NEW ANCILLARY SERVICES REQUIRED TO ELECTRICAL STORAGE SYSTEMS FOR CORRECT NETWORK PLANNING AND OPERATION

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ABSTRACT

The growing of electric energy produced by distributed energy resources (DER) and, more in particular, from renewable energy resources (RER) in particular, with the need to reduce grid transmission costs and the general reduction of incentives for the produced energy, have turned the economical convenience for end users from the delivery of energy to the grid to self-consumption. In this change, manufacturers effort is aimed to both introducing in the market new technologies, mainly battery electric storage system and acting at Standards level. Even with actual low numbers, also DSOs and TSOs are interested in storages applications, because of their potential as deferral investment, security congestion management, losses reduction, power quality, voltage control etc.

Consequently, in some countries new technical rules have been issued in order to facilitate the integration between renewable energy resources and storage needs, both in MV and LV distribution networks (i.e., Italian Standard-CEI 0-16 and CEI 0-21).

The paper describes the main aspects related to the integration and management of the BESSs in (transmission and) distribution grids, starting from those similar for traditional generating plants, to other ones, not new as concepts, but surely different concerning the implementation for the DSOs (TSOs)

INTRODUCTION

In the last years there has been a huge increase of renewable energy resources (RER) connected to the distribution network, consequently reducing the percentage weight of traditional generation connected to the transmission network, with many consequences which results in new requirements for distributed generation based on DER/RER.

Electrical energy storage systems (EESS) mainly based on battery are also growing up in the customer premises, because of their interesting synergy with RER.

Nowadays, DSOs and TSO are unaware of battery electric storage system (BESS) working mode, being not clearly defined (charge or discharge cycle, charge status, etc.), so it’s clear that any forecast, relative to energy balance between loads and sources, may be heavily influenced in presence of considerable BESS.

On the other hand, BESS may become a “wild cards” to better integrate RERs if these devices will be managed properly. BESS represent one of the tools that can be used to match some of the new requirements arising from the large spread of DG but connection and operation function of the BESS needs to be managed by standards and laws.

So, many current approaches have to be necessarily updated, adding more additional information, both real time and predictive, coming from various sources (whether, energy exchange, economical and social conjunctures, etc…).

BESS MAIN USES CASES FOR DSO/TSO

Deferral of investment

BESS may be used to defer or even avoid Distribution investment.

When make a network upgrade, its size is selected to accommodate future load growth over the next 20- to 30-years planning horizon. Therefore, a large portion of this investment is underutilized for most of the new equipment’s life and, in addition, the generation plant connection could be significatively delayed. The network upgrade could be deferred by using a storage system during peak periods. In fact, it’s important to underline that for most nodes in a distribution network, the highest loads occur on few days per year, for just a few hours per day and that main constraints to hosting capacity is the excessive voltage value due to active power injection along a feeder.

EESS can so contribute to defer the reinforcement of a line or the building of a new line that would be really underutilized.

In addition, storage systems can also advantageously be used in slow and uncertain load growth or they may represent the only practicable solution when permissions are too long or impossible to obtain.

The dissemination of BESS in MV networks requires the
development of specific methodologies for siting and sizing of BESS in order to assess their technical viability and economic benefits.

Future technological advances may reduce costs for BESS which will make the option for BESS installation even more interesting comparing with grid reinforcement strategies.

**Grid support**

BESS usage may bring additional benefits for grid operation. They could be used to absorb some energy in off-load hours and to supply a certain amount of power/energy during peak periods so reducing substation transformers and line overloading, substantially increasing hosting capacity, and also contributing to reduce network losses and improve voltage profiles. Furthermore, if the BESS is installed into a container, then it can be physically moved to other network node where it can continue to defer investments. Moreover a storage system could provide voltage control on the distribution lines (in some way related to investment deferral).

This is especially important on long radial MV overhead lines where in some part of the day there is a load and in other part of the day there is reverse energy flow due to DG. This load excursions may be the cause of unacceptable overvoltages on customers, following by sudden voltage decrease when the Interface Protection Systems disconnect the RER/DER generators due to excessive voltage values. These voltage fluctuations could be damped with adequate siting and sizing of BESS in distribution networks as well as many disconnections of generating plants followed by the automatic reconnection procedure could be avoided.

**NEW REQUIREMENT FOR BESS**

Generally the first classification of the EESS can be made using the discharge time (DT), that is the time to fully discharge the EESS at nominal active power (Figure 1). Obviously today a storage technology economically competitive in the full range of DT does not exist; so a wide range of alternative (including BESS) is today available and to develop universal requirement is a challenge.

However, the most part of the EESS connected (or in progress) are BESS; for that reason the following requirement are mainly inspired by BESS.

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**Power capability**

A BESS is able to supply and/or absorb reactive power to provide grid services like voltage control.

In its normal operation, the BESS operates at unitary power factor, the active power coincides with the nominal apparent power.

When operating at power factor other than 1, the system shall perform accordingly to specific performance curves (“capability” curves defined in the P-Q plane).

The capability of a BESS is the combination of the curve of the inverter (circular) with that of the battery (defined as a rectangle of height \(P_{\text{MAX}}\) to \(P_{\text{c MAX}}\) and width equal to the inverter rated reactive power, \(-Q_n\) to \(+Q_n\)).

**Active power response for under/over frequency**

RERs are able to participate to the control of over-frequency transients in the grid, reducing the active power generation accordingly to a specific P(f) rule.

On the other hand, no contribution to under-frequency control can be given, because they always operate at the max possible power.

On the contrary, the capability of BESS to increase and decrease the active power, even reversing the flux direction (in case of bi-directional system) can be profitably used in controlling both under- and over-frequency situations.
A possible requirement for implementing this P(f) regulation (as specified in [2] and [3]) is shown in the following figure, where:

- $P_{\text{MAX}}$ is the maximum output power that the system shall guarantee (within a specific range of status of charge).
- $P_{c\text{MAX}}$ is the maximum charging power that the system shall guarantee (within a specific range of status of charge).

![Figure 3: Active power response for under/over frequency](image)

The central rectangular area defines the standard operating points of the system. When the grid frequency overpass the specific thresholds the system is required to leave its previous status and reduce/increase its power evolving towards the vertices of the quadrilateral with a linear trend as a function of the frequency (see dashed lines) eventually changing the direction of the power (from charge to discharge or vice-versa).

At the moment to RER generators only active power response for over frequency is required, with uncontrolled islanding problems. The extension of P(f) to under frequency zone may further increase uncontrolled islanding probability on distribution networks.

**Synthetic inertia**

The inertia is an important requirement for the stabilization of grids and it is “naturally” given by rotating generators.

Infact, a generating unit capable of delivering inertia will inject or absorb extra power to the grid respectively with a deceleration or acceleration of the grid frequency. This requirement, not fulfilled by a large part of RERs (e.g. photovoltaic generator) but could be emulated by the “synthetic inertia” (e.g. emulation of inertia) that could be provided by BESS. But its “usage” has to be achieved via the inverter controls and the inverter size because all inverter based generation is limited in terms of maximum current through the valves.

In addition this requirements has to be evaluated with respect to the probability increases of unintentional islanding.

Therefore the use of synthetic inertia” have to be carefully considered for BESS.

**Voltage control**

Also related to deferral of investments and to grid support electric networks shall be operate within voltage limits defined by EN50160. Generating units and BESS shall be able to contribute to meet those requirements during normal and not normal network operation (Figure 4).

![Figure 4: Reactive power response according to voltage](image)

If actually required, the form of the contribution to voltage control shall be specified by the DSO in order to avoid voltage problems in other nodes and to avoid the uncontrolled islanding conditions.

If a local control strategy is adopted, each generator operates with local law according some parameters ($V_{1s}$, $V_{2s}$, $k_1$, $k_2$ in figure 4).

On the other hand, if a centralized strategy is adopted, each generator is under a central control (i.e DMS) to better fit the desired voltage profile. In any case, BESS may contribute to the strategy adopted as a device able to exchange reactive power.

The voltage variation in a node of the feeder can be explained with the following simplified formula:

$$\Delta V = r \Delta P + x \Delta Q$$  

(1)

where $r$ and $x$ are the resistive and the reactive parts of the line impedance respectively (considering the electrical connection from local nodes to the network point with “infinite” short circuit power).

Because of that, this strategy is much more effective in MV networks than in LV ones.

For situations where the actions for voltage control by means of reactive power were insufficient to limit the voltage on the distribution networks, a limitation active power may result effective to avoid RERs disconnection due to an over voltage protection.

For the effective control of the voltage value will be necessary implement specific requirement for each kind of line where BESS is connected. In particular:

- $P(V)$ requirement for LV lines
• Q(V) requirement for MV overhead lines
• Q(V) and P(V) requirements for MV underground lines

In order to obtain an optimized operating point for the distribution network a centralized control strategy is needed, where all regulation resources are coordinated and equipment are adjusted remotely. BESS gives to the generator another chance storing energy in the batteries without reducing RERs production.

**Voltage support**

In case of faults in the network, BESS could have the capability to provide additional reactive current in order to reduce the voltage dip. Hence, BESS should be capable of activating the dynamic reactive current support if at least one of the following conditions occurs:

- the voltage is outside of a normal voltage range;
- a sudden change in voltage.

At least the rated current of the generating unit should be injected according to Figure 5 [1].

![Figure 5: Reactive power response for voltage dips](image)

The requirements apply to voltage steps of the positive and the negative sequence component of the fundamental voltage. Voltage steps in the positive sequence result in additional reactive current in the positive sequence, voltage steps in the negative sequence result in additional reactive current of the negative sequence. BESS provide additional reactive current up to the current limitation of inverter. Once more this requirement is absolutely unnecessary for LV network because of \( r >> x \) and is not much effective on the MV because of maximum value of the current (short current) in inverter is limited to 1.2 to 1.4 of the nominal current. Anyway, consequences should have to be evaluated on distribution networks, as voltage support may have important consequences at local level, negligible ones at system level.

**MAIN ASPECTS RELATED TO THE INTEGRATION AND MANAGEMENT**

**Anti islanding**

Islanding is the electrical phenomenon in a portion of a power network disconnected from the main supply, where the local loads are entirely supplied by the local embedded generation and where the voltage and frequency levels are maintained within permissible limits around nominal values. Due to its uncontrolled nature and considering the fact that it is often originated by faults, an islanding situation poses risks to equipment, network protections efficiency, quality of supply and safety of persons either third parties or workers. The unintentional islanding occurs when, in a portion of a power network disconnected from the main supply, the embedded generation and the local load demand match closely in terms of both active and reactive power. The presence of BESS increases the probability of unintentional islanding because of the management of P(f) in over- and under-frequency.

The enlargement of the loss of mains detection settings of DGs (e.g. Annex A70 of Italian Grid Code) has driven to a greater network stability during the system transient. To avoid the presence of unintentional islanding, distribution network operators make sure that suitable anti-islanding protections are installed for each distributed generators connected to MV and LV networks.

For this reason the actual efforts of TSOs and DSOs in European regions are oriented to avoid the unintentional islanding due the presence of DERs and also BESS. The future standard EN 50549 1 / 2 and the actual Italian standards CEI 0-16 and CEI 0-21 (CEI is the Italian standardization body) specify the possibility to set a delay in the activation of response to frequency deviation and voltage support by reactive power, which permit to make less stable the island operation [4] [5] [6].

**Forecast-Management of source**

The relevant amount of DG, RER in particular, poses new challenges to the electricity grid, not only at local level but also for large penetration at system level. There is a need to increase the observability, controllability and predictability of distributed generation.

Today the error on the prediction of production from RER is one order of magnitude greater than the error of load forecasting. In addition, in the network where BESS are installed, DSOs and TSO are unaware of BESS working mode (charge or discharge cycle, charge status, etc.), so it’s clear that any forecast, relative to energy balance between
loads and sources, is worse in presence of considerable BESS. All current forecast methods have to be necessarily updated, including more additional information, both real time and predictive, coming from various sources (whether forecast, energy exchange, economical and social conjunctures, etc…). The dispatching rules are complex and articulated, and its development must take into account many factors.

In order to obtain an optimized operating point for the distribution network a centralized control strategy is needed, where all regulation resources are coordinated and equipment are adjusted remotely. This solution relies on the telecommunication infrastructure connecting the control centre and the different controls in the network (DG, on load tap changers in HV/MV substations, etc.), on a state estimation function which evaluates the real-time operating point of the network. The ancillary services to the energy transmission and distribution can be offered both during normal operation (control services and dispatching, such as frequency control, voltage regulation, delivery/absorption of reactive power and preparation of the reserve) both in emergency situations following a command imposed by the TSO and/or by the DSO (participation in the re-feeding of the electrical system, services of interruptibility of the load), and can be offered to enable both to local problems (occurring on distribution network) and to global problems (occurring on the transmission grid).

CONCLUSION
The advent of storage involves additional challenges but also the creation of new opportunities within an electrical system dominated by renewable sources. The diffusion of embedded storage have to be carefully managed through the definition of rules and technical standards to assess the different point of view of the stakeholder involved (DSO, TSO, producers). The rules will have to include the system requirements needed to ensure stability and security of the network system in order to facilitate the integration between DSO/TSO network and storage. In addition it's necessary develop the rule for implementation the services offer by storage in order to fully develop the opportunities. The paper describe some system requirements and some grid service that BESS can supply. In addition are also describe the possibility to use BESS for defer or even avoid Distribution investment in situation where the new plant would be really underutilized or in situation of slow and uncertain load growth or for practicable solution when permissions are too long or impossible to obtain.

In conclusion, if the grid services that the storage can offer are controlled and managed by DSO/TSO they will be allowing:

- to improve the management of the network of DSO/TSO
- creating a new opportunity of remuneration based on the ability to provide services effectively within the areas of not regulation of frequency and voltage

It's important that the BESS are predisposed to perform network services. The possible grid services that storage are able to offer have had a long process of definition in Italy, in which all stakeholders are involved, and eventually led to the creation national standards (CEI 0-16 and CEI 0-21).

REFERENCES