DIPARTIMENTO DI INGEGNERIA
CORSO DI DOTTORATO IN INGEGNERIA INDUSTRIALE E DELL'INFORMAZIONE -
PHD COURSE IN INDUSTRIAL AND INFORMATION ENGINEERING -
34TH CYCLE

Title of the research activity:	Innovative and hybrid energy storage solutions coupled to RES plants
State of the Art:	In the European scenario, production from renewable energy sources (RES) is strongly encouraged by Community policies to achieve EU2050 decarbonisation objectives. However, the penetration of renewable energy in the electricity mix causes problems relative to grid congestion and perturbation due to its high variability over time (i.e. fluctuating and intermittent production profiles, particulatly for solar and wind power plants). For these reasons, RES are defined as non-programmable energy sources that negatively affect the stability and safety of the electric grid [1] and also performance of thermal plants. Combined cycles fed by natural gas are often operated as back-up of RES plants and subjected to a cycle operation which leads to a significant deterioration in terms of efficiency and wear [2-6]. To mitigate grid instability, RES plants are often curtailed during low consumption periods, with negative effect on both revenues and DSCR. In some European local areas, the need of RES curtailment is also greater due to infrastructure critical issues of specific grid districts interested by large RES installations. Synchronization of network reserves and ESS integration in the electric grid can be seen as two effective and complementary solutions to overcome the above-mentioned RES technical limits. This is consistent with the objectives of the IEC T120 work program [7], where ESSs are identified as a solution to efficiently deliver sustainable, economic and secure electricity supplies, allowing a better RES exploitation and penetration [8-10]. Moreover, ESSs, coupled to RES plant, deserve a relevant interest with reference to micro-grids in remote and non or low-interconnected areas, including also the case of not developed countries. Anyway installed energy storage capacity is currently very limited in the European and worlwide scenarios. The challenge for energy storage penetration is technological and mainly economic. Regarding technological issues, the crucial key for their penetration is the improvement of ESS performance in terms of availability, durability, efficiency, energy density, response time and a contextual cost reduction with respect to current state of the art. This goal necessarily must be achieved through the development of enhanced technologies and also their implementation in hybrid storage systems. Hybridization allows multi-operation modes of the ESS, merging the positive features of base-technologies and extending their application ranges.
Short description and objectives of the research activity:	The reserach activity in this field is aimed to the development of both innovative storage technologies and hybrid configurations, as well as to their application. Concerning enhanced technologies the research activity, performed through both experimental and simulation activities, is mainly focused on innovative flow batteries considering their advantages for large-scale stationary installations as the independent scaling of power and capacity, high efficiency and cycling (long lifespan) and security [11]. Aiming to provide a general view of the possible ambit of activity, also solid oxide cells for reverse operation (electrolizer/fuel cell) rSOCs are object of study, exploring new and optimized operating conditions on the base of previous work of the research group [12-14]. Concerning hybrid systems, our reserch group already investigated flywheel hybridization with other technologies characterized by higher energy capacity (as rSOC and batteries [16]), extending its application range. At the same time, hybridization provides, mainly thanks to flywheel fast response, beneficial effects towards the other base technologies. If batteries are considered, it was already highlighted by our research the potential enhancement of their duration due to the flywheel peak shaving function [15], as well as a significant reduction of fluctuations toward the grid in case of grid-connected systems [16]. The design of these hybrid systems is innovative particularly in the small-size. The research activity will be further focused in this direction to optimize and design hybrid systems customized for specific applications. Also the integration of enhanced and hybrid ESSs in complex systems will be investigated in view of the Multi-Energy systems application, whereby multiple energy sectors (e.g. energy, transport)

	are optimally integrated to increase flexibility, allowing a smart integration of renewable sources in the energy system.
Bibliography:	[1] Moseley, P. T.; Garche, J. Electrochemical Energy Storage for Renewable Sources and Grid Balancing; 2014; ISBN 9780444626103. [2] **Barelli, L.**; Desideri, U.; Ottaviano, A. Challenges in load balance due to renewable energy sources penetration: The possible role of energy storage technologies relative to the Italian case. Energy 2015, 93, doi:10.1016/j.energy.2015.09.057. [3] Keatley, P.; Shibli, A.; Hewitt, N. J. Estimating power plant start costs in cyclic operation. Appl. Energy 2013, 111, 550–557, doi:10.1016/j.apenergy.2013.05.033. [4] Van Den Bergh, K.; Delarue, E. Cycling of conventional power plants: Technical limits and actual costs. Energy Convers. Manag. 2015, 97, 70–77, doi:10.1016/j.enconman.2015.03.026. [5] Perez-Arriaga, I. J.; Batlle, C. Impacts of Intermittent Renewables on Electricity Generation System Operation. Econ. Energy Environ. Policy 2012, 1, 3–18, doi:10.5547/2160-5890.1.2.1. [6] Eser, P.; Singh, A.; Chokani, N.; Abhari, R. S. Effect of increased renewables generation on operation of thermal power plants. Appl. Energy 2016, 164, 723–732, doi:10.1016/j.apenergy.2015.12.017. [7] IEC T120 Available online: http://www.iec.ch/dyn/www/f?p=103:7:11494349307735::::FSP_ORG_ID,FSP_LANG_ID:9463,25 (accessed on Jan 31, 2018). [8] Kaldellis, J. K.; Zafirakis, D. Optimum energy storage techniques for the improvement of renewable energy sources-based electricity generation economic efficiency. Energy 2007, 32, 2295–2305, doi:10.1016/j.energy.2007.07.009. [9] Evans, A.; Strezov, V.; Evans, T. J. Assessment of utility energy storage options for increased renewable energy penetration. Renew. Sustain. Energy Rev. 2012, 16, 4141–4147, doi:10.1016/j.rser.2012.03.048. [10] **Barelli, L.;** Bidini, G.; Bonucci, F. A micro-grid operation analysis for cost-effective battery energy storage and RES plants integration. Energy 2016, 113, 831–844, doi:10.1016/j.energy.2016.07.117. [11] **Barelli, L**. et al. Redox flow battery instead of rSOC for resilient energy systems in off-grid remote areas or in non- or low interconnected islands: why not?, Proceedings of the EFC2017 European Fuel Cell Technology & Applications Conference - Piero Lunghi Conference, December 12-15, 2017, Naples, Italy [12] **Barelli, L.**; Bidini, G.; Cinti, G.; Ottaviano, A. Study of SOFC-SOE transition on a RSOFC stack. International Journal of Hydrogen Energy, 42/41 (2017) 26037-26047 10.1016/j.ijhydene.2017.08.159 [13] **Barelli, L.**; Bidini, G.; Cinti, G. Air flow management in SOE operation: performance analysis. ChemEngineering 1/2 (2017) 13; doi:10.3390/chemengineering1020013 [14] **Barelli, L.**; Bidini, G.; Cinti, G. Air variation in SOE: stack experimental study. International Journal of Hydrogen Energy, 43/26 (2018) 11655-11662; doi:10.1016/j.ijhydene.2018.01.070 [15] **Barelli, L.** et al. Flywheel hybridization to improve battery life in energy storage systems coupled to RES plants. Energy, Under review [16] **Barelli, L.** et al. Dynamic analysis of a hybrid energy storage system (H-ESS) coupled to a PV plant, Energies 2018, 11, 396; doi:10.3390/en11020396 [17] **Barelli, L.**; Bidini, G.; Ottaviano, A. Hydromethane generation through SOE electrolyser: advantages of H_2O-CO_2 co-electrolysis. Energy, ELSEVIER, 90 (2015) 1180-1191, DOI 10.1016/j.energy.2015.06.052
Scientific coordinator (s)	Prof.ssa Linda Barelli
Contact (s)	linda.barelli@unipg.it Phone:+39 0755853740