RESIDENTIAL STORAGE TO IMPROVE SYSTEM RESILIENCE: TECHNICAL DESIGN AND COST ESTIMATION

Philippe LOEVENBRUCK
EDF – France
Philippe.loevenbruck@edf.fr

ABSTRACT

Facing exceptional events (storms in the USA, the great earthquake in East Japan…), several countries have launched efforts to improve the resilience of the electrical system, ie its ability to limit outages in case of these incidents. We clarify what improving resilience means, and show how it differs from reliability. We study how technically and economically, distributed storage could improve the electric system resilience.

We explain how a distributed storage device could contribute to resilience in case of exceptional events: in an emergency operation, it could feed a local grid, possibly carbon-free, which would then feed the priority uses of residential customers.

The study does not address the economic profitability of improving the resilience of an electrical system. But knowing how storage could improve the resilience, we study the costs of such a solution and propose a first quantification of these costs.

To do that, we characterize the typical client and define the emergency local grid (for instance, a building of 100 residential clients); then we choose and quantify priority uses, with reference to international experience. The priority needs are estimated both in power and energy, in mean value and in standard deviation.

We review the different types of exceptional incidents, their consequences in outage duration and if the exceptional event is partially predictable.

In the important case of a storm, we can estimate the cost of the solution of resilience by distributed storage. First, if the solution is devoted to improve resilience: 128 €/year/customer in a typical case. Secondly, the approach considers that the cost of storage can be partially compensated for if storage contributes to other services in normal situation. Then, at least marginally, the cost could be reduced by 52%.

INTRODUCTION

Facing exceptional events (storms, earthquakes etc.), some countries have launched initiatives to improve the resilience of the electrical system, ie its ability to limit outages in case of these incidents. The distributed storage is part of resilience solutions.

In this paper, we study how technically and economically, distributed storage could improve the electric system resilience for residential customers.

To do that, we clarify the objective of improving resilience, and show how it differs from reliability. Then we define the typical client characterization that we consider and define the scale of the emergency local grid; then we choose and quantify the priority uses of residential clients.

We review the different types of exceptional incidents, their consequences in outage duration and if the exceptional event is partially predictable.

Finally, in the important case of storms, we estimate the cost of a solution of resilience by distributed storage. First, if the solution is only devoted to improve resilience. Secondly, the approach considers that the cost of storage can be partially compensated for if storage contributes to other services in normal situation.

A DEFINITION OF RESILIENCE

Our definition of resilience is close to that of US Department of Homeland Security.

The term "resilience" means the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from exceptional events. We consider all natural and human risks (human error or attacks). Thus electric system resilience deals with rare and large incidents.

Resilience and reliability should be distinguished

Though somehow related, these two objectives are not similar. Indeed reliability means the grid availability, quantified by criteria of frequency and annual duration of outage. However, these indicators take into account in particular frequency and annual duration of current incidents (for instance, single electric faults), which are not covered by resilience. Besides, unlike resilience, reliability takes into account the effect of preventive measures to reduce the frequency of incidents.

TYPICAL CLIENT AND EMERGENCY LOCAL GRID

We study a resilience solution, by an energy storage system, suitable for residential buildings. The storage facility would be at the foot of the building; it would be mutualized among different customers, obviously in order to reduce the costs depending on the sizing of storage.

We consider two cases for the typical number of clients:

- 100 clients
- 20 clients: in this case, the number of clients is too low to calculate the load curve from mean profiles.

CHOOSING AND QUANTIFYING PRIORITY USES

To minimize the investment cost in storage, emergency power will be reserved for certain uses of electricity which are considered essential. In the international experiences, in general, the sizing of a resilience solution for residential customers is not calculated from a list of priority uses: the backup power or energy is set a priori; in case of an outage, the customer will choose the uses in the limit of the allowed backup.

Nevertheless we chose the following essential uses:

- lighting
- cool to preserve food
- information media : computer or television.

To profile the lighting and cold uses of a typical client, we consider a day in the third week of the year, so in mid-January. To model the computer and television uses, we have daily profiles, independent on the season. Then we get the standard consumption for each essential use by residential customer.

Essential use	maximum power in W	mean power in W
cold	71.8	66.5
lighting	105.7	38.1
Main laptop	8.9	6.7
TV	90.0	26.0
total PC + TV (1 equipment on at the same time)	90.0	32.7
Total by client in W	**267**	**137**
All the building (100 clients) in kW	**26.7**	**13.7**

Table 1: Maximum and mean power by essential use

DIFFERENT KINDS OF EXCEPTIONAL EVENTS NEEDING A RESILIENCE SOLUTION

General incident on the electric system

It results of errors in the management of the electrical system (design of equipments, grid operation, etc.), the exogenous cause of the incident being limited.

As it results of human errors, the general incident is quite unpredictable.

Earthquake

The great east Japan earthquake of 11 March 2011 has given a large feedback [1]. Especially the Sendai microgrid worked well for most of the outage time after the earthquake. The earthquakes are unpredictable.

Storms

After the storms which hit the USA, in particular the North East (Irene, Halloween, Sandy, Katrina etc.), the outage time was between one week and 23 days.

In France, after the feedback of the storms of end 1999, refeed targets have been set: in the case of a similar event, the operator shall restore 80% of customers cut into 24 hours and 95% in 5 days.

In the following we consider only this kind of exceptional event, which is the most frequent. We choose two scenarios of outage time, according to the feeding targets in France: 5 days and 24 hours.

Additionally, these events are partially predictable, which allows to use the storage system for other services in normal operation.

COST OF A SOLUTION OF RESILIENCE BY DISTRIBUTED STORAGE

Need in power and energy

Now we calculate the sizing in power and energy of the local storage system to give resilience against a storm by feeding the essential uses of each client. We have to deal with 4 cases depending on the number of customers (100 or 20) and the backup time to provide (5 days or 1 day).

For 100 customers, we consider that the number of clients reduces the relative value of the dispersion compared to the curve demand resulting from standard profiles. Thus power and energy are simply 100 times the profile of the residential customer (Table 1).

For 20 clients, we have to take the dispersion of each client compared to his profile. In a simple way, the standard deviation of the typical client is:

$$\sigma(client) = 70\% \times Power(client) = 0.7 * 267\,W = 187\,W$$

Equation 1 : standard deviation of each client

Client dispersions are considered independent, so the standard deviation of 20 clients is the hypotenuse of the individual standard deviations. We set at 5% the accepted risk of not feeding the priority uses of the building, thus we take as margin twice the standard deviation of the building, ie 1.68 kW.

By a similar approach, we calculate a margin in energy, necessary to estimate the back-up energy needed for 1 or 5 days of outage.

Then we get the sizing in power and energy, in these 4 cases of resilience goal depending on the number of clients and the backup time:

Number of clients	100		20	
Outage time in days	5	1	5	1
Maximum power in kW	26.7	26.7	7.0	7.0
Energy in kWh	1648	330	383	77

Table 2 : need in maximum power and energy depending on the number of clients of the building and the backup time

Cost of the solution of resilience by distributed storage

We evaluate the cost of a resilience solution by storage by lithium-ion battery, for residential buildings, considering the combination of the number of clients and the backup time. Storage costs come from the prospective assumptions for 2020-2030 on the lithium-ion of EASE (European Association for Storage of Energy):

Cost hypotheses in 2020-2030	
CAPEX by power in BOP in €/kW	400
CAPEX by energy in €/kWh	250
Life duration in years	15

Table 3 : cost hypotheses for lithium-ion (source: EASE)

Theoretically, we can thus calculate the storage cost, with these prospective hypotheses in the 4 scenarios. These hypotheses shall nevertheless be considered both optimistic and uncertain, as no such systems exist commercially today: the necessary solution associates the characteristics of residential storage (power of a few kW) and more centralized storage (energy to store > 1 MW).

Number of clients	100		20	
Outage time in days	5	1	5	1
CAPEX en k€	423	93	99	22
Annuity in k€/year	49	11	12	3

Table 4 : cost of the storage solution

For instance, in the scenario where the resilience service is designed for 24 hours of backup for a building of 20 customers, the cost of the storage system would be 128 € per year per customer, which is still high.

Note that a solution by diesel generator, certainly less favorable to the environment, would generally be less expensive: between 6 and 8 k€/year, except in the case of lower sizing (24 hours of backup, 20 customers).

Sharing storage with other services in normal operation

Mutualizing a storage device over various services is an active field of research, both on the technical and economic sides [2] [3] [4]. The storms being predictable, we try to share storage between resilience and other services of residential storage:

• primary frequency regulation (residential storage can supply this service for the Transmission System Operator (TSO))

• backup in case of outage; it can be valued by the reduced investment in distribution for continuity of supply (particularly the target on the outage time).

The second service may seem redundant with resilience. It is in fact legitimate to add:

• A qualitative gain: give resilience for a set of customers, in case of exceptional incidents by definition of resilience

• An economic benefit: achieving the same overall objectives in supply continuity with less conventional grid investments.

Assuming storage for resilience can be developed for all residential buildings, the value of these additional services is limited by the saturation of the needs they satisfy. With optimistic parameters on the cost of the primary reserve and potential savings on investment in grid quality, it would reduce the cost of storage by 52%. In particular we have considered the current public price of primary reserve of the French TSO RTE: 18.2 € by MW by hour, knowing that this remuneration scheme will certainly evolve in the coming years, and the service' value also depends on storage's development (the more storage is deployed, the smaller the marginal gain is; in case batteries would satisfy all the need, estimating a related remuneration is challenging). As regards the reduction of investment in grid quality, we consider an estimation of the investment cost needed to gain one minute in SAIDI (System Average Interruption Duration Index) on a DSO scale.

In the scenario (24 hours of backup, building of 20 customers), we have seen that the cost of a devoted storage system would be 128 € per year per customer. According to the values of both other services, the extra cost attributable to the resilience would be 62 € per year per customer.

CONCLUSION

To design a resilience solution for residential clients in collective housing, we selected a set of essential uses. Considering the important risk of storms, we studied 4 cases (number of clients by building, outage time to compensate for). Then we could calculate the sizing of a storage solution and its cost if we select a lithium-ion battery.

To reduce the cost of storage equipment for resilience, a solution would be to compensate for the cost of investment by "current" services of storage in normal operation, knowing that the storms are largely predictable. We studied primary frequency regulation and backup as a contribution to the target on the outage time. In an optimistic estimation, this would diminish the cost of the solution by 52% - such a number takes into account the saturation of the needs but would probably be lower: if batteries for resiliency were massively deployed, the marginal gain would diminish. Estimating these revenues in such a scenario with a price maker approach, and considering other services are both perspectives for further research.

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