Question 1.1.2 *Have others identified ways to integrate grid forming or smart load shedding / non-firm connection capacity to improve resilience?*

Resilience enhancement is a major target for system operators, due to climate changes which provoke an increasing of the frequency and severity of extreme events. The reduction of the energy not supplied to customers in case of severe weather events is also required by some national energy regulators, e.g. ARERA in Italy. To achieve this target, the Italian regulator itself in [1] indicates that resilience can be improved not only via the hardening of grid infrastructure (i.e. reducing infrastructure vulnerability to threats) but also via a more efficient and effective recovery phase (i.e. reducing the amount of energy not supplied to customers). In general, resilience enhancement can be obtained by a suitable mix of passive measures (aimed at hardening the infrastructure) and of active measures (operational measures aimed at reducing the impact of a disturbance in terms of lack of energy delivered to customers, and at speeding up the recovery to a normal state). Some operational measures are applied before, or to prevent, the occurrence of a contingency (preventive measures) when there is a high probability of a severe weather condition in operational planning horizon, while other operational measures are deployed only after the occurrence of the contingency (corrective measures).

Monitoring may also play an important role, namely, innovative technological solutions aimed at anticipating critical weather situations, to enable the evaluation and adoption of possible preventive and real-time solutions aimed at reducing recovery time. Terna, the Italian TSO, uses drones, helicopters with LidaR (Laser Imaging Detection and Ranging) and a network of sensors installed on power grid (an outcome of the IoT4theG "IoT for the Grid" project) to support the infrastructure observability and decision support systems for real time operation like WOLF (Wet snow Overload aLert and Forecasting). The latter is a forecast and alert system for «wet-snow» mechanical overload of overhead lines, that is able to foresee the overload and the minimum necessary current for an "anti-icing" action. In the context of the National Program for Electric System Research, RSE has also developed an advanced risk based resilience assessment and enhancement tool, called RELIEF (ResiLIEnce measures For the grid) [2], which allows to anticipate critical grid situations, by combining the short term forecasts of forthcoming threats with the vulnerability models of the components, thus identifying the components with higher failure probabilities (henceforth "critical components") and the set of multiple contingencies which involve critical components and which most contribute to the overall risk of load disruption. The impact of each contingency, expressed in terms of lost load or energy not served, is quantified considering also potential cascading outages, by running a quasi-static cascading outage simulator. The tool also allows to model both hardening and operational countermeasures, thus quantifying the technical benefits of such measures as the difference of the load disruption risk before and after the measure deployment.

The possibility to split the grid into islands to stop cascading outages, the application of smart load shedding schemes and the adoption of flexible points of power delivery/absorption (such as DSM - Demand Side Management) represent examples of advanced actions which can improve power system resilience to threats. Another example is the redispatching of dispatchable generators to assure minimum anti-icing currents on overhead lines expected to be exposed by the formation of wet snow sleeves [3].

In the international research context, some schemes applying such measures have been proposed and applied to test systems [3][4]: for example, defensive islanding is used as smart operational measure in [4]. However, a relatively low frequency of occurrence of extreme events suggests the application of operational measures, because it may not justify high capital costs for hardening solutions; on the contrary, high frequencies of extreme events can suggest the deployment of passive measures. Thus, a major objective of the current research is to help operators identify the most convenient and effective portfolio of resilience boosting measures, including operational ones.

To this purpose, in the context of the national research context RSE has proposed an optimization via simulation (OvS) framework to identify the optimal mix of active and passive measures, considering a probabilistic model for the climate evolution over a multi-year time horizon, and the actual cascading outages the system may be subject to, in case of multiple contingencies provoked by adverse weather conditions. Currently, the operational measures modelled in the framework consist in load and generation shedding (for corrective measures), and in the redispatching of dispatchable generators and the renewable curtailment (for preventive measures). Anyway, the OvS approach allows to easily integrate the models of other measures such as the grid forming algorithm or DSM, in the optimization framework.

The advantage of such a framework is the ability to identify the best portfolio of both hardening and operational measures by comparing the benefits and (capital and operational) costs of many alternatives and accounting for the evolution of the climate changes, the response of power system to disturbances, including cascading outages, and the unitary cost of each measure.

References

[1] ARERA (Italian Regulatory Authority), « Incentivazione degli interventi finalizzati all'incremento della tenuta alle sollecitazioni », deliberation nr. 460/2018/r/eel (in Italian), 2018.

[2] E. Ciapessoni, A. Pitto, D. Cirio, «An Application of a Risk-Based Methodology to Anticipate Critical Situations Due to Extreme Weather Events in Transmission and Distribution Grids», *Energies,* Vol 14, 2021, p. 1-25.

[3] E. Ciapessoni, D. Cirio, A. Pitto, M. Sforna, « Quantification of the Benefits for Power System of Resilience Boosting Measures », *Appl. Sci.*, Vol 10, 2020, p. 1-31.

[4] M. Panteli, D.N. Trakas, P. Mancarella, N. Hatziargyriou, « Power Systems Resilience Assessment: Hardening and Smart Operational Enhancement Strategies ». Proc. Of
Institute of Electrical and Electronics Engineers. Vol 105, no 7, pp. 1202 - 1213.