INTEGRATIVE ANALYSIS OF THE OPERATIONAL IMPACT OF A MV STORAGE SYSTEM IN BACK-UP AND ANCILLARY SERVICES MODES: MICROGRID AND ISLANDED SIMULATION

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ABSTRACT

The multifunctionality of Energy Storage Systems (ESS) has being viewed as a powerful resource for a stable and reliable grid operation in an environment of high DER penetration at all voltage levels. The Portuguese DSO, EDP Distribuição, established a multi-sourced partnership with Siemens and the University of Évora, to implement, test and execute a pioneer Energy Storage project. A medium-voltage (15kV) storage facility has been installed at Évora University and is today capable of working in both grid-connected and microgrid mode, providing various types of services to the grid such as frequency and voltage control. This paper aims to present the know-how acquired by EDP Distribuição in operating and exploring the ESS in both grid-connected and islanding modes as well as to evaluate the quality of service provided to clients and distribution secondary substations in stationary and transient periods.

INTRODUCTION

The advent of flexibility, resilience, demand response and self-supply needs of the integrative electric systems is today a challenging reality for many European and worldwide DSO´s. EDP Distribuição, the Portuguese DSO, established a partnership with Siemens and the University of Évora to implement pilot project based on an ESS.

EDP Distribuição´s ESS is powered by lithium batteries modules, with a peak power of 472kVA and a capacity of 360kWh. The portable and extensible characteristics of the ESS make it a powerful instrument for different uses and capable to be installed in different locations. The ESS established in Valverde (Évora) was connected to the Medium-Voltage (15kV) node which provided the possibility to operate the grid both in grid-connected and islanded modes. The referred grid node was selected so it could allow the supply of both the University of Évora (Medium-Voltage client) and the Valverde´s residential low-voltage clients for a period dependent on the actual demand and ESS battery capacity.

In the Figure 1, a photography of the EDP´s storage system is presented and in the Figure 2 a schematic representation of the topologic interconnection of the Storage system with the MV/LV grid and the MV client.

Figure 1 – EDP Distribuição Energy Storage System

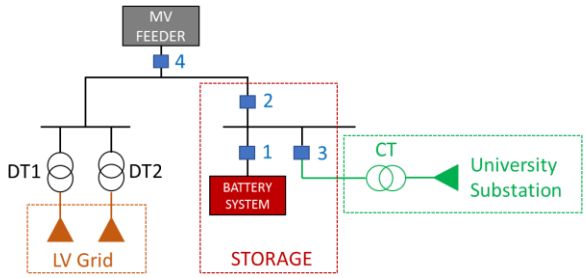


Figure 2 – Micro Distribution Grid of Valverde (Évora)

The Figure 2 contains a schematic representation of the EDP Distribuição´s micro distribution grid of Valverde and the interconnection of the ESS to the up-stream MV grid. In the same figure, it is possible to recognize two different voltage levels and two different kinds of secondary substations – DSO (storage included) and client. In green color is represented the University´s secondary substation and the transforming point (named CT – Client Transformer) and in orange the DSO´s transforming secondary substations (DT 1 and 2 - Distribution Transformers) that feed the low-voltage residential clients of the village. The four numbered blue squares represent the remotely controllable circuit breakers and the recloser (number 4) that are permanently visible and operated from the MV dispatch center. The interconnection between the microgrid and the up-stream grid supplied by the substation (60/15kV) of Évora City

(MV Feeder in the Figure 2) is represented by the recloser number 4 and is the responsible to connect and disconnect the microgrid from the MV grid, determining the activation of the Islanded Microgrid Mode – "ESS to Grid". From the ESS perspective, the represented square 2 is the circuit breaker responsible for the transition from connected to islanded operation of the ESS with the MV client secondary substation, situation characterized in this paper as Islanded MV Client Mode – "ESS to Client". This transition can occur automatically or manually depending if the transition is activated by protection trip of the circuit breaker or by manual open command.

The innovative character of this project required the acquisition of deep knowledge on this subject that leaded EDP Distribuição to the development of collaborative studies and tests to collect the necessary information to the safety and efficient performance of the storage system [1]. Different and complementary computer and short-circuit tests were performed to assess the quality and capacity of the system to perform a grid connection and a coherent island operation.

In this paper, it is presented a detailed description of the results and achievements of the islanded tests performed in planned systems transitions that were manually performed in order to mitigate the impact of outage faults and improving the University´s quality of service ("ESS to Client") or to establish an innovative self-supplied microgrid that could extend the scope and explore the capabilities and the potential of the ESS in the upstream network feeding two nearby distribution transformers ("ESS to Grid").

ENERGY STORAGE SYSTEM (ESS) DESCRIPTION AND FUNCIONALITIES

The storage system of EDP Distribuição was designed to perform in different and complementary modes that could sustain multiple operational benefits for the grid and its clients. Both, the grid-connected and the island modes were developed to provide flexibility and ancillary services to the grid, where peak shaving and voltage control are the most salient activities for the grid-connected mode and the uninterruptible power feeding of the University on a power outage for the island mode.

Backup Mode:

Having in mind the impact of avoidance of an outage on a sensitive client like the University of Évora, the system is operated in a stationary hot standby – backup mode, in which, any outage or voltage fluctuation below the input standards will cause the ESS to activate the client island mode ("ESS to Client") avoiding this way an outage interruption and voltage sags, improving the quality of service of the MV client.

Grid Support:

Regarding the flexibility services that the system can perform, this operation mode of supporting the grid intends to ensure the reshape of the demand power diagram by charging and discharging accordingly to the minimum and maximum power consumption, respectively. With a continuous monitoring measure of the average consumption of the MV client a grid optimization can be obtained with the peak-shaving valence included in the ESS.

Advance User:

The engineering mode provides a benefit of directly controlling and optimizing setpoints of voltage, frequency, active and reactive power for a specific purpose or different future use cases.
As one of the main purposes of this paper, the potentiality of the ESS can be extended by creating a microgrid formed by the MV client and the two MV/LV transformation sites shown in the figure 2. The same ESS would enable an operational mode that follows the voltage and frequency control and self-supply a microgrid, extending this way the uninterruptable feeding effect to the upstream network of MV/LV transformers ("ESS to Grid").

ISLANDED OPERATION MODES

Given the operational capabilities of the ESS, EDP Distribuição started by using a protection scheme that automatically disconnects the client (University of Évora) from the grid whenever a fault occurs in the upstream network, thus avoiding outages to the University. The number and duration of any fault were potentially mitigated for the University, improving the quality of service of the client, and ensuring a proper and innovative case study using ESS for other similar or complementary planning challenges. To better understand the analysis of this and other modes, in this paper this mode is named "ESS to Client".
Furthermore, after performing several tests to ensure the proper response of the ESS, EDP Distribuição aimed to extend the scope and explore the capabilities and the potential of the ESS in the upstream network. An extended island mode was established with a larger number of LV clients by feeding two nearby distribution transformers. Both secondary substation's frequency and voltage control were set accordingly to the standards of 15kV/400V (MV/LV) and 50Hz, and to sustain the transient period between grid connected to islanding mode, several input changes were performed in the protection system.

Islanded MV Client Mode ("ESS to Client")

In Figure 3, it is presented the schematic representation of the "ESS to Client" island mode, where the automatic or manual commutation of the circuit breaker number 2 establishes an exclusive island mode with the University of Évora (MV client).

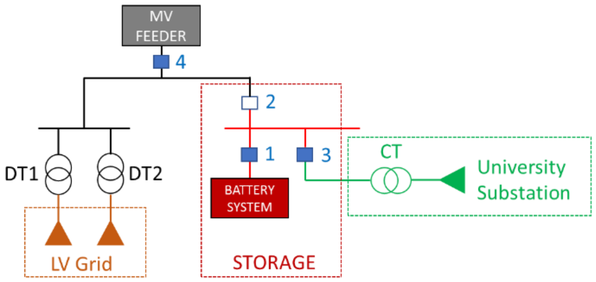


Figure 3 – Islanded MV Client Mode – "ESS to Client"

Normally the ESS is operated on backup mode, and whenever a fault occurs in the up-stream MV grid, the ESS is expected to switch to island mode, ensuring that all the MV client´s load. The opening of the circuit breaker number 2, the system pulls the frequency and voltage to a controlled level in accordance to the nominal setpoints of island transition - 15 kV and 50hz. The process of Voltage and frequency stabilization back to regulated values take less than 400ms [2]. The opening of the circuit breaker forces the system to switch to VF control mode so the island can be successfully maintained afterwards.

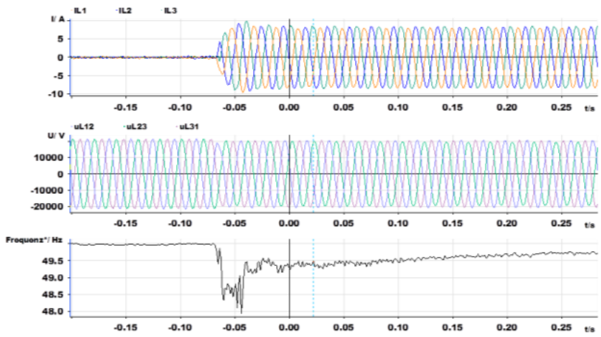


Figure 4 – ESS Current, MV Voltage and Frequency observed in "ESS to Client" mode

In Figure 4, the Current, Phase to Phase Voltages and Frequency at the ESS injection point (circuit breaker 1) are shown, during and after the successful manual commutation to the "ESS to Client" mode. In this case, the ESS supplying successfully the MV client for a period of around 15 minutes. This test shows the stability and the robustness of the system to overcome the transient connection period and to establish a stationary feeding within the standards of quality of service.

Islanded Microgrid Mode ("ESS to Grid")

In Figure 5 is presented the schematic representation of the "ESS to Grid" island mode, where the manual opening of the recloser (number 4 in figures) established an island mode with the MT client and also with 242 LV clients of the Valverde village supplied by two transformers of 250 KVA each.

The activation of the "ESS to Grid" mode, as an extend of the initial ESS scope, to fully explore the capabilities and the potential of the system, required the redefinition of the protection parameters associated to the system.

For these tests, the protection relay associated to circuit breaker 2 was disabled and the protection relay settings associated with circuit breaker 1 were maintain. With this change, the microgrid protection was granted by the relay in square 1.

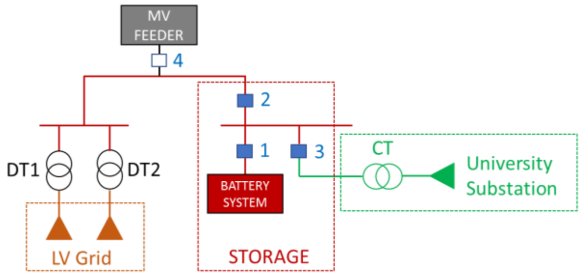


Figure 5 – Islanded Microgrid Mode – "ESS to Grid"

The settings used in relay (square1) can be obtained in [2].

First Attempt

Regarding the inhibition of the protections of the circuit breaker 2, the different input set of parameters for relay of the circuit breaker 1 and activating the V/F mode, when manually switched off the recloser, the ESS was enabled in the "ESS to Grid" mode for a short period of time.

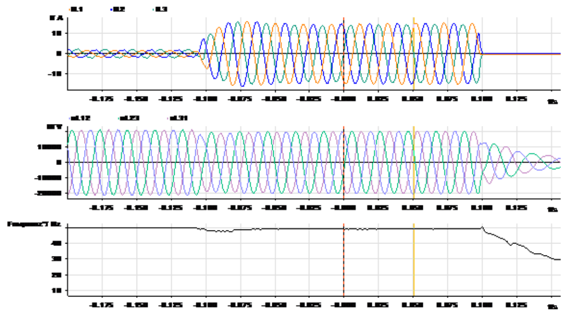


Figure 6 – ESS Current, MV Voltage and Frequency observed in the failed attempt to establish the "ESS to Grid" mode

As shown in Figure 6, after 50 ms of the transition point, the protection system tripped and created an outage of both MV and LV clients occurred due to under-frequency protection function. After analyzing the data obtained from this first attempt, it was concluded that system need more time to recover the frequency.

Second Attempt

After the unsuccessful attempt established in the first approach, and after analyzing the output protection data, changes on the under-frequency protection function parameter were made for the relay associated to the circuit breaker 1, this time, 49.5Hz at 1s. This new setting still ensured the fulfillment of the legal fault clearance times.

Successfully, at the second attempt, the island mode "ESS to Grid" was established without any major constrains. In Figure 7, the Current, Phase to Phase Voltages and Frequency at the ESS injection point (circuit breaker 1) are shown, during and after the successful manual commutation to the enlarged island mode.

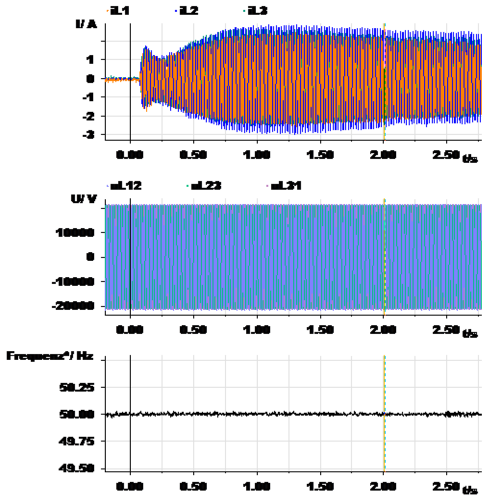


Figure 7 – ESS Current, MV Voltage and Frequency observed in the succeed attempt establishing the "ESS to Grid" mode

In this case, the ESS ensured the islanded supply mode of the MV and LV clients for a controlled period of 18 minutes, both the University of Évora and the LV clients of the Valverde village were for the first time together supplied by a single electric energy storage system, keeping the voltage and frequency levels within the expected standards.

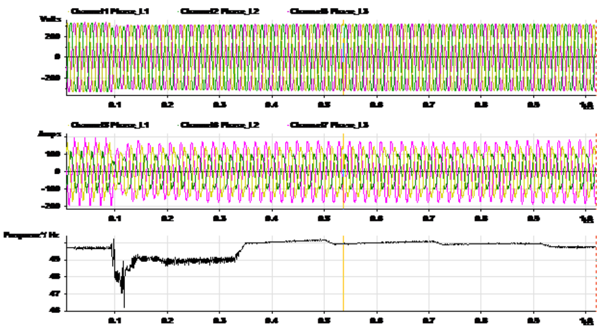
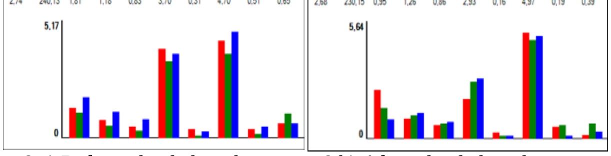


Figure 8 – Distribution Transformer 1 Current, Low Voltage and Frequency in the "ESS to Grid" mode.

Whether for the MV grid, the impact of the ESS has been substantially proved to be as an operational surplus, the impact of such system on the LV systems was not clear. Therefore, in Figure 8 as well as in Figure 9, it is shown the redefining and innovative impact of an ESS on a conventional grid, where an overall aggregate load of 1100KVA was supplied independently from the MV up-stream grid conditions keeping the continuity indexes of quality of service as well as the harmonic distortion of the aggregated power supply.

THD %	H1	H2	H3	H4	H5	H6	H7	H8	H9
2,62	238,27	1,34	0,80	0,51	3,92	0,40	4,28	0,40	0,65
2,30	238,07	1,13	0,54	0,35	3,38	0,11	3,73	0,21	1,09
2,74	240,13	1,81	1,18	0,83	3,70	0,31	4,70	0,51	0,65

THD %	H1	H2	H3	H4	H5	H6	H7	H8	H9
2,69	229,75	2,38	1,01	0,69	1,92	0,32	5,12	0,60	0,23
2,63	230,66	1,51	1,14	0,77	2,77	0,17	4,74	0,67	0,77
2,68	230,15	0,95	1,26	0,86	2,93	0,16	4,97	0,19	0,39



9 a) Before islanded mode 9 b) After islanded mode
Figure 9 – Distribution Transformer 1 (DT1) Voltage Harmonic distortion before and after to activate to "ESS to Grid" mode

Redeeming the affirmation about the impact of storage system in the harmonic distortion and considering the successful commutation from connected grid to "ESS to Grid" of the Figure 7, it is revealed in Figure 9 the positive impact of the ESS on the most components of harmonic distortion. In Figure 9 a) form presents the data obtained immediately before the microgrid formation while in the 9 b) the is presented the values measured in the microgrid supplied by the Siemens ESS and reveals a consistently balanced waveform regardless the feeding origin.

CONCLUSIONS

This paper aimed to present two different and complementary real use cases scenarios of EDP Distribuição Energy Storage System uses which are focus in the ability to operate in full potential the ESS in islanded modes with direct impact on MV and LV clients of the village of Valverde (Évora).

The system response behavior for islanded transitions in planned situations with both the "ESS to Client" and "ESS to Grid" configuration modes was shown and discussed with particularly encouraging results. The robust and out-of-initial-planned achievement of extending the purpose of the ESS in order not only to improve a quality of service of a single MV client, but also to complement the capabilities of such system to, within the boundaries of an usual quality of service levels, serve and improve the flexibility of a secondary LV electric system. The data shown on both islanded modes reveals the robustness of the ESS and the overall results prove the benefits that the ESS brought to the DSO, to the community and to the near future of the Portuguese electric distribution system. A satisfactory operating capacity was observed in the ESS, as the system successfully performs controlled switches between operation modes and can sustain a microgrid with the MV client and LV clients, assuring a reliable and accountable voltage and frequency control within regulatory standards.

The results accomplished in this paper fully proved the benefits and direct impact on grid operation of the integration of an Electric Storage System. Mainly improving the quality of service, grid flexibility and resilience of the network. Progressively, EDP Distribuição and DSOs should consider the use of ESS as potential instruments for future grid and incorporate them in operational planning.

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