Question 1.1.3 *Have others identified ways to integrate power electronic control or fast restoration, to improve resilience?*

The role of power electronics in power systems (PS) is increasingly important, notably due to the penetration of renewable generation such wind and PV, which is typically interfaced with the PS via power converters. Also the expansion of HVDC transmission in many parts of the world contributes to bringing power electronics in the spotlight of power system operation. This is also in line with EU target of the massive development of offshore wind farms (WFs) with up to 300 GW to be installed by 2050.
Power electronics can play a significant role in enhancing PS resilience, which is defined by CIGRE WG C4.47 as « the ability to limit the extent, severity and duration of system degradation following an extreme event ».
In fact, the control flexibility assured by power electronics, together with a suitable tuning of protection schemes, allows to define fault-tolerant control schemes for the converters, so that they can survive transient large deviations of the operating quantities (such as voltage and frequency) from nominal values – as during multiple contingencies due to extreme events - without causing the disconnection of the generation.
Depending on how they are tuned, control systems are classified as Passive Fault Tolerant Control System (PFTCS) and Active Fault Tolerant Control System (AFTCS). In the former case, the control system is designed starting from a limited set of contingencies established a priori. In the latter case, the control law is adjusted to face also unexpected faults: this modality is promising in case of resilience applications, where multiple and out-of-design contingencies are considered.
Fault tolerant control is particularly important in different contexts where power electronics is adopted, e.g. for an effective management of microgrids as reported in [1]. Another important application consists in the HVDC grids which are being developed to integrate large amounts of offshore wind power into the bulk AC power system. These (also multi-terminal) HVDC grids can connect asynchronous AC grids, offshore wind farms to the bulk AC system, and synchronous systems (embedded HVDC), allowing to transfer large power flows over very long distances. Of course, the introduction of such large DC grids adds new problems for the reliability and resilience of the overall AC/DC systems (for example, faults on DC cables, the potential loss of large power injections).
However, HVDC technology has a potential not only to reduce the risk coming from HVDC grids themselves but also to improve the overall reliability and resilience of the overall system.

To unveil this potential, many several projects (e.g. TWENTIES, BEST PATHS, PROMOTION, MIGRATE) have been performed in the last decade, to study the behaviour of hybrid AC/HVDC grids (and of their control and protection schemes) in case of both DC side and AC side faults and during the restoration process: in particular, the adoption of the VSC technology which allows a decoupled control of two variables provides many opportunities also to face resilience issues. For example, the application of an AC voltage/frequency control on the grid side VSC of a DC grid (DCG) makes the DCG a black start source for the bulk AC system. In Demo 3 of Best Paths project [2], RSE modelled advanced control and protection schemes for a «VSC-based version» of the tri-terminal SACOI DC link between Sardinia, Corsica and the continent and it simulated both its response to faults and the black start of Sardinian system exploiting the VSC of the HVDC link. Two different controls were tested for restoration studies: (1) in the former the VSC is used as a black-start resource, providing active and reactive power to carry out the restoration process. This scenario implies that the continental grid is in operation. (2) In the latter, the VSC is used as a static compensator (STATCOM) for the AC voltage support of a restoration path, within a conventional restoration path. In this scenario, the status of the mainland grid is not relevant. The VSC use as a black start source has several benefits (early pick up of ballast loads already during the ramping phase of thermal unit, the possibility of using much smaller amount of ballast loads thanks to the power inversion capability of VSCs).
Moreover, the VSCs help the DCG survive severe disturbances on the AC systems (such as multiple contingencies triggered by extreme events) thanks to its FRT (Fault Ride Through) capability established by ENTSO-e codes [3], enhancing the resilience of overall AC/DC system.
Specific resilience oriented control schemes can be envisaged: for example, in TWENTIES project [4], RSE proposed a risk based control of the injections of a MTDC grid for the integration of offshore wind power: this control exploits the redispatch of both dispatchable generators and grid side VSC injections of the DCG to reduce the risk of branch overloads in case of severe contingencies on AC grid system [5].

RSE is also partner in a recently approved EU project, called HVDC WISE, which intends to investigate more in depth the benefits of DC grids with a specific focus on the reliability and resilience of the integrated AC/DC system.

References

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[3] EU Commission, « Commission regulation (EU) 2016/1447 of 26 August 2016 establishing a network code on requirements for grid connection of high voltage direct current systems and direct current-connected power park modules≫, 2016.

[4] TWENTIES Consortium, « Transmission system operation with a large penetration of wind and other renewable electricity sources in electricity networks using innovative tools and integrated energy solutions (TWENTIES) », Final report, June 2013, p.1-24.

[5] E. Ciapessoni, D. Cirio, A. Pitto, S. Massucco, «A Probabilistic Risk Assessment and Control Methodology for HVAC Electrical Grids Connected to Multiterminal HVDC Networks », *Proc. of IFAC Conference*, Milan, 2011, pp. 1727-1732.