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Distributed storage for the provision of ancillary services to the main grid: project PRESTO

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Abstract

This paper presents the three-year PRESTO research project (2013-2015). PRESTO is a self-funded project developed by the Department of Energy of Politecnico di Milano in cooperation with FIAMM Storage, Elvi Energy and MCM Energy Lab (an Italian spin-off). Within the project, experimental tests and numerical simulations were performed in order to evaluate the effectiveness of an Energy Storage System (ESS) in the provision of ancillary services to the main grid. This paper focuses specifically on the experimental and numerical analyses carried out in the project to develop an innovative control law for the primary frequency regulation, able to maximize the performances of the regulating service and effectively manage the ESS state of charge.

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Keywords: Energy Storage System; Ancillary Services; Dispersed Generation; Grid Code

1. Introduction

Dispersed Generation (DG) allows to exploit Renewable Energy Sources (RES) spread over the territory and to reduce the use of fossil fuels. Nevertheless, with the growth of DG, MV and LV distribution networks require more

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and more complex (and potentially less efficient) monitoring and regulation approaches [1]. At present, the management and planning of the electrical system is more critical than in the past, leading to higher costs for system operators: adequacy costs (a certain amount of capacity of traditional power plants is necessary to guarantee meeting energy needs, managing the RES fluctuant generation), balancing costs (a high penetration of intermittent generation requires a greater flexibility to respect the power balance and the network stability criteria) and costs for the network reinforcement in order to host new DG within the electrical system. Focusing on the power balance, in the standard operation of interconnected electric networks, frequency deviations should be limited as much as possible in order to guarantee the quality of the power transmission. The frequency behavior is affected primarily by both stochastic changes of loads and RES intermittency. In addition, generation power imbalances owing to the liberalized market rules [2] greatly affect the frequency profile. Consequently, as the DG penetration increases, it becomes a technical and economic imperative to identify new resources to provide ancillary services for a secure and reliable grid operation. These services involve both the transmission and distribution system management. Within this perspective, Energy Storage Systems (ESSs) are one of the most promising technologies to enable RES to meet this challenge [3]. Generally speaking, they are suited to a variety of grid uses, such as frequency control, secondary reserve, voltage regulation, peak shaving, load shifting and energy trading [4, 5]. They can operate both as individual units or associated with RES plants. In the second option, the use of an ESS can make the ancillary services market more attractive for the owner of the RES power plant. Indeed, ESSs allow a more flexible operation of DG, without limiting the exploitation of the primary source. For these reasons, in a few countries ESSs already have the opportunity to offer ancillary services on the electricity market.

Currently, Germany and Italy are the two EU countries with the highest DG penetration; in Germany, according to the Energy Act, four different Transmission System Operators (TSOs) are responsible for the frequency control [6]. Each of the four TSOs, namely 50Hertz, Amprion, TenneT and Transnet BW, operates a separate control area in which the system balance needs to be guaranteed by the operation and coordination of different control mechanisms, with the arising cost charged to the users [7, 8, 9]. Moreover, the TSOs in Germany, the Netherlands, Switzerland and Austria recently activated a common platform to manage tenders for Primary Control Reserve (PCR) [10]. In Italy, since 2010, a huge deployment of DG occurred, leading to an important change in the technical and regulatory framework, e.g. technical prescriptions for the connection to the HV, MV [11] and LV [12] grids have been completely redefined. Currently, the main contributions to the system stability are assumed as mandatory services (primary frequency control, voltage regulation, etc.), while energy services (secondary frequency control, congestion management, etc.) are regulated in a specific ancillary services market (named MSD [13]). Recently, a new resolution (AEEGSI 231/2013/R/eel [14]) of the Italian Energy Authority activated a new mechanism for the reimbursement of the primary frequency control provision [15] on a voluntary basis [16].

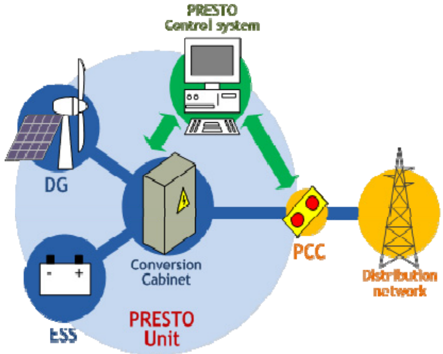
In this context, the paper describes the experimental and research actives carried out within the PRESTO project. In particular, Chapter 2 describes the project, its goal and the experimental activities carried out; while Chapter 3 focuses on the theoretical research, aimed at developing suitable control laws for the ESSs and assessing their performance through numerical simulations. Finally, conclusions are provided in Chapter 4.

2. PRESTO Project: the proposed approach & the experimental tests

The PRESTO (Primary REgulation of STOrage) apparatus was developed within a research activity collaboration among the Department of Energy of Politecnico di Milano, MCM Energy Lab, Elvi Energy with the technical support of the FIAMM Energy Storage. The project aimed to develop new regulation schemes/functions devoted to manage DG integrated with ESS in order to provide ancillary services to the main grid (Fig. 1). Actually, the PRESTO prototype, connecting to the LV system (i.e. it is a small-scale ESS), was designed to provide primary frequency control (active power regulation), primary voltage control (reactive power regulation), and energy arbitrage. This paper focuses specifically on the provision and the performance assessment of the primary frequency regulation, which is managed with respect to a standard droop control law: i.e. the real power is modulated as function of the frequency deviation from the nominal value (Fig. 2).

PRESTO apparatus was installed and tested within an Alpine Space research project (named ALPSTORE) in the Technocity area (Milan area in Italy; Fig. 3). The experimental campaign lasted for three months (May – June – July

2014), collecting data about voltage level and frequency transient in the LV distribution grid [3, 17]. It is worth underlining that the PRESTO project is related to a LV apparatus supposed to be coupled to “small” DG units (up to 100 kW according to the Italian grid code), consequently the experimental application was developed adopting

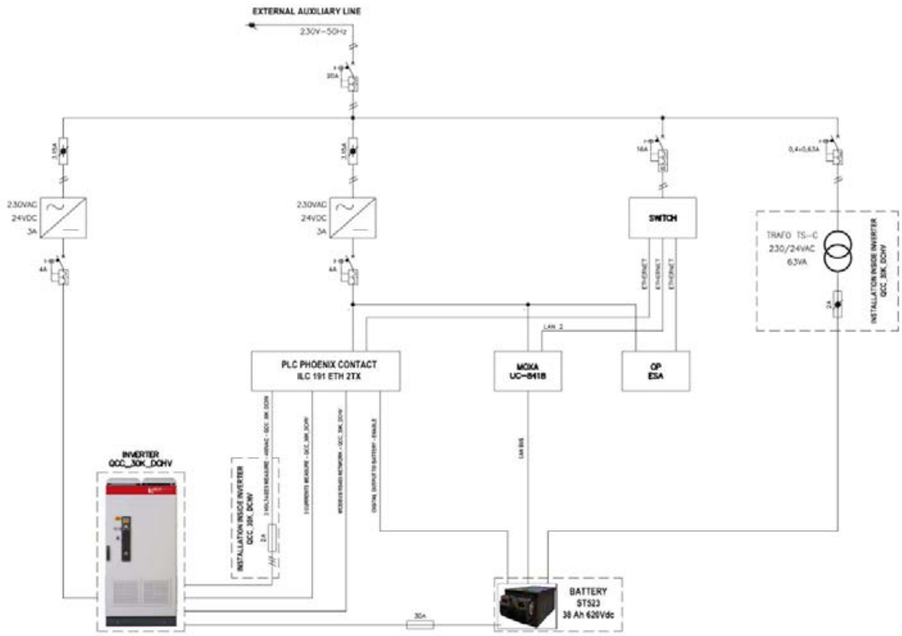


“standard” components in order to limit the economic costs of the ESS.

Fig. 1. PRESTO architecture and electrical scheme.

Fig. 1 reports the architecture and the electrical scheme of the PRESTO prototype, in which an ESS is coupled to a DG unit to provide services to the main grid. The goal is to propose a solution for the short-term scenario, consequently no communication interface was supposed with the TSO or the DSOs. In fact, RES power plants connected to the MV and LV distribution system do not allow an easy and feasible remote controllability; the installation of a proper communication system may require long-term investments and large amounts of capital. Therefore, in the project, one of the main goal regarded the exploitation of local measurements to solve a global issue.

The PRESTO prototype is based on a 30 kVA three-phase inverter (within the project a maximum power limit of 10 kVA was adopted) managed by a PLC (Phoenix Contact ILC-191-ETH-2TX). An electrochemical battery (FIAMM SONICK ST523) is integrated on the DC BUS, using sodium-nickel chloride technology, rated at 23 kWh.



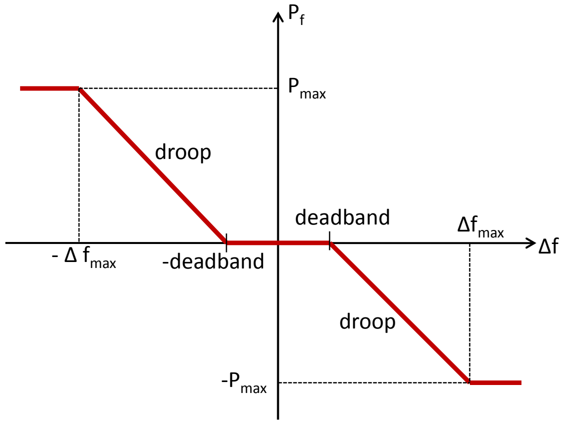


Fig. 2. Primary frequency regulation control law.

Fig. 3. PRESTO prototype in place during the experimental campaign.

In spring 2014, a three-month experimental campaign was developed, testing PRESTO unit with respect to different regulation settings. Fig. 4 reports frequency samples and power flows samples in a standard working day. Actually, data were sampled each 500 ms and, consequently, a new active power set-point was calculated. As already introduced, PRESTO unit has been realized adopting commercial components, consequently accuracy of measurements and energy efficiency are representative of a (cost-effective) LV apparatus. Fig. 5 compares the theoretical regulation curve (power injections vs frequency) with the experimental samples. Mismatches are due to energy losses, to measurement accuracy and to the dynamic performance of the PRESTO unit. Energy efficiency resulted to be compliant with the nominal value of the battery and of the adopted inverter (corresponding to literature data), similarly the measurement accuracy resulted quite good. Whilst, the dynamic response of the PRESTO unit worth a better investigation: as reported in Fig. 6, after a frequency perturbation, the experimental PLC quickly calculates a new active power set-point (less than 1 s). Within the PRESTO architecture, such a set-point is then managed by a MODBUS interface with the inverter and, in cascade, the inverter interacts (i.e. exchanges control and enabling signals) with the electrochemical battery. At the end, a settling time close to 2.6 s is recorded. As a matter of facts, these dynamic performances are relevant to small ESSs (LV apparatuses) based on “standard” components (e.g. MODBUS interface is not the best-performing interface, but a standard cost-effective solution). Within the project such performances (the static and the dynamic ones) were recorded in order to characterize the mathematical models developed for techno-economic studies.

3. Project PRESTO: numerical simulations

Over the three years of the PRESTO project, experimental activities were coupled to numerical simulations devoted to developing ESSs mathematical models and performing studies to broaden the spectrum of investigation. In particular, two main research activities were carried out. In a first step, a dynamic model of the PRESTO ESS was developed and different settings of the regulation were evaluated. The model was set comparing the dynamic response obtained by the mathematical model with the one measured in the experimental campaign. Thanks to these analyses, a better understanding (i.e. critical factors, real life performances, etc.) of the ESSs exploitation for the ancillary services provision was obtained. Actually, one of the regulations most impacting on the ESSs effectiveness resulted to be the SOC management; consequently, a second research activity covered a literature review of the SOC control procedures and, in particular, a new strategy was proposed and tested. Thanks to this new approach, ESS capacity limits could be effectively managed and, consequently, a reliable ESS contribution to the ancillary services is achieved. In the following paragraphs, these steps are presented and the results of the performed analyses are discussed.

3.1. Mathematical modeling of the PRESTO ESS

After the experimental activities, the research group developed a numerical model of the PRESTO prototype adopted in the Digsilent Power Factory package (Fig. 7) [18]. The goals of the model are to validate the data obtained by the experimental tests and to test a larger set of regulation parameters of the ESS. The model developed represents the MV distribution grid as the slack bus of the system and is conceived to represent the ESS and the RES power plant coupled to it. In particular, see Fig. 7, a PV power plant is simulated. The PV and the ESS are connected to a MV distribution network through a MV/LV transformer (INVERTER-Trafo) and a DC/AC converter (INVERTER) in a grid-following operation mode.

In the proposed configuration, the PV system, the ESS and the AC network are connected to the DC-link by means of appropriate converters, in order to match the PV and ESS voltages and to control the AC side independently. The PV system is connected to the common DC bus through a DC-DC converter (MPPT Converter) to ensure the optimal power exchange; whereas the ESS is connected using a bidirectional DC-DC converter (ESS Converter) to guarantee the charge and discharge of the storage device. In the following, the functions of each component presented in the scheme are listed. The power balance equation at the DC-Link is:

$$P_{PV} - P_{ESS} - P_{AC} = C \cdot V_{DCLink} \cdot \frac{dV_{DCLink}}{dt} \quad (1)$$

P_{PV} is the power produced by the PV system (set to the MPPT);
P_{ESS} is the power absorbed by the ESS;
P_{AC} is the power injected to the AC network by the inverter;
C is the capacitance of the DC-Link;
V_{DCLink} is the voltage measured at the DC-Link.

The P_{PV} power is assumed constant and represents an external and non-controllable value of the power balance equation. The power injected into the grid (P_{AC}) depends on the PV power (P_{PV}) and the power required for the frequency control. Actually, the power provided by the ESS (P_{ESS}) is exploited to compensate the power mismatch between the PV production and the injection to the AC side. The system is connected to the AC network through an AC-DC inverter (INVERTER) modeled as a DC-voltage controlled AC-voltage source:

$$V_{AC} = \left(P_{mr} + jP_{mi}\right) \cdot V_{DCLink} \quad (2)$$

where V_{AC} is the AC voltage phasor, V_{DCLink} is the voltage at the common DC bus and P_{mr} and P_{mi} are the pulse modulation factors on the real and imaginary axes.

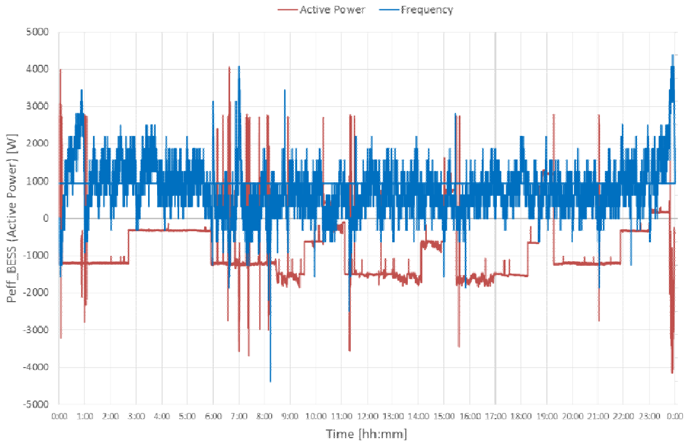


Fig. 4. Power flows of the ESS (red line) vs grid frequency samples (blue) (spring working day).

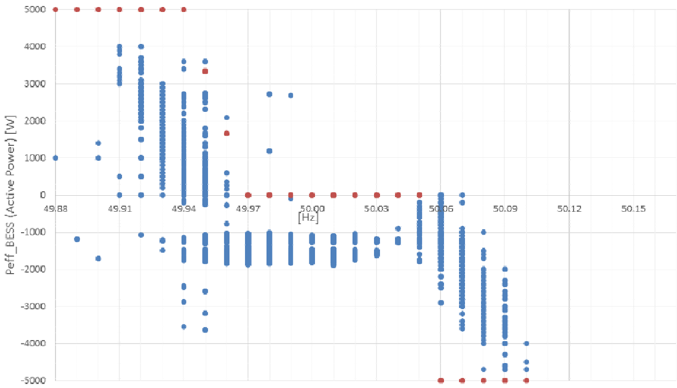


Fig. 5. Power [W] vs frequency [Hz] regulation law (theoretical - red vs experimental - blue samples).

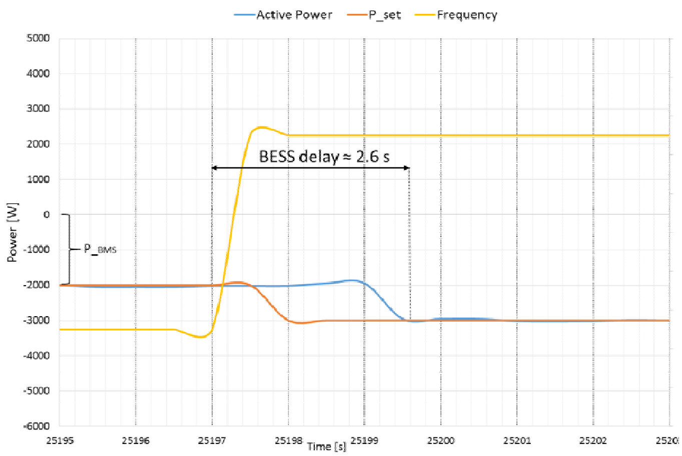


Fig. 6. Dynamic response of the PRESTO prototype (power [W] vs time [s]).

The ESS Converter is a bidirectional DC-DC buck-boost converter that controls the V_{DCLink} voltage by charging and discharging the ESS module. The DC-Link voltage V_{DCLink} is compared with the voltage reference and the error is taken into a PI regulator that outputs the reference current I_{DCLink} absorbed at the DC-Link by the converter. During the boost mode the ESS provides energy to the DC-Link, whereas in the buck mode the ESS is charged in order to compensate the power mismatch between the real power output of the INVERTER and the PV system. The model is completed with the power balance equation:

$$\begin{cases} P_{ESS} = V_{ESS} \cdot I_{ESS} = V_{DCLink} \cdot I_{DCLink} \\ \alpha = \dfrac{V_{DCLink}}{V_{ESS}} = \dfrac{I_{ESS}}{I_{DCLink}} \end{cases} \tag{3}$$

where *VESS, IESS, VDCLink, IDCLink* are the voltage and current measured at the ESS bus and at the DC-Link, and α is the duty ratio of the ESS Converter. The INVERTER injects into the network an amount of power equal to (P_{MPPT} + P_f) with P_f defined by the primary frequency control curve. Finally, the ESS is modeled through an ideal capacitance and an equivalent series resistance (kept constant over the simulations):

$$\begin{cases} V_{ESS} = V_C + R \cdot I_{ESS} = V_C + R \cdot \dfrac{P_{ESS}}{V_{ESS}} \\ \dfrac{dV_C}{dt} = \dfrac{1}{C_{ESS}} \cdot I_{ESS} = \dfrac{1}{C_{ESS}} \cdot \dfrac{P_{ESS}}{V_{ESS}} \end{cases} \tag{4}$$

where R is the resistance of the ESS model, C_{ESS} is the capacitance of the ESS model and V_C is the voltage at the terminals of the ESS capacitor. In the project, the real frequency oscillation collected in the experimental campaign was superimposed on the model (Fig. 8).

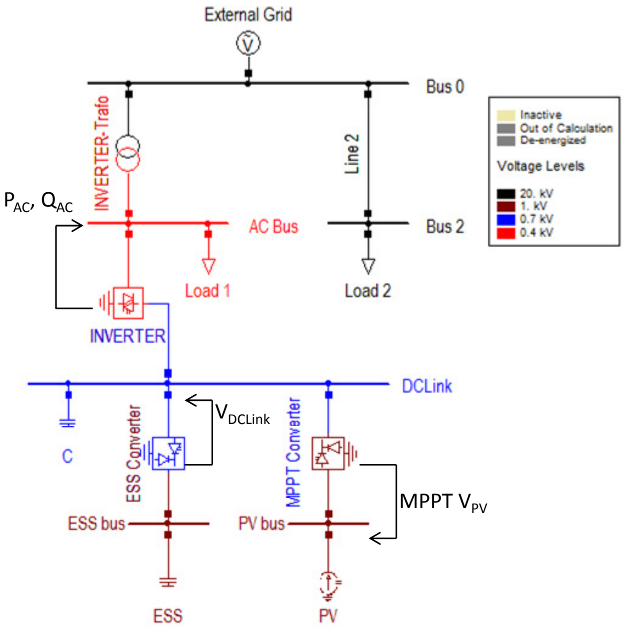


Fig. 7. Network scheme of the PV system integrated with an ESS in a DC-coupled system.

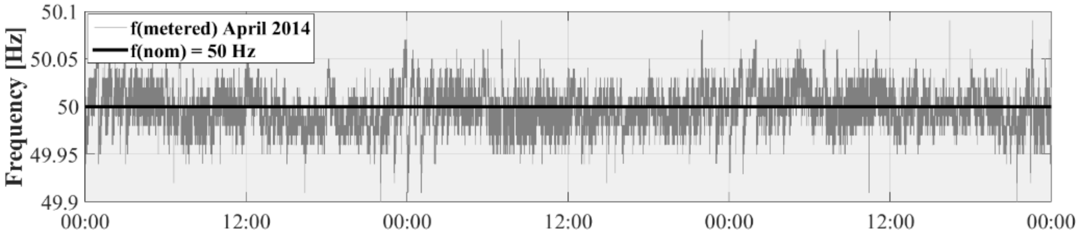


Fig. 8. Frequency trend profiles adopted in the simulations (superimposed to the model).

The output of the simulation represents the behavior of the ESS in response to the frequency regulation, i.e. a simulation of the ESS response to the frequency sample collected, for different settings of the control law. Several dynamic simulations were carried out in the research project, each one with different parameters of the frequency control strategy (droop and deadband) and of the ESS converter (Tab. 1). During the 24 h simulation, the INVERTER reads the frequency oscillations and modulates the real power on the AC side P_{AC} according to the frequency control strategy. In order to evaluate the effect of the regulation on the ESS, the following energetic indexes are computed (they represent the energetic response of the ESS to frequency oscillations):

E_{ch}, E_{dis}	the total charge - discharge energy of the ESS;
E	nominal capacity of the ESS;
E_{mch}, E_{mdis}	the energy margin during the charge / discharge phase;
h_{ch}, h_{dis}	the equivalent hours at the maximum capability P_{max} during charge / discharge;
N_{ch}, N_{dis}	the equivalent number of complete charge / discharge cycles.

In particular, with respect to the energy capacity design of the ESS, the prescription in place in the Italian grid [19] was adopted: primary frequency control is based on the power band to be provided to the grid within 30 s and to be maintained for at least 15 min.; consequently, a power vs capacity ratio [MW/MWh] of ¼ resulted. Therefore, the equivalent charge/discharge cycles of the ESS are calculated for each of the settings investigated (Tab. 2) as the ratio of the ESS charge/discharge energy vs the nominal capacity.

Index N_{ch} is exploited to compare results obtained with the different settings; this index is directly connected to the energy adopted for the frequency regulation. On the basis of the results obtained, it can be stated that the parameters deadband and droop of the curve have a significant effect on the energy modulated by the ESS.

Increasing the deadband (from Set 1 to Set 3) the number of equivalent cycles N_{ch} strongly decreases (from 5.6 to 2.8); similarly, by increasing the deadband value (from Set 1 to Set 2) N_{ch} increases to 7.5 and, vice versa, increasing the droop (from Set 1 to Set 5) the number of equivalent cycles N_{ch} strongly decreases (from 5.6 to 4.0). Moreover, the SOC restoring function also has an effect on the energy stored in the ESS: if it is disabled (from Set 1 to Set 8) the number of equivalent cycles N_{ch} decreases (from 5.6 to 3.1) and the ESS is less stressed in terms of charge/discharge cycles; anyway, the SOC is not under control and the energy availability for the primary frequency regulation can be compromised.

Nowadays, commercial storage solutions can manage up to 5000 charge and discharge cycles (full charge/discharge cycles). Adopting this parameter, a qualitative forecast of the ESS lifetime in a frequency control regulation was calculated. The setting values play an important role in the amount of energy involved in the ESS: the system lifetime can be even lower if the ESS is more involved in the service, on the contrary it could be higher paying with lower regulation performances.

Actually, the frequency control regulation results to have an important effect on the storage lifetime and, practically speaking, an oversizing of the ESSs capacity (oversized with respect to the grid code frequency control requirements) would be required in commercial uses to guarantee an adequate ESS lifetime.

Setting	droop Df/DP [%]	deadband [Hz]	Δf_{max} [Hz]	V_{ESSmin} [p.u.]	V_{ESSmax} [p.u.]	DP_{max} [MW]
Set 1	2	0.02	0.05	0.8944	0.4472	0.0025
Set 2	2	0.01	0.04	0.8944	0.4472	0.0025
Set 3	2	0.04	0.07	0.8944	0.4472	0.0025
Set 4	1	0.02	0.035	0.8944	0.4472	0.0025
Set 5	4	0.02	0.08	0.8944	0.4472	0.0025
Set 6	2	0.02	0.05	0.8944	0.4472	0.0025
Set 7	2	0.02	0.05	0.8944	0.4472	0.0025
Set 8	2	0.02	0.05	1	0	0
Set 9	2	0.02	0.05	0.8944	0.4472	0.00025
Set 10	2	0.02	0.05	0.8944	0.4472	0.00125

Tab. 1. ESS simulation settings.

Setting	E_{ch} [kWh]	E_{dis} [kWh]	E [kWh]	E_{mch} [kWh]	E_{mdis} [kWh]	h_{ch} [h]	h_{dis} [h]	N_{ch} [cycle]	N_{dis} [cycle]	ESS lifetime [years]
Set 1	21.17	-20.81	0.36	158.83	159.19	2.822	2.774	5.645	5.549	2.4
Set 2	28.06	-26.74	1.32	151.94	153.26	3.742	3.566	7.484	7.132	1.9
Set 3	10.57	-11.46	-0.89	169.43	168.54	1.409	1.528	2.818	3.056	4.7
Set 4	25.17	-24.49	0.68	154.83	155.51	3.355	3.265	6.711	6.530	2.1
Set 5	14.98	-14.53	0.46	165.02	165.48	1.997	1.937	3.995	3.873	3.5
Set 6	21.03	-20.61	0.42	158.97	159.39	2.804	2.748	5.609	5.497	2.5
Set 7	21.06	-20.69	0.37	158.94	159.31	2.808	2.759	5.616	5.518	2.5
Set 8	11.66	-11.99	-0.33	168.34	168.01	1.554	1.599	3.109	3.198	4.3
Set 9	13.26	-12.52	0.74	166.74	167.48	1.767	1.669	3.535	3.338	4
Set 10	17.62	-16.71	0.91	162.38	163.29	2.349	2.227	4.698	4.455	3

Tab. 2. Energetic indexes computed from the ESS for each simulation setting.

3.2. Focus on the ESS SOC restoring function

One of the key factors in the exploitation of ESSs for the provision of ancillary services is the management of the ESS SOC, i.e. the management of the energy stored in order to avoid saturation of the regulation due to bounds of maximum and minimum State of Charge. If saturation occurs, ESS will not provide support to the grid for the time required to restore the SOC within the operational bandwidth. In the literature, several approaches are proposed in order to manage the ESS SOC: losses within the ESS cause the discharge of the battery, requiring to recharge the ESS through the SOC restoring function. Consequently, in [20] a predefined number of charging periods are proposed to schedule the SOC restoring function. However, these approaches could be effective only if the ESS power flows could be predicted in advance. Generally, the most used strategy is based on the adoption of a suitable deadband, restoring the SOC only when the grid frequency is within the deadband [21, 22]. More advanced approaches are based on a cooperation with the TSO in order to change the power plants schedule, adding a time-dependent offset to the frequency control signal in order to promote charging and discharging processes that keep the SOC within acceptable levels. The offset signal is normally very slow in order to not interfere with the fast response for the ancillary services provision [23, 24].

Within the PRESTO research project, a new strategy was evaluated numerically: primary frequency regulation is a regulation based on local measures (frequency measure at the Point of Common Coupling – PCC) and the collection of the regulating contribution from all the generating units is obtained without a telecommunications infrastructure (the frequency itself coordinates all the units). The approach proposed is designed according to such assumptions, with the purpose to guarantee adequate resources for the grid in any moment but, at the same time, to allow an effective management of the SOC for every ESS. A non-conventional droop-control law with variable-droop mode of operation was adopted; indeed, moving from a fixed-droop approach to a variable-droop approach. Specifically, the proposed variable-droop mode exploits at maximum the fast response capability of the ESS when SOC is in good condition (thus helping effectively the electric power system stability), while it works at minimum when SOC moves towards saturation (thus protecting the owner's interests). In this approach, ESS droop control is regulated between the maximum and minimum bound: the first correlated to the performances of the ESS (maximum charge/discharge power), the latter compliant with the minimum performance (contribution to the frequency control) defined in the grid code prescription. Reverse control laws are applied when the ESS is close to the SOC upper bound (ESS almost fully charged). In the following, the mathematical formulation of the control law developed is reported:

$$\begin{array}{l} if\ \left(SOC - SOC_{ref}\right) > \pm threshold_1\ \&\ \left(f - f_{ref}\right) > \pm threshold_2 \\ \quad DROOP = DROOP\_standard \pm \left(\frac{DROOP_{max} - DROOP_{min}}{f_{max} - f_{min}}\right)\left(f - f_{ref}\right) \\ else\ DROOP = \frac{DROOP_{max} - DROOP_{min}}{2} \end{array} \tag{5}$$

where:

$f_{ref} = 50\ [Hz]$; $SOC_{ref} = 50\%$; $threshold_1 = 10\%$; $threshold_2 0.01[Hz]$;

ESS is modeled as an ideal capacitor and, finally, charge/discharge losses are supposed to be proportional to the power flows (i.e. it is adopted the same ESS model introduced in Chapter 3.1). Within the project, a 24 h frequency profile (gathered during the experimental test; Fig. 5) was superimposed to an ideal capacity model plus a loss factor (supposed to model all the losses due to the ESS, to the power electronic converters, etc., up to the PCC), regulating the power flows with the proposed variable-droop law. In particular, the droop coefficient was designed to range from 0.12 to 0.3% (upper and lower bound compliant with the Italian grid code for traditional power plants [19]). In the numerical tests, the ESS capacity was set according to a power vs energy ratio of 1 (i.e. assuming bounds greater than the grid code prescriptions). In the previous chapter, it was demonstrated how the ESS (supposed to be fully dedicated to the frequency control service) has to be oversized in order to guarantee an adequate lifetime. The power vs capacity ratio adopted is compliant, whatever setting is adopted, to guarantee a lifetime greater than 10 years and, moreover, this ratio is completely compliant with the technical limits of the commercial apparatuses today on the shelf (i.e. a very high performing storage technology is not required, which in the study results could be applied to a large spread of technologies). Several tests were performed, changing the regulation band (i.e. the maximum power provided for the frequency control with respect to the nominal power of the ESS) and the losses factor.

The goal of the simulation is to evaluate the variable droop control law effectiveness in managing the SOC without requiring the ESS to have a Loss of Regulation (LoR) due to the activation of a classic SOC restoring function (i.e. to interrupt the frequency control contribution in order to restore the SOC; see Tab. 3). The SOC upper bound was set to 100% while the SOC lower bound was limited to 40% (these conservative assumptions, once again, are supposed to generalize the results for several storage technologies).

Tab. 3 and Tab. 4 depict the results obtained by the parametric simulations performed: respectively, the LoR coefficient (as percentage of the whole simulation time) and the minimum SOC (percentage of the ESS energy capacity) evaluated over the simulations. In particular, the table compares the results obtained checking different round trip efficiencies and ESS power limits (regulation band, measured in p.u. with respect to the ESS nominal power). The results clearly demonstrate the performance of the proposed approach, effective in avoiding any LoR up to a charge/discharge efficiency of 95% each. Thanks to this approach, the capacity bound of the ESS does not limit the ESS contribution to the primary frequency control, solving one of the critical problems affecting this specific ESS application in real life uses.

		Regulation-band [p.u.]			FIX droop control (0.3%)
		0.1	**0.25**	**0.5**	**0.25**
Charge/Discharge Efficiencies [%]	**97.5 / 97.5**	0.00	0.00	0.00	0.76
	95 / 95	0.15	0.22	0.00	2.46
	92.5 / 92.5	1.47	1.16	0.21	4.15

Tab. 3. Results of the sensitivity analysis for different ESS regulation-bands: Loss of Regulation (LoR) [%].

		Regulation-band [p.u.]			FIX droop control (0.3%)
		0.1	**0.25**	**0.5**	**0.25**
Charge/Discharge Efficiencies [%]	**97.5 / 97.5**	41.49	41.29	42.72	40.00
	95 / 95	40.00	40.00	41.18	40.00
	92.5 / 92.5	40.00	40.00	40.00	40.00

Tab. 4. Results of the sensitivity analysis for different ESS regulation-bands: minimum SOC [%].

4. Conclusions

The paper presented the three-year PRESTO research project (2013-2015), a self-funded project developed by the Department of Energy of Politecnico di Milano in cooperation with FIAMM Energy Storage, Elvi Energy and MCM Energy Lab (an Italian spin-off). Within the project, experimental tests and numerical simulations were performed in order to evaluate the effectiveness of an ESS in the provision of ancillary services to the main grid. In particular, the PRESTO prototype was designed to be coupled to DG power plants, i.e. in order to integrate RES generation in the grid, increase the regulation resources and limit the environmental impact caused by centralized (large) storage systems. The PRESTO project assessed the best settings for the ESS control law with respect to their effects on the ESS itself, suitably taking into account also the coordination of the ESS regulation with the control actions performed by traditional power plants. In particular, the experimental campaign allowed to check the viability of the proposed regulations with respect to low cost commercial apparatuses, and to collect “real-life” parameters for tuning the mathematical models. In a second step, numerical simulations were adopted to test a wide set of control laws, in order to quantify the effect of these regulations on the ESS efficiency and lifetime. The research activity focused on the management of the ESS SOC and a new approach was proposed and validated.

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