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To cite this version:

Andrea Michiorri, Georges Kariniotakis, Fiona Foucault. An aggregator for distributed energy storage units under multiple constraints in the nice grid demonstrator. CIRED Workshop 2014 - Grid operation and congestion management, Jun 2014, Rome, Italy. hal-01016026

HAL Id: hal-01016026

https://minesparis-psl.hal.science/hal-01016026v1

Submitted on 27 Jun 2014

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AN AGGREGATOR FOR DISTRIBUTED ENERGY STORAGE UNITS UNDER MULTIPLE CONSTRAINTS IN THE NICE GRID DEMONSTRATOR

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ABSTRACT

This paper presents the description of an algorithm for the management of a portfolio of distributed energy storage systems able to provide flexibility services to the distribution system operator. The algorithm will be referred to as Network Battery Aggregator (NBA).
The work described in this paper is realized within the framework of the NiceGrid, a demonstration of the Grid4EU project. The project aims at developing a smart solar neighbourhood in an urban area near the city of Nice, France, and to combine controllable distributed electricity and thermal storage devices with forecasts of solar power production and load in a local energy management system. The local network energy manager (NEM) developed in this project will provide voltage control at the distribution level and congestion control at the transmission level.

INTRODUCTION

The interest in the use of storage for grid applications is growing, because of its potential for facilitating renewable energy integration and thanks to innovations in the field of storage technologies [1]. An advantage of distributed energy storage (DES) devices over large, transmission connected storage facilities such as traditional pumped hydro is that they can be used both for helping the load-generation balance and for solving network congestion problems, since the location is not dependent on particular site characteristics [2].
Because of the dynamic nature of the problem and the relatively high cost of the storage, the use of DES is usually associated with the definition of a schedule considering prices, load or renewable production forecasts, and the eventual constraint violations on the network. This is shown clearly in [3] for a virtual power plant application, where a DES is used for reducing the effects of the uncertainty in the production of a local wind farm. The study does not consider network constraints but is focused on the comparison of different optimisation criteria and methods.
The work presented in this paper is related to the Nice Grid project [4], the French demonstrator of the FP7 European project Grid4EU. In this project local storage devices and other flexibilities are used in order to provide voltage control services to the distribution system operator and congestion alleviation services to the transmission system operator. The services provided by the aggregators that take part to the project will be mediated through a local flexibility market managed by the NEM. Attention on the use of storage in the electric network was given recently for cases of combined use of storage with solar or wind power in order to alleviate connection issues or facilitate their participation in electricity markets, such as in [5] and [6]. Another problem typically associated with the use of storage in electric networks concerns the use of pumped hydro storage to bidding into traditional electricity markets [7]. But because of the lack of a specific regulation and existing markets, works on DES for providing multiple services through markets is still in its infancy. In the future such markets might evolve towards the exchange of ancillary services [8], where a local prices design might be chosen [9].

METHODOLOGY

The objective of the NBA is to manage a portfolio of Li-ion batteries connected to the LV distribution grid and to propose flexibility offers to the NEM. Each offer is composed of a plan for each commercial location (CL) object of a flexibility request (FR) by the NEM. If the offer is accepted, the NBA is then called to define the optimal plans for each battery influencing the CL. An overview of the architecture developed in the NiceGrid project can be found in [4]
The challenges associated with the development of the NBA have been identified in:

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) Avoiding or managing conflicts between batteries;
4) Avoiding or managing conflicts between CLs;
5) Proposing a reduced number of offers answering effectively to the FRs.

Grid and battery model

The microgrid is considered to contain an ensemble of batteries and commercial locations: each commercial location can be part of a larger commercial location, and each commercial location can have zero or more batteries managed by the aggregator. This situation can be represented with a topology matrix $T = [CL_i, A_j]$, as shown in Table 1, where CL_i represents the commercial location (in this example i = 1, 3) and A_j represents the aggregators present in the microgrid (in this example j = a,b). Each aggregator manages a series of batteries, represented as $B_{Ai,j}$.
In this example, several batteries from the same or from different aggregators are present under the same commercial location, and each battery is part of one or more commercial locations. This example will be used later in the Results section.
Each battery is modeled as a storage unit characterized by a maximum charge and discharge power, an energy storing capacity and a round trip efficiency for the charge and discharge cycle.

Table 1: Microgrid topology example

Commercial locations		
CL_1	CL_2	CL_3
$B_{Aa,1}$,$B_{Ab,1}$		
$B_{Aa,2}$,$B_{Ab,2}$	$B_{Aa,2}$,$B_{Ab,2}$	
$B_{Aa,3}$,$B_{Ab,3}$	$B_{Ab,3}$	$B_{Aa,3}$
$B_{Aa,4}$,$B_{Ab,4}$		$B_{Aa,4}$,$B_{Ab,4}$

Each battery is also characterized by a minimum and maximum possible State of Charge (SOC) along with its real time measured or estimated SOC, an availability status, its cost and finally its estimated lifetime in cycles. These parameters, summarized in Table 2 are used for defining the optimal flexibility offer and for estimating the associated cost. Data relative to different storage technologies can be found in [10].

Table 2: Parameters used for the battery model

Parameter	Unit	Batteries of A_a	Batteries of A_b
Status	Boolean	1	1
Maximal discharge	kW	-50	-100
Maximal charge	kW	25	33
Energy capacity	kWh	50	100
Initial SOC	%	50	50
Minimal SOC	%	20	20
Maximal SOC	%	90	90
Efficiency	%	90	95
Lifetime in cycles	n	4000	5000
Cost	€	40000	100000

Table 3: Description of a flexibility request for a commercial location

From	To	Min	Max	Up	Down
hh:mm	hh:mm	kW	kW	kW	kW
11:30	12:00	30	30	0	0
12:00	12:30	30	30	0	0
12:30	13:00	30	30	0	0
13:00	13:30	30	30	20	0
13:30	14:00	30	30	20	0
14:00	14:30	30	30	20	0
14:30	15:00	30	30	0	0

Each commercial location is defined by time series describing the minimum and maximum allowable injection and consumption of power from the network at any given time step. FRs are also described through time series as shown in Table 3. In this case the CL has a minimum and maximum import or export of 30 kW and requires an extra consumption of 20 kW between 13:00 and 14:30.

Optimisation problem

The optimisation problem solved by the NBA consists in minimizing a cost function taking into account the characteristics of the storage and the FRs of each commercial location. The general formulation of the problem for aggregator j is shown in Equation 1.

$$\begin{cases} P = \min\left(\mathrm{cost}(P), CL_i^T, B_{A_{i,j}}\right) \\ P_{\min B_{A_{i,j}}} < P_{t,i} < P_{\max B_{A_{i,j}}} \\ SOC_{\min B_{A_{i,j}}} < SOC_{t,i} < SOC_{\max B_{A_{i,j}}} \\ P_{\min,CL_i} < \sum_{B_{A_{i,j}}} P_{t,i} \cdot e(P_{iB}) \cdot t_{iB,iCL} < P_{\max,CL_i} \end{cases} \quad (1)$$

where:

P = (Pm,n) is the array describing the n-steps schedules for the m batteries managed by the aggregator j in the microgrid.

- cost(P) is the cost function to be minimised
- SOC = SOC(m,n) is the array describing the n-steps state of charge for the m batteries.
- CL_i^T is the target for each commercial location represented by the flexibility request.
- $P_{\min B_{A_{i,j}}}$, $P_{\max B_{A_{i,j}}}$ are the minimum and maximum power allowed for each battery, as found in Table 2.
- $P_{\min,iCL}$, $P_{\min,iCL}$ are the minimum and maximum power allowed in the commercial location at each time step, as found in Table 3.

The cost function cost(P) 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, taking into account the topology matrix as shown in Equation (2). The term $e(P_{iB})$ in Equation (2) represents the effect of the efficiency eff of the charge discharge process of the battery and is calculated as in Equation (3). The state of charge of each battery is then calculated as in Equation (4), where Cap is the capacity of the battery and dt is the time frame.

$$\mathrm{cost} = \sum_{iCL}\left(\mathrm{target}_{iCL} - \sum_{iB} P_{iB} \cdot e(P_{iB}) \cdot t_{iB,iCL}\right) \quad (2)$$

$$e = \begin{cases} 1/\sqrt{\mathrm{eff}} & \text{if } P_{iB} > 0 \\ \sqrt{\mathrm{eff}} & \text{if } P_{iB} < 0 \end{cases} \quad (3)$$

$$SOC(i) = SOC_0 + \sum_{t=1}^{i} P_{iTS} \frac{dt}{Cap} \quad (4)$$

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

Generation of flexibility offers

A second part of the problem is to generate flexibility offers to the NEM: the objective is to cover the requests of flexibility as well as possible, while maintaining feasible schedules for the batteries and taking into account the effects of each battery plan in the possible multiple CLs to which it belongs. Two commercial locations are considered dependent if they share one or more batteries, whilst they are considered independent if they do not share any battery.
In order to do this, the following approach has been implemented:

1) For each CL, the dependent CLs are identified.
2) For each dependent CL, several fractions of the flexibility request (eg: 10) are defined.
3) For each fraction of the flexibility request, an optimal plan for the portfolio is calculated along with its cost.

With this approach it is possible to propose an offer satisfying the broad necessity of the microgrid within the capabilities of the batteries portfolio, along with separate offers aiming at solving at the best the specific problem of each single commercial location. For each offer, a time series representing the combined effect of all the batteries in the commercial location is sent to the NEM, whilst the time series representing the optimal plans for each battery of the commercial location are kept by the NBA and transmitted to the battery control if the offer is accepted.

Table 4: Example of an offer from aggregator Ab for a flexibility request in CL2, with its price, the power proposed schedule for the CL disclosed to the NEM and the schedules for the two batteries involved non disclosed to the NEM

Offer from Ab for CL2, Price 2,52€				
From	To	CL2	Bb2	Bb3
hh:mm	hh:mm	kW	kW	kW
12:30	13:00	0	0	0
13:00	13:30	20	15	5
13:30	14:00	20	15	5
14:00	14:30	20	15	5
14:30	15:00	0	0	0

An example for one offer for a flexibility request in CL2 by the aggregator Ab is shown in Table 4. The choice among the several offers and their combination is done by the NEM, and is not covered in this article.

RESULTS

The optimisation algorithm described above was developed and tested against different use cases, as in the example reported below.
The example is based on the case study described in Table 1. Three different flexibility requests are expressed by the three CLs:

1) In CL1 an injection of 250 kW for a total of 750 kWh between 18:30 and 20:00
2) In CL2 a consumption of 90 kW for a total of 360 kWh between 13:00 and 15:00
3) In CL3 a consumption of 25 kW for a total of 200 kWh between 06:30 and 10:30

The flexibility requests for the three commercial locations are shown in Figure 1 and they correspond to a situation where an excess of solar production is expected during the day and load peak shaving is requested during the evening. The schedules for an offer from aggregator Aa is shown in Figure 2. In this case, an offer optimized for the power needs of CL1 and CL3 thanks to the presence of one battery in the two CLs is shown.

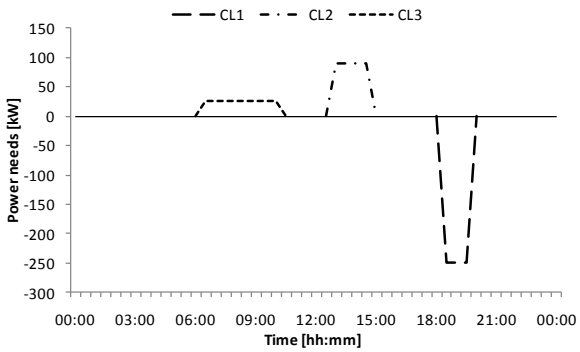

Figure 1: Flexibility request for the three commercial locations during the day.

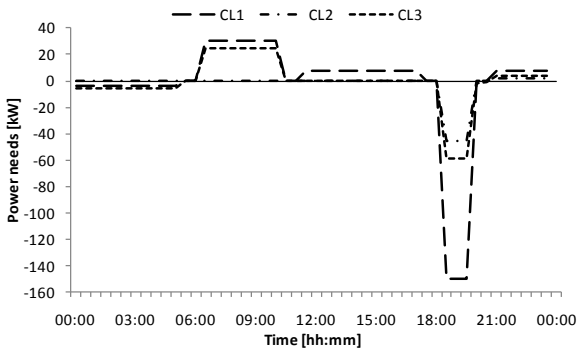

Figure 2: Example of flexibility offer from Aa

The algorithm described above has been used to prepare several offers for the NEM from the two aggregators Aa and Ab. It has been assumed that the two aggregators use different batteries as shown in Table 2.
The results of the offers proposed by the aggregators are summarized in Table 5. In this case the two algorithms propose the same number of offers for the same CL, since no different strategies have been implemented in this example. The different number of offers for different commercial location (eg: 60 offers for CL1 and 50 offers for CL2 and CL3) are due to the offer

generation procedure described above.

Table 5: Summary of the flexibility offers proposed by the two aggregators. The columns relative to the Cover [%] and the Price [€/kWh] of the offers are independent of each other, and they represent the minimum, mean and maximum value of the two parameters respectively.

CL	Aggregator	Offers	Value	Cover	Price
		#		%	€/kWh
1	Aa	60	Min	0	0,2
			Mean	20	1,4
			Max	48	9,7
	Ab	60	Min	0	0,2
			Mean	24	1,7
			Max	60	10,0
2	Aa	50	Min	2	0,0
			Mean	10	2,9
			Max	22	8,3
	Ab	50	Min	2	0,1
			Mean	12	4,1
			Max	31	11,8
3	Aa	50	Min	8	0,1
			Mean	25	0,9
			Max	86	2,2
	Ab	50	Min	8	0,2
			Mean	26	1,3
			Max	102	2,8

The differences between the offers of the two aggregators are due to the different type of batteries in their portfolio, with smaller cheaper batteries in the case of Aa and larger, more expensive batteries in the case of Ab. This difference can be seen also in the price of the price of the offers, which are in general cheaper in the case of Aa and in the percentage coverage of the request, which is larger in case of Ab.

CONCLUSION

The NBA has been evaluated against simple and complex problems in an offline study, but it will be necessary to verify its behaviour in combination with the NEM when the two systems will be operational and before the field tests of summer 2014. The Network Batteries Aggregator has the objective to manage a portfolio of batteries and to propose flexibility offers to the NEM. Each offer is composed by a plan for each commercial location object of a flexibility request by the NEM. If the offer is accepted, the NBA is then called to define the optimal plans for each battery influencing the commercial location. In this work, a simple market design where participants are non strategic, and the DSO/NEM adapts its demand according to the local participants/aggregators has been considered. The NBA is only one example of the many aggregators that could be part of a flexibility markets such as the one demonstrated in Nice Grid.

ACKNOWLEDGEMENTS

This research is realised in the frame of the NiceGrid project, funded in part by ADEME, and the Grid4EU project, funded in part by the European Commission under the 7th FrameWork Programme.

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