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Quantifying Power System Adequacy And Security In Net-Zero Energy Transition Scenarios

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To reach the 2050 net zero emissions goals, the electricity generation mix of European countries must radically change towards higher shares of Variable Renewable Energy Sources (VRES). This increase in variable generation leads to a greater need for system flexibility to guarantee system adequacy and security. In this work, we assess the expected system adequacy and security for the Swiss electric transmission system in 2050 and compare it to the 2018 reference values. To do so, we first use a quantitative flexibility metric to assess system adequacy under normal operations considering the minutes-to-hours timescale. Second, we use a cascading failure model to assess system security under contingent operations and identify optimal locations for grid upgrades to increase operational reliability. The process is illustrated in Figure 1 and further explained below.

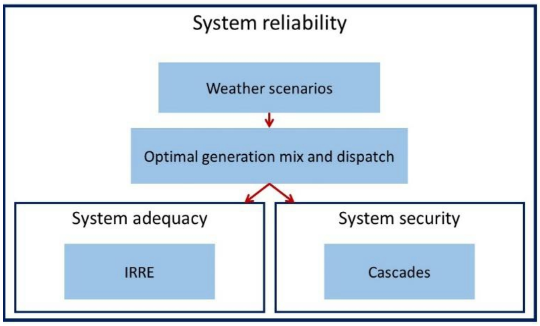

Fig. 1. System reliability is assessed by analyzing system adequacy and security.

System adequacy is assessed through the quantification of system flexibility with the Insufficient Ramping Resource Expectation (IRRE) metric (Lannoy et al., 2012). This metric computes the likelihood of having insufficient available flexibility in the power system (due to insufficient power, energy or ramping capacity) to accommodate the changes in net load. It is therefore an indicator for system adequacy. To compute the IRRE, a generation dispatch is required. This is computed with CentIv, an optimal generation expansion and dispatch model, applied to scenarios for Switzerland in 2050 (Raycheva et al., 2020; Gjorgiev et al., 2022). Since the 2050 generation mix is characterized by high shares of VRES, the model outputs are highly dependent on weather data. Thus, we consider variability in the weather data by running CentIv for several climate years. The diverse set of results for generation mix and dispatch are then used to compute the IRRE.

System security is assessed by deploying Cascades (Gjorgiev et al., 2020; Stankovski et al., 2022), a model simulating cascading failures under contingencies. To do so it considers the same set of results for generation mix and dispatch as for the IRRE computation. The algorithm, depicted in Figure 2, begins with a simulated grid outage, followed by an iterative set of actions, including island identification, frequency control, emergency actions, power flow computations, and identification of overloaded branches. These branches are then disconnected to simulate a cascading failure event. In this process, Cascades computes the Demand Not Served (DNS) for each contingency and uses this information to quantify system security. The expected results will be summarized in risk curves showing the exceedance probability of observing DNS larger than the value reported on the x-axis. This will provide a quantitative comparison between the current and the future system security.

In the process explained above, Cascades also quantifies the use of flexibility activated to match supply and demand, and to avoid voltage violations. Additionally, it keeps track of the occurrence of voltage violations at each node. These results are crucial in the identification of the locations that would benefit the most from active and reactive power support from flexible units and compensators (capacitors and reactors). Additionally, the algorithm identifies a set of critical branches as lines or transformers that 1) have a high impact on the DNS when disconnected or 2) are frequently overloaded. Those branches are the optimal candidates for grid expansion plans, which aim to improve system security.

In this work, we quantify how system adequacy and security change in a net-zero energy transition characterized by high shares of VRES. We observe a reduction in the future system adequacy compared to the 2018 reference values. Additionally, this study identifies the optimal transmission branches for grid expansion plans and the nodes for additional active and reactive power support units. Therefore, it contributes to planning reliable power systems for the future.

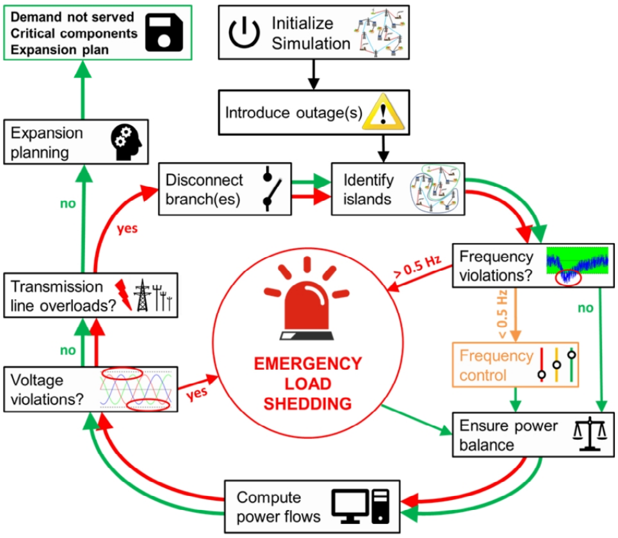

Fig. 2. The iterative algorithm of Cascades.

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