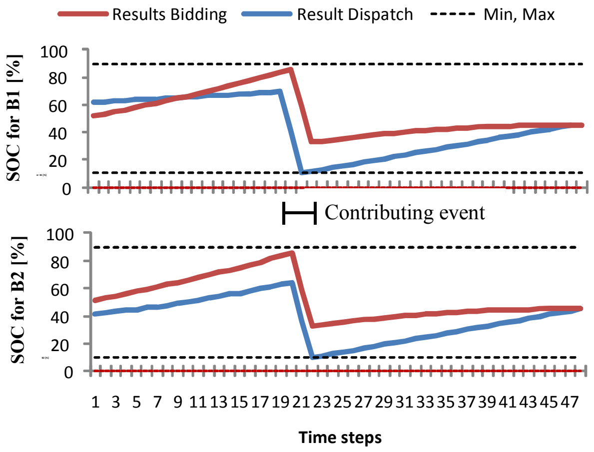

Figure 3: Example of dispatch correcting an unexpected SoC derivation

CONCLUSION

The control and supervision system for distributed BESS shall be able to embrace a large range of Operation Modes, either running individually or on a large scale. An implementation for a Smart Grid demonstration project is described. The system relies on several distinct business applications, which can be expressed as optimization problems with distinct objectives, constraints and time horizons. They are run in a workflow ensuring continuously an appropriate multi-stage schedule optimization process. This study shows how innovative solutions of BESS management systems can facilitate the integration of the BESS into network system operation.

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