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RESILIENCE FINDINGS

Quantifying the Difference Between Resilience and Reliability in the Operation Planning of Mobile Resources for Power Distribution Grids

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Findings

Modern power grids have high levels of distributed energy resources, automation, and inherent flexibility. Those characteristics have been proven to be favorable from an environmental, social and economic perspective. Despite the increased versatility, modern grids are becoming more vulnerable to high-impact low-probability (HILP) threats, particularly for the distribution networks. On one hand, this is due to the increasing frequency and severity of weather events and natural disasters. On the other hand, it is aggravated by the increased complexity of smart grids. Resilience is broadly defined as the capability of a system to mitigate the effects of and recover from HILP events, which is often confused with reliability that is concerned with low-impact high-probability (LIHP) ones. In this paper, a distribution system in Portugal is simulated to showcase how the utilization of flexibility and mobile energy resources (MERs) should be considered differently relative to HILP vs LIHP threats.

1. Questions

A common misconception is that a reliability-informed approach to the planning and operation of flexible resources in modern smart distribution systems consequently ensures their resilience. This stems from the wide-spread confusion between the two characteristics, which are complementary yet not identical (Panteli, Mancarella, et al. 2017). A reliable power system can guarantee stable operation with minimal energy not served (ENS) in spite of low-impact high-probability (LIHP) events such as the loss of a limited number of lines or generators (e.g. N-1 or N-2 contingencies). In contrast, the system's resilience is in relation to its preparedness to mitigate the effects of and recover from a high-impact low-probability (HILP) event, such as a wind storm. Accordingly, a reliable system is not necessarily a resilient one, and measures taken to enhance of the two characteristics may have little effect on the other, acting as a "double-edged sword" (Panteli, Mancarella, et al. 2017; Li et al. 2017). Distribution networks are particularly vulnerable to disruptive events due to their radial topologies and must therefore rely on standby flexible resources. In this context, we aim to explore and quantify the following question in this article: Can reliability-informed strategies that guide the planning and operation of flexible resources in modern distribution systems (mainly flexible loads and mobile dispatchable resources) simultaneously enhance distribution system resilience?

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2. Methods

Traditional reliability-driven operation and planning of distribution networks is centered around switching and topology reconfiguration solutions, which have been extensively studied the literature. For the medium- and long-term operation planning time horizons, the effectiveness of these traditional reliability-centered solutions is firmly established. However, for short-term operation planning, the technical constraints associated with switching actions, optimal placement of tie-switches, and number of installable switches, all pose a challenge in terms of operational feasibility. For resilience against HILP, the narrow window between the event alert and onset make it necessary to consider other flexible resources. Modern distribution networks have a plethora thereof, largely thanks to decades of successful demand-side management strategies.

More recently, mobile energy resources (MERs) have emerged as a highly versatile asset in resilient distribution systems. From a reliability perspective, MERs availability and positioning can be predetermined to ensure the system can withstand specified contingencies with minimal service disruption (Nazemi et al. 2021). From a resilience perspective, MERs can be readily dispatched to mitigate the effects of a previously unforeseen event (e.g. excessive overloading, or extreme weather) once an alert of the event is captured (Lotfi et al., n.d.).

Using the methodology for optimal MER dispatch considering real-world road networks that was presented in Lotfi et al. (n.d.), day-ahead operation planning was simulated for a Portuguese distribution system (shown in Fig. 1). The network is radial with 125 buses and 124 lines. Typical Portuguese load profiles are used according to ERSE (2021), which account for self-injection from small-scale DERs. No fixed dispatchable generation is present aside from the slack bus, which provides the active power injection to meet the net load demand, and is located at (39.1835 °N, 8.5695 °W). Accordingly, a failure of any branch results in ENS, and the option is to either dispatch available MERs to specific buses or have unavoidable load shedding. Five buses in the network are assumed to contain critical loads (shown in red in Fig. 1). For the simulated day the total energy demand is 209.46 MWh, of which 13.75 MWh is of critical loads. According to the methodology in Lotfi et al. (n.d.), critical loads are modeled by setting their value of lost load (VoLL) as an order of magnitude higher than other buses, prioritizing them in the optimal dispatch solution.

Two analyses were carried out and compared to effectively capture and quantify the differentiation between reliability-driven and resilience-driven approaches:

- **Reliability-Centric Analysis**: An N-1 contingency study for LIHP was performed, in which 124 cases were simulated each corresponding to a single branch failure.

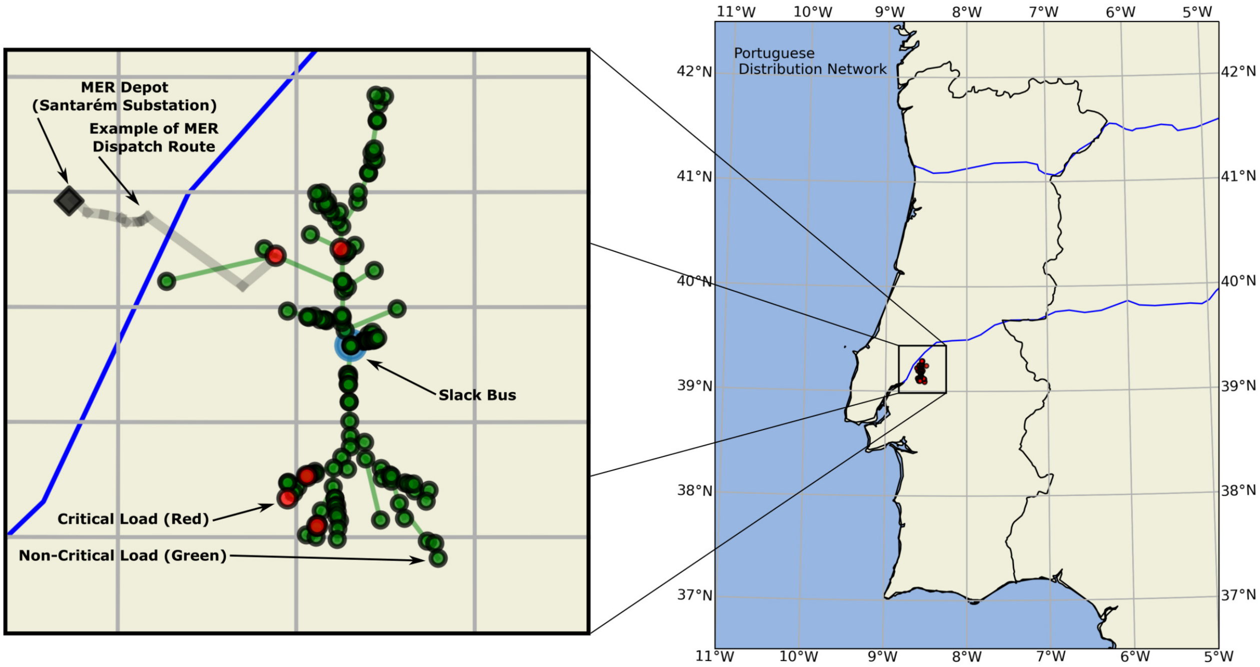

Figure 1. The considered Portuguese distribution network and an illustration of the conceptual model of MER dispatch.

- **Resilience-Centric Analysis**: A study of HILP events was performed by simulating 124 random wind storms according to the methodology in Panteli, Trakas, et al. (2017).

In each simulation, the optimal dispatch of MERs is calculated to minimize the load shedding (prioritizing critical loads). The simulations are repeated for a varying number of available MERs, albeit with the same combined capacity (1 MER x 1800 kW, 2 MERs x 900 kW, and 3 MERs x 600 kW). This is performed to also investigate whether it is more favorable to invest in one large MER or several smaller ones.

3. Findings

The results clearly show the contrast between the reliability and resilience assessments and corresponding utilization of MERs. By comparing Fig. 2 (a) and (b), it is seen that from a reliability perspective, the number of available MERs is irrelevant, given that their combined capacity can supply the critical load demand. However, from a resilience perspective as seen in Fig. 2 (c) and (d), investing in a higher number of smaller-capacity MERs is significantly better than having one large MER in terms of ensuring uninterrupted critical loads during a wind storm event. This provides further knowledge to better understand the power system performance under both normal or expected disturbances as well as extreme, tail risk events, shedding light on the complementarity of the reliability and resilience concepts respectively.

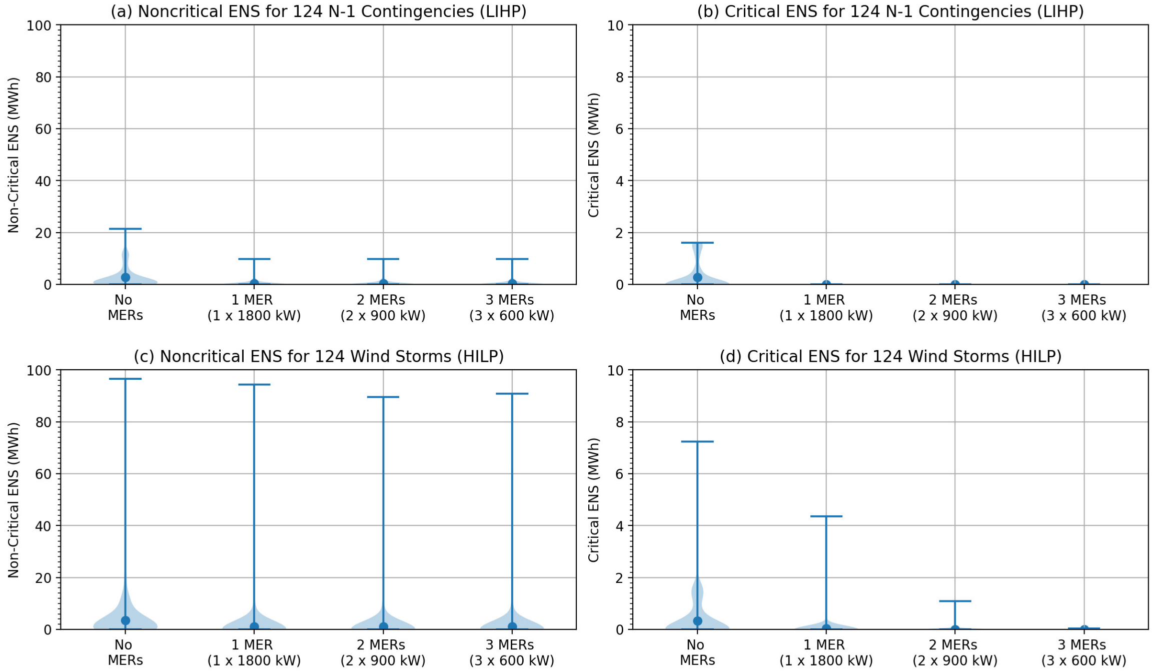

Figure 2. ENS results for the performed analyses showing the mean values and probability distributions, comparing LIHP (top) and HILP (events) for non-critical (left) and critical (right) loads in the network.

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