Resource Adequacy and Reliability Standard in future energy constrained and interconnected power systems

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Overview

Most liberalized power systems now incorporate a specific mechanism to ensure the security of supply. These capacity mechanisms (or markets) are designed to meet a reliability standard, typically expressed as a Loss of Load Expectation (LOLE) – i.e., the expected number of hours or days per year with load curtailment, or variations of this metric (see (Pfeifenberger et al., 2013) for a detailed discussion). The determination of the LOLE target, which reflects the economic trade-off between new capacity additions and the Value of Lost Load, is well documented in the literature (Cramton, Ockenfels and Stoft, 2013) and is usually illustrated within a closed system framework that includes only conventional dispatchable resources. This approach is even embedded in European legislation (ACER, 2020). However, new system features that will fully be deployed in the next decades – such as the large-scale deployment of short-term energy storage, or increased integration of power systems through interconnections - challenge the traditional definition of the reliability standard, which may no longer be adequate for a decarbonized power system facing energy constraints. In such systems, different allocations of load curtailment across time and space during scarcity events achieve the same total welfare outcome. As the long-term optimum is not characterized by a unique LOLE value, this paper argues that system adequacy is better represented by a price-based metric.

Methods

The analysis is realized by modelling the constraints of a general expansion problem for electricity systems and minimizing the total system costs. Starting from the historical status quo, we justify the current reliability standard is well defined for a closed and power-constrained system, through a study of the Kuhn-Tucker optimality conditions. We then generalize the problem to open and energy-constrained systems, by incorporating storage and interconnections constraints and point out the appearance of degenerate solutions (in time and space) with different LOLE.

Results

This degeneration of the LOLE value points out the need for a new reliability metric which is not solution-dependent: price spikes hours. We then reformulate a new reliability standard ensuring economic optimality of the system: the duration of Loss of Load episodes, which englobes but is not restricted to loss of load hours. Still, this better definition does not solve the practical operational problem of dispatching unserved energy in time and space.

Conclusions

The results are aligned with previous work on this topic considering constraints on the flexibility operations (De Vries and Sanchez Jimenez, 2022; Gonzato, Bruninx and Delarue, 2023; Energy Systems Integration Group, 2024; Lebeau, 2024). Concretely, a biased definition of reliability standard can impair adequacy assessment by underestimating the tension of the system at the expense of social welfare. It must be explored whether the reliability standard used in reality in some regulations integrate properly those dimensions.

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