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Question 1.1.1 *Have others applied asset management tools and methods to set resilience measures or metrics?*

Asset management (AM) represents a fundamental task for the TSOs in order to assure the best value to the assets through their useful life. According to ENTSO-e [1], asset management is performed over different time scales: from the long term horizon (encompassing future planning and investments on new assets or their upgrading) to the mid term horizon (involving the optimal scheduling of equipment maintenance and allocation of available resources with the aim of expanding the life span of existing facilities through proper maintenance) up to the real time (where AM assesses the effects of the outages which may occur during operation).

Probabilistic and risk based methods are of the utmost importance in AM because they allow to quantify the potential effects of ageing mechanisms and/or of the damages caused by threats to power system assets: this capability can be exploited in optimization frameworks also to improve power system (PS) resilience in short, medium, and long term.

In fact, an effective asset management may also lead to a higher resilience of assets and, in turn, of the PSs, to extreme events. Resilience is in fact defined by CIGRE WG C4.47 as «*the ability to limit the extent, severity and duration of system degradation following an extreme event* » and increasing the resilience of assets is of paramount importance to increase the resilience of the system.

In the long term planning, the knowledge of the frequency and the severity of extreme events in a grid area (e.g. via the Generalised Extreme Value – GEV – distributions of stress variables acting on the physical assets like wind speed, snow load, etc.) can help prioritize the interventions to improve the resilience of the system in the most efficient way and to reduce the number of future damages to the grid infrastructure.

In the mid term horizon, information about the seasonal trends of specific threats can help the TSO improve the preparation phase, by managing the maintenance phase in an effective way (assuring the availability of sufficient assets during periods when threats are expected to strike the grid).

In real time, short term forecasts of the forthcoming threats can help the TSO react in a proper way to the threat, by minimising the load disruptions to customers, e.g. pre-allocating emergency generators, or redispatching conventional generation to assure a minimum anti-icing current on exposed OHLs: the latter mentioned preventive measure helps preserving the integrity of the infrastructure.

The tools adopted worldwide for these tasks have to cope with the uncertainties which inevitably are present at the different horizons (from the uncertainties concerning the power system operating points and the threat extreme values in the long term analyses, to the uncertainties concerning the seasonal evolution of the threat in mid term analyses, up to the uncertainties in the numerical prediction models which provide short term weather forecasts for real time applications).

The application of risk based probabilistic techniques to manage assets and improve power system resilience has encountered some barriers e.g. the data availability and quality to characterise the probabilistic models of the threats and the vulnerability of the physical assets, the complexity (and the computational burden) of the approaches with respect to more conventional PS management criteria still widely used.

However, the situation is rapidly evolving, e.g. larger and larger amounts of data are made available by advanced technologies, also applied in the context of asset management (e.g. condition monitoring systems).

In the international research context, some methodologies have been proposed to quantify asset resilience (in terms of return period for the outage of an asset) [2] as well as PS resilience via suitable metrics (e.g. EENS, CVAR, VAR) [3]: their relevant applications often concern limited portions of real-world power systems and they don't include climate change modeling.

In the Italian context, RSE and TERNA, the Italian TSO, have jointly developed a risk based resilience assessment methodology to prioritize the grid interventions over a long term horizon (for grid planning purposes) [4]. This methodology has been applied to a model of the whole Italian EHV and HV transmission system to select the priorities in the interventions to be presented in the « *Grid resilience Plan* » required by the Italian Energy Authority, ARERA.

This methodology currently focuses on « hardening solutions » to increase asset resilience, as measured by the increase of the return period for the asset outage, such as support reinforcements. Furthermore, the methodology models the climate changes by characterising the extreme events with probabilities of occurrence which change over the time horizon of analysis.TSO's Cost Benefit Analysis (CBA) used to prioritize the interventions is fed with (both operational and capital) costs for the proposed measures and the relevant benefit to resilience is quantified as the difference of the EENS (Expected Energy Not Served) between the post intervention and the pre-intervention phase. Such a prioritization of the resilience boosting measures in the long term helps assure the best value of the TSO assets also in terms of response to extreme events.

References

[1] Webpage « Asset Management, Tools and Procedures » from ENTSO-e technopedia, available at : https://www.entsoe.eu/Technopedia/techsheets/asset-management-tools-and-procedures

[2] E. Ciapessoni, D. Cirio, G. Pirovano, A. Pitto, F. Marzullo, A. Lazzarini, F. Falorni, F. Scavo, “Modeling the overhead line vulnerability to combined wind and snow loads for resilience assessment studies”, Proc. of 2021 Powertech Conference, Madrid, 2021.

[3] T. Lagos, R. Moreno, A.N. Espinosa, M Panteli, R. Sacaan, F. Ordonez, H. Rudnick, P. Mancarella, "Identifying Optimal Portfolios of Resilient Network Investments Against Natural Hazards, With Applications to Earthquakes," in *IEEE Transactions on Power Systems*, vol. 35, no. 2, pp. 1411-1421, March 2020.

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