EDP DISTRIBUIÇÃO'S INOVGRID FIRST ELECTRICAL ENERGY STORAGE PROJECT

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ABSTRACT

The aim of this article is to describe EDP Distribuição first electrical energy storage (EES) project, its concept and its goals. The proposed system will be installed on a medium voltage distribution overhead grid, within a smart grid concept (EDP Distribuição's InovCity) and its main load is a university type client. A description of the methodology used to size and fit the storage system in a first-of-a-kind plant, will be described. This article takes advantage of a scientific study that has been developed for this specific purpose, in which system simulations have been performed, in both transient and steady state, at the Point of Common Coupling (PCC) between the grid and EES. The conclusions of the above mentioned scientific study, are well suited and further supports the developed concept, namely on subjects such as system sizing, applications, added value to the Electrical Energy Sector's value chain. Such key factors allows to understand the best operating schemes and management principles for EDP Distribuição's Energy Storage System. This paper results of a strong cooperation amongst EDP Distribuição, Siemens, Instituto Superior Técnico and Instituto Superior de Engenharia de Lisboa.

INTRODUCTION

Electrical Energy Storage is a state-of-the-art topic in the Electrical engineering community. All around the world and particularly in Europe, hundreds of projects are under development, based on different technologies connected on different layers of the electrical system (generation, transport, distribution and client). At each level of the system, in terms of where EES are connected, there are different needs and specifications to fulfil, so EES must be sized and fitted accordingly. EDP Distribuição, Portuguese main Distribution System Operator (DSO), is developing an EES pilot project on national distribution grid, which will be integrated in EDP Distribuição smart grid project (InovGrid- Évora).

EDP Distribuição storage project main goal is to show how distributed energy storage concept can be developed according to the DSO mission, serving its client's needs, regarding service quality and reliability. It is important to notice that this project is EDP Distribuição's first experience with energy storage technologies, which takes into account expected learning path along the way with this Proof of Concept (PoC), which justifies some of the options made.

PROJECT CONCEPT

The purpose of this PoC is to demonstrate how an EES can contribute to EDP Distribuição's main technical challenges: i) Increase grid reliability; ii) improve grid power quality and iii) grid loss reduction.

In fact this EES system main function is to provide *backup* to the main load/client. Nevertheless, there are other auxiliary functions, such as fault-ride-through (for grid support), peak-shaving (for grid loss reduction) and voltage control, as shown in figure 1.

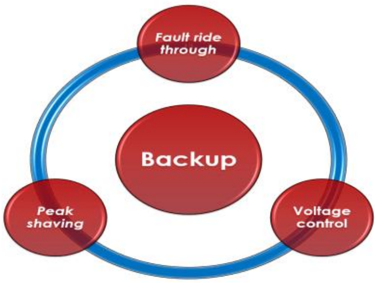

Figure 1 – EES functions

In spite of the EES standalone nature, this system will be connected to EDP Distribuição dispatch centre, through IEC 60870-104 protocol.

The EES PCC will be in MV (15 kV) side of a secondary substation where the university client is connected. EDP Distribuição EES will be commissioned in 2015.

EES SYSTEM DESCRITION

EES Sizing Methodology

The sizing of EES must take into account both energy and power requirements. Two criteria were established in order to evaluate the sizing needs for the given project, namely:

- EES Capacity (one hour supply vs. half an hour);
- EES Power (max annual consumption power vs. a power conservative value).

The sizing was based on the client's needs, regarding the track record of number and duration of outages and the client's consumption profile. As shown in figure 2 there is a huge difference between working (WD) and non-working days (NwD) profile. This issue must be considered, due to the fact that NwD represent about 49% of the year. This detail is particularly relevant because PCC is connected in a capillary region of the distribution grid, in its end, thus subject to a significant influence of grid losses alongside with the load profile variations.

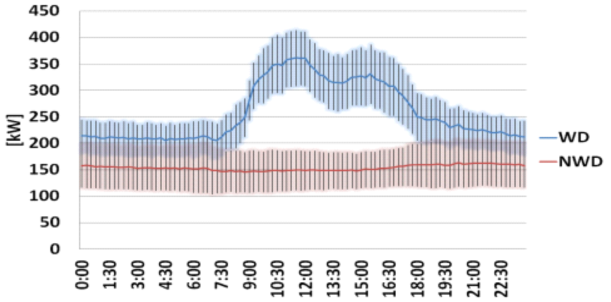

Figure 2 – Yearly average WD and NwD consumption.

The grid that supplies this client is a rural overhead power line, which is subjected to some power failures, as represented in figure 3, grouped according to its duration.

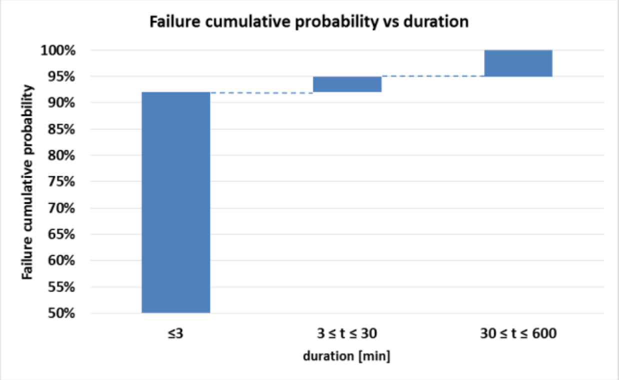

Figure 3 – Grid failure frequency vs duration

Grid outage's duration clearly shows that EES backup capacity should be sized to 30 min, rather than one hour, because this option will cover 95% of the events. Regarding EES power sizing, a link between grid outage profile and client average power consumption was established, according to figure 4.
Based on previous data, some studies concluded that an EES capacity corresponding to client yearly average power consumption plus standard deviation (393 kW) and energy to half an hour at rated power (196 kWh) is the best sizing regarding EES performance vs. investment. Covering 91% (winter) to 98% (year), considering a random failure and reducing the investment in EES by 11%, when comparing to a full power (client yearly max consumption) EES sizing.

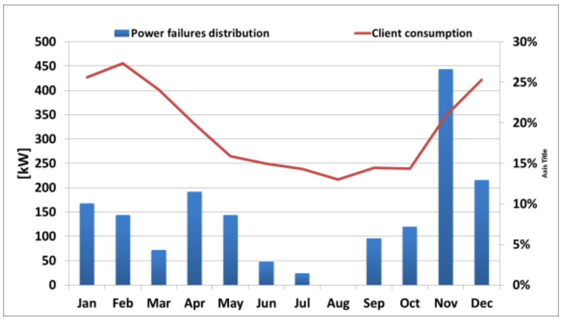

Figure 4 – Link between number of grid outages and client average power consumption.

EES Main Characteristics

As stated in the previous section, the EES was sized to be 393 kW/196 kWh. Furthermore it was specified in EDP Distribuição tender that the proposed solutions had to fulfil the established requirements for a period of 10 years after commissioning, thus battery performance degradation had to be considered.
A calculation regarding EES State of Charge (SoC) and Deep of Discharge (DoD) estimation was also performed, based on failure data estimation. A summary of results is represented on table 1.

Number of cycles per year	Estimated depth of discharge	Functionality
30	3.7%	Backup
7	19%	
3	80%	
260	[55-65%]	Peak-shaving

Table 1 - EES usage estimation

Considering the EES capacity needs at the system's End-Of-Life (EoL), overall EES system losses (inverter, batteries, transformer) of 8 to 10% and its degradation over time, starting at Beginning of Life (BoL), the system sizing is calculated by equation 1 (with resulting curve on figure 5).

Figure 5 – EES capacity degradation over lifecycle

It was estimated that in order to fulfil EDP's specification at PCC considering EES efficiency and its degradation over 10 years the capacity of the system had to be oversized to 360 kWh, which implied a 472 kW to keep the same c-rate, according to Siemens proposed solution.

$$ESS_{cap} \,@\, BOL = f(ESS_{cap} @\, EOL, ESS_{\eta}, DoD, SoC) \qquad (1)$$

Following the EES sizing methodology, Siemens system consists of four battery rack modules, four three-phase inverters coupled with output filters and a three winding main transformer. The system is connected at the same MV PCC of the university client, supplied by a secondary substation through a rural power line. The global system schematics is presented in figure 6 and the main characteristics of the EES subsystems are summarized in table 2.

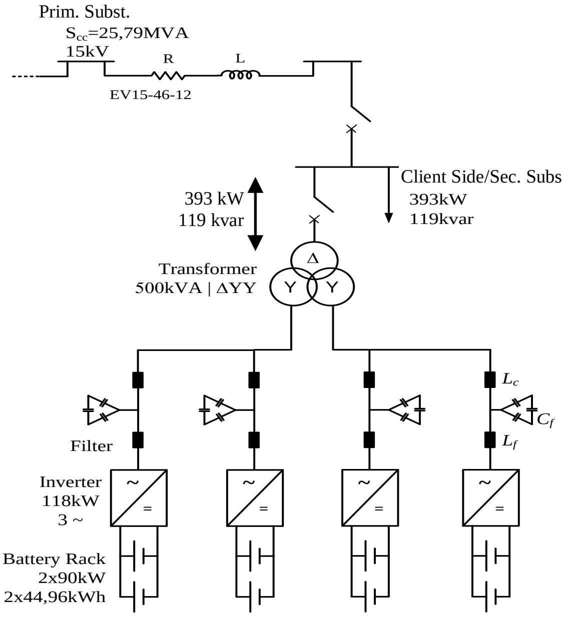

Figure 6 – EES global circuit.

Transformer	Filter	Inverter	Battery Rack
15kV/400V ΔYY	L_f=162,5μH	3 ~	Lithium
S_n=500kVA	C_f=40μF	P_n=118kW	U_{dc}=550V-800V
U_{cc}=6%	L_c=2μH	f_c=5kHz	P_n=2x90kW
P_{sc}=5800W	-	PWM	E=2x44,96kWh
P_o=1600W	-	-	-

Table 2 – EES main characteristics

Control Architecture

The EES system is controlled in order to achieve the above-mentioned predefined technical objectives.

For this purpose, the AC current control is the first system control loop. Figure 7 shows a block diagram of this control loop. The output phase currents are controlled using a 5kHz carrier PWM sinusoidal modulator and the modulator signals are given by the PI controller of *dq* phase current components. These *dq* current components are respectively related with active and reactive power flow.

Upon current control loop, other controllers may be designed according to the system's functions, such as: output AC voltage control for standalone operation; active and reactive power control concerning load peak-shaving for grid loss reduction; U_{dc} voltage control in respect to batteries state of charge. A system model was built in *matlab-simulink* with the aim of performing real time simulations to evaluate system's capabilities.

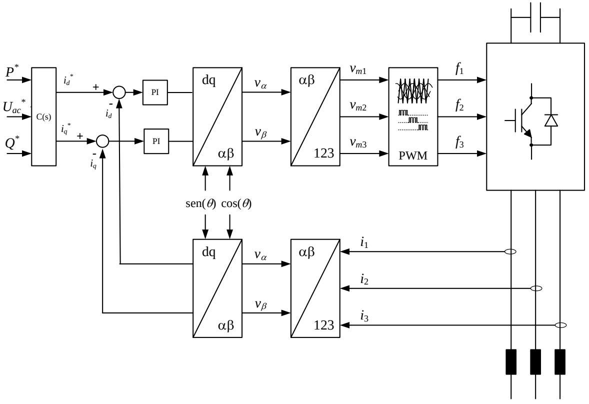

Figure 7 – Inverter control diagram.

SIMULATION RESULTS

Power flow simulation

Some power flow simulations were performed, considering EES on this specific grid. Regarding feeder losses, an average reduction of 15% is expected and the voltage profile deviation will also be improved, as represented in figure 8. Since EES main function is power backup, a control system regarding the prioritization of auxiliary functions must be developed. Figure 8 also shows that, depending on client yearly consumption profile, EES performance will vary widely, depending on system functions prioritization. As soon as EES is installed a performance study will be carried out, in order to ratify these assumptions.

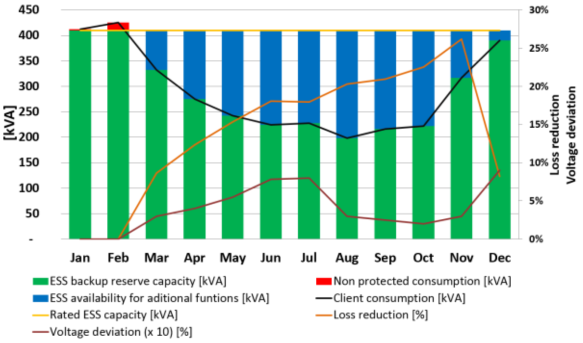

Figure 8 – System performance

Black Start simulation

Figure 9 shows a black-start operation example, where the load voltage is restored after a main power break / interruption. The system will remain in standalone operation, while stored energy is available until the grid is re-established.

Peak-shaving simulation

An example of peak-shaving is shown in figure 10, where the client active power P_{load} (at 1pu) is totally supported by the grid P_{grid} until EES system starts to supply P_{EES}, afterwards the grid P_{grid} decreases in the same quantity of P_{EES}. Figure 8 clearly shows that the EES backup reserve capacity will vary widely, alongside with the load profile variations. Since backup function is a priority, EES complementary capacity for additional functions will also differ and these functions performance will vary in inverse proportion.

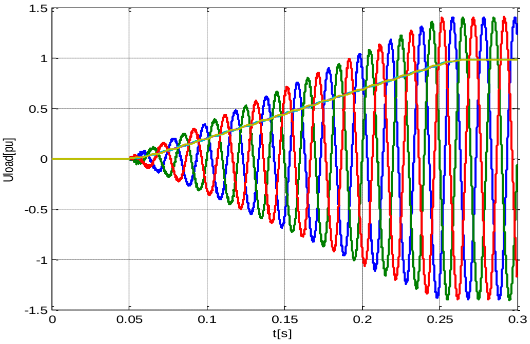

Figure 9 – Time evolution of load voltage and rms value during black start.

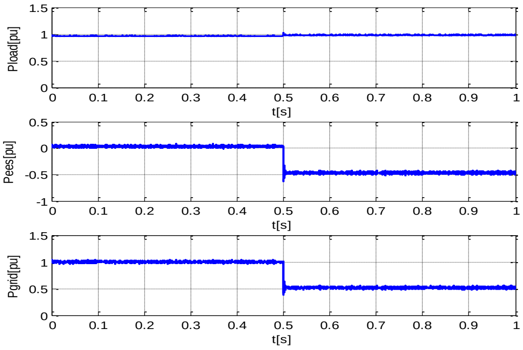

Figure 10 – EES active power injection dynamic response

Voltage Sags simulation

Voltage sag compensation and voltage regulation, using reactive power injection, is one of the system capabilities. Figure 11 shows an example of a voltage recovery after a slight voltage sag. Considering EES rated power the system achieves normative voltage values for around 13,5% deep sags.

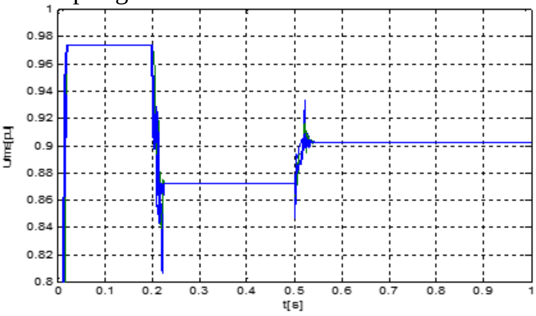

Figure 11 – Time evolution of load *rms* voltage value.

CONCLUSIONS

Nonconventional EES systems can effectively contribute to DSO technical goals such as grid reliability, power quality and loss reduction. With this aim, EDP Distribuição started a nonconventional EES pilot project in Portuguese distribution grid, within the smart grid project InovGrid-Évora. Due to EES physical size, its installation in areas where space is limited is still a concern.

The main function of the EES system is to provide client backup assuring a service reliability. In addition, other benefits can be achieved, like fault-ride-through, load peak-shaving or voltage regulation. The EES system sizing was done considering power and supply capacity. Analysing client load diagram and grid failures number and duration along the year, it is concluded that half an hour supply capacity at rated power of 393kW is the best commitment between EES performance and investment. The system must be oversized up to 360kWh and 472kW to take into account EES capacity degradation and EES system overall losses (transformer, inverter, batteries) of about 8 to 10%. The Siemens EES system solution includes eight battery rack modules, four three-phase inverters with output filters and a three-winding main transformer. The EES system is current controlled using PWM techniques, where current references are calculated depending on the selected EES function, such as standalone operation, peak-shaving or voltage sags compensation. Simulation studies of EES performance show the potential capabilities of the nonconventional storage system. Once several functionalities are available on nonconventional EES system, a priority management plan must be developed to achieve system optimization. After the EES is set into operation, performance studies will be carried out to confirm the study assumptions.

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