UNITED STATES OF AMERICA

BEFORE THE

FEDERAL ENERGY REGULATORY COMMISSION

Grid Resilience in Regional Transmission Organizations and Independent System Operators	)))	**Docket No. AD18-7-000**

COMMENTS OF WIRES

WIRES[1] respectfully submits the following comments in response to the January 8, 2018 *Order Terminating Rulemaking Proceeding, Initiating New Proceeding, and Establishing Additional Procedures* issued by the Federal Energy Regulatory Commission ("FERC" or "Commission") in the above-captioned docket.

WIRES strongly supports the Commission's efforts to ensure increased resilience of the electric power system, including its rejection on policy and legal grounds of the Secretary of Energy's proposal to provide out-of-market relief for certain sources of electric generation.[2] WIRES believes grid resilience will only increase in importance as the economy continues to become more dependent on reliable electric power. At the same time, cyber and physical threats, as well as natural events of unparalleled ferocity and unpredictability pose new challenges to our increasingly electrified economy. Since electric power disruptions are most likely to arise through the disruption of distribution and transmission systems, the Commission's determination to help achieve greater resilience in bulk electricity markets must focus on the key role of critical transmission infrastructure in supporting overall system resilience. In fact, it is particularly appropriate and important that the Commission re-focus this resilience proceeding on the planning, financial support for, and development of electric transmission because the

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[1] WIRES is an international non-profit trade association of investor-, publicly-, and cooperatively-owned transmission providers, transmission customers, regional grid managers, and equipment and service companies. WIRES promotes investment in electric transmission and progressive state and federal policies that advance energy markets, economic efficiency, and consumer and environmental benefits through development of electric power infrastructure. For more information, visit www.wiresgroup.com.

[2] Grid Resiliency Pricing Rule, 82 Fed. Reg. 46940 (proposed October 10, 2017) (to be codified at 18 C.F.R. pt. 35).

interstate high-voltage grid is more squarely within its plenary jurisdiction[3] and responsibilities than is resource adequacy at the generation level, notwithstanding the importance of addressing fuel supply problems that threaten generation reliability. Specifically, WIRES believes that proactive transmission planning must be made more integral to any resilience strategy, just as resilience must be a strong component of transmission planning. To that end, WIRES recommends Commission action in the following areas:

- In assessing how to move forward in the area of grid resilience, especially as it pertains to the role of more robust transmission infrastructure, the Commission should swiftly and aggressively evaluate the extent to which RTOs and ISOs should be obligated to integrate (or to demonstrate that they have integrated) resilience planning into their regional and interregional transmission planning processes.[4] Each region should be afforded flexibility to implement such integration in a manner that reflects the characteristics of that region, subject to oversight of the Commission.
- The Commission should update its Order No. 890 transmission planning principles to include resilience as a separate and distinct planning driver for RTOs and ISOs.
- The Commission should clarify that it has authority under the Federal Power Act to include resilience in its lawful transmission planning regime, similar to its authority to promote reliable operation of the Bulk Electric System (BES).
- FERC should also clarify that regional planning responsibilities of RTOs and ISOs include planning for resilience, especially in WIRES' view the prevention or mitigation of loss or disruption of critical transmission infrastructure and its services.

In support of these recommendations, WIRES respectfully submits the following Comments and the appended paper on transmission and resilience written by economists and utility analysts at The Brattle Group, entitled *Recognizing the Role of Transmission in Electric System Resilience.*

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[3] *New York v. FERC*, 534 U.S. 1, 16-17, 19-20 (2001); *S. Carolina Pub. Service Authority v. FERC*, 762 F.3d 41 (D.C. Cir. 2015).

[4] *E.g.,* "[T]he Commission should articulate in this docket that the regional planning responsibilities of RTOs include an obligation to assess resilience. After confirming that resilience is a component of such planning, the Commission should also consider initiating rulemakings or other proceedings to further articulate the role of RTOs in resilience planning to include, among other things, thresholds to mitigate and build." Comments and Responses of PJM Interconnection, L.L.C., (PJM Comments) at p. 81.

I. Defining Resilience to Incorporate Transmission Network Considerations

A. Grid Resilience Has Many Components

The Commission's goals in this proceeding are to (1) develop a common understanding or definition of resilience, (2) determine how each ISO and RTO assesses resilience in its footprint, and (3) ascertain whether the Commission ought to take action in furtherance of a more resilient grid, based on the information submitted herein. In WIRES' view, resilience as generally defined[5] entails the identification and mitigation of vulnerabilities and threats to the system, plus the ability to absorb, adapt to, and recover from disruptive events as they occur. There is a critically important human resource and coordination component to resilience as well. Resilience is distinguishable from reliability in the sense that a reliable system may not be resilient, and resilience does not ensure that lights stay on day-to-day. Fundamentally, resilience focuses on low-frequency, high-impact disruptions; however, the Commission is cautioned not to unduly limit the category of system vulnerabilities or potential impacts for which it might require planning, preparation, or recovery measures, recognizing that the frequency and extreme impact (in economic, environmental, or human terms) of events and developments that are unprecedented or occur without warning can be difficult to predict.

Commenters in this proceeding offer several similar definitions of resilience. Whichever the Commission concludes will help it support strengthening of the grid, there is no silver bullet for achieving an optimally resilient electric system. Industry and the Commission must plan for the unforeseeable by taking into account the various processes, practices, and investments that could contribute to preventing or effectively resolving the effects of system disruptions without undue delay. Most RTO/ISO comments focus on what has been called "precaution-based

[5] Resilience is defined by the DOE and the National Infrastructure Advisory Council ("NAIC") as the ability to reduce the magnitude and/or duration of disruptive events, including physical changes to infrastructure known as "hardening." Reliability is defined by the North American Electric Reliability Corporation ("NERC") as a function of adequacy, which is the ability of the system to supply aggregate electric power and energy at all times. *See* U.S. Department of Energy, *Staff Report to the Secretary on Electricity Markets and Reliability*, August 2017, at pp. 61-63 ("*DOE Staff Report*") *See also*, the important consensus study report of The National Academy of Sciences, *Enhancing the Resilience of the Nation's Electricity System* (2017), which takes a comprehensive view of grid resilience, offers a series of practical recommendations in moving toward a more resilient grid, and recognizes the importance of involving state and regional grid operators, emergency preparedness organizations, and national and state regulators. (https://doi.org/10.17226/24836.) For a description of NERC's enterprise activities that support the NAIC outcome-focused framework for addressing resilience challenges, see Mark Lauby, "Resilience Framework", WIRES Winter Meeting, at http://wiresgroup.com/docs/WIRES%20Winter%20Mtg%202018%20Lauby.pdf

strategies" to advance resilience, meaning identifying vulnerabilities and employing industry best practices to thwart or mitigate the economic or adverse health effects of potential power disruption, and "discourse-based strategies" that raise awareness, share information, and initiate collective action.[6] On the whole, the recommended solutions involve operational flexibility and coordination, improving generation services, and market reforms.[7] In WIRES' view, these precautionary, coordination, and mitigation strategies must also focus directly on infrastructure investment solutions. Most disruptions of consumers' access to electricity occur at the distribution level[8] but are a distinguishable resilience challenge from disruptions of the high-voltage transmission service which, while quite infrequent, can result in widespread and possibly prolonged power outages and resulting damage. The transmission system must therefore be prepared to withstand disruptions and to mitigate the potentially broad or severe consequences that flow from severe weather, physical attack, or disruption of generation supplies or system operations. In such cases, the resilience that a robust and integrated transmission network provides is of critical importance.

Regional power markets, grid infrastructures, and operating circumstances differ but, as a rule, generation and fuel supply policies offer only a limited hedge against potential disruption. Moreover, while distributed resources are important for rapid recovery, they are of limited long-term capability without the grid's transfer capabilities.[9] A robust grid offers resource diversity and operational flexibility that is critically important to both prevent and recover from service disruptions. Transmission investment ensures system stability and productivity during normal operations and optionality when disruption strikes. New investments in transmission expansion and upgrades that reflect deliberate consideration of the benefits of this optionality will add

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[6] PJM *Comments* at p. 14 *et seq.*

[7] On the operations side, transmission owners and operators manage and operate key resilience and reliability measures, including emergency drills, spare parts inventories, mutual assistance, long-term system planning, routine monitoring, operation scheduling, dispatch and maintenance, and system restoration and recovery. Silverstein, "Transmission and power system resiliency," presented at WIRES Winter Meeting, at http://wiresgroup.com/docs/WIRES%20Winter%20Mtg%202018%20Silverstein.pdf

[8] According to the Department of Energy's *Quadrennial Energy Review* (2017), failures on the distribution system are typically responsible for more than 90 percent of electric power interruptions, both in terms of the duration and frequency of outages. Such interruptions of service, while unpleasant, are relatively routine, often predictable, and typically of short duration. *See* the appended study by The Brattle Group (Chupka and Donohoo-Vallett), *Recognizing the Role of Transmission in Electric System Resilience*, prepared for WIRES (May 9, 2018), at p. 7.

[9] *See* London Economic International, *Market Resource Alternatives: An Examination of New Technologies in the Electric Transmission Planning Process*, a Report for WIRES (October 2014) available at www.wiresgroup.com

immeasurably to system reliability and resilience. Conversely, an inadequate network of transmission facilities left unprepared and not fully modernized to ensure resilience against threats to system stability and operations will increase the risk of greater and more prolonged economic losses from unanticipated events.[10] To the extent resilience is predicated on having multiple ways to respond effectively to adverse events and developments not yet foreseen, or perhaps not foreseeable, a robust transmission network that affords operators the ability to marshal diverse resources may be the best investment compared to even fuel-secure generation resources.

WIRES' recognizes that a variety of measures will contribute to making the electric system more resilient, including access to diverse sources of electric generation, essential ancillary services such as frequency and voltage support, resource flexibility in the form of storage and other new technologies, storm hardening of infrastructure, mutual assistance programs, and reliable supplies of fuels like natural gas as well as long-term plan to address the vulnerability of substations and transmission system to high impact, disruptive events. It expects the Commission will receive numerous thoughtful comments in this proceeding.

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[10] The vulnerabilities of specific grid components demonstrates the risks of inadequate transmission: For example, substations and transmission systems are critical to get power from generators to load, so increasing the resilience of the transmission system is just as important as improving the resilience of supply resources. A generator with sufficient fuel supplies cannot contribute to increased reliability and system resilience if the congested transmission system prevents it from delivering its energy. As the generation and fuel mix in regional markets changes and evolves, and as climate and technological disruptions pose new challenges to the grid, another cycle of transmission expansions and upgrades will be a top priority.

Second, measures that ensure protection of the transmission system from potential physical or cyber intrusion provide more consequential risk mitigation than the concerns about the unavailability of on-site fuel. Damage to transmission and distribution structures and substations can take weeks to repair, even assuming replacement parts are available.

Third, some parts of the transmission system are extremely over-used, potentially leading to severe operational constraints that make it vulnerable to outages of individual elements. Transmission planning predicated on establishing a more flexible and more liquid bulk electricity markets would result in at least as great an enhancement to reliability and resilience of the electric system as any other major investment. The CEO of the North American Electric Reliability Corporation ("NERC") acknowledged as much when describing the most pressing reliability issues in North America. In a letter to the Secretary of Energy, cited in the DOE Staff Report, the NERC CEO made clear that electric transmission is one of the critical methods of addressing reliability concerns in a more decentralized electric system environment where generation is also being retired, when he stated: "Because the system was designed with large, central station generation as the primary source of electricity, significant amounts of new transmission may be needed to support renewable resources located far from load centers.." *DOE Staff Report*, at pp. 62-63.

Recommendations for action may vary widely depending on local and regional risks and conditions. That said, WIRES maintains that robust transmission facilities and interconnections will be essential to mitigating risks faced by virtually any electric power system.

The RTO/ISO responses in this proceeding generally emphasize the need for timely operational responses to disruptions. However, they acknowledge that resilience will also be measured by the robustness of the physical infrastructure and its inherent ability – as an integrated network -- to withstand shocks or absorb them and still provide operators with options for bringing additional generation and technological resources to bear on a problem. The existence of alternative supplies of energy and the means to deliver them through transmission, the grid's inherent flexibility, and broader access to an assortment of technologies – from storage to microgrids, demand response, and other distributed resources – are the essential characteristics of a fully developed and integrated wired network.

B. The Benefits of Transmission Should Be Central to This Proceeding

The multiple benefits of electric transmission investments are well-documented. The blackouts of the 1960s (e.g., in New York City) triggered the expansion of regional transmission interconnections such that neighboring regions could assist each other under adverse circumstances. A number of studies have found that expansion and integration of transmission links today would provide additional benefits due to the diversity of loads and resources and the dispatchability of new technologies.[11] These studies support the proposition that the U.S. is not investing in enough transmission infrastructure, particularly transmission designed to deploy new technologies or interregional transmission, to ensure that all customers have access to lower cost energy resources and that wholesale energy markets can discipline electricity prices.[12] In fact, the 2017 DOE Staff Report acknowledges that the flexibility and resource

[11] The results of several U.S. and European analyses of the benefits of diverse kinds of transmission projects are summarized in The Brattle Group, *Well-Planned Electric Transmission Saves Customer Costs: Improved Transmission Planning Is Key To The Transition To A Carbon-Constrained Future*, June 2016 ("Brattle 2016 Study"), Section III, at pp. 6 – 11. Domestic studies by the Southwest Power Pool, the Midcontinent ISO, the Eastern Interconnection States Planning Council, the Eastern Interconnection Planning Collaborative, and the Western Electricity Coordinating Council show that forward-looking planning of regional and interregional transmission that takes into account the range of benefits of transmission results in substantial net benefits to consumers, the economy, and the environment.

[12] Interregional transmission planning is still in its infancy and, despite the call for it in Order No. 1000, interregional projects are not developing as expected or as needed. Improving interregional planning and expanding interregional interties would provide a unique opportunity to improve the resilience of the nation's grid. *See also*, The Brattle Group, *Toward More Effective Transmission Planning: Addressing the Costs and Risks of An Insufficiently Flexible Electricity Grid*, April 2015 ("Brattle 2015 Study");

integration benefits provided by transmission contribute to both resilience and consumer savings:

> Transmission investments provide an array of benefits that include providing reliable electricity service to customers, relieving congestion, facilitating robust wholesale market competition, enabling a diverse and changing energy portfolio, and *mitigating damage and limiting customer outages (resilience) during adverse conditions.* Well-planned transmission investments also reduce total costs. . . .
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> A robust transmission system is needed to provide the flexibility that will enable the modern electric system to operate. Although much transmission has been built to enhance reliability and meet customer needs, continued investment and development will be needed to provide that flexibility.[13]

C. The Special Insurance Value of Robust Grid Infrastructure

Transmission provides a significant measure of insurance against risks associated with future uncertainties.[14] For instance, regardless of how fast load grows or precisely how much renewable generation is built in one location versus another, a robust transmission grid facilitates the delivery of low-cost electricity. Such insurance comes with widening options for the future, which in turn will be very valuable as both federal and state policymakers consider a variety of possible strategies for meeting future energy needs,

The industry (through NERC reliability standards) has been improving reliability-based planning of the transmission grid. Planning to meet immediate reliability objectives differs from economics-driven planning or planning transmission to meet public policy goals. In 2015, a study written for WIRES by The Brattle Group discussed extensively the "insurance value" of a more robust transmission grid from an economic planning perspective.[15] Economic transmission planning should be modified to ensure consideration of this insurance value against economic disruptions caused or exacerbated by insufficient transmission. If transmission planning were to include serious consideration of the long-term benefits of a more

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The Brattle Group, *The Benefits of Electric Transmission: Identifying and Analyzing the Value of Investment,* July 2013; *Also*, Southwest Power Pool, *Benefit Metrics Manual*, May 8, 2017. All are available at www.wiresgroup.com.

[13] DOE Staff Report, at p. 75 (emphasis added).

[14] For further discussion of transmission planning as a risk mitigation tool, *see* the appended study by The Brattle Group, *Recognizing the Role of Transmission in Electric System Resilience*, at pp. 16-19.

[15] Brattle 2015 Study, at pp. 17, 36-37, 40.

resilient regional and interregional grid, such an improvement would likely produce significant reliability and resilience benefits that would dwarf the benefits of prolonging the operation of power plants that the market has already determined are uneconomic and excessively costly to operate.

II. SPECIFIC COMMENTS AND RECOMMENDATIONS

A. Holistic Transmission Planning Supports Resilience

In a 2015 study for WIRES, The Brattle Group delineated the benefits of holistic and anticipatory transmission planning:

> One of the most strategically significant aspects of major new transmission projects that is seldom taken into account explicitly in the planning phase is the multiple purposes that transmission might serve. That is, a well-designed transmission system enhancement will not only enable the reliable transfer of electricity from Point A to Point B—it will also strengthen and increase the flexibility of the overall transmission network. Stronger and more flexible networks in turn, create real options to use the transmission system in ways that were not originally envisioned.[16]

Consistent with Brattle's findings, WIRES has long advocated for transmission planning that seeks to evaluate and capture the full range of potential benefits of proposed projects. Resilience is another such driver, but RTOs and ISOs are under no current obligation to conduct the kind of risk-based analyses that commenters are developing in this and other proceedings. In general, the current practice of focusing almost exclusively on reliability needs tends to steer policymakers and regulators away from regional and interregional transmission planning approaches that can reduce risks and long-term customer costs. Planning for reliability is a well-understood first resort because the benefits are near term and quantifiable. Beyond the important task of hardening local systems, developing infrastructure, and instituting practices that ensure resilience present a different set of planning problems because risks differ among locales and regions and across time. Identifying system vulnerabilities is a first step.

However defined, grid resilience entails "hardening" the larger, interconnected system against low-frequency, high-impact (and potentially high cost) threats and configuring that system to prevent or reduce disruptions. Planners are always faced with uncertainty, but making the grid more resilient requires them to discern potential risks and clear trends

[16] *Brattle 2015 Study*, at p. 5. Economists at the Brattle Group strengthen that point in the paper appended to these Comments.

surrounding major threats, and to try to understand these uncertainties in terms of their potential magnitude and timing. If transmission infrastructure can be more proactively-planned, policy makers, operators, and customers will ultimately have a much wider range of valuable options with which to cope with future challenges. They will be able to choose among those options with lower risks and costs. Ensuring, for example, that major load centers are served flexibly by diverse kinds of resources that are accessible through several major and possibly redundant delivery paths is critical insurance against extended disruptions and escalating consumer costs.

B. New Approaches to Planning Infrastructure for Resilience

As noted earlier, while resilience is closely related to a traditional conception of reliability, it is also fundamentally unique because it seeks to achieve a different end state – namely, a power grid that can withstand or quickly recover from low-frequency, high-impact events, and one in which key system vulnerabilities have been considered and mitigated. Efforts to proactively plan the transmission grid to be more resilient will require consideration of a unique set of parameters and criteria. Broadly conceived, transmission planners seeking to bolster resilience must: 1) conduct an assessment of system vulnerabilities, 2) evaluate a set of low-frequency, high-impact events and model their impacts on the system, and 3) develop criteria to evaluate mitigation strategies to address the identified vulnerabilities. Complicating matters, resilience planning can be evaluated by traditional benefit-cost analysis only when the potential threat is identified; however, it is difficult to identify low probability threats or to assess the likelihood of such potential threats.

To be clear, current forms of transmission planning may have the "side effect" of promoting resilience because transmission, by its very nature, is integral to the successful delivery of power from generation to load. However, existing transmission planning drivers (reliability, economics, and public policy) are not necessarily designed or intended to provide a basis for addressing resilience as a primary rationale for investment. Thus, today's processes may not result in the desired end state – a more resilient power delivery system. To remedy this, WIRES believes that resilience must now be expressly considered as a transmission planning driver, to be studied and incorporated within any regional and interregional RTO planning process. RTOs and ISOs should report annually on the extreme events considered in their specific resilience-focused scenarios and on the actions, if any, arising from their review of the grid's performance and resilient characteristics.

WIRES notes that, in answering the Commission's request, the RTOs and ISO's have offered a range of views on how, or whether, resilience is currently being addressed within each of their regions. Like these commenters, WIRES acknowledges the importance of efficient operations, better monitoring and control technology, physical interconnectedness between systems, and trained personnel[17] in promoting resilience. PJM notes in its comments that resilience is related to reliability, but it also affirms the distinctive nature of resilience. PJM also recognizes the crucial role that transmission planning plays in ensuring resilience.[18] On both counts, WIRES agrees. By contrast, other regions largely confine their responses to a description of existing processes, and thus do not fully address resilience or its implications for transmission planning. ISO-New England, meanwhile, focuses largely on fuel security, an important issue in its own right (especially in that region) but only one part of a comprehensive approach to resilience.

WIRES contends that RTOs and ISOs should play a central role in addressing resilience through transmission-focused solutions, as part of a broader resilience strategy. Of course, utility efforts to harden systems, replace aging infrastructure, and coordinate operations offer clear resilience benefits and should be recognized in any policy actions taken by the Commission.[19] However, as regional transmission planners and operators, RTOs and ISOs are well-placed to identify regional vulnerabilities and consider mitigation strategies as part of their regional transmission planning processes.[20] In fact, effective transmission planning can be the

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[17] These strategic components of resilience are exemplified by the recent observation by Admiral Jim Eckelberger , Board Chairman of the Southwest Power Pool, to the effect that an RTO must look externally, not just internally, for the ingredients of real resilience – stating that SPP's interconnection to ERCOT is "next to zilch", to the West it is "good but not great", and to the east the interconnections "has been almost academic, as opposed to real." FERC ought to study "much more about how can neighbors help neighbors. It's part of the deficiency of our national system, and it ought to be highlighted." Quoted in *Megawatt Daily*, *FERC Resiliency Effort Needs Broader Coordination Study: SPP Stakeholders*, at p. 4, Feb. 26, 2018.

[18] "PJM is actively evaluating how to incorporate resilience into the planning process, including discussions regarding (a) making sure that system changes done as part of the Regional Transmission Expansion Plan do not make the [Bulk Electric System} less resilient, (b) developing procedures to compare solution alternatives and ensure selection of the alternative that enhances resilience, and (c) developing resilience criteria where the system has vulnerabilities that require mitigation. . . .To be clear, RTO resilience planning not only includes traditional transmission planning, but also an enhanced role in guiding regional restoration planning efforts." PJM Comments, at p. 33.

[19] Individual utilities have an important role to play in ensuring resilience, as these utilities constitute the first line of defense against potential threats.

[20] Increasingly, RTOs utilize scenario planning in anticipation of possible developments 10 to 15 years (or more) in the future. Those needs may include differences in locations and rates of load growth, different locations and rates of renewable generation, and thermal generation retirements. These changes involve determining the long term needs for transmission expansions and upgrades in anticipation. *See*, *e.g., Joint Comments of the Electric Reliability Council of Texas, Inc. and the Public Utility Commission of Texas*, at p. 9. ("Comments of ERCOT and PUCT").

most critical element of ensuring system resilience. For example, as part of its scenario planning to correct reliability criteria violations, ERCOT develops a corrective action plan that "typically involves building new transmission facilities."[21] Planning for resilience should likewise incorporate transmission solutions. As stated by the PJM Interconnection, "System resilience should be a consideration in the evaluation of planning solution alternatives so that PJM can select solutions that enhance the resilience of the system and address other system needs. Furthermore, resilience vulnerabilities that are significant enough to warrant a transmission system enhancement designed specifically to mitigate the resilience vulnerability could be designed and integrated into the (Regional Transmission Expansion Plan]."[22]

In short, WIRES advocates for further action to ensure that planning processes exist that will directly address grid resilience. WIRES respectfully requests the Commission to do the following:

- First, the range and complexity of resilience issues argue for extending this Commission proceeding in order to consider generic enhancements to the RTO/ISO transmission planning processes established under the Commission's authority to ensure that strong and cost-effective grid infrastructure is a principal tool for anticipating and mitigating the risks and heavy costs that disruption of bulk power markets could impose on the health and economic welfare of the American public. In WIRES' view, grid resilience can only be ensured if regional and interregional transmission enhancements are part of the solution. The Commission should examine whether, in pursuit of a more resilient grid, it should require RTOs and ISOs to integrate (or demonstrate that they have integrated) resilience planning into their regional and interregional transmission planning processes. While planning for resilience necessarily entails coordination and facilities expansion across regions and between markets, each region should be afforded such flexibility as is needed to promote and enhance grid resilience in a manner that reflects the operating characteristics of that region, including the

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[21] *Id.*, at p. 7. "When planning new transmission projects, ERCOT strives to build greater resilience into the system. This includes considering the geographic diversity of transmission lines serving a load center. . . . When appropriate, ERCOT has also conducted studies to determine the potential contingency impacts of placing a proposed line in a common right-of-way with one or more existing transmission lines." *Id.*at p. 8

[22] Comments of PJM, at p. 50

likelihood of particular adverse events or threats. However, as the above-cited RTO/ISO observations demonstrate, planning for adequate transmission investment is an accepted, valuable, and workable part of making any regional grid or any interregional systems more resilient.[23]

- Second, in order to make certain that RTOs and ISOs can effectively carry out any Commission planning directives that might come from this proceeding, FERC should first clarify that resilience is included in its existing statutory authority to promote reliable operation of the Bulk Electric System (BES). This is essential given the newness of resilience as a planning issue and the potential risks that uncertainty or ambiguity could create for RTOs/ISOs and Commission policy. Likewise, certainty in the administration of new policy must be provided by clarifying that the regional planning responsibilities of RTOs and ISOs also includes planning for resilience.

- Finally, the Commission should update its prescribed planning principles and criteria as they apply to resilience objectives through its rules or tariff requirements for regional grid operators and planners. That should entail updating its Order 890 transmission planning principles to include resilience as a planning driver.

CONCLUSION

WIRES anticipates that the Commission's focus on resilience can and should drive significant portions of its electric power policies. It also anticipates that, together with reliability issues, the economic benefits of a more integrated electric power system, the need to deploy and dispatch new technologies, the bulk power market's evolution, and public policy, transmission development will be driven by the need for greater resilience in the continuous delivery of electricity. In that sense, this proceeding can be part of a larger focus and initiative that prepares the grid for a more intensely electric and economically dynamic future. WIRES looks forward to further Commission deliberations on the role that transmission grid upgrades, modernization, and planned resilience will play in determining the future health and effectiveness of the North American economies.

[23] Similar recommendations are made by the PJM Interconnection in response to several of the Commission's questions. PJM Comments at pp.32-34, 40-41, 48-52.

WIRES wishes to thank the Commission for initiating this proceeding and considering WIRES' Comments about the importance of transmission investment as a resilience strategy.

Respectfully submitted,

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APPENDIX

"RECOGNIZING THE ROLE OF TRANSMISSION IN ELECTRIC SYSTEM RESILIENCE"

The Brattle Group (May 9, 2018)

Recognizing the Role of Transmission in Electric System Resilience

PREPARED FOR

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May 9, 2018

THE Brattle GROUP

This report was prepared for WIRES. All results and any errors are the responsibility of the authors and do not represent the opinion of The Brattle Group or its clients.

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Table of Contents

Executive Summary ii
I. Introduction 1
II. The Transmission Network Enables Bulk-System Resilience 3
III. Transmission System Investments Improve Electricity System Reliability and Resilience 7
A. Developing a More Robust Transmission Network 8
B. Ameliorating Damage Arising From an Event 11
C. Recovering Quickly to Restore Service After an Event 13
D. Learning Resilience Lessons 14
IV. Anticipating Resilience Challenges 15
A. Operational Response Exercises 15
B. Transmission Planning 16
V. Conclusion 19

Executive Summary

Resilience of the electric power system is the ability of the nation's electricity infrastructure to prevent or diminish damage from high-impact, low-probability events without undue disruption and to rapidly restore service when such disruptions occur. The robustness and flexibility of the high-voltage transmission grid will be critical to the FERC's consideration of electric system resilience for two reasons that track the definition of resilience itself:

- First, the transmission grid can absorb the damage potentially arising from multiple local generator outages without customer service disruptions by providing access to a network of technologically diverse and geographically dispersed set of power supplies. When sufficiently robust to maintain the flow of power under stressful conditions, transmission systems are inherently resilient.
- Second, the transmission sector has been pursuing investments in both physical assets and operational changes that strengthen the ability of the regional and inter-regional transmission grid to keep operating when challenged by adverse events and to aid the rapid restoration of service when damage and customer outages do occur.

The Federal Energy Regulatory Commission (FERC) can recognize the central role of the transmission grid in promoting electric system resilience by: (1) continuing to support an array of investments to strengthen the transmission grid and (2) expanding the role of resilience in regional and inter-regional transmission planning to build upon and expand the inherent resilience benefits that the transmission grid already provides.

Transmission planning has thus far focused primarily on the distinguishable (and valid) need for reliability in the short run. Accounting for the "insurance value" of a more flexible and robust transmission grid in the long-run can protect consumers from costly disruption during severe adverse events that likely will happen without forewarning of their timing, location, and severity. Like any insurance policy, transmission-focused planning and investments could provide cost-effective solutions to address fuel security concerns in some regions without requiring a redesign or rethinking of the competitive generation markets that have produced substantial consumer benefits. Finally, the FERC should consider resilience in addition to the Order 1000 goals of reliability, economics, and public policy, as a planning objective for both regional and inter-regional transmission expansion to help insure against large-scale disruption of electricity supply. This would represent an important step forward in transmission planning analysis and improve overall electric system resilience.

I. Introduction

The business of generating, transmitting and delivering electric power has always involved a singular focus on "keeping the lights on" under all possible conditions, regardless of what labels – such as "reliability" or "resilience" – are used to describe the primary goal. Recently, concerns about the security and availability of generating fuels such as natural gas have been identified as potential threats to the resilience of the electricity system. This recent focus on generation has diverted attention from other key segments of the industry – particularly the high-voltage transmission grid – that traditionally have been and should continue to be a central focus of efforts to enhance resilience. This study explores the important role that transmission plays in grid resilience and how policies and investments directed at strengthening the transmission system can cost-effectively enhance the resilience of electricity supply.

In contrast to the well-developed and intensively-managed issue of electric service reliability, the understanding and analysis of electricity grid resilience is still developing. The concept of resilience focuses on how critical infrastructure manages through and, when necessary, recovers from high-impact, low-probability events such as severe weather or physical or cyber-attacks. For this report, we follow the widely-cited 2009 National Infrastructure Advisory Council (NAIC) definition of infrastructure resilience as:

> The ability to reduce the magnitude and/or duration of disruptive events. The effectiveness of a resilient infrastructure or enterprise depends upon its ability to anticipate, absorb, adapt to, and or rapidly recover from a potentially disruptive event.[1]

This definition was expanded upon in a follow-up 2010 report, *A Framework for Establishing Critical Infrastructure Resilience Goals*, to include a resilience construct based on robustness, resourcefulness, rapid recovery, and adaptability as shown in Figure 1.

1 National Infrastructure Advisory Council, *Critical Infrastructure Resilience: Final Report and Recommendations,* September 8, 2009, p. 17.

Figure 1: The Sequence of the NIAC Resilience Construct

Source: National Infrastructure Advisory Council, *A Framework for Establishing Critical Infrastructure Resilience Goals: Final Report and Recommendations by the Council,* October 19, 2010.

The evolution of the modern bulk power system, from municipal central stations serving local customers to large regional and interregional networks connecting distant resources to growing loads, has been driven by the inextricably linked goals of resilience, reliability, and economics. Increasing the geographic size or "footprint" of the bulk power system through transmission interconnection allows customers to capitalize on economies of scale and scope in energy, capacity, and reserves. As far back as the 1965 blackout that affected 30 million customers in the eastern United States and Canada, the recommendation has been to move toward more connected systems. The official report on the 1965 blackout states, "Isolated systems are not well adapted to modern needs either for purposes of economy or service" and recommended "… an acceleration of the present trend toward *stronger transmission networks within each system and stronger interconnections between systems* in order to achieve more reliable service at the lowest possible cost."[2]

As the connection between bulk power generation and the local distribution system to serve retail customers, the transmission system is critical to the overall performance of the power sector and its resilience when challenged by infrequent but significantly adverse events. Strengthening the resilience of individual generators or the generation fleet overall will not increase the overall resilience of the system if the power cannot be delivered into an intact distribution system to serve customer loads. This applies within a recognized transmission region within Regional Transmission Organizations (RTOs) and between regions. Within regions, the

[2] Federal Power Commission, "Report to the President on the Power Failure in the Northeastern United States and the Province of Ontario on November 9-10, 1965," December 6, 1965. p. 43 (emphasis added).

transmission network connects a diverse set of generators to distribution systems that serve customers. Inter-regionally, the transmission network connects neighboring systems to increase overall reliability and resilience by providing access to additional generation resources to increase benefits of trading across regions and for providing resources during emergency situations. Finally, transmission has been recognized as critical infrastructure since the resilience concept was defined, and therefore policies and investments to strengthen the transmission system have been central to the electricity industry's overall effort to promote and enhance resilience.[3]

This report highlights how existing transmission contributes to power system resilience and describes how evolving policies and new investments in transmission will further enhance power system resilience. In the next section, we explain how the transmission system helps maintain or restore power in cases where multiple simultaneous generation failures might threaten customer disruptions. We follow this with a discussion of how policies and investments in the transmission system mitigate vulnerabilities of the transmission system to high-impact low-probability events that can compromise resilience, and then we conclude by discussing how transmission owners and operators anticipate future resilience challenges through preparation and planning.

II. The Transmission Network Enables Bulk-System Resilience

The power system can be vulnerable to disruptions originating at multiple levels, including events where a significant number of generating units experience unexpected outages. The transmission system provides an effective bulwark against threats to the generation fleet through the diversification of resources and multiple pathways for power to flow to distribution systems and ultimately customers. By providing customers access to generation resources with diverse geography, technology, and fuel sources, the transmission network buffers customers against extreme weather events that affect a specific geographic location or some external phenomenon (unavailability of fuel and physical or cyber-attacks) that affect only a portion of the generating units. In addition to other economic and reliability benefits, these resilience benefits occur both within and between regions.

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[3] See, for example, *Hardening and Resiliency: U.S. Energy Industry Response to Recent Hurricane Seasons,* U.S. Department of Energy, August 2010.

On a regional basis, transmission networks provide customers with access to a variety of generators, where resource and fuel diversity decreases the vulnerability to common mode failures and promotes resilience. For example, the transmission networks provide Southern California customers access to hydropower from the Pacific Northwest, nuclear energy from Arizona, solar and wind power from neighboring states, and natural gas generation from neighboring states. As a result of this diversity, customers did not experience interruption when the 2.2 GW San Onofre nuclear power plant unexpectedly shut down in 2012 and then officially retired in 2013. Likewise, southern California customers did not experience outages from the 2011-2016 drought, which affected the state's entire hydropower fleet,[4] or the 2015 Aliso Canyon gas leak, which affected natural gas availability for a whole fleet of generating plants in southern California. While the fuel diversity among generators may exist over geographic regions, customers only benefit from such diversity when these resources are interconnected through the transmission network.

The broad geographic scope of the transmission system provides resilience to the system. For example, severe or extreme weather events typically affect only a portion of the region served by the wider grid. During and following such an event, customers in the affected regions are able to draw power from unaffected generating plants through the regional transmission system. For example, during a cold snap in January 2018 that significantly affected MISO South, power flows from MISO into MISO South (parts of Arkansas, Louisiana, Mississippi and Texas) briefly exceeded the contractual regional directional transfer (RDT) limit, enabling MISO South to avoid load shedding. By drawing power from the rest of MISO, the southern region maintained power delivery during a period of record demand and significant generator outages.[5]

The diversity of the resources interconnected through the transmission network also provides robustness to cyber or physical attacks waged against a specific generator type, fuel source, or utility service area. From a reliability perspective, the bulk power system is designed to withstand outages, and a certain level of unexpected generator outages are part of standard

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[4] According to the California Department of Water Resources, this included four of the driest consecutive years on record, 2012-2014. California Department of Water Resources, "Water Year 2017: What a Difference a Year Makes," September, 2017. p.2

[5] See "Exceeding transmission limits prevented MISO South blackouts in Jan: IMM" by Mark Watson, *MW Daily*, March 27, 2018.

operating and planning procedures within the power system. From a resilience perspective, should multiple units within a region or a type of generating station across regions become unavailable to supply power, operators will be able to draw from other, unaffected and available resources to the extent enabled by the transmission network.[6]

If an adverse event overwhelms the regional ability to absorb or manage the event, inter-regional transmission connections allow regional operators to "lean" on neighbors for emergency support. Thus, in cases where generation outages in one region threaten reliability, interties with neighboring regions can substitute for the inadequate generating capacity within that region. The weaknesses associated with lack of inter-regional transmission were vividly on display during the 1965 Northeast Blackout, which affected more than 80,000 square miles and 30 million customers across the United States and Canada with most outages lasting several hours.[7] Recognition that stronger interregional transmission links could have prevented these outages led to the expansion of the transmission grid into the large regional networks we rely on today.

The reliability benefit of such regional and interregional transmission network has not changed since. A 2013 study that Brattle and Astrape Consulting conducted for FERC found that interties offer substantial benefits from both a physical reliability and economic perspective:

> Strong interties with neighboring regions provide both economic and physical reliability value during peaking conditions. Load and generation diversity mean that the most extreme scarcity conditions are unlikely to occur at the same time in neighboring markets.[8]

As the quote above implies, when regional resource adequacy is threatened because of a lack of generation diversity, then interties with neighboring systems with a different fuel and technology mix (one less affected by the conditions adversely affecting specific regional

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6 This does not negate the potential for events for which insufficient power is capable of importing into the region or regions with units unexpectedly out of service.

7 A tripped relay in Ontario caused the outage, which then cascaded through New York and New England; all service was restored within 14 hours. Additional interregional transmission capacity could have mitigated the outage. See Federal Power Commission, "Report to the President on the Power Failure in the Northeastern United States and the Province of Ontario on November 9-10, 1965," December 6, 1965.

8 See Johannes P. Pfeifenberger, Kathleen Spees (Brattle) and Kevin Carden, Nick Wintermantel (Astrape) *Resource Adequacy Requirements: Reliability and Economic Implications,* September 2013, p. 57, found at https://www.ferc.gov/legal/staff-reports/2014/02-07-14-consultant-report.pdf.

resources) can provide a cost-effective alternative to retaining or building new resources to address generation diversity or overreliance on a particular fuel. One of the steps taken by PJM during the Polar Vortex episode in the Eastern U.S. in January 2014 was to access energy and reserves from adjacent regions on an emergency basis, which helped manage shortages within the RTO.[9] The potential value of creating resource diversity through inter-regional interconnection is well illustrated by ISO New England's analysis of diminishing its heavy reliance on natural gas combined with natural gas delivery constraints.[10] One option studied to address the current lack of fuel diversity in New England is the expansion of interregional transmission from New York, Quebec, and New Brunswick designed in part to access more hydro and other renewable generation facilities located in Canada.[11]

The ability for transmission systems to increase reliability and resilience of regional or inter-regional power systems is dependent upon the strength of interconnections. This strength depends both on the number of lines and the capacity of those transmission lines. In its comment to FERC, PJM noted that transmission designs that are "robust and electrically dense" (compared with sparse networks) provide resilience benefits.[12] A dense network with many interconnections is more resilient as power can flow over many parallel routes. The ability for that power to flow, however, is dependent upon having sufficient capacity. Thus, to realize resilience benefits, the transmission network must be able to provide capacity beyond the normal day-to-day level, and perhaps even beyond the anticipated stress scenario utilization of the facilities.[13] Transmission planning should take into account the potential resilience value of investments when considering expansion projects.

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9 See *Analysis of Operational Events and Market Impacts During the January 2014 Cold Weather Events,* PJM Interconnection, May 8, 2014, p. 19-20.

10 See for example, ISO New England, "Operational Fuel-Security Analysis," January 17, 2018.

11 Ibid.

12 *Comments and Responses of PJM Interconnection, L.L.C.*, Docket No. AD18-7-000, March 9, 2018, p. 43.

13 Transmission lines are typically rated for both "normal" and "emergency" operation, with the "emergency" rating available for short time periods of overloading. For the transmission system to accommodate unanticipated and potentially large flows for a sustained period, the headroom created through emergency ratings may be insufficient.

III. Transmission System Investments Improve Electricity System Reliability and Resilience

Although recent concern surrounding electric system resilience has focused on fuel security and resource adequacy, inadequate generation almost never results in customer outages. Instead, the vast majority of customer outages occur from damage to distribution systems caused by such events as severe storms. According to the Quadrennial Energy Review:

> Failures on the distribution system are typically responsible for more than 90 percent of electric power interruptions, both in terms of the duration and frequency of outages. Damage to the transmission system, while infrequent, can result in more widespread major power outages that affect large numbers of customers and large total loads.[14]

Because the transmission system has been designed to withstand contingencies and adverse conditions, the transmission network routinely experiences severe weather events without causing customer outages. When the robustness of the transmission infrastructure is overwhelmed, however, sustained and widespread customer outages can occur, for example when extreme weather topples transmission towers across a wide region or operators are unable to manage grid instability arising from faults or outages. Due to their broad impact, these rare events are extensively studied *ex post* to advance understanding of vulnerabilities and explore and adopt measures to reduce future impacts. As a result, much of the analysis of resilience in the bulk power system focuses on high-impact, low probability events that directly affect transmission, which has supported some policy reforms and investments to address transmission resilience issues. Nevertheless, much more can be achieved, and we discuss the evolving policies and investments relating to transmission planning, physical infrastructure development and operations below, using the four NIAC resilience elements – robustness, resourcefulness, rapid recovery, and adaptability – as a framework to describe their overall role in responding to a resilience threat or event.[15]

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14 U.S. Department of Energy, *Transforming the Nation's Electricity Sector: The Second Installment of the QER,* January 2017, Chapter 4 "Ensuring Electricity System Reliability, Security and Resilience" p. 4-29.

15 It should be noted that transmission and distribution facilities share some failure modes, particularly extreme weather damage. Because distribution facilities are more vulnerable to storm damage, some of the programs that we highlight below primarily focus on distribution infrastructure; however,

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A. DEVELOPING A MORE ROBUST TRANSMISSION NETWORK

The robustness of the transmission network, its ability to absorb shocks and continue functioning, continues to be enhanced by the hardening of existing infrastructure and increasing connectivity within and between regions. Hardening the current infrastructure makes it less vulnerable to equipment failure as a result of major events, such as severe weather or human attack. This hardening of the existing infrastructure can include upgrading the physical strength of existing infrastructure (e.g., storm resilience), relocation of assets to less vulnerable locations, increasing transmission system capacity and connectivity, adding physical or cyber security, and improving operational practices.

Storm damage to the transmission network frequently results in reinvestment into more robust infrastructure. While not nearly as vulnerable to storm damage as local distribution systems, the transmission network has suffered damage from especially severe weather events, such as the catastrophic ice storm that hit New England and Eastern Canada in 1998. That storm resulted in the collapse of 770 transmission towers,[16] and in eastern Maine, a damaged switch affected about 40% of Eastern Maine Electric Coop's customers for nine hours.[17] Overall, the transmission damage which, combined with extensive damage to distribution systems, caused outages affecting hundreds of thousands of customers for three weeks or more. Hurricane Katrina in 2005 destroyed 1,515 transmission structures and forced 300 substations offline.[18] Likewise, Superstorm Sandy affected over 200 transmission lines across the northeast and mid-Atlantic.[19]

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storms can damage high voltage power lines and substations through flooding, high winds, ice accumulation and other modes that can and do affect both transmission and distribution elements.

16 National Academies of Sciences, Engineering and Medicine, 2017, *Enhancing the Resilience of the Nation's Electricity System*, p. 13.

17 Jones, Kathleen and Nathan Mulherin, U.S. Army Corps of Engineers, *An Evaluation of the Severity of the January 1998 Ice Storm in Northern New England: Report for FEMA Region 1*, April 1998.

18 These events are described in National Academies of Sciences, Engineering and Medicine, 2017, *Enhancing the Resilience of the Nation's Electricity System*, p. 13. It should be noted that when severe weather damages both transmission and distribution systems, attributing the length of customer outages to restoring transmission or distribution may not provide an accurate appraisal of the relative impacts for specific cases.

19 Office of Electricity Delivery and Energy Reliability U.S. Department of Energy, *Comparing the Impacts of Northeast Hurricanes on Energy Infrastructure*, April 2013.

After the 2004-2005 hurricane season in Florida, the state legislature ordered the Public Service Commission to "conduct a review to determine what should be done to enhance the reliability of Florida's transmission and distribution grids during extreme weather events, including the strengthening of distribution and transmission facilities." The resulting program included inspection, forensic analysis of failed transmission structures and a schedule for upgrading and replacing vulnerable equipment.[20]

In response to physical attacks, utilities have added physical security measures following the creation of the NERC Critical Infrastructure Protection (CIP) standards. In April 2013, PG&E's Metcalf Transmission Substation was targeted by gunman, resulting in the damaging of 17 transformers. Former FERC Chairman Jon Wellinghof referred to the attack as "the most significant incident of domestic terrorism involving the grid that has ever occurred."[21] The attack caused more than $15 million in damage and took nearly a month to repair, but did not result in service disruption to customers due to the resilience of the local transmission and distribution system.[22] In Nogales, Arizona, a failed attempt to detonate an explosion at a peaking plant by igniting the diesel fuel tank in June 2014 would have affected 30,000 customers if the attack had damaged the adjacent substation. As a large infrastructure system with thousands of exposed assets, including substations and transmission lines, individual assets are vulnerable to physical attack,[23] and the CIP standards, authorized under FERC Order 802, were put in place following the Metcalf substation attack. These standards require utilities to identify and protect

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20 Florida Public Service Commission, *Report to the Legislature on Enhancing the Reliability of Florida's Distribution and Transmission Grids During Extreme Weather*, July 2007.

21 Smith, Rebecca, "Assault on California Power Station Raises Alarm on Potential for Terrorism," Wall Street Journal. Published February 4, 2014.

22 Barker, David, "FBI: Attack on PG&E South Bay Substation wasn't Terrorism," SF Gate. Published September 11, 2014.

23 In addition to the incidents discussed here, transmission insulators are frequent targets for vandalism, and transmission lines may be targeted for protest. For example, in the 1970s, protesting against a new transmission line in Minnesota, a group called the Bolt Weevils shot out over 5,000 insulators and destroyed 8 transmission towers.

Minnesota Historical Society, Minnesota Powerline Construction Oral History Project, Ed Schrom narrator and Edward P. Nelson interviewer, 1981.

key assets.[24] As physical threats to the system increase and new assets are identified as critical to system operation, transmission owners will continue to enhance physical security.

The robustness of the transmission system also has been enhanced by increasing the connectivity of the network and the transfer capabilities on those connections. When unanticipated failures do occur on the network, increased connectivity can help diminish the impact on the system and may lessen the importance of any single element failure. Essentially, operators can re-route power in response to economic, reliability, or resilience events. The 1965 blackout was an illustration of the lack of interconnectivity, but following the blackout, the transmission capacity was increased within and between New England, New York, and the mid-Atlantic regions, greatly improving the power system's reliability and resilience.

Nationally and across regional networks, transmission system regulators and operators have responded to resilience challenges by improving operational practices and creating standardization and information sharing protocols. In reaction to the 1965 blackout, NERC was created and initially established voluntary protocols. Forty years later in 2005, NERC guidelines and protocols that set forth common reliability metrics, definitions, and requirements became mandatory, in part as a response to the operational failings that precipitated the blackout that affected the U.S. Northeast/Midwest and Canada on August 14, 2003.

A December 2015 cyber-attack in Ukraine that resulted in service interruptions to 225,000 customers clearly demonstrated the potential impact of a cyber-attack on the transmission and distribution sectors. These attacks disconnected seven 110 kV substations and twenty-three 35 kV substations for three hours through disruption of the Supervisory Control and Data Acquisition System (SCADA). While focused mostly on a local transmission and distribution system assets, the event highlighted the potential vulnerability of regional power system networks to malicious cyber intrusion. In March 2018, the Department of Homeland Security issued an alert outlining how Russian government cyber actors were actively targeting U.S. energy and other critical

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24 These key assets are those that, "if rendered inoperable or damaged as a result of a physical attack, could result in instability, uncontrolled separation, or cascading within an interconnection." NERC Standard CIP-014-2. p.1

infrastructure sectors.[25] Although cyber-attacks against U.S. utilities have not yet caused sustained reported damage, the vulnerability is widely acknowledged and the industry has been actively sharing information and establishing protocols to harden against such an attack for nearly two decades. As far back as 2000, NERC established the Electricity Information Sharing and Analysis Center (E-ISAC) to share information on potential vulnerabilities, and in 2018 the Department of Energy (DOE) launched its own Office of Cybersecurity, Energy Security, and Emergency Response to prepare for and respond to cyber-attack, physical attacks, and storm damage.

B. AMELIORATING DAMAGE ARISING FROM AN EVENT

Investments in sensing equipment and control operations can allow transmissions system operators to react more quickly and effectively to system disturbance by isolating the damage and re-routing power to non-damaged areas. Re-routing power and isolating damaged areas relies on operators having access to up-to-date information on component status and access to tools and technology to re-route power flows without causing more problems. Ongoing investments in sensing equipment and potential investments in technologies that allow operators greater control of flows increase the ability of operators to manage an event as it unfolds.

Operator responses to transmission events can be prophylactic, adapting the system to accommodate a particular asset approaching failure, or responsive to an event, such as a physical attack, on the grid. Whether anticipatory or responsive, transmission owners have installed additional sensing equipment to the transmission system to provide system operators with accurate real-time system status information. For example, during hurricanes in Florida, operators were unaware in real-time of flooding in substations. Without this knowledge, operators were unable to triage the situation by removing the substations from service. In response to the outages caused by damaged substations, Florida Power and Light installed real-time water monitors at 223 substations to allow the company to proactively shut-down substations to limit and mitigate damage.[26]

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25 See U.S. Computer Emergency Readiness Team (US-CERT) Alert TA 18-074A, "Russian Government Cyber Activity Targeting Energy and Other Critical Infrastructure Sectors" found at https://www.us-cert.gov/ncas/alerts/TA18-074A.

26 This type of investment also enhances rapid recovery by avoiding repair or replacement needs.

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During the 2003 Northeast/Midwest U.S. blackout, operators did not have access to accurate information on the wider-system status, which could have helped limit the blackout's reach. The 2003 blackout was, at a high level, caused by transmission line outage in combination with operator errors. The initiating event for the blackout was a transmission line that was heated up through heavy usage, sagged, came into contact with vegetation, and then tripped offline. When that transmission line tripped offline, power flowed through alternative routes, overloading those lines, and causing cascading failures before operators were able to understand and react to the event. While the power system is planned to withstand the loss of one or several major elements, operators were initially unaware of the system outages and then failed to communicate with neighboring systems. The cascading blackout resulted in the loss of power to over 50 million customers in Canada and the United States, and the outage lasted for up to four days in some areas.[27] The economic cost of this event has been estimated between $4 billion and $10 billion.[28] In response to the need to understand and communicate operational status, over 800 phase measurement units (PMUs) that provide real-time system-status data were installed, and this data is shared within and across regions.[29] The measurements from these devices could have allowed operators to isolate the transmission failure and prevent the wide-area outages in the 2003 blackout.

New technologies and tools have the potential to allow transmission operators greater control over the flows on the network and proactively manage events. One of the central challenges to operating the transmission system is that flows on individual transmission lines are largely dictated by physics rather than a system operator's preferences or needs. The ability to actively control power flows would allow an operator to avoid, for example, overloading certain lines that may result in cascading failures. Technologies such as Flexible AC Transmission System (FACTS)

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Florida Power and Light, "FPL expects approximately 4.1 million customers may lose power at some point as a result of Hurricane Irma." News release published September 8, 2017.

27 U.S.- Canada Power System Outage Task Force, *Final Report on the August 14, 2003 Blackout in the United States and Canada: Causes and Recommendations,* April 2004. p. 1

28 National Academies of Sciences, Engineering, and Medicine. *Enhancing the Resilience of the Nation's Electricity System*. Washington, DC: The National Academies Press. 2017. p.13

29 North American SynchroPhaser Initiative, *PMUs and synchrophasor data flows in North America as of March 19, 2014,* No date.

devices and "topology control" can enhance a system operator's availability to respond to events, as well as increase the efficiency of unit dispatch.[30] Investment in FACTS devices have the potential to allow operators to change flows by modifying transmission line properties through power electronics. Likewise, transmission switching, which is actively used by ISO/RTOs, allows operators to re-route flows by disconnecting and reconnecting lines; however, this is usually executed on longer timescales (*e.g.*, seasonal). Several RTOs have analyzed new approaches that would allow topology control on operational timescales.

C. Recovering Quickly to Restore Service After an Event

Rapid recovery following a transmission event requires the inspection, replacement or repair of damaged transmission system components. These actions can require specialized workforces and components that can be expensive for individual utilities to maintain or replace; specialized workforce personnel might include helicopter pilots, and required components may include multi-million dollar assets such as large transformers. In response, utilities have been expanding sharing agreements to improve restoration time through increased access to components and workforces.

The most visible recovery initiatives in the power sector are utility mutual assistance programs, which dispatch lineman and other skilled workers to respond to large-scale events; these programs have reacted to major resilience events through a focus on nation-wide events and reorganization for improved efficiency. Electric companies organize into voluntary Regional Mutual Assistance Groups (RMAGs) and respond to regional and national events that affect multiple regions. For example, during the 2012 derecho that caused more than four million customers to lose power across the mid-Atlantic and Ohio, crews came from as far as Canada, Texas, and Wyoming to restore power,[31] and restoration following Superstorm Sandy involved crews from all RMAGs.[32] The scale of the response required for Superstorm Sandy revealed weaknesses in the organization for national-scale responses, and as a result, three RMAGs in New England consolidated into a single entity and the Edison Electric Institute (EEI) members

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30 Topology control refers to the re-routing of power by adding and remove transmission lines from service.

31 Edison Electric Institute, *Understanding the Electric Power Industry's Response and Restoration Process*, No date. p. 4

32 Ibid. p. 5

developed a framework to coordinate national responses.[33] EEI runs storm drills to prepare utilities for the nation-wide events as well table-top drills with federal organizations.[34] The scale and duration of these events qualify as tests to resilience, and although they involved damage to both distribution and transmission system elements, the repair to the transmission system was a necessary part of the restoration process.

In addition to personnel, utilities maintain spare components and form pools to maintain spare components that are too expensive or difficult to obtain for restoration purposes. There are currently industry-led sharing programs, including NERC's Spare Equipment Database, Edison Electric's Spare Transformer Equipment Program (STEP), SpareConnect, Grid Assurance, Wattstock, and the Regional Equipment Sharing for Transmission Outage Restoration (RESTORE) group. The RESTORE group, for example, includes 28 utilities that agree to sell equipment to other members following a triggering event.[35] Several of these groups arose from vulnerabilities associated with the availability of Large Power Transformers (LPTs), which have limited domestic production capabilities, long lead times, and cost millions of dollars each. Utilities also maintain stockyards with spare conductors, towers, and related equipment for restoration purposes.

D. Learning Resilience Lessons

Because transmission resilience events have the potential to affect a broad geography, the events are closely studied and frequently result in changes to the system and system operations. That is, lessons learned provide the basis for improvements that reduce the impact of similar future events. These studies of transmission-related events mark the importance of the event and range from storm reports required by state governments to reports by the Federal Emergency Management Agency (FEMA), NERC, DOE, and others. As discussed in the sections above, these reports have resulted in actions including transmission line hardening, increased sharing of threat information, changes in reliability planning and system design standards, and improvements to wide-area sensing.

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33 Fishbach, Amy, "Tactical Tips for Utility Mutual Assistance," T&D World. Published August 30, 2017.

34 Ibid.

35 Peter Maloney, "28 utilities join RESTORE program to boost grid resilience, reliability," Utility Dive, October 4, 2017.

IV. Anticipating Resilience Challenges

The ongoing policy reforms and investments in the transmission sector largely reflect an adaptive response to major events and disturbances. However, the industry also proactively plans for unprecedented events that could plausibly threaten grid resilience. We highlight two of these activities below: war-game type response simulations and enhanced transmission planning.

A. Operational Response Exercises

As mentioned above, cyber-attacks in the U.S. have not yet disabled a significant transmission component or system, but the industry intensively prepares for that threat. In addition to the information sharing discussed previously, utilities practice responding to physical and cyber-threats through national simulations. NERC organizes biennial exercises, called GridEx, that allow utilities, law enforcement, federal agencies, and other operators of critical infrastructure systems to test and improve protocols in case of attack. The GridEx exercises include two day simulations for utilities and their partners as well as a one day executive-level tabletop game. Thus far, NERC has executed four GridEx events with 2017's GridEx IV drawing participation from over 450 entities, including water utilities, oil and natural gas companies, and telecommunication utilities.[36] The executive tabletop game in 2017 included participants from the White House National Security Council, DOE, the Department of Homeland Security, FEMA, the Department of Defense, the Federal Bureau of Investigation, the state of Maryland, the state of Virginia, and the National Guard in Illinois and Wisconsin.[37]

The GridEx simulations result in recommendations for policies, procedures, and investments within the power sector to increase readiness, including recommendations for regional and national programs and tools. During GridEx III, the need for cyber mutual assistance, analogous to the RMAGs for physical infrastructure, was highlighted. In response, a Cyber Mutual Assistance (CMA) program was developed that provides a pool of cyber security experts that are able to assist during an event, and the CMA program now includes more than 140 organizations, including natural gas and electric utilities, regional transmission operators, and independent

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36 NERC, *Grid Security Exercise GridEx IV: Lessons Learned*, March 2018. p. 1

37 *Ibid.* p.2

system operators across the United States and Canada.[38] Likewise, GridEx IV identified the need for alternative communications when actors were unable to communicate effectively due to a simulated communications blackout and produced a recommendation to establish contingency plans and make use of existing federal communication programs.[39]

B. TRANSMISSION PLANNING

The goals for transmission planning arising from FERC Order 1000 are sometimes listed as reliability, economics and public policy; so-called "multi-value projects" serve these needs by enhancing reliability, increasing market efficiency and supporting public policies. It is reasonable to ask how "resilience" might fit into this framework, although that is not straightforward to answer. Resilience is related to reliability, but broader. It is a public policy goal, but other public policy goals, such as support for clean energy, may also be considered. Resilience is an economic issue in the same way that insurance and disaster preparedness has an economic dimension. In other words, resilience can involve all three Order 1000 objectives while remaining distinct in some ways. The Venn diagram below in Figure 2 shows the relationship between resilience and other transmission planning objectives, where resilience encompasses the entire area where economics, reliability and public policy intersect. This representation suggests that transmission planning that appropriately values economics, reliability and public policy objectives will also further resilience goals, and that considering resilience will enhance the benefits attributed to multi-value projects. It also suggests that stand-alone "resilience projects" could warrant consideration in planning processes, although that possibility remains unlikely in the current environment. Regardless of the degree of potential overlap between resilience and the other goals, however, a valuation of potential resilience benefits should help inform a more comprehensive analysis of the benefits of transmission projects.

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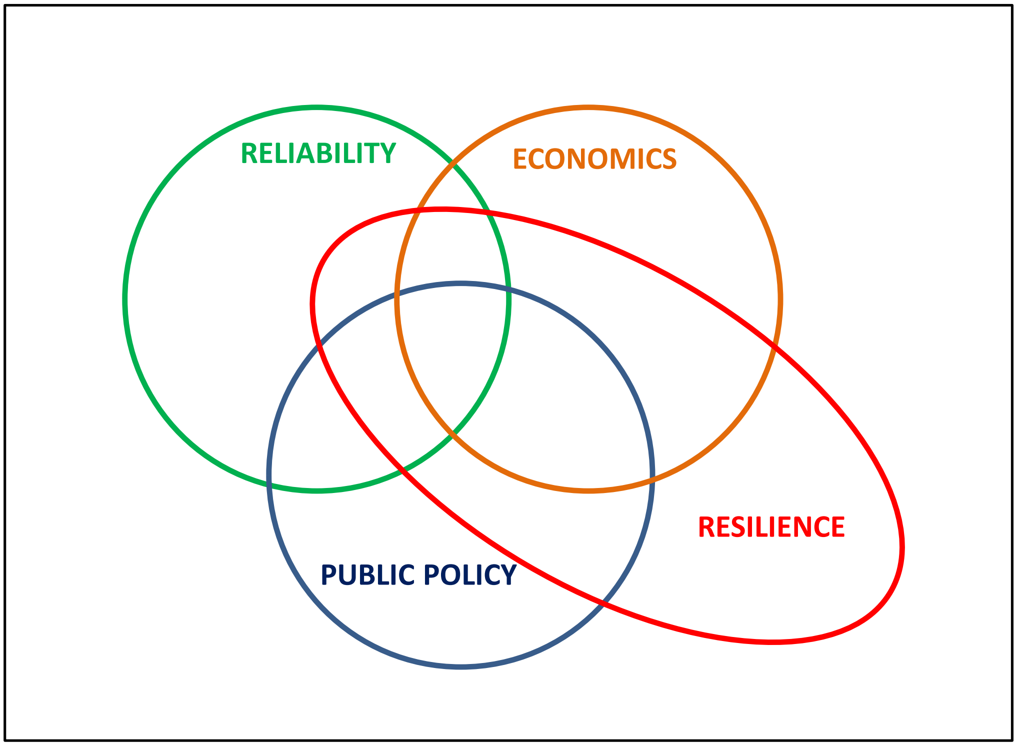
38 Electricity Subsector Coordinating Council, *The ESCC's Cyber Mutual Assistance Program,* January 2018.

39 NERC, *Grid Security Exercise GridEx IV: Lessons Learned*, March 2018. p. 15

Figure 2: The Relationship between Transmission Planning Objectives



Reliability planning for the transmission system already incorporates some high-impact, low-probability events, such as single or multiple large contingencies during 90th percentile peak load conditions, or simultaneous outages of the largest transmission and generation facilities during summer heat waves. To further incorporate potential resilience considerations, more extreme conditions could be evaluated, such as situations where a significant portion of the generating fleet becomes unavailable for an extended period of time, when assessing the expected benefits of constructing and sizing of a proposed transmission line.

Such assessments of low-probability, high-impact events are sometimes included in the economic assessment of transmission investments. For example, in a 2015 study, The Brattle Group recommended that "anticipatory" transmission planning also assess the economic benefits that might arise in unlikely but extremely adverse scenarios, in order to fully capture the insurance value of transmission.[40] The Brattle study examined the 2004 analysis of a second Palo Verde to

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[40] Johannes Pfeifenberger, Judy Chang, and Akarsh Sheilendranath, *Toward More Effective Transmission Planning: Addressing the Costs and Risks of an Insufficiently Flexible Electricity Grid*, The Brattle Group, April 2015. See also Johannes Pfeifenberger and Judy Chang, *Well Planned Electric Transmission Saves Customer Costs: Improved Transmission Planning is Key to the*

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Devers line (PVD2) that would enable imports from Arizona into California. One high-impact, low-probability event considered was a long-term outage at the San Onofre nuclear plant—an outcome that actually occurred in 2012. While the case study focused on the economic benefits from lower-cost replacement power enabled by the PVD2 line, comparable reliability and resilience benefits would arise if other conditions impaired generation availability elsewhere in California.

Both economic and reliability benefits are highly correlated with resilience benefits, although these benefits (e.g., protection against high costs and possible service disruptions) are typically quantified in the context of analyzing a less extreme range of adverse conditions or scenarios. Quantifying the expected benefit of transmission under more severe disruptions will augment the overall benefits from transmission investment. Because additional transmission capacity can enhance the overall level of reliability and resilience of the bulk power system, planning should increasingly assess the potential resiliency benefit of adding transmission within and between RTOs and other market areas. A 2013 Brattle Group report for WIRES found that estimating the benefits of mitigating the impacts of extreme events and system contingencies was crucial to a comprehensive analysis of transmission benefits:

> Transmission upgrades can provide insurance against extreme events, such as unusual weather conditions, fuel shortages, and multiple or sustained generation and transmission outages. Even if a range of typical generation and transmission outage scenarios are simulated during analyses of proposed projects, production cost simulations will not capture the impacts of extreme events; nor will they capture how proposed transmission investments can mitigate the potentially high costs resulting from these events. Although extreme events occur very infrequently, when they do they can significantly reduce the reliability of the system, induce load shed events, and impose high emergency power costs. Production cost savings from having a more robust transmission system under these circumstances include the reduction of high-cost generation and emergency procurements necessary to support the system. Additional economic value (discussed further below) includes the value of avoided load shed events.
>
> The insurance value of additional transmission in reducing the impact of extreme events can be significant, despite the relatively low likelihood of occurrence.

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Transition to a Carbon-Constrained Future, The Brattle Group, June 2016, pp 6-11 for a synopsis of studies that address the economic benefits of transmission, including under severe adverse conditions.

> While the value of increased system flexibility during extreme contingencies is difficult to estimate, system operators intrinsically know that increased system flexibility provides significant value. One approach to estimate these additional values is to use extreme historical market conditions and calculate the probability-weighted production cost benefits through simulations of the selected extreme events. For example, a production cost simulation analysis of the insurance benefits for the Paddock-Rockdale 345 kV transmission project in Wisconsin found that the project's probability-weighted savings from reducing the production and power purchase costs during a number of simulated extreme events (such as multiple transmission or nuclear plant outages similar to actual events that occurred in prior years) added as much as $28 million to the production cost savings, offsetting 20% of total project costs.[41]

Transmission planning should incorporate resilience considerations. In addition, transmission options should be considered to address resilience concerns such as regional resource shortage or fuel diversity/security issues. Secure electricity imports enabled by expanded transmission may provide cost-effective resilience benefits even in cases where generation fuel security is identified as the proximate resilience threat. Analysis of interregional transmission proposals could also incorporate the potential to avoid or mitigate damage from high-impact, low-probability events that pose resilience threats.[42] Because resilience is a systemic issue, the design of public policy to enhance resilience should look broadly at potential solutions.

V. Conclusion

Transmission has occupied a central role in the discussion of critical infrastructure resilience since that discussion began over a decade ago, and it continues to play an important role in the current resilience debate because:

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41 See Judy Chang, Johannes Pfeifenberger, J. Michael Hagerty, *The Benefits of Electric Transmission: Identifying and Analyzing the Value of Investments*, Prepared by The Brattle Group for WIRES, July 2013, p. 39; for additional detail on the Paddock-Rockdale analysis see American Transmission Company LLC, Planning Analysis of the Paddock-Rockdale Project, April 5, 2007 (filed in PSCW Docket 137-CE-149, PSC Reference #75598) pp. 50-53.

42 Of course, interregional transmission planning faces unique challenges. See Johannes Pfeifenberger, Judy Chang, and Akarsh Sheilendranath, *Toward More Effective Transmission Planning: Addressing the Costs and Risks of An Insufficiently Flexible Electricity Grid*, April 2015, pp. 25-37.

- Transmission can *enable* or *enhance* resilience, for example, when power from neighboring regions can flow to a region beset by outages of available generation (e.g., multiple outages associated with a particular fuel or technology);
- The transmission sector has *invested steadily* in enhanced reliability and resilience owing to rare but significant, widespread customer outages that can occur when transmission systems suffer physical damage or operations fail to avoid or contain delivery outages; and
- *Additional investments* in transmission expansion, innovative technology and operational controls can enhance grid resilience cost-effectively in the face of emerging threats.

The current focus on increasing the resilience of generation fleets in certain regions should not obscure or divert attention from the importance of the transmission grid to the overall resilience of the power system. Even as the generation fleet faces new and intensified challenges, the transmission system is needed to deliver the generated power to the distribution system and retail customers. Because the critical role of transmission to system reliability and resilience has long been recognized, continuous improvements have made the transmission more resilient over the past decades. Continuing attention and focus on transmission operation and investments will be necessary to identify and address existing and new threats to power system reliability and resilience.

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