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Power System Resilience: A Primer

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The issue of 'resilience' of the power system—including how to best define, measure, and ensure it—has garnered substantial attention in recent months.

The energy policy community turned its collective focus to resilience issues following the devastating electric grid failures in Puerto Rico as a result of Hurricane Maria, as well as the U.S. Department of Energy's (DOE) September 2017 proposal of the Grid Resiliency Pricing Rule. DOE submitted the proposed rulemaking to the Federal Energy Regulatory Commission (FERC) with the stated purpose of expeditiously bolstering the grid's resilience and reliability. The proposal called for tariff changes to ensure the recovery of costs and a fair rate of return for qualifying generators with 90-day on-site fuel storage. FERC received more than 1,500 comments on the rulemaking. Many of these submissions commented on whether the issue of resilience has been sufficiently defined.

On January 8, 2018, FERC issued a unanimous decision to end consideration of the proposed Grid Resiliency Pricing Rule and to initiate a new proceeding to holistically examine the resilience of the bulk power system. The commission gave RTOs and ISOs 60 days (until March 9) to respond to a series of questions about resilience in their geographic footprint. At the close of that comment period, other interested parties will have 30 days to issue comment. The Commission

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plans to review comments and decide whether additional FERC action to address grid resilience is warranted.

This primer seeks to provide a high-level introduction to the concept of power sector resilience- highlighting what research has been done on the topic as well as key areas where more work is needed. This includes a discussion of how resilience is defined and measured; what threats the power system should be resilient to; how this term is related to, but distinct from, reliability; and what organizations are working to better define and measure resilience.

Defining Power System Resilience

Unlike the term 'reliability', there is no formal, widely agreed upon definition of power system resilience. However, there is a common understanding about what the term means. Most working definitions of resilience refer to the ability of the system—which includes generating sources, transmission, and distribution—to bounce back from high-impact, low-frequency events. This could include events that are natural, such as hurricanes or ice storms, as well as man-made, such as cyber or physical attacks on grid infrastructure. As discussed later in this primer, resilience and reliability are closely related yet distinct terms.

In its January 2018 order, FERC proposed a definition for bulk power system resilience as, "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 events." The order seeks comment on the proposed definition.[1]

Defining Resilience

National Academies of Sciences, Engineering, and Medicine's "Enhancing the Resilience of the Nation's Electricity System" (July 2017)

> "Resilience is not just about lessening the likelihood that that these outages will occur. It is also about limiting the scope and impact of outages when they do occur, restoring power rapidly afterwards, and learning from these experiences to better deal with the events in the future."

PJM's "Evolving Resource Mix and System Reliability" (March 2017)

> "Resilience, in the context of the bulk electric system, relates to preparing for, operating through and recovering from a high-impact, low-frequency event. Resilience is remaining reliable even during these events."

President Barack Obama's Presidential Policy Directive-Critical Infrastructure Security and Resilience (February 2013)

> "The term 'resilience' means the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions. Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents."

Electric Power Research Institute's "Electric Power System Resiliency: Challenges and Opportunities" (February 2016)

> "In the context of the power system, resiliency includes the ability to harden the system against—and quickly recover from—high-impact, low-frequency events."

How Should Resilience Be Measured?

While there are no commonly accepted metrics, work is underway to define and operationalize the measurement of grid resilience. Metrics refer to physical or economic characteristics that can be measured to help determine the resiliency of the system. Without consistent resilience metrics, large amounts of money could be spent on improvements with little understanding of actual resilience benefits and with much of this cost passed on to ratepayers.[2]

Resilience metrics are not easy to formalize. Because they are focused on individual, low-frequency events, it is often not possible to base metrics on historical data. Many metrics will likely be based on extensive simulations of 'what-if scenarios.'[3] In addition, many of the technologies and strategies for increasing the resilience of the electricity system are expensive, particularly when implemented on a large scale.

In a 2015 paper focused on developing a framework for resilience metrics, the Sandia National Laboratory recommended that metrics use a 'risk based approach.' This implies 1) resilience should be defined with respect to a specific threat (e.g. resilient to hurricanes); 2) resilience metrics should be focused on the consequences of a system failure rather than the system failure itself; and 3) resilience should be defined with respect to a specific system. Sandia created a seven-step Resilience Analysis Process to help utilities think through the creation of risk-based metrics. The process describes how utilities can define resilience goals, assess baseline resilience, and evaluate resilience improvements.[4]

DOE is utilizing this Resilience Analysis Process in its three-year Foundational Metrics Analysis project run by its Grid Modernization Lab Consortium. The project aims to select, describe and define key metrics in the electric sector, including power sector resilience. The effort is intended to enhance the state of metrics in order to provide federal, state and municipal regulators more comprehensive information, support self-assessment by utilities, and enable DOE to better set its research and development priorities. In May 2017, DOE released a paper documenting progress made in the project's first year.[5]

Resilient to What?

Resilience metrics are intended to harden the system against specific low-frequency, high-impact events. In a 2016 report on the state of power sector system resilience, the Electric Power Research Institute (EPRI) included a list of possible events that could harm the power system and lead to life-threatening outcomes. This includes natural disasters such as hurricanes, tornadoes, earthquakes, wildfires, ice storms and severe geomagnetic disturbances. It also includes manmade disasters such as cyber attacks, physical attacks and electromagnetic pulse attacks. Other threats include unanticipated severe shortages of fuel or water for power generation and extreme weather that impacts a variety of generating sources.[6]

Advancing resilience must begin with the characterization of the most important threats, which often vary by region. Some actions to promote resilience are specific to a particular risk. Burying transmission and distribution lines underground, for example, makes power lines less vulnerable to wind damage but more vulnerable to flooding. Other actions may enhance resilience broadly. Backup power that can quickly be brought online when outages occur or equipment fails makes the system more resilient to multiple threats. A smart grid that can detect failed equipment and automatically correct it or shut it down can also improve overall resilience (although the information technology that makes a grid 'smart' can also entail cyber security risks). And some complex human systems, such as plans, standards, protocols, communications channels, and clear assignment of institutional roles and responsibilities, enhance system-wide resilience.[7]

While most power outages are related to the distribution system,[8] generation systems also face risks that must be characterized and mitigated. Because there are so many possible threats to the electric system, some analysts have concluded that generation diversity is a key overall resilience strategy.[9] Generation diversity helps to ensure that if a threat emerges against one type of generator, other generators that are not vulnerable to that particular threat can remain operational.

PJM is reviewing the fuel diversity in its markets and the impact this diversity has on system reliability and resilience. Generators in PJM include natural gas, coal, nuclear, renewables, demand response and other resource types. PJM has found that this mix is both reliable and diverse. The market operator said in a March 2017 report that a more diverse system is better able to 1) reduce the risk associated with equipment design issues or common modes of failure in similar resource types; 2) address fuel price volatility and fuel supply disruptions; and 3) reliably reduce risk caused by weather and other unforeseen system shocks.[10]

Reliability vs. Resilience

Power system reliability and power system resilience are related but distinct concepts. Conceptually, resilience pertains to low-probability, high-impact events. Reliability generally pertains to high-probability, low impact events stemming from outages and disruptions under routine operating conditions.[11]

While resilience metrics are still being formulated, there are mature standards addressing reliability. For decades, the electric sector complied with voluntary reliability standards. Following the passage of the Energy Policy Act of 2005, FERC approved the industry's first set of mandatory and enforceable reliability standards. FERC has designated the North American Electric Reliability Corporation (NERC) as the country's official electric reliability organization charged with establishing these mandatory reliability standards for the industry.

NERC defines bulk-power system reliability as the ability to "meet the electricity needs of end-use customers even when unexpected equipment failures or other factors reduce the amount of available electricity." According to NERC, system reliability depends on both resource adequacy and security.[12] NERC's reliability standards cover the design, planning and operation of the bulk power system. They also address physical and cyber security. Users, owners and operators of the bulk power system in the contiguous U.S. are subject to the standards.[13]

Organizations undertaking efforts to formalize resilience metrics have begun to highlight differences between emerging resilience metrics and existing reliability metrics. For example, Sandia National Laboratory points out that reliability metrics are not cause-specific (e.g. when a load is de-energized, reliability standards are not focused on the specifics of why or how it occurred) while resilience metrics are (e.g. a hurricane caused the load to be de-energized). Sandia also notes that reliability metrics address the power system's ability to accomplish its objective- delivering power- but does not deal with how the system's response to threats may affect a community or other social elements. Resilience metrics are intended to bridge this gap.[14]

History of Mandatory Reliability Standards

Prior to 2007, the electric industry relied on voluntary protocols and guidelines for reliably operating and planning the bulk power system. The August 2003 blackout that affected large swaths of the U.S. and Canada provided the catalyst for legislative changes that led to the mandatory reliability standards.*

- **August 2003:** A large-scale blackout affects an estimated 50 million people and 61,800 MW of electric load in the Midwestand Northeastern United States as well as eastern Canada.
- **August 2005:** President George W. Bush signs into law the Energy Policy Act of 2005. The Energy Policy Act adds a new section to the Federal Power Act titled "Electric Reliability." Section 215 authorizes FERC to certify an entity to operate as an independent electric reliability organization to establish and enforce mandatory reliability standards, which are subject to FERC review.
- **July 2006:** FERC certifies the North American Electric Reliability Corporation (NERC) as the electric reliability organization for the 48 contiguous states.
- **March 2007:** FERC issues Order 693 approving 83 reliability standards.
- **June 2007:** The 83 standards take effect and become mandatory and enforceable.
- **February 2018:** Today there are about 100 mandatory, enforceable standards in the United States.

* Federal Energy Regulatory Commission, Reliability Primer, December 2016, https://www.ferc.gov/legal/staff-reports/2016/reliability-primer.pdf

Potential Next Steps for Defining, Evaluating and Enhancing Power Sector Resilience

FERC's January 2018 order ended consideration of DOE's proposed Grid Resiliency Pricing Rule and instead opened a new docket to examine the resilience of the bulk power system. The Commission gave RTOs and ISOs 60 days (until March 9) to respond to a series of questions about resilience in their geographic footprint. For example, FERC asked RTOs and ISOs to explain the primary resilience risks they face, how they identify them, and what challenges they face in planning for high-impact, low frequency events. The RTO/ISO comment period will be followed by a 30-day public comment period for other interested parties. According to FERC's order, the Commission will review comments and decide whether additional FERC action to address grid resilience is warranted.[15]

Other existing efforts to move forward on power sector resilience, include:

• DOE's Grid Modernization Laboratory Consortium's Foundational Metrics Analysis's three-year effort to select, describe and define key metrics in the electric sector, including power sector resilience.[16]

• NERC's ongoing work through its Reliability Issues Steering Committee (RISC). NERC plans to build on the National Infrastructure Advisory Council's October 19, 2010, *Framework for Establishing Critical Infrastructure Resilience Goals* and NERC's May 10, 2013, Informational Filing on the Definition of 'Adequate Level of Reliability.'

• RTOs and ISOs continue to do important work. Given the differences that exist across markets in terms of the types of vulnerabilities they face, approaches to resilience will likely vary by region. As evidenced from the docket for the FERC NOPR proceeding, regional grid operators on their own have begun to identify and address the most important risks they face.

• In addition, some recent analyses have helped to highlight possible next steps. For example, The National Academy of Sciences, Engineering, and Medicine's July 2017 report includes a set of recommendations for next steps, including:[17]

- More back-up infrastructure;
- More regional emergency planning and exercises;
- More rapid implementation of available technical capabilities and operational strategies as well as faster adoption of new ones;
- "Visioning" of major grid disruptions;
- Establishment of small system resilience groups at FERC and NERC;
- Guidance to states from the National Association of Regulatory Utility Commissioners (NARUC) and the National Association of State Energy Officials (NASEO);
- Enhanced resilience capability at individual state energy offices and PUCs; and.
- Work by DOE to 1) improve understanding of customer and societal value associated with increased resilience; 2) review and operationalize resilience metrics; 3) increase research and development on grid modernization, systems integration, cyber monitoring and controls and 4) engage with other key groups, such as NERC, in a coordinated assessment of the numerous proposed resilience metrics.

Conclusion

Regulatory and real-world events have pushed power sector resilience into the policy world limelight. Important work is underway at federal agencies, market operators, and other organizations to better define, measure, and assess power sector resilience. This includes standardizing a definition for resilience, specifying how it differs from power system reliability, identifying what the power sector should be resilient to, and proposing metrics to measure and account for resilience characteristics.

Endnotes

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