DIPARTIMENTO DI INGEGNERIA
CORSO DI DOTTORATO IN INGEGNERIA INDUSTRIALE E DELL'INFORMAZIONE - PHD COURSE IN INDUSTRIAL AND INFORMATION ENGINEERING - 37TH CYCLE

Title of the research activity:	Innovative and hybrid energy storage solutions coupled to RES plants with low or mitigated safety issues, with attention to raw materials exploitation, cyrcular economy, safety and social impact aspects
State of the Art:	In the European scenario, production from renewable energy sources (RES) is strongly encouraged by Community policies to achieve the full decarbonisation target at 2050. 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).[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 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. Moreover, also safety issues have to answered. 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 -10 ÷ 90 °C and 2.3 ÷ 4.1 V. 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. 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

	distortions. Countermeasures can be taken using dedicated products and adopting accurate equipment controls planning. 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 the use of sustainable, available and cheap materials and to safety issues at both components and system levels.
Short description and objectives of the research activity:	The activity should address one or more topics detailed in the following to provide the description of the research activity framework on energy storage technologies (for both stationary and transportation applications) development and integration. 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 [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. Also air-flow battery technology and Na/seawater battery are of interest as innovative and promising technologies. 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. Also molten carbonate technology is of interest for the innovative application as electrolyzer or reversible operation. 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 (stationary, transport, …) and assess their environomic impact. 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. Finally also social aspects related to energy storage technologies development with attention to the produced social impact, taking into consideration also the social perception towards innovative devices and systems, can be object of the research acitvity.
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