

**DIPARTIMENTO DI INGEGNERIA  
CORSO DI DOTTORATO IN INGEGNERIA INDUSTRIALE E  
DELL'INFORMAZIONE -  
PHD COURSE IN INDUSTRIAL AND INFORMATION ENGINEERING -  
35TH CYCLE**

|                                 |  |
|---------------------------------|--|
| Title of the research activity: | Innovative and hybrid energy storage solutions coupled to RES plants with low or mitigated safety issues   |
| State of the Art:               | <p>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, particularly for solar and wind power plants).[1]. 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 [2], where ESSs are identified as a solution to efficiently deliver sustainable, economic and secure electricity supplies, allowing a better RES exploitation and penetration [3-5]. 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 worldwide 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. Moreover, also safety issues have to be answered.</p> <p>As well-known lithium-ion batteries technology is the most limited by safety issues and fire and explosion incidents history shows numerous events. Thermal runaway phenomenon is originated by an internal short circuit leading to fast heat release, temperature increase, explosion, fire and emission of hazardous substances. Battery Management Systems absolve the function of active protection but residual risk must be taken into account in life cycle and plant feasibility analysis. System vulnerability is intrinsic, because of a small safety window in T-V diagram with operational limits of <math>-10 \div 90</math> °C and <math>2.3 \div 4.1</math> V.</p> <p>Sodium sulfur batteries exhibit still risks, even if safety measures like internal fuses and anti-fire boards are implemented. In any case sodium burns in contact with air and moisture, which is the most important issue to take into account particularly to avoid external causes of incident like natural calamities. Hazardous substances are contained in the batteries and may be released in case of fire.</p> <p>Also power to gas systems, based on water electrolysis, exhibit flammable gas connected risks. A specific task is hydrogen material compatibility. Dedicated metal alloys can be used as hydrogen permeation barriers, which adoption must be evaluated to avoid metal embrittlement in piping and the consequent risk of fracture and leak. Polyphenylenesulphide liners can be used in high pressure pipelines, high density polyethylene in pressure vessels. Equipment such as pressure regulators in decompression stations is based on elastomeric rubber membranes, which materials are often subject to hydrogen permeation, leading to the risk of pressure increase in the downstream systems. Hydrogen permeation is a phenomenon that can affect manometers and pressure transmitters, with consequences such as signal loss and measurement</p> |

|  |  |
|--|--|
|  | <p>distortions. Countermeasures can be taken using dedicated products and adopting accurate equipment controls planning.</p> <p>For what indicated above, the development of enhanced energy storage technologies and also their implementation in hybrid storage systems is strongly needed with attention to safety issues at both components and system levels.</p>   |
| <p><b>Short description and objectives of the research activity:</b></p> | <p>The research 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 [6]. Vanadium redox flow batteries is a promising technology also for safety issues. Vanadium electrolyte is an aqueous solution, not inflammable, with no risk of ignition, explosion and thermal runaway thanks to electrolyte flowing. Solutions toxicity is lower than lead-acid batteries and risk of corrosion leak can be restrained by double containers. Aiming to provide a general view of the possible ambit of activity, also solid oxide cells for reverse operation (electrolizer/fuel cell) rSOCs and solid oxide electrolyzers for power to gas applications are object of study, exploring new and optimized operating conditions on the base of previous work of the research group [7-9] and focusing at system level on safety aspects concerning hydrogen.</p> <p>Concerning hybrid systems, our research group already investigated flywheel hybridization with other technologies characterized by higher energy capacity (as rSOC and batteries [11, 12]), 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 [10], as well as a significant reduction of fluctuations toward the grid in case of grid-connected systems [11]. 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.</p> |
| <p><b>Bibliography:</b></p>  | <p>[1] Moseley, P. T.; Garche, J. <i>Electrochemical Energy Storage for Renewable Sources and Grid Balancing</i>; 2014; ISBN 9780444626103.</p> <p>[2] IEC T120 Available online:<br/> <a href="http://www.iec.ch/dyn/www/f?p=103:7:11494349307735:::FSP_ORG_ID,FSP_LANG_ID:9463,25">http://www.iec.ch/dyn/www/f?p=103:7:11494349307735:::FSP_ORG_ID,FSP_LANG_ID:9463,25</a> (accessed on Jan 31, 2018).</p> <p>[3] Kaldellis, J. K.; Zafirakis, D. Optimum energy storage techniques for the improvement of renewable energy sources-based electricity generation economic efficiency. <i>Energy</i> 2007, 32, 2295–2305, doi:10.1016/j.energy.2007.07.009.</p> <p>[4] Evans, A.; Strezov, V.; Evans, T. J. Assessment of utility energy storage options for increased renewable energy penetration. <i>Renew. Sustain. Energy Rev.</i> 2012, 16, 4141–4147, doi:10.1016/j.rser.2012.03.048.</p> <p>[5] Barelli, L.; Bidini, G.; Bonucci, F. A micro-grid operation analysis for cost-effective battery energy storage and RES plants integration. <i>Energy</i> 2016, 113, 831–844, doi:10.1016/j.energy.2016.07.117.</p>  |

|                            |  |
|----------------------------|--|
|                            | <p>[6] 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 &amp; Applications Conference - Piero Lunghi Conference, December 12-15, 2017, Naples, Italy</p> <p>[7] 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</p> <p>[8] Barelli, L.; Bidini, G.; Cinti, G. Air flow management in SOE operation: performance analysis. ChemEngineering 1/2 (2017) 13; doi:10.3390/chemengineering1020013</p> <p>[9] 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</p> <p>[10] Barelli, L. et al. Flywheel hybridization to improve battery life in energy storage systems coupled to RES plants. Energy, Under review</p> <p>[11] 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</p> <p>[12] A. Baldinelli, L. Barelli, G. Bidini, Progress in renewable power exploitation: reversible Solid Oxide Cells-flywheel hybrid storage systems to enhance flexibility in micro-grids management, Journal of Energy Storage 23 (2019) 202-219</p> |
| Scientific coordinator (s) | Prof.ssa Linda Barelli   |
| Contact (s)                | <a href="mailto:linda.barelli@unipg.it">linda.barelli@unipg.it</a><br>Phone: +39 0755853740  |