IEEE Power & Energy Society

April 2018

TECHNICAL REPORT

PES-TR65

The Definition and Quantification of Resilience

PREPARED BY THE
IEEE PES Industry Technical Support Task Force

Comments on the Definition and Quantification of Resilience

April 6, 2018

IEEE Task Force on Definition and Quantification of Resilience

A. Stankovic, K. Tomsovic, Co-Chairs

The purpose of this brief white paper is to provide an IEEE viewpoint on the important industry topic of Resilience of the Electric Grid, with a focus on the Definition and Quantification of Resilience. With timeliness as the main goal, these remarks have been put together using contributions by the IEEE Task Force (TF) members (L. Mili, M. Panteli, J. Kavicky, K. Thomas, R. Desalvo, J. Liu, and H. Chao).

Resilience Definition

The definition presented to the TF:

"The ability to withstand and reduce the magnitude and/or duration of disruptive events, which includes the capability to anticipate, absorb, adapt to, and/or rapidly recover from such an event."

Remarks:

- TF members consider this definition adequate – somewhat general, but useful framing tool. It contains the main ingredients - absorptive, adaptive and recovery features.
- It may be useful to distinguish between two aspects or time horizons – operational (near term) and infrastructural (long-term). The operational resilience focuses on the task at hand during and immediately after a major disruption, namely reducing the frequency/number of disconnected customers or the reconnection time of all impacted customers. The long-term aspect deals with properties that will be important for future scenarios encompassing structural strength and robustness.
- Given the centrality of the concept of reliability, it is important to outline in what ways is resilience different. Key distinguishing features include:
    1. Resilience encompasses all hazards and events, including high-impact low-probability events that are commonly excluded from reliability calculations,
    2. Resilience quantifies not only the states in which system ends up (like reliability), but also transition times among the states. Thus, it requires a more detailed characterization of the preparation process prior to any events occurring, the operational process during the event, and the response process after the event.
    3. Resilience aims to capture both the effects on customer (like reliability), effects on the grid operators and staff, and effects on the infrastructure itself (possibly on two or more time horizons).
- Resilience naturally ties-in with risk-based approaches to power system quantification; the challenge of obtaining adequate statistical parameters remains a key obstacle.
- A widely used temporal resilience diagram [1] is shown in Fig. 1; please note that the pre-disturbance resilience level R_0 and the post-disturbance resilience level are not necessarily equal; R_{pd} is the lowest value of resilience reached during the disturbance.

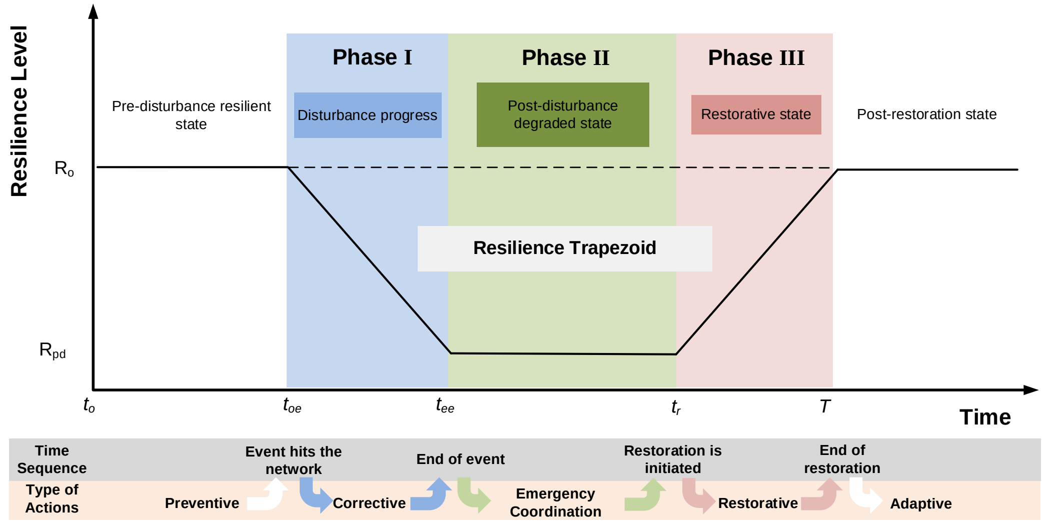

Fig. 1: The resilience trapezoid associated with an event (courtesy of M. Panteli)

Traceability of Resilience

"What attributes of the bulk power system contribute to resilience? How do you evaluate whether specific components of the bulk power system contribute to system resilience? What component-level characteristic, such as useful life or emergency ratings, support resilience at the system level?"

- Every quantifiable concept of resilience uses both "hardware" and "software" aspects of a power system (e.g., a technical capability **and** how it is utilized in operation). It is thus unlikely that the resilience can be strongly identified solely with a component-level characteristic, as the real-time operational aspects are also key. However, a set of best practices may well be identifiable, and it is one of the key aims of the IEEE Resiliency TF.
- The quantification of resilience is invariably connected to a set of scenarios that capture the domain of deliberation. The criticality of a component, and hence its contribution to resilience, varies depending on the type of the event (e.g. intensity, trajectory, etc.) and the operating condition of the power grid and other critical infrastructure (communication networks, gas infrastructure, etc). Hence, although it is possible to define and rank the criticality of the components for a specific event, it is difficult to generalize this to all types of disruptive events. Hence, the criticality of a component or set of components/attributes is hazard- and network-specific.
- In terms of system planning, the resilience-driven investment decisions can be significantly different than the (N-1), (N-1-1), and (N-2)-based reliability-driven investment decisions. It was shown in the literature [2] that for distribution systems it is more resilience-effective to make the network smarter and more responsive to extreme weather rather than making the network more redundant in terms of energy flow-level components.
- A new dimension to the resilience improvement stems from the increasing interaction and collaboration between TSOs and DSOs, with new flexibility and resilience services arising from the low voltage distribution networks.
- Another enlargement of the domain of consideration comes from the growing interconnectivity of and interdependencies between critical infrastructures (as well as multiple energy carriers), it is possible a failure in one infrastructure could escalate and propagate to another infrastructure, resulting in cascading events among multiple infrastructures. Therefore, to define the criticality and contribution of a specific attribute or component to the overall system resilience, a study may have to look into interconnected infrastructures.
- ISO/RTO/TO/GO/etc. conducted system operator training, emergency management, and power system restoration activities are examples of system-level actions that have a profound impact on resilience, yet do not always have a clear link with particular energy-level components.

[1] M. Panteli, P. Mancarella, D. N. Trakas, E. Kyriakides, and N. D. Hatziargyriou, "Metrics and Quantification of Operational and Infrastructure Resilience in Power Systems", *IEEE Transactions on Power Systems*, vol. 32, no. 6, November 2017
[2] M. Panteli, P. Mancarella, C. Pickering, S. Wilkinson, and R. Dawson, "Power System Resilience to Extreme Weather: Fragility Modelling, Probabilistic Impact Assessment, and Adaptation Measures", *IEEE Transactions on Power Systems*, vol. 32, no. 5, September 2017