STORAGE DEVICES IMPACT ON ELECTRICITY DISTRIBUTION

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ABSTRACT

This paper addresses the potential impact that distributed energy storage systems have in the distribution networks, in terms of applications and available technologies in the market.
Among the several components of the electrical system, the distribution network is the one experiencing the most profound changes, particularly in terms of technological evolution. At this stage, the recent deployment of some new technologies may play a significant role in the distribution networks development, one of them is energy storage.
Although the energy storage devices are not bound to a specific technology, but rather on a broad spectrum, they do have in common the potential of influencing (balancing) power variations and in this way to contribute to supplying totally or partially the distribution grid, namely when disturbances and variations take place.
This potential is driving this technology into the forefront particularly when the growing usage of variable energy resources and an increasing need of power quality are considered. At a moment in which the impact of variable renewable energy sources is expected to increase in the European Union, distributed storage has the potential to play a key role in stabilizing the network.

INTRODUCTION

The power sector has been undergoing several changes in the last decade. However, the steps taken are just the presage for a challenging development. This development will occur in several aspects, for instance, in the reference scenario [1] it is stated that, between 2005 and 2030, the share of renewable energy sources (RES) in the 27 European Union Member States (EU-27) gross power generation will more than double from 14.3% to 36.1%. In fact, the share of intermittent RES will reach 20.7% of the total power generation in 2030.
In this framework, electrical energy storage may play a crucial role in the EU-27 grid, providing several services for the network, beside balancing and smoothing variations in both load and generation. This capability is of utmost importance in such a scenario of increased implementation of renewables where storage can act as a buffer to the effects of the variability of some natural power sources such as wind and solar radiation.
In economic terms, however, this raises questions, such as how to overcome the present limited price difference between peak and valley hours that usually does not correspond to the real cost difference between the two situations. Another issue is the lack of experience in terms of commercial deployment regarding some of the technologies that seem to be already cost-effective especially with respect to network services.
Moreover, in regulatory terms, a change of the current EU-27 regulatory framework towards giving more emphasis to energy supply, when compared to power supply, would foster the deployment of storage technologies.

THE BENEFITS OF STORAGE IN THE POWER SYSTEM

The capability of storage behaving as a shock absorber for the electricity infrastructure, enhancing its efficiency, reliability and security, is an important asset for the future electricity network [2] states that "by maintaining even a relatively modest amount of reserves on storage facilities – big and small – will have a positive impact on the market." The benefits would, for instance, be the damping of the volatility of the electricity market prices, increasing this market efficiency, fostering the quantification of the ancillary services value and improving network security [2]. In the retail energy sector storage can reduce energy costs through peak shaving, while improving the quality of power supply and providing increased reliability of service.
In fact, storage devices do not replace existing components of the electricity value chain, but rather allow the existing ones to do their job better and cheaper [2].
Storage has the potential of escalating its deployment in the market with an increasing cost difference between peak and valley hours. Nevertheless, storage has to be integrated moderately, since an excessive storage capacity decreases its utilization factor. Therefore, an accurate estimation of the storage capacity in order to cope with the variability of some renewable power plants and the consequences for the system and the network is important. This estimation is more dependent on the percentage of variability of the resource than on the total value of this variation [3].

THE ENERGY STORAGE SYSTEMS CHARACTERISTICS

Several criteria are used to evaluate and distinguish the different storage technologies available today. Those criteria have to be scrutinized in order to select the most suitable devices for every application. There is no perfect technology on storage yet, which means that each and every solution should take the best use from the available technologies. Another option is to use two or more

complementary technologies.
It is possible to break down the above aspects in [3]:

- **Storage properties:**
  Which include efficiency, energy density, storage scale, power density, charge rate, discharge rate, and peak power capability.
- **Operation properties:**
  Which include durability in both terms of cycles and aging, response time, ramp rate, and reliability.
- **Physical deployment properties:**
  Which include modularity, transportability, safety, location, construction time, and lead time.

From the literature it is possible to detect different categorizations of the applications of storage technologies [4, 5]. The following one stresses the voltage level at which the device is connected [4]:

- *Bulk energy storage;*
- *Distributed appliances;*
- *Power quality improvement equipment.*

The first category, bulk energy storage, puts more emphasis on load levelling, transmission congestion relief and reserve capacity. Whereas in the distributed category, prominent applications are peak shaving and distribution upgrade deferral. Finally, power quality addresses more in-depth end-use power quality and reliability improvement.
For this paper the applications at distribution level of particular interest are described in the following section.

THE APPLICATIONS OF DISTRIBUTED ENERGY STORAGE SYSTEMS

Presently, the major use of storage is done at transmission level, through pumped hydro storage (PHS). However, the potential of using storage technologies is not limited to PHS nor to the connection at transmission level. Moreover, depending on the application the technology should be chosen accordingly. Several applications exist for storage at distribution level, including:

Transmission congestion relief

Connecting distributed energy storage systems (DESS) downstream of a part of a transmission network under congestion allows the optimization of the overall usage of the grid. This optimization provides a better usage of the network in the off-congestion periods and minimizes / relieves congestions when they occur. This is applicable for flows in both directions, either when the distribution network has a surplus or when it has a deficit of power.

Transmission and distribution upgrade deferral

Storage devices connected at distribution level optimize the usage of these networks. Strategically applied, it allows the deferral of the upgrade of both transmission and distribution if appropriate.

Peak shaving

DESS can provide a demand reduction at the generation system at peak times, discharging at those moments, minimizing, therefore, the usage of the less cost/effective power plants.

Time of use energy cost management

The deployment of DESS provides the supply operator a strategic tool to improve the revenues, allowing the acquisition of energy at low prices and the retail of that energy at higher prices.

Voltage support

Strategically located near loads that highly impact the network voltage, DESS has the ability to minimize the impact of these voltage variations directly at the distribution level.

Variable renewables grid integration

Variable RES present, as stated above, fluctuations that destabilize the power system. For short-term variations, DESS can be used to smooth out and absorb these fluctuations, therefore reducing the need for voltage regulation in the local power system, while increasing the power quality. For longer term variations, e.g., hours, DESS reduces the grid impact of the fluctuating RES.

Variable renewables energy time-shift

Storage allows the time-shift of energy produced during off-peak hours by renewables, variable or not, to moments when that energy has an increased value. This type of storage can be located either close to the renewable power plants or somewhere else in the grid, including close to the loads, depending of the grid's particular set-up.

Variable renewables capacity firming

Coordinated with forecasting tools, DESS will support the access of variable RES to the market, allowing renewables to be seen as a solid and reliable option to the power generation market.

Reserve capacity

DESS can provide reserve capacity at different levels, depending on the technology used. Their usage as a spinning, secondary or tertiary reserve is possible the same way as the bulk connected storage is. Like any energy storage system, DESS can provide twice its rating as a reserve. This may be achieved when the device is charging, as it can firstly stop charging and then start discharging [5].

Power quality

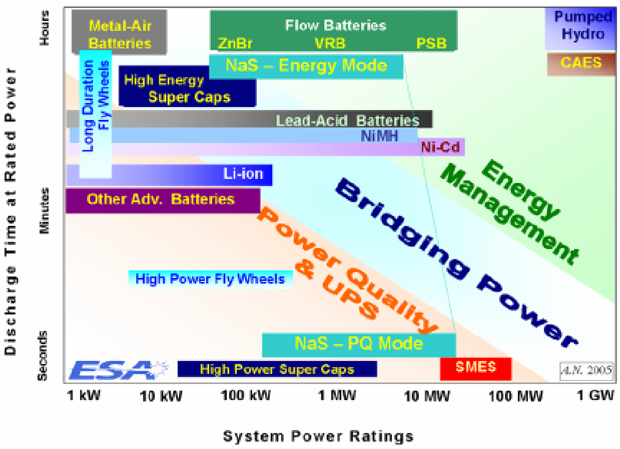
Keeping a near-constant level of voltage and frequency is one of the main goals of all energy providers. Storage can support this feature minimizing the effect of short-duration events such as sags, spikes, interruptions, as well as limiting harmonics, power factor variations and frequency variation.

Reliability

If a local network is undergoing an interruption that takes longer than the ones described in power quality applications, DESS can be used to keep the network functioning. Either supporting the grid's intentional islanding or/and supporting the black-start of both local and upstream networks. This capability is highly valued in the micro grids concept. The question of reliability will be further highlighted in one of the following sections.

THE TECHNOLOGIES FOR DESS

The technologies for DESS are quite varied and their usage depends on the applications chosen. An overview of the different technologies and the relation with their applications is displayed on Figure 1.



(Source: Energy Storage Association)

Figure 1: Relation between power ratings, discharge time at rated power, and applications for several storage technologies.

Among the most relevant technologies for DESS it is possible to find:

Surface Compressed Air Energy System (Surface CAES)

Based on the same concept as the compressed air energy systems deployed at transmission level, Surface CAES technology uses surface vessels instead of subterranean caves. CAES presents high durability and has improved its efficiency with the development of adiabatic systems. It is one of the technologies which is said to be already cost-competitive.

Super capacitors

Super capacitors is a comparable new technology which has been steadily developing in the late years. Super capacitors are ideal for short-time applications.

Chemical batteries

Although based on the same functioning mode and presenting in common their modularity, several types of chemical batteries exist. These types are Sodium-Sulphur (NaS), Lead-Acid, Nickel-Cadmium (NiCd), Lithium Ion (Li-Ion), Nickel-Metal Hydride (NiMH) and Zebra.
Nevertheless, they are all usually in the middle of the spectre in what concerns the balance between power and time of discharge / energy stored. Several of these technologies have been already deployed at utility level, particularly NaS, Lead-Acid and NiCd.

Flywheels

There are two main types of flywheels, high-power and high-energy. The first one is suitable for short-time applications (seconds to a few minutes), whereas the second one is designed for slightly longer times (around one hour). This technology presents the advantage of a high modularity.

Flow batteries

The fore-runners of flow batteries are Vanadium Redox (VRB) and Zinc Bromide (ZnBr). Even though they can be considered as a technology under development they do present already some interesting advantages such as the quick inversion of cycle, fast response times and durability.

Micro-Superconducting Magnetic Energy storage (Micro-SMES)

Promising a very high efficiency and extreme durability, Micro-SMES come with a comparable high cost. Also, the social concern around magnetic fields may hinder its deployment.

Thermal Energy Storage Systems (TESS)

Several technologies are grouped under this designation. However, all use a thermal difference to store energy. For instance, some use ice to store cold, others use molten salt to store heat. The latter technology has been used for energy generation time-shift in some solar farms.

Electric vehicles and the concept of Vehicle to Grid (V2G)

Although not a technology in itself but rather a concept that intends to take advantage of a total optimization in order to comply with the fulfilment of different needs, V2G can be seen as a movable storage in the point of view of the grid. Several business cases have been presented and will start their deployment in later years.

THE IMPACT OF STORAGE ON THE RELIABILITY STUDIES OF ELECTRICITY NETWORKS

According to a recent global survey to measure how electric utilities are progressing with smart grid initiatives [6],, reliability emerged as the first reason why these initiatives are being implemented (operations costs savings coming in as second).

In the deterministic modelling of reliability, at HL1 level are evaluated quantities and location of generation capacity, as well the amounts of sufficient reserve power, and of preventive and corrective maintenance.
At HL2 level are estimated the system ability to perform its function of moving energy provided by the generation system to the Bulk Supply Points (BSP). A distribution system with DG and DESS can be seen as an equivalent to a transmission system connected with traditional generation, therefore some authors state that HL2 reliability assessment may be used to model DG and DESS, bearing in mind, however, that the objective of the distribution system is to supply end-customers, and of the transmission system, to supply BSP.
At the HL3 level, the overall system is evaluated, including thus distribution networks. A traditional network model gets its input directly from the HL2, since a single BSP is generally used to connect the distribution network with the transmission network. This approach loses its validity when DG and DESS are included, as the energy flows from more than one point.
Furthermore, the deployment of DG and DESS raises the question if these technologies, in case of disruptions / disturbances at the transmission level, should be allowed to continue to supply the distribution network, thereby entering the so-called intentional islanding mode or whether it should be tripped due to safety constraints.
The usage of the intentional islanding and black-start would increase the reliability levels in the areas of the distribution networks where enough DG and/or storage are available. As 80% to 95% of customer electricity unavailability is due to problems at distribution level, the impact of this possibility cannot be underestimated [7].
But in order to do so the protection system has to be adapted to this potential situation. Moreover, local frequency and voltage regulation abilities from the available distributed energy resources would be also needed [8].

CONCLUSIONS

In the European Union a massive deployment of RES is expected before 2030, increasing the gross power generation from RES to more than one third (36.1%). Moreover, from these 36.1%, the major part, 20%, will be generated by variable renewables.
In this forthcoming framework, storage technologies will play a key role. Furthermore, not only storage connected at transmission level will be active but also the one connected at distribution level.
Storage has the potential of increasing deployment with an increasing cost difference between peak and valley hours. Nevertheless, an accurate estimation of the storage capacity is of importance, in order to cope with the random variability of some renewable power plants and to have an adequate utilization factor.
Distributed storage, in particular, can take advantage of increased synergies with distributed generation, demand side management and the increased deployment of information and communication technologies at distribution level. DESS presents all the conditions to be the next in line in terms of distributed energy resources deployment.
Distributed storage presents several applications in terms of the power system, as they are transmission congestion relief, transmission and distribution upgrade deferral, peak shaving, time of use energy cost management, voltage support, variable renewables grid integration, variable renewables capacity firming, reserve capacity, power quality and reliability improvement.
Several DESS technologies that seem to have potential were presented in this paper as well.
In terms of future work, the intention is to evaluate the impact of DESS on the electrical networks using a commercial tool running a deterministic contingency enumeration method.

Disclaimer: The views expressed in this paper are the sole responsibility of the authors and do not necessarily reflect the views of the European Commission.

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