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Resilience for Black Sky Days

Supplementing Reliability Metrics for Extraordinary and Hazardous Events

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NARUC's *Resilience in Regulated Utilities* provides the basis for establishing common definitions and developing a methodology for utility commissioners and others to consider when exploring the regulatory issues regarding investments in utility resilience.[1] This companion report examines how commissioners can further define resilience as a regulatory term of art, and build additional tools to assess resilience initiatives, by focusing on *black sky days*: i.e., extraordinary and hazardous catastrophes utterly unlike the blue sky days during which utilities typically operate.

The resilience challenges posed by black sky days also go above and beyond those posed by Superstorm Sandy, the Derecho Storms of 2012, or other recent Major Outage Events (MOEs). Building resilience against Sandy-scale events is vital, given the increasing frequency and severity of such storms. This report will briefly survey the progress that Public Utility Commissions and utilities are making in that effort. Yet, commissioners also face the risk of outages lasting even longer and covering a wider area than those caused by Sandy. A range of natural and manmade hazards could create "worse than Sandy" events. Federal and State emergency management agencies are treating preparedness for such catastrophes as a rapidly growing priority. These extraordinary and hazardous events will pose special risks to the resilience of electric utilities. Accordingly, State Commissions may wish to proactively consider assessment frameworks for investments in resilience that are structured to account not only for Sandy-scale major outage events, but also for black sky days.

If a State Commission determines that it is interested in exploring what would be needed for preparedness against the worst effects of black sky events, perhaps the best place to start would be the foundational metrics already in place for electric reliability. Metrics for resilience should *supplement*, not replace, the proven reliability metrics that have been refined over many decades. This study provides the starting point to do so by proposing a definition of a black sky day (versus MOEs) in terms of the percentage of utility customers experiencing an outage and the duration of the event. The study also examines where reliability metrics fall short of the assessment tools that commissioners will need for such extraordinary and hazardous events. In particular, commissioners and their staffs may want to assess how cascading failures of critical infrastructure in such events could create unprecedented problems for power restoration, and "look under the hood" of utility restoration plans and capabilities. Commissioners may want to collaborate more closely with State emergency management and energy assurance officials to account for specific catastrophic risks in their region, and expand partnerships with these officials to strengthen grid resilience. Existing enterprise risk management and cost-effectiveness methodologies may also need to be refined to account for black sky days, given the potentially massive scale of their consequences and (especially for manmade events) the uncertainty of their likelihood.

Many of these assessment efforts are also likely to be useful for Sandy-scale major outage events. Indeed, by developing ways to fill the assessment gaps highlighted by black sky days, it should be possible to "work back towards the middle" of the spectrum of events, and apply these initiatives to less catastrophic but more frequent electric outages. Working in this direction

[1] Keogh, Miles, and Christina Cody, (2013) *Resilience in Regulated Utilities*, NARUC, November 13, 2013

might also be integrated with efforts taking the opposite approach: that is, analyzing how resilience initiatives for MOEs might be scaled up and modified as needed for black sky days.

Creating such an overarching assessment framework for resilience will almost certainly require years to complete. Moreover, as with reliability metrics, that development process can best be advanced by a collaborative dialogue between commissioners and their staffs, utilities, Regional Transmission Organizations (RTOs) and Independent Service Operators (ISOs), and other stakeholders. To help advance that dialog, this study concludes with a set of questions for informal discussions and consensus-building outside the context of rate cases.

I. Defining Resilience and Differentiating It from Reliability

NARUC's *Resilience in Regulated Utilities* (hereinafter referred to as the NARUC Resilience Report) notes that resilience has been defined in a variety of ways.[2] Many definitions, however, are similar to that provided by Presidential Policy Directive 21 (PPD-21), which defines resilience as "the ability to prepare for and adapt to changing conditions and *withstand* and *recover rapidly* from disruptions [emphasis added]. Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring incidents."[3]

In some respects, this definition of broad resilience would fit with the system of metrics developed to assess reliability. Measures of electric outage frequency, such as the System Average Interruption Frequency Index (SAIFI), can help commissioners assess the ability of utilities to "withstand" incidents without incurring a loss of service. Measures of outage duration, such as the System Average Interruption Duration Index (SAIDI), can help assess the ability of utilities to "recover rapidly" from disruptions. Reducing the frequency and duration of outages will remain an essential goal for PUCs, and reliability metrics provide the indispensable foundation on which to build a framework to assess resilience. Appendix A summarizes reliability metrics that help provide this foundation. Yet, as severe storms and other major outage events have become more frequent, issues of whether and how to fit those events into measures of reliability have come to the fore -- with important implications for building assessment tools for the still more hazardous black sky days.

A. Major Outage Events (MOEs): From Reliability to Resilience

Most of the days during the course of a year are blue sky days - that is, days without major storms or other potential external sources of service interruptions. Of course, interruptions can still be caused by animals (squirrels need better power line safety training!), foliage, equipment that fails due to age, and other hazards. SAIDI and SAIFI are perfectly attuned to assess the frequency and duration of such outages over the course of a reporting period, as well as those occurring on what we might call "gray sky" days created by low-intensity weather events. These metrics are essential to help commissioners assess proposed investments to improve *availability*, or day-to-day utility performance.[4]

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[2] NARUC (Keogh, et al., 2013) pp. 4-6.

[3] *Presidential Policy Directive -- Critical Infrastructure Security and Resilience*, February 12, 2013,

[4] Warren, Cheryl, (2005) *Measuring Performance of Electric Power Distribution Systems, IEEE Std 1366-2003*,

In addition, however, a growing number of State PUCs require utilities to establish a separate reliability reporting category for Major Outage Events such as Hurricane Irene (2011), the Derecho Storms (2012), and Superstorm Sandy. The Institute of Electric and Electronics Engineers (IEEE) argues that segmenting reliability data into two distinct sets for review in this fashion offers important advantages. In particular, collecting data on MOEs facilitates the review of how utilities respond to crisis events, as opposed to reliability in the day-to-day operating environment that typifies a one year or multi-year assessment period.[5]

Many states have yet to require their utilities to provide separate reporting on Major Outage Events.[6] Moreover, for the states that do collect reliability data for MOEs, varying definitions exist for a "major" event. Some identify MOEs in terms of specific numbers of customer service interruptions. One such definition, for example, characterizes a major power outage as affecting at least 1,000 customers and entailing a total downtime of at least 1,000,000 customer hours.[7] The problem with this definitional approach is that one size will not fit all: a state with a small population might categorize such an event as much more catastrophic than a state with ten times as many customers. Another approach is provided by the "2.5 Beta Methodology" provided in IEEE Standard 1366-2003. Under this definition, major event days occur when the daily System SAIDI exceeds a threshold based on historical outage data in the state.[8] A number of State PUCs have also adopted threshold criteria for MOEs based on sustained outages that exceed a certain percentage of a utility's customers and/or or a specific number of customers who experience outages. California, for example, specifies that a major outage occurs when 10 percent of an electric utility's serviceable customers experience a simultaneous, non-momentary interruption of service. For utilities with less than 150,000 customers within California, a major outage occurs when 50 percent of the utility's serviceable customers experience such an interruption.[9]

Regardless of definition, however, collecting reliability data on MOEs can allow commissioners to more clearly assess a key focus of resilience – that is, *recovery*, which reflects how quickly utilities can "bounce back" after disasters and restore service when a crisis occurs. Maryland, for example, has established requirements for MOE reporting that include not only average duration

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[5] Warren (2005)

[6] Eto, Joseph, Kristina Hamachi LaCommare, Peter Larsen, Annika Todd, and Emily Fisher (2012). *An Examination of temporal trends in Electricity Reliability Based on Reports from U.S. Electric Utilities,* Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley CA. January, 2012;
Rouse, Greg and John Kelly, (2011) *Electricity Reliability: Problems, Progress and Policy Solutions*, Galvin Electricity Initiative, February 2011,

[7] McLinn, James, (2009) "Major Power Outages in the US, and Around the World," IEEE Reliability Society 2009 Annual Technology Report, p. 1,

[8] Warren (2005)

[9] California Public Utility Commission, *Public Order No. 166*, Maryland's reporting threshold for MOE's is set at events where: a) more than 10 percent or 1000,000, whichever is less, of the electric utility's Maryland customers experience a sustained interruption of service, and the restoration of service to any of these customers takes more than 24 hours; or b) the Federal, State or local government declares and official state of emergency in the utility's service territory. Maryland Public Service Commission, COMAR 20.50.01.03. B (27); Sustained outages exceed 10 percent of a company's customers or 100,000 customers, whichever is less. See COMAR 20.50.07.07;
For an example of a State PPUC that sets utility-specific criteria for MOE's see State of New York Public Service Commission, *PSC Redefines Major Outages for Con Edison*, June 18, 2008

of customer service interruption, but also more detailed data on factors that can help accelerate restoration, including information on the provision of outside assistance from other utilities.[10] Some PUCs are also specifying service restoration requirements in Major Outage Events. Maryland's PSC has established the following requirement:

> During each calendar year, a utility shall restore service within 50 hours, measured from when the utility knew or should have known of the outage to at least 95 percent of its customers experiencing sustained interruptions during Major Outage Events where the total number of sustained interruptions is less than or equal to 400,000 or 40 percent of the utilities total number of customers, whichever is less.[11]

B. Beyond Major Outage Events: Metrics for Black Sky Days

One feature shared by all current definitions of Major Outage Events is that they have no upper boundary -- no cutoff point that could help commissioners and utilities differentiate between events causing power outages for 10% of customers versus 90%. The IEEE's Distribution Reliability Working Group has found that this lack of an upper boundary creates problems for measuring utility performance. IEEE found that when companies applied the Beta Method threshold, unusually large, catastrophic events would distort overall measures of SAIDI performance. IEEEE is now developing methods for handling "extreme outlier days" so that performance measures are not "tainted" by such extreme events.[12]

There are also vastly more important reasons to focus on extreme threats to the grid as a unique challenge for reliability and resilience. As will be explained in the next section, catastrophic events pose risks to the grid over and above those created by Major Outage Events, and will likely require the development of new risk management and resilience initiatives. The NARUC Resilience Report set the stage for this development effort by proposing to narrow the definition of resilience. The Report defines resilience as the "robustness and recovery characteristics of utility infrastructure and operations, which avoid or minimize interruptions of service during an *extraordinary and hazardous event*" [emphasis added].[13] To build an assessment framework for extraordinary and hazardous events, which this study terms black sky events, it will be helpful to further clarify the definition of such events and differentiate them from Major Outage Events.

The best way to do so is to set an upper threshold for MOEs, above which events would be categorized as black sky/extraordinary and hazardous events. Two options exist to set such a threshold. The first would be to build on the Beta Method approach in IEEE Standard 1366, and identify black sky events when the daily System SAIDI exceeds a threshold (based on historical outage data in the State) much higher than the Standard set for the lower boundary of MOEs. A methodology of this kind may be able to provide a statistically valid and broadly applicable

[10] Maryland Office of the Secretary of State. *Major Outage Event Reporting,*
[11] Maryland Public Utility Commission, (2013). *Order No. 85385, In the Matter of the Electric Service Interruptions in the State of Maryland due to the June 29, 2012 Derecho Storm,* February 27, 2013, p. 15
[12] McDaniel, John, *Uses of IEEE 1366 and Catastrophic Days*
[13] NARUC (Keogh, et al, 2013) p. 5

threshold for black sky events, which would be especially useful to facilitate cross-State performance assessments.[14]

A second option would be to establish a black sky threshold for specific utilities or States, based on a specified percentage of customers experiencing service interruptions and a specified duration for the outage. Defining black sky events as those where a minimum of 50 percent of customers lose power would easily put a number of recent severe storms into that category, depending on the duration criteria that were chosen. In the Derecho storm, for example, 77 percent of Pepco customers experienced outages during the peak of the Derecho Storm.[15] Moving such outlier storms into the category of black sky events, versus keeping them in the MOE category, would help resolve the problem identified by the IEEE of having these storms "taint the data" for SAIDI reporting on major events.

Yet, if commissioners and utilities are interested in proactively exploring this issue, they may also want to consider setting the black sky threshold above the SAIDI levels experienced in the Derecho Storm, Sandy, or any other event experienced to date. Doing so would help focus analysis on the special resilience challenges and regulatory issues posed by the extraordinary and hazardous risks examined in the remainder of the paper. This study proposes to define black sky days as events where more than 90% of a utility's customers experience outages of more than 25 days. This definition would create a threshold well above any recent weather event by combining the most severe characteristics of both Sandy and Hurricane Katrina -- what might be termed the "Santrina" benchmark.[16]

Specific threshold components:

- *Percentage of customers without power*. In Superstorm Sandy, utilities such as the Long Island Power Authority (LIPA) faced extraordinarily large-scale outages, with the utility estimating that 90% of its 1.1 million customers lost power at the peak of the event.[17] The proposed definition of back sky days would be for events that exceed this 90% level.

- *Event duration*. Measured by how many days it took to restore service to 95% of customers, Hurricane Katrina (2005) was a more extreme event than Sandy. LIPA and other New York utilities restored power to 95% of its customers 13 days after Sandy made landfall.[18] After 23 days in Katrina, only 75% of customers had their power

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[14] Note, however, that after examining a number such options to identify catastrophic events, an IEEE working group found that thus far "no objective method has been devised that can be applied universally." That working group recommended instead that the threshold for catastrophic events should be determined on an individual company basis by regulators and utilities. McDaniel, (p. 15)
[15] Maryland PSC, *Order No. 85385*, p. 9.
[16] I offer special thanks to Christina Cody of NARUC for suggesting this term.
[17] Long Island Power Authority (LIPA), (2013) *Presentation: Investor Update Conference Call*, January 16, 2013
[18] "Length of Outage after Sandy Not Unusual," (2012) Associated Press, November 16, 2012;
LIPA, (2012) "LIPA Completes Restoration to 95% of Homes and Businesses that are safe to Receive Power," November 11, 2012

restored before Hurricane Rita struck the affected area and created additional outages. The proposed definition for black sky days would be 25 days or more.[19]

II. Black Sky Risks and Resilience Challenges

Across the Federal Government and in a growing number of States, emergency management leaders are shifting their preparedness efforts towards events "worse than Sandy." The Federal Emergency Management Agency (FEMA), which leads Federal disaster response efforts when States request assistance, has helped drive this new focus on catastrophic events. FEMA Administrator Craig Fugate emphasizes that "We need to understand that as bad as Sandy was, that may not be the benchmark that we need to limit ourselves to. There are threats and potential disasters that could be even larger."[20] Administrator Fugate has made planning and preparing for such catastrophes a top priority for the Agency.[21]

FEMA is partnering with States across the nation to build plans for catastrophic events, many of which focus on the specific hazards in that State that pose the greatest risk -- that is, 1) hazards that are most *likely* to strike; 2) are hazards to which the State is especially *vulnerable*; and 3) are hazards that would have most devastating *consequences* should an event occur. California has three such plans for region-specific hazards from South to North: the Southern California Catastrophic Earthquake Response Plan, the Bay Area Readiness Response Plan, and the Cascadia Earthquake and Tsunami Response Plan.[22] Hawaii, Florida, and many other States are also building hazard-specific plans for events more destructive than they have ever before experienced.[23]

Many of these hazards pose risks of creating long-term, wide area outages at "Santrina" level or above -- i.e., where at least 90 percent of a utility's customers have lost power for at least 25 days. The New Madrid Seismic Zone exemplifies these risks. The New Madrid fault roughly parallels the Mississippi River, and produced of a 7.7 earthquake in 1812. A recurrence of that earthquake today (which was the focus of a 2011 National Level Exercise) would damage or destroy many hundreds of electric substations, high voltage transformers and transmission lines, generators, and other grid components over a multi-state region including Illinois, Indiana, Missouri, Arkansas, Kentucky, Mississippi, Tennessee, and potentially other States.[24] The Department of Energy assessed that such an event would not only disrupt power in the New Madrid region but far beyond, with outages potentially affecting 100-150 million people across

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[19] "Length of Outage after Sandy Not Unusual" (AP, 2012)
[20] Miles, Donna. Northcom, "FEMA Build on Hurricane Sandy Response Lessons," January 14, 2013
[21] "Planning and preparing for catastrophic disasters is a top priority at FEMA," (2013) *Disaster Resource Guide 2013*,
[22] California Governor's Office of Emergency Services, *Catastrophic Planning.*
[23] Federal Emergency Management Agency (FEMA), FEMA, (2009) "Hawaii State Civil Defense Sign Catastrophic Plans into Operation," September 2, 2009; Florida Division of Emergency Management, (2011) *Catastrophic Planning Project Overview,* April 6, 2011,
[24] Mid America Earthquake Center, (2009) *Impact of New Madrid Seismic Zone Earthquakes on the Central USA, Vol. 1*, October 2009,

the Northeast, Southeast and Midwest United States.[25] The DOE report also found that the earthquake would cause breakages in ten interstate natural gas pipelines and damage oil pipelines and coal railway distribution systems as well.[26] Severe damage would also occur to the infrastructure on which utility power restoration crews depend on to repair or replace damaged equipment, including communications systems, gasoline and diesel fuel distribution systems, and critical bridges and roads, as well as "lifeline" infrastructure such as hospitals and water systems.[27]

In addition to these State- and region-specific hazards, power distribution systems in *all* States are at potential risk to nationwide hazards from both natural and manmade threats. Two studies commissioned by the North American Electric Reliability Corporation (NERC) are especially valuable for assessing these risks: *High-Impact, Low-Frequency Event Risk to the North American Bulk Power System (2010),* and *Severe Impact Resilience: Considerations and Recommendations (2012).*[28] Both studies focus on risks with the potential to cause catastrophic impacts on the electric power system, but which either rarely occur or (in some cases) have not yet struck but may do so in the future. These risks include coordinated cyber, physical, and blended attacks; the electromagnetic pulse effects created by the high-altitude detonation of a nuclear weapon; and major natural disasters like earthquakes, tsunamis, large hurricanes, pandemics, and geomagnetic disturbances (GMD) caused by solar weather.

More recently, the Department of Energy and Executive Office of the President have issued studies examining how climate change will create risks of increasingly severe storms and other hazards to grid resilience.[29] Following the direction by the Federal Energy Regulatory Commission that NERC propose reliability standards for GMD on the bulk power system, attention is also growing to the potentially catastrophic risks posed by such events.[30] Disagreement persists over the degree to which a GMD event would cause physical damage to high voltage transformers and other critical grid components. However, after assessing the overall risks posed by GMD events on the scale of the Carrington event that occurred 154 years ago, Lloyds of London and other reinsurance companies have concluded that insurers face potentially massive exposure to business interruption and other claims. The Lloyd's study finds that while the probability of a Carrington-level event is relatively low at any given time, it is almost inevitable that one will occur eventually. The study also concludes that the total U.S.

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[25] US Department of Energy, (2010) *DOE New Madrid Seismic Zone Electric Utility Workshop Summary Report*. August 25, 2010, pp. 2-4. Note that the DOE assessment was based on the simultaneous occurrence of both the New Madrid and Wabash faults

[26] DOE, (2010) pp. 4-7.

[27] Mid America Earthquake Center, Impact of New Madrid, and Central United States Earthquake Consortium, (2011). *CUSEC After-Action Report (AAR)*, pp. 50-1

[28] North American Electric Reliability Corporation (NERC), (2010) *High-Impact, Low-Frequency Event Risk to the North American Bulk Power System*, June 2010; NERC, (2012) *Severe Impact Resilience: Considerations and Recommendations*,

[29] Department of Energy, (2013) *U.S. Energy Sector Vulnerabilities to Climate Change and Extreme Weather*, July 2013; Executive Office of the President, (2013) *Economic Benefits of Increasing Electric Grid Resilience to Weather Outages*, August 2013.

[30] Federal Energy Regulatory Commission, (2013) *Reliability Standards for Geomagnetic Disturbances*, May 16, 2013

population at risk of extended power outage in such a GMD event is between 20-40 million, with outage durations of 16 days to 1-2 years.[31]

Taken together, such events pose a characteristic set of potential consequences and power restoration challenges of black sky events. These distinguishing characteristics help clarify the special problems that assessment frameworks for black sky resilience will need to encompass, and (paired with data on event likelihood and vulnerability) can also help build an enterprise risk management approach for such events. Key potential consequences and power restoration challenges:

- *Massive, multi-state damage to critical power generation, transmission and distribution components*. Note that black sky events will likely cause such damage not only to distribution systems, but also to power generators and the high voltage transmission lines that are under the regulatory jurisdiction of FERC (versus PUCs), and are essential to distribution system functionality. Equipment repair and replacement challenges for very wide-area events -- which industry now terms "National Response Events" (NREs)[32] -- could entail extraordinary challenges for mutual aid, especially in responding to non-traditional threats such as coordinated cyber and/or kinetic attack. Large scale damage to high voltage transformers other difficult-to-replace grid components would create further challenges for restoration and resilience.

- *Disruption of energy infrastructure essential for fueling the grid*. In major earthquake or many other black sky events, interdependent infrastructure and systems essential for power generation (such as natural gas pipelines, water, transportation, communications, public health and safety, and other systems) might not only be disrupted by electricity outages, but would also suffer physical devastation on a multi-state scale. This damage would create a second contributor to event duration, over and above the damage to the electrical system.

- *Disruption of infrastructure critical for power restoration operations*. The infrastructure sectors most vital to support power restoration could themselves be severely disrupted. Destruction of cell towers and other communication system components would have an especially significant impact in this regard. Damage to roads and bridges essential to move utility crews and replacement grid components would further impede restoration operations, as would damage to the other supporting infrastructure on which they rely (such as the availability of fuel for utility vehicles). This downstream damage constitutes a third component of the overall restoration challenge.

- *Loss of emergency power to critical facilities and functions*. Hospitals, water and wastewater infrastructure, emergency operations centers, nursing homes, centralized food and pharmaceutical distribution nodes, and other facilities essential for public health and

[31] Lloyd's, Atmospheric and Environmental Research Inc., (2013) *Solar Storm Risk to the North American Electric Grid*, , 2013, p. 4 and *passim*.
[32] Edison Electric Institute, (2013) "*Overview of the electric Power Industry's Mutual Assistance Process During a National Response Event*, November 2013,

safety typically have emergency power generators and fuel stored on-site to power them. In a long duration, wide-area outage, however, these critical facilities would be disrupted as generators failed and demands for emergency fuel resupply outstripped supply (especially if fuel distribution systems were themselves disrupted). The Nuclear Regulatory Commission and its industry partners have made special arrangements to ensure that their emergency power needs can be met. However, chemical plants and other at-risk facilities could also pose risks to nearby population centers as emergency power generators and fuel supplies for them came under stress. And of course, as was highlighted in Fukushima, radiological or chemical events (and perhaps even the perceived possibility of such an event occurring) would greatly magnify the difficulties of power restoration and further lengthen outage duration.

- *Extraordinary Political Pressures*. Black sky events would also create a supercharged political environment for power restoration operations. Indeed, a black sky event will be the signature political crisis for every elected official in the affected region. Federal, state and local leaders will create urgent and incessant demands for information on Estimated Time of Restoration (ETRs), restoration priorities, and how scarce restoration resources are being allocated. Commissioners and utilities can expect that leadership engagement -- from the U.S. President on down -- would be vastly greater than even in Sandy-scale events, with attendant problems for setting and communicating ETRs and managing other crisis-driven restoration issues.

III. Initiatives to Assess and Strengthen Resilience: Preliminary Steps

State Commissions will need to decide for themselves if exploring preparedness against the worst effects of black sky days is worthwhile. Many PUCs and utilities are already taking major steps to strengthen preparedness for Sandy or Derecho-scale major event outages.[33] However, to assess and incentivize proposals to build resilience against black sky days, commissioners and their staffs may want to further extend the range of their analysis and the scope of their interagency relationships. This section proposes that commissioners and utilities discuss how to do so along three lines of effort: 1) the development of additional assessment priorities and tools; 2) the creation of deeper partnerships with emergency management leaders and State officials responsible for energy assurance; and 3) the adaptation of enterprise risk management techniques to account for black sky days; and 4) the creation of new analytic approaches to assess the cost-effectiveness of initiatives targeted on these extreme and hazardous events.

[33] For a comprehensive summary of these utility initiatives, see Edison Electric Institute, (2013) *Before and After the Storm*, January 2013; For additional proposed initiatives, including those timed to "smart gird" modernization, see The Gridwise Alliance, (2013) *Improving Electric Grid Reliability and Resilience Lessons Learned from Superstorm Sandy and other Extreme Events*, June 2013;
New York State 2100 Commission, (2012) *Recommendations to Improve the Strength and Resilience of the Empire State's Infrastructure*, November 2012; and the Office of Governor martin O'Malley, (2012) *Weathering the Storm: Report of the Grid Resiliency Task Force*, September 2012; Examples of Public Utility Commission order to improve resilience include the State of New Jersey Board of Public Utilities, (2013) *In the Matter of the Board's Review of the Utilities' Response to Hurricane Irene*," January 23, 2013; And Maryland Public Utility Commission, *Order No. 85385*, p.4 and p.17

A. Supplementing SAIFI, SAIDI, and CAIDI: New Priorities and Requirements for Assessing Resilience

As a measure of the frequency of power outages, SAIFI will be useful for certain extraordinary and hazardous threats. In particular, since electric power systems undergo near-constant probing by prospective attackers, and since the cyber weapons available to them continue to grow in potential destructiveness, it will be important to assess the frequency with which future computer network attacks (CNAs) create electric outages. That same assessment value helps justify the inclusion of outage avoidance in the definition of resilience.

Against a New Madrid earthquake or equivalently catastrophic event, however, it will be impossible to avoid power outages, and spending money to pursue such a goal would require limitless rate increases. The more appropriate objective for resilience will be to minimize service interruptions. Even limited progress in achieving that goal could have enormous benefits, since threats to public safety and the economy will rapidly escalate as emergency supplies become problematic. In theory, SAIDI could measure overall outage duration even in extraordinary and hazardous events. So could the Customer Average Interruption Duration Index (CAIDI), which helps assess the impact of an outage on an average customer by dividing how long each customer experiences an outage by how often they experience one. In practice, however, many States exclude longer duration events from SAIDI and other reliability metrics because including them would distort assessments of utility performance during normal operating days. An initial step that commissioners may want to make to adapt these reliability metrics for resilience purposes is to separate assessments of utility performance in catastrophic events versus blue sky and major outage events. [34]

For the much longer-term effort needed to identify and fill gaps in assessment tools for black sky events, commissioners and utilities may want to start by accounting for the special problems these events will create for power restoration, and by broadening their analysis beyond what a typical rate case would encompass. Moving into these areas of analysis could take some State PUCs beyond what is provided for in their existing regulatory processes and statutory authorities; those PUCs will need to carefully consider whether and how to pursue such an expanded role. To set the stage for considering such issues, and to help provide the basis for informal discussions with utilities on black sky assessment and investment priorities, topics to examine should include:

- *Assessments of power restoration requirements*. In an extraordinary and hazardous event, where N-1 or N-2 analysis will be inadequate for assessing requirements to mitigate damage to distribution system components, scaled-up analysis of such requirements (to N-20 or beyond) will be essential. Ongoing FEMA Region planning for Region-specific catastrophic hazards can help provide a basis for such analysis. New analytic techniques, particularly network analysis, may also help provide more effective assessments of requirements for replacement components, system redundancy options, and operational measures to mitigate the effects of damaged equipment in distribution systems (and

[34] Warren (2005), pp. 18-20; NARUC (Keogh et. al, 2013) pp. 7-8

perhaps also at least some consideration of bulk power system generation and high voltage transmission issues). The analysis should also include mitigating the risks posed by the disruption of the energy infrastructure on which the electric system depends, and the communications and other infrastructure critical for restoration. These assessments will help commissioners determine which investments will be most cost-effective in reducing event duration. Finally, given the dependence of distribution systems on bulk power system generation and high voltage transmission assets, and the risk that these assets may by severely damaged in a black sky event, commissioners may need to further broaden the scope of their resilience analysis to consider such issues.

- *Black Start.* As a further step towards looking "under the hood" of resilience requirements, commissioners may also want to discuss with utilities how they will use black start generators to launch the restoration of grid functionality, and better understand the "cranking path" that the utility will follow. Extraordinary and hazardous events may disrupt those paths and damage black start generators. During the past decade, the retirement of coal-fired power plants and stringent EPA regulations have helped spur a decline in black start capabilities for electricity and fuel systems in many regions. A large number of utilities are now in the process of strengthening their capacity to conduct black start operations. Analyzing requirements for such capabilities, and for emergency fuel and other supporting components of black start systems, could help commissioners determine whether additional investment in this realm would have significant risk-reduction benefits. Such an analysis may also require commissioners to look beyond distribution system issues and also examine bulk power system factors (potentially involving assets located in other States).

- *Assessments of mutual assistance mechanisms*. The Regional Mutual Assistance Group (RMAG) system provides a proven, highly effective system by which utilities can support each other with utility crews and other assets. Many municipal power systems and electric cooperatives also have strong mutual support arrangements. The Spare Transformer Equipment Program (STEP) and other mechanisms to share critical grid components between utilities further strengthen their ability to speed power restoration in large-scale power interruptions. Yet, as noted in a 2013 NARUC Resolution on major outage-triggering events, events of the scale of Sandy and beyond will require an even stronger resource sharing and allocation system (and, potentially, supporting efforts by State transportation agencies and other departments).[35] Under the leadership of the Edison Electric Institute, utilities are now developing major improvements to the RMAG system that will scale it for National Response Events. Commissioners would benefit from assessment tools that help them examine how proposed improvements to mutual assistance mechanisms can shorten restoration times in their States, and the degree to which cyber-related hazards and other non-traditional threats may render these mechanisms problematic.

[35]NARUC, (2013) *Resolution on Electric Utility Industry-Wide Response to Major Outage-Triggering Events*, 20 November 2013,

- *Assessing and incentivizing other operational improvements.* A growing number of States are encouraging utilities to adopt the Incident Command System (ICS) for event management and response.[36] ICS offers a proven, standardized, and highly effective way to organize infrastructure restoration operations when multiple organizations and agencies must coordinate their efforts (as would certainly be the case in a black sky event). Other ways to make operational improvements for resilience are proposed in NERC's *Severe Impact Resilience.* That study examines a range of operational measures to mitigate the effects of a catastrophic event on the bulk power system, including innovative ways to reroute power flows around damaged equipment and the development of new strategies for load shedding. Some of these operational measures might be adapted to strengthen distribution system resilience for black sky events.

- *Applying new technologies*. The Edison Electric Institute's report *Before and After the Storm* identifies a number "smart grid" technologies (including smart meters) that can speed power restoration by providing better situational awareness of outage locations and more effective real time monitoring of the grid.[37] Phasor measurement units may prove to be especially helpful in this regard. Gathering additional data on their actual effectiveness in reducing event duration in MOEs and other outages, and prioritizing the development of technologies tailored for long term/wide area service interruptions, could provide major resilience benefits for black sky days.

- *Prioritized restoration plans and guidelines.* In extraordinary and hazardous events, it may not be possible to restore power simultaneously to all the priorities that exist within a given service area. Special needs populations, police departments, life-sustaining infrastructure, and other critical customers will be increasingly at risk as emergency generators and fuel for them fall short of requirements. PUCs vary greatly in the degree to which they are briefed on utility restoration priorities, guidelines, and criteria for classifying customers. As part of the resilience focus on minimizing the impact of interruptions of service, commissioners and their staffs may want to examine these guidelines in greater detail, and perhaps even offer recommendations on them. They should also consider engaging with key customers who operate critical infrastructure that depend on reliable electricity in order to better understand the cascading effects on communities and the State associated with a long-term outage.

- *Preparedness against novel response challenges.* Non-traditional threats could require power restoration plans and capabilities very different from those that industry has developed for hurricanes, ice storms and other familiar hazards. Cyber threats exemplify this challenge. For investments to prevent and protect against cyber attacks, NARUC's *Cybersecurity for State Regulators 2.0* provides a comprehensive set of criteria and recommended actions (from a wide variety of sources) for PUCs to use as assessment tools.[38] Cyber response assessment criteria and best practices are much less well

[36] The State of New Jersey Board of Public Utilities, (2013) *In the Matter of the Board's Review of the Utilities' Response to Hurricane Irene*, January 23, 2013

[37] Edison Electric Institute, (2013). *Before and after the Storm,*

[38] NARUC, (2014) *Cybersecurity for State Regulators 2.0,* February 2014

developed. Indeed, responding to a cyber attack, for example, could require the cleanup of malware though operations entirely different from typical utility crew restoration operations, and from traditional mutual assistance support. Other non-traditional hazards may also require specialized, supplementary plans for power restoration. For example, the risk of terrorist attacks against crews in a coordinated, Metcalf-style kinetic attack on critical grid components would require security support completely unlike that provided by law enforcement or National Guard personnel in previous events.

B. New Partnerships

State Commissions and companies engaging in risk-oriented assessments of whether (and how much) to prepare for the highest impact events may want to explore how they can leverage the existing efforts and resources of other agencies, entities, and stakeholders. Developing and assessing resilience initiatives for black sky days may require much deeper collaboration with State and Federal emergency management leaders and energy officials, and -- in some cases -- with their counterparts in Canada and Mexico. Of course, these officials have powerful incentives of their own to strengthen collaboration with PUCs and utilities. Utility commissioners can play a decisive role in strengthening preparedness against black sky days; reliability-based investments, prudently chosen, may be able to greatly reduce the overall duration of service interruptions and the threats they pose to public health and safety. But in many states, such collaborative efforts remain limited. Too many “stovepipes of excellence” exist; emergency managers are striving to create increasingly rigorous catastrophic response plans, and PUCs and utilities are making equally strong efforts to strengthen grid resilience against severe hazards, but only rarely are these efforts integrated.

To help States mitigate the risks that extraordinary and hazardous events will pose to their energy systems, the Department of Energy’s Office of Electric Delivery and Energy Reliability provides a range of activities to support State and local energy assurance planning and emergency response operations.[39] The National Association of State Energy Officials (NASEO) has also partnered with DOE and NARUC to advance a range of initiatives that can help provide a foundation to build preparedness against extraordinary and hazardous events.[40] Later sections of this report will recommend specific ways that commissioners and their staffs can deepen their collaboration with emergency managers and Federal and State energy officials to advance such efforts.

As Commissioners and utilities deepen their partnerships with State and local emergency managers to prepare against black sky events, the National Response Framework and Emergency Support Function 12 (Energy) provide the crucial starting point to examine how power restoration can become an integrated part of overall disaster response planning and operations.[41]

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[39] Department of Energy, *State and Local Energy Assurance Planning*, at http://energy.gov/oe/services/energy-assurance/emergency-preparedness/state-and-local-energy-assurance-planning.

[40] National Association of State Energy Officials (NASEO) and NARUC, State Energy Assurance Guidelines, December 2009, at http://www.naruc.org/Publications/State_Energy_Assurance_Guidelines_Version_3.1.pdf.

[41] Federal Emergency Management Agency (FEMA), (2013). *National Response Framework: Second Edition*, May 2013; and Federal Emergency Management Agency (FEMA), (2008). *Emergency Support Function #12 – Energy Annex*, January 2008

Section I of this report noted that a growing number of States are developing catastrophic response plans. Those efforts provide especially valuable and timely opportunities for PUCs and utilities to engage with emergency managers. Since black sky events are almost certain to cross state lines, collaborative planning with FEMA Region leaders (and with PUCs and utilities on a regional basis) will also be essential.

Exercises offer another means to strengthen collaboration and better prepare for black sky operations. A prime example of such opportunities is provided by the Central United States Earthquake Consortium's "Capstone 14" exercise in June, 2014. This multi-State exercise will engage local, State and Federal emergency managers with the private sector companies (including utilities and the infrastructure sectors crucial for power restoration) to plan for response and recovery from a catastrophic New Madrid earthquake.[42] As other States and FEMA regions begin to exercise their own evolving catastrophic plans, these events will provide unique opportunities for PUCs and utilities to build working relationships with the officials who will actually lead disaster response operations when an event strikes. Involving PUCs and utilities in these exercises will also help identify shortfalls in existing efforts to integrate power restoration and response planning. Similar benefits might be provided by including commissioners and their staffs in future cyber exercises such as GridEx II, which can highlight the special restoration and resilience problems of wide area, long duration outages caused by SQL injection attacks, advanced persistent threats, and other cyber weapons.

C. Assessing and Managing Black Sky Risks

Many of the most significant threats of black sky events either rarely happen (as in Carrington-level GMD events), or have yet to occur (as in the case of large scale, coordinated cyber attacks on industrial control systems and control center data essential for operating the power grid). If these events do occur, however, their effects would be catastrophic. How can PUCs build an enterprise risk management system to account for black sky days?

Under a risk management system (where risk is assessed in terms of threat, vulnerability, and consequence), the starting point for commissioners and their staffs should be to develop an assessment of the threats that their utilities are most likely to confront. There are a number of possible sources of threat data to build such an assessment. State Energy Assurance Plans -- developed by the State Energy Offices under the umbrella of the National Association of State Energy Officials (NASEO) in partnership with the US Department of Energy (DOE) -- often include data on significant State-specific hazards. In each of the ten Federal Emergency Management (FEMA) regions, FEMA Regional Coordinators and their State and local partners are examining the most likely catastrophic threats to their areas, which will then serve as a basis for catastrophic response planning (including preparedness for the impact of extended power outages on public health and safety). State National Guard Joint Force Headquarters assesses natural and manmade hazards in each State. The Department of Homeland Security supports Fusion Centers in many States that track threat data. The Federal Bureau of Investigations Joint

[42] Central United States Earthquake Consortium's Capstone 14 Exercise, Private Sector Workshop, at http://www.cusec.org/plans-a-programs/capstone14/176

Terrorism Task Forces (JTTFs) may also, in certain circumstances, be able to provide helpful data on manmade threats.

While necessary, however, these assessments of likely threats will fall short of providing reliable predictions of event probability. Risk methodologies for black sky events should therefore take special account of vulnerability and consequence components of the risk equation. Building a risk management framework for extraordinary and hazardous events would also benefit from moving beyond the critical components of the distribution system in question. Given the unique destructiveness of such events, risk assessments should account for the interdependencies that exist with other energy sectors and for the supporting infrastructure on which utilities depend for power restoration.

Once PUCs and commissioners built a shared understanding of criticality, interdependencies and risks of cascading infrastructure failure, the consequences and likelihood associated with various hazard and threat scenarios should be assessed as part of a composite risk profile for both a utility and the greater region it serves. From that profile, alternative mitigation measures could be proposed and evaluated for cost and efficacy. Only by taking such a composite view will it be possible to account for a full range of mitigation options. As joint participants in what should be a common risk management process for catastrophic events, State and local government officials and owners and operators of interdependent infrastructure would likewise benefit from participating in such analysis.

Based on this approach, a risk management process for black sky events would involve three primary components: 1) a comprehensive region-wide assessment of risks to the critical assets identified and their interdependencies, including a detailed assessment current protection measures and response and recovery capabilities; 2) an evaluation of risk mitigation solutions, including cost-benefit analysis to compare the life-cycle cost of identified solutions with their risk reduction potential; and 3) time-based tracking and comparison of region-wide risk, including an evaluation of changes in criticality, threat, and preparedness that would alter the overall risk profile of the utilities within each region.

D. Cost-Benefit Analysis: Issues for Future Consideration

Commissioners already have a set of highly effective assessment tools, including the Interruption Cost Estimate (ICE) Calculator, to help them assess the costs and benefits of proposed investments in resilience. Adapting or supplementing these tools to help commissioners perform cost-benefit analysis for resilience investments will be essential as utilities generate multi-billion dollar proposals over the next few years. Indeed, given the potentially limitless funds that might be spent to minimize or eliminate the risks of outages in catastrophic events, commissioners will have especially strong incentives to develop tools that help them avoid low-payoff investments.

The first step in adapting the ICE Calculator and other metrics for resilience would be to adjust them to accommodate larger-scale events. The Calculator is “not meant to be applied to major outages or blackouts longer than 8 hours.”[43] As with SAIDI, it will likely be necessary to build a complementary formula to accommodate much longer events. In addition, building cost-

[43] Interruption Cost Estimate (ICE) Calculator – BETA, “About the Calculator,” at http://icecalculator.com/

assessment tools focused on extraordinary and hazardous events will also have to account for their enormous, cascading effects and the lost value of service in a long-duration event. Doing so will require analytic initiatives to 1) better estimate the compounding value of lost load over the course of a long-term event; 2) assess the value of lost load form a customer perspective, versus for utilities; 3) differentiate the value of that lost electricity across different types of customers; and 4) account for the difficulty of predicting extraordinary and hazardous events.

The NARUC Resilience Report suggests that the value of electricity is likely to compound over time. If commissioners believe that assessments of value should include the impact of lost load on public health and safety, and on business interruption, this compounding effect will be vastly stronger. Existing econometric models could be adapted to help commissioners estimate the economic damage resulting from the dependencies on electrical power by other critical sectors to include transportation, health services, liquid fuel distribution, communications, and water and wastewater treatment. The cascading effects arising from these cross-sector interdependencies can then be translated into loss of employment and reductions in State GDP that power outages will create as a function of time. It would also be possible to develop more detailed estimates of how public safety hazards will escalate, and develop risk-based decision criteria on how much to invest in reducing event duration.

The NARUC Resilience Report also notes that two different approaches might be taken to conduct cost-benefit analysis. The first is to assess costs of outages to utilities. An alternative would be for PUCs to focus on the value of lost load to customers. Taking that customer-based approach would again tend to increase the costs associated with lost load over time; spoiled food in the refrigerator would quickly become a minor inconvenience compared to the hazards that would emerge in a long-duration outage. Yet, the validity of methodologies to assess the cost of lost load to customers, including the contingent valuation method (which includes measures of willingness of customers to pay to avoid outages) remains a subject of debate.[44]

The scale and scope of economic damage from lost load in a black sky also creates special challenges for assessing costs and determining who should pay for investments to reduce them. John Holdren, the science adviser to President Barack Obama, estimates that a major GMD event could cause $2 trillion dollars in economic losses in the United States in the first year alone, with recovery taking four to ten years.[45] Estimating the potential economic costs of such events in a particular State or service region will pose major challenges. For example, beyond the direct costs of lost load to utility customers, the indirect costs caused by the cascading failures of critical infrastructure and their additional effects on business interruption and disaster response/power restoration costs would be enormous. But who should pay for investments that would benefit society as a whole, when State economies and many thousands of lives are in jeopardy? Should rate-payers bear the full burden? And if utilities prioritize power restoration to certain classes of customers, should those customers pay more for that status? Answering these questions (and the many others that resilience entails) will require new levels of consensus building between commissioners, utilities, and other key stakeholders.

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[44] Executive Office of the President, Economic Benefits, pp. 19-20, reviews this debate.
[45] John P. Holdren, "Celestial Storm Warnings," *New York Times*, March 10, 2011.

Predicting the likelihood of extraordinary and hazardous events will also create difficulties for applying familiar cost-benefit methodologies, just as such predictions do for risk assessments. Where at least some historical data exists on severe natural hazards, stochastic modeling may help deal with event uncertainty. Monte Carlo analysis may also be of value in that regard. For manmade events, however, developing more tailored analytic approaches will likely be essential.

III. SAMPLE RESILIENCE QUESTIONS

State Commissions will need to decide for themselves if they want to explore preparedness against the worst effects of black sky days with companies and other stakeholders. If a Commission decides to explore this issue, this section provides questions that it might ask in informal discussions on overall resilience goals, challenges and priorities. PUC resilience needs and concerns vary, so commissioners will likely need to modify these questions accordingly. Most important: do not ask questions whose answers might create vulnerabilities to cyber or kinetic attack.

A. Reliability versus Resilience

Utilities in your State may already be developing proposals to invest in resilience, or are likely to do so in the future. In advance of rate cases, asking utility personnel how they define resilience can help set common perspectives on resilience goals and priorities.

1. How does your company integrate resilience into your enterprise risk management structures?

2. What corporate structures and governance drive performance for resilience?

3. What constitutes resilience, and how can we distinguish it from reliability? Is it useful to differentiate them on the basis of the severity of an event (with resilience focused on the most extreme, high consequence hazards)?

4. How might investments in resilience differ from those for reliability? What kinds of projects would fall into which basket?

5. Do you conduct exercises to prepare for severe, non-traditional hazards? How have you adjusted your restoration plans and crew training for severe events?

B. Extraordinary and Hazardous Threats: Which are of Greatest Concern?

1. Which catastrophic threats does your company see as most probable? What “keeps you up at night?”

2. Have you had discussions with State and local emergency managers, National Guard leaders, or other officials within your State and region on the probability of (and preparedness against) catastrophic hazards, and the challenges these hazards create for power restoration?

3. Have you had discussions with key stakeholders or other critical sectors on the consequence for those sectors of a long-term power outage?

4. In a severe event, natural gas pipelines and other energy infrastructure systems essential for power generation may not only be disrupted by electricity outages, but may themselves be damaged. How do you account for these risks in your restoration planning?

5. In a similar way, the infrastructure that your utility crews need to restore power may be disrupted. Communications systems are a prime example. What measures are you taking to address these challenges for resilience?

C. Deepening Partnerships

1. Have you engaged with the State Energy Office or other State agency on its energy assurance plan?

2. Has your organization engaged with State and Federal emergency management, homeland security, and law-enforcement agencies to plan for "black sky days," and build an integrated approach to power restoration and disaster response and recovery?

D. Specific Challenges for Resilience against Severe Hazards

PUC's will differ in the degree to which they believe it is appropriate or necessary to "get under the hood," and examine the specific power restoration and crisis management issues that could contribute to the duration of an outage. Please adjust these questions to fit your own preferences.

1. Have you engaged in contingency analysis to identify vulnerable assets? If N-1 or N-2 will not be adequate to assess resilience requirements against extraordinary events, what planning factors do you use for these larger-scale events?

2. Have you engaged with the entity responsible for your system's black start capabilities? If you are responsible for this function, do you update and practice the plan for your black start capabilities to get the grid back up and running in an extraordinary event?

3. Utilities are pursuing major improvements in the mutual assistance agreements to help scale up such assistance to deal with regional and national response events. What initiatives are you exploring in this regard?

4. What kinds of facilities and functions do you believe are most urgent for prioritized restoration, and why? To what extent have you shared your actual restoration plans with State officials?

5. If appropriate for your region, to what extent do your contingency plans take into account cross-border capabilities in Canada or Mexico?

6. The Incident Command System (ICS) offers a proven, standardized, and highly effective way to organize infrastructure restoration operations when multiple organizations and agencies must coordinate their efforts (as would certainly be the case in a black sky event). Does your company employ this system? If not, what might be the advantages or potential problems in doing so?

E. Supplementing Reliability Metrics to Assess Black Sky Resilience Investments

While SAIDI, SAIF, CAIDI, MAIFI, CEMI and other reliability metrics will continue to provide an essential foundation for assessing utility performance, supplementary evaluative tools may also be useful for resilience projects.

1. How should we assess utility resilience against especially severe hazards? How well do SAIDI and her sisters apply to this assessment challenge, and what other metrics might be appropriate?

2. How are risk management tools applied to identifying and prioritizing risk factors such as consequence, likelihood, and vulnerability?

F. Tools for Assessing Cost-Effectiveness

1. What set of tools is your company using to address cost-benefit analysis for resilience investments? Do you use the ICE calculator, and if so, how can we address its limitations for use regarding long term outages?

2. Do these tools need adaptation to address specific needs faced by your company?

3. In addition to examining the costs of outages from the perspective of utilities, could it also be helpful to assess the value of lost load to customers? How could that best be done? Would that value differ across varying types of customers?

4. What do your key stakeholders believe will be the value of lost load that compounds over time?

5. Do certain types of events carry more weight than others based on an analysis of likelihood and potential consequences? How might those factors be weighted in a cost effectiveness test?

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