Primary frequency control by using a 1 MW battery: study at grid scale on the Concept Grid EDF platform

Fabien LUCET
EDF - France
fabien.lucet@edf.fr

Etienne RADVANYI
EDF - France
etienne.radvanyi@edf.fr

Benoit PULUHEN
EDF - France
benoit.puluhen@edf.fr

ABSTRACT

A power reserve is needed to regulate the grid frequency. Currently this reserve is provided by electricity producers, who dispatch it on their generation plants by keeping a margin of power.
Recent large scale storage systems could be an alternative means to contribute to this reserve.
To study this opportunity, EDF has just bought and installed on its versatile Concept Grid platform a 1 MW Li-ion battery with its 1 MW inverter in order to deeply analyze the behavior of the system when it is used as a power reserve. In this paper, we present the battery and inverter features, the power solicitations associated with a frequency control service, the way we plan to manage the system and particularly the State Of Charge (SOC) of the battery, and finally the forecasted equipment lifetime.

INTRODUCTION

Generation and load must be permanently balanced in order to maintain the grid frequency at a stable value, 50 Hz in Europe. Indeed a mismatch between load and generation impacts directly the speed of the rotating machines, and therefore the value of the grid frequency.
To roughly perform this balance, the Transmission System Operator forecasts in the evening for the next day the load curve and plans the generation accordingly. However, on the one hand, the load cannot be forecasted with high accuracy because it also depends on variables such as weather or people's behavior and on the other hand some outages can affect the generation plants. Another mechanism is thus needed to ensure a fine balance: the primary power reserve.
This primary reserve is an amount of power delivered to the grid automatically and proportionally to the frequency deviation. This reserve is also fundamental to maintain the grid stability in case of a sudden generation drop. At the European scale, it represents 3000 MW and about 700 MW of this reserve is provided by France[1]. Full power of the primary reserve must be available in maximum 30 seconds and maintained, if necessary, for 15 minutes. This reserve is provided by electricity producers, such as EDF, who keep a margin of power on its generation plants.
Instead of keeping margins, recent large scale energy storage systems such as batteries represent an interesting alternative means to provide this power reserve. Some large scale batteries have already been deployed, but the interest of this type of equipment to regulate the frequency and its interaction with the grid need to be deeper investigated. To study the opportunity of using electrochemical storage systems to supply primary power reserve, EDF has just bought and installed on its versatile Concept Grid platform a 1 MW / 30 min Li-ion battery with its 1 MW inverter[2]. The goal of this project is to deeply analyze the behavior of the system when it is used as a power reserve, identify the related challenges and tackle them. In this paper, we present the battery and inverter features, the power solicitations associated with a frequency service, the way we plan to manage the system and particularly the SOC of the battery, and finally the forecasted equipment lifetime.

SYSTEM TECHNICAL FEATURES

Figure 1. Picture of the battery and the inverter at the EDF concept grid platform.

The installed system is composed of two 20 feet-containers (Figure 1):

- The first one contains the battery. It is composed of 4500 elementary 3 V cells, assembled in series and parallel. The full nominal voltage is 700 V DC. When fully charged, the battery is able to provide a 1 MW power for 30 min, corresponding to an energy of 500 kWh.
- The second one is the inverter. It converts the 700 V DC to 700 V AC. Then this 700 V AC is brought to 20 kV through a transformer.

FREQUENCY DEVIATION

At the European grid scale, frequency deviations are mainly little, due to small gaps between forecast and real consumption regarding the grid size. Figure 2 shows the frequency values obtained in 2013 over a week on the European grid. Not surprisingly, the distribution is very tight around the target value of 50 Hz.

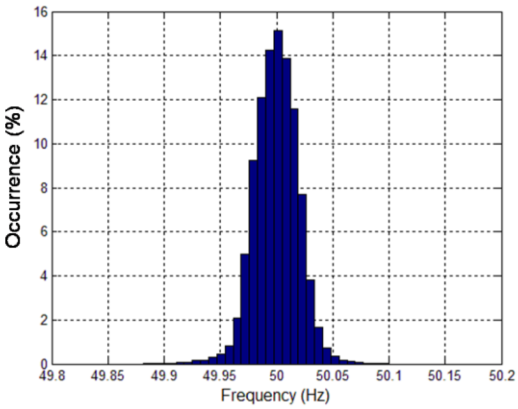

Figure 2. Frequency distribution obtained over a week in 2013 on the European grid.

COMMAND-CONTROL SYSTEM

Power solicitations

The 1 MW battery is dedicated here to primary frequency regulation in order to help maintaining the frequency at a stable value of 50 Hz. The power solicitations of the system are inversely proportional to the frequency deviation. When the frequency decreases and becomes inferior to 50 Hz, the system delivers power to the grid (counted positively): there is a discharge of the battery. Theoretically, if the delivered power of the whole reserve is sufficient, the frequency recovers its 50 Hz value. On the contrary, when the frequency increases and becomes superior to 50 Hz, the system absorbs power from the grid (counted this time negatively): there is a charge of the battery. Again, if the consumed power is sufficient, the frequency recovers its target value.

Figure 3 shows the required power as a function of the frequency value. As said previously, the power is inversely proportional to the frequency deviation. The maximum power of 1 MW is reached for an upward and downward 200 mHz deviation. Interestingly, there is no dead band: the system is permanently operated.

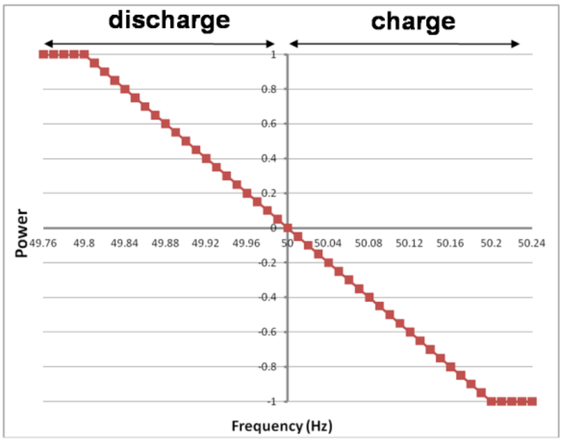

Figure 3. Required power *vs* frequency for a 1 MW power reserve.

Following this control law, Figure 4 shows the required power associated with the frequency distribution shown on Figure 2: not surprisingly, the power solicitations are mainly under |0.2| MW far below |1| MW.

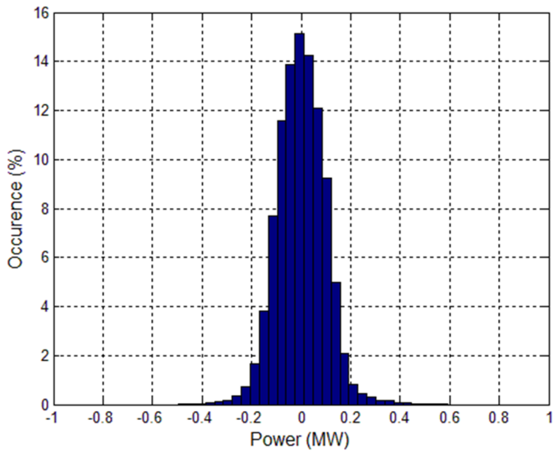

Figure 4. Distribution of the power solicitations based on the frequency distribution shown on Figure 2.

SOC management

As a primary power reserve, the system should be permanently able to provide and absorb 1 MW for 15 min. Thus, maintaining a battery SOC at 50% is a critical issue. Considering a 50% initial SOC and based on the power solicitations shown on Figure 4, Figure 5 represents the evolution of the SOC as a function of time without SOC management. We can see that quickly, after less than 12 hours, the battery is completely empty and therefore not useable any more. This result can easily be explained: the power solicitations are symmetrical in terms of charge and discharge as shown on Figure 4, but on a long period (Figure 4 is for a week). However, for a shorter time, the solicitations in charge and discharge are unbalanced. Thus, a SOC management is needed.

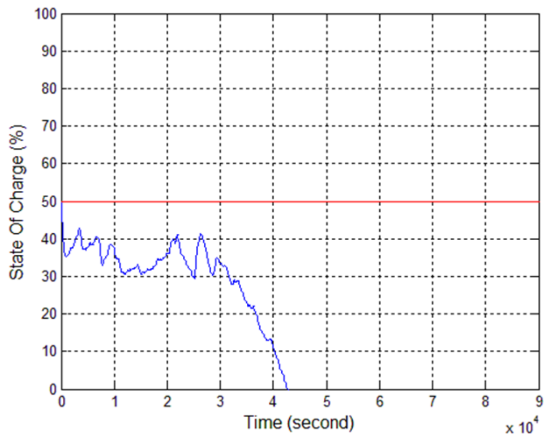

Figure 5. Evolution of the battery SOC as a function of time without a SOC management.

On Figure 6, we play the same solicitations while activating some flexibilities of SOC management: when necessary and possible, the system provides a higher power (either in charge or discharge) to the grid than intended. For instance, if the SOC is too low and the frequency deviation corresponds to a 100 kW charge, we will charge at a higher rate.

We can see that although the SOC is not totally equal to 50% during the whole week, it is more stable.

On Figure 6 we fixed arbitrary limits, in green dashed lines at a SOC of 40% and 60%, to introduce an availability notion. As long as the SOC is between these limits, we can consider that the service can be provided: a constant power of 800 kW can be charged (respectively discharged) from (respectively to) the grid during the 15 minutes requirement. This 800 kW represents a charge (or discharge) of 40% of the 500 kWh total energy battery during 15 minutes.

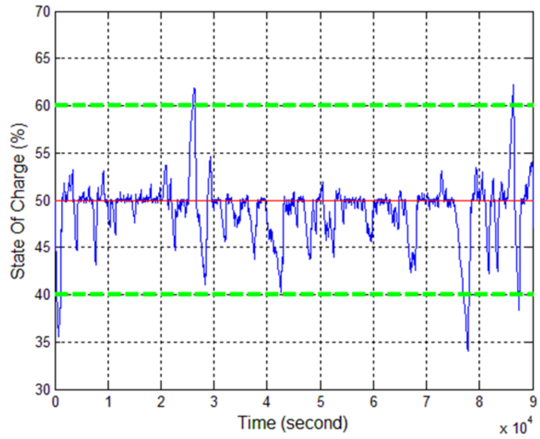

Figure 6. Evolution of the battery SOC as a function of time with a SOC management

BATTERY LIFETIME

The number of cycles the battery achieves can be calculated in many ways. For instance, a partial cycle can be counted only from the 50% SOC line (Figure 7A)). In this case, some micro-cycles are not counted. Another way is to cumulate the mileage covered in energy (Figure 7B)).

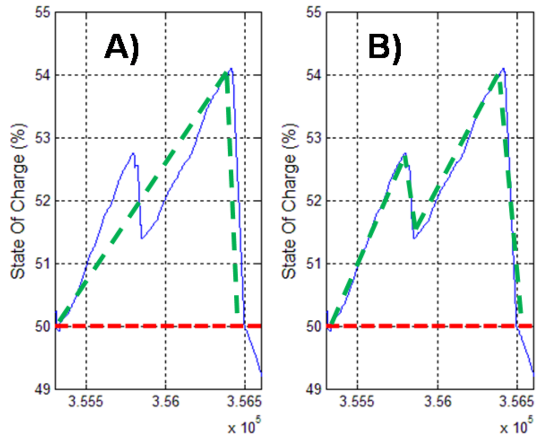

Figure 7. Two ways to count the number of cycles.

Based on (i) the frequency distribution from Figure 2, (ii) the power solicitations from Figure 3, (iii) the SOC management from Figure 6, and (iv) the way of calculating the number of cycles shown on Figure 7B), all the partial cycles represent 14 equivalent full cycles a week, more than 700 cycles a year. Thus, considering a 10 years lifetime, it is 7.000 equivalent full cycles, which is difficult to reach for a classic Li-ion battery[3]. Figure 8 shows the corresponding distribution of the Depth Of Discharge (DOD): these 7.000 equivalent full cycles are mainly composed of micro-cycles.

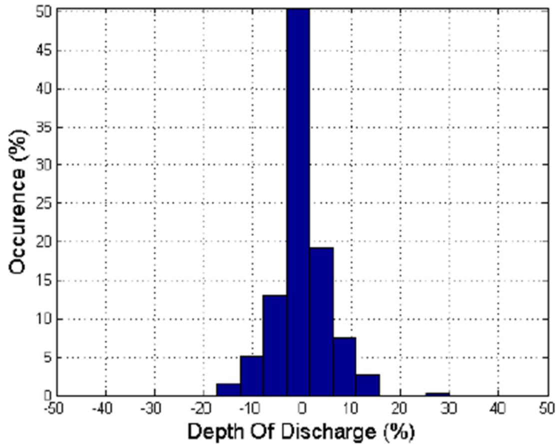

Figure 8. Partial cycles distribution achieved by the battery.

Figure 9 shows the battery lifetime as a function of the DOD. Considering an average DOD of 10% (Figure 8), the estimated lifetime of the battery is over 500.000 10% cycles, corresponding to more than 50.000 full equivalent cycles. This estimated battery lifetime can be compatible with a use as a primary power reserve over 10 years.

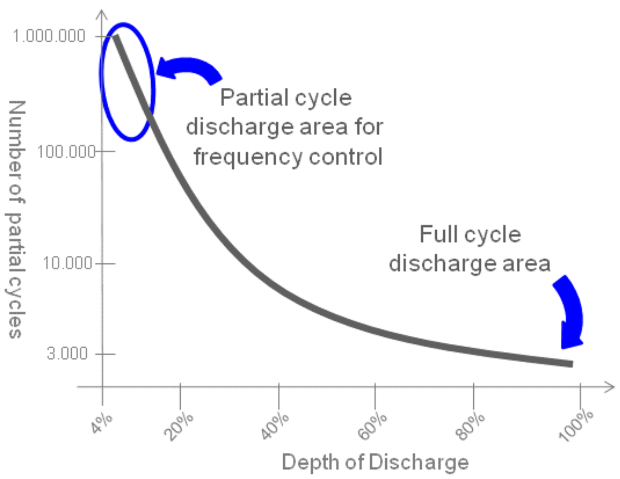

Figure 9. Number of achievable cycles *vs* the DOD.

CONCLUSION

To study the opportunity of using electrochemical storage systems to regulate the grid frequency, EDF has just bought and installed on its Concept Grid platform a 1 MW / 30 min Li-ion battery. Based on a frequency signal obtained on the European grid over a week in 2013, we calculated the associated battery power solicitations, determine a way to maintain permanently the battery SOC at 50% and evaluated the battery lifetime; this lifetime appears compatible with a 10 years use. We plan to analyze in 2015 the behavior of the system on the grid. The Concept Grid platform and the planned test are detailed in the final section below.

EXPERIMENTATION

Concept Grid Platform

In this study, the storage system will be connected to the 20kV network of the Concept Grid platform which is very versatile and where a wide variety of tests can be performed thanks to its different facilities:

- Rotating machine, which can be used as generation or load;
- Real loads : houses, heat pumps, fridges, electric vehicle charging stations;
- Resistive programmable loads;
- Wind turbine, solar panels;
- Impedant, compensated or active neutral;
- Four quadrant amplifiers, linked to real-time simulation for *Power Hardware In the Loop* tests.

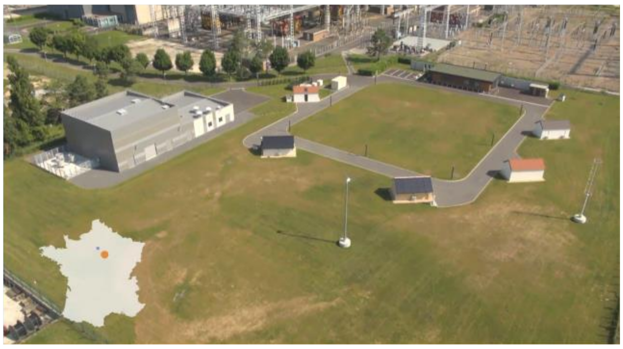

Figure 10. Aerial view of the Concept Grid platform.

The storage system could be power supplied either by the 20kV network of the “Les Renardières” EDF site, or by low voltage amplifiers of the Concept Grid through a HV/LV transformer. This second option will permit to generate our own grid and therefore play unusual scenarii of frequency deviation and analyze the battery behavior.

Planned tests

As the storage system should normally be autonomous for primary frequency control, the first way to test it is to connect it to the medium voltage network and let it work. But in this case, the battery is solicited directly by the grid frequency and we do not have control on it.

A second way is to send to the battery a fake frequency measurement, in order to reproduce special event, for instance a winter week with a lot of frequency deviation due to the weather and saturated grid. This will be useful to validate the performance of the SOC management.

A third, and last way, is to connect the storage system to the Concept Grid network and isolate it from the French grid. In this configuration, some sophisticated cases can be imagined:

- The voltage and frequency are generated by the rotating machine. With this network we supply the battery and a resistive load we can control to have an impact on the speed of the rotating machine, and therefore on the frequency. We look at the battery behavior, which should compensate the unbalance and maintain the frequency at 50 Hz;
- The voltage and frequency are generated by the amplifiers. We also simulate a network with loads and generation thanks to our real-time simulation linked to the amplifiers;
- We use both amplifiers and rotating machine, either as load or generation.

In addition, thanks to the Concept Grid facilities, we will be able to look at the battery behaviour while a true medium voltage short-circuit occurs, or any disturbances that can be generated by the amplifiers.

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